Research Reports

Factors Associated with Decay in Table Beets Identified by a Statistical Analysis of Grower and Processor Records

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SUMMARY. Data collected on 181 fields from 1998 to 2000 were analyzed for associations among cultural practices in table beet (*Beta vulgaris*) and levels of decay in the harvested beet roots. Increased risk of decay was associated with short rotations between beet crops, certain crop rotations in the four years before beets, the frequency of row cultivation, and narrow row spacing. Shielding during cultivation was associated with increased risk of decay, but the effect may be an indirect one. Decay levels were not associated with beet variety, the use of manure or preplant fertilizer. Decay did increase with higher rates of nitrogen side dressing. Mean decay differed significantly among growers, and could be explained in part by the set of cultural practices used by a grower. The results suggest that the

risk of decay is determined by interacting biological and cultural factors. Manipulation of cultural practices and cropping sequence may be useful in managing levels of beet decay.

New York vegetable growers and processors are increasingly concerned over the levels of decay which have occurred in the last few years on table beet roots. Concern was heightened by especially high decay levels in the 2000 season. Even low levels of decay in beet roots are problematic, since processors have a standard of no more than 4% of beets showing visible symptoms of decay in loads delivered.

Growers need quantitative assessments of the relative risks of decay associated with different factors. Decay of beet roots may be caused by various biological and cultural factors, either alone or in combination. Soilborne pathogen activity is possibly the main biological determinant of beet decay, though there may be a physiological aspect to decay also. The two major soilborne pathogens that cause beet decay in New York are *Pythium ultimum* and *Rhizoctonia solani* (Abawi et al., 1986). In addition to causing root decay, *R. solani* can also cause a foliar infection, leading to open areas within rows where the plants have been killed by the pathogen. This disease is called pocket rot, because of the open pockets, which become visible in the field (Olaya et al., 1994).

Sometimes a longer term or regional perspective can provide useful insights into complex agronomic problems. For example, Hardwick et al. (2001) used data collected over 10 years to examine trends and changes in winter wheat (*Triticum aestivum*) dis-

eases in England. Similarly, Gladders et al. (2001) also used a 10-year dataset to identify variables correlated with the severity of leaf blotch of wheat (caused by *Septoria tritici*). Beet growers in New York have accumulated detailed records on cultural practices associated with beet production. Processors have detailed records on the levels of decay in loads harvested from these fields. The objective of this research was to use combined grower and processor records on beet production to identify factors associated with an increased risk of beet decay.

Materials and methods

DATA COLLECTION. Data were collected from 1998 to 2000. Levels of beet decay were assessed, using a count by weighing protocol (Ridout and Suntharalingam 1997), by N.Y. Dept. of Food and Agriculture inspectors as loads were delivered to the processing plant. Beets are graded according to size from 1 to 4, with the smallest beets being assigned grade 1. Grades 1 and 2 beets are preferred by processors for canning whole. In assessing decay levels, first a 25-lb (11.3-kg) sample is removed just before the beets enter the grading hopper. The sample is sorted by grade manually, and all grades 3 and 4 beets are removed. The sample (now consisting of grades 1 and 2 beets only) is weighed (tw). The beets are then inspected visually, and any showing symptoms of decay are separated. The subsample of beets with visual signs of decay is weighed (dw). The incidence of decay (I) is then calculated as $I = dw/tw$.

We matched the processor recorded decay incidence data to the agronomic practices associated with the fields from which loads were harvested. Data on field specific agronomic practices were gathered through one-on-one meetings with individual producers and by searching through producer records. New York beet producers are required by the food processing companies to keep records of certain agronomic practices, and fields are assigned specific numbers by the companies so that loads can be traced back to individual fields. Some producers kept more detailed records than others. A spreadsheet was developed for each grower listing each beet field by field number over the 1998 to 2000 period. Columns were created for the following data: number of acres, variety, planting and harvest dates, yield, grade percentages, number

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of years out of beets, previous crops and cover crops, soil type, tillage and cultivation methods, number of cultivations, presence or absence of shields on cultivators, fertilizer applications, row spacing, and irrigation frequency. Producers provided data verbally, in writing, or granted access to records from which we could obtain data. This gave us a dataset of field-specific information for 181 fields over the 3 years.

DATA ANALYSIS. Data were first combined across years and growers to examine the association of decay with several variables at the field level. These included beet variety, the number of years between beet crops on the field, whether a cover crop had been planted before the beet crop, the number of cultivations on the beet crop, whether shields had been used during cultivation, whether manure was used, the previous 4 years' crop history on the field, row spacing, and the rates of fertilizer used on the fields.

