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Yield Components in Several Apple Clones

G. W. EATON[1]

Abstract

Three experiments with cultivars within the 'Delicious,' 'Golden Delicious' and 'McIntosh' groups were followed for 2 years in young commercial orchards. Differences in yield and its components were detected among cultivars within groups. While differences were not consistent from one year to the next there was no indication of alternate cropping. The number of fruits harvested accounted for most of the variation in yield in 1984 but the number of flower clusters was more important in 1985. Significant strain differences in yield were detected in 'Golden Delicious' in 1984 (due to differences in the number of fruit harvested), in 'Delicious' in 1985 (not attributable to a single yield component) and in 'McIntosh' in 1985 (due to differences in the number of flower clusters).

Introduction

Closely related apple strains or cultivars may be expected to be similar in many respects, but small differences may be of economic importance (3, 4, 5). Such differences include color, growth habit, physiological characteristics and yield. It has long been recognized that yield can be regarded as dependent upon a number of yield components such as flower number, fruit set, fruit drop and fruit enlargement. It is also well known that such factors can respond to horticulture manipulation. Yield components may differ among cultivars for genetic reasons or in response to the environment. It is interesting not only to know of differences in yield among cultivars but how such differences are generated by changes in yield components.

Only recently have statistical techniques been adapted to the study of yield and its components in a way that can show how yield depends upon its components in a way that is modified by treatments (2). The statistical method is called 'two-dimensional partitioning of yield variation' (TDP), where the two dimensions are simply the rows and columns of a table in which the rows partition variation as in an analysis of variance. The columns of the TDP table can be used in various ways, but especially to represent information about yield and its components. Additionally, columns of the TDP table may provide information about the interaction or competition of one component with another. For example conditions which favor fruit set might increase both seed number and fruit weight but on the other hand fruit size might be decreased by competition from the increased number of fruits. TDP employs analysis of variance (ANOV) in the rows. The data for the columns are both prepared and analysed by regression procedures.

TDP (2) allows an integrated approach to the study of the reasons for differences in yield as influenced by its components and their interactions. It is impossible to do a study large enough to answer all the important questions. The scope of such investigations will probably always be limited by available resources. The present study used TDP in commercial orchards to examine differences among some apple cultivars in their yield and in several of its components.

[1]Department of Plant Science, 2357 Main Mall, University of British Columbia, Vancouver, Canada V6T 2A2.

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Materials and Methods

Orchards of three commercially important groups, 'Delicious,' 'Golden Delicious' and 'McIntosh,' were arranged as three separate experiments designed as randomized complete blocks, each in 6 blocks with 11 trees per plot. The ten cultivars or strains in the 'Delicious' group were 'Ace,' 'Gardiner,' 'Oregon Spur,' 'Redchief,' 'Redspur,' 'Ryanred Spur,' 'Starkrimson,' 'Sturdeespur,' 'Ultrared' and 'Wellspur.' The five cultivars or selections in the 'Golden Delicious' group were 'Summerland 9E-13-47,' 'Criterion,' 'Golden Delicious,' 'Sinta' and 'Smoothee.' The four 'McIntosh' were 'Dewarspur,' 'Macspur,' 'Morspur' and 'Summerland Red.' The 'Delicious' are all spur types while the 'Golden Delicious' are all standard growth habit types. 'Macspur' and 'Morspur' are spur types while 'Dewar' is intermediate (1) and 'Summerland Red' is of standard growth habit.

All trees were on M4 rootstocks planted in 1981 at a spacing of 2.43 x 4.86 m (8 x 16 feet) except that 'Ultrared' was planted in 1982. The orchards are the property of the B.C. Fruit Growers' Association Test Orchard Limited and are located near Oliver, British Columbia, Canada. Trees were managed under standard commercial conditions and exhibited excellent health and growth and typical productivity.

