worker-min. per plot vs. 10.3 for the conventional method. Thus, using the new method, plots can be evaluated in only 42% of the time required when plants are pulled from the plots by hand.

The best system for simulated once-over harvest of those tested would be treatment of the vines with 0.6 kg/ha paraquat when 10% of the fruit were oversized. The following day, fruit could be lined up in each plot and rolled 180° to facilitate evaluation for yield and quality. Rolling the fruit 180° would be unnecessary if fruit color were not rated.

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# Salt Tolerance of Lettuce Introductions


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***Abstract.*** **Salt tolerance differences among 115 plant introductions of lettuce (*Lactuca sativa* L.) were screened in sand cultures under greenhouse conditions. Leaf and root fresh weights of plants grown for 4 to 5 weeks in salinized sand cultures were compared to a benchmark cultivar, 'Buttercrunch'. Plant introductions showed a wider range of salt tolerance than standard cultivars of the United States and therefore have some potential in breeding programs designed to increase the salt tolerance of this crop.**


One approach to managing saline soils and waters is to improve salt tolerance in cultivated species. This tolerance may be achieved by exploiting intraspecific variability (2, 3). Although Ayers et al. (1) reported little variability in salt tolerance among 6 lettuce cultivars, variability was found among 85 U.S. lettuce cultivars and breeding lines that were screened recently for salt tolerance during germination and early seedling growth (5). Results from the greenhouse screening technique used in that study were correlated with field salt tolerance tests. Vegetative fresh weights of 30-day-old seedlings irrigated with salinized nutrient solution were used as the criterion upon which to evaluate salt tolerance.

This previously established screening technique was used in this study to test salt tolerance differences among 115 (*L. sativa*) plant introductions (PIs) and to compare selections from this study to those obtained from the study of the U.S. cultivars (5).


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The *L. sativa* PIs were taken at random from the collection maintained at the U.S. Department of Agriculture, Agricultural Research Service, Western Regional Plant Introduction Station, Pullman, Wash. The PIs were chosen from different countries of origin. The number from each country is about proportional to the total number from each country in the PI collection.

All seeds used in this study were produced in the greenhouse in the spring and summer of 1980. Seeds were planted in screen-lined, wood boxes (0.35 × 0.35 m), and filled to a depth of 0.1 m with washed, medium-textured sand. A plastic mesh bottom allowed free drainage and supported the nylon screen. Within each box, 4 rows (entries) of seed were planted and thinned to 20 plants per row. Irrigation solutions contained 35 mM NaCl, 17.5 mM $CaCl_2$, 6 mM $KNO_3$, 6 mM $Ca(NO_3)_2$, 3 mM $MgSO_4$, 0.18 mM $KH_2PO_4$, 0.1 mM Fe as diethylene-triamine pentaacetate, 46 μM $H_3BO_3$, 9 μM $MnCl_2$, 0.8 μM $ZnSO_4$, 0.3 μM $CuSO_4$, and 0.1 μM $H_2MoO_4$ and were pumped from 100-liter reservoirs. Sand cultures were irrigated twice daily, and solutions were gravity-drained back into the reservoirs.

Three tests were conducted, each consisting of 4 trials. Each trial consisted of 16 entries and included 'Buttercrunch' as a benchmark cultivar. Three 20-plant rows (replications) were tested for each entry in each trial. The first 2 tests, conducted in Nov. 1980 and Jan. 1981, respectively, compared the salt tolerance responses of 115 PIs. Fresh leaf and root weights were measured. The 3rd test, conducted in Mar. 1981, compared 30 U.S. cultivars, which had been tested previously (5), to 30 introductions which had demonstrated either tolerance or sensitivity to salt in the first 2 tests.

