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STABILITY AND COMPONENTS OF YIELD IN HIGHBUSH BLUEBERRY CULTIVARS

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STABILITY AND COMPONENTS OF YIELD
IN HIGHBUSH BLUEBERRY CULTIVARS

By

James Henry Siefker

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ABSTRACT

STABILITY AND COMPONENTS OF YIELD

IN HIGHBUSH BLUEBERRY CULTIVARS

By

James Henry Siefker

Genetic and cultural advances in the highbush blueberry could be facilitated by a more thorough understanding of the factors that affect the magnitude and variability of yield. Stability and yield component analyses have been used in other crops to gain such information but they had not been employed in highbush blueberry cultivars.

A stability analysis of 17 cultivars revealed differences in response to environmental variation. There were significant differences among cultivars in the regression of cultivar yield on environmental mean yield. Significant deviations from regression were also observed.

Regression, path analysis and the "W" statistic were used to explore the relationships among the components of yield in 9 cultivars. There were significant differences among cultivars for canes per bush, berries per cane, berry weight, and yield. Variability in canes per bush and berries per cane were found to be more important in determining yield per bush than was variability for berry weight. Component interactions were neutral to additive in two cultivars and compensatory in the others.

The effect of pruning on the components of yield was studied in "Jersey". Pruning was found to decrease yield and increase berry weight. In the first harvest season after pruning the increase in berry weight was due to the decreased number of berries per bush, but the strength of this relationship decreased in subsequent years. There was a strong, linear relationship between the number of canes removed and new cane production by the bushes.

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Guidance Committee:

The journal paper format was chosen for this thesis in accordance with departmental and university regulation. The thesis is divided into four Chapters. Chapter 2 is intended for publication in the Fruit Varieties Journal. Chapters 3 and 4 are intended for publication in The Journal of the American Society for Horticultural Science.

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CHAPTER 1

INTRODUCTION

The productive potential and economic value of the highbush blueberry crop is sufficiently high to justify the expenditure of a great amount of effort in the establishment and maintenance of plantings. It is important to have valid information to guide this expenditure of effort. The pioneers of highbush blueberry culture made progress both in elucidating cultural requirements (7, 15) and in producing genetically improved cultivars (8, 18). This progress is evident from the success of the blueberry industry. The early workers did not have access to the sophisticated methods of data analysis that are available today. They were therefore limited in the degree to which they could quantify their results. There is a great deal of work to be done which can be described as "fine tuning", not work upon which the success or the failure of the industry depends, but work which can have an important impact on the economic well-being of individual producers.

The selection of cultivars and pruning strategies is critical to the highbush blueberry producer. The selection of cultivars is important because of the long range effects of the decision. The maximum life span of the highbush blueberry is not known, but well maintained plantings are still highly productive after 40 years. As new, "improved" cultivars are released, producers are forced to choose between the proven performance of old cultivars and the potential of the new. This problem is exacerbated by genotype-environment interactions, which may limit the usefulness of cultivar performance data gathered at other locations. There is a need for cultivar trial results which provide more information than just the yield of cultivars under optimal conditions. More information about yield component interactions in different cultivars would be helpful in predicting the effects of environmental stresses on productivity.

The value of pruning is difficult to demonstrate because its benefits may not be evident for several years, while the costs are apparent immediately. The changing relationship between the cost of labor and the price of fruit dictates that pruning methods produce the maximum benefit with the least investment of time. The increase in size of blueberry farms means that much of the labor involved in pruning must be done by hired labor. Such workers are unlikely to develop the kind of expertise needed to carry out detailed pruning instructions. Suggestions that a certain proportion of laterals be removed or that laterals be tipped or canes headed back are too complicated and require too much effort. The optimal pruning strategy would remove the required amount of wood with the fewest and easiest cuts.

Even the best pruning strategy is still expensive, and growers need to be convinced that the effort expended is justified. Experimental evidence of the benefits of pruning can do this.

To approach the problem of pruning on a quantitative basis, it is helpful to understand the variability among cultivars for yield components. Such variability may have implications for cultivar improvement through breeding. Furthermore, marked genotypic differences in the relationships among components may make it difficult to generalize results of pruning experiments.

Data on the field performance of blueberries is expensive in terms of both time and land. The methods of analysis used on this work were selected because they derive the maximum amount of information from the available data.

