# Population Dynamics of *Laetisaria arvalis* and Low-Temperature *Pythium* spp. in Untreated and Pasteurized Beet Field Soils

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## ABSTRACT

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Addition of *Laetisaria arvalis* was highly effective in suppressing reproduction of *Pythium ultimum* in pasteurized and untreated field soils planted to table beets (*Beta vulgaris*). The number of germinable propagules of *P. ultimum* reached a maximum of approximately 300 and 6,500 per gram in pasteurized soils amended and nonamended, respectively, with *L. arvalis*. Addition of *L. arvalis* to field soil similarly reduced buildup of germinable propagules of low-temperature *Pythium* spp. In one test, in field soil infested with 455 germinable propagules of low-temperature *Pythium* spp. per gram of soil, a maximum of approximately 500 and 2,000 propagules per gram in *L. arvalis*-amended and nonamended soils, respectively, occurred after 3-wk of incubation. The number of sclerotia of *L. arvalis* was lower in field soil infested with *Pythium* spp. than in pasteurized soil, but was still relatively high (30 sclerotia per gram of soil) after 16 wk. Significantly greater emergence, lower postemergence damping-off, and subsequently greater survival of table beet seedlings was obtained in soils amended with *L. arvalis* in comparison to similar treatments lacking *L. arvalis*. Soils that were planted repeatedly to table beets developed suppressiveness that was characterized by reduced numbers of *P. ultimum* propagules, increased numbers of *L. arvalis* sclerotia, and lower seedling disease incidence.

*Additional key words*: beet root rot, biological control.

*Laetisaria arvalis* Burdsall (3) has been demonstrated to be an effective agent for control of pre- and postemergence damping-off of table beets (*Beta vulgaris* L.) induced by *Pythium ultimum* Trow (5). *Laetisaria arvalis* also has shown potential for control of diseases induced by *Rhizoctonia solani* Kühn on cucumbers (*Cucumis sativus* L.) (7), and on snap beans and dry edible beans (*Phaseolus vulgaris* L.), and sugar beets (9).

This biological-control fungus has been utilized as a seed treatment (9), added to the soil directly (7), and added to the soil indirectly as colonized organic amendments (5,7,9). To date, however, we have very little information regarding how well *L. arvalis* competes and survives in the soil or how the target organisms are affected.

In this paper, we report on the population dynamics of *L. arvalis*, *P. ultimum*, and other low-temperature *Pythium* spp. singly and in combination in both untreated and pasteurized beet field soils; further evaluate *L. arvalis* for control of seedling disease of table beet under greenhouse conditions; and determine the effect of planting soils repeatedly to table beet on the population dynamics of *P. ultimum* and *L. arvalis* and on disease incidence of table beet seedlings.

## MATERIALS AND METHODS

**Inoculum production.** Soil was collected from a beet field with a history of severe Pythium root rot, screened (1-cm sieve openings) to remove rocks and debris, and stored in a cold room (4 C). A portion of the soil was pasteurized at 60 C with aerated steam for 30 min. An isolate of *P. ultimum* (P4) that produced abundant sporangia on snap bean pods in distilled water (11) was used as inoculum to infest pasteurized soils. The inoculum suspension obtained was atomized onto moist pasteurized soil, incorporated thoroughly into the soil, and stored for approximately 12 hr at 4 C.

*Laetisaria arvalis* isolate NRRL 11375 was used in all experiments. *Laetisaria arvalis* was increased on either corn leaf meal (CLM) for preliminary experiments, or spent sugar beet pulp (BP) for later experiments. The CLM was prepared from senesced field-dried corn leaves ground with a Wiley mill to allow passage through a 2-mm-mesh screen. The BP was obtained from a feed mill in Geneva, NY, and was similarly ground in a Wiley mill. Mycelial disks from *L. arvalis* cultures grown on potato-dextrose agar (PDA) were aseptically introduced into 500-ml flasks containing 6 g CLM and 35 ml of distilled water, or into 1,000-ml flasks containing 100 g BP and 90 ml of distilled water. Flasks containing the inoculum were incubated for 4 wk on a laboratory bench at room temperature (20–25 C), which allowed for thorough colonization of CLM and BP by *L. arvalis*.

