

*Short Communication***Thermal Properties of Overwintered Piles of Cull Potatoes**

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ABSTRACT

Annual epidemics of late blight of potato have lead to debate as to the relative importance of overwintering sources of inoculum. Host availability is a key factor for overwinter survival of *Phytophthora infestans* and the initiation of epidemics of potato late blight. Temperature within discarded piles of cull potatoes may influence tuber tissue temperature and therefore affect survival of meristematic tissue. Consequently the risk of initiation of an epidemic of late blight from cull piles is closely related to the thermal experience of overwintered potato culls. Temperature monitoring of cull piles over two years indicated that temperature was stable in the interior of the piles regardless of cull pile size (1-15 ton) or year. The possible use of ambient temperature information gathered during winter months in potato-growing regions may not help estimate the risk of an epidemic of late blight initiated from cull piles as, although highly correlated with the surface temperature of cull piles, ambient temperature was not correlated with the temperature within the cull piles. The presence of cull piles in excess of 1 ton may enhance the survival of the host and thus the development of *P. infestans* from infected tubers.

INTRODUCTION

Epidemiological factors that influence disease development in plants are myriad and effective control measures must therefore encompass and affect identification and estimation of the amount of initial sources of inoculum (Van der Plank

1963). Speculation as to the source of annual epidemics of late blight of potato caused by *Phytophthora infestans* (Mont.) De Bary has lead to debate as to the relative importance of overwintering sources of inoculum (Partipillo et al. 2000). *P. infestans* overwinters in potato tubers that are intended for replanting as seed (Davidse et al. 1989; Grinberger et al. 1995; Kadish and Cohen 1992; Van der Zaag 1956), but the infection may also be harbored in waste or cull potato tubers (Boyd 1974; Zwankhuizen et al. 1998) or within late-blight-infected volunteer potatoes returned to the soil during harvest the previous season, although it is generally agreed the latter is of minor importance (Easton 1982; Zwankhuizen et al. 1998).

In North America, proper disposal of potato culls remains an issue. It is difficult to estimate the probability that infected potato stems or foliage will emerge from an infected tuber. Several factors can influence the fate of the infected tuber (Lambert et al. 1998; Powelson and Inglis 1999), temperature being one of the most important (Kirk et al. 2001). The survival of viable host tissue, from infection through dormancy to re-emergence the following spring, is vital for survival of *P. infestans* (Zwankhuizen et al. 1998). *Phytophthora infestans* can survive within infected tubers at 3 C as stored seed (Kirk et al. 2001). The fate of tubers, infected with *P. infestans* or not, and in particular sprout survival in overwintered culls, however, has not been monitored and correlated.

Temperature profiles of stacks of potatoes in controlled temperature storage conditions were reported in detail (Burton 1992). Convective cooling resulted in maximum temperatures to be reached 0.5-1 m below the surface of the stack and temperatures were 3 to 5 C higher than the ambient temperature in potato stacks 1.85 and 3.7 m high, respectively. Surface temperatures of potato stacks were closely related to the ambient temperature surrounding the stack. Ambient temperatures at which uncontrollable overheating resulting in sprout and tuber death

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could start were reported to be dependent on stack height and ranged from 8-24 C (1.85 m stack height) to 0-19 C (3.7 m stack height) depending on the maturity and cleanliness of the tubers.

The objectives of this study were to profile the thermal characteristics of potato cull piles from late autumn through spring and to determine whether culled tubers and sprouts survived North American winters. Ambient temperature information gathered during winter months in potato growing regions should help estimate the risk of an epidemic of late blight initiated from cull piles.

