AN INVESTIGATION OF YIELD COMPONENTS
IN 'MONTMORENCY' AND 'METEOR'
SOUR CHERRY

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Abstract

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Two sour cherry (Prunus cerasus L.) cultivars, 'Montmorency' and 'Meteor' were evaluated over 2 seasons to determine the relative importance of different components. A path coefficient analysis was performed to determined the direct and indirect effects of primary, secondary, and tertiary components on limb yield. Fruit number, fruit weight, the number of lateral buds and spurs, and fruit set were found to be the most important components affecting limb yield in both cultivars. However, the fruiting habit of the 2 cultivars was significantly different. 'Montmorency' produced 68% of its fruit on lateral buds on one-year-old wood, while 'Meteor' had 70% of its fruit on two-year-old spurs. When the data was standardized by dividing by limb cross-sectional area, 'Meteor' had a higher flower bud density and yield efficiency (grams of fruit/cross-sectional area) than 'Montmorency'.

Although 'Meteor' had higher limb yields than 'Montmorency', the 'Montmorency' trees sampled had approximately 4 times more limbs than 'Meteor' and therefore higher tree yields.

Yield prediction equations for 'Montmorency' and 'Meteor'

were developed using the yield component factors included in the study. With these equations, 'Montmorency' tree yield could be predicted with 99.5% accuracy, while 'Meteor' tree yield could only be predicted with an accuracy of 30%.

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CHAPTER ONE

Chapter one

An Investigation of Yield Components in 'Montmorency' and 'Meteor' Sour Cherry

Introduction

Michigan's cherry industry produces about 70% of the nation's sour cherry supply. In 1984, Michigan produced 210 million pounds of the approximately 271 million pounds of sour cherries produced in the United States. However, almost all the sour cherry production is based on one cultivar, Montmorency, which represents 97% of the sour cherry acreage in the United States (4).

'Montmorency', a cultivar which originated from France about 300 years ago (24), was first studied at the Michigan Agricultural Experimental Station in 1922 (18). Much of the work focused on fruit set because of the possibility of increasing fruit set by cultural factors and because research indicated that increased fruit set might result in higher yields (19,22,36,37,38,40).

Little work has been done in the United States on yield component analysis comparing sour cherry cultivars. Roberts (37) reported that the higher yield of 'Montmorency' compared to 'Richmond' was the result of higher fruit set on 'Montmorency' shoots and spurs vs 'Richmond' shoots and spurs. However, 'Richmond' has a similar French origin as 'Montmorency'. All of the additional literature pertains to 'Montmorency'.

Path analysis can be used in plant breeding to measure each component affecting a complex trait such as yield. Those characters can be identified which would be most effective as selection criteria to improve crop productivity. So far, no studies have been reported which discuss the influence of individual yield components in sour cherry. Approximately 70% of the fruit on mature 'Montmorency' trees is produced on last year's shoots. However, sour cherry cultivars which bear most of their fruit on spurs have been reported (3,25). For ideotype breeding, it would be useful to have a model of the most productive orchard canopy which would include components ranging from the number of leaves per tree to fruit size and number. This analysis could ultimately be related to total yield per acre.

In this study, 2 cultivars of sour cherry, 'Montmorency' and 'Meteor', were evaluated. 'Montmorency' was chosen because it represents approximately 97% of the sour cherry acreage in the United States, and 'Meteor' was chosen because observations indicated that its fruiting habit is different than 'Montmorency'. The objectives of this study were: 1) determine the relative importance of different yield components for 'Montmorency' and 'Meteor', 2) measure the effects of the individual components on yield, and 3) describe the morphological basis of these differences.

Literature review

A. Factors affecting sour cherry yield.

Bradbury (7) reported that 30-50% of the flowers on 'Montmorency' sour cherry trees produced fruits. Flower and fruit drop in sour cherry can occur at any of three stages. 1) One week after bloom, the flowers may drop due to a defective pistil with the pedicel or peduncle attached. 2) Two weeks after full bloom, the fruit with the pedicel attached may fall due to ovule degeneration. Pollination may have occurred but not fertilization. 3) Three to five weeks after full bloom, the endosperm may fail to develop and the fruit abscises with the pedicel attached.

Gardner (19) identified fruit set as one of the factors influencing 'Montmorency' tree yields. He concluded that the low yields on 'Montmorency', obtained following profuse blossoming, were due to poor fruit set. However, the correlation between fruit set and yield, which was calculated using data in the paper, was 0.468 and not significant at the 5% level. This lack of association between fruit set and yield at the 5% significance level reflects the complex set of factors which influence 'Montmorency' yields.

Numerous cultural and environmental factors have been reported which affect sour cherry flower number and fruit set. Roberts (36) stated that 'Montmorency' fruit set was higher when 'Early Richmond' was used as a pollen source. Shoemaker (40) found that 'Montmorency' trees caged with bees

had 20% higher fruit set than the control. However, Roberts (37) concluded that poor yield was not due to poor pollination and that sour cherry being self-fertile, commonly set fruit without insect pollination. Gardner (19) believed that the difference in the abundance of pollinating insects was the major reason for the difference in fruit set in his experimental orchards. Redalen (35) investigated fruit set in 35 sour cherry cultivars and concluded that 'Montmorency' was only partly self-compatible thereby suggesting a genetic reason for the reduced fruit set in 'Montmorency'.

Roberts (37) and Roberts and Langord (38) reported that shading cherry trees with burlap cages gave a significant fruit set reduction compared to unshaded trees, 0.92% to 18.92% respectively. Gray (22) showed reduction in 'Montmorency' fruit set due to shading with screen, muslin, and burlap. However, Langord (29) reported that poor light conditions could reduce fruit set because of reduced photosynthesis.

