Yield Component Analysis of 'Harrow Delight', 'Kieffer', and 'Harvest Queen' Pear

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Abstract. Yield components of 8- to 10-year-old trees were compared among 'Kieffer' [*Pyrus communis* (L.) x *Pyrus pyrifolia* (Burro.)] and 'Harrow Delight' and 'Harvest Queen' [*Pyrus communis* (L.)]. 'Kieffer' set more fruit than the other cultivars, even though flower density was similar. 'Kieffer' also had similar size or larger fruit than 'Harrow Delight' or 'Harvest Queen'. Path analysis showed that the direct and indirect effect of fruit number on yield was important for all cultivars. Flower density only had a small direct effect on yield and this was at times negative. Fruit size had a small effect on yield when compared to fruit number.

Low fruit yield is a problem in pear orchards in eastern Canada (Quamme, 1982) and in the eastern United States (Lombard et al., 1980). Fruit yield of pear depends on the number of blossoms, fruit set, fruit number, and fruit size (Bell et al., 1982). A problem with any of these components could reduce the yield potential.

The primary objective of this study was to determine how the pear cultivars Kieffer, Harrow Delight, and Harvest Queen differ in number of blossoms, fruit number, and fruit size. A second objective was to determine the relative importance of these components of yield to the final yield for each cultivar. 'Kieffer' pear has consistently had higher yields in various trials, but has poor fruit quality and is no longer considered a desirable cultivar. 'Harrow Delight' and 'Harvest Queen' are resistant to fireblight and have good fruit quality (Quamme and Spearman, 1983), but are less productive than 'Kieffer'. The aim of this study was to provide a better understanding of how yields are determined in different pear cultivars and how they may be manipulated. Path analysis was used because it separates the correlation coefficients into components of direct and indirect effects and measures the relative importance of number of blossoms, fruit number, and fruit size as components of yield (Sieffer and Hancock, 1986). Flowering and fruit set can be affected by nitrogen fertility (Williams, 1965), rootstock (Lombard and Westwood, 1976), pruning (Westwood and Bjornstad, 1974), and frost and growth regulators. This information might also be useful for evaluating and selecting pear breeding material for high productivity. For sour cherry, fruit number, fruit weight, the number of reproductive buds, and fruit set were identified as the most efficient characters to select for yield increases (Chang et al., 1987).

Materials and Methods

The trees used for this study were part of an orchard at the Agriculture Canada Research Station, Harrow, Ont., for the testing of advanced selections from the pear breeding program. The trees were planted in 1978 and the rootstock was 'Bartlett' seedling. Trunk cross-sectional areas at 20 cm above the soil were measured in Spring 1985 before growth started (Table 1). Branch units with circumferences between 10 and 20 cm were

chosen in 1985 through 1987; branch circumferences were measured in the spring of each year before growth started and converted to branch cross-sectional area. The branch units chosen were not necessarily the same branches each year. Blossom clusters were counted on each selected branch for each cultivar and, after June drop, the number of fruits was counted in 1985 and 1986. Fruit counts were not taken in 1987. The trees were not thinned.

The fruits were harvested at optimum maturity for each cultivar. Total fruit number and fruit weight for each of the trees and selected branches were determined and mean fruit weight was calculated. In 1985, the number of seeds of 10 randomly selected fruit from each branch unit was counted.

The leaves were counted on the selected branches in late Aug. and early Sept. 1986. Every 10th leaf was removed and the leaf area of the subsample was measured using a LI-COR leaf area meter (model LI-3100). The leaf areas of the subsamples of leaves were used to estimate the total leaf area on the selected branches by multiplying by 10.

In 1987, the effective pollination period (EPP) was determined following the procedures outlined by Williams and Wilson (1970). The same year, 10 fruits per tree were tagged and measured with a vernier caliper at weekly intervals until they were harvested.

The three cultivars and four replicates were arranged in a randomized complete block design with single trees as experimental units and three branches per tree as sub-samples. Initially, the data were tested by analysis of variance and, if the F-value was significant, mean separation was performed using Duncan's multiple range test. Path analysis (Li, 1975) was used to calculate the relationship between the components of yield for the branch units. The causal relationship is represented in Fig. 1 and is represented by the standard model equation, yield = P_{01} number of blossom clusters + P_{02} fruit number + P_{03} fruit size + U. The double-headed lines show a mutual association as estimated by the correlation coefficients r_{ij} and the single-headed lines represent direct influence as estimated by the path coefficients P_{ij} . The "U" variable consists of all the residual factors, including sampling errors.

