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EFFICIENCY OF 3 SINGLE-HARVEST TESTS FOR EVALUATION OF YIELD IN PICKLING CUCUMBER

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SUMMARY

Three rapid tests for measuring yield (small plots harvested once-over, and single plants harvested at the green and at the mature fruit stage) of pickling cucumber (*Cucumis sativus* L.) were evaluated for efficiency compared with the standard multiple-harvest trial with 2 or 3 replications and large plots. Fifteen genotypes were tested in 1981 and 18 in 1982 to determine the correlation among the 4 methods. In 1981, single plants were tested at 4 densities to evaluate the effect of using spaced or crowded plantings in selecting for yield. The spaced and crowded plantings were less efficient than the standard density, but none of the single-plant tests run in 1981 or 1982 were more efficient than the standard method in measuring yield. The most efficient method was 1, 2 or 3 replications of small-plots harvested once-over at green fruit stage, with 160% more gain from selection expected than for the replicated, multiple-harvest trial.

INTRODUCTION

Plant breeders developing new cultivars of cucumber (*Cucumis sativus* L.) often test advanced lines and hybrids using a replicated multiple-harvest trial. These time-consuming trials often are run at several locations using large plots (6 m or more in length). These trials are necessary for final evaluation of experimental materials, but usually it is not possible to use them for evaluation of large numbers of progeny rows in early stages of breeding.

Evaluation of single plants or of progeny rows in small plots, usually with a single harvest at a particular stage of fruit development may provide a solution to the above problem. The easiest method for evaluation of yield and other fruit characteristics is the harvest of single plants at mature fruit stage (fruits losing their green color and seeds mature). At the time, the foliage is dying, exposing the fruits for easy evaluation. Selections made at that time can be harvested for seeds.

With a little more effort, single plants can be evaluated at green stage (10% of the fruits oversized, i.e. diameter over 51 mm), which has been identified as the optimum

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stage for once-over harvest of pickling cucumbers under North Carolina production conditions (MILLER & HUGHES, 1969). Selections can be flagged, and seeds harvested later when the fruits have matured.

The small plot test harvested once-over at green stage permits evaluation of the genotypes over replications and/or locations to adjust for environmental variation.

All of the above 3 methods are easier to run than the replicated, multiple-harvest trial, and permit the evaluation of more genotypes.

SMITH & LOWER (1978) estimated the effectiveness of some of those rapid tests. They found that mature stage fruit number was slightly correlated ($r = 0.36$) with green stage fruit number, and green stage fruit number was highly correlated with fruit value ($/ha) in pickling cucumbers harvested once-over. Another study of a monoecious pickling cucumber population found the genetic correlation to be 1.01 and the phenotypic correlation to be 0.78 between fruit number and fruit value (SMITH et al., 1978). Correlation of green stage fruit number with fruit value ranged from 0.64 to 0.85 for the 3 harvests of a multiple-harvest trial, all highly significant (SMITH & LOWER, 1978). However, fruit number from once-over harvest was not significantly correlated with fruit value from a simulated multiple-harvest trial. For fresh-market cucumbers, the most efficient procedure for early evaluation of lines used small plots harvested once-over at the green stage with 1 to 3 replications (WEHNER & MILLER, 1984). That method proved to be more efficient than single plants harvested at green or mature fruit stage, or large, replicated plots in a multiple-harvest trial.

Single-plant (hill plot) tests are used frequently to evaluate segregating generations. In many breeding programs, the use of widely-spaced plants provides an easy method for measuring yield and is convenient if selections are to be hand pollinated. Conversely, it may be advantageous to evaluate plants at high density in order to get more genotypes into limited space. However, either of those methods may provide misleading results if plants respond differently in crowded or in widely-spaced plantings than at a standard density.

The rapid methods for evaluating single plants or small plots for yield allow the handling of 17 to 286 times more genotypes than the replicated, multiple-harvest trial, as estimated for the North Carolina State University breeding program (Table 1). The selection intensity, i.e. the selection differential in units of standard deviations, (k) was 2.5 to 3.4 times higher as a result. Thus, except for final evaluation of experimental hybrids, the rapid tests offer considerable power to the plant breeder for testing and selecting genotypes in the early stages of development of lines and hybrids. The major question is how well correlated the rapid tests are with the multiple-harvest trial.

