Yields of Onion Cultivars in Midwestern Organic Soils Infested with *Fusarium oxysporum* f. sp. *cepae* and *Pyrenochaeta terrestris*

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ABSTRACT

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Long-day, yellow-skinned onion (*Allium cepa*) cultivars and experimental hybrids were evaluated for yield response in a field experiment on muck soils naturally or artificially infested with *Fusarium oxysporum* f. sp. *cepae* or *Pyrenochaeta terrestris* or both. Infestation with *Pyrenochaeta* significantly reduced numbers of plants but not weights of bulbs; infestation with *Fusarium* significantly reduced both numbers of plants and weights of bulbs per hectare. There was a significant interaction of *Fusarium* × cultivar ($P = 0.01$) and of *Fusarium* ×*Pyrenochaeta* × cultivar ($P = 0.05$) but not of *P. terrestris* × cultivar. Across the entire experiment, the cultivars XPH 419, Inca, XPH 70, Epoch, and MSU 8155 × 826 were in the highest yield range. Some cultivars not in this group yielded well in *Pyrenochaeta*-infested soil but not in *Fusarium*-infested soil. Overall, *Fusarium* reduced yields and stands more than *Pyrenochaeta*.

Basal rot, caused by *Fusarium oxysporum* f. sp. *cepae* (Hanz.) Snyd. & Hans., and pink root, caused by *Pyrenochaeta terrestris* (Hansen) Gorenz, J. C. Walker, & Larson, are among the important soilborne diseases of onion (*Allium cepa* L.) that occur in midwestern organic soils. Basal rot has long been recognized as a serious soilborne disease in the midwestern and eastern United States (1,2). Pink root has long been a severe problem annually in the southern and southwestern United States, and it may be severe on midwestern organic soils during periods of relatively high soil temperatures (4,12). Both basal rot and pink root develop best under controlled conditions at soil temperatures of 26–30 C (4,6,13).

The traditional method of control of these diseases has been through disease resistance, using genetic material developed by U.S. Department of Agriculture and agricultural experiment station researchers (4–6,8). The reaction of a limited number of onion cultivars to *F. oxysporum* in naturally infested midwestern organic soils has been studied, with significant yield reductions occurring with a high proportion of cultivars (1,2,7,10). Published studies of pink root resistance in the Midwest have been carried out in the greenhouse but not in the field (8,9).

The objective of this study was to evaluate in the field the yields of long-day, yellow-skinned onion cultivars when grown in organic soil artificially infested with high levels of *F. oxysporum* f. sp. *cepae* or of *P. terrestris*, with both pathogens together, or in soil with low, naturally occurring populations of both fungi (not artificially infested).

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MATERIALS AND METHODS

Inoculum for artificial infestation of soil was produced by growing isolates of *F. oxysporum* f. sp. *cepae* and *P. terrestris* on autoclaved wheat seed. Wheat seed (250 ml) plus 100 ml of distilled water were placed in a 1-L flask and autoclaved 1 hr, cooled, and inoculated with 1 cm^2 of colonized potato-dextrose agar. Flasks were shaken by hand daily (10 sec each). After 2 wk of incubation, the colonized wheat seed was air-dried and then coarsely ground in a Wiley mill, using a 3-mm screen. Inoculum was stored in a refrigerator at 2 C until used.

Onions were seeded in 3.1-m rows 56 cm apart at the Michigan State University Muck Experimental Farm, Bath, using a custom-built, V-belt seeder pushed by hand. Fonofos (*O*-ethyl-*S*-phenylethylphosphonodithioate; Dyfonate, 10% granules; 1.5 g) for onion maggot control and 180–200 onion seeds were uniformly placed on the seeder belt and drilled into each 3.1-m row. In each of three blocks, 10 ml of *Fusarium* inoculum, 10 ml of *Pyrenochaeta* inoculum, or 10 ml of *Fusarium* inoculum + 10 ml of *Pyrenochaeta* inoculum was added to the seed and insecticide prior to planting. The inoculum was thus placed in the row in contact with the seed. In a fourth block, no inoculum was added to the seed and insecticide. This block served as a naturally infested control. All cultivars were replicated four times randomly within the main plots.

Seeds for these studies were obtained from Dessert Seed Company, El Centro, CA; Asgrow Seed Company, Kalamazoo, MI; Crookham Seed Company, Caldwell, ID; J. W. Jung Seed Company, Randolph, WI; Krummrey Farms, Stockbridge, MI; and Horticulture Department, Michigan State University.

Plots were irrigated with a sprinkler system whenever soil from 8 cm below the soil surface would not retain its shape when squeezed in the hand. Weeds were controlled by treatment with recommended rates of chlorpropham (isopropyl *m*-chlorocarbanilate; Chloro IPC) and allidochlor (*N,N*-diallyl-2-chloroacetimide; Randox) before emergence and with nitrofen (2,4-dichlorophenyl-p-nitrophenyl ether; Tok) after emergence. Weeds were also removed by hand late in the season. Insects were controlled with weekly sprays of malathion or parathion at 998 g a.i./ha.