Results

The yield of 'Kieffer' was two to six times greater than the yield of 'Harrow Delight' or 'Harvest Queen' (Table 1). The yield of 'Kieffer' continued to increase each year, whereas the yield for 'Harrow Delight' and 'Harvest Queen' appeared to follow a biennial bearing pattern. Fruit number followed a sim-

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Table 1. Trunk cross-sectional area, yield, fruit number, and fruit weight of 'Harrow Delight', 'Kieffer', and 'Harvest Queen' trees for 1985, 1986, or 1987.^z

Cultivar	Trunk cross-sectional area ^y , 1985 (cm ²)	Yield (kg/tree)			No. fruit/tree			Fruit wt ^x (g)		
		1985	1986	1987	1985	1986	1987	1985	1986	1987
Harrow Delight	88.8 a	20.9 b	44.4 b	29.8 b	210 b	398 b	286 b	93.0 a	113.0 a	107.5 b
Kieffer	57.6 b	67.3 a	89.0 a	103.1 a	511 a	651 a	724 a	135.6 a	132.4 a	142.1 a
Harvest Queen	62.3 b	19.6 b	25.1 b	16.9 b	181 b	239 b	158 b	103.0 a	108.5 a	108.7 b

^zMean separation within columns by Duncan's multiple range test at $P = 0.05$. Data shown are means of four observations, except 'Kieffer' in 1986, which are means of three observations.

^yThe same trees may not have been used every year. Trunk cross-sectional area measured at 20 cm above the soil.

^xFruit weight = (yield × 1000)/fruit number.

Fig. 1. Causal system illustrating the relationship among number of blossom clusters, fruit number, fruit weight, and yield. The single-headed lines represent direct influence as estimated by the path coefficients P_{ij} , and the double-headed lines show mutual associations as estimated by the correlation coefficients r_{ij} . U = the unresolved variability.

ilar pattern as yield, with 'Kieffer' having more fruit than the other two cultivars. There were no significant differences in fruit size in 1985 or 1986, but, in 1987, the fruits of 'Kieffer' were larger than those of 'Harrow Delight' or 'Harvest Queen'.

Flower density (number of blossom clusters per branch cross-sectional area) was similar for all three cultivars in 1985 and 1986 (Table 2). In 1987, flower density for 'Harvest Queen' was 1.4 and 1.9 times larger than for 'Kieffer' or 'Harrow Delight', respectively. However, crop density (number of fruits per branch cross-sectional area) after June drop was about twice as high for 'Kieffer' as for the other two cultivars. Fruit set of 'Kieffer' was 1.5 to 2.5 times higher than that of 'Harrow Delight' or 'Harvest Queen'. Branch and whole-tree yields followed a pattern similar to fruit set, with 'Kieffer' having significantly higher yields than the other two cultivars. Fruit weight was not significantly different among the cultivars in any of the years ranging from 92 to 140 g.

'Kieffer' and 'Harrow Delight' had almost twice as many seeds per fruit as 'Harvest Queen' (Table 3). These were counted after the fruit were harvested in 1985. The EPP for 'Harrow Delight' was three times as long in 1987 as the EPP for 'Kieffer' and 'Harvest Queen'.

'Harvest Queen' had $\approx 28\%$ to 48% more leaves per branch cross-sectional area than either 'Kieffer' or 'Harrow Delight' (Table 4). 'Harvest Queen' also had the greatest leaf area per branch cross-sectional area (range 1350 to 1790 cm²·cm⁻²), but the differences were not significant.

The number of flower clusters was significantly correlated with fruit numbers for all cultivars in both years, but was not significantly correlated with fruit size for any of the cultivars (Table 5). The number of flower clusters was significantly correlated (in both years) with branch yields for 'Kieffer' and 'Harvest Queen', but not for 'Harrow Delight'. Fruit number was significantly correlated with branch yields for 'Kieffer' in both years, but only in 1986 for 'Harrow Delight' and 'Harvest Queen'. The relationship between fruit weight and yield was poor for all cultivars in both years.

Results of path analysis (Table 6) showed that the direct effect of the number of flower clusters on yield was variable, but it tended to be small compared with the indirect effect of the number of flower clusters via fruit number. The indirect effect via fruit number was important for all cultivars in 1985 and 1986. The indirect effect of the number of flower clusters via fruit weight was small, and, except for 'Harrow Delight' in 1986, was negative. The direct effect of fruit number on yield was quite large for all cultivars and in both years. In 1985, 'Harrow Delight' had a larger direct effect and in 1986 'Harvest Queen' had a larger direct effect of fruit number on yield. The indirect effect of fruit number on yield via fruit weight was small and was negative. The indirect effect of fruit number via flower clusters also tended to be small, except for 'Kieffer' in 1985. The direct effect of fruit weight on yield was larger than any of the indirect effects, but was lower than the direct effects of fruit number on yield. The unresolved variability tended to be high for 'Harrow Delight' in 1986 and for 'Harvest Queen' in 1985.