In Test 1 (trials 1 to 4) only two PIs, 169503 and 278108, were significantly more tolerant than the benchmark 'Buttercrunch' as determined by fresh leaf weight (Table 1). Nine PIs were more sensitive than the benchmark. The response of root fresh weight to salinity was similar to leaf weight; plants with the largest leaf fresh weight generally had the largest root weights. 'Climax' and 'Climax 84' were included in Trial 4. These cultivars previously had demonstrated high salt tolerance compared to 'Buttercrunch', and this test reconfirmed that finding. Average electrical conductivities of the irrigation solutions ($\kappa_s$) were 7.7, 7.8, 8.1, and 8.0 $dSm^{-1}$, respectively, for Trials 1 to 4. Test 2 (Trials 5 to 8) was conducted over a 5-week period in contrast to the 4-week period used in Test 1. Consequently, plant size at harvest was

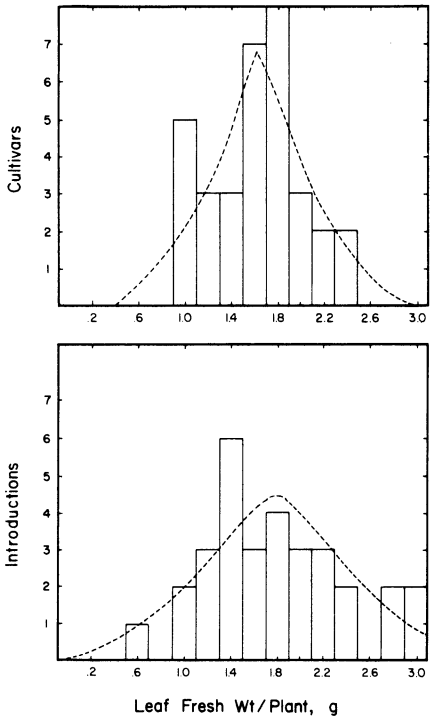


Fig. 1. Distribution of fresh weights in populations of lettuce (*Lactuca sativa*) cultivars and introductions grown under saline conditions.

Table 1. Mean fresh weights of shoots and roots of lettuce plant introductions (PI) and cultivars in Test 1 after 4 weeks growth in saline sand culture.

| Trial | Entry | Fresh wt Shoot (g) | Fresh wt Root (mg) | Trial | Entry | Fresh wt Shoot (g) | Fresh wt Root (mg) |
|---|---|---|---|---|---|---|---|
| 1 | PI 278097 | 1.16 a[z] | 130 ab | 2 | PI 278108 | 1.33 a | 111 ab |
| | PI 278075 | 1.12 a | 146 a | | PI 358013 | 1.12 ab | 88 bcd |
| | PI 169514 | 1.94 a | 113 abc | | PI 187238 | 1.52 bc | 137 a |
| | Buttercrunch | 1.72 ab | 83 bcde | | PI 278077 | 1.38 bcd | 83 bcde |
| | PI 342459 | 0.98 abc | 93 bcd | | Buttercrunch | 1.10 bcde | 78 bcdef |
| | PI 167139 | 0.97 abc | 113 abc | | PI 169493 | 0.96 bcde | 99 bc |
| | PI 342519 | 0.92 abc | 107 abc | | PI 372589 | 0.94 bcde | 70 cdef |
| | PI 368630 | 0.90 abcd | 93 bcd | | PI 372589 | 0.94 bcde | 96 bc |
| | PI 179295 | 0.89 abcd | 96 bcd | | PI 342477 | 0.77 cdef | 79 bcdef |
| | PI 358007 | 0.88 abcd | 77 cde | | PI 342552 | 0.74 def | 55 def |
| | PI 358035 | 0.81 abcde | 77 cde | | PI 289019 | 0.72 efg | 66 cdef |
| | PI 181882 | 0.80 abcde | 83 bcde | | PI 358026 | 0.62 fgh | 47 ef |
| | PI 289016 | 0.66 bcde | 110 abc | | PI 370472 | 0.57 fgh | 52 def |
| | PI 273600 | 0.61 cde | 67 cde | | PI 274373 | 0.48 fgh | 56 def |
| | PI 289042 | 0.50 de | 53 de | | PI 289061 | 0.44 gh | 53 def |
| | PI 289057 | 0.43 e | 43 e | | PI 171675 | 0.42 h | 41 f |
| 3 | PI 169503 | 1.60 a | 175 a | 4 | Climax | 1.41 a | 117 ab |
| | PI 358024 | 1.21 a | 136 a | | Climax 84 | 1.32 ab | 106 abc |
| | Buttercrunch | 0.99 bc | 83 bc | | PI 285650 | 0.94 bc | 126 a |
| | PI 373912 | 0.92 bc | 83 bc | | PI 386628 | 0.90 cd | 108 abc |
| | PI 342439 | 0.85 bc | 76 bc | | PI 289032 | 0.86 cd | 92 abcde |
| | PI 176583 | 0.84 bc | 83 bc | | PI 177419 | 0.83 cde | 87 abcdef |
| | PI 373914 | 0.80 c | 83 bc | | Buttercrunch | 0.82 cde | 80 bcdef |
| | PI 289026 | 0.78 c | 72 bc | | PI 169507 | 0.67 cde | 101 abcd |
| | PI 278082 | 0.77 cd | 89 b | | PI 278096 | 0.64 cde | 71 cdef |
| | PI 284702 | 0.77 cd | 77 bc | | PI 379356 | 0.62 cde | 68 cdef |
| | PI 289042 | 0.71 cd | 77 bc | | PI 342448 | 0.62 cde | 68 cdef |
| | PI 278063 | 0.67 cd | 57 bc | | PI 278069 | 0.59 cde | 47 ef |
| | PI 204708 | 0.66 cd | 52 bc | | PI 342493 | 0.54 cde | 58 def |
| | PI 342556 | 0.60 cd | 69 bc | | PI 34369 | 0.53 cde | 51 ef |
| | PI 342483 | 0.60 cd | 39 c | | PI 344369 | 0.43 de | 49 ef |
| | PI 358041 | 0.37 d | 41 bc | | PI 289047 | 0.40 e | 42 f |