To examine possible associations of the above variables with beet decay, we sought a model which accounted for the variances due to factors which could influence decay, but were not of direct interest. For example, weather conditions on a regional scale (e.g., rainfall) vary spatially within a production season and also across years. Our model therefore accounted for variation associated with the year of production, and also accounted for the possibility that loads harvested from the same field were more likely to have similar levels of decay compared with loads harvested from different fields.

Beet decay level in individual loads was recorded as the proportion of beets with visual symptoms of decay. Proportional (incidence) data range from 0 to 1, and have variances which are distributed binomially. Therefore, models were implemented using the SAS Glimmix macro (SAS Institute, Cary, N.C.), which allows for a more natural modeling of binomial data. This avoided the need for and undesirable effects associated with data transformation (Littell et al., 1996).

After identifying cultural practices associated with increased levels of decay, we examined whether differences in decay levels among growers were correlated with these practices.

Results and discussion

Within each year, there was much variability in decay levels, though the

overall mean decay increased from 1998 to 2000. The mean incidence of decay in 1998, 1999, and 2000 was 3.23%, 3.54%, and 4.89%, respectively. Rainfall was not necessarily correlated with mean decay levels. For example, the mean cumulative monthly rainfall from May to August was lower in 1999 than in 1998 (Fig. 1), but decay levels in 1999 were on average higher than in 1998. May 2000 was wetter than May 1998, but by August about the same amount of rain had fallen on beet growing regions in both 1998 and 2000 (Fig. 1). Yet, decay levels were on average higher in 2000 than in 1998. The timing of rainfall relative to beet development may therefore have some influence on decay levels, but investigating that relationship requires rainfall data at the resolution of individual beet production fields (unavailable in this study).

BEET VARIETY.

Four varieties were included in the analysis: 'Kestral,' 'Red Ace,' 'Red Queen,' and 'Scarlet Supreme.' Some fields had been sown to a mixture of varieties, and these fields were included in the analysis as well (variety = mixed). There were no differences among varieties in the percentage of beets with decay ($P = 0.2007$).

YEARS BETWEEN BEET CROPS.

The number of years the field had been out of beet production was placed into one of the following three categories: 0 to 3 years, 4 to 7 years, and >7 years. The number of years between beet

Fig. 1. Mean cumulative monthly rainfall across the 16 counties of central and western New York from May to August, 1998 to 2000. Data were obtained from the National Climatic Data Center (Asheville, N.C.) for the recording weather stations across the central and western New York region (1 inch = 25.4 mm).

Fig. 2. Association of number of cultivations with the level of beet decay. Mean decay levels followed by the same lowercase letter are not significantly different ($P > 0.05$).

Fig. 3. Association of shielding during cultivation with the levels of beet decay.

Table 1. Association of nitrogen (N) side dressing rate with an increased risk of beet decay.

N rate (lb/acre) ^a	Odds ratio ^b
30	1.14
60	1.30
120	1.68
160	1.99

^a1 lb/acre = 1.12 kg·ha⁻¹.

^bThe odds ratio here measures the associated increased risk of decay due to N use compared with no nitrogen side dressing. The odds ratio (Ψ) was calculated as $\Psi = [p_x(1 - p_0)]/[p_0(1 - p_x)]$, where p_0 is the probability of decay associated with no N side dressing, and p_x is the probability of decay associated with a N rate of x lb/acre.

crops was significantly associated with decay ($P = 0.0005$). Mean incidence of decay when the length of the rotation between beet crops was 0 to 3, 4 to 7, or >7 years was 4.64%, 3.72%, and 3.14%, respectively. There was no difference in decay levels among fields with rotations of 4 to 7 years between beets compared with rotations >7 years ($P = 0.0547$). The incidence of decay associated with the shortest rotation was significantly greater than found with the longer rotations ($P < 0.03$).

The decrease in beet decay associated with longer rotations between beet crops is consistent with the hypothesis that pathogenic, soilborne fungi are involved in beet root decay. Generally, soilborne populations of fungal pathogens decrease within a few years when the field is rotated to a nonhost (Abawi and Widmer, 2000; Gilligan et al., 1996). Although soilborne populations of pathogenic fungi usually remain relatively low in the absence of a suitable host crop (Herr, 1987), populations increase rapidly when a susceptible host is planted (Gilligan et al., 1996).

COVER CROPS. Cover crop establishment before beets was not associated with the level of decay ($P = 0.6060$). This result contrasts with other research showing the disease suppressive nature of cover crops and green manures (Abawi and Widmer, 2000; Lazzeri and Manici, 2001).

