Use of Transplants Instead of Direct Seeding to Reduce Corky Root Severity and Losses Due to Corky Root in Iceberg Lettuce

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ABSTRACT

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Severity of corky root and reduction in fresh and dry weights of heads were lower in transplanted than in direct-seeded iceberg lettuce (*Lactuca sativa*) in microplots infested with *Rhizomonas suberifaciens*. Disease severity was also lower in transplanted than in direct-seeded lettuce in field experiments in the Salinas and Santa Maria valleys in California. Increased yields were associated with the use of transplants when disease severities were high, but not when they were low. In greenhouse experiments, disease severity increased with duration of plant growth in infested soil and decreased with plant age (2, 3, 4, or 5 wk) at the time of transplanting. Use of 4- to 5-wk-old transplants are recommended for reduction of corky root and increase in lettuce yield in fields heavily infested with *R. suberifaciens*.

In the coastal valleys of California, approximately 40,500 ha of lettuce (*Lactuca sativa* L.) are planted annually, with a total value of about $450 million (1). In recent years, corky root has become one of the most damaging lettuce diseases in this region (16). The disease is widespread and occurs on various soil types ranging from heavy clays to sandy loams. Commonly all plants become afflicted, and the number of unmarketable heads can be so high that it is not economical to harvest the field. The causal agent is a gram-negative bacterium, *Rhizomonas suberifaciens* van Bruggen, Jochimsen, and Brown (25,26).

All lettuce cultivars grown in California are susceptible to corky root (3). Control by fumigation is theoretically possible, but no fumigants have been registered for lettuce in California, and their costs may be prohibitive (14). Cultural practices such as the use of cover crops (24), minimal nitrogen fertilization (22), increased bed height, and a limited number of irrigations have been recommended (17) but are not completely effective.

Most types of lettuce, particularly iceberg lettuce, are direct-seeded in California. Corky root has become so severe in certain fields that some lettuce growers have attempted to reduce the impact of this disease by using transplants instead of sowing seed. Scientific evidence for less corky root on transplanted than on direct-seeded plants was lacking, however.

Objectives of this study were to determine if the severity of corky root is less, and the yield of lettuce greater, when plants are grown from transplants than when they are grown from seed in the field. An additional objective was to determine if disease severity is affected by the period of growth of transplanted lettuce in soil infested with *R. suberifaciens* and by the age of seedlings at the time of transplanting into infested soil.

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MATERIALS AND METHODS

Microplot experiments. In two factorial experiments in the spring of 1989 and 1991, corky root on transplanted lettuce was compared with that on direct-seeded lettuce in microplots infested with *R. suberifaciens* and in noninfested plots at Davis, California. The microplots were enclosed by fiberglass rings and measured 1 × 2 m (25). The first experiment had a completely randomized design, and the second a randomized complete block design, both with five replications.

In the fall before each experiment, the microplots were covered with clear plastic and fumigated with a mixture of methyl bromide and chloropicrin (57%:43% and 75%:25% [w/w] in 1989 and 1991, respectively) at a rate of about 110 g per microplot. The plots were uncovered 1 mo later, and the soil was listed (shaped in ridges) for preparation of the beds. One week before planting, 60-cm-wide beds were prepared in each plot. In 1989, 140 g of Osmocote 18-6-12 (Sierra Chemical Co., Milpitas, CA) was incorporated per plot. In 1991, 34 g of ammonium nitrate plus 70 g of superphosphate were incorporated per plot.

Seeds of the iceberg lettuce cultivar Salinas were planted 2.5 cm apart in two rows per bed, 50 cm apart. The seedlings were thinned 5 or 6 wk later to a spacing of 30 cm (14 plants per plot). Salinas seeds for transplants were planted 5 days after or on the same day that the seeds were planted in the microplots in 1989 or 1991, respectively. In 1989, these seeds were planted in sterilized U.C. mix (12) containing 1.5 g of Osmocote 18-6-12 per liter in 51-cell trays containing 50 ml of soil mix per cell. In 1991, the seeds were planted in sterilized U.C. mix in 200-cell trays, with 35 ml of mix per cell. Seedlings were fertilized weekly with half-strength Hoagland's solution (10). Five or six weeks after seeding, 14 seedlings were transplanted into each of the designated microplots.

