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Effect of Powdery Scab Root Galls on Yield of Potato in the Columbia Basin

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Powdery scab of potato, caused by the soilborne, plant endoparasitic slime mold, *Spongospora subterranea*, is a major concern for potato production in the Columbia Basin. Occurrence of powdery scab in the Columbia Basin before 1981 was limited and sporadic, whereas now the disease occurs at high severities in many fields throughout the region. The pathogen is present in many potato production regions worldwide. Infected seed tubers and contaminated soils are means of disseminating the pathogen, and *S. subterranea* also transmits the *Potato mop top virus* that causes potato mop top.

Powdery scab symptoms are confined to belowground plant organs, and generally do not become visible for three or more weeks after infection. Infection results in abnormal enlargement or hypertrophy of cells. Infected roots and stolons develop wart-like galls, which are white at first and turn brown to black as they mature. Galls vary in size up to that of a pea. Disease symptoms on young tubers consist of small, gray, elevated pustules on the tuber surface. Pustules later dry and break open, leaving circular to oval, small, scabby pits. The pits contain a yellow-brown powder that consists of a mass of clustered spores. Pustules on tubers can be entry points for infection by pathogens that cause pink rot and late blight. Pustules on tubers additionally break the preventive chemical barrier to pink rot and late blight pathogens formed at the tuber periderm from systemic fungicides such as metalaxyl.

Most commercial potato cultivars develop root galls at various severities when inoculum levels and environment favor infection. Tubers of white and red skinned potato cultivars are susceptible, and those of russet skinned cultivars are partially resistant and are usually not damaged significantly (Nitzan et al. 2010). Resistances to the root and tuber phases of the disease appear to be inherited independently.

Plants with a severe level of root galls have been reported to wilt and die, but this is seldom observed (Christ 2001). Powdery scab root galling was stated to cause yield losses of up to 5 to 12 metric tons/ ha in Washington State (Brown et al. 2007); however, a non-infected control treatment for comparison with infected plants, and the elimination of other soilborne pathogens such as *Verticillium dahliae* (Verticillium wilt) and *Colletotrichum coccodes* (black dot) were not done in that study to make a reliable loss estimation. In a controlled experiment in Colombia, reductions of 23% for plant length, 32% for foliar dry weight, and 30% for tuber weight were attributed to powdery scab root galling for the cultivar Diacol Capiro, which is a member of the *andigena* subspecies of *S. tuberosum* (Gilchrist et al. 2011). Infested and non-infested soil in containers was used in that study in Colombia, but methods were not described for how the soil was infested and whether other pathogens were successfully excluded (Gilchrist et al. 2011). Tuber yield of potato was also reduced in a shadehouse environment

Results

Trials in 2007 and 2008. Powdery scab root galls were not observed on plants grown in the non-infested soil at Othello, WA in both years of the trial. Root galls were not recorded on potato plants grown at Warden, WA in 2007, but they were observed at that location in 2008. All plants of Umatilla Russet and Shepody had root galls, whereas only 11% of Summit Russet plants had root galls (Table 1). Plants of Summit Russet had significantly fewer ($P < 0.05$) galls than Umatilla Russet or Shepody; whereas plants of Shepody had significantly more ($P < 0.05$) galls than either Summit Russet or Umatilla Russet in 2008. Mean gall index for Shepody, Umatilla Russet, and Summit Russet were 2.67, 1.22, and 0.11, respectively (Table 1).

Mean yield/ plant was significantly greater ($P < 0.05$) for Shepody and Umatilla Russet than for Summit Russet at both locations in both years (Table 1). Mean yield/ plant in 2008 ranged from 2078 to 2263 g for Shepody and Umatilla Russet and from 1078 to 1300 g for Summit Russet. Mean number of tubers/ plant was significantly less ($P < 0.05$) for Summit Russet (4.1) than the other two cultivars at Warden in 2008 (6.3 for Shepody and 10.2 for Umatilla Russet). Mean tuber weight was significantly greater ($P < 0.05$) for Shepody than for Umatilla Russet and Summit Russet, and did not significantly differ ($P > 0.05$) between Umatilla Russet and Summit Russet at both locations in 2008 (Table 1).