Measurements were made on one selected and marked main framework branch, judged to be representative, on each of the third, sixth and ninth tree in each plot. In 1984, on each branch, the basal cross-sectional area, total number of flower clusters, total number of harvested fruits and total fruit weight were determined for the 'Delicious' and 'Golden Delicious' experiments. In 1985, on each selected branch, the basal cross-sectional area, total number of flower clusters, total number of fruits set, total number of fruits harvested and total fruit weight were determined for all three experiments.

The data were analysed by TDP (2) but, because some data values were equal to zero, no rations of components were calculated nor were logarithmic transformations performed. Cluster numbers were transformed to residuals from regression on limb cross-sectional area, thus producing a new orthogonal variate, or adjusted cluster number, to account for just that yield variation beyond that which was already accounted for by limb

Table 1. Means[z] for attributes of 'Delicious' apple trees, 1984.

Strain	Limb area (mm^2)	Cluster no.	Fruit no.	Yield (kg)	Adjusted variates		
					Cluster	Fruit	Yield
Ace	429	8.5	7.0^{a}	1.30	1.2	2.8^{a}	-0.17
Gardiner	429	5.8	4.2^{ab}	0.94	-1.5	0.2^{ab}	0.03
Oregon Spur	399	7.3	4.6^{ab}	0.93	0.4	0.5^{ab}	-0.05
Redchief	432	6.7	3.8^{ab}	0.81	-0.7	-0.3^{ab}	-0.01
Redspur	465	7.5	4.1^{ab}	0.86	-0.3	-0.2^{ab}	-0.03
Ryanred Spur	382	7.3	5.4^{ab}	1.18	0.7	1.4^{ab}	0.02
Starkrimson	607	9.9	4.7^{ab}	0.97	0.2	-0.2^{ab}	-0.02
Sturdeespur	485	7.9	2.9^{ab}	0.62	-0.2	-1.5^{ab}	-0.02
Ultrared	443	6.3	1.3^{b}	0.28	-1.2	-2.8^{b}	-0.05
Wellspur	466	9.1	4.5^{ab}	1.28	1.3	0.1^{ab}	0.32
Mean	454	7.6	4.2	0.92	0.0	0.0	0.00
HSD .05	ns	ns	4.82	ns	ns	4.61	ns

Means are averages of 18 trees, 3 trees per block in each of 6 complete blocks. F-tests for strain differences had 9 and 45 degrees of freedom.

[z]Mean separation within columns by Tukey's HSD at the 5% level if the F-test was significant in the ANOVA.

cross-sectional area. Similarly, each measured variable was adjusted from the multiple regression on the chronologically preceding variates.

A residual variate was computed and included in the TDP in order to account for all of the variation in yield. In the TDP, an ANOV was carried out on all variates, yield was regressed on all variates, and finally total variation in yield was partitioned in two dimensions, one (the columns) according to the components of total yield and the other (the rows) according to the ANOV model appropriate to the particular experimental design.

Results and Discussion

Some trees of the 'Delicious' group in 1984 had more fruits per limb than others, even after adjusting for differences in cluster numbers per limb (Table 1). This finding is indirect evidence of tree differences in fruit set and 'Ace' thus had significantly more fruit than 'Ultrared' (the latter was a year younger), even after adjustment. While yield differences were large, they were not statistically significant and could not therefore reasonably be called strain differences.

In the 1985, comparisons of 'Delicious' 'Ultrared,' planted a year later than the others, could not be distinguished from the others in any respect (Table 2). 'Redspur' had greater fruit set than 'Sturdeespur' and greater fruit numbers and yield of fruit at harvest than 'Sturdeespur' or 'Ryanred Spur.' Only 'Welspur' and 'Ryanred Spur' had less yield in 1985 than in 1984, but only 'Ryanred Spur' had a smaller number of fruit.

In the 'Golden Delicious' group, 1984 yields differed with 'Sinta' being substantially higher than 'Criterion' or 'Golden Delicious' (Table 3). Since adjusted yields were similar, it appears that the yield differences were primarily due to differences in fruit number. The differences in fruit number in turn were probably due to differences in fruit set, since fruit numbers even after adjustment for limb area and cluster number were still greater in 'Sinta' (Table 3).