Inoculum of *R. suberifaciens*, prepared from a 5-day-old culture in S-medium (25), was applied immediately after seeding or transplanting by sprinkling 10 L of a suspension containing 3.6×10^8 cfu/ml or 5 L containing 3.6×10^7 cfu/ml onto each bed in 1989 or 1991, respectively. The same amounts of water were sprinkled on control plots.

Cultural practices were similar to those used in production fields in the central coastal regions of California. Plots were irrigated with sprinklers during the first month after seeding. After the plants in direct-seeded plots had been thinned and transplants had been planted, irrigation was applied from a drip system into furrows. Two months after seeding, the plants were side-dressed with ammonium nitrate at a rate of 27 g/m^2 (270 kg/ha). Insecticides, diazinon (Diazinon 50W, CIBA-GEIGY Corp., Greensboro, NC) at 0.5 kg of formulated product (f.p.) per hectare and *Bacillus thuringiensis* Berliner (Javelin, Sandoz, Des Plaines, IL) at 0.5 L of f.p. per hectare, were applied once per season to control aphids and lepidopteran insects, respectively.

Ten plants were harvested from the center of each plot 85 and 93 days after direct seeding and starting the transplants, respectively, in 1989, and 99 days after seeding of the directly sown and transplanted plants in 1991. The harvest dates were based upon maturity (as determined by firmness) of the lettuce heads. Untrimmed heads were weighed, and roots of direct seeded plants were scored for corky root severity according to a discrete-interval 0–6 scoring scale (22,25). The same scale was used for transplants (Fig. 1), with 0 = healthy, 1 = <25% of taproot stump affected, 2 = 25–50% of taproot stump affected, 3 = 51–75% of taproot stump affected and laterals healthy, 4 = 76–100% of taproot stump affected and <50% of laterals affected. Disease severities similar to scores 5 and 6 for direct-seeded lettuce were not observed on transplanted lettuce. Percentages of taproot surface area and lateral root length with corky root symptoms were also estimated in 1991, using a calibrated pictorial scale (15). Ten roots and 10 half heads per plot were dried in a forced-air drying oven at 80 C for at least 4 days and weighed.

Experiments in growers' fields. One experiment was conducted in the summer of 1989 in the Salinas Valley, California, and three experiments were conducted in the summer and fall of 1990 in the Santa Maria Valley, California. Two crops of lettuce had preceded the experimental planting, and corky root had been severe in each field. The experiments consisted of two treatments, transplanting versus direct seeding, in a randomized complete block design with five blocks. The plot size was 5 × 6 m (five beds) and 3 × 6 m (three beds) in the Salinas and Santa Maria valleys, respectively. Lettuce seeds were sown by the grower in the whole experimental area. Transplants were set in designated plots after removal of direct-seeded plants, so that the preexperimental treatment of direct-seeded and transplanted plots was the same.

At Salinas, N-P-K-Mg fertilizer (5:20:3:1) was drilled into the soil (Mocho silty clay loam) at 140 kg ha^{-1} before planting. Seeds of Salinas 88 lettuce were planted 2.5 cm apart in two rows 50 cm apart in 1-m-wide beds. The plants were thinned 1 mo later to one plant per 30 cm. Salinas 88 transplants were grown at Native Plants, Inc., in Salt Lake City, Utah, using Sunshine II potting mix (Fisson, Salt Lake City, UT) in transplant trays, with 98 cells per tray and 25 ml per cell. Seeds for transplant production were planted 4 days after direct seeding. Seedlings in transplant trays were fertilized daily for the first 3 wk with 20-2-20 fertilizer at a rate of 10 g L^{-1} water. The plants were hardened by placing them outside 1 wk before transplanting. Four-week-old transplants were planted in the field 2 days after thinning the direct-seeded plants. Standard commercial cultural practices were used. All plots were side-dressed with ammonium nitrate at a rate of 56 kg of N ha^{-1} 1 day after transplanting. Direct-seeded plants were harvested 68 days after seeding, and transplanted plants 78 days after seeding. Fresh weights of untrimmed heads and severity of corky root (Fig. 1) were recorded for all plants from a 2-m-long section of the three middle beds in the center of each plot. Ten roots per plot were collected randomly to estimate percentages of taproot surface area and lateral root length with corky root symptoms by using a calibrated pictorial scale (15). Dry weights were determined for 10 roots and 10 half heads per plot after drying at 80 C for 10 days.