Yield ratios for mean yield per plant, mean number of tubers and mean tuber weight were $\geq$ 0.99 for Shepody and > 1.00 for Umatilla Russet in 2008 (Table 1). Yield ratios for Summit Russet were < 1.00 for mean yield per plant (0.83) and number of tubers (0.65) and > 1.00 for tuber weight (1.30) in 2008.

Trials in 2010 through 2012. Powdery scab root galls were not observed on plants grown in the non-infested soil at Othello, WA in all three years of the trial. Root galls were observed on potato plants in the infested soil at Warden in 2010, 2011, and 2012 (Table 2). All plants of Umatilla Russet and Shepody had root galls, whereas, only 41 to 53% of the Mesa Russet plants had root galls over the three years (Table 2). Severity of galls and incidence of root systems with galls were both significantly less ($P < 0.05$) for Mesa Russet than for Umatilla Russet in 2010, and were significantly less ($P < 0.05$) for Mesa Russet than for Umatilla Russet and Shepody in 2011 and 2012. Mean gall index for Shepody were 3.53 in 2011, and 4.13 in 2012. Mean gall index the three years for Umatilla Russet ranged from 1.83 in 2010 to 2.87 in 2012, and for Mesa Russet it ranged from 0.46 in 2010 to 0.65 in 2012.

Mean yield per plant, mean number of tubers per plant, and mean tuber weight were significantly greater ($P < 0.05$) for Umatilla Russet than for Mesa Russet in infested and non-infested soil in 2010 (Table 2). Mean yield per plant did not significantly differ ($P > 0.05$) among the three cultivars in infested and non-infested soil in 2011 and in infested soil at Warden in 2012, but was significantly greater ($P < 0.05$) for Umatilla Russet (2874 g) than for Shepody (1899 g) and Mesa Russet (1718 g) in non-infested soil at Othello in 2012. Mean number of tubers were significantly greater ($P < 0.05$) for Umatilla Russet (10.0 and 9.2 in infested and non-infested, respectively) and Mesa Russet (9.8 and 9.3 in infested and non-infested, respectively) than for Shepody (6.1 and 7.0 in infested and non-infested, respectively) in infested and non-infested soil in 2011, and was significantly greater ($P < 0.05$) for Umatilla Russet (16.4 and 22.6 in infested and non-infested, respectively) than Mesa Russet and Shepody (ranged of means from 9.8 to 10.3) in infested and non-infested soil in 2012. Mean tuber weight did not differ significantly ($P > 0.05$) between Mesa Russet and Umatilla Russet in infested and non-infested soil in 2011, and between Mesa Russet and Shepody in infested and non-infested soil in 2012 (Table 2).

During 2010 to 2012, the yield ratio for total yield for Umatilla Russet was < 1 only in one of the three years (0.82 in 2012), but was $\geq$ 1 in two of two years (1.00 and 1.28 in 2010 and 2011, respectively) (Table 2). Total yield ratio was > 1 for Shepody in two of two years (1.26 and 1.14 in 2011 and 2012, respectively), and was > 1 for Mesa Russet in two of the three years (1.25 and 1.45 in 2011 and 2012, respectively). Total yield ratio for Mesa Russet was 0.91 in 2010. The yield ratio for number of tubers was < 1 in two of three years for Umatilla Russet (0.82 and 0.73 in 2010 and 2012, respectively), in two of two years for Shepody (0.87 and 0.89 in 2011 and 2012, respectively), but only in one of three years for Mesa Russet (0.92 in 2010). The ratio for mean tuber weight was notably > 1 in three of three years for Umatilla Russet (1.23, 1.24, and 1.13 in 2010, 2011, and 2012, respectively); in two of two years for Shepody (1.44 and 1.30 in 2011 and 2012, respectively); and in two of three years for Mesa Russet (1.19 and 1.43 in 2011 and 2012, respectively). The ratio for mean tuber weight was 0.97 for Mesa Russet in 2010.

Mean yield per plant, mean number of tubers, and mean tuber weight for Umatilla Russet and Shepody either did not significantly change ($P > 0.05$) or significantly increased ($P < 0.05$) as gall index increased in 2010 (Fig. 1), 2011 (Fig. 2), and 2012 (Fig. 3). Mean yield per plant for Shepody decreased as gall index increased in 2011, but only at the 11% ($P = 0.11$) significance level, not the 5% ($P = 0.05$) levels of testing (Fig. 2). Mean tuber weight significantly increased as gall index increased for Umatilla Russet ($P = 0.016$) in 2010 and 2012 ($P = 0.015$). Mean number of tubers for Mesa Russet significantly decreased ($P = 0.02$) as gall index increased in 2012 (Fig. 3), but not for any other yield component for Mesa Russet the other two years (Figs. 1 and 2).