In the 1985 comparisons of 'Golden Delicious,' no significant differences among the strains were detected (Table 3). Of course a two-year study cannot establish a pattern of alternate cropping, but there was no evidence of alternation. For example, 'Sinta' and 'Criterion' which had been the high and low yielding strains respectively in 1984, gave no indication of reversal

Table 2. Means[z] for attributes of 'Delicious' apple trees, 1985.

Strain	Limb area (mm^2)	Cluster no.	Fruit Set no.	Fruit Harvest no.	Yield (kg)	Adjusted variates			
						Cluster	Set	Harvest	Yield
Ace	623	6.1	9.6^{ab}	9.6^{ab}	2.01^{ab}	0.9	1.3	0.5	0.05
Gardiner	685	7.2	8.3^{ab}	7.1^{ab}	1.41^{ab}	1.6	-1.3	-0.9	0.01
Oregon Spur	660	5.3	7.2^{ab}	6.8^{ab}	1.37^{ab}	-0.2	-0.4	-0.1	0.00
Redchief	676	5.7	6.4^{ab}	6.1^{ab}	1.19^{ab}	0.1	-1.6	-0.1	-0.02
Redspur	653	9.1	14.2^{a}	14.1^{a}	2.78^{a}	3.7	2.7	0.7	-0.07
Ryanred Spur	588	2.4	4.4^{ab}	4.4^{b}	0.93^{b}	-2.5	0.0	0.3	-0.01
Starkrimson	613	5.4	8.4^{ab}	7.9^{ab}	1.51^{ab}	0.4	0.7	0.0	-0.11
Sturdeespur	662	3.0	4.0^{b}	3.7^{b}	0.80^{b}	-2.5	-1.2	-0.2	0.05
Ultrared	480	5.1	7.2^{ab}	6.6^{ab}	1.46^{ab}	1.0	0.1	-0.2	0.12
Wellspur	720	3.4	5.3^{ab}	5.3^{ab}	1.08^{ab}	-2.5	-0.3	0.2	-0.02
Mean	636	5.3	7.5	7.2	1.45	0.0	0.0	0.0	0.00
HSD .05	ns	ns	9.42	9.04	1.82	ns	ns	ns	ns

Means are averages of 18 trees, 3 trees per block in each of 6 complete blocks. F-tests for strain differences had 9 and 45 degrees of freedom.

[z]Mean separation within columns by Tukey's HSD at the 5% level if the F-test was significant in the ANOVA.

Table 3. Means[z] for attributes of 'Golden Delicious' apple trees.

Strain	Limb area (mm^2)	Cluster no.	Fruit Set no.	Fruit Harvest no.	Yield (kg)	Adjusted variates: Cluster	Set	Harvest	Yield
1984									
9E-13-47	259	7.6		3.2^{ab}	0.42^{ab}	1.7		0.5^{ab}	-0.01
Criterion	242	4.4		0.1^{b}	0.01^{b}	-1.6		-2.7^{b}	-0.01
Golden Delicious	244	6.2		1.7^{b}	0.22^{b}	0.2		-1.0^{b}	-0.02
Sinta	238	5.6		5.7^{a}	0.74^{a}	-0.5		2.9^{a}	-0.02
Smoothee	285	6.1		2.8^{ab}	0.43^{ab}	0.2		0.3^{ab}	0.05
Mean	254	6.0		2.7	0.36	0.0		0.0	0.00
HSD .05	ns	ns		3.52	0.44	ns		3.40	ns
1985									
9E-13-47	366	5.8	5.0	4.5	0.80	2.3	-0.8	0.0	-0.04
Criterion	483	0.8	0.4	0.1	0.03	-3.4	-1.4	-0.4	0.00
Golden Delicious	489	3.1	5.6	4.8	0.87	-1.3	1.8	0.1	-0.03
Sinta	461	4.6	5.1	5.1	0.97	0.4	0.1	0.7	0.02
Smoothee	436	5.9	6.4	5.3	1.05	2.0	0.3	-0.3	0.04
Mean	447	4.0	4.5	4.0	0.74	0.0	0.0	0.0	0.00
HSD .05	ns	ns	ns	ns	ns	ns	ns	ns	0.09

Means are averages of 18 trees, 3 trees per block in each of 6 complete blocks. F-tests for strain differences had 4 and 20 degrees of freedom.