For the experiments at Santa Maria, transplants of Salinas 102, Bix, and Bounty lettuce were grown in 200-cell (35-ml volume) plastic trays with Supersoil mix (Rod McLellan Co., South San Francisco, CA) at Davis. Nutrition was provided with weekly applications of half-strength Hoagland's solution (10). The seedlings were hardened by placing them outside 1 wk before transplanting.

Direct-seeded Salinas 102 lettuce was grown in a Bayshore silty clay loam as described for the experiment at Salinas. Urea (UN32) was applied before planting at a rate of 112 kg/ha. Additional fertilizer (112 kg of UN32 per hectare) was applied as side-dressing just after thinning, 6 wk after sowing. When direct-seeded plants were thinned, 7-wk-old transplants of Salinas 102 were planted in designated plots. Direct-seeded and transplanted plants were harvested on the same day, 85 days and 90 days after seeding, respectively. Marketable heads were harvested by experienced field crew from a 6-m-long section of the middle bed in the center of each plot. Marketable and total numbers of heads were counted, and percentage of marketable heads calculated. Ten fresh, randomly selected, marketable trimmed heads per plot were weighed. The yield (cartons per hectare) was calculated by dividing the number of marketable heads per hectare by 24 (number of heads per carton). Corky root severity was assessed on 10 roots per plot, using the discrete scoring scale and percentages of taproot surface area and lateral root length infected as described above.

Bounty and Bix were direct seeded in adjacent fields of Sorrento sandy loam. Cultural practices were as described for Salinas 102, except that preplant N-P-K fertilizer (8:8:8) was applied at a rate of 550 kg/ha, followed by three equally spaced side-dress applications of 20:10:0 fertilizer at a rate of 150 kg/ha. Seven-wk-old transplants of Bounty and Bix were planted in designated plots when the direct-seeded plants were thinned, 1 mo after direct seeding. Direct-seeded and transplanted plants were harvested on the same day, 86 days and 90 days after seeding, respectively. Marketable heads were harvested and weighed, percentages of marketable heads calculated, the yield in cartons per hectare calculated, and corky root severity assessed on 10 roots per plot as described above.

Greenhouse experiments. Yolo sandy loam from Yolo County, California, was pasteurized (90 C for 3 hr) and aired for 1 mo. A suspension of *R. suberifaciens* strain CA1 (10^7 cfu per milliliter of water) was then mixed with the soil at a rate of 25 ml per liter of soil in a concrete mixer or in plastic bags in the first and second experiment, respectively.

There were nine treatments in the first experiment (Fig. 2). In four treatments the period between seeding and harvest was kept constant (7 wk), and in five treatments the period of growth in infested pots was kept constant (7 wk). Salinas lettuce seeds were either planted in 4-L pots containing infested soil or in 200-cell transplant trays containing 35 ml of noninfested sterilized U.C. mix (12) per cell. Seedlings in transplant trays were transplanted into 4-L pots containing infested soil 2, 3, 4, or 5 wk after seeding. Seeding in transplant trays was staggered, so that all seedlings were transplanted simultaneously, coinciding with direct seeding in infested soil. For

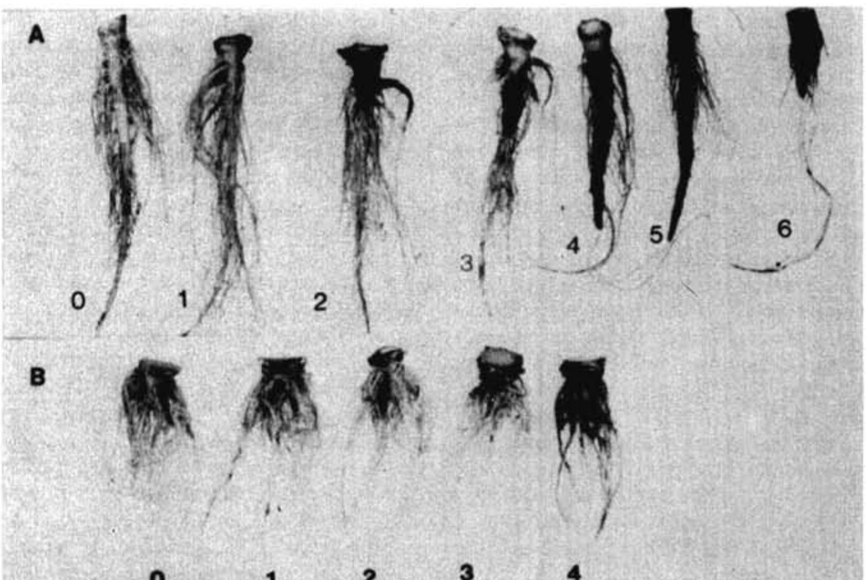

Fig. 1. Scoring scales for severity of corky root on direct-seeded iceberg lettuce **(A)** and for transplanted iceberg lettuce **(B)** at maturity.