Discussion

Potato tuber yields for the three yield components of yield/ plant, number of tubers/ plant, and weight of tubers/ plant were not negatively affected by powdery scab on roots of Umatilla Russet and Shepody, as indicated by the yield ratio measure for three of the four years, and by regression analyses calculated for three of three years. Regression lines with a non-significant slope or slopes that significantly increased with gall index also indicated that the number of root galls/ plant did not reduce yield significantly. The yield ratios between infested and non-infested fields for mean yield per plant and mean numbers of tubers for Umatilla Russet in 2012 were the exception, and, as this cultivar displayed, had low yield ratios. However, the regression slopes for those two variables for Umatilla Russet in 2012 did not decrease, indicating that yield was not affected by the number of powdery scab galls. The low yield ratios for Umatilla Russet that year were likely due to the cultivar producing a relatively high yield in the non-infested field, as significant differences were not recorded for total yield between the infested and non-infested soils. Shepody was more susceptible to root galling than Umatilla Russet but total yield was not affected significantly in either cultivar.

The significant increase in mean tuber weight with increasing root gall index for Umatilla Russet in 2010 and 2012 in this study was likely due to a decrease in number of tubers/ plant, which increased mean tuber weight. This was supported by a yield ratio < 1.0 for the number of tubers/ plant in 2010 and 2012, but not in 2011 (Table 2). Consequently, tuber number/ plant may be reduced with increasing number of powdery scab root galls/ plant and, therefore, increase the mean tuber weight.

The yield ratios and regressions analyses in this study were both satisfactory methods of assessing the effect of powdery scab root galls on yield. The slopes of the yield component plots against number of galls or gall index likely gave a more precise indication of the effect of galling on yield than yield ratios. This is because the effect of disease severity on yield was considered using adjacent plants within the same plots and not compared between plots in different fields. However, yield ratios as determined in this study have validity in giving an estimate of the effect of disease on yield.

An action threshold greater than the number of galls encountered in this study on roots of Umatilla Russet and Shepody is needed before an economic loss can be expected at more severe levels of powdery scab, and to assess the economic viability of control tactics for powdery scab (Rowe and Powelson 2008). The mean gall index for Shepody was 4.13 in 2012, which represents 141 galls/ plant. A greater number of galls/ plant may reduce potato yields. Consequently, the outcome of this study suggests that specific control tactics directed solely at preventing powdery scab galls on roots are not economically justified for powdery scab root galls in the Columbia Basin. However, *S. subterranea* and *Colletotrichum coccodes*, the cause of potato black dot, may interact to produce more severe disease and plant damage (D.A. Johnson, *unpublished data*). Resistant germplasm to both *S. subterranea* root galling (Nitzan et al. 2008, 2010) and stem and root invasion by *C. coccodes* (Nitzan et al. 2009) are available, and the development of cultivars resistant to both pathogens is desirable to reduce the harmful effects of interactions between the two pathogens on potato. Resistance to root galling could be important to prevent a buildup of soilborne inoculum for future growing seasons, even though there is no evidence of a direct effect of the disease on yield at levels of soilborne inoculum that have been detected in the Columbia Basin to date. On account of a potential synergistic interaction with *C. coccodes*, resistance to black dot development in roots should be sought.

The decrease in yield with increasing gall index observed on Mesa Russet in 2012 does not indicate that yield was affected by root galls on this resistant cultivar. The gall index for Mesa Russet ranged from 0 to 1 and represented a maximum of 15 galls/ plant. One gall/ plant resulted in a gall index of 1. The narrow range for the dependent variable gall index was not sufficient to detect an effect on yield by regression analysis for Mesa Russet. A gall index was used in this study because counting individual galls on root systems was time consuming. Estimating the number of root galls and using the gall index was sufficiently accurate for the objectives of the study. The value of gall index, as expected, was directly correlated to the number of root galls observed/ plant.