[z]Mean separation within columns by Tukey's HSD at the 5% level if the F-test was significant in the ANOVA.

in 1985. No member of this group had lower yield although 'Sinta' had fewer fruits in 1985 than in 1984.

In comparisons of 'McIntosh,' available only in 1985, there were strain differences for each attribute measured and for cluster number adjusted for limb cross-sectional area (Table 4). 'McIntosh' had the largest limbs, although it was significantly different only from 'Morspur' which in turn was not significantly smaller than 'Dewarspur' or 'Macspur.' 'Macspur' greatly exceeded 'Dewarspur' in cluster numbers, fruit set, number of fruit harvested and in yield.

The differences in 1985 in 'McIntosh' fruit set, number of fruit harvested and yield could all be attributed primarily to the very large advantage of 'Macspur' in cluster numbers both unadjusted and adjusted for limb area. The adjusted values for numbers of fruit set and harvested and the amount of yield differed very slightly for the 4 subclones.

In 1984 most of the variation in yield of 'Delicious' was attributed to variation in the number of fruits harvested (65.0%) which in turn received an important contribution (7.6%) from strain effects (Table 5). Much (89.0%) of the total variation in yield was also explained by experimental error and block X strain interaction (Table 5).

In 1985 there was significant yield variation (10.1%) due to strains (Table 5). Clearly, this variation was due to the sum of strain differences in yield components, but no single component of yield (even cluster number with 4.6% of the total variation) demonstrated statistically significant strain effects when tested separately. The main contributors to yield were cluster numbers (65.9%) and fruit set (21.5%). These values could be attributed mainly to tree variability (or branch variability, since there was only one measured branch per tree), with 41.3% and 13.3% of total yield variation accounted for by tree variation within plots for cluster numbers and fruit set respectively (Table 5).

In the 'Golden Delicious' trial, strain differences made a significant contri-

Table 4. Means[z] for attributes of 'McIntosh' apple trees, 1985.

Strain	Limb area (mm^2)	Cluster no.	Fruit Set no.	Fruit Harvest no.	Yield (kg)	Adjusted variates			
						Cluster	Set	Harvest	Yield
Dewarspur	435^{ab}	12.6^{b}	14.4^{b}	12.8^{b}	2.31^{b}	-10.2^{c}	-2.3	-0.5	-0.17
Macspur	505^{ab}	33.4^{a}	33.2^{a}	32.7^{a}	4.75^{a}	10.1^{a}	-0.6	0.3	-0.26
Morspur	429^{b}	24.6^{a}	26.5^{a}	24.7^{a}	3.76^{ab}	2.0^{ab}	0.5	-0.2	-0.11
McIntosh	569^{a}	22.1^{ab}	28.2^{a}	25.9^{a}	4.41^{a}	-1.9^{bc}	2.4	0.3	0.20
Mean	485	23.2	25.6	24.0	3.81	0.0	0.0	0.0	0.00
HSD .05	87	11.6	11.9	11.7	2.06	11.9	ns	ns	ns

Means are averages of 18 trees, 3 trees per block in each of 6 complete blocks. F-tests for strain differences had 3 and 15 degrees of freedom.

[z]Mean separation within columns by Tukey's HSD at the 5% level if the F-test was significant in the ANOVA.

bution of 17.4% to total yield variation in 1984 (Table 6). The adjusted number of fruit harvested accounted for 96.9% of the total variation in yield. Further partitioning of variation in this component revealed that 17.4% of the total variation in yield was attributed to strain differences in adjusted number of fruit harvested (Table 6). In this instance the TDP has clarified the origins of strain differences in yield. They differed in yield mainly because of differences in the number of fruit harvested. I find this effect is much easier to see in Table 6 than in Table 3, although Table 3 presents further information on the strains, especially the high yield of 'Sinta' and the lower yield of 'Criterion.'