MATERIALS AND METHODS

Potatoes (cv Snowden) for the cull piles were obtained from commercial potato storages in Michigan. The cull potato tubers were below commercially acceptable standards and included, for example, physically damaged, oversized (>6 cm diameter, any plane) and undersized tubers (<2 cm diameter, any plane) and tubers that were infected with pathogens such as *Erwinia caratovora* var *caratovora* (soft rot), *Alternaria solani* (early blight), *Fusarium sambucinum* (dry rot), *Pythium ultimum* (leak) and/or *P. infestans* (late blight). The tubers were delivered to the Muck Soils Research Farm, Michigan State University, in semi-articulated carriers (15 ton/carrier) and deposited into piles each of about 1, 5, 10, and 15 ton in both 1996 and 1997. The culls were deposited on 15 November 1996 and 10 November 1997. Wooden railway ties were used to contain the piles within squares with dimensions of 1 m² (1 ton, height = 1.5 m), 4 m² (5 ton, height = 1.12 m) and 9 m² (10 and 15 ton, height = 0.89 and 0.98 m, respectively).

General purpose surface temperature thermocouple probes (Model Number U-08519-66, Cole-Parmer Instrument Company, Vernon Hills, IL 60061-1844, USA) were placed at the base, the center, and on the surface of each pile while the tubers were being deposited. The thermocouples were connected to a 12-channel scanning thermocouple thermometer (Model Number 92000-00 Benchtop, Cole-Parmer Instrument Company, Vernon Hills, IL 60061-1844, USA). Temperatures were recorded hourly from November to April. Ambient air temperature at 1 m above soil level was recorded with a weather station (Groweather, Spectrum Technologies, Inc., Plainfield, IL 60544) at the Muck Soils Research Farm.

Thermal profiles for each location within the cull piles were plotted for each pile in both years. Average temperatures over the duration of the study were calculated to determine if

average temperature was a good predictor of sprout survival on cull tubers. The number of hours at temperatures encompassing those experienced over the duration of the study for each location within cull piles were plotted for each pile in both years. No specific analyses were attempted to compare temperature characteristics within cull piles between years; data were interpreted descriptively.

Sprout viability of tubers was determined after winter exposure in both years. Samples of 50 tubers were collected from each of the piles from the base, center, and surface. Sprout viability was determined by storing the sample tubers in light at 18 C for 7 days after collection and counting the number of sprouts with developing leaf initials at the meristematic dome (Kirk et al. 1985). The presence of *P. infestans* in sample tubers was tested for by ELISA (ELISA immuno-diagnostic Alert Multiwell kit-*Phytophthora* sp. Neogen Corporation, Lansing, MI, USA). Sprout viability was compared between locations within all cull piles by three-way ANOVA (SigmaStat ver. 2.0, Jandel Scientific, San Rafael, CA, USA). From these results additional sets of two-way ANOVA were conducted to compare between locations within individual piles when a significant interaction was obtained from the three-way analysis of variance.

RESULTS AND DISCUSSION

Temperature profiles of each cull pile are shown in Figure 1 (1996 only). In 1996 and 1997, the surface temperatures of all cull piles were close to ambient temperature. Although in general, the surface temperature remained marginally greater than ambient especially during the first 40 days after deposition. The surface temperature of the 1-ton cull piles was highly correlated with ambient air temperature in both years ($r^2 = 0.99$ [1996] and 0.97 [1997]). Surface temperature in the larger cull piles was also correlated with ambient temperature in both years ($r^2 = 0.90, 0.70$ and 0.69 [1996; 5-, 10- and 15-ton, respectively] and $0.89, 0.77$ and 0.77 [1997; 5-, 10- and 15-ton, respectively]). In 1996, both ambient and cull pile surface temperature fluctuated most in the 1-ton cull pile and 30 days after deposit the fluctuation of temperature at the surface of the 5-ton cull pile was also evident (Figure 1). The fluctuation in hourly temperature at the surface of all cull piles was less evident in 1997 until about 120 days after deposit. The initial heights of individual piles were 0.95 m (15 ton) and 0.89 m (5 ton); 80 days after cull deposit heights were about 0.5 m and by mid-April (about 180 days after deposit) 0.25 m in height.