The rapid methods for measuring yield as described above may be useful in the early stages of selection to eliminate families or lines with low yield potential. However, they should not be used for final evaluation of lines unless they predict adequately the yield in replicated multiple-harvest trials. Thus, the objectives of this study were to determine which of the methods of measuring yield best predicts the results of the replicated, multiple-harvest trial, and which is most efficient for rapid evaluation of cultivars and experimental lines of pickling cucumbers.

Table 1. Number of lines tested, selection intensity, and relative capacity to handle lines for 4 methods of yield measurement.

Evaluation method	Number of replications	Number of genotypes tested[1]	Selection intensity[2] (k)	Relative selection intensity[3]
Replicated, multiple-harvest yield trial	3	50	0.951	1.000
Small plots harvested at green stage	3	850	2.361	2.483
	2	1150	2.472	2.599
	1	1700	2.610	2.744
Single plants harvested at green stage	1	4300	2.915	3.065
Single plants harvested at mature stage	1	14300	3.273	3.442

[1] Estimated using the resources of the North Carolina State University cucumber breeding project (i.e. the costs for all methods were approximately the same).
[2] Obtained under the assumption that 20 genotypes were selected out of the total number tested for each method.
[3] Capacity of each evaluation method relative to the replicated, multiple-harvest yield trial, which was calculated by taking the ratio of the selection intensities.

MATERIALS AND METHODS

The experiment was conducted for 2 years using single plants harvested once-over at green and at mature fruit stages in 1981; and small plots harvested once-over at green stage, in addition to single plants harvested once-over at green and at mature stages, in 1982. Those rapid tests were evaluated against a replicated, multiple-harvest trial each year. All plots were planted at the Horticultural Crops Research Station near Clinton, North Carolina. For the 5 single-harvest tests, yield was measured as fruit number per plant or plot.

Cultural practices. Soil was treated the previous October with nematicide (dichloropropene at 93.4 l/ha). Fertilizer (90 kg/ha N; 20 kg/ha P; 74 kg/ha K) was broadcast just before bed formation. At that time, tank-mixed bensulide and naptalam were incorporated at the rates of 9.9 and 4.5 kg active ingredient/ha, respectively, to control weeds. Plants were sidedressed at vine tip-over stage with fertilizer at the rate of 34 kg/ha N. Irrigation was applied to supplement natural rainfall for a total of 25 to 38 mm of water each week.

For the multiple-harvest trial, yield was measured according to commercial practice. Fruits were graded into the 4 North Carolina size grades, weighed, and converted into \$/ha. Grades were 0 to 27 mm, 28 to 38 mm, 39 to 51 mm, and over 51 mm in diameter for grades 1, 2, 3 and 4, respectively. Fruits were then weighed (tons), and dollar value was calculated as (wt. 1 × \$298) + (wt. 2 × \$143) + (wt. 3 × \$88) + (wt. 4 × \$0).

1981 experiment. Three test methods were evaluated in 1981, single plants harvested once-over at the green fruit stage and at the mature fruit stage, and the replicated, multiple-harvest trial. Fifteen hybrids of pickling cucumbers chosen for diversity of background were used (Table 2). They included gynoecious and monoecious types, 2-way and 3-way hybrids, determinate and indeterminate types, and cultivars and experimental hybrids. All tests were planted 27 April. The multiple-harvest trial was harvested twice weekly 15 June through 29 June, totaling 5 harvests. The single plants were harvested 19 June for green stage, and 16 July for mature fruit stage.

Seeds were planted on raised, shaped beds 0.5 m wide on top and 1.5 m apart (center-to-center). For the multiple-harvest trial, plots were 9 m long, and were overplanted and thinned to 51870 plants/ha. The experimental design for the that trial was a randomized complete block with 15 hybrids and 2 replications. Single-plant tests were randomized complete block designs with 4 plant densities and 5 replications for each harvest stage (green and mature fruit). Plots 1, 1.5, 4 or 8 m long were thinned to 123 500 (crowding), 61 750 (standard), 20 580 (widely-spaced) on 10 300 (widely-spaced) plants/ha, respectively. Lower densities required longer plots to simulate conditions in a selection field. All plots for the 3 test methods were separated by 1.5 m alleys at each end. Replications for the single-plant tests were used to detemine the variation for prediction value of the tests.

1982 experiment. Four methods were evaluated in 1982, the same 3 as in 1981, plus once-over harvest of small plots. Eighteen diverse cultivars and lines were used to evaluate the correlations among the 4 methods (Table 3). Cultural practices were the same as for 1981 with the exception of plot size. The multiple-harvest test used 6 m long plots (63 200 plants/ha) arranged in a randomized complete block with 3 replications. The once-over harvested small-plot test, and the single-plant tests used 30-plant, 3 m long plots replicated 4 times. Plots 3 m long have been shown to be near the optimum plot size for pickling cucumbers harvested once-over (SMITH & LOWER, 1978; SWALLOW & WEHNER, 1985).