[z]Mean separation within trials by Duncan's multiple range test, 5% level.

Table 2. Mean fresh weights of shoots and roots of lettuce introductions and cultivars in Test 2 after 5 weeks growth in saline sand cultures.

| Trial | Entry | Fresh wt Shoot (g) | Fresh wt Root (mg) | Trial | Entry | Fresh wt Shoot (g) | Fresh wt Root (mg) |
|---|---|---|---|---|---|---|---|
| 5 | PI 234624 | 3.24 a[z] | 409 a | 6 | PI 342055 | 3.41 a | 505 a |
| | Shawnee | 2.99 ab | 222 abcd | | PI 358017 | 3.31 ab | 367 ab |
| | PI 278084 | 2.76 ab | 324 abcd | | PI 289024 | 2.77 abc | 286 bc |
| | PI 278068 | 2.71 abc | 318 abcd | | PI 358040 | 2.65 abc | 307 bc |
| | PI 176583 | 2.50 abc | 288 abcd | | PI 278079 | 2.64 abc | 380 ab |
| | PI 342444 | 2.41 abc | 203 bcd | | Wintergreen | 2.56 abcd | 188 cd |
| | PI 284702 | 2.36 abc | 343 abc | | PI 289041 | 2.32 abcd | 220 bcd |
| | PI 289045 | 2.36 abc | 229 abcd | | PI 372895 | 2.29 abcd | 182 cd |
| | PI 342492 | 2.26 abc | 320 abcd | | Buttercrunch | 2.21 abcd | 221 bcd |
| | PI 169503 | 2.21 abc | 375 ab | | PI 175735 | 2.17 bcd | 327 bc |
| | Buttercrunch | 2.20 abc | 277 abcd | | PI 339262 | 2.40 cd | 266 bcd |
| | PI 368625 | 2.08 abc | 320 abcd | | PI 342482 | 1.97 cd | 189 cd |
| | PI 344366 | 1.00 abc | 364 abc | | PI 169493 | 1.89 cd | 332 bc |
| | PI 373915 | 1.98 abc | 167 cd | | PI 274900 | 1.83 cd | 183 cd |
| | PI 289026 | 1.78 bc | 220 abcd | | PI 278100 | 1.83 cd | 174 cd |
| | PI 358026 | 1.35 c | 126 d | | PI 187239 | 1.36 d | 94 d |
| 7 | PI 183234 | 3.54 a | 599 a | 8 | PI 177424 | 3.53 a | 454 b |
| | PI 358006 | 3.23 ab | 336 cdef | | PI 278097 | 3.35 ab | 629 a |
| | PI 342476 | 2.82 abc | 304 cdefg | | PI 368631 | 3.10 abc | 448 bc |
| | PI 167139 | 2.56 abcd | 491 ab | | PI 278071 | 2.82 abcd | 390 bcde |
| | PI 278075 | 2.48 bcd | 378 bcd | | PI 342452 | 2.75 abcd | 316 bcdef |
| | PI 368631 | 2.40 bcd | 356 bcde | | PI 177425 | 2.52 bcde | 446 bcd |
| | PI 289018 | 2.34 bcd | 207 efg | | PI 169507 | 2.47 bcde | 425 bcde |
| | PI 373911 | 2.29 bcd | 233 defg | | Buttercrunch | 2.34 cdef | 266 defg |
| | PI 274358 | 2.26 bcd | 285 cdefg | | 90269[y] | 2.32 cdef | 408 bcde |
| | Buttercrunch | 2.23 bcd | 345 bcde | | PI 289047 | 2.29 cdef | 258 efg |
| | PI 289059 | 2.07 cd | 422 bc | | PI 289034 | 2.01 defg | 255 efg |
| | PI 342521 | 1.93 cd | 322 cdef | | PI 289016 | 1.98 defg | 270 cdefg |
| | PI 358011 | 1.75 cd | 244 defg | | PI 271937 | 1.60 efg | 204 efg |
| | PI 278103 | 1.71 cd | 189 fg | | PI 358003 | 1.59 efg | 179 fg |
| | PI 285655 | 1.69 d | 163 g | | PI 368629 | 1.45 fg | 172 fg |
| | PI 169514 | 1.51 d | 212 efg | | PI 342509 | 1.17 g | 112 g |