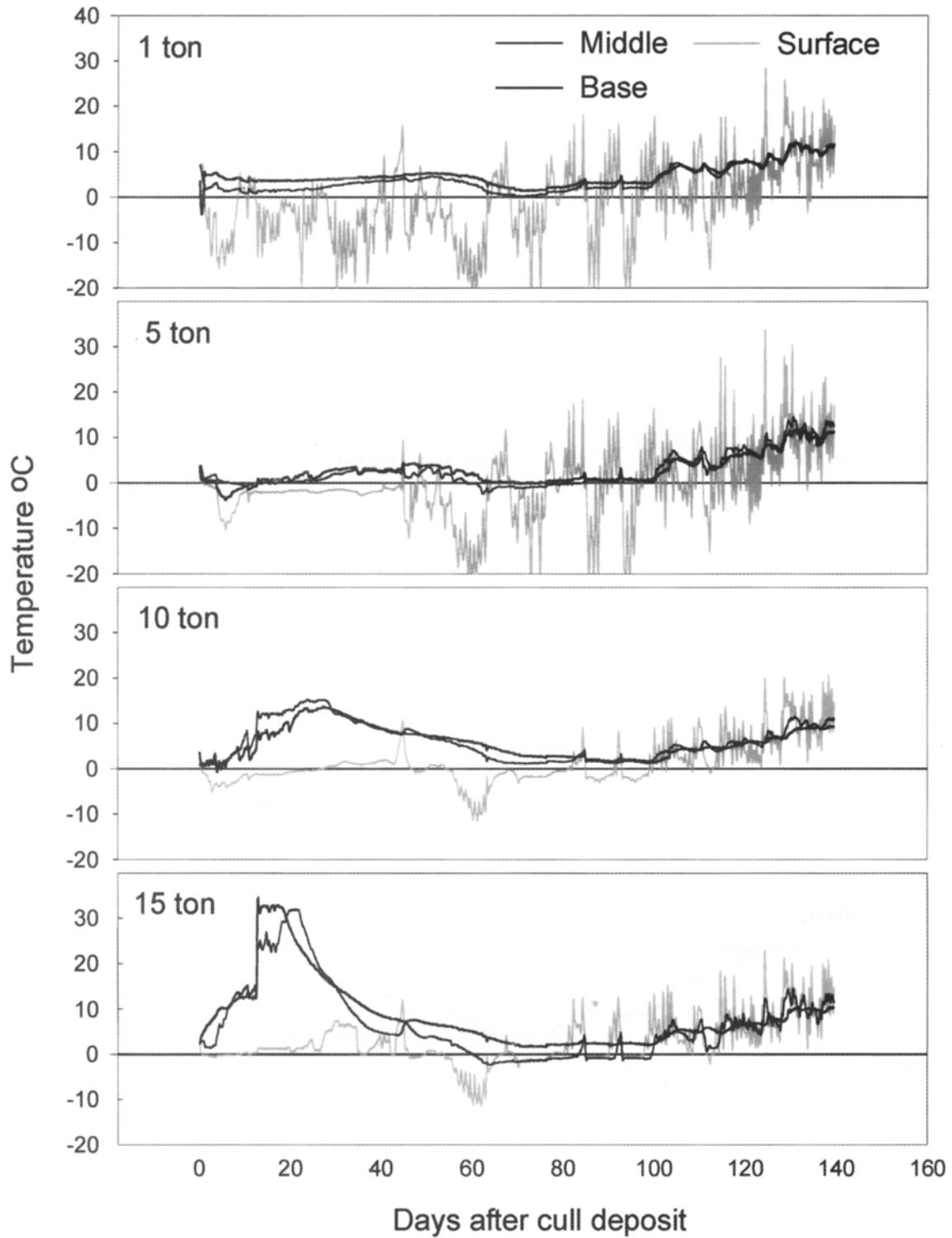


FIGURE 1. Thermal profiles of discarded potato cull piles (about 1, 5, 10 and 15 ton at initial deposit) from 15 Nov 1996 to about 160 days after deposit in mid-April 1997. The temperatures were measured continuously at one-hour intervals at the base (solid black line), the center (thinner solid black line) and the surface (solid gray line) of each of the piles.