In mid-September, bulbs were harvested from 1.55-m sections of row in each plot, counted, and weighed after bulbs rotted by *F. oxysporum* or other organisms were culled and discarded. Because *P. terrestris* does not cause a bulb rot (11),

Table 1. Split-plot analysis of variance of onion plots infested with *Fusarium oxysporum* f. sp. *cepae* or *Pyrenochaeta terrestris* with whole plots treated as a 2 × 2 factorial

Source of variation[a]	d.f.	Plants (no./ha) Total SS	Mean SS	F^b	Bulb weights (kg/ha) Total SS	Mean SS	F
Pyrenochaeta (P)	1	10,287.16	10.287.16	149.65**	66.27	66.27	3.74
Fusarium (F)	1	85,052.35	85,052.35	1,237.28**	3,138.30	3,138.30	176.98**
P × F	1	6,851.81	6,851.81	99.68**	12.63	12.63	0.71
Error a (r + [P×R] + [F×r] + [r×P×F])	12	824.90	68.74		212.79	17.73	
Cultivar (C)	31	15,576.50	502.47	10.14**	1,021.11	32.94	11.97**
P × C	31	4,578.53	147.69	2.98**	89.51	2.89	1.05
F × C	31	4,229.34	136.43	2.75**	213.33	6.88	2.50**
P × F × C	31	3,487.62	112.50	2.27**	139.11	4.49	1.63*
Error b ([r×C] + [P×r×C] + [F×r×C] + [P×F×r×C])	372	18,428.85	49.54		1,023.81	2.75	
Total	511	149,317.06			5,916.85		

[a] r = number of replicates, a = number of whole plots, and b = number of subplots (11).
[b] * Indicates significance at $P = 0.05$, ** indicates significance at $P = 0.01$.

$S_{\bar{x}}$ of whole plot means across subplots $= \frac{E_a}{rb}$;

$S_{\bar{x}}$ of subplot means across whole plots $= \frac{E_b}{ra}$;

$S_{\bar{x}}$ of subplot means for one whole plot $= \frac{E_b}{r}$; and

$S_{\bar{x}}$ of whole plot means for one subplot, $S_{\bar{x}}$ of any whole plot mean for any one subplot $= \frac{(b-1)E_b + E_a}{ra}$

Table 2. Average stands and yields (healthy bulbs) of onion cultivars grown on muck soil over four treatments[y]

Cultivar	Stand[z] (no. plants/ha × 10^3)	Yield[z] (kg/ha × 10^3)
Simcoe	104.4 k[z]	12.8 i
Imperial Spice	277.1 efghij	16.7 hi
Hybrid PLK	355.0 bc	21.0 gh
Early Yellow Globe	277.8 efghij	21.2 gh
Rocket	274.1 efghij	21.9 gh
XPH 75	294.7 cdefghi	22.7 gh
Spartan Sleeper	307.2 cdefgh	26.8 fg
Rialto	231.5 ij	27.0 fg
Downing Yellow Globe	271.9 efghij	27.2 efg
Ontario	294.0 cdefghi	28.1 efg
Capable	297.7 cdefghi	31.1 def
Abundance	266.1 efghij	31.1 def
Yellow Sw. Span. (Asgrow)	255.8 fghij	31.2 def
Spartan	233.0 ij	31.3 def
Empire	239.6 hij	31.9 def
Taurus	321.9 bcdefg	32.5 def
Encore	269.7 efghij	32.6 def
Hybrid 9010	524.0 a	33.5 cdef
Yellow Sw. Span. (Dessert)	211.7 j	33.6 cdef
Garnet	267.5 efghij	34.4 cdef
XPH 25	281.5 cdefghij	34.6 cdef
White Sw. Span. (Peckham)	349.1 bcd	34.9 cde
Downing Yel. Globe (Krummrey)	253.6 ghij	37.3 bcd
Granada	330.0 bcde	37.9 bcd
Brown Beauty	330.0 bcde	38.2 bcd
Spartan Banner	297.7 cdefghi	38.3 bcd
Fiesta	318.2 bcdefg	38.5 bcd
MSU 8155 × 826	255.0 ghij	40.4 abc
Epoch	378.5 b	40.6 abc
XPH 70	272.6 defghij	43.4 ab
Inca	325.6 bcdef	44.0 ab
XPH 419	326.3 bcdef	47.2 a

[y] Naturally infested soil or soil artificially infested with *Pyrenochaeta terrestris, Fusarium oxysporum* f. sp. *cepae*, or both.
[z] Figures within a column followed by the same letter do not differ significantly (Duncan's multiple range test ($P = 0.05$). $S_{\bar{x}}$ for subplot mean $= \frac{E_b}{ra}$ was used to determine the significant ranges.

bulbs with pink roots were not culled.