A reduction in potato yield due to powdery scab root galling was expected but not encountered in this study. The different reactions to root gall measured on potato in Colombia (Gilchrist et al 2011) and Australia (Shah et al. 2012) vs. this study may be associated with the cultivars, severity of root galls, environment, available soil moisture, and method of estimating the effect of the pathogen on yield. Severity of root galls on Shepody in this study was severe with > 30% of the root area displaying galls. Potato roots with galls were demonstrated to have a reduced capacity to take up water in a study by Falloon et al. (2004), in which test plants were grown in soil infested with spores obtained by scraping powdery scab lesions from tubers produced in the field. An impediment of water uptake due to root galls might be overcome in the field with ample soil moisture provided by irrigation or rainfall. Pivot irrigation systems in the Columbia Basin of Washington State supply 50 to 76 cm/ha for a growing season, which is a plentiful supply of water.

A comparison of yield from cultivars resistant and susceptible to root galling in naturally infested and non-infested field soil was used to measure the effect of powdery scab root galls on potato yield in this study. Yields of potato cultivars Shepody and Umatilla Russet, two commonly grown cultivars in the Columbia Basin, were not impaired by the levels of root galling caused by *S. subterranea* in this region. Evaluations were done in fields under conditions used for commercial potato production in the Columbia Basin of Washington State, not in a greenhouse or shadehouse. Consequently, control tactics directed solely at reducing powdery scab galls on roots are not economically justified at the levels of soilborne inoculum of *S. subterranea* encountered in the Columbia Basin fields used for this study.

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Table 1. Severity and incidence of root galls, yield components, and yield ratios for Summit Russet, Umatilla Russet, and Shepody planted in soils naturally infested with powdery scab (*Spongospora subterranea*) and in non-infested soils in separate locations in the Columbia Basin, WA in 2007 and 2008

Year	Disease/Location Cultivar [a] (n) [b]	Gall Index	(%) Gall Incidence	Yield/ plant (g)	Number of tubers/plant	Mean tuber weight (g)
2007	Non-infested/Warden					
	Shepody (4)	0	0	1801 a	5.3 b	340 a
	Umatilla Russet (4)	0	0	1784 a	10.8 a	166 c
	Summit Russet (5)	0	0	630 b	3.3 c	193 b
	Non-infested/Othello					
	Shepody (5)	0	0	2098 a	6.4 b	331 a
	Umatilla Russet (6)	0	0	1995 a	10.9 a	183 b
	Summit Russet (5)	0	0	1061 b	6.6 b	161 b
2008	Infested/Warden					
	Shepody (6)	2.67 a	100 a	2098 a	6.3 b	333 a
	Umatilla Russet (5)	1.22 b	100 a	2263 a	10.2 a	221 b
	Summit Russet (4)	0.11 c	11 b	1078 b	4.1 c	261 b
	Non-infested/Othello					
	Shepody (6)	0	0	2078 a	6.2 b	334 a
	Umatilla Russet (6)	0	0	2080 a	9.5 a	219 b
	Summit Russet (6)	0	0	1300 b	6.4 b	203 b
	Yield Ratio [c]					
	Shepody (6)	-	-	1.01 ab	1.02 a	0.99 b
	Umatilla Russet (5)	-	-	1.09 a	1.08 a	1.01 b
	Summit Russet (4)	-	-	0.83 b	0.65 b	1.30 a

[a] Values for each set of cultivars within a site and year with the same letter are not significantly different at $P = 0.05$ using analysis of variance.

[b] (n) number of replicated plots (experimental units) where each plot was a mean of 18 subsampled plants.

[c] Yield ratio was calculated for each yield component from each cultivar plot from infested soil divided by the mean of all plots of that cultivar from non-infested soil where means were compared among cultivars using analysis of variance.

