# Effects of Soybean Stand Reduction and Phytophthora Root Rot on Yield

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**ABSTRACT**

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In this study, two near-isogenic soybean lines, Corsoy, susceptible, and L27, resistant to Phytophthora root rot (and the removal of plants to simulate the effects of stand reduction due to the disease) were used to examine how *Phytophthora* reduces yield. Results from experiments in two of the three environments tested indicated that factors other than stand reduction were contributing to yield reduction due to Phytophthora root rot. In the third environment, which had the lowest disease incidence, reduction in the number of plants per plot was the most critical factor influencing yield loss.

Phytophthora root rot, caused by *Phytophthora megasperma* f. sp. *glycinea*, is one of the most destructive diseases of soybean (*Glycine max* (L.) Merr.). The disease is most severe on poorly drained, clay soils and can attack plants at any stage of growth (8).

Reports of yield losses due to Phytophthora root rot (PRR) are numerous (3,14), although experiments designed to study how the pathogen reduces yield are limited. When measuring yield losses due to natural infestations of the pathogen, it is necessary to establish both diseased and disease-free treatments in the same field experiment. Several methods, including use of fungicides, isogenic lines, and cultivars that vary in susceptibility but have similar yield potential in the absence of disease, have been used (6). Removal of plants also has been used to simulate the effects of diseases that cause the loss of whole plants (7). Tooley and Grau (16) used the systemic fungicide metalaxyl and cultivars with similar yield potential to express cultivar resistance in terms of fungicide equivalency. As part of their finding, they concluded that a reduction in the number of yielding plants was the most critical factor contributing to yield reduction due to PRR. These results differ from those of Meyer and Sinclair (10), who found that plant height and yield of susceptible isolines was reduced with no visible disease symptoms.

The objectives of this study were to determine if yield reduction seen in the susceptible cultivar Corsoy vs. resistant isoline L27 was due solely to stand

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reduction, or if PRR also was affecting the yield of surviving plants.

## MATERIALS AND METHODS

This study was conducted at two locations: at the University of Illinois, Agronomy-Plant Pathology South Farm, Urbana (South Farm) on a Flannagan silt loam soil (Aquic Argindoll) and at the Agricultural Engineering Farm, Urbana, IL, on a Drummer silty clay loam soil (Typic Haplaquoll) in 1983 and 1984. The Drummer soil is poorly drained, while Flannagan is somewhat poorly drained. Both locations have a natural infestation of *P. m.* f. sp. *glycinea*. Fields used on the South Farm were in a corn-soybean rotation, while the field used at the Agricultural Engineering Farm had been planted to soybeans prior to 1983. Weeds were controlled both years at the Agricultural Engineering Farm with a preplant application of 2.8 kg a.i./ha of metolachlor (2-chloro-*N*-[2-ethyl-6-methylphenyl]-*N*-[2-methoxy-1-methylethyl] acetamide) and with 3.36 kg a.i./ha of chloramben (3-amino-2,5-dichlorobenzoic acid), cultivation, and hand hoeing. Weeds were controlled both years at the South Farm with a preplant application of 1.12 kg a.i./ha of trifluralin ($\alpha,\alpha,\alpha$-trifluoro-2,6-dinitro-*N,N*-dipropyl-*p*-toluidine), cultivation, and hand hoeing. The study at the Agricultural Engineering Farm was part of a soil compaction study. Prior to planting, the compaction treatment was imposed on strips selected at random in the plot area by repeatedly driving a tractor over the plots. Soil compaction treatments significantly increased bulk density in compacted vs. uncompacted plots both years.

The near-isogenic lines Corsoy and L27 (Corsoy$^8$ × Kingwa) (Bernard, *personal communication*) were planted in plots with four rows (seeding rate of 32 seeds per meter of row), 76 cm apart and 4.6 m in length, on 26 May and 8 June 1983, and 14 and 31 May 1984 at the South Farm and on 11 and 24 May 1983, and 2 and 31 May 1984 at the Agricultural Engineering Farm. The two lines differ in PRR resistance, with Corsoy (*rps*$_1$) susceptible, and L27 (*Rps*$_1$$^k$) resistant to races 1–11 and 13–15 (1). Stand reduction treatments of 0, 25, 50, and 75% were imposed at the V-8 growth stage (4) on plots planted to L27 by cutting off the stem below the cotyledonary node. The resulting experimental units were four-row plots of Corsoy, L27, L27-.25 (every fourth plant removed), L27-.50 (every other plant removed), and L27-.75 (three of every four plants removed). The experiments at the Agricultural Engineering Farm were replicated three times in a split-plot arrangement of a randomized complete block design in which the compacted or uncompacted treatments were whole plots; stand reduction treatments and planting dates were subplots. The experiments at the South Farm had three replications in a randomized complete block design.