**Soil propagule density assays.** In all experiments, germinable propagules of *Pythium* spp. were monitored using a medium of Tsao and Ocana (12) as modified by Pieczarka and Abawi (11). A single 5-g soil sample was taken from thoroughly mixed soil from each pot and represented one replication. Soil dilutions of 1:50 or 1:200 were made in 0.3% sterile water agar, with three plates for each sample. The soil-surface-dilution plate technique (8) was used, with 1.0-ml subsamples of the appropriate dilution added to each plate. Soil dilution plates were incubated at 19–20 C in the dark for 18–24 hr, after which the diluted soil was washed from the plates and colonies of *Pythium* spp. were counted and recorded as number of germinable propagules per gram of oven-dry soil. In untreated soils, low-temperature *Pythium* spp. were assumed to be mostly *P. ultimum*, based on the results of Pieczarka and Abawi (11).

Pasteurized soil was infested with *P. ultimum* at an initial rate of 147 sporangia per gram of dry soil in preliminary experiments, whereas the initial inoculum level of low-temperature *Pythium* spp. in untreated soil was 263 germinable propagules per gram. In later experiments utilizing BP colonized by *L. arvalis*, the initial sporangium density of *P. ultimum* in pasteurized soil was 200 per gram, whereas untreated field soil contained 455 germinable propagules per gram.

Propagule levels of *L. arvalis* in soils were determined by a

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wet-sieving procedure (14) and were determined only in experiments utilizing BP as the carrier for *L. arvalis*. A 5-g sample of soil was removed from thoroughly mixed soil and added to 50–75 ml of tap water in a 200-ml flask that was then agitated on a wrist-action shaker for 30 min. The resulting mixture was further diluted with a turbulent stream of tap water and the liquid with suspended particles was immediately decanted through a sieve with 250-$\mu$m openings (60-mesh) to collect sclerotia and organic debris. This process was repeated three to four times until only mineral components were left in the flask as determined by visual examination. Debris from the sieve was collected on 9-cm-diameter filter paper disks in a Büchner funnel fitted to a suction flask. Sufficient vacuum was applied to remove excess water from the debris on the filter papers. The filter paper disks were allowed to air dry, after which all of the debris was gently scraped into 10-cm-diameter plastic petri plates. Only enough debris was added to each plate to allow visualization of individual colonies of *L. arvalis*. Approximately 20 ml of a modified Ko and Hora (6) medium was added to each plate to suspend the debris. This medium contained $K_2HPO_4$, 1.0 g; $MgSO_4 \cdot 7H_2O$), 0.5 g; KCl, 0.5 g; $FeSO_4 \cdot 7H_2O$, 10 mg; $NaNO_2$, 0.2 g; chloramphenicol, 50 mg; streptomycin sulfate, 50 mg; propamocarb (Nor-Am Agricultural Products, Inc., Chicago, IL 60606), 100 mg; agar, 15 g; and distilled water, 1 L. The antibiotics and propamocarb were added to cooled (50 C) basal medium before it was dispensed into petri plates. This medium was clear and allowed better visualization of colonies of *L. arvalis* than the original medium (6). The plates were incubated (20–25 C) on a laboratory bench overnight. Colonies of *L. arvalis* were counted by inverting the plates and examining them at ×20 with a dissecting stereomicroscope. Colonies of *L. arvalis* could be distinguished from *Rhizoctonia* spp. by branching habit, septum formation, presence of clamp connections, and the fact that most colonies of *L. arvalis* originated from free sclerotia which are quite distinct from sclerotia of *R. solani* or binucleate Rhizoctonia-like fungi. *Rhizoctonia* spp. were present in the untreated soil at <4 propagules per 100 g of soil. Colonies of *L. arvalis* were counted and recorded as propagules per gram of oven-dry soil.