The effect of temperature on fruit set was also apparent in Gray's work (22). Based on the data from Gray's paper, I calculated the mean temperature during the 10-day bloom period and related that to flower count and fruit set in burlap shade and the unshaded control. The lower temperature 10 days after bloom in 1931 compared to 1930 and 1932 may have resulted in the reduced fruit set. In Gray's

Year	Mean temp.(C)	Flower count		Fruit set(%)	
		burlap	control	burlap	control
1930	16	1236	3191	20.0	25.5
1931	11	1917	2392	10.0	20.1
1932	15	2040	2289	16.5	32.5

experiments, only one tree was sampled for each shading observation, resulting in large variation due to tree and year effects. Eisensmith et al (13) and Flore (15,16) studied the light interception effect on cherry tree growth. They found that shading begun during stage II of fruit development significantly reduced flower bud differentiation when the reduction was under 20% of full sunlight. This low level of full sunlight frequently occurs in mature Montmorency trees under field conditions.

Fruit set and yield in sour cherry is influenced by pruning practices and fertilization. Kenworthy (27) showed that a 1.8kg nitrogen application resulted in a 13.6kg increase of fruit per tree. The nitrogen effect on Montmorency yields may be due to the positive effect on vegetative growth. Kesner et al (28) suggested that summer hedging increased fruit set and yield but did not affect the number of flowers per bud. However, Flore (15) did not detect any change in canopy light pentration after 3 consecutive years of summer hedging. Bradbury (7) mentioned that early thinning could increase sour cherry fruit set.

Diaz (9) thinned 'Montmorency' flowers to different numbers and at different stages and found no evidence of competition between and within flower clusters on fruit set. Also the next year's fruit load was not affected by the thinning treatments. He did not identify any effects influencing fruit set after pistil differentiation; however, he observed that at bud swell tetrad formation in the anthers occurs consistently 2 days earlier on the most expanded flowers while embryo-sac degeneration is significantly more frequent in the least advanced flowers.

B. Statistical analysis of yield components.

Yield is a complex quantitative character influenced by numerous factors. In 1923, Engledow and Wadham (14) proposed that yield was the product of the number of grains per ear and the average weight of a single grain. Additionally, they suggested that selection for these components rather than yield itself would accelerate the gain from selection in a breeding program. However, yield is not a simple function. Instead it is the product of complex factors occuring throughout plant development. Therefore, simple correlation between each factor and yield may not be the best approach to describe the relative contribution of each component to yield.

In 1921, Wright (43) published his path coefficient analysis which partition the correlation into direct and indirect effects. The path coefficients are calculated as standard partial regression coefficients. The direct effect is the influence of one component on another component without considering the interaction between components. The indirect effect is the difference between the correlation and the direct effect. Li (31) described the features and application of path coefficient analysis. Since Li's introduction, path analysis has been frequently used in crop plant breeding to measure the relative contribution of each component to complex traits, such as yield.

Grafius (20) developed the geometrical concept of yield components in oats. Oat yield was described as the products of the number of panicles per unit area, the number of kernels per panicle, and the average weight of each kernel. Leng (30) found the heritability of yield components to be much higher than the heritability of yield alone in maize. This concept enables the plant breeder to separate yield into the product of its part and then choose parents selected for their independent yield component superiorities.

In 1967, Adams (1) introduced the concept of yield component compensation to explain the common failure of selection based on yield components. Yield compensation, expressed as negative correlations between components, occurs if the input of metabolic products to the component system is limiting in the developmental sequence resulting in competition for these metabolic products (1,2). Nickell and Grafius (32) found that component compensation could retard the genetic advance in winter barley selection, Grafius and co-workers (21,41) developed approaches to the mathematical analysis of yield component relationships by the standardized the original data using log transformation since there were large genotype x environment interactions associated with these components.

Path analysis has been used in agronomic studies to identify components having strong direct effects on yields. Dewey and Lu (8) used path analysis to determine components affecting crested wheatgrass seed yields. They found that fertility and plant size were major factors. Duarte and Adams (10) used path analysis to study the effect of the primary components on dry bean yield and the secondary components (leaf size and leaf number) on the primary components. They found that leaf size contributed to seed weight and that leaf number was correlated with pod number; however, the number of pods per plant was the most important factor affecting yield. Bhatt (5) showed that spike number and kernel weight exerted a predominent effect on spring wheat yield, but the residual factors in the path analysis were relatively large indicating that other traits should be considered. Pandley and Torrie (33) concluded that selection for high pod and seed number were the most critical factor for increasing soybean yield. They also found negative correlations existing among yield components. In *Brassica*, Thurling (42) also reported yield component compensation with seed number per pod negatively correlated with pod number per plant. Borojesvic and Williams (6) stated that the spike number was the most important contribution to wheat yields, but the environmental variability for spike number was greater than the genetic variability for spike number. Kang et al. (26) concluded that stalk number and stalk diameter were more important than plant height in determining sugarcane yield.

Path coefficient analysis has been applied less often to horticultural crops so other types of analysis have been employed to measure yield component interaction. For example, Eaton and MacPherson (11) used stepwise regression to estimate the relative contribution of several variables to cranberry yield. They found that the number of flowering uprights per unit area made a major contribution to yield. Using stepwise regression the variation of the number of flowering uprights per unit area contributed about 80% to cranberry yields. However, if the number of berries per flower was included in their analysis, the relationships changed and the number of berries per flower contributed about 43% to yield as compared to 29% for the number of flowering uprights per unit area. Stepwise regression could not precisely determine the direct effect of these components. Later Eaton and Kyte (12) using multiple regression concluded, that not flowering uprights but fruit set was also a major factors influencing cranberry yield. In their paper, fruit set and flowering upright number compensated for each other; however, the correlations for those negative significant relationships between components were not presented.