The 4 tests were planted 19 April; the multiple-harvest trial was harvested twice weekly from 14 June through 1 July for a total of 6 times. The once-over harvest plot trial was harvested at 10% oversized fruits on 17 June, and the single-plant trials were harvested 17 June for green stage, and 12 July for mature stage.

Data analysis. Correlations between fruit value in the replicated, multiple-harvest trial and fruit number in the other 3 tests were calculated. The correlations were run for all possible combinations of 1, 2, 3 and 4 replications between each of the rapid tests and the combined replications of the multiple-harvest trial.

The rapid tests were compared to the multiple-harvest trial using the formula for estimating correlated gain, rather than the ratio for gain from selection for one test relative to another as done by WEHNER & MILLER (1984). The ratio of gain formula is appropriate for choosing among methods for use in testing. The correlated gain formula is appropriate where one test is the standard for comparison for the other tests. The correlated gain expected in performance of selections in the multiple-harvest trial (M) when using the rapid tests (R) for evaluation was calculated using a formula modified from KRAMER et al. (1982) as shown in equation (1) below.

$$\frac{CG}{G_M} = \frac{G_R \cdot b_{G(M) \cdot G(R)}}{G_M} = \frac{k_R \cdot h_R \cdot r_{G(M) \cdot G(R)}}{k_M \cdot h_M} = \frac{k_R \cdot r_{P(M) \cdot P(R)}}{k_M \cdot h^2{}_M} \qquad (1)$$

where CG is the correlated gain from selection, G is the gain from selection, $b_{G(M)\cdot G(R)}$ is the regression of multiple-harvest on rapid test genotypes, k is the selection intensity, h^2 is the broad-sense heritability: $\sigma^2_G/(\sigma^2_G + \sigma^2_E)$, h is the square root of the broad-sense heritability, $r_{G(M)\cdot G(R)}$ is the correlation of multiple-harvest and rapid test genotypes, and $r_{P(M)\cdot P(R)}$ is the correlation of multiple-harvest and rapid test phenotypes.

The last step in the equation is derived using the relationship shown below, which assumes a covariance of environments for the multiple-harvest and rapid tests ($\sigma_{E(M)\cdot E(R)}$) of zero.

$$r_{P(M)\cdot P(R)} = \frac{\sigma_{P(M)\cdot P(R)}}{\sigma_{P(M)}\cdot\sigma_{P(R)}} = \frac{\sigma_{G(M)\cdot G(R)}}{\sigma_{G(M)}\cdot\sigma_{G(R)}}\cdot\frac{\sigma_{G(M)}\cdot\sigma_{G(R)}}{\sigma_{P(M)}\cdot\sigma_{P(R)}} = r_{G(M)\cdot G(R)}\cdot h_R\cdot h_M$$

Thus, according to the above equation, the advantage of the 3 rapid tests over the multiple-harvest trial can be calculated using the ratio of selection intensities for the test methods (k_R/k_M) times the phenotypic correlation between the tests ($r_{P(M)\cdot P(R)}$) divided by the broad-sense heritability for yield in the multiple-harvest test. Correlations were measured from field data. The ratio of the selection intensities was calculated assuming that 20 genotypes were selected out of the total number tested. The broad-sense heritability was calculated from the analysis of variance for the multiple-harvest test using variance components (assuming a random model). The heritability was 0.53 for yield ($/ha).

RESULTS AND DISCUSSION

Study of the rankings of the means of the 15 hybrids tested in 1981 shows that they performed quite differently in the 2 single-plant tests compared with the multiple-harvest trial (Table 2). The single-plant test planted at an optimum density (61750 plants/ha) and harvested at mature fruit stage provided little variation for yield (in number of fruits per plant), having a range smaller than the LSD (5%) for the test. Neither the single-plant test harvested at green fruit stage, nor the one harvested at the mature fruit stage provided results related to the multiple-harvest trial.