**Greenhouse tests.** In preliminary experiments, untreated and pasteurized field soils were infested with CLM alone or CLM colonized with *L. arvalis* at a ratio of 10% (v/v). Nontreated or treated soils were added to 10-cm-diameter plastic pots and were either left fallow or were planted with 20 nontreated beet seedballs of table beet cultivar Ruby Queen at a depth of 2.0 cm. All treatments (listed in Table 1) were replicated four times per sampling period. Germinable propagules of *Pythium* spp. were assayed from treatments in untreated soil after 5, 9, and 16 wk of incubation in a greenhouse at 18–25 C. Soils were assayed similarly for *P. ultimum* in pasteurized soil after 3, 7, 11, and 15 wk of incubation.

In later experiments, BP colonized with *L. arvalis* was employed; these were designed to further evaluate changes in propagule levels of both *L. arvalis* and *P. ultimum*. Soils of all treatments were assayed initially for *Pythium* spp. and *L. arvalis*. Treated soils (listed in Table 2) were added to 10-cm-diameter plastic pots and planted to table beets. Ten seedballs were planted per pot with five replicate pots per treatment and per sampling time. *Pythium* spp. and *L. arvalis* propagule densities were determined after 3 days and 1, 2, 3, 5, 7, 10, and 16 wk of incubation. Data were collected weekly for emergence, postemergence damping-off, and subsequent survival in remaining pots (representing the last four sampling times). At the 5- and 7-wk sampling dates, surviving beet seedlings were examined for wire stem-type symptoms.

**Greenhouse replant experiments.** Soils from selected treatments (see Table 3) for the first four sampling dates were combined, screened through a 1-cm-mesh screen, and mixed thoroughly. Care was taken to avoid contamination among the different treatments. These soils were added to six sterile 13-cm-diameter clay pots (for the first four replant periods) or five pots (for the fifth and last replanting) as replications. Propagule densities of *Pythium* spp. and *L. arvalis* were determined as before at each planting time. This process of sampling for *L. arvalis* and *Pythium* spp., remixing soils by treatment and replanting, was continued for five replanting periods. As before, data were collected for emergence, postemergence damping-off, and subsequent survival. The final population determinations for *Pythium* spp. and *L. arvalis* were made 200 days after the original beet planting in these soils. Only population data and disease incidence data of the final replant period are included. Propagule densities, emergence, survival, postemergence damping-off, and proportions of seedlings with wire stem-like symptoms were analyzed by orthogonal comparisons of appropriate treatments.

## RESULTS

Addition of *L. arvalis* to naturally and artificially infested soils prevented significant increase in the population of *P. ultimum* and other low-temperature *Pythium* spp. when such soils were planted to beets (Table 1). However, *L. arvalis* had no effect on populations of *Pythium* spp. when such soils were left fallow. Noncolonized CLM added to pasteurized soil previously infested with *P. ultimum* and planted to beets resulted in substantial buildup of germinable propagules, with densities approaching 4,000 propagules per gram after 15 wk (Table 1).

Similar results were obtained from experiments using BP colonized with *L. arvalis* when all treatments were planted to beets. Without *L. arvalis*, the population of *P. ultimum* in pasteurized soil

TABLE 1. Effect of *Laetisaria arvalis* (LA) on number of germinable propagules (GP) of low-temperature *Pythium* spp. and *P. ultimum* in untreated and pasteurized field soil over time