Parameters measured were plant height, lodging, seed weight, total number of plants emerged, total number of dead plants, and seed yield. All data were collected on the center two rows of each plot from a 3.1-m section. Plant height was measured at maturity as height in centimeters of an average plant from the soil surface to the uppermost node. Lodging was rated on a scale of 1 (all plants erect) to 5 (all plants prostrate). Seed weight was measured as g/100 seeds. Total number of plants emerged was measured at 14 days after planting in 1983 and 21 days after planting in 1984. Total number of dead plants were identified and removed at 1-wk intervals, and later in the season at 2-wk intervals. Seed yield (kg/ha) was measured by harvesting the center two rows that had been trimmed to 3.1 m prior to maturity. Disease incidence was calculated for each plot by expressing dead plants as a percent of the total number of plants emerged. Final stand was calculated for each plot by subtracting the total number of dead plants and the number of plants removed by the stand reduction treatments. Yield per plant was calculated by dividing the seed yield by the final number of plants. Percent of L27 was calculated as the percent yield of that cultivar to the overall mean yield of L27 in that particular experiment.

Data were analyzed by analysis of covariance and analysis of variance for each year and location, and combined over years for each location (13). In the combined analysis of the experiments at the Agricultural Engineering Farm, replications were considered random effects, while year, compaction, stand reductions, and planting dates were considered fixed effects. In the combined experiments at the South Farm, replications were considered random effects, while year, stand reductions, and planting dates were considered as fixed effects.

## RESULTS AND DISCUSSION

The combined analysis of variance for the two years at the South Farm showed significant stand treatment effects for all variables measured (Table 1). Year effects were also significant for seed weight, plant height, number of plants emerged, and final number of plants.

The mean of all stand treatments averaged over years indicated a large difference in disease incidence between Corsoy and L27 treatments (Table 2). Although the mean disease incidence for L27 treatments was less than 1%, L27 plots were not *Phytophthora*-free and full yield potential probably was not reached. Significantly fewer Corsoy seedlings emerged than in the L27 treatments, which may indicate Corsoy suffered some preemergence damping-off. Due to disease incidence and number of plants emerged, final number of plants for

**Table 1.** Analysis of variance for the plant density study grown at two planting dates in 1983 and 1984 at the Agronomy-Plant Pathology South Farm

| | | Mean squares | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Source of variation[a] | df | Seed yield | Seed weight | Plant height | Lodging | Total plants emerged | Final plants (no.) | Yield/plant | Percent of L27 | Disease incidence |
| Year (Y) | 1 | 549,633 | 3.26 | 10,737** | 0.82 | 15,424*[b] | 14,337* | 790 | 514 | 107 |
| Error A | 4 | 760,205 | 1.01 | 396 | 0.22 | 1,262 | 839 | 234 | 714 | 26 |
| Stand treatments (S) | 4 | 2,699,315** | 1.35* | 488** | 0.86** | 2,353* | 35,695** | 1,846** | 2,525** | 817** |
| Y × S | 4 | 242,849* | 1.50* | 167* | 0.45** | 2,996** | 4,427** | 265* | 227* | 153** |
| Date (D) | 1 | 98,862 | 1.87* | 1,548** | 0.15 | 345 | 217 | 18 | 92 | 263** |
| Y × D | 1 | 901,742** | 0.86 | 27 | 0.07 | 166 | 288 | 10 | 211* | 764** |
| S × D | 4 | 94,060 | 0.11 | 13 | 0.12 | 706 | 557 | 158 | 88 | 271** |
| Y × S × D | 4 | 196,625* | 0.20 | 97 | 0.04 | 553 | 2,012** | 158 | 184* | 594** |
| Error B | 36 | 70,527 | 0.45 | 53 | 0.04 | 610 | 295 | 77 | 66 | 12 |
| C.V.[c] (%) | | 10.2 | 4.60 | 9.40 | 12.90 | 14.20 | 14.80 | 30.80 | 10.20 | 82.60 |

[a] Replication was considered a random effect; years, cultivars, and planting dates were considered fixed effects.
[b] * = Values exceed the 0.05 probability level; ** = values exceed the 0.01 probability level.
[c] C.V. = coefficient of variation.