[z]Mean separation within trials by Duncan's multiple range test, 5% level.
[y]Identity unknown.

increased in Test 2. Fresh leaf weights averaged about 2.3 g per plant (Table 2). Average $\kappa_s$ were 9.1, 9.2, 9.4, and 9.4 $dSm^{-1}$, respectively, for Trials 5 to 8. Introductions 177424, 183234, and 278097 demonstrated higher salt tolerance than the test cultivar. Four PIs were significantly less tolerant than 'Buttercrunch'. The 2 other U.S. cultivars in Test 2, 'Shawnee' and 'Wintergreen', had higher fresh weights than the test line.

Generally, root weights corresponded well with leaf weights as indicators of salt tolerance (Tables 1 and 2). Plants having high leaf weights also had higher than average root growth as well. The coefficient of correlation between leaf (x) and root (y) weights was 0.82 ($y = 7.00 + 0.092x$) after 4 weeks salinization. Respective values after 5 weeks were $R^2 = 0.73$ and $y = -44.9 + 0.148x$.

Tolerant and sensitive cultivars and PIs were compared in Test 3 (Trials 9 to 12), (Table 3). Average $\kappa_s$ for the 4 trials were 8.8, 9.0, 9.0, and 8.9 dS $m^{-1}$, respectively. Only fresh shoot weights are presented. Also included in Table 3 are the rankings in salt tolerance of the entries as determined in previous tests. The symbols indicate tolerance (t) or sensitivity (s) compared to the test line, i.e., a higher or lower ranking compared to 'Buttercrunch'. In all instances, this ranking may indicate a statistically significant difference. However, we chose those cultivars that showed the greatest differences relative to that of the benchmark in each previous trial.

In general, the results supported previous conclusions (5). Cultivars rated tolerant had higher mean fresh weights (2.05 ± 0.46 g) than those rated sensitive (1.38 ± 0.38 g). Introductions 169503, 183234, and 278108 again were statistically more tolerant than 'Buttercrunch' (Trials 9, 10, and 11), and 177424 and 278097 had higher mean fresh leaf weights than the benchmark cultivar. Cultivars that had been retested in this screening system also showed results consistent with previous tests.

PIs in Test 3 were more variable than cultivars in the distribution of mean leaf fresh weights. Mean leaf fresh weights of the cultivars ranged from 0.90 to 2.70 g compared to the PIs that ranged from 0.5 to 3.1 g (Fig. 1). Mean leaf fresh weights of PIs and cultivars were 1.78 g and 1.62 g, respectively, in Test 3.