Results were analyzed as a split-plot design (11) with main plots treated as a 2 × 2 factorial; the experimental design included cultivars (subplots) randomized and replicated four times within the main plots (*Fusarium* or *Pyrenochaeta* infestation, infestation with both, or naturally infested soil). Analysis of variance was done using the STAT4 statistical package on the Michigan State University Cyber 750 computer.

RESULTS

Thirty-two onion cultivars and lines were tested. Analysis of variance revealed that all treatments and interactions tested were significant ($P = 0.01$) with respect to plant numbers at harvest. However, with respect to weights of bulbs at harvest, only the effects of *Fusarium* infestation, cultivars, *Fusarium* × cultivar interaction ($P = 0.01$), and *Pyrenochaeta* × *Fusarium* × cultivar interaction ($P = 0.05$) were significant according to the F test (Table 1). *Pyrenochaeta* infestation, *Pyrenochaeta* × *Fusarium* interaction, and *Pyrenochaeta* × cultivar interaction were not significant ($P = 0.05$).

When cultivar performance was evaluated across all main plots with Duncan's multiple range test, the cultivars XPH 419, Inca, XPH 70, Epoch, and MSU 8155 × 826 were in the highest range of bulb weights (Table 2). There was not a significant correlation ($P = 0.05$) between bulb numbers and bulb weights ($r = 0.66$); for example, although Hybrid 9010 had by far the highest average number of bulbs across all treatments, it was ranked 15th out of 32 cultivars in average bulb weight. This evidently reflected the varying ability of cultivars to compensate for losses in stand with increased bulb size.

It was evident that *Fusarium* infestation of soil had a greater effect on both plant numbers and weights of bulbs at harvest than did *Pyrenochaeta* infestation (Table 3), although these effects varied considerably between cultivars. The greater effect of *Fusarium* may have been partly because *F. oxysporum* f. sp. *cepae* causes a bulb rot in the field (rotted bulbs were discarded at harvest), and *P. terrestris* damage is confined to the roots and does not affect the bulb directly except by reduction in bulb size. There was a significant interaction ($P = 0.01$) between *Fusarium* and *Pyrenochaeta* with respect

Table 3. Stands and yields (healthy bulbs) of onion cultivars grown on muck soil naturally or artificially infested[a] with *Pyrenochaeta terrestris*, *Fusarium oxysporum* f. sp. *cepae*, or both

Cultivar	Seed source	Noninfested Stand (no. plants/ ha × 10³)	Noninfested Yield (kg/ha × 10³)	*Pyrenochaeta* Stand (no. plants/ ha × 10³)	*Pyrenochaeta* Yield (kg/ha × 10³)	*Fusarium* Stand (no. plants/ ha × 10³)	*Fusarium* Yield (kg/ha × 10³)	*Fusarium* and *Pyrenochaeta* Stand (no. plants/ ha × 10³)	*Fusarium* and *Pyrenochaeta* Yield (kg/ha × 10³)
Encore	Dessert	482.1	40.9	305.7	40.0	199.9	26.6	117.6	17.5
Empire	Dessert	458.6	48.5	388.0	54.7	105.8	9.8	94.1	9.5
Simcoe	Dessert	223.4	19.9	188.1	21.2	47.0	1.1	58.8	6.8
Epoch	Dessert	776.1	53.1	458.6	55.7	223.4	25.3	223.4	21.6
Abundance	Dessert	552.7	44.2	341.0	41.4	164.6	15.1	141.1	18.4
Imperial Spice	Dessert	776.1	25.9	399.8	26.6	211.7	8.0	176.4	3.6
Spartan	Dessert	635.0	40.5	282.2	43.3	152.9	23.8	94.1	12.4
Hybrid 9010	Dessert	1,081.1	46.7	446.8	32.7	352.8	28.6	270.4	20.3
Hybrid PLK	Dessert	705.5	34.4	305.7	20.9	317.5	13.2	223.4	12.0
Yellow Sweet Spanish	Dessert	317.5	42.6	305.7	51.6	117.6	20.2	105.8	14.4
Capable	Dessert	564.4	48.7	505.6	46.9	117.6	12.2	94.1	10.7
Brown Beauty	Asgrow	599.9	51.7	423.3	48.5	258.7	22.5	223.4	23.7
Fiesta	Asgrow	482.1	60.9	341.0	40.2	294.0	24.9	211.7	21.5
Garnet	Asgrow	540.9	53.1	329.2	42.9	164.6	16.0	164.6	19.9
Granada	Asgrow	693.8	54.1	341.0	42.4	188.1	22.7	199.9	26.0
Ontario	Asgrow	646.7	39.0	341.0	37.4	211.7	15.2	223.4	15.9
Rocket	Asgrow	587.9	37.7	400.0	30.0	176.4	8.2	152.9	8.3
Inca	Asgrow	658.5	65.1	317.5	55.7	199.9	26.1	152.9	21.7
Taurus	Asgrow	587.9	41.6	411.6	45.2	246.9	24.2	152.9	13.8
Rialto	Asgrow	458.6	33.5	329.2	40.2	141.1	11.6	141.1	18.0
XPH 25	Asgrow	529.1	43.2	400.0	50.3	176.4	25.5	211.7	17.6
XPH 70	Asgrow	458.6	56.1	364.5	50.3	164.6	30.2	199.9	29.7
XPH 75	Asgrow	623.2	33.1	329.2	27.4	246.9	13.5	188.1	12.8
XPH 419	Asgrow	552.7	65.1	388.0	59.5	235.2	37.0	152.9	19.5
Downing Yellow Globe	Asgrow	587.9	45.4	305.7	33.3	176.4	11.1	152.9	14.3
Early Yellow Globe	Asgrow	634.9	38.2	294.0	22.5	129.3	10.7	129.3	9.8
White Sweet Spanish (Peckham)	Asgrow	635.0	55.6	411.6	43.3	129.3	16.0	176.4	18.7
Yellow Sweet Spanish	Asgrow	505.6	52.9	235.1	30.9	141.1	17.8	164.6	17.9
Spartan Banner	Crook-ham	587.9	54.0	388.0	51.6	188.1	25.5	105.8	15.5
Spartan Sleeper	M.S.U.	611.5	45.0	341.0	31.3	141.1	11.9	152.9	14.6
MSU 8155 × 826	M.S.U.	470.3	61.5	376.2	58.5	141.1	22.3	82.3	12.7
Downing Yel. Gl. (Krummrey Special)	Krumm-rey	517.4	60.7	235.1	39.8	176.4	19.5	117.6	23.0