The brevity of the next three chapters of this work is consistent with the journal format, but limits the depth of discussion of some important issues. The statistical methods used are likely to be unfamiliar to many readers and there is a considerable body of prior work on pruning that merits discussion. Finally, the results with respect to yield component interactions need to be put in perspective with respect to the type of selection that may be practiced.

Statistics of Component Interactions and Stability:

Knowledge about yield components interactions can aid in the development of genetic and cultural strategies to increase yield. A statistical analysis of individual components is not satisfactory for this purpose because it fails to clarify component interactions.

The correlation coefficient provides a measure of the association between pairs of variables. A significant correlation can arise if there is a causal relationship between them. However, such a relationship is not a requirement for a significant correlation. Other variables not considered in the correlation may affect both variables in such a way that a strong correlation is observed.

Multiple regression can be used to estimate the ability of several variables together to predict a single response variable. One potential problem with multiple regression is that the relative importance of the predictors cannot be assessed if different scales of measurement are used for the different variables. That difficulty can be circumvented if all the variables are standardized to zero mean and unit variance. This is done by subtracting from each observation the mean for that variable and dividing the result by the standard deviation. The standardized regression coefficients obtained in this way estimate the relative ability of the independent variables to predict the response variable.

However, prediction alone is not always satisfactory. An understanding of the mechanisms underlying the observed relationships is often desired. Such mechanisms may involve complex interactions among variables. Path analysis was developed by Wright (34) as a "means of relating the correlation coefficients between variables in a multiple system to the functional relations among them." Path analysis treats the correlation coefficient as a standardized covariance which is partitioned into contributions from various paths between two variables. These may include the direct effect of one variable on the other, and one or more indirect effects through intervening variables.

The first step in performing a path analysis is to formalize all knowledge or assumptions about the kinds of interactions between pairs of variables by constructing a path diagram. A functional relationship between variables is indicated by an arrow drawn from the independent variable to the dependent variable. A residual correlation between two variables (one that cannot be ascribed to other variables) is represented by a double arrow between them and is calculated as an ordinary correlation coefficient. Path coefficients are calculated as standardized regression coefficients, as described above with the regression equations constructed according to the path diagram. One regression is performed for each variable that is at the lead end of one or more single headed arrows, with that variable as the dependant variable. Each variable that is at the tail end of one of these arrows is then included in the equation as an independant variable.

The brief coverage of path analysis in 'The Statistical Package for the Social Sciences' (19) is an excellent introduction. The subject has also been discussed in more detail by Li (17).

Path analysis can quantify interactions between pairs of variables but it does not provide a quantitative summary of the types of overall interactions. The "W" statistic, developed by Hardwick and Andrews (12) is a useful means for quantifying all the component interactions in a set of data. It compares the standard deviations of the log-transformed components to the standard deviation of the complex trait. "W" can range from 0 to 1. Values below 0.5 indicate compensatory interactions. Values above 0.5 indicate additivity. Independence is suggested by values around 0.5.

The regression of cultivar performance on environmental mean (1, 9) can also provide quantitative measures of the responses of genotypes to environmental variation. This method requires only the means of several cultivars in a number of environments so it can easily be applied to data collected previously for other purposes.

<u>Pruning</u>:

Pruning may be done for a number of purposes: 1) to direct the growth of the bush, 2) to eliminate wood that is non-productive because of position, damage, disease, vigor or age, 3) to prevent overbearing, 4) to reduce crowding and provide a more advantageous distribution of resources, 5) to stimulate the production of new, vigorous and productive wood, 6) to reduce bush size.

Much of the previous work on pruning the highbush blueberry is of limited value because treatments were not quantified and because tests of significance were not performed on treatment effects. These deficiencies are not necessarily due to the quality of the work done or the abilities of the investigators. They are more a reflection of a lack of experience with the cultivated blueberry and the inability of the statistical methods available at the time to handle the intrinsic complexity. It is also important to note that the increasing cost of labor has made some pruning methods that were practiced in the past, such as lateral removal and tipping, economically unfeasible.

Johnston (15) performed pruning trials on plantings of blueberry bushes taken from the wild. Moderately pruned bushes produced more fruit than either unpruned or heavily pruned bushes. This effect could not be ascribed to pruning alone because competing trees and shrubs had been removed from the pruned plots but not from the unpruned, check plots. Brightwell and Johnston (4) found that 10 year old bushes that were pruned had lower yields and larger berries than unpruned bushes. Howell et al. (13) sawed off large, unthrifty bushes at ground level and found that their yields surpassed those of unpruned controls by the third harvest season after pruning.