Hancock et al.(23), Pritts and Hancock (34), and Siefker (39) used path coefficient analysis to determine the factors contributing to strawberry and bluebery yields. Crown and fruit number played a significant role in strawberry production. The number of buds per cane exerted the most significant effect on blueberry yields. Canes per plant and fruit set also played an important role in blueberry yields.

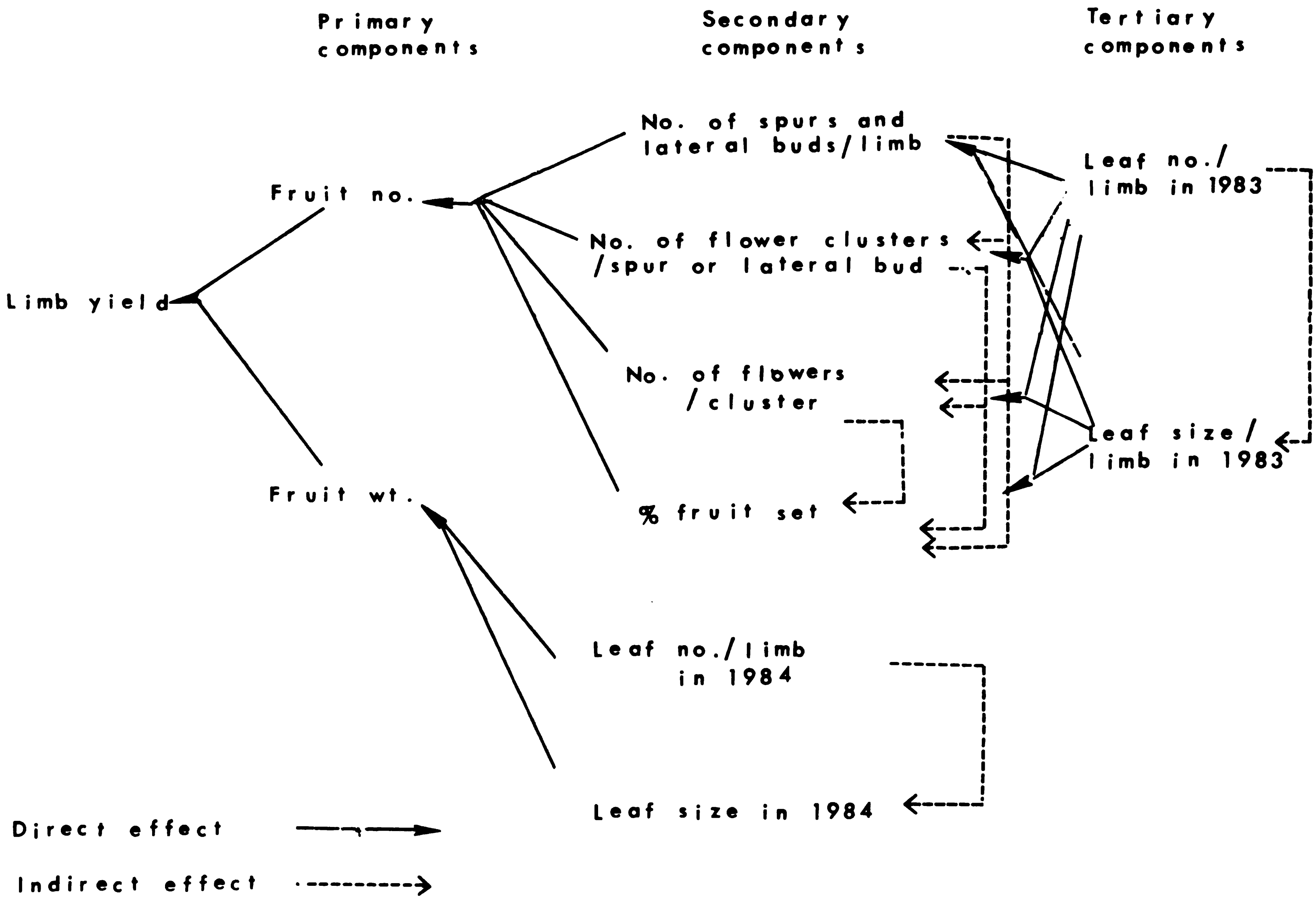
Materials and Methods

In 1983 and 1984, data was taken from three representative trees each of 'Montmorency and 'Meteor' at 2 locations, Clarksville Horticultural Experiment Station, Clarksville, Mich., and Hilltop Orchards and Nurseries, Hartford, Mich.. The trees at Clarksville and Hartford were 7 and 8 years old in 1983, respectively. The two cultivars were grafted on *P. mahaleb* seedling rootstocks and trained to a modified central leader.

One 3 or 4-year-old representative limb was randomly selected from each tree and the following totals were counted in both 1983 and 1984: number of flowers, number of flower clusters, number of lateral flower buds, number of spurs, number of flowering branches, and limb diameter. Three limbs within a tree were also selected and the number of leaves along the main branch of each limb were counted. Five leaves from each limb were randomly selected for leaf area measurement in cm, using a L1-3000 leaf area meter(cm). Fruit at maturity was counted and weighed for each limb and kept separate within the limb by age of wood. Total tree yield were taken at both locations in 1984.

Path analysis (23,34) was used to calculated the relationships between yield components using the causative relationships diagrammed an Fig. 1. The path coefficient analysis partitions the correlation into the direct and indirect effects. The direct effect is the influence of one component on another component without considering the interaction between components. The indirect effect is the difference between the correlation and the direct effect. The significance of each path coefficient was analyzed with an F-test.

Fig. 1. Causal system of path-coefficient analysis in this study.