Discussion

The major difference among the cultivars was the ability of 'Kieffer' to set more fruits than 'Harrow Delight' or 'Harvest Queen'. In addition, 'Kieffer' had the capacity to enlarge the increased number of fruit. The number of blossoms for all cultivars was similar.

The ability of 'Kieffer' to set more fruit with a similar number of blossoms might be explained by differences in pollination. Seed set does not appear to be a factor because 'Harrow Delight' and 'Kieffer' had a similar number of seeds per fruit. EPP is a function of ovule longevity and rate of pollen-tube growth and does not appear to explain the difference, because the EPP for

Table 2. Flower density, crop density, fruit set, and yield for 'Harrow Delight', 'Harvest Queen', and 'Kieffer' pears from 1985 to 1987.^z

Cultivar ^y	Flower density ^x (no./cm)			Crop density ^w (no./cm)		Fruit set (no. fruit/ 100 clusters)		Branch yield (kg)		
	1985	1986	1987	1985	1986	1985	1986	1985	1986	1987
Harrow Delight	4.1 a	3.4 a	3.4 b	2.8 b	2.7 b	65.8 b	84.4 b	1.6 b	3.4 b	2.5 b
Kieffer	4.5 a	4.7 a	4.5 b	5.7 a	5.7 a	135.0 a	127.3 a	8.3 a	8.5 a	8.9 a
Harvest Queen	4.9 a	5.2 a	6.5 a	3.2 b	2.7 b	65.2 b	51.7 c	1.9 b	3.1 b	1.9 b

^zMean separation within columns by Duncan's multiple range test at $P = 0.05$. Data shown are the means of 12 observations, except 'Kieffer' in 1986, which are means of nine observations.

^yThe same branch units may not have been used every year.

^xFlower density = number of blossom clusters/branch cross-sectional area.

^wCrop density = number of fruit/branch cross-sectional area.

Table 3. Seed content and effective pollination period for 'Harrow Delight', 'Kieffer,' and 'Harvest Queen' pear^z.

Cultivar	Seed content ^y , 1985 (no. seeds/fruit)	Effective pollination period ^x , 1987 (days)
Harrow Delight	5.9 a	9.8 a
Kieffer	6.5 a	3.2 b
Harvest Queen	3.3 b	3.2 b

^zMean separation within columns by Duncan's multiple range test at $P = 0.05$.

^yData shown are the mean of 120 observations.

^xData shown are the mean of 12 observations.

Table 4. Leaf number per branch cross-sectional area of 'Harrow Delight', 'Kieffer', and 'Harvest Queen' in 1986.

Cultivar	Leaf number per branch cross-sectional area ^x (no./cm ²)
Harrow Delight	75.0 b
Kieffer	86.7 ab
Harvest Queen	111.2 a

^xLeaf number and leaf area measurements were taken in late Aug. and early Sept. 1986. Mean separation within columns by Duncan's multiple range test at $P = 0.05$. Data shown are the mean of 12 observations, except for 'Kieffer', which are means of nine observations.

'Kieffer' was much shorter than that of 'Harrow Delight'. Brain and Landsberg (1981) developed a pollination model to describe pollination, initial fruit set, and fruit drop in apples. Variables in the model were EPP, ovule fertility, insect visiting rate, and the probability that insects would be carrying compatible pollen. They suggested that insect visiting rate was the most important factor to ensure a high level of pollination success, whereas their model predicted that variations in EPP would result in only small differences. Because our experimental trees were in close proximity, they would have had the same number of bees available for pollination. 'Kieffer' blossoms may be more attractive than 'Harrow Delight' or 'Harvest Queen', but there is no direct evidence that this is the case. Lombard (1982) reported that 'Kieffer' can achieve partial fruit set with its own pollen. Free (1966) reported that pollinating efficiency of bee visits to self-

compatible apple cultivars was greater than visits to self-incompatible apple cultivars. This may also help explain the increased fruit set of 'Kieffer'.

The blossoming data were also interesting because the flower density for all three cultivars was similar regardless of whether 'Harrow Delight' or 'Harvest Queen' were in an "on" or "off" year in terms of yield (Tables 1 and 2). Biennial bearing is generally not a problem with pears, but is considered to be due to lack of fruit bud initiation in the on year (Jonkers, 1979). For these pears, fruit bud "quality" may be affected in the on year because of high fruit numbers; this may affect fruit set the following year. Path analysis showed that blossoming only had a small direct effect on yield, which, in some cases, was negative. Therefore, increasing blossom numbers would not necessarily result in an increase in yield.