| Treatment | Sampling period | | | | | | |
|---|---|---|---|---|---|---|---|
| | 3 wk | 5 wk | 7 wk | 9 wk | 11 wk | 15 wk | 16 wk |
| Untreated field soil[x] | | | | | | | |
| +LA[y]; planted | ... | 272[w]a | ... | 363 a | ... | ... | 465 a |
| −LA; planted | ... | 955 b | ... | 1,082 b | ... | ... | 1,138 b |
| +LA; fallow | ... | 208 a | ... | 274 a | ... | ... | 214 a |
| −LA; fallow | ... | 232 a | ... | 290 a | ... | ... | 264 a |
| Pasteurized soil[z] | | | | | | | |
| +LA; planted | 258 b | ... | 374 b | ... | 350 b | 267 bc | ... |
| −LA; planted | >2,800 a | ... | 4,549 a | ... | 3,268 a | 3,657 a | ... |
| CLM; planted | >2,800 a | ... | 3,525 a | ... | 4,330 a | 3,748 a | ... |
| No amendments; planted | ... | ... | ... | ... | ... | 0 c | ... |
| +LA; fallow | ... | ... | ... | ... | ... | 246 bc | ... |
| −LA; fallow | ... | ... | ... | ... | ... | 251 bc | ... |

[w] Mean GP level of low-temperature *Pythium* spp. and *P. ultimum*; means within a column and followed by the same letter are not significantly different according to the Waller-Duncan, *k*-ratio *t*-test.

[x] Untreated beet field soil with an initial 263 germinable propagules per gram of oven-dry soil.

[y] LA was amended as colonized corn leaf meal (CLM) at a ratio of 10% (v/v).

[z] Soil was pasteurized at 60 C, for 30 min; infested pasteurized soil had an initial 147 germinable propagules of *P. ultimum* per gram of oven-dry soil.

increased progressively over the sampling period and reached a maximum of nearly 6,500 germinable propagules per gram after 5 wk of incubation. In the presence of *L. arvalis*, the population of *P. ultimum* increased only slightly and reached a maximum of approximately 300 germinable propagules per gram after3 wk, then gradually declined to a density of approximately 150 propagules per gram after 16 wk (Fig. 1A). At each sampling date except the initial one (time 0), the population of germinable propagules in the pasteurized soil lacking *L. arvalis* differed significantly from the population in soil amended with *L. arvalis* (Fig. 1A). Noninfested pasteurized soils remained free of *Pythium* spp. throughout the duration of these experiments (16 wk).

Results in the untreated field soil were similar in trend to those obtained in pasteurized soil, but differed in magnitude (Fig. 1B). Maximum germinable propagule density of low-temperature *Pythium* spp. in field soil lacking *L. arvalis* approached 2,000/g after 5 wk. In contrast, when the soil was amended with *L. arvalis*, the maximum population was approximately 500 propagules per gram after 3 wk and gradually declined to a density of about 350 germinable propagules per gram after 16 wk (Fig. 1B). Addition of *L. arvalis* resulted in significant differences in propagule densities at each sampling date including the initial sample (Fig. 1B) when compared to untreated soil lacking *L. arvalis*.

Initial numbers of sclerotia of *L. arvalis* ranged from 50 to 83/g and differed considerably among the treatments during the first 5 wk of incubation (Fig. 1C). After 5 wk, the relative positions of the curves for particular treatments appeared to stabilize (Fig. 1C). After 16 wk, the numbers of sclerotia per gram of untreated soil was lower than that in pasteurized soil (infested and noninfested with *P. ultimum*) and averaged approximately 30 and 60–70/g, respectively (Fig. 1C).

Significantly greater emergence, and significantly lower postemergence damping-off were obtained in both pasteurized and untreated soils amended with *L. arvalis* as compared to similar treatments lacking *L. arvalis* (Table 2). These effects were also apparent for wire stem-type symptoms in the pasteurized soil but not in the untreated field soil. Data could not be analyzed for wire stem symptoms in pasteurized treatments with *P. ultimum* infestation and lacking *L. arvalis* because there were no surviving beet plants.