It should be noted that our tolerance ratings are in terms of absolute growth under high salinity and, as such, do not account for natural differences in growth rate or total growth potential that may exist between cultivars or PIs. Relative tolerance is defined as growth under saline conditions relative to growth under nonsaline conditions. Judged by such a criterion, a slow-growing plant may express high tolerance and low yield if it has environmental stability to the salinity stress (4). Conversely, a vigorously growing plant with low stability to the salinity environment may still outyield the former in agricultural conditions having only moderate salinities (4). Thus, entries rated tolerant in these tests can assimilate sufficient carbo-

Table 3. Mean shoot fresh weights of lettuce cultivars, introductions, and advanced breeding lines selected for tolerance (t) or sensitivity (s), after 4 weeks growth in salinized sand cultures.

| Trial | Entry | Rank[z] | Shoot fresh wt (g) | Trial | Entry | Rank | Shoot fresh wt (g) |
|---|---|---|---|---|---|---|---|
| 9 | PI 169503 | t | 2.92 a[y] | 10 | PI 183234 | t | 2.16 a |
| | Climax | t | 2.45 ab | | Imperial 847 | t | 1.83 ab |
| | PI 342555 | t | 2.30 abc | | Fairton | t | 1.75 abc |
| | PI 177424 | t | 2.12 abcd | | PI 278075 | t | 1.74 abc |
| | Parris Island | t | 2.04 abcd | | PI 278097 | t | 1.63 abcd |
| | Buttercrunch | --- | 1.77 bcd | | Climax 84 | t | 1.48 abcd |
| | Tom Thumb | t | 1.76 bcd | | PI 358041 | s | 1.37 abcd |
| | Oakleaf | s | 1.67 bcd | | PI 234624 | t | 1.37 abcd |
| | PI 169514 | t | 1.61 bcd | | PI 344369 | s | 1.33 bcd |
| | Simpson's Curled | t | 1.54 bcde | | Prizehead | s | 1.04 bcd |
| | Paris White | s | 1.37 bcde | | Buttercrunch | --- | 1.03 bcd |
| | PI 289047 | s | 1.36 cde | | Red Salad Bowl | s | 0.99 cd |
| | Grand Rapids | s | 1.30 cde | | Bibb | s | 0.97 cd |
| | PI 289057 | s | 1.21 cde | | PI 169514 | s | 0.95 cd |
| | PI 285655 | s | 1.14 de | | PI 342509 | s | 0.94 cd |
| | PI 289061 | s | 0.51 e | | Ruby | s | 0.90 d |
| 11 | PI 278108 | t | 2.90 a | 12 | PI 368631 | t | 3.10 a |
| | Wintergreen | t | 2.20 ab | | PI 358013 | t | 2.87 a |
| | PI 278099 | t | 2.07 abc | | PI 358024 | t | 2.38 ab |
| | Shawnee | t | 1.91 bc | | 54364 | t | 2.36 ab |
| | PI 285650 | t | 1.79 bc | | 72-136-8 | t | 2.19 ab |
| | PI 358006 | t | 1.77 bc | | PI 339262 | s | 2.15 ab |
| | Calicel | s | 1.71 bc | | Gustoverde | s | 2.05 ab |
| | Buttercrunch | --- | 1.70 bc | | Vanmax | s | 2.00 ab |
| | Primaverde | t | 1.65 bc | | PI 278103 | t | 1.94 ab |
| | Great Lakes 659 | s | 1.65 bc | | Valtemp | s | 1.88 ab |
| | Deer Tongue | s | 1.61 bc | | Buttercrunch | --- | 1.88 ab |
| | Red Coach | t | 1.58 bc | | PI 278103 | s | 1.82 ab |
| | PI 187239 | s | 1.50 bc | | Oasis | s | 1.53 b |
| | PI 171675 | s | 1.44 bc | | PI 358026 | s | 1.45 b |
| | Calmar | s | 1.37 bc | | 640161 | s | 1.29 b |
| | PI 274373 | s | 1.12 c | | PI 289026 | s | 1.17 b |

[z]Tolerant (t) or sensitive (s) in previous tests.
[y]Mean separation within trials by Duncan's multiple range test, 5% level.

hydrates for growth in the presence of significant salt stress and they can do this at an early growth stage. In cultivars, this character is of practical importance. The value of this character in PIs must await further experimentation.

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