Pruning has probably received the most extensive consideration in grapes. Grapes are a good experimental system because vegetative vigor can be estimated from the weight of cane prunings, and cropping can be controlled by regulating the number of buds retained at pruning. Partridge (20) investigated the relationship between yield and vine vigor. He developed a system of balanced pruning based on the idea that more vigorous vines could tolerate higher cropping stress (21). Shaulis and coworkers (29, 30, 32) showed that the yield of balance pruned vines was affected by the training system used. Shaulis and Robinson (31) showed that in 'Concord' and 'Fredonia' grapes less severe pruning than recommended by Partridge could produce higher yields without delaying maturity or reducing the quality of the juice. Kimball and Shaulis (16) found that yield, cluster per vine, shoots per vine and buds per vine were all highest for the least severely pruned vines. Berries per cluster, shoots per bud and percent soluble solids were highest for the most severely pruned vines. They related delayed maturity of large crops on the lightly pruned vines in part to inadequate exposure of the large leaf surface.

Howell et. al. (14) found that severe pruning increased the cold hardiness of primary buds as did cluster thinning, but the development of hardiness was delayed if increased vigor resulted in more shading or if reduced cropping stress prolonged the period of vine growth. Defoliation reduced hardiness, vine size, fruitfulness and soluble solids.

Byrne and Howell (5) found that increased cropping was associated with decreased vegetative growth and regarded fruit and vines as competitive sinks. Sucker removal and higher pruning severity delayed the development of cane and bud hardiness but pruning was associated with greater hardiness at mid-winter. Stergios and Howell (33) found that primary bud hardiness was decreased by defoliation but that it increased with severity of pruning.

There has also been a great deal of work on pruning in apples. Roberts (28) employed a single pruning treatment that involved heavy topping and removal of half of each multiple spur or small branch. Pruning increased vegetative vigor and leaf and fruit size. It was concluded that reductions in harvesting costs, due to the reduced need to pick and handle undersized apples, more than offset the cost of pruning. Benson et. al. (3) employed three pruning treatments which ranged from less severe than was commercially practiced to the most severe commercial methods. Pruning did not significantly reduce the yield of either 'Starkling' or 'Golden Delicious' apple trees, but it did significantly increase fruit size in 'Starkling'.

Preston (22) investigated the effects of pruning system on the growth and yield of 'Laxton's Superb' apple. There were significant differences among treatments for shoot growth, trunk girth, total crop and biennial bearing. Data was presented on the amount of new and old wood removed in each treatment, but statistical measures of the degree of association between these quantities and the measures of vegetative growth and yield were lacking. Preston (23) investigated the same pruning treatments on Cox's Orane Pippin apple. Significant differences among treatments were found for mean trunk girth and total crop per tree.

Batjer (2) compared the vegetative growth and fruiting characteristics of pruned and unpruned young 'Delicious' apple trees. Pruned trees produced consistently lower yields but significantly larger fruit. It was concluded that the higher yield of the unpruned trees resulted from a greater number of fruiting branches. Preston (24) reported that the removal of feathers significantly decreased trunk growth, crotch angle of primary branches, number of shoots and total length of shoot growth for trees on 2 rootstocks.

Preston (25) found significantly larger crops in Worchester Pearmain apple trees pruned in alternate years than in trees pruned every year. Trees in which fruits were thinned to one per cluster produced smaller total crops than unthinned trees, but larger amounts of fruit in the > 2.5 in. size class.

The work on both apples and grapes suggests that pruning can increase some yield components, notably fruit per cluster in grapes and fruit weight in apples, while decreasing other components, such as clusters per vine. It can also increase fruit quality and winter hardiness. It is clear that vegative growth and fruit production are competing for limited resources. Increased cropping reduces vegetative growth. When photosynthetic production is reduced by defoliation the quantity and quality of both vegetative and fruit production suffer.

An Ideotype for the Highbush Blueberry:

Early blueberry breeders emphasized selection for those aspects of fruit quality that were important for the fresh market. Many aspects of fruit quality have been described in relation to breeding (18). Visual scales were provided for rating berry size, berry color and scar type on a scale from 1 to 10, with 10 representing the most desirable state of the character. A score of 6 was the lowest considered satisfactory for commercial production. Darrow and Scott (8) ranked a number of cultivars on a scale from 1 to 10 for size, color, scar, flavor and season.