TABLE 1—Average temperature (C) from time of deposit of potato cull piles on 15 Nov to April, 160 and 180 days in 1996 and 1997, respectively, at the Muck Soils Research Farm, Bath, MI.

| Year | Cull pile description ¹ (ton) | Average temperature (C) from time of deposit of cull piles to about mid-April ² Temperature source within cull pile | | | | | |
|------|---|---|---------------------|--------|--------|---------|--------|
| | | base | | middle | | surface | |
| | | Temp | SEM | Temp | SEM | Temp | SEM |
| 1996 | 1 | 4.2 | (0.04) ³ | 3.1 | (0.05) | -2.4 | (0.15) |
| | 5 | 1.9 | (0.05) | 1.7 | (0.06) | -1.8 | (0.14) |
| | 10 | 8.4 | (0.13) | 6.3 | (0.14) | 1.8 | (0.09) |
| | 15 | 5.6 | (0.06) | 5.7 | (0.07) | 0.2 | (0.09) |
| 1997 | 1 | 5.0 | (0.04) | 3.9 | (0.05) | 3.2 | (0.04) |
| | 5 | 6.1 | (0.07) | 4.8 | (0.08) | 3.2 | (0.06) |
| | 10 | 6.3 | (0.07) | 5.2 | (0.08) | 4.5 | (0.07) |
| | 15 | 7.2 | (0.08) | 5.9 | (0.09) | 3.8 | (0.07) |

¹Initial weight at deposit.

²160 and 180 days in 1996 and 1997, respectively.

³Standard error of estimate, n = 3840 and 4320 hourly temperature measurements in 1996 and 1997, respectively.

Therefore, as time progressed, the surface temperatures became closer to those recorded at the center of the piles, and in both years as the piles degraded, the surface temperatures became more closely related to ambient temperature.

In 1996 and 1997, temperatures at the middle and base of the piles increased for the first 20 days then decreased (Figure 1, 1996). In 1996, in the 1- and 5-ton piles, internal cull pile temperatures increased over a longer period and tended not to rise as much as those in the 10- and 15-ton cull piles (Figure 1). The 15-ton cull pile attained internal temperatures in excess of 30 C in 1996 (Figure 1) for about 5 days, 10 days after deposit. In 1997, the internal temperature of all cull piles increased from the time of deposit to about 20 days after deposit. The maximum temperatures reached were about 20 C in the 5-, 10- and 15-ton piles. Internal hourly recorded temperatures were occasionally below 0 C up to 10 days after deposit in the 1-, 5- and 10-ton cull piles in 1996 (Figure 1), but did not fall below 0 C in the 15-ton cull pile. In 1997, internal temperatures of all cull piles remained above 0 C throughout the winter.

In 1996, the 10- and 15-ton cull piles had both higher average temperatures than the 1- and 5-ton cull piles at the base and middle (Table 1). The aver-

TABLE 2—Percent of viable sprouts on tubers after exposure to overwinter environments from time of deposit of potato cull piles on 15 Nov to April, 160 and 180 days in 1996 and 1997, respectively, at the Muck Soils Research Farm, Bath, MI.

| Pile Size (ton) | Percent of viable sprouts | | | | | | | |
|-----------------------|---------------------------|--------|---------|------|--------|---------|-------------------|-------------------|
| | 1996 | | | 1997 | | | SEM | |
| | Base | Middle | Surface | Base | Middle | Surface | size ¹ | size ² |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | nsd | nsd |
| 5 | 0.04 | 0.08 | 0 | 0.12 | 0.12 | 0 | nsd | nsd |
| 10 | 0.12 | 0 | 0 | 0.16 | 0.04 | 0 | nsd | nsd |
| 15 | 0.04 | 0.04 | 0 | 0.12 | 0.08 | 0 | nsd | nsd |
| SEMloc ^{2,4} | nsd | nsd | nsd | *6 | * | nsd | | |

¹Standard error of mean at P = 0.05 for comparison of cull pile size in 1996 (SEM = 0.016)

²Standard error of mean at P = 0.05 for comparison of thermocouple location in 1996 (SEM = 0.019)

³Standard error of mean at P = 0.05 for comparison of cull pile size in 1997 (SEM = 0.026)

⁴Standard error of mean at P = 0.05 for comparison of thermocouple location in 1997 (SEM = 0.022)

⁵Significant difference at P = 0.05 (In 1997; survival of sprouts was significantly higher on tubers from the base of the piles in comparison to those sampled from the surface; there were no significant differences between tubers from any other locations).