MANURE. Manure application was not associated with the level of beet decay ($P = 0.2033$). Other studies though have documented the suppressive effects of animal manures on soilborne populations of pathogenic fungi (Lazarovits et al., 2001).

ROW CULTIVATION FOR WEED CONTROL. More frequent cultivations of the beet field were associated with an increased risk of decay (Fig. 2). There were no

differences in mean decay when one, two, or three cultivations were done ($P > 0.05$). Decay when cultivation was done (regardless of the frequency) was significantly higher compared with decay levels when the field was not cultivated ($P < 0.02$). A possible explanation is that during cultivation pathogen-infested soil is thrown into the crown area. Soil deposition in the beet crown is associated with increases in root rot (Schneider et al., 1982). More frequent cultivations would also be associated with distributing pathogen-infested soil over a larger area (Truscott and Gilligan, 2001).

Shields, which are flat or slightly curved disks attached to the cultivation implement so as to run between the cultivator sweeps and the plant row, are often used during cultivation. Shields protect plants from cultivator damage and prevent potentially pathogen infested soil from being thrown into the crowns, and so their usage could be expected to reduce the incidence of beet decay. Therefore, we examined the association of beet decay with shielding of rows during cultivation (Fig. 3). As before, increases in the levels of decay

were associated with the number of cultivations performed. Unexpectedly, the results indicated that decay was significantly higher when shields were used ($P = 0.0005$). A possible explanation for the association of shielding with increased levels of decay invokes the combined effects of root decay and pocket rot. Shielding can reduce the incidence of pocket rot, because soil is not thrown upon the beet crown. Soilborne pathogens have a patchy distribution in soil (Gilligan et al., 1996; Truscott and Gilligan, 2001), which therefore means that not all areas of a field are at risk of beet decay. During cultivation with shielding, little or none of the soil is thrown upon the crowns when a pathogen-infested patch is reached, and therefore the plants are not at risk of pocket rot. The underlying beet roots, being in a pathogen-infested patch, are at risk of decay however, and are harvested. On the other hand, if shielding is not used, soil is thrown up on the crowns when a pathogen-infested patch is reached, increasing the risk of crown rot. This creates open pockets when the infected plants eventually die, which means that the underlying

Table 2. Association of 4-year crop rotations before beets with the incidence of decay.

Crops on the field (years before beets)				Decay (%)
1	2	3	4	
Hay	Hay	Hay	Hay	1.14
Sweet corn	Sweet corn	Sweet corn	Wheat	1.68
Corn	Wheat	Beans	Corn	2.26
Corn	Corn	Beans	Corn	3.08
Beans	Hay	Hay	Hay	3.74
Wheat	Peas	Sweet corn	Beets	4.19
Peas	Peas	Cabbage	Beets	4.93
Cabbage	Wheat	Sweet corn	Beets	5.41
Alfalfa	Alfalfa	Alfalfa	Beets	6.45
Beets	Beans	Peas	Beans	7.56

Table 3. Model-predicted decay levels in beets as a function of designed 4-year rotations.

Crops on the field (years before beets)				Decay (%)
1	2	3	4	
Hay	Peas	Hay	Hay	0.18
Hay	Beans	Hay	Hay	0.22
Hay	Cabbage	Hay	Hay	0.23
Corn	Sweet corn	Hay	Hay	0.44
Beans	Sweet corn	Hay	Hay	0.52
Corn	Peas	Hay	Hay	0.52
Sweet corn	Sweet corn	Hay	Hay	0.54
Peas	Sweet corn	Hay	Hay	0.59
Beans	Peas	Hay	Hay	0.62
Corn	Beans	Hay	Hay	0.63
Sweet corn	Peas	Hay	Hay	0.64
Corn	Cabbage	Hay	Hay	0.66
Alfalfa	Sweet corn	Hay	Hay	0.68

Fig. 4. Mean levels of beet decay by grower from 1998 to 2000. Growers are identified by number rather than name for protection of identity.

beets (which are at risk of decay) are not harvested, leading to reduced levels of decay in the load.

ROW SPACING. Fields were placed into one of three categories based on the row spacing at which beets were sown: 19 inches (48.3 cm), 21 to 22 inches (53.3 to 55.9 cm), 24 to 26 inches (61.0 to 66.0 cm). There was a significant association of row spacing with beet decay level ($P = 0.0009$). The mean incidence of decay when the row spacing was 19, 21 to 22, and 24 to 26 inches was 3.61%, 3.62%, and 2.66%, respectively. A row spacing of 24 to 26 inches was associated with significantly lower levels of decay compared with closer spacings of 19 to 22 inches ($P < 0.05$). The effect of plant density on disease incidence is well documented (Burdon and Chilvers, 1982).