The validity of these measures of fruit quality depends on the use to which the berries will be put. Large berries (>2.0 gm) are more attractive for the fresh market, and the presence of a waxy bloom indicates that the berries have been gently treated and will not be prone to rapid spoilage. However, small berries (1.0 - 2.0 gm) are preferred by most processors and freezing or canning destroys any waxy bloom. A small, dry scar is important to impede the entry of decay organisms which reduce shelf life, but most berries are processed in a short enough time that spoilage is minimized regardless of the scar type.

The blueberry industry in Michigan has evolved to the point where 60 - 70% of the crop is processed and most acreage is picked specifically for processing. By reducing selection for those traits that are not important in processed genotypes, more effort could be devoted to improving yield, disease resistance, cold tolerance and bush structure.

Desirable characters for processed blueberries are:

1. Moderate vegetative vigor. If too many canes are produced, some may become weak and a drain on bush resources unless they are removed. If too few renewal canes are produced, there may not be enough vigorous canes to produce good crops.

2. Moderate stature. Processed blueberries are harvested primarily by machine. The harvesters require that bushes be no more than 2 meters tall. The height of bushes can be reduced by pruning but this involves extra labor and the production of wood above the desired maximum height represents a waste of resources which might otherwise be used for the production of fruit.

3. Upright habit. A spreading bush obstructs normal cultural and harvest operations and projecting canes are especially susceptible to injury. The tendency of canes to grow upright is determined by the angle

at which the cane grows from perpendicular, the length and strength of the cane, and the size and distribution of the crop born by the cane. These factors can be considered components in the sense that each can be determined separately from the others and so each could be the basis for selection.

4. <u>High yield</u>. Selection should be practiced to maximize the product of the primary yield components. Past selection has been quite successful in increasing berry weight, but at the expense of berry number (27). The narrow germplasm base of highbush blueberry cultivars (10) may necessitate the incorporation of wild germplasm into highbush blueberry breeding programs if yields are to surpass those of the best cultivars presently available (26). Any wild genotypes used for this purpose are likely to contribute reduced berry weight. Rather than expend effort to try to counter this reduction it may be better to attempt to increase yield by selecting for increased berry number. As discussed above, modest berry size is acceptable for processing.

5. <u>Narrow bush base</u>. A wide base increases harvester losses because it is not possible to collect berries that fall into this area (6). Bases can be narrowed by grinding but it is less expensive to avoid or delay this procedure.

6. <u>Appropriate season of harvest</u>. It is desirable to have a series of cultivars ripening at different times. This lengthens the period during which fresh fruit can be marketed and it spreads out the work of harvesting.
7. <u>Stability</u>. Hardiness with respect to winter cold and spring freezes is required for consistent production of good crops. Tolerance to summer heat is another factor that may contribute to stability.
9. <u>Tight ripening period</u>. If ripening occurs over a long period of time it may be necessary to make several pickings in order to harvest as much of the crop as possible. Aside from the cost involved in each harvest there is inevitably some damage to the bushes with each pass of the harvester. Increased synchrony of berry development is highly desirable.
10. <u>Processing quality</u>. The properties of fruit that contribute to the quality of canned, frozen or baked products are largely unknown in blueberries. In other crops sugar content, acidity and color are important.
11. <u>Moderate pull force</u>. The proper development of the abscission layer at the stem end of the berry is important so that ripe fruit can be easily shaken from the bush. If the force required is too low the fruit may drop prior to harvest.

12. <u>Disease resistance</u>. Blueberries are susceptible to wide variety of common diseases including mummyberry, shoestring, powdery mildew, phomopsis canker and red ringspot. Resistance to these diseases should be incorporated in breeding programs.

Phenotypic differences have been observed for many of these characteristics among varieties grown in Michigan (11). Since blueberries are propagated vegetatively, it is possible to reduce the environmental contribution to phenotypic differences. However, there is very little information that can be used to assess the relative importance of general and specific combining abilities for any of these traits so the rates of progress for selection are difficult to estimate.