TABLE 3—Percentage of time spent within specified temperature intervals after exposure to overwinter environments from time of deposit of potato cull piles on 15 Nov to April 160 and 180 days in 1996 and 1997 respectively, at the Muck Soils Research Farm, Bath, MI.

| Cull pile description | | Percentage of time spent within specified temperature intervals over the winter following deposition of cull tubers. | | | | | |
|--------------------------------------|--|--|--------|-------|-------------------|--------|-------|
| Initial weight ¹ (ton) | Temperature source within cull pile | 1996 ² | | | 1997 ² | | |
| | | <0 C | 0-10 C | >10 C | <0 C | 0-10 C | >10 C |
| 1 | Base | 0 | 93 | 6 | 0 | 91 | 9 |
| | Middle | 0 | 94 | 6 | 2 | 91 | 7 |
| | Surface | 56 | 34 | 10 | 1 | 94 | 5 |
| 5 | Base | 9 | 86 | 5 | 0 | 82 | 17 |
| | Middle | 24 | 67 | 8 | 2 | 81 | 17 |
| | Surface | 65 | 25 | 10 | 0 | 90 | 9 |
| 10 | Base | 0 | 74 | 26 | 1 | 81 | 18 |
| | Middle | 26 | 48 | 25 | 0 | 83 | 17 |
| | Surface | 33 | 55 | 10 | 0 | 85 | 15 |
| 15 | Base | 0 | 87 | 12 | 0 | 80 | 20 |
| | Middle | 0 | 79 | 21 | 0 | 80 | 20 |
| | Surface | 51 | 41 | 7 | 0 | 88 | 12 |

¹Initial weight at deposit.

²160 and 180 days in 1996 and 1997, respectively.

age temperature at the surface of the larger piles, although close to 0 C, was about 3 C greater than the 1- and 5-ton piles. In 1997, the average temperature for each location within the culls was similar (Table 1). Average temperature was greatest at the center and base of the largest pile and decreased with pile size; however, at the surface of the piles there was little difference in temperature between cull piles of different sizes (Table 1).

Incidence of sprout survival after overwintering was very low (less than 1%) from tubers sampled from all locations within each size of cull pile in both years (Table 2). Sprout survival was always zero on tubers sampled from the surface of the piles. In 1997, a significantly greater number of tubers sampled from the base of cull piles had surviving sprouts in comparison with tubers from the surface of the piles but not from the middle of the piles (Table 2). *Phytophthora infestans* was not detected in any of the tubers sampled from any location within any of the cull piles. *Phytophthora infestans* was not detected at the start of the experiment, therefore the absence of infected sprouts was not unexpected.

The percentage of time spent over the winter, following deposition of cull tubers, within specified temperature intervals that may be significant in terms of sprout survival, is shown in Table 3. In 1996 and 1997, the percentage of time tubers were at temperatures below 0 C was minimal at the base and center of the piles. The implications for survival of a potential source of host tissue in cull piles and sources of initial inoculum of *P. infestans* are clear. Neither surface temperature of cull piles nor ambient temperature would enhance prediction of late blight epidemics initiating from potato cull piles. The relation between internal temperature of the cull piles and ambient temperature would be further complicated by the presence and duration of snow cover, which would insulate the potato tubers. The presence of cull piles in excess of 1 ton may enhance the survival of the host and thus the development of *P. infestans* from infected tubers. Such implications have resulted in enforcement of state laws in Michigan to deter growers from depositing culls and recommendations for cull management, which include disposal and spreading rates on fields intended for crops other than potatoes.

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