FERTILIZER. Preplant nitrogen, phosphorus or potassium levels were not associated with decay. There was, however, a significant association with nitrogen side dressing ($P < 0.0001$; Table 1). The risk of decay increased with heavier applications of nitrogen (Table 1). For example, the odds of decay were twice as high when a nitrogen side dress was used at 160 lb/acre (179.3 kg·ha⁻¹) compared with no nitrogen side dressing. The effect of fertilizer rates on decay may be complex and indirectly related to soilborne pathogen activity. Other studies have found that the form of nitrogen in fertilizer used can impact the severity of decay by soilborne pathogens (Elmer, 1997; Rodrigues et al., 2002). For example, the severity of rhizoctonia root rot in beans (*Phaseolus*

vulgaris) increased linearly with increasing rates of sodium nitrate (NaNO₃), but decreased linearly if ammonium sulfate [(NH₄)₂SO₄] was used instead (Rodrigues et al., 2002). Nitrogen form data were not available for the current study.

CROP ROTATION. Beet growers used a variety of rotation combinations. The dataset was large enough to examine the effects of the following crops: alfalfa (*Medicago sativa*), (dry or snap) beans (*Phaseolus vulgaris*), beets, cabbage (*Brassica oleracea*), field corn (*Zea mays*), hay (mainly timothy (*Phleum pratense*) mixed with legumes), field pea (*Pisum sativum*), sweet corn (*Zea mays* var. *rugosa*) and winter wheat. There were significant effects of the previous 4-year's crops before beets on the incidence of decay. Table 2 lists model-fitted decay levels for some of the rotations used, sorted by level of decay. The results indicated that 4-year previous crop rotations including hay as a component were associated with a reduced risk of decay in the subsequent beet crop. We therefore examined the effect of hay in the rotation by generating model-predicted decay levels for designed rotations which included hay as the third and fourth year's crop before beets (Table 3). The

model-predicted decay levels for such rotations were less than 1%. The actual effect of rotations with hay (or other crops) on reducing the risk of decay in beets would have to be tested by field experimentation. Nevertheless, the results derived from the fitted model to beet decay as a function of crop rotation are useful in generating testable hypotheses.

DIFFERENCES AMONG GROWERS IN DECAY LEVELS. The above analysis indicated that certain cultural practices were associated with reduced levels of decay. Furthermore, there were significant differences in decay among beet growers ($P < 0.0001$; Fig. 4). Therefore, we next asked whether the differences in decay among growers were associated with the cultural practices identified in the analysis above. Growers for which we had sufficient data were classified as having either low (<3%) or high (>3%) decay on average. Growers with low decay levels were found to practice longer rotations between subsequent beet crops compared with growers with higher levels of decay (Table 4). They also tended to use wider beet row spacings (Table 4) and lower nitrogen side dressing rates (Table 5). Our model results indicated that rotating with hay as far back as 3 or 4 years previous to beets was associated with reduced decay. We found that growers with lower decay levels were more likely to have used

Table 4. Number of years between beet crops, row spacing, and use of hay in the rotation sequence for growers classified as having either low (<3%) or high (>3%) levels of beet decay.

Grower class ^a	Parameter		
	Time in between beet crops (years)		
	0–3	4–7	>7
	Proportion of fields (%)		
Low	0.0	27.5	72.5
High	35.5	38.7	25.8
	Row spacing (inches) ^b		
	19	21–22	24–26
	Proportion of fields (%)		
Low	0.0	25.0	75.0
High	0.0	100	0.0
	Year previous to beets		
	2 nd	3 rd	4 th
	Proportion of fields with hay (%)		
Low	7.7	10.8	13.5
High	1.1	1.4	1.6

^aFour growers classified as having low decay levels on average, three growers classified as having high decay on average.

^b1 inch = 2.54 cm.

Table 5. Mean nitrogen (N) side dressing rates between growers classified as having low decay (<3%) or high decay (>3%) levels.

Grower class ^z	No. of fields	Mean decay (%)	N side dressing rate (lb/acre) ^y
Low decay	37	2.17	5.59
High decay	55	5.13	54.11

^zFour growers classified as having low decay levels on average, three growers classified as having high decay on average.

^y1.00 lb/acre = 1.121 kg·ha⁻¹.

hay in the rotation in the years previous to beets compared with growers with higher levels of decay (Table 4).

In conclusion, the levels of decay in New York table beets from 1998 to 2000 were associated with the length of rotation between beet crops, certain crop rotations during the 4 years before beets, the frequency of cultivation for weed control, the amount of nitrogen applied as a side dress, and row spacing.

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