The effect of fruit number was important for all cultivars, as a direct or indirect effect. Path analysis demonstrated that fruit number had the largest impact on yield. Fruit weight also had an important direct effect on yield. Similar yield component effects were reported by Chang et al. (1987) for sour cherry. The direct effect of fruit size on yield was only revealed by path analysis. In correlation analysis, the effect of fruit weight on yield was masked by a negative indirect effect of fruit number on fruit weight. Thus, while the data for fruit number would suggest that increasing the number of fruit of 'Harrow Delight' and 'Harvest Queen' would increase yields, a problem might be encountered because the indirect effect of fruit number on fruit weight is negative. Yet 'Kieffer', with its many fruit, also had heavy fruit, which may be due to its longer growing season. 'Harrow Delight' and 'Harvest Queen' have similar growth rates (0.06 cm in diameter/day), whereas the unit growth rate for 'Kieffer' was only 0.04 cm; but 'Kieffer' was harvested ≈ 50 days after the other cultivars.

Partitioning of dry weight to the fruit for 'Kieffer' appeared to be more efficient than that for 'Harrow Delight' or 'Harvest Queen'. Even with many fruit, the number of leaves or leaf area for 'Kieffer' was not much greater than those for 'Harrow Delight' or 'Harvest Queen'. Number of leaves per fruit in 1986 for 'Harrow Delight', 'Kieffer', and 'Harvest Queen' was 28, 16, and 43, respectively. Although the branches that were chosen were representative of the fruit load on the rest of the tree, conclusions regarding partitioning of dry weight are open to question because the data were collected from branch units and photosynthates could have been redistributed from other portions of the tree.

Table 5. Correlation coefficients for number of flower clusters, fruit number, fruit weight, and yield for branch units for 'Harrow Delight,' 'Kieffer,' and 'Harvest Queen'.

Characteristic ^z	Year	Fruit number			Fruit wt			Branch yields		
		Harrow Delight	Kieffer	Harvest Queen	Harrow Delight	Kieffer	Harvest Queen	Harrow Delight	Kieffer	Harvest Queen
Number of flower clusters	1985	0.632*	0.884***	0.801**	-0.185 ^{NS}	-0.487 ^{NS}	-0.018 ^{NS}	0.019 ^{NS}	0.761**	0.621*
	1986	0.594*	0.978***	0.880***	0.126 ^{NS}	-0.194 ^{NS}	-0.373 ^{NS}	0.547 ^{NS}	0.666*	0.793**
Number of fruit	1985				-0.073 ^{NS}	-0.480 ^{NS}	-0.418 ^{NS}	0.486 ^{NS}	0.792**	0.538 ^{NS}
	1986				-0.337 ^{NS}	-0.141 ^{NS}	-0.488 ^{NS}	0.637*	0.718*	0.937***
Fruit weight	1985							0.544 ^{NS}	0.057 ^{NS}	0.221 ^{NS}
	1986							0.387 ^{NS}	0.491 ^{NS}	-0.303 ^{NS}

^zTwelve branch units (n = 12) were used for each cultivar, except for 'Kieffer' in 1986, when n = 9.

*, **, ***, ^{NS}Correlation coefficients are significant at $P = 0.05, 0.01, \text{ or } 0.001$, or not significant, respectively.

Table 6. Path coefficients showing direct and indirect effects of number of blossom clusters, fruit number, and fruit weight on branch yields of 'Harrow Delight,' 'Kieffer,' and 'Harvest Queen' pear.