Results and Discussion

Sour cherry buds are simple, producing either floral or vegetative growth. Therefore the number of flower buds on 1-year-old-wood reduces the number of nodes which become spurs or lateral branches the following season. In 1983, an average of 152 lateral buds flowered on the sampled limbs of 'Montmorency' (Table 1). In 1984, the mean number of flowering spurs on those limbs was only 27. In contrast, the mean number of flowering lateral buds on the sampled limbs of 'Meteor' was 26 in 1983 and the following year the mean number of flowering spurs was 168. The number of flowering lateral buds and spurs on 'Montmorency' has been reported to be influenced by vigor (19,27,36,37). If tree vigor is moderate to low, where shoot growth is less than 25.4 cm., then the majority of the lateral buds are floral buds. As vigor increases to more than 45.7cm,, more buds on the shoot remain vegetative producing spurs at the basal portion of the shoot. Although very few flowers are produced, an increased bearing surface is formed for the next year. Fruiting spurs develop on these 1-year-old branches. For the 2 years, 1983 and 1984, the average terminal shoot growth for 'Montmorency' and 'Meteor' was 38 cm and 47 cm respectively. Therefore, 'Montmorency' tree vigor would be classified as moderate.

In 1984, 'Meteor' had a significantly larger number of flower clusters, flowers, and fruits per limb and a greater

Table 1. Means values ($\bar{x}$) and coefficients of variation (cv) for yield components from limbs of 'Montmorency' and 'Meteor' in 1983 and 1984.

	Montmorency				Meteor			
	1983		1984		1983		1984	
Yield component	$\bar{x}$	cv	$\bar{x}$	cv	$\bar{x}$	cv	$\bar{x}$	cv
No. of flowering lateral buds/limb	152a[z]	79	135a	33	26b	60	152a	143
No. of flowering spurs/limb	31b	41	27b	80	70b	45	168a	51
No. of flower clusters/limb	213b	57	214b	40	194b	51	789a	69
Flower no./limb	573b	82	523b	20	528b	64	2131a	68
Fruit no./limb	226b	57	242b	30	163b	89	486a	36
No. of flowering branches/limb	31ab	65	51a	26	17b	51	53a	91
Limb yield (gms)	854b	22	910b	25	759b	91	2248a	59

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

Table 2. Mean values ($\bar{x}$) and coefficients of variation (cv) for limb cross sectional area, flower bud number per limb and, flower bud number, fruit number, and yield per cross sectional area (cm^2) for 'Montmorency' and 'Meteor' in 1983 and 1984.

Trait	Montmorency		Meteor	
	$\bar{x}$	cv	$\bar{x}$	cv
Limb cross-sectional area	6.71	11	7.51	10
Flower bud no./limb	212.25 b[z]	38	493.9 a	16
Flower bud no./cross-sectional area	32.94 b	14	60 a	8
Fruit no./cross-sectional area	37.56	16	46	13
Yield (gms)/cross-sectional area	134.08 b	19	211 a	12

[z]Mean separation in rows by LSD, 5% level.

limb yield than 'Montmorency' (Table 1). However, in 1983 there were no differences between the cultivars for these traits. The cultivar x year interaction was highly significant and 'Meteor' exhibited large differences between the 2 years. In general, 'Meteor' also had greater variation within years than 'Montmorency' as indicated by the coefficients of variation.

When several of the yield components were standardized by dividing by the limb cross-sectional areas, the year effect was largely eliminated and there were significant differences between 'Montmorency' and 'Meteor' (Table 2). 'Meteor' had a higher flower bud density than 'Montmorency'; however, the difference in crop density was not significant. This lack of difference in fruit load resulted because 'Montmorency' had a higher fruit set (46%) than 'Meteor' (28%). However, there was a significant difference in crop density between the Clarksville and Hartford orchards, presumably resulting from different weather conditions influencing fruit set. Even though 'Montmorency' and 'Meteor' had similar crop densities, 'Meteor' had a higher yield efficiency (grams of fruit/cross-sectional area) than 'Montmorency', because of differences in fruit weight. Individual fruit weight for 'Meteor' was approximately 4.7 grams compared to 3.6 grams for 'Montmorency'.

The average limb yields for 'Montmorency' and 'Meteor' were 882 grams and 1504 grams, respectively. However, the

Fig. 2. Yield for 8 and 9 year-old trees of 'Montmorency' and 'Meteor' in 1984 partitioned by the age of wood. Yield is expressed as kg per tree.