Table 2. Severity and incidence of root galls, yield components, and yield ratios for Mesa Russet, Umatilla Russet, and Shepody planted in soils naturally infested with ~~the~~ powdery scab (*Spongospora subterranea*) and in non-infested soils in separate locations in the Columbia Basin, WA from 2010 to 2012

Trial Year	Disease/Location Cultivar [ab]	Gall Index	(%) Gall Incidence	Yield/ plant (g)	Number tubers/plant	Mean tuber weight (g)
2010 [c]	Infested/Warden					
	Umatilla Russet	1.83 a	100 a	2810 a	11.9 a	235. a
	Mesa Russet	0.46 b	41 b	2194 b	7.1 b	311. b
	Non-infested/Othello					
	Umatilla Russet	0	0	2803 a	14.7 a	191 a
	Mesa Russet	0	0	2400 b	7.7 b	312 b
	Yield Ratio [d]					
	Umatilla Russet	-	-	1.00 a	0.82 a	1.23 a
	Mesa Russet	-	-	0.91 a	0.92 a	0.97 b
2011	Infested/Warden					
	Shepody	3.53 a	100 a	2245 a	6.1 b	362 a
	Umatilla Russet	2.23 b	100 a	2331 a	10.0 a	233 b
	Mesa Russet	0.53 c	53 b	2633 a	9.8 a	265 b
	Non-infested/Othello					
	Shepody	0	0	1779 a	7.0 b	254 a
	Umatilla Russet	0	0	1742 a	9.2 a	190 b
	Mesa Russet	0	0	2101 a	9.3 a	226 ab
	Yield Ratio [d]					
	Shepody	-	-	1.26 a	0.87 a	1.44 a
	Umatilla Russet	-	-	1.28 a	1.07 a	1.24 a
	Mesa Russet	-	-	1.25 a	1.05 a	1.19 a
2012	Infested/Warden					
	Shepody	4.13 a	100 a	2161 a	9.8 b	220 a
	Umatilla Russet	2.87 b	100 a	2366 a	16.4 a	144 b
	Mesa Russet	0.65 c	48 b	2498 a	10.2 b	245 a
	Non-infested/Othello					
	Shepody	0	0	1899 b	11.0 b	172 a
	Umatilla Russet	0	0	2874 a	22.6 a	127 b
	Mesa Russet	0	0	1718 b	10.3 b	166 a
	Yield Ratio [d]					
	Shepody	-	-	1.14 b	0.89 ab	1.30 ab
	Umatilla Russet	-	-	0.82 c	0.73 b	1.13 b
	Mesa Russet	-	-	1.45 a	0.99 a	1.43 a

[a] Values for each set of cultivars within a site and year with the same letter are not significantly different at $P = 0.05$ using analysis of variance.
[b] Calculated from a mean of three subsampled plants each for gall index and yield per cultivar with ten replications.
[c] Shepody was not grown in 2010.
[d] Yield ratio was calculated for each yield component from each cultivar plot from infested soil divided by the mean of all plots of that cultivar from non-infested soil where means were compared among cultivars using analysis of variance.