The 18 hybrids evaluated in 1982 followed the same pattern for the single-harvest tests as in 1981 (Table 3). The performance of the hybrids in the mature stage test was not related to the yield of the hybrids in the multiple-harvest trial, and the single-plant test harvested at the green stage test was not much better. However, the small-plot test harvested once-over at the green stage was a good predictor of yield in the multiple-harvest trial. The top 2 yielding hybrids out of 18 were the same for the 2 tests. There were some differences, however. For example, the third highest line ranked sixth in the small-plot test. The small-plot test was very discriminating, however, with the smallest CV of the 4 tests and an LSD (5%) only 36% as large as the range (compared with 43 to 87% for the other 3 tests).

The single-plant tests were poor at distinguishing among genotypes for yield. As expected, yield per plant differed for the 4 densities of single plants evaluated (Table 4). The number of fruit per plant increased from less than 2 for the high density (123 500 plants/ha) to more than 3 for the low density (10 300 plants/ha), with yield about the same for green stage as for mature stage harvest. Unfortunately, the single-plant yields

Table 2. Yield of 15 pickling cucumber hybrids tested in 1981 using 2 rapid methods (single plants harvested at the green stage and at the mature stage) compared with the standard multiple-harvest method.

Hybrid	Seed source	Multiple-harvest yield ($/ha)	Single plant yield			
			green stage		mature stage	
			mean[3]	optimum[4]	mean[3]	optimum[4]
Castlepik	Castle Seed	3283	2.4	2.0	3.1	1.4
Greenpak	Harris-Moran	3268	3.0	2.6	3.3	1.8
G56	NC State Univ.	3095	2.4	2.2	3.0	2.2
Tamor	Asgrow Seed	3008	3.0	2.4	3.4	2.0
Regal	Harris-Moran	2920	2.4	1.8	3.2	2.2
Multipik	PetoSeed	2680	2.8	2.4	4.0	1.6
Blitz	PetoSeed	2616	2.4	2.2	3.6	2.2
Calico	PetoSeed	2522	2.4	2.6	3.0	2.6
Triplemech	PetoSeed	2430	2.6	2.2	3.0	2.4
G76	NC State Univ.	2281	3.0	3.2	3.7	2.6
Tempo	Harris-Moran	2159	2.7	1.6	3.6	1.4
Calypso	Ferry-Morse	2100	2.8	1.8	3.2	2.4
Explorer	PetoSeed	2040	2.8	2.2	2.8	1.8
Score	Asgrow Seed	2013	2.2	1.8	3.2	2.6
Sampson	PetoSeed	1793	2.0	1.2	3.2	2.2
$\overline{x}$		2547	2.6	2.2	3.3	2.1
LSD (5%)		1099	0.6	1.2	1.0	1.9
CV (%)		20	37	37	46	46

[1] Means across 2 replications of total yield summed over 5 harvests. Plant density was 51 870 plants/ha.
[2] Means across 5 replications.
[3] Means across 4 densities (123 500, 61 750, 20 580 and 10 300 plants/ha).
[4] Optimum density of 61 750 plants/ha.

were not consistently correlated with yields in the multiple-harvest trial regardless of harvest stage or plant density (Table 5). There was considerable difference among replications for correlation with yield in the multiple-harvest trial, ranging from +0.56 to −0.48. The best of the single-plant tests was green stage harvest of plants at the standard density of 61 750 plants/ha. That test most closely represents the conditions of the multiple-harvest trial in harvest stage and planting density. However, the results indicate that neither the low-density plantings nor the crowded plantings were acceptable for evaluating early-generation materials in a breeding program.

In 1982, the small-plot, once-over harvest test with 1, 2 or 3 replications provided the greatest efficiency in evaluating genotypes for yield (Table 6). That makes sense in view of its greater capacity for handling lines compared with the replicated, multiple-harvest trial, and its higher correlation with fruit value ($/ha) compared with the 2 single-plant tests. The single-plant test harvested at the green stage was as efficient as the replicated, multiple-harvest trial, but the test harvested at the mature stage provided no gain. That was due to the lack of correlation of yield between the 2 tests. However, the 2 or 3 replication small-plot, once-over harvest test gave 160% more correlated gain than if the same resources were spent on the replicated, multiple-har-

Table 3. Yield of 18 hybrids tested in 1982 using 3 rapid methods (plants or plots harvested once-over) compared with the standard multiple-harvest method[1]