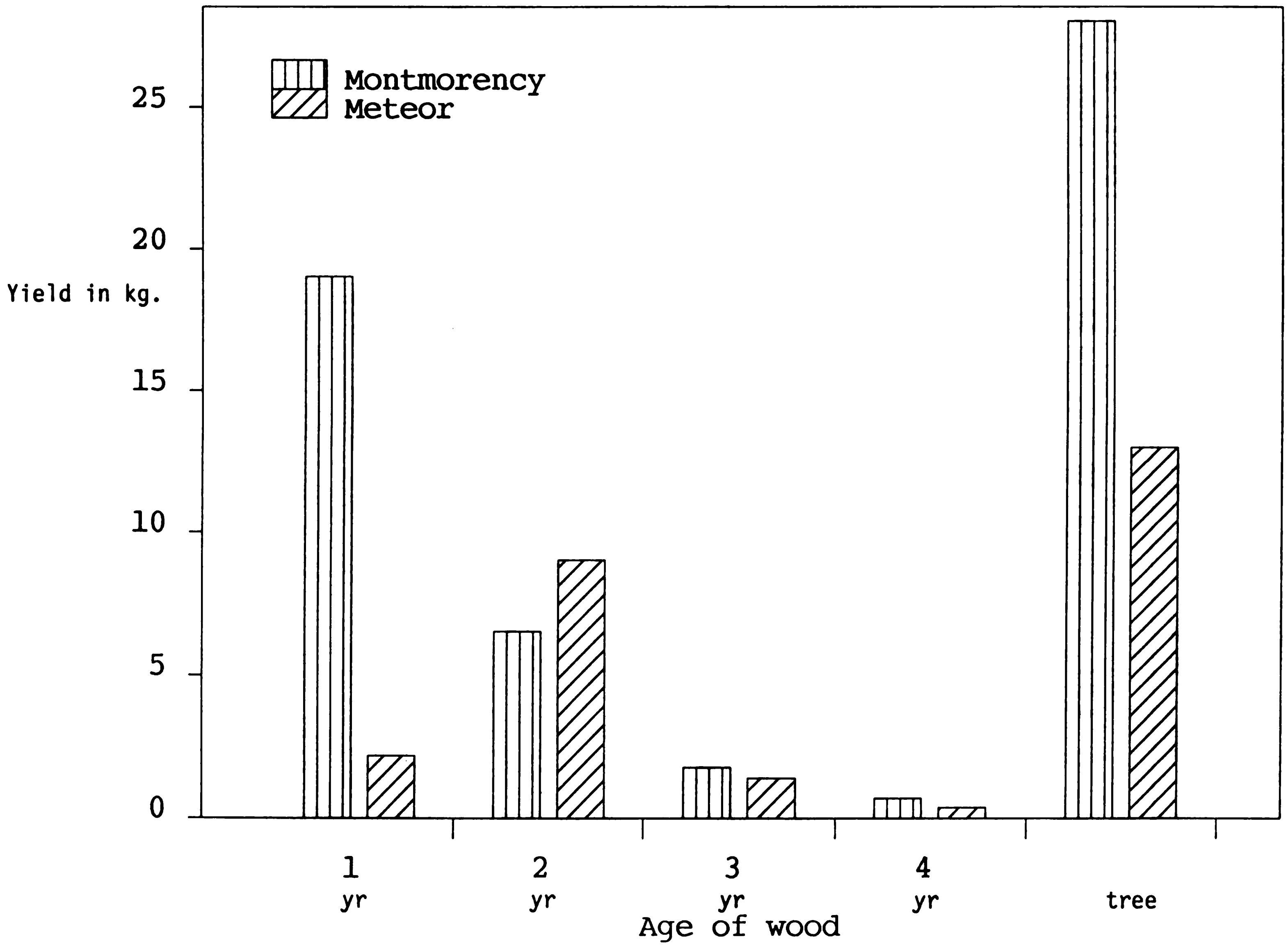


Table 3. Mean values of primary yield components associated with spurs and lateral buds for 'Montmorency' and 'Meteor' in 1983 and 1984.

Yield component	'Montmorency'		'Meteor'	
	Lateral bud	Spur	Lateral bud	Spur
Total no. of lateral buds or spurs	144 a	29 b	89 a	120 a
No. of flower clusters	1.01 c	2.42 b	1.04 c	2.99 a
No. of flowers/cluster	2.63 a	2.47 a	2.54 a	2.66 a
% fruit set	41 ab	52 a	28 ab	27 b
Individual fruit weight (gms)	3.86 b	3.38 b	4.7 a	4.6 a
Yield gms	609 b	272 b	376 b	1127 a

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

'Montmorency' trees sampled had approximately 4 times as many 4-year-old-limbs than 'Meteor' (33.3 compared to 8.5) and therefore a considerably higher tree yield.

The average tree yields for 'Montmorency' and 'Meteor' were 28 and 13 kg, respectively (Fig 2). The fruiting habit of the 2 cultivars also differed significantly. 'Montmorency' had 19 kg or 68% of its fruit on one-year-old wood while 'Meteor' had 9 kg or 70% of its fruits on 2-year-old spurs.

Lateral bud and spur reproduction was considered separately because there was a highly significant interaction between cultivar and reproduction location. Although the cultivar x year interaction was significant, the age of wood for reproductive type x year interaction was not significant for all parameters. 'Meteor' had significantly more spurs, flower clusters per spur, and spur yield than 'Montmorency' (Table 3). However, 'Meteor' spurs had significantly lower fruit set than 'Montmorency' spurs (52% and 27%, respectively). Individual fruit weight for 'Meteor' was approximately 4.75 gms compared to 3.62 gms for 'Montmorency'. The fruit set on 'Montmorency' spurs was higher than the 30% fruit set reported by Diaz (9) on 'Montmorency' limbs. It is most likely that differences between years contribute to the differences in fruit set.

Limb yield of the 2 sour cherry cultivars was designated as the product of fruit number and fruit weight (Fig 1). Fruit number had a larger direct effect on yield than fruit

Table 4. Path coefficients showing direct and indirect effects of fruit number and fruit weight on limb yields of 'Montmorency' and 'Meteor' sour cherry. Yield is divided into the yield from lateral buds and spurs.

Type of effect	'Montmorency'		'Meteor'	
	Lateral buds	Spurs	Lateral buds	Spurs
Fruit no. (x)				
Direct effect (P_{zx})	1.04**	1.02**	1.00**	0.99**
Indirect effect via fruit wt.	-0.04	-0.02	0.00	0.00
Fruit wt. (y)				
Direct effect (P_{zy})	0.13**	0.08**	0.03**	0.02

**Indicates significance at the 1% level.

Table 5. Path coefficients showing direct and indirect effects of secondary yield components on fruit number of 'Montmorency' and 'Meteor' sour cherry in 1983 and 1984. Yield is divided into that from lateral buds and spurs.

Type of effect	'Montmorency'		'Meteor'	
	Lateral buds	Spurs	Lateral buds	Spurs
No. of spurs and lateral buds per limb (a)				
Direct effect (P_{xa})	0.81**	0.92**	1.00**	0.78**
Indirect effect via:				
No. of flower clusters per spur or lateral bud	0.00	-0.13	-0.01	-0.19
No. of flowers per cluster	0.18	-0.03	-0.00	-0.02
% of fruit set	0.02	-0.11	-0.01	-0.15
No. of flower clusters per spur or lateral bud (b)				
Direct effect (P_{xb})	0.03	0.37**	0.03	0.34**
Indirect effect via:				
No. of flowers per cluster	-0.03	-0.10	0.00	0.04
% fruit set	-0.05	-0.16	-0.08	-0.04
No. of flowers per cluster (c)				
Direct effect (P_{xc})	0.21*	0.35**	0.00	-0.17
Indirect effect via:				
% fruit set	-0.05	0.01	0.05	0.44
% fruit set (d)				
Direct effect (P_{xd})	0.21*	0.71**	0.16**	0.63**

**, * Indicates significance at the 1 and 5% level, respectively.

weight for both cultivars (Table 4), although fruit weight also had a very significant positive effect on 'Montmorency' yield. The indirect effect of fruit number via fruit weight on yield was small and insignificant.