Literature Cited

1. Allard, R.W. and A.D. Bradshaw. 1964. Implications of genotype-environmental interactions in applied plant breeding. Crop Sci. 4503-506.
2. Batjer, L. P. 1962. Effects of pruning, nitrogen,and scoring on growth and bearing characteristics of young delicious apple trees. Proc. Amer. Soc. Hort. Sci. 82:5-10.
3. Benson, N. R., R. M. Bullock, I. C. Chmelir and E. S. Degman. 1957. Proc. Amer. Soc. Hort. Sci. 70:27-38.
4. Brightwell, W. T. and Johnston, S. 1944. Pruning the highbush blueberry. Mich. St. Coll. Tech. Bull. 192.
5. Byrne, M.E. and G.S. Howell. 1977. Initial response of baco noir grapevines to pruning severity, sucker removal, and weed control. Am. J. Enol. Vitic., 29(3):192-198.
6. Cargill, B. F. and J. W. Nelson. 1979. Research results on harvester recovery. Proc. N. Am. Blueberry Research Workers Conf. 4:373-381.
7. Coville, F. V. 1911. Taming the wild blueberry. The National Geographic Magazine. 22(1):137-147.
8. Darrow, G. M. and D. H. Scott. 1966. Varieties and their characteristics, p. 94-110. In P. Eck and N. Childers (eds.). Blueberry culture. Rutgers University, New Brunswick, N.J.

9. Finlay, K.W. and G.N. Wilkinson. 1963. The analysis of adaptation in a plant-breeding programme. Aust. J. Agric. Res. 14:742-754.

10. Hancock, J. H. and J. H. Siefker. 1982. Levels of inbreeding in highbush blueberry cultivars. HortScience 17(3):363-366.

11. Hancock, J., J. Siefker and J. Nelson. 1980. Highbush blueberry varieties for Michigan. Mich. St. Univ. Coop. Ext. Bul. E-1456.

12. Hardwick, R. C. and D. J. Andrews. 1980. Genotypic and environmental variation in crop yield. A method of estimating the interdependance of the components of yield. Eyphytica. 29:177-188.

13. Howell, G. S., C. M. Hansen, H. C. Bittenbender and S. S. Stackhouse. 1975. Rejuvenating Highbush Blueberries. J. Amer. Soc. Hort. Sci. 100(5):455-457.

14. Howell, G.S., B.G. Stergios and S.S. Stackhouse. 1977. Interrelation of productivity and cold hardiness of Concord grapevines. Am. J. Enol. Vitic., 29(3):187-192.

15. Johnston, S. 1934. The Cultivation of the Highbush Blueberry. Mich. St. Coll. Special Bull. 252.

16. Kimball, K. and N. Shaulis. 1958. Pruning effects on the growth, yield, and maturity of Concord grapes. Proc. Am. Soc. Hort. Sci. 71:167-176.

17. Li, C.C., 1975. Path Analysis - a primer. Pacific Grove: The Boxwood Press.

18. Moore, J. N. 1966. Breeding, p. 45-74. in P. Eck and N. F. Childers (eds.), Blueberry Culture, Rutgers University Press, New Brunswick, New Jersey.

19. Nie, Norman H., 1975, Statistical Package for the Social Sciences. McGraw-Hill. p. 383-397.

20. Partridge, N. L. 1925. Growth and yield of Concord grape vines. Proc. Amer. Soc. Hort. Sci. 22:84-87.

21. Partridge, N. L. 1925. The fruiting habits and pruning of the Concord grape. Michigan Agr. Exp. Sta. Tech. Bul. 69.

22. Preston, A. P. 1957. Pruning trials with Laxton's Superb apple. J. Hort. Sci. 32:133-141.

23. Preston, A. P. 1960. Pruning trials with Cox's Orange Pippin apple. J. Hort. Sci. 35:146-156.

24. Preston, A. P. 1968. Pruning and rootstock as factors in the production of primary branches on apple trees. J. Hort. Sci. 43:17-22.

25. Preston, A. P. 1968. Pruning trials with Worchester Pearmain apple. J. Hort. Sci. 43:175-183.

26. Pritts, M. P., J. F. Hancock and J. M. Roueche. 1985. Identifying superior genotypes of blueberry in wild populations. HortScience 20(3):409-411.

27. Pritts, M.P., J.H. Siefker and J.F. Hancock. 1984. Yield component variation in wild and cultivated blueberries. Proc. N. Amer. Blueberry Research Workers Conf. 5:30-38.