The insignificant and small differences in adjusted yield (Table 3) are consistent with the fact that 97.1% of the variation in yield was explained by limb area, cluster number and number of fruits harvested (Table 6). It is tempting to suppose that this indicates uniform size of fruit, but it does so somewhat indirectly since total fruit weights were determined for each limb and fruits were not weighed individually.

Most of the 1985 yield variation in the 'Golden Delicious' experiment was accounted for by adjusted cluster

Table 5. 'Delicious,' partitioning of the percentage of the total sum of squares for yield.

Source	df	Adjusted variated				Residual	Products[z]	Yield
		Limb area	Cluster no.	Fruit Set no.	Fruit Harvest no.			
1984								
Block	5	0.1°°	0.1		1.8	0.6	0.5	3.1
Strain	9	0.2	0.0		7.6°	1.3	-1.1	7.9
B X S	45	0.7°°	0.2		16.4	9.3	-1.8	24.8
Error	120	0.5	0.6		39.3	21.5	2.3	64.2
Total	179	1.5	0.8		65.0°°	32.7	0.0	100.0[y]
1985								
Block	5	0.1	5.4°	0.6	0.0	0.1	1.3	7.5°
Strain	9	0.4	4.6	1.9	0.3	0.1	2.8	10.1°
B X S	45	1.3°°	14.6	5.7	1.8	0.6	-1.1	22.9
Error	120	1.8	41.3	13.3	4.8	1.2	-3.1	59.4
Total	179	3.7°°	65.9°°	21.5°°	7.0°°	2.0	0.0	100.0[y]

°, °° — significant at P = .05 and .01 respectively; total rows in multiple regression, others by ANOVA.

[z]Cells in this column contain the sums of products for the adjusted variates.

[y]The total sum of squares for yield (kg) was 196.5 and 528.33 in 1984 and 1985 respectively.

Table 6. 'Golden Delicious,' partitioning of the percentage of the total sum of squares for yield.

Source	df	Adjusted variated: Limb area	Cluster no.	Fruit Set no.	Fruit Harvest no.	Residual	Products[z]	Yield
1984								
Block	5	0.1°°	0.0		8.1	0.1	-0.6	7.6
Strain	4	0.0	0.0		17.4°°	0.2	-0.2	17.4°
B X S	20	0.1°°	0.0°°		13.1	0.4	-0.9	12.8
Error	60	0.1	0.0		58.3	2.0	1.7	62.3
Total	89	0.4	0.0		96.9°°	2.7	0.0	100.0[y]
1985								
Block	5	0.2	3.4	0.4	0.2	0.0	3.8	8.0
Strain	4	0.2	4.7	1.2	0.2	0.0°	0.0	6.4
B X S	20	0.7	11.2	2.9	3.5	0.1	-0.8	17.6
Error	60	1.1	52.1	10.4	6.9	0.4	-3.0	68.0
Total	89	2.2	71.5°°	14.9°°	10.8°°	0.6	0.0	100.0[y]

°, °° — significant at P = .05 and .01 respectively; total rows in multiple regression, others by ANOVA.
[z]Cells in this column contain the sums of products for the adjusted variates.
[y]The total sum of squares for yield (kg) was 30.65 and 189.78 in 1984 and 1985 respectively.

numbers and fruit set (Table 6). The further contribution due to number of fruit harvested suggests that fruit numbers changed in an important way after fruit set, perhaps at June drop which was not measured. The small, less than 0.5%, residual contribution of strains to yield variation after the number of fruits harvested suggests that there may have been a small difference among the strains with respect to fruit size.

In 1985 in 'McIntosh,' the results indicate a major contribution to yield from adjusted cluster numbers and further contributions from fruit set and harvest numbers (Table 7). Strains were a source of significant variation in cluster numbers (Table 7).

The products columns of Tables 5, 6 and 7 contain sums of products for adjusted variates. These represent measures of competition which are partitioned according to sources of variation specified by the ANOV model. Although each cell entry in these columns is twice the sum of several potentially positive and negative terms, the fact that these values are invariably rather small is consistent with the absence of competition among components. If so, fruit set

Table 7. 'McIntosh,' 1985, partitioning of the percentage of the total sum of squares for yield.