Corsoy was not significantly different from L27-.25. If reduction in the number of plants is the most important factor contributing to yield reduction by PRR, then Corsoy and L27-.25 should have similar yield. Seed yield and percent yield of L27 indicated lower yields in Corsoy than L27-.25 or L27-.50, although only significantly lower than L27-.25. Cultivars Corsoy and L27 were also tested using analysis of covariance to determine whether the cultivars differed in yield when final plant numbers were adjusted to a common level. The adjusted yields were 2,338 and 3,237 kg/ha for Corsoy and L27, respectively, and were significantly different. These data suggest that PRR reduced yield by adversely affecting the yield of susceptible plants not killed by the pathogen. This substantiates results of Meyer and Sinclair (10) who reported that even in the absence of PRR symptoms, susceptible cultivars had decreased yields, reduced root systems, and were stunted by PRR. These results, however, differ from Tooley and Grau (16) who concluded that reduction in the number of yielding plants per row was the most critical factor contributing to yield reduction by PRR. The basis for this conclusion was that stand reduction from PRR was more highly correlated with yield reduction than were reductions in seed weight or pods per plant.

A trend toward shorter plants and less lodging as plant density decreased agreed with previous studies (12,15). The height of Corsoy was less than L27-.25, which may indicate stunting as a result of PRR. The yield per plant increased as the plant density decreased showing the ability of soybean plants to compensate for reduced stands. The yield increase per plant with increasing stand reduction was due to an increase in seed number, since there were only small differences in seed weight. These results are similar to those of Burmood and Fehr (2).

The combined analysis of variance for 1983 and 1984 at the Agricultural Engineering Farm revealed highly significant stand treatment effects for all variables measured, and soil compaction effects for all variables except yield per plant. The stand density study at the Agricultural Engineering Farm will be considered as two experiments: the study planted in compacted plots combined over years and planting dates, and the combined study planted in uncompacted plots.

Significant year effects were detected for all variables except disease incidence in the analysis of variance for compacted plots, while stand treatment effects were significant for all variables except total number of plants emerged (Table 3). A substantial difference in disease incidence was seen between the L27 and Corsoy, although not as great as at the South Farm (Table 4). Final plant numbers per plot for stand treatment were all significantly different from each other with the mean of Corsoy between that of L27 and L27-.25. The seed yield of L27 was significantly higher than other stand treatments, while L27-.25, L27-.50, and Corsoy had similar yields. The results indicate a PRR effect on the yield of the remaining Corsoy plants. Covariance analysis, however, detected no difference

**Table 2.** Comparison of isolines and stand treatment traits averaged over planting dates and years in 1983 and 1984 at the Agronomy-Plant Pathology South Farm

| Treatment | Seed yield (kg/ha) | Seed weight (g/100) | Plant height (cm) | Lodging[a] (score) | Total plants emerged | Final plants (no.) | Yield/ plant[b] (g) | Percent of L27[c] (%) | Disease incidence[d] (%) |
|---|---|---|---|---|---|---|---|---|---|
| L27-.00 | 3,270 | 14.8 | 87 | 2.0 | 190 | 189 | 18.1 | 100.0 | 0.13 |
| L27-.25 | 2,847 | 14.7 | 92 | 1.7 | 180 | 135 | 21.6 | 87.1 | 0.93 |
| L27-.50 | 2,494 | 14.4 | 74 | 1.5 | 173 | 86 | 29.5 | 76.3 | 1.26 |
| L27-.75 | 2,059 | 14.5 | 70 | 1.3 | 175 | 44 | 49.5 | 63.0 | 0.26 |
| Corsoy | 2,305 | 14.0 | 76 | 1.3 | 152 | 126 | 24.2 | 70.5 | 19.07 |
| LSD 0.05[e] | 220 | 0.5 | 6 | 0.2 | 20 | 14 | 7.3 | 6.7 | 2.96 |
| Mean | 2,595 | 14.5 | 78 | 1.6 | 174 | 116 | 28.6 | 79.4 | 4.33 |

[a] Score of 1 (all plants erect) to 5 (all plants prostrate).
[b] Percent of yield to yielding plants.
[c] Percent of yield to yield of L27.
[d] Percent of dead to total plants emerged.
[e] LSD for within-column comparisons, if the *F* test was significant at the 0.05 probability level.