[a] Ten milliliters of colonized wheat seed inoculum was placed evenly in 3.1 m of row at planting.

to their effect on plant numbers, but not with respect to bulb weights, as indicated by the *F* test ($P = 0.01$; Table 1). Comparison of main plot means with expected main plot means using a linear additive model showed that the two organisms together killed fewer plants than would be predicted from the sum of the two organisms separately.

Without exception, artificial soil infestation reduced stands and yields over naturally infested controls. Cultivars that yielded well under this high level of disease pressure could be expected to perform well in fields where either or both of these diseases has been a problem in the past.

DISCUSSION

In previous studies of the effects of both *F. oxysporum* f. sp. *cepae* and *P. terrestris* on onion cultivars in the field (14) or greenhouse (6), percentage of disease incidence or a visual severity rating was used as the main criterion for evaluating cultivars. In this study, survival of plants and final yields after culling rotted bulbs were used as the main criteria of evaluation. We found that it was very difficult to determine accurately in the field whether damage observed (eg, collapsed roots or rotted bulbs) was caused only by one pathogen or the other without spending an inordinate amount of time on isolation of pathogens. In heavily infested soils, survival and yields should be a direct index of resistance to the organisms used to infest the soil.

Most of the cultivars that yielded well in the *Fusarium*-infested plots also yielded well in plots infested with both fungi (Table 3). Some cultivars that yielded well in *P. terrestris*-infested soil did not yield well in *F. oxysporum*-infested soil. *F. oxysporum* appeared to be the more important influence on yields in plots infested with both fungi. There was no evidence for the inverse relationship between pink root and basal rot resistance reported by Wooliams (14).

Stands were greatly reduced in *Fusarium*-infested plots in the field during seedling development, and *F. oxysporum* f. sp. *cepae* was recovered from diseased seedlings. Seedling death resulting from *F. oxysporum* f. sp. *cepae* infection has been reported (1,3,6), but it is often overlooked as a cause of yield reductions.

Number of bulbs per hectare and weight of bulbs per hectare were not significantly ($P = 0.05$) correlated, probably because of variations in average bulb weight. For example, the cultivar XPH 70 ranked third in yield over all treatments but had significantly fewer bulbs per hectare than Epoch, which ranked fourth (Table 2). Bulbs of XPH 70 averaged 159.2 g each, whereas bulbs of Epoch averaged only 107.3 g each.

Two of the cultivars most commonly grown in Michigan (Downing Yellow Globe and Spartan Banner) were among the higher yielding cultivars tested (Tables 2 and 3). The hybrid Spartan Banner appeared to be slightly more resistant to *Pyrenochaeta* than the open-pollinated Downing Yellow Globe.

MSU 8155 × 826 (soon to be named and released) appeared to be a good candidate for mild Sweet Spanish onion production, which is increasing in acreage in northern muckland soil areas.

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