Source	df	Adjusted variated: Limb area	Cluster no.	Fruit Set no.	Fruit Harvest no.	Residual	Products[z]	Yield
Block	5	0.1	3.9	0.5	0.4	0.3	1.7	6.9
Strain	3	1.1°°	19.3°°	1.0	0.1	1.0	1.6	24.2
B X S	15	0.6	11.5	3.0	1.0	0.7	8.8	26.5
Error	48	2.7	33.3	8.4	7.4	2.7	-12.1	42.4
Total	71	4.5	68.1°°	12.9°°	8.8°°	5.7	0.0	100.0[y]

°, °° — significant at P = .05 and .01 respectively; total rows in multiple regression, others by ANOVA.
[z]Cells in this column contain the sums of products for the adjusted variates.
[y]The total sum of squares for yield (kg) was 259.60.

would not have been inhibited by large cluster counts nor did large fruit set lead to larger amounts of fruit drop or small fruit size. Neither would small fruit numbers seem to have improved fruit size detectably.

Summary

In 1984, yield variation in both experiments was mainly due to variation in the number of fruit harvested (Tables 5 and 6). In 'Delicious' 65% of the total yield variation (sum of squares) was explained and 7.6% of the total was due to strain differences in numbers of fruits harvested (Table 5). In 'Golden Delicious' 96.9% of the total yield variation (sum of squares) was explained and 17.4% of the total was due to strain differences in numbers of fruits harvested (Table 6).

In 1985, yield variation in all three experiments was mainly due to variation in the number of flower clusters (Tables 5, 6 and 7). In 'Delicious' and 'Golden Delicious' 65.9% (Table 5) and 71.5% (Table 6) of the total yield variation (sum of squares) was explained by differences in the number of flower clusters, but there were no significant differences among strains in either of the two groups. In 'McIntosh' 68.1% of the total yield variation (sum of squares) was explained by differences in the number of flower clusters but 19.3% of the total was due to strain differences in numbers of flower clusters (Table 7).

Literature Cited

1. British Columbia Ministry of Agriculture and Food. 1986. Tree fruit production guide for interior districts for commercial growers. Victoria, B.C., Canada.
2. Eaton, G. W., P. A. Bowen, and P. A. Jolliffe. 1986. Two-dimensional partitioning of yield variation. HortScience 21: 1052-1053.
3. Fear, C. D., and P. A. Domoto. 1986 The 'Delicious' apple. Fruit Varieties J. 40:2-4.
4. Fisher, D. V., and D. O. Ketchie. 1981. Survey of literature on red strains of 'Delicious.' Washington State University College of Agriculture Research Center, Bulletin 0898.
5. Looney, N. E., and W. D. Lane. 1984. Spur-type growth mutants of McIntosh apple: a review of their genetics, physiology and field performance. Acta Horticulturae 146:31-46.

Book Review

Plant Breeding Reviews Volume 4, Edited by Jules Janick, contains 407 pages and is available for $54.00 from AVI Publishing Company, 250 Post Road East, P.O. Box 831, Westport, Connecticut 06881. The latest volume is dedicated to Dr. Henry M. Munger who released 68 cultivars and inbreds of 8 different vegetables during his productive career. Included in the 11 chapters of this issue is a discussion of the following: Pollen, Pistil, and Reproduction Function in Crop Plants, Mobile Elements in Maize, Somaclonal Variation in Alfalfa, Cell Selection for Crop Improvement, Oil palm Improvement via Tissue Culture, Breeding Soybeans for Drought Resistance, Breeding Common Bean for Yield in Mixtures, Inheritance of Tomato Fruit Quality Components, Breeding Sweet Potatoes, Breeding Blight-Resistant Chestnuts. aThe authors are to be commended for pulling together the references on these subjects and summarizing the information in a concise manner. This book has many topics of interest to the breeders in our society who are interested in crop improvement.