Replanting beets in pasteurized and untreated field soils resulted in several noticeable effects. Germinable propagule levels of *P. ultimum* and other low-temperature *Pythium* spp. declined in both pasteurized and untreated field soils after 200 days (Fig. 1A and B). After a total of five plantings of table beet, density of germinable propagules averaged 96 and 190/g pasteurized soil with and without *L. arvalis*, respectively (Fig. 1A). A similar decline in the germinable propagule level of *Pythium* spp. was apparent in untreated soil, with an average of 240 and 100 germinable propagules per gram of unamended soil alone and containing *L. arvalis*, respectively (Fig. 1B). In both untreated and pasteurized field soils, germinable propagule densities of *Pythium* spp. were significantly lower when *L. arvalis* was present in comparison to the level in the absence of *L. arvalis*.

Numbers of sclerotia of *L. arvalis* were higher after 200 days than they were after 112 days (16 wk) in both pasteurized and untreated soils. Levels of *L. arvalis* were still much greater in pasteurized soil than in untreated soil, regardless of the presence or absence of *P. ultimum*. After 200 days, there was an average of 95, 92, and 38 sclerotia/g pasteurized soil, pasteurized soil initially infested with

TABLE 2. Evaluations of disease symptoms in table beet seedlings grown in untreated and pasteurized beet field soil containing low-temperature *Pythium* spp., *Pythium ultimum*, and/or *Laetisaria arvalis*

| Treatments | Disease symptom evaluated | | | |
|---|---|---|---|---|
| | Emergence | Post emergence damping-off (%) | Survival | Wire-stem symptoms (%) |
| Past.[a] | 93.0[b] | 26.4[c] | 69.0[c] | 56.0[c] |
| Past.+LA[d] | 83.2 | 0.9 | 82.4 | 3.5 |
| Past.+P4[e] | 2.0 | 73.2 | 0.8 | ··· |
| Past.+P4+LA | 83.4 | 21.5 | 65.2 | 18.4 |
| Untr.[f] | 48.8 | 44.4 | 27.4 | 21.0 |
| Untr. + LA | 80.4 | 19.0 | 65.2 | 13.9 |
| Treatment contrasts (mean squares[g]) | | | | |
| Past. vs Untr. | 4.3 | 9.4 | 473.4** | 25.3 |
| Past. vs Past.+P4 | 10,305.8** | 5,671.7** | 9,073.8** | ··· |
| Past. vs Past.+LA | 240.1* | 1,623.1* | 448.9** | 6,832.9** |
| Past.+P4 vs Past.+P4+LA | 16,564.9** | 6,677.1** | 10,304.1** | ··· |
| Untr. vs Untr. + LA | 2,496.4** | 1,605.3* | 3,572.1** | 126.7 |
| Error mean square = | 18.1 | 255.0 | 22.2 | 334.0 |

[a] Past. means the soil was pasteurized at 60 C for 30 min.
[b] Data are treatment means pooled over four sampling times with five replications and 40 seedballs per replication; except wire-stem symptoms, which were based on pooled data from two sampling times and 20 seedballs planted per replication.
[c] Postemergence damping-off, low survival, and wire-stem symptoms in pasteurized soil lacking *P. ultimum* was caused by *Phoma betae* (see Discussion).
[d] *L. arvalis* was added as colonized beet pulp at a ratio of 10% (v/v).
[e] P4 is a sporangia-producing isolate of *P. ultimum*, infested initially at a density of 200 germinable propagules per gram of oven-dry soil.
[f] Untr. means untreated (nonpasteurized) beet field soil initially infested with low-temperature *Pythium* spp. at a density of 455 germinable propagules per gram of oven-dry soil.
[g] Mean squares followed by *, or ** indicate the statistical significance of the appropriate orthogonal contrast at $P = 0.05$ and $P = 0.01$ levels, respectively.