28. Roberts, R. H. 1952. Pruning Golden Delicious to secure good apple size. Proc. Amer. Soc. Hort. Sci. 59:184-186.

29. Shaulis, N. J. and G. D. Oberle. 1948. Some effects of pruning severity and training on Fredonia and Concord grapes. Proc. Amer. Soc. Hort. Sci. 51:263-270.

30. Shaulis, N. J., H. Amberg, and D. Crowe. 1966. Response of Concord grapes to light exposure and Geneva double curtain training. Proc. Am. Soc. Hort. Sci. 89:268-280.

31. Shaulis, N. J. and W. B. Robinson. 1953. The effect of season, pruning severity, and trellising on some chemical charasteristics of Concord and Fredonia grapes. Proc. Amer. Soc. Hort. Sci. 62:214-220.

32. Shaulis, N. J. K. Kimball and J. P. Tompkins. 1953. The effect of trellis height and training systems on the growth an yield of concord grapes under controlled pruning severity. Proc. Amer. Soc. Hort. Sci. 62:221-227.

33. Stergios, B.G. and G.S. Howell. 1975. Effects of defoliation, trellis height, and cropping stress on the cold hardiness of Concord grapevines. Am. J. Enol. Vitic., 28(1):34-42.

34. Wright, S. 1934. The Method of Path Coefficients. Ann. Math. Stat. 5:161-215.

CHAPTER 2

STABILITY OF YIELD IN

HIGHBUSH BLUEBERRY CULTIVARS

Abstract

Seventeen blueberry cultivars were harvested for 13 years at a single site in Michigan. Yield stability was estimated using a linear regression of cultivar yield on the mean of all cultivars for each year. Cultivars with a history of successful performance in Michigan had better than average yield and a regression coefficient near 1.0. Cultivars with low yields often had low regression coefficients, indicating an inability to respond to favorable environmental conditions.

Introduction

Stability of yield is particularly important in fruit crops. A year of low production and high prices can result in reduced demand in subsequent years as consumers and processors turn to more available and therefore cheaper alternatives. Exceptionally high production may exceed consumer demand and processing capacity.

Methods of quantifying stability have been developed by several authors. Finlay and Wilkinson (3) used the regression coefficient of cultivar mean on environmental mean as a measure of stability to take into account the dynamic response of genotypes to different environments. Eberhart and Russell (2) established criteria for a desirable cultivars as: 1) high yield, 2) regression coefficient near 1.0 and

3) low deviation from regression. The regression coefficient represents that portion of the variability in yield that can be ascribed to a common environmental influence, while the deviation from regression represents that portion that is due to other sources. Eberhart and Russell did not consider very low regression coefficients a practical goal because maize hybrids with regression coefficients below 1.0 usually had lower than average yields.

In perennial crops, factors come into play which are not important in annuals. The performance in a given year is affected by environmental conditions not only in that year but also previous years. The regression coefficient of cultivar mean on environmental mean will be increased for a cultivar with a higher than average rate of growth or recovery from injury. In addition, vigorous genotypes may reach their maximum yield early and then have a yield plateau while the yields of other genotypes are still increasing. This will increase deviation from regression.

The regression method has been employed in several perennial species including cocksfoot (1), bromegrass (10), and strawberries (4, 5 and 11), but in none of these cases was data collected for more than two years. In this study, we examined the relationship between yield and stability in a number of highbush blueberry cultivars over 13 years to determine which were the most consistent producers.

Materials and Methods

Seventeen cultivars were planted at Grand Junction, Michigan in 1966 in a completely randomized design, with 4, 4-bush replicates of each cultivar. Bush spacing was 1.2 meters within rows and 3 meters between rows. Bushes were maintained according to standard cultural practices (8). No treatments were applied to increase environmental variability. The significant environmental conditions in Michigan for the years of the study are listed in Table 1.

Fruit yield was recorded for each plot starting in 1969 and continuing through 1981. Fruit was generally harvested by hand held shaker in two pickings. On rare occasions fruit was hand picked. Berries harvested by shaking were sorted to remove green fruit, damaged fruit, and debris. The weight of the remaining "marketable" fruit was used to represent yield.

The regression of plot means for each genotype on yearly means was performed using the method described by Sokal and Rohlf (9) for more than 1 value of Y per value of X. The regression coefficients (b) and mean squared deviation from regression (s_d^2) were calculated.