the first four treatments, all plants were uprooted and rated for disease severity when they were 7 wk old (2, 3, 4, or 5 wk after transplanting and 7 wk after direct seeding). For the other five treatments, all plants were grown in infested soil for 7 wk, but the age of the seedlings at the time of transplanting or direct seeding varied from 0 to 5 wk. Consequently, plant age at harvest ranged from 7 to 12 wk (Fig. 2).

In the second experiment, 7 treatments were added (Fig. 2) to distinguish between effects of plant age at harvest and period of growth in infested soil, while keeping age at (trans)planting the same (i.e., 0 or 5 wk). The pot volume was 1 L in this experiment.

For both experiments, the pots were placed in a greenhouse with supplemental lighting provided by 400-in. multivapor lamps for 14 hr per day. Light intensity at plant level was 400–800 $\mu E \cdot m^{-2} \cdot s^{-1}$ during daylight and 100–200 $\mu E \cdot m^{-2} \cdot s^{-1}$ after sunset. Daily temperatures were 24–28 C during the day and 20–22 C at night. The plants were watered with distilled water daily and with half-strength Hoagland's solution weekly. There were five and eight single-plant replications in the first and second experiment, respectively, in a randomized complete block design. Disease severity was assessed with the discrete scoring scales and by estimating the percentages of the taproots and laterals with corky root symptoms as described above. As controls for potential accidental infection during transplant production, five additional plants per sowing date were kept in the transplant trays for 7 wk and inspected for corky root symptoms.

Statistical analysis. Disease severity scores obtained with the discrete interval scoring scale were analyzed with contingency tables and chi-square tests (19). Disease severity, estimated as percentage of roots affected, and plant weight data were subjected to analysis of variance (20).

RESULTS

Microplot experiments. Disease severity was significantly lower on transplanted than on direct-seeded plants in plots infested with *R. suberifaciens* (Table 1). Severity scores ranged from 1 to 6 for direct-seeded plants and from 1 to 4 for transplanted plants. Both direct-seeded and transplanted plants in noninfested control plots became slightly diseased (average scores were 1.1 and 1.2 for experiments 1 and 2, respectively). The reduction in fresh weights of heads in infested plots compared to noninfested plots was significantly larger for direct-seeded than for transplanted lettuce in both years (Table 1). The reduction in dry weight of heads due to corky root was significantly larger for direct-seeded plants in the first experiment only. Changes in root dry weight in infested plots compared to noninfested plots were similar for direct-seeded and transplanted plants. In general, head and root weights of transplants were significantly ($P < 0.01$) higher than those of direct-seeded plants in the first experiment (when the growing period for transplants was 8 days longer than that for direct-seeded plants) and lower in the second experiment (when the growing period was the same for transplants and direct-seeded plants) (*data not shown*).

Field experiments. *Salinas.* Taproots of transplanted plants were 2–4 cm long and supported numerous thickened lateral roots, whereas taproots of direct-seeded plants were 15–20 cm long and had relatively few thin, lateral roots. Disease severity was significantly lower on transplanted than on direct-seeded plants (Table 2). Percentages of taproot area affected were also lower in transplants than in direct-seeded plants, but the lateral roots of transplants were more severely infected. Fresh and dry weights of untrimmed heads of transplanted and direct-seeded plants were not significantly different, despite the longer growing period of transplants (78 days versus 68 days). Dry weight of roots was significantly less for transplanted than for direct-seeded plants.