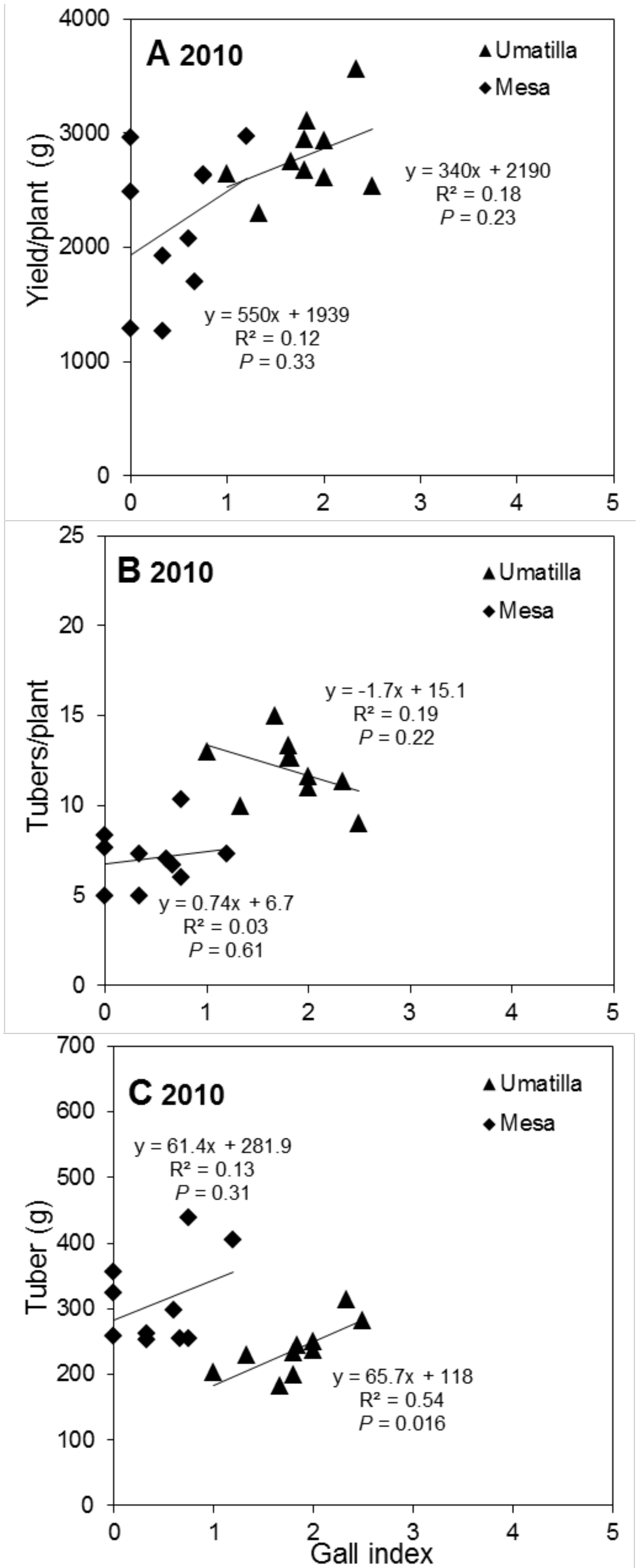

Fig. 1. Yield components for the potato cultivars Umatilla Russet, and Mesa Russet in relation to root gall index for galls caused by *Spongospora subterranea* at Warden, WA in 2010.