Fruit number was expressed as the product of the following secondary components: the number of spurs or lateral buds, the number of flower clusters per spur or lateral bud, the number of flowers per cluster, and % fruit set (Fig 1). The number of spurs or lateral buds was the most important secondary yield component influencing fruit number in both cultivars (Table 5). Fruit set also had a significant direct effect on fruit number which was more important for spur fruit production. 'Montmorency' spur fruit number was significantly associated with the number of flower clusters per spur and flower number per cluster. For 'Meteors' accumulated spur fruit number, the number of flowers per cluster also had a positive indirect effect via fruit set indicating that flower competition within clusters had little effect on fruit set. These results are similar to those of Diaz (9) who concluded that in 'Montmorency' competition between and within flower clusters did not affect fruit set.

There were no significant effects of leaf number and leaf size on that year's fruit weight in either cultivars (Table 6). Possibly this is because leaf number was above the threshold value which would affect fruit development.

Table 6. Path coefficients showing direct and indirect effects of leaf number per limb and leaf size in 1984 on fruit weight for 'Montmorency' and 'Meteor' sour cherry in 1984.

Type of effect	'Montmorency'	'Meteor'
Leaf no. (n)		
Direct effect (P_{yn})	0.12	-0.35
Indirect effect via leaf size	0.09	0.05
Leaf size (s)		
Direct effect (P_{ys})	0.44	-0.26

Table 7. Path coefficients showing direct and indirect effects of leaf number and size per limb in 1983 on the secondary yield components in 1984 for 'Montmorency' and 'Meteor sour cherry.

Tertiary component Type of effect	Secondary component	'Montmorency'	'Meteor'
Leaf no. (e)			
Direct effect (P_{ea})	No. of spurs and lateral buds	1.01*	0.82
Indirect effect via leaf size		0.29	-0.06
Direct effect (P_{eb})	No. of flower clusters per spur or lateral bud	-0.73	-0.72
Indirect effect via leaf size		0.39	0.01
Direct effect (P_{ec})	No. of flowers per cluster	-0.71	0.24
Indirect effect via leaf size		0.05	-0.31
Direct effect (P_{ed})	% fruit set	-0.54	-0.07
Indirect effect via leaf size		-0.01	-0.04
Leaf size			
Direct effect (P_{fa})	No. of spurs and lateral buds	-0.47	-0.10
Direct effect (P_{fb})	No. of flower clusters per spur or lateral bud	0.64	-0.01
Direct effect (P_{fc})	No. of flowers per cluster	0.08	0.49
Direct effect (P_{fd})	% fruit set	0.02	-0.06

*Indicates significance at the 5% level.

Flore (17) reported that a minimum of 2 leaves per fruit are necessary for optimum fruit size and development for 'Montmorency'. However, there was a significant positive effect of 'Montmorency' leaf number in 1983 on the number of spurs and lateral buds in 1984 (Table 7). Presumably more lateral buds were vegetative in 1983 resulting in more spurs the next year. 'Meteor' also had a similar positive effect for leaf number, however it was not significant. Leaf number and size had no other significant effects on the secondary yield components in 1984.

Fruit number, fruit weight, the number of reproductive buds, and fruit set appear to be the most important components influencing limb yields. For 'Montmorency', cultural or environmental factors which increase fruit weight may increase yields. Alternatively for 'Meteor', increasing the fruit set ratio may result in a yield increase. For maximizing the yield per acre, it may be of value to consider the spur fruiting habit because of the higher yield efficiency. However, it must be emphasized that the yield efficiency of 'Meteor' was on a per limb basis. Yield evaluations of sour cherry clones with different fruiting habits must include the number of limbs per tree since this may be one of the most crucial factors influencing the productivity of the orchard canopy.

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Chapter two

Yield Prediction for 'Montmorency' and 'Meteor' Sour Cherry Using Stepwise Regression

Introduction and literature review

Reliable yield prediction is critical to the marketing of agricultural products. The most common method of predicting yield is correlation. Waring (14) reported that the correlation coefficient was 0.30 to 0.75 between apple tree yield and trunk circumference, however, the coefficient of variability for yield and trunk circumference was relatively large. Sudds and Anthony (12) confirmed Waring's reports but found the trunk growth of one year was more highly correlated with the following year's load than the load in the same year. Reed (11) investigating fruit load in apricot showed that negative correlation values existed between yield and the current growth whereas positive values existed between yield and the preceding years' wood growth. Cummings and Jenkins (2) indicated a close correlation between wood growth and sweet cherry yields. Hofmann (7) reported a significant association between terminal growth in the preceding year and apple yields. Wilcox (16) used a growth index on apples obtained by multiplying the mean terminal growth and trunk circumference increase. He found a positive correlation between terminal growth and increased trunk circumference, but negative relationships between growth index and percentage bloom and between both trunk circumference and percentage bloom. Overholser et al (8,9) confirmed the negative relationship between growth index and fruit load in apple, but found little association between terminal growth and trunk circumference. However, simple correlation values r = 0.35 to 0.75 between trunk circumference and fruit load were relatively low. Negative or positive associations might exist between growth and yield depending on environmental circumstances, and the cultivars investigated.