Santa Maria. For all three cultivars, disease severities (score and percent of taproot area affected) were lower on transplants than on direct-seeded plants (Table 2). Differences in disease severity between direct-seeded and transplanted plants were larger for Bounty and Bix than for Salinas 102. Percentage of lateral root length affected was significantly higher for transplanted than for direct-seeded Salinas 102, but there was no significant difference between disease severity on laterals of transplanted and direct-seeded Bounty. Corky root was slightly more severe on lateral roots of direct-seeded than of transplanted Bix. Yield parameters were not affected by the treatments of Salinas 102, but head yield was significantly higher on transplanted than on direct-seeded Bounty and Bix.

Greenhouse experiments. In the first greenhouse experiment, disease severity of 7-wk-old plants increased significantly ($P < 0.01$) with period of growth in infested soil (Table 3). When the period of growth in infested soil was constant, disease severity decreased significantly ($P < 0.01$) with increasing age of seedlings at transplanting. Period of growth in infested soil had a greater effect on disease severity than did transplant age. The latter, however, was unavoid-

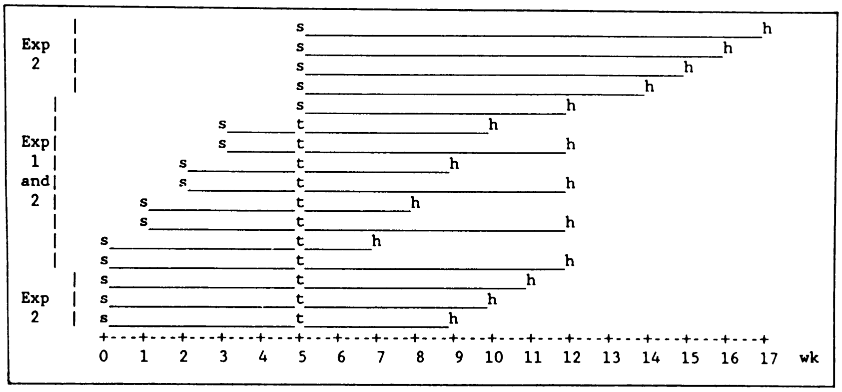

Fig. 2. Schematic overview of the time (in weeks) of seeding (s), transplanting (t), and harvest (h) for nine treatments in the first and 16 treatments in the second greenhouse experiment to determine the effects of transplant age and period of growth in soil infested with *Rhizomonas suberifaciens* on severity of corky root on iceberg lettuce.

Table 1. Severity of corky root and weights of Salinas lettuce heads and roots in microplots as influenced by direct seeding versus transplanting

Variable	1989		1991	
	Direct-seeded	Transplanted	Direct-seeded	Transplanted
Disease severity score[a]	5**[b]	3**	5**	3**
Taproot surface area diseased[c]	...[d]	...	89*	69*
Lateral root length diseased[c]	...	...	68*	20*
Fresh weight of heads[e]	60*	95*	76**	89**
Dry weight of heads[e]	67*	96*	74	93
Dry weight of roots[e]	106	82	78	98

[a] Median score on a 0–6 scale.
[b] * and ** = Significant differences at $P = 0.05$ and $P = 0.01$, respectively, between direct-seeded and transplanted plants in chi-square tests for severity scores or *F* tests in analyses of variance for the other variables.
[c] Percentage of surface area or root length diseased.
[d] No data.
[e] Mean percentages of noninfested controls.

Table 2. Effect of transplanting on severity of corky root, weights, and yield of iceberg lettuce in growers' fields in the Salinas and Santa Maria valleys

	Cultivar[a]							
	Salinas 88		Salinas 102		Bix		Bounty	
Variable (mean)	Direct-seeded	Trans-planted	Direct-seeded	Trans-planted	Direct-seeded	Trans-planted	Direct-seeded	Trans-planted
Disease severity score (median, 0–6 scale)	4**[b]	3**	4**	1**	5**	1**	4**	1**
Taproot surface area diseased (percentage)	93**	53**	93**	19**	95**	12**	95**	14**
Lateral root length diseased (percentage)	10**	51**	11**	30**	30*	23*	26	32
Fresh weight of heads (g)	644	622	836	816	782**	990**	844**	1,134**
Dry weight of roots (g)	3.2**	2.6**	...[c]	...	...	...	...	...
Marketable heads (percentage)	...	...	84	82	69**	92**	70**	89**
Yield (cartons/ha)	...	...	2,100	2,285	1,717**	2,535**	1,730**	2,493**

[a] Experiments were conducted in the Santa Maria Valley, except for that of Salinas 88, which was conducted in the Salinas Valley.
[b] * and ** = Significant differences at $P = 0.05$ and $P = 0.01$, respectively, between direct-seeded and transplanted plants in chi-square tests for severity scores or F tests in analyses of variance for the other variables.
[c] No data.