TABLE 3. Final disease indices of table beet seedlings grown in replanted untreated and pasteurized beet field soil containing low-temperature *Pythium* spp., *Pythium ultimum* and/or *Laetisaria arvalis*

| Treatments | Disease symptom evaluated | | |
|---|---|---|---|
| | Emergence | Postemergence damping-off (%) | Survival |
| Past.[a] | 23.2[b] | 43.5[c] | 13.4[c] |
| Past.+LA[d] | 36.6 | 0.0 | 36.6 |
| Past.+P4[e] | 28.6 | 12.7 | 25.0 |
| Past.+P4+LA | 36.4 | 11.2 | 32.4 |
| Untr.[f] | 26.6 | 30.3 | 18.8 |
| Untr. + LA | 31.6 | 14.8 | 26.8 |
| Treatment contrasts (mean squares[g]) | | | |
| Past. vs Untr. | 29.4 | 220.4* | 109.4** |
| Past. vs Past. + P4 | 33.8 | 488.1** | 68.5* |
| Past. vs Past.+LA | 448.9** | 4,730.6** | 1,345.6** |
| Past.+P4 vs Past+P4+LA | 152.1** | 4.5 | 136.9** |
| Untr. vs Untr.+LA | 62.5* | 600.6** | 160.0** |
| Error mean square = | 18.3 | 63.6 | 21.1 |

[a] Past. means soil was pasteurized at 60 C for 30 min.
[b] Data are means based on the fifth replant experiment (five plantings of beets lasting a total of 200 days) and are based upon five replicates per treatment, and 20 seedballs of table beet planted per replicate.
[c] Postemergence damping-off and low survival of beets in pasteurized soil lacking *P. ultimum* was caused by *Phoma betae* (see Discussion).
[d] *L. arvalis* added originally as colonized beet pulp at a ratio of 10% (v/v).
[e] P4 is a sporangia-producing isolate of *P. ultimum*, and was infested initially at a density of 200 germinable propagules per gram of oven-dry soil.
[f] Untr. means untreated (nonpasteurized) beet field soil initially infested with low-temperature *Pythium* spp. at a density of 455 germinable propagules per gram of oven-dry soil.
[g] Mean squares followed by *, or ** indicate significance of the appropriate orthogonal contrast at $P = 0.05$ and $P = 0.01$ levels, respectively.

*P. ultimum*, and untreated soil, respectively (Fig. 1C).

Even though germinable propagule levels of *Pythium* spp. decreased in natural and pasteurized soils after 200 days in replanting experiments (Fig. 1A and B), there was still sufficient inoculum of *P. ultimum* to induce considerable disease on beets in soil treatments lacking *L. arvalis*. There was no significant difference in emergence of beet seedlings in pasteurized soils compared to untreated field soils when all *Pythium* spp. and *L. arvalis* treatments were considered together (Table 3, pasteurized versus untreated). There was, however, a significantly greater percentage of postemergence damping-off of beet seedlings in untreated soils compared to pasteurized soils and, therefore, significantly greater survival in pasteurized soil (Table 3, pasteurized versus untreated field soil treatment). Before replanting experiments were begun, pasteurized soil infested with *P. ultimum* allowed very little emergence of beet seedlings (Table 2). However, after replanting, there was significantly greater emergence and a significantly lower percentage of postemergence damping-off in pasteurized soil initially infested with *P. ultimum* than pasteurized soil initially lacking *P. ultimum* (Table 3). Assays of pasteurized soil initially lacking *P. ultimum* indicated that some *P. ultimum* was present after the fifth replanting (about two germinable propagules per gram) and was apparently due to contamination, perhaps by infested seed or splashed soil from other infested soils. Replanted soils with *L. arvalis* had significantly increased beet seedling emergence, decreased postemergence damping-off (untreated soil only), and greater survival than soils lacking *L. arvalis* (Table 3).