In an attempt to reduce variability in 'Elberta' peach performance, Proebsting (10) provided constant growing conditions and found a linear relationship between trunk cross-sectional area and crop load in 8- to 10-year-old peach trees. He calculated that each kilogram of peach fruit produced exhausted a 0.128 cm trunk cross-sectional area increment. However, Proebsting did not show the correlation between growth and yield. Webster and Brown (15) found no association between trunk cross-sectional area increase and mean yields in 'McIntosh' apple trees ranging from 8- to 17-years-old. However, they found a linear relationship between crop load and the change in trunk circumference using the concept developed by Proebsting for estimating 'Elberta' peach yields.

The existing correlation between limb growth and bearing potential has been used as an aid in the evaluation of pome fruit thinning (5,6,13). Forshey (4) tried to predict the 'McIntosh' apple crop and found a higher correlation between fruit number and yield than between fruit size and yield. However, he did not present the yield prediction equation which used the following data: bloom count, fruit size, and fruit weight, nor did he consider leaf fruit ratio for apple yield prediction.

Several methods have been developed for cherry yield prediction. Chaplin and Westwood (1) proposed the equation $Y = -240.7 + 2039.6X$ where X was the actual yield and Y was the yield index equal to $[(\sum WiFi/Li)/n]*Ti$. To calculate their yield index requires the following data: (a) fruit weight from 2 liters of harvested fruit (Wi), (b) fruit numbers from 10 limbs per tree (Fi), (c) limb diameter for conversion to cross-sectional area (Li), (d) trunk cross-sectional area (Ti), and (e) limb number (n). They obtained a coefficient of determination equal to 0.846 in the prediction model. Several problems occurred in this formula: (a) tree yield was treated as an independent variable in the formula; however, tree yield was a dependent variable which responded to the growth index, (b) the equation could only be used in the harvesting season; it would be advantageous to be able to predict yield in the early season, (c) sampling procedures were cubersome requiring data collected from 10 sampled limbs of each tree, (d) yield was also reduced by the amount collected to provide data for the yield index, and (e) the coefficient of determination (0.846) was good but no validation of the equation was presented in the paper.

For the sour cherry yield survey in Michigan, one method has been developed based on the computer simulation (personal communication with Don Fedewa, Michigan Agricultural Reporting Service). The estimated fruit per tree = fruit count * 1/Pi * 1/Pi+1 * ---- * 1/Pi+n, where Pi is the ratio between prime limb cross sectional area and the summation of all limb cross sectional area at the specific notch. For collecting data, 2 terminal limbs and one prime limb of each tree are selected and the fruit is counted twice, once in mid-June and than again 3 days before harvest. This equation has been used in the sour cherry market survey for 15 years and the differences between the survey predictions and actual yields in Michigan range from 5 to 15%. However, since yield prediction requires a ripe-fruit count, the yield data needed for marketing purposes is only available shortly before harvest. However, no data validating the equation or showing a correlation between the equation and the yield has been presented based on individual trees.

Several regression equations for prediction have been demonstrated and widely used (3). One is refered to as the 'all possible' regression (3). However, in 'all possible' regression the computation is cubersome involving many factors and the choice between equations with large numbers of factors is subjective. The other method is refered to as 'backward elimination' regression. However, the problems with backward elimination are: (a) Once the variable has been deleted, it is never considered again. (b) The matrix singularity would cause a computation problem. (c) There is no guarantee that the model achieved is a reliable model or the best fitted. With stepwise regression, these problems do not exist. In stepwise regression, if a predictor has been eliminated once, it still has the possibility of being considered again. However in backward elimination, once a predictor has been eliminated it can not be considered in the model again. Stepwise regression, including addition and deletion procedures, may present an alternative model using different predictive characters. However, the characters used in the predictive equation are objective, since selection is automatically performed in the computer by the computer program eliminating the involvement of the researchers.

The objective of this paper is to develop and validate a yield prediction formula for yield of 'Montmorency' and 'Meteor' sour cherry using stepwise regression.

Materials and Methods

In 1984, data was taken from (I) 3 trees of 23-year-old and 2 trees of 16-year-old 'Montmorency' trees at the Botany Farm, East Lansing, Mich., and (II) 3 trees each of 'Montmorency' and 'Meteor' at 2 locations, Clarksville Horticultural Experimental Station, Clarksville, Mich. and Hilltop Orchards and Nurseries, Hartford, Mich.. 'Montmorency' tree yield at Clarksville were also collected in 1983. The trees at Clarksville and Hilltop were originally 7 and 8-years-old, respectively. The two cultivars were grafted on P. mahaleb seedling rootstocks and trained to a modified central leader.

One representative 3 or 4-year-old limb was randomly selected from each tree at Clarksville and Hartford. Three 4-year-old limbs were randomly selected from each tree at East Lansing. The following totals were counted: (I) total tree yield, (II) number of lateral buds per limb, (III) number of spurs per limb, (IV) flower number per limb, (V) fruit set (total fruit count/total flower count), (VI) average fruit weight of 50 fruits, (VII) flowering branch number, (VIII) limb circumference (cm) (IX) trunk circumference (cm), (X) crown area (m^2) calculated from πr^2 , (XI) leaf number along the terminal growth of the limb, (XII) leaf area measured with a L1-3000 leaf area meter of 5 randomly selected leaves (cm^2), (XIII) average flower cluster number (total cluster number)/(spur number + lateral bud number).

Predictors wre added to the multiple regression equation in the order in which they were weighted to the partial F test (STAT 4 program by Dr. Charles Cress, M. S. U., East Lansing, Mich.). The procedures for stepwise regression are as follow:

(I) The variable most highly correlated with yield was selected by partial F criterion rather than its fit to the regression model $\hat{Y} = f(Xi)$.

(II) The partial F values for variables not in the model were computed and the variable with the highest F values was ntered if it was significant.