Table 3. Effect of transplant age, period of growth in soil infested with *Rhizomonas suberifaciens*, and age at harvest on percent of taproot surface area diseased and disease severity

Transplant age (wk)	Period in infested soil (wk)	Plant age at harvest (wk)	Taproot surface area diseased (%)	Disease severity score (0–6)
0[a]	7	7	79	2.6
2	5	7	43	2.2
3	4	7	43	2.0
4	3	7	6	0.8
5	2	7	4	1.0
2	7	9	98	4.8
3	7	10	88	4.6
4	7	11	72	3.4
5	7	12	61	2.8

Analysis of variance

Effect of:	df	Mean squares: Diseased taproot (%)	Mean squares: Disease score
Block	4	1,879**[b]	7.7**
Transplant age	4	2,935**	4.3**
Period in infested soil	4	7,515**	14.2**
Error	31	371	1.0

[a] Direct-seeded into infested soil.
[b] ** = Significant at $P < 0.01$.

ably confounded with harvest age. After 7 wk of growth in infested soil, disease severity was relatively low for the direct-seeded plants compared with the transplants, possibly due to differences in age at harvest (7 wk compared to 9–12 wk).

In the second greenhouse experiment (Table 4), disease severity again increased with period of growth in infested soil ($P < 0.01$) and decreased with age of seedlings at transplanting ($P < 0.01$). Unlike the previous experiment, disease severity was affected more by transplant age than by period of growth in infested soil.

DISCUSSION

In six field experiments, the severity of corky root on mature lettuce plants was greater if the crops were grown from seeds sown in the field than if they were grown from transplants. Fresh weights of heads were higher for transplanted plants in three of the six field experiments. They were similar to those of direct-seeded plants in two experiments and lower in one experiment. When heads of transplanted plants were larger than those of direct-seeded plants, corky root was generally more severe than when heads of transplanted and direct-seeded plants were similar in size (Tables 2 and 3). However, head weights at harvest can depend on many other factors besides corky root, such as age of seedlings at transplanting (27) and cell size of the transplant tray (9), which influence the time to maturation. Transplant age varied from 4 to 7 wk, and transplant cell size from 25 to 50 ml in our field experiments, but there seemed to be no relationship between transplant age or cell size and head weight. In the one experiment when transplanting resulted in lower head weights than direct seeding (the second microplot experiment), the transplanted and direct-seeded plants were sown and harvested on the same dates. In all other experiments, the period from planting seed to mature heads was 7–10 days longer for transplants than for direct-seeded plants.

Transplanted crops are generally delayed in maturation compared to direct-seeded crops because of transplant shock (2,21). This shock can be reduced by allowing the seedlings to harden outside the greenhouse before transplanting (2,21). This practice was followed in all our experiments, but apparently transplants need to be started some time before direct-seeded plants for proper comparison.

Timing of seeding, transplanting, and harvest was less critical when both transplanted and direct-seeded crops in soil infested with *R. suberifaciens* were compared with crops in noninfested soil. In both microplot experiments, the reductions in head weights in plots infested with *R. suberifaciens* compared with noninfested plots were significantly larger for direct-seeded than for transplanted plants. This is consistent with the report that transplanting resulted in a larger increase in marketable yield over direct seeding for Ithaca than for Montello lettuce in Florida (6). Corky root is an important disease of lettuce in Florida (5,6,23), and Ithaca and Montello are susceptible and resistant, respectively, to this disease (6).

The root system of transplanted lettuce differs profoundly from that of direct-seeded lettuce. The former becomes air-pruned in transplant trays, resulting in a small taproot stump remaining from the original taproot and numerous lateral roots that undergo secondary thickening and assume the function of the original taproot. In some experiments, lateral roots of transplants became more severely affected by corky root than those of direct-seeded plants. The lateral roots of direct-seeded plants seemed to have been formed recently, probably to replace earlier laterals that had rotted due to corky root. In contrast, lateral roots of transplanted plants were older and thicker than those of direct-seeded plants. Thus, comparison of disease severity on the laterals of transplants with that on taproots of direct-seeded plants may be an appropriate indication of the reduction in corky root on transplants. Disease severity was, indeed, lower on lateral roots of transplants than on taproots of direct-seeded plants, which is in agreement with lower corky root scores on transplants.