**Table 3.** Analysis of variance for the plant density study grown in compacted plots at two planting dates in 1983 and 1984 at the Agricultural Engineering Farm

| | | Mean squares | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Source of variation[a] | df | Seed yield | Seed weight | Plant height | Lodging | Total plants emerged | Final plants (no.) | Yield/ plant | Percent of L27 | Disease incidence |
| Year (Y) | 1 | 4,542,209**[b] | 22.48** | 181* | 24.07** | 135,660** | 69,666** | 4,064** | 5,575** | 75 |
| Error A | 4 | 97,972 | 0.61 | 85 | 0.35 | 219 | 76 | 173 | 120 | 19 |
| Stand treatments (S) | 4 | 1,412,675** | 2.60* | 336** | 1.49** | 568 | 20,196** | 2,254** | 1,734** | 265** |
| Y × S | 4 | 344,906 | 0.66 | 61 | 0.91 | 717 | 3,468** | 141 | 423 | 7 |
| Date (D) | 1 | 11,911 | 0.76 | 1,325** | 0.07 | 1,550* | 1,274** | 16 | 15 | 128** |
| Y × D | 1 | 121,768 | 2.67 | 1,627** | 1.35 | 360 | 81 | 60 | 149 | 160** |
| S × D | 4 | 158,200 | 0.34 | 19 | 0.01 | 146 | 253 | 109 | 194 | 47** |
| Y × S × D | 4 | 318,095 | 1.56 | 124* | 0.09 | 162 | 38 | 187 | 390 | 41** |
| Error B | 36 | 160,407 | 0.68 | 44 | 0.22 | 327 | 165 | 136 | 197 | 8 |
| C.V.[c] (%) | | 16.40 | 5.80 | 8.60 | 24.60 | 12.60 | 13.40 | 35.30 | 16.4 | 82.80 |

[a] Replication was considered a random effect; years, cultivars, and planting dates were considered fixed effects.
[b] * = Values exceed the 0.05 probability level; ** = values exceed the 0.01 probability level.
[c] C.V. = coefficient of variation.

in adjusted yield means of L27 and Corsoy. Stand reduction was the most important factor contributing to yield reduction due to PRR in this experiment, although the analysis of variance results also indicate an effect on the yielding ability of surviving Corsoy plants. Plant height and lodging score were reduced as plant population decreased. Plant height of Corsoy was less than L27-.25 and L27-.50, but not significantly different.

Stand treatment effects were significant for all variables measured across years in the study at the Agricultural Engineering Farm in uncompacted plots (Table 5). Disease incidence of Corsoy was much lower in this experiment than the experiments in compacted plots or at the South Farm (Table 6). Comparison of seed yield and final number of plants per plot showed that yields were reduced as

**Table 4.** Comparison of isolines and stand reductions grown in compacted plots, averaged over planting dates and years in 1983 and 1984 at the Agricultural Engineering Farm

| Treatment | Seed yield (kg/ha) | Seed weight (g/100) | Plant height (cm) | Lodging[a] (score) | Total plants emerged | Final plants (no.) | Yield/ plant[b] (g) | Percent of L27[c] (%) | Disease incidence[d] (%) |
|---|---|---|---|---|---|---|---|---|---|
| L27 | 2,854 | 14.8 | 84 | 2.5 | 145 | 143 | 21.9 | 100.0 | 1.7 |
| L27-.25 | 2,519 | 13.9 | 78 | 1.9 | 136 | 102 | 28.8 | 88.2 | 1.6 |
| L27-.50 | 2,511 | 13.8 | 77 | 1.8 | 149 | 75 | 36.3 | 88.0 | 1.3 |
| L27-.75 | 1,903 | 13.5 | 70 | 1.5 | 151 | 38 | 55.3 | 66.7 | 0.7 |
| Corsoy | 2,428 | 14.2 | 74 | 1.7 | 136 | 121 | 22.9 | 85.1 | 11.8 |
| LSD 0.05[e] | 332 | 0.7 | 5 | 0.4 | NS | 11 | 9.7 | 11.6 | 2.4 |
| Mean | 2,443 | 14.1 | 77 | 1.9 | 143 | 96 | 33.0 | 85.6 | 3.4 |

[a]Score of 1 (all plants erect) to 5 (all plants prostrate).
[b]Percent of yield to yielding plants.
[c]Percent of yield to yield of L27.
[d]Percent of dead to total plants emerged.
[e]LSD for within-column comparisons, if the $F$ test as significant at the 0.05 probability level.