	Path	Harrow Delight		Kieffer		Harvest Queen	
Type of effect	criterion ^z	1985	1986	1985	1986	1985	1986
Number of blossom clusters vs. yield							
	<i>r</i>	0.02	0.55	0.76	0.67	0.62	0.79
Direct effect	<i>P</i> ₀₁	-0.36	-0.10	0.45	-0.19	0.07	-0.20
Indirect effect via fruit number	<i>r</i> ₁₂ <i>P</i> ₀₂	0.47	0.56	0.61	1.03	0.56	1.07
Indirect effect via fruit weight	<i>r</i> ₁₃ <i>P</i> ₀₃	-0.10	0.09	-0.30	-0.12	-0.01	-0.08
Total		0.01	0.55	0.76	0.72	0.62	0.79
Number of fruit vs. yield							
	<i>r</i>	0.49	0.64	0.79	0.72	0.54	0.94
Direct effect	<i>P</i> ₀₂	0.75	0.94	0.69	1.05	0.70	1.21
Indirect effect via fruit size	<i>r</i> ₂₃ <i>P</i> ₀₃	-0.04	-0.24	-0.29	-0.09	-0.21	-0.11
Indirect effect via blossom cluster	<i>r</i> ₁₂ <i>P</i> ₀₁	-0.22	-0.06	0.40	-0.19	0.06	-0.18
Total		0.49	0.64	0.80	0.77	0.55	0.92
Fruit size vs. yield							
	<i>r</i>	0.54	0.39	0.06	0.49	0.22	-0.30
Direct effect	<i>P</i> ₀₃	0.53	0.72	0.61	0.62	0.51	0.22
Indirect effect via fruit number	<i>r</i> ₂₃ <i>P</i> ₀₂	-0.05	-0.32	-0.33	-0.15	-0.29	-0.59
Indirect effect via blossom clusters	<i>r</i> ₁₃ <i>P</i> ₀₁	0.07	-0.01	-0.22	0.04	-0.001	0.08
Total		0.55	0.39	0.06	0.51	0.22	-0.29
Unresolved variability		0.23	0.59	0.27	0.06	0.69	0.31

^z r = correlation coefficient.

The ability of 'Kieffer' to set many fruit and to enlarge fruit even though the number of fruit clusters was similar was the greatest contributor to the yield differences among cultivars. This difference needs to be explored further to determine whether this trait can be exploited in a fruit breeding program. The ability of 'Kieffer' to partition large amounts of photosynthates to the fruit also needs to be explored.

Fruit number was the most important yield component for all cultivars, followed by fruit weight. The extent to which fruit number can be increased in 'Harrow Delight' and 'Harvest Queen' without adversely affecting fruit weight is another question that needs to be answered. Obviously, cultural practices that will increase fruit weight without reducing the number of fruit would also increase yields.

Literature Cited

- Bell, R. L., T. van der Zwet, and R.C. Blake. 1982. The pear breeding program of the United States Department of Agriculture, p. 157-170. In: T. van der Zwet, and N. Childers (eds.). The pear: cultivars to marketing. Horticultural Publications, Gainesville, Fla.
- Brain, P. and J.J. Landsberg. 1981. Pollination, initial fruit set and fruit drop in apples: analysis using mathematical models. J. Hort. Sci. 56:41-54.
- Chang, L. S., A.F. Iezzoni, and J.A. Flore. 1987. Yield components in 'Montmorency' and 'Meteor' sour cherry. J. Amer. Soc. Hort. Sci. 112:247-251.
- Free, J.B. 1966. The pollinating efficiency of honey-bee visits to apple flowers. J. Hort. Sci. 41:91-94.
- Jonkers, H. 1979. Biennial bearing in apple and pear: a literature survey. Scientia Hort. 11:303-317.
- Li, C.C. 1975. Path analysis, a primer. Boxwood Press, Pacific Grove, Calif.
- Lombard, P.B. 1982. Pear pollination and fruit set, p. 91-103. In: T. van der Zwet and N. Childers (eds.). The pear: cultivars to marketing. Horticultural Publications, Gainesville, Fla.
- Lombard, P. B., J. Hull, Jr., and M.N. Westwood. 1980. Pear cultivars of North America. Fruit Var. J. 34:74-83.
- Lombard, P.B. and M.N. Westwood. 1976. Performance of six pear cultivars on clonal Old Home, double rooted and seedling rootstock. J. Amer. Soc. Hort. Sci. 101:214-216.
- Quamme, H.A. 1982. Breeding new pear cultivars for Canadian conditions. p. 180-188. In: T. van der Zwet and N. Childers (eds.).

- The pear: cultivars to marketing. Horticultural Publications, Gainesville, Fla.
- Quamme, H.A. and G.A. Spearman. 1983. 'Harvest Queen' and 'Harrow Delight' pear. *HortScience* 18:770-772.
- Siefker, J.H. and J.F. Hancock. 1986. Yield component interactions in cultivars of the highbush blueberry. *J. Amer. Soc. Hort. Sci.* 111:606-608.
- Westwood, M.N. and H.O. Bjornstad. 1974. Fruit set as related to girdling, early cluster thinning and pruning of 'Anjou' and 'Cornice' pear. *HortScience* 9:342-344.
- Williams, R.R. 1965. The effect of summer nitrogen application on the quality of apple blossom. *J. Hort. Sci.* 40:31-41.
- Williams, R.R. and D. Wilson. 1970. Towards regulated cropping. A report of recent fruit-set experiments in British orchards. Grower Books, London.
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