(III) The partial F values of the variables were checked for possible deletion at each step for making decisions to either reject or retain the corresponding prediction.

(IV) Procedures were stoped when no variable could be added or deleted that significantly improved the prediction equation.

Results and Discussion

'Meteor' tree yield was about half of 'Montmorency' tree yield (Table 1). 'Meteor' leaf number along the terminal growth of the limb was about 3 times that of 'Montmorency', which may reflect an increased number of spur leaves retained on the main branches in 'Meteor'. The coefficients of variation for most characters from both sour cherry cultivars were relative high. A detailed discussion of the flowering and fruiting habits of 'Montmorency' and 'Meteor' is presented in Chapter I. The variables in Table 1 were used to develop the prediction equation for the healthy and mature 'Montmorency' and 'Meteor' sour cherry cultivars.

The equations developed by stepwise regression for 'Montmorency' and 'Meteor' tree yields were: 'Montmorency' tree yield,

$\hat{Y} = 104.6237 - 12.449\ X_1 - 0.381X_2 + 0.015X_3 - 8.268X_4$

where X_1: average flower cluster number per spur and lateral bud, X_2: leaf number per prime terminal shoot of the limb, X_3: flower number per limb, X_4: limb circumference (cm); 'Meteor' tree yield: $\hat{Y} = -9.3119 + 0.3102X$ where X: leaf number per prime terminal shoot of the limb.

To develop a useful and reliable model, 2 criteria have to be achieved: (I) Involve as many as predictors as possible so that reliable fitted values can be determined. (II) Include

Table 1. Mean values ($\bar{x}$) and coefficients of variation (c.v.) for variables sampled from 'Montmorency' and 'Meteor'.

Variable	'Montmorency' $\bar{x}$	'Montmorency' c.v.	'Meteor' $\bar{x}$	'Meteor' c.v.
Yield (kg)	28.8	26.0	13.1	67.8
No. of lateral buds/limb	175.7	41.4	152.2	142.7
No. of spurs/limb	37.3	53.8	168.2	53.0
No. of flowers/limb	784.9	40.2	2138.2	70.6
Fruit set (%)	38.7	33.5	22.7	27.6
Fruit weight (gms)	3.8	15.7	4.5	8.8
No. of branches/limb	43.3	32.1	53.8	52.2
Limb circumference (cm)	7.2	12.5	3.3	27.2
Trunk circumference (cm)	45.6	39.4	28.3	18.3
Projected crown area (m^2)	11.5	19.1	9.0	15.5
Leaf no.	26.8	32.0	75.6	40.9
Leaf area (cm^2)	48.0	19.1	54.4	11.3
Average flower cluster no.	1.4	21.4	2.8	17.8

Table 2. **Validation of the prediction equation between harvested yield and calculated yield for 14 'Montmorency' trees ranging from 7 to 23 years old.**

Harvested Yield	Variables in the prediction equation						
from individual trees (y) (kg)	Average flower cluster no.	Leaf no.	Flower no.	Limb circumference (cm)	Calculated yield ($\hat{y}$)	Yield difference ($y - \hat{y}$)	X^2 values
29.58	1.662	31.67	566	6.08	30.08	-0.50	0.00845
23.65	1.303	28.33	420	7.19	24.46	-0.81	0.02774
27.29	1.636	36.89	533	6.18	27.10	0.19	0.00132
37.64	1.193	25.00	706	5.87	42.30	-4.66	0.57692
30.55	1.121	29.22	464	6.88	29.61	0.94	0.02892
20.30	1.107	24.75	449	8.04	21.67	-1.37	0.09245
20.48	1.295	25.89	1004	8.78	21.11	-0.63	0.01937
19.68	1.838	19.44	1123	8.73	19.00	0.68	0.02349
19.80	1.867	18.44	1186	8.30	23.52	-3.72	0.69890
36.94	1.647	10.14	1007	7.26	35.33	1.61	0.07017
42.59	1.061	15.55	1223	7.94	38.18	4.41	0.45663
28.37	1.754	36.70	438	6.13	24.69	3.68	0.47734
31.66	1.265	33.70	709	6.84	29.73	1.93	0.11765
35.72	1.040	39.40	1.61	6.96	36.53	-0.81	0.01836
							2.61778

as few predictors as possible in the resulting equation to simplify data collection. The model for 'Montmorency' sour cherry tree yield appears to be meet both requirements.

Coefficient of determination (R^2 = 0.892) and F values (18.6) (degree of freedom = 12, and P = 0.001) for the prediction equation for 'Montmorency' tree yield indicate that the stepwise regression equation is highly reliable. The chi-square values between predicted yield for 'Montmorency' tree and actual yields equaled 2.62 resulting in a validation wehich was greater than 99.5% (Table 2).

Coefficient of determination (R^2 = 0.951) and F (59.02) values for the prediction model for 'Meteor' tree yields were high, however, the chi-square values for validation between tree yield and predictive yield was 4.88 which was about 30% of validation. This low value may be due to the reduced number of trees sampled for 'Meteor', or more complex interrelationships in 'Meteor'. Since the number of predictors was larger than the number of 'Meteor' trees harvested, there was a matrix singularity problem existing in the deletion procedures which terminated the computer performed calculations in the early stage.

Table 3. Variation of the prediction equation between harvested yield and calculated yield for five 'Meteor' trees either seven or eight years old.

Harvested yield from individual trees (Y) (kg)	Variable in the prediction equation: Leaf no.	Calculated yield ($\hat{y}$)	Yield difference ($y - \hat{y}$)	X^2 values
11.34	70.3	12.49	-1.15	0.11662
12.02	58.1	8.71	3.31	0.91148
22.45	99.5	21.54	0.91	0.03688
14.57	100.5	21.86	-7.29	3.64750
5.11	49.5	6.04	-0.93	0.16925
				4.88175

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