Results and Discussion

An analysis of variance demonstrated statistical significance for the cultivar effect ($F = 40.36$, $df = 16, 663$, $p < 0.01$) and the cultivar by year interaction ($F = 2.74$, $df = 192, 663$, $p < 0.01$). The regression coefficients and

Table 1. Total Michigan blueberry production and significant environmental conditions from 1969 to 1981. (Source - Michigan Agricultural Reporting Service, Lansing, Michigan).

Year	10^6 Kg	Environmental Characteristics
1969	18	Dry during and after harvest
1970	12	Moderate winter injury
1971	18	
1972	8	Freeze in early June
1973	18	
1974	15	Dry August and September, Mummy berry
1975	13	Early spring, Hail on July 13
1976	14	Early spring, Frost in May
1977	5	Severe winter injury
1978	10	
1979	16	Cool spring, Wet August
1980	18	
1981	16	Spring freeze

deviations from regression for the cultivars in this study are presented in Table 2. Yields ranged from 0.722 kg per bush per year for 'Bluehaven' to 2.844 kg per bush per year for 'Elliot'. Regression coefficients ranged from 0.31 for 'Bluehaven' to 1.64 for 'Elliot'. Mean squared deviations from regression ranged from 0.81 for Elizabeth to 5.57 for Bluetta.

Since all the cultivars have been at least moderately successful in some part of the country, it is doubtful that the low mean yields obtained for some of them are representative of their true yield potential. The 3 lowest yielding cultivars had the lowest regression coefficients. This suggests that the cultivars that were not adapted to the site were not only suffering yield reductions in particularly bad years but were not performing well under any conditions.

'Bluecrop', 'Jersey' and 'Rubel' are mid-season cultivars that have been widely planted in Michigan. They all had above average yields and regression coefficients near 1.0. Thus they can be expected to produce above average yields over a wide range of climatic conditions. 'Blueray' is a midseason cultivar that had high yields, but had a low regression coefficient and a high mean squared deviation from regression, indicating that much of the variability in its yield was unpredictable. 'Bluejay', a relatively new cultivar, had average yield. Its high regression coefficient indicates that it responded well to favorable environmental

Table 2. Mean yields, regression coefficients (b) and mean squared deviations from regression (s_d^2) for total marketable yield, 1969 to 1981.

Cultivar	Kg/Bush	b	s_d^2
Bluehaven	0.72	0.31 **[z]	1.37 **[y]
Darrow	0.74	0.59	1.06 **
Elizabeth	0.81	0.50	0.81 **
Berkeley	1.23	0.98	2.76 **
Earliblue	1.26	0.93	1.59
Coville	1.40	1.20	2.76 **
Collins	1.62	1.39 *	2.59 **
Bluejay	1.74	1.33 *	2.02
Bluetta	1.76	1.02	5.57 **
Spartan	1.89	1.18	1.51
Rubel	1.98	0.95	1.28 *
Bluecrop	2.06	0.94	1.46
Lateblue	2.14	1.32 *	2.62 *
Blueray	2.26	0.79	2.59 **
Jersey	2.27	0.94	2.99
Northland	2.83	1.00	4.16 *
Elliot	2.84	1.64 **	2.43 *
Mean	1.74	1.00	2.33

* Significant at 5% level of probability.

** Significant at 1% level of probability.

[z]Tested for b significantly different from 1.

[y]Tested for s_d^2 significantly different from 0.

conditions but suffered worse than average losses in bad years. 'Northland' had the highest yield of any of the mid-season cultivars and a regression coefficient of 1.0. Its high mean squared deviation from regression may be related to its high vegetative vigor which results in a pattern of periodic high yields followed by severe pruning and a reduction in yield.

Of the early season cultivars, 'Earliblue' had a low mean yield and a regression coefficient near 1.0 which suggests that it did not perform well under any conditions. 'Bluetta' had a mean yield near the grand mean and a regression coefficient near 1.0 which indicate average yields in all environments. However, it had the highest mean square deviation from regression of any of the cultivars. 'Spartan' had the highest yield of the early season cultivars and a low mean squared deviation from regression. Its regression coefficient was higher than 1.0, but it had the best combination of yield and stability of any of the early season cultivars.

The late season cultivars 'Lateblue' and 'Elliot' had higher than average yields but low stability. Neither of these cultivars could be recommended for reliable production.

When stability with respect to climatic variability is considered in conjunction with other factors that affect fruit yield and quality (6,7) it should help growers to choose cultivars that will more closely satisfy their requirements.