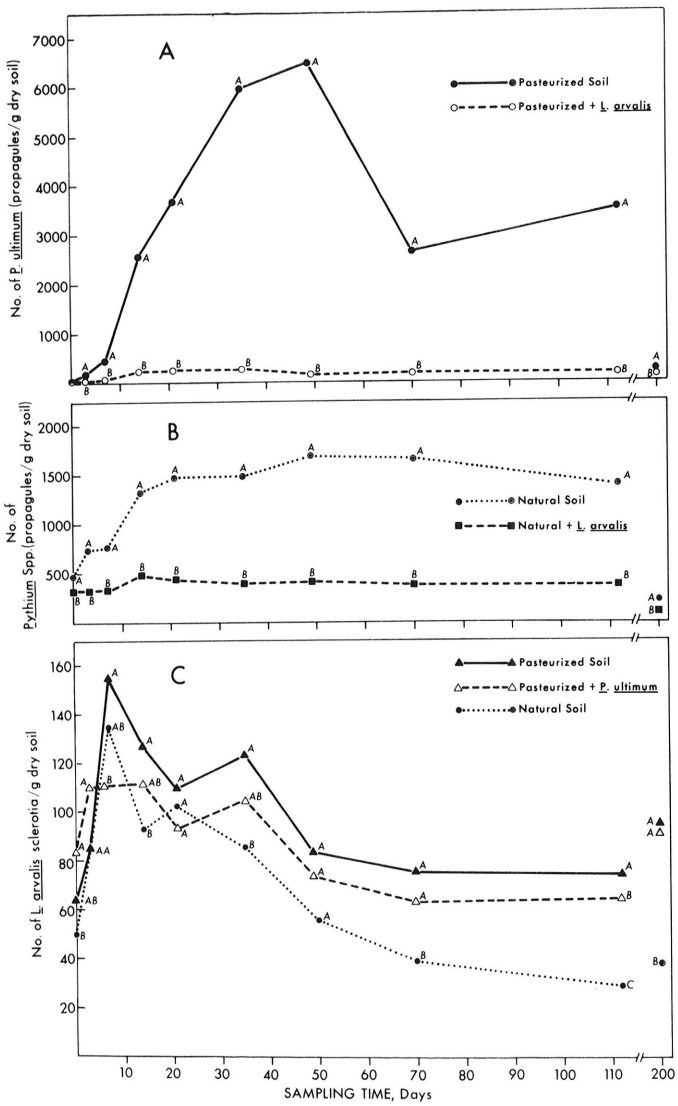


**Fig. 1.** Population dynamics of *Pythium* spp. and *Laetisaria arvalis* in infested, untreated and pasteurized field soils planted to table beets. **A,** Numbers of germinable propagules of *P. ultimum*/g oven-dry pasteurized soil alone and in combination with *L. arvalis*. **B,** Numbers of germinable propagules of low-temperature *Pythium* spp./g oven-dry untreated soil alone and in combination with *L. arvalis*. **C,** Numbers of viable sclerotia of *L. arvalis*/g oven-dry pasteurized or untreated soil. Data at 200-days sampling time represent propagule levels after replanting soils repeatedly to table beets. Points followed by different letters at each sampling time (vertically) are significantly different at $P = 0.05$, based on orthogonal contrasts of *L. arvalis*-amended versus nonamended soils (**A and B**). Statistics in Fig. 1C are based on the Waller-Duncan, $k$-ratio $t$-test ($P = 0.05$).

## DISCUSSION

Results of these experiments indicated that *L. arvalis* grown on either CLM or BP was effective in suppressing reproduction of low-temperature *Pythium* spp. in both untreated and pasteurized field soil planted to beets. When soils were left fallow, the germinable propagule density of *Pythium* spp. did not increase, indicating that host material, such as exudates from seeds or seedlings or other readily utilizable substrates, are necessary for reproduction. When pasteurized soil infested with *P. ultimum* was amended with CLM alone, the germinable propagule level increased at rates in agreement with previously published results (4). However, the germinable propagule levels of *P. ultimum* and other low-temperature *Pythium* spp. in fallow soils were not affected by *L. arvalis*. These results suggested that *L. arvalis* was not active against nongerminated *Pythium* spp. propagules. Increased emergence and decreased postemergence damping-off, and therefore increased seedling survival, were results of *L. arvalis* amendments in untreated and pasteurized soils. This was in agreement with previous experiments utilizing *L. arvalis* to control diseases induced by *P. ultimum* (5).