We do not know why transplanted lettuce had less corky root than direct-seeded lettuce at maturity. The difference in exposure time to the pathogen seemed to provide a plausible explanation, but in a greenhouse experiment various periods of growth in infested soil had less effect on disease severity when transplant age was the same than when period of growth in infested soil and transplant age varied in opposite directions while plant age at harvest was the same. For a given period in infested soil, disease severity decreased as the age of the seedlings at transplanting increased. Thus, there may be some form of mature plant resistance, possibly because openings in the taproot where lateral roots emerged were no longer suitable for infection when transplants were exposed to *R. suberifaciens*. The first symptoms of corky root on young seedlings are usually observed where the lateral roots emerge (van Bruggen, *unpublished*). Emergence points of lateral roots have also been reported as possible ports of entry for *Agrobacterium tumefaciens* (11) and *Pseudomonas solanacearum* (4).

The optimal transplant age that would result in minimal corky root at maturity was not determined in these experiments. The greenhouse experiments indicated, however, that transplants need to be at least 4 wk old to result in a reduction in corky root. The usual transplant age in California is 4–5 wk, but transplanting could be performed with 10- to 14-day-old seedlings grown in the Techniculture transplant system with 4-ml plugs (18,27). Younger transplants would suffer less from transplant shock (21,27) and result in more uniform plants (27). The use of such young seedlings would probably not result in less corky root, however.

For lettuce producers in California to use transplants to lessen the severity of corky root, the physical and economic feasibility of transplant use must be justified. The present total production costs of direct-seeded lettuce range from $7,400 to $9,900 per hectare (13). Transplanting costs range from about $1,500 to $1,700 per hectare. This additional cost should be offset by gains in yield or quality or through reductions in other production costs. Transplants generally provide a more complete stand than direct-seeded plants (7,8) and may yield more per unit area. Transplanted crops tend to be more uniform in maturity (8,9) and hence may make harvesting more efficient and possibly eliminate a second harvest. A yield increase of 250 cartons per hectare would probably compensate for transplant costs, depending on the market price per carton. This increase was realized in two of three experiments in the Santa Maria Valley (Table 2). Potential cost savings would accrue from a shorter cropping season, creating the possibility for an additional crop (9), and from reductions in weed management, seed costs, fertilizer use, irrigation, and exposure to pests and diseases. Transplanting also eliminates the need for thinning. A conservative estimate of these savings might be $600/ha. Finally, a major consideration is whether transplants will allow use of severely infested fields for lettuce production. In some situations, the use of lettuce transplants may permit the production of a crop that otherwise could not be grown.

Table 4. Effect of transplant age, period of growth in soil infested with *Rhizomonas suberifaciens*, and age at harvest on percent of taproot surface area diseased, percent of lateral root diseased, and disease severity

Transplant age (wk)	Period in infested soil (wk)	Plant age at harvest (wk)	Taproot surface area diseased (%)	Lateral root length diseased (%)	Disease severity score (0–6)
0[a]	7	7	99	30	5.4
0	9	9	100	85	5.9
0	10	10	100	99	6.0
0	11	11	100	100	6.0
0	12	12	100	100	6.0
2	5	7	59	7	3.6
3	4	7	5	7	0.8
4	3	7	1	2	0.3
5	2	7	0.3	0.4	0.3
2	7	9	78	38	4.8
3	7	10	78	34	4.3
4	7	11	5	11	1.1
5	7	12	23	20	1.9
5	2	7	0.3	0.4	0.3
5	4	9	4	7	0.4
5	5	10	0.8	7	0.3
5	6	11	24	6	1.4
5	7	12	23	20	1.9

Analysis of variance

Effect of:	df	Mean squares: Diseased taproot (%)	Diseased laterals (%)	Disease score
Block	7	491	187**[b]	1.7**
Transplant age	4	50,205**	34,256**	152.3**
Period in infested soil	9	2,356**	4,117**	7.4**
Age × Period	2	3,150**	427*	5.4**
Error	103	256	128	0.6

[a] Direct-seeded into infested soil.
[b] * = Significant at $P = 0.05$; ** = significant at $P = 0.01$.

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