Cultivar or line	Seed source	Multiple-harvest yield ($/ha)[2]	Once-over yield (no. fruits) small plot[3]	single-plant stage[4]	
			green	green	mature
Castlepik	Castle Seed	5666	88	3.0	3.3
4J73	Harris-Moran	5167	91	4.3	2.0
HYB 79-1197	Musser Seed	5088	73	2.0	2.7
Regal	Harris-Moran	5012	73	3.0	2.0
Lucky Strike	PetoSeed	4735	55	3.0	2.3
Triple Crown	Ferry-Morse	4619	65	2.7	3.0
4JC2	Harris-Moran	4609	73	3.0	1.7
Blitz	PetoSeed	4451	87	2.3	1.0
Pikmaster	Northrup King	4263	70	2.3	1.7
Gynomite	Asgrow Seed	4194	75	4.0	2.3
Calico	NC State Univ	4073	55	2.7	2.0
GG 7	NC State Univ	3972	82	2.7	2.3
Calypso	PetoSeed	3885	78	2.3	2.3
Score	Asgrow Seed	3875	55	3.0	3.0
XPH 1369	Asgrow Seed	3791	70	2.3	3.3
Explorer	PetoSeed	3357	66	2.7	1.7
Saladin	Sluis & Groot	3300	60	3.0	4.3
Carolina	PetoSeed	3216	47	2.0	2.7
$\bar{x}$		4293	70	2.8	2.4
LSD (5%)		1052	16	2.0	1.6
CV (%)		15	14	42	39

[1] All plots thinned to a density of 63200 plants/ha.
[2] Means across 3 replications of total yield summed over 6 harvests.
[3] Means across 4 replications of plants grown at 62000 plants/ha.
[4] Means across 4 plants grown at 60250 plants/ha.

Table 4. Yield (number of fruits per plant) at 4 densities for 15 cultivars and lines harvested once-over at green or mature fruit stage in 1981.[1]

Harvest stage	Density (plants/ha) 123500	61750	20580	10300	LSD (5%)
Green	1.71	2.15	3.15	3.39	0.31
Mature	1.91	2.09	3.56	3.59	0.49

[1] Means across 5 replications.

vest trial. That result proves to be advantageous for many selection programs where progeny rows are evaluated in 2 or 3 locations using seed produced from a single

Table 5. Pearson product-moment correlations of multiple-harvest yield ($/ha) with once-over harvest yield (number of fruits per plant) from single plants harvested at green and mature fruit stages and grown at 4 plant densities in 1981.[1]

Replication	Density (plants/ha)			
	123500	61750	20580	10300
	Green fruit stage			
1	0.48	0.40	0.30	−0.11
2	0.04	0.56*	0.01	0.11
3	0.37	0.11	0.22	0.49
4	−0.31	0.10	−0.11	−0.03
5	0.20	0.13	−0.22	−0.09
$\bar{x}$	0.16	0.26	0.04	0.07
	Mature fruit stage			
1	0.06	0.08	0.55*	−0.48
2	−0.20	−0.14	0.30	−0.09
3	0.32	−0.47	0.17	−0.19
4	−0.10	−0.16	0.27	0.28
5	0.40	0.03	−0.07	0.07
$\bar{x}$	0.02	−0.13	0.24	−0.08

* Significant at the 5% level.
[1] Multiple-harvest trial was run with 2 replications and 5 harvests.

Table 6. Relative selection intensity, phenotypic correlation (r), and calculated advantage of handling lines with 3 rapid methods of yield measurement compared with yield ($/ha) from the standard method (replicated multiple-harvest trial with 3 replications) in 1982.

Evaluation	Number of replications	Relative selection intensity[1]	Phenotypic correlation (r)	Calculated advantage[2]
3 m plots harvested once-over at green stage	3	2.483	0.58*	2.6
	2	2.599	0.55*	2.6
	1	2.744	0.49*	2.5
Single plants harvested once-over at green stage	1	3.065	0.19	1.1
Single plants harvested once-over at mature stage	1	3.442	−0.12	0

* Significant at the 5% level.
[1] See Table 1.
[2] Calculated advantage = (relative selection intensity) × (r)/h^2_B. (h^2_B = the broad-sense heritability = 0.53).

pollination per progeny row. Usually, a single pollination will produce just enough seed for a 2- or 3-replication (location) test, leaving remnant seed for intercrossing or self-pollination of those progenies that are selected.

Based on the data presented, it appears that genotypes to be developed for high yield in a multiple-harvest production system should be evaluated initially in a 2 or 3 replication, once-over harvest, small-plot test. Single-plant tests should not be used to evaluate yield. Small-plot tests could be used until the final evaluation stage is reached. At that point, a multiple-harvest trial should be run, perhaps using several locations and years to provide sufficient data to prove the worth of the new genotype.

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