**Table 5.** Analysis of variance for the plant density study grown in uncompacted plots at two planting dates in 1983 and 1984 at the Agricultural Engineering Farm

| | | Mean squares | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Source of variation[a] | df | Seed yield | Seed weight | Plant height | Lodging | Total plants emerged | Final plants (no.) | Yield/ plant | Percent of L27 | Disease incidence |
| Year (Y) | 1 | 622,964 | 37.97** | 2,550** | 16.54** | 29,882** | 19,234** | 1,066** | 544 | 31.97** |
| Error A | 4 | 150,859 | 0.72 | 28 | 0.08 | 421 | 163 | 29 | 132 | 1.29 |
| Stand treatments (S) | 4 | 3,108,181**[b] | 4.58** | 552** | 3.14** | 737* | 36,004** | 1,611** | 2,712** | 57.90** |
| Y × S | 4 | 224,341* | 0.97 | 58 | 0.38* | 762* | 2,289** | 31 | 196* | 17.71** |
| Date (D) | 1 | 27,883 | 2.83* | 1,989** | 1.50** | 14 | 91 | 27 | 24 | 32.27** |
| Y × D | 1 | 244,209 | 5.14** | 1,349** | 0.01 | 6,636** | 2,050** | 571** | 213 | 55.30** |
| S × D | 4 | 119,934 | 2.36* | 11 | 0.22 | 456 | 133 | 4 | 105 | 24.29** |
| Y × S × D | 4 | 203,873 | 1.38 | 105* | 0.05 | 297 | 90 | 143** | 178 | 29.55** |
| Error | 36 | 84,653 | 0.62 | 32 | 0.10 | 227 | 132 | 28 | 74 | 2.20 |
| C.V.[c] (%) | | 10.10 | 5.30 | 6.50 | 15.30 | 8.60 | 9.50 | 18.20 | 10.10 | 108.30 |

[a]Replication was considered a random effect; years, cultivars, and planting dates were considered fixed effects.
[b]* = Values exceed the 0.05 probability level; ** = values exceed the 0.01 probability level.
[c]C.V. = coefficient of variation.

**Table 6.** Comparison of isolines and stand treatments grown in uncompacted plots averaged over planting dates and years in 1983 and 1984 at the Agricultural Engineering Farm

| Treatment | Seed yield (kg/ha) | Seed weight (g/100) | Plant height (cm) | Lodging[a] (score) | Total plants emerged | Final plants (no.) | Yield/ plant[b] (g) | Percent of L27[c] (%) | Disease incidence[d] (%) |
|---|---|---|---|---|---|---|---|---|---|
| L27 | 3,385 | 15.4 | 93 | 2.7 | 184 | 183 | 18.9 | 100.0 | 0.3 |
| L27-.25 | 2,989 | 15.0 | 91 | 2.4 | 172 | 129 | 23.9 | 88.3 | 0.1 |
| L27-.50 | 1,898 | 15.1 | 84 | 2.0 | 181 | 91 | 32.5 | 85.6 | 0.4 |
| L27-.75 | 2,034 | 14.0 | 76 | 1.3 | 176 | 44 | 47.6 | 60.1 | 0.8 |
| Corsoy | 3,110 | 15.4 | 87 | 2.0 | 164 | 156 | 21.9 | 91.9 | 5.3 |
| LSD 0.05[e] | 241 | 0.7 | 5 | 0.3 | 12 | 10 | 4.4 | 7.1 | 1.2 |
| Mean | 2,883 | 15.0 | 86 | 2.1 | 176 | 121 | 29.0 | 85.2 | 1.4 |

[a]Score of 1 (all plants erect) to 5 (all plants prostrate).
[b]Percent of yield to yielding plants.
[c]Percent of yield to yield of L27.
[d]Percent of dead to total plants emerged.
[e]LSD for within-column comparisons, if the $F$ test was significant at the 0.05 probability level.

plant numbers decreased with no changes in cultivar rank. There were also no differences in adjusted yield means between L27 and Corsoy, using analysis of covariance. The results of this experiment indicate that yield reduction due to PRR was related to reduction in the number of yielding plants.

Data from this study indicate that the level of disease incidence may affect the way yield is reduced. The experiment at the South Farm had the highest disease incidence in Corsoy. There were factors other than reduction in plants per plot that clearly affected yield. The experiments at the Agricultural Engineering Farm had low disease incidence and showed slight to no yield reduction from factors other than plant loss. Environmental factors such as soil, temperature, and moisture have been found to have an effect on disease severity (9). The ability of soybean plants to compensate for stand reduction is also influenced by environmental conditions (5). These environmental effects add to the difficulty in establishing clear relationships between disease incidence and yield loss.

The results of this study point out that Meyer and Sinclair (10) and Tooley and Grau (16) may both be correct in their evaluation of factors contributing to yield reduction by Phytophthora root rot. Additional studies are needed to determine the relationship between disease incidence and severity, and to develop other methods of measuring the presence or intensity of the disease. Detection and measurement of root infection by PRR may be a more sensitive measure of disease intensity than plant death (11). Plant death is the most advanced symptom of the disease and is greatly influenced by the host and environment.

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