It was discovered late in our experiments that the nontreated beet seeds which we were using were about 80% infested with *Phoma betae* Frank. *Phoma betae* was detected by plating seedballs on the diagnostic medium of Bugbee (2). *Phoma betae* has been reported to induce symptoms on table and sugar beet seedlings similar to those induced by *P. ultimum* (13). Consequently, some of the observed disease symptoms (reduced plant stands, postemergence damping-off, and wire stem-type symptoms) could have been due to this seed-borne fungus. We later investigated this possibility by isolating fungi (using appropriate techniques) from diseased beet seedlings planted in field soils that were untreated, pasteurized, or pasteurized and then infested with *P. ultimum*. The soil used was from the same location as that used in the experiments mentioned above. The same table beet seed source and greenhouse conditions were also used. *Phoma betae* was only isolated or detected from diseased seedlings taken from pasteurized soil lacking *P. ultimum*. *P. ultimum* was isolated most frequently from diseased seedlings taken from untreated field soil and was isolated exclusively from diseased seedlings in *P. ultimum*-infested pasteurized soil (*unpublished*). Also, in pasteurized soil lacking *P. ultimum*, but amended with *L. arvalis*, very little disease was observed, indicating that the biological-control agent was also effective against *Phoma betae*. Although the presence of seeds infested with *P. betae* complicated interpretation of the disease data, the presence of the contaminant did not obscure the effects of *L. arvalis* on population dynamics of *P. ultimum* and other low-temperature *Pythium* spp. in pasteurized and untreated soils.

Replanted untreated and pasteurized field soils had much lower *Pythium* spp. levels than before replanting. Even pasteurized soils infested with *P. ultimum* and untreated soils lacking *L. arvalis* had decreased germinable propagule densities of *P. ultimum* and other low-temperature *Pythium* spp. We believe this was due to a buildup of microorganisms or substances other than *L. arvalis* which were also inhibitory to *Pythium* spp. Replanted *P. ultimum*-infested pasteurized soils lacking *L. arvalis* also eventually supported increased emergence and survival of beets, although there was still better suppression of *Pythium* spp. reproduction and lower disease incidence in similar soils infested with *L. arvalis*. Therefore, we believe *L. arvalis* was partially responsible for disease suppression

and decreased reproduction of *Pythium* spp. after replanting, although the lower inoculum densities of *Pythium* spp. may have contributed to the reduced disease incidence. It is well known that some soils may be induced to become suppressive to certain plant pathogens, although mechanisms of induced suppression are not well understood (10). Also, pasteurization of soils may allow for recolonization of soils by known antagonists of certain pathogens (1) and this could also be offered as explanation for "induced" suppressiveness in the pasteurized soil.

The primary strategy employed to control damping-off and root rot of table beet with *L. arvalis* is concerned with protection of the plants during the first 3 wk after planting, when beet seeds and seedlings are highly susceptible. However, the reduction of the inoculum density of *P. ultimum* later in the growing season or in the following year(s) could also be important in disease management. To evaluate the potential of these strategies, we have elected to "overwhelm" the pathosystem with *L. arvalis* grown on an organic base that was incorporated into soil at an elevated level. Large amendments of *L. arvalis* would not be economically feasible for a single season or crop. However, if such amendments enhance establishment of *L. arvalis* to provide control for many seasons, the cost of soil amendment with *L. arvalis* may become economically feasible. These strategies represent a reevaluation of conventional disease management systems.

The data presented in this paper indicated the ability of *L. arvalis* at high initial amendment levels to effectively suppress reproduction of low-temperature *Pythium* spp. The survival of *L. arvalis* over winter, whether or not certain cover crops are employed following beet cultivation, and other cultural practices, could also affect the initial populations of *P. ultimum* in the spring. We consider long-term population suppression of *P. ultimum* an additional desirable characteristic of *L. arvalis* as a biological-control organism, and a characteristic that may enhance induction of a suppressive soil. Both the short-term and long-term suppression of reproduction of *P. ultimum* by *L. arvalis* indicates the potential of this organism as one component of a disease management system.

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