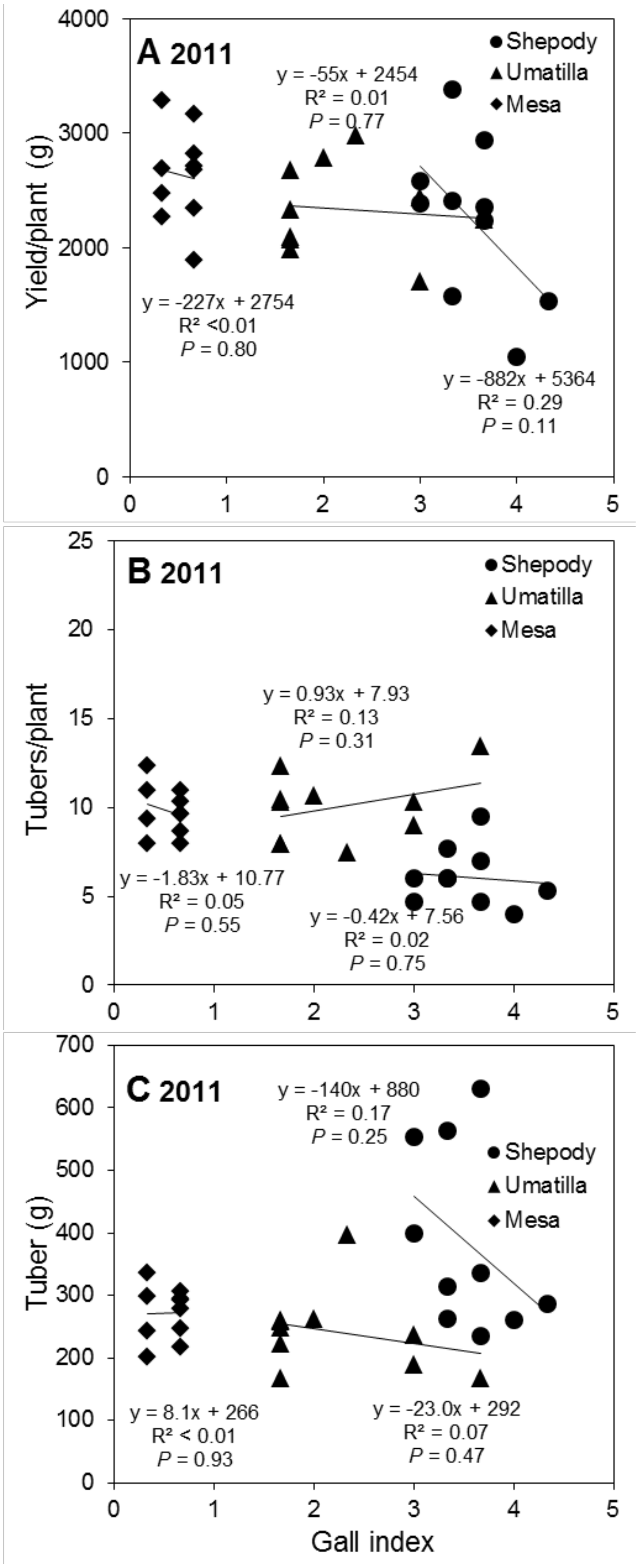

Fig. 2. Yield components for the potato cultivars Shepody, Umatilla Russet, and Mesa Russet in relation to root gall index for galls caused by *Spongospora subterranea* at Warden, WA in 2011.

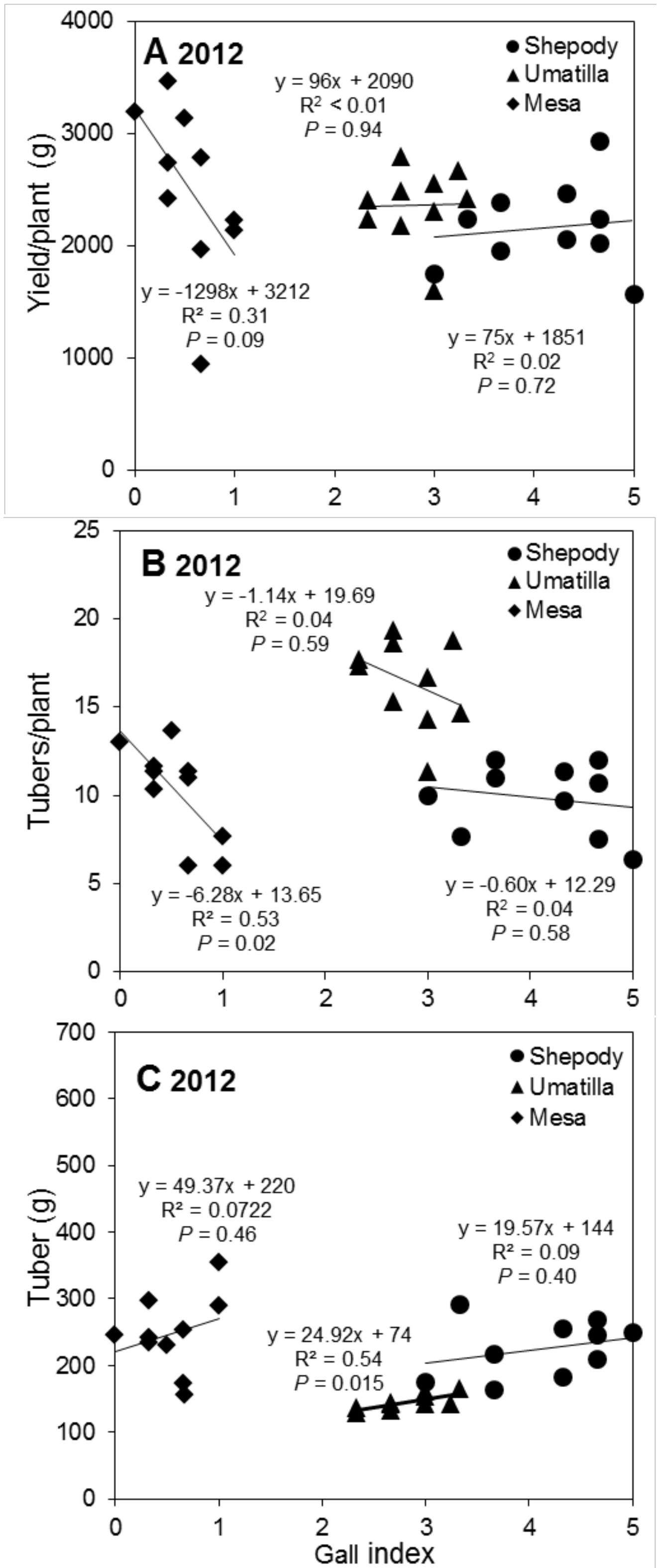

Fig. 3. Yield components for the potato cultivars Shepody, Umatilla Russet, and Mesa Russet in relation to root gall index for galls caused by *Spongospora subterranea* at Warden, WA in 2012.