Acknowledgments

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Literature Cited

1. Breese, E.L. 1969. The measurement and significance of genotype-environment interactions in grasses. Heredity 24:27-44.

2. Eberhart, S.A., and W. A. Russell. 1966. Stability parameters for comparing varieties. Crop Sci. 6:36-40.

3. Finlay, K.W. and G.N. Wilkinson. 1963. The analysis of adaptation in a plant-breeding programme. Aust. J. Agric. Res., 14:742-754.

4. Guttridge, C. G. and H. M. Anderson. 1981. Assessing fruit yield characteristics and potential in strawberry. Hort. Res., 21:83-98.

5. Hancock, J.F. 1985. Yield stability in 10 cultivars of strawberry. Fruit Varieties Journal 39:18-21.

6. Hancock, J. F. and J. Nelson. 1985. Critical factors determining yield of blueberries in Michigan. In press. Acta Hort.

7. Hancock, J., J. Siefker and J. Nelson. 1980. Highbush blueberry varieties for Michigan. Mich. St. Univ. Coop. Ext. Bul. E-1456.

8. Johnston, S., J. Moulton and J. Hull Jr. 1969. Essentials of Blueberry culture. Michigan State University Cooperative Extension Service, Bulletin E-590.

9. Sokol, R.R. and J.R. Rohlf. 1969. Biometry. W.H. Freeman and Company, San Francisco, 428-440.

10. Tan, W., G. Tan and P.D. Walton. 1979. Regression analysis of genotype-environment interaction in smooth bromegrass. Crop Sci. 19:393-396.

11. Williams, H. 1975. Genotype-enviromnent interaction in strawberry cultivars. Hort. Res. 14:81-88.

CHAPTER 3

YIELD COMPONENT INTERACTIONS IN CULTIVARS OF THE HIGHBUSH BLUEBERRY *VACCINIUM CORYMBOSUM* L.

Abstract

Yield component analysis of 9 cultivars indicates that yield was more strongly determined by canes per bush and berries per cane than by berry weight, although higher numbers of berries per cane were associated with lower berry weights in all cultivars. Component interactions ranged from slightly additive in 'Bluecrop' and 'Spartan' to highly compensatory in 'Rubel' and 'Berkeley'. The consideration of component interactions in cultivar trials may allow for the more accurate identification of desirable genotypes.

Introduction

In attempting to discover ways to maximize productivity of crop species, researchers have found it useful to separate yield into components. Engeldow (4) represented yield as the algebraic product of a small number of metrical components which were inter-related and highly "fluctible". Leng (9) found that the heritability of yield components was much higher than the heritability of total yield. Adams (1) demonstrated that negative correlations can develop among yield components as a result of competition for a limited environmental resource. Rasmusson and Cannell (11) reported that the efficiency of component selection for yield depended on the selected component.

Yield component analyses may be useful in blueberries. Not only could knowledge about the deployment of bush resources in different genotypes be useful for purposes of selecting breeding material, but such an analysis would also be helpful in developing pruning stratigies. In this paper, the components of total fruit yield and their interactions in mature blueberry bushes are explored.

Materials and Methods

Nine highbush blueberry cultivars established in 1966 at Grand Junction, Michigan were studied. The cultivars were represented by 3 plants per plot in each of 3 replications in a completely randomized design. The cultivars were selected on the basis of their commercial importance.

The planting was maintained according to established procedures (7). Plants were annually pruned by removing diseased and damaged canes and those greater than 2.5 cm in diameter. In the spring of 1981 and 1982, the canes of each bush were measured at 10 cm above ground level and the numbers of canes in 0.5 centimeter size classes were recorded. Ripe fruit was harvested by hand picking or by hand held shaker. When harvested by shaker, the fruit was sorted and the weight of undamaged, ripe fruit was recorded. Two pickings were made on each bush in each season. Berry weights, based on 100 gram samples and total yields were obtained for each bush. Berries per cane was calculated by dividing yield per bush by number of canes per bush and berry weight.

Similar data was collected in 1982, 1983 and 1984 from

3 commercial "Jersey" plantings near Holland and Fruitport, Michigan. Twenty four 3 bush plots were randomly selected from the outer 5-7 rows of each planting.

In order to determine the contribution of different sized canes to yield, a multiple regression for yield was performed using the numbers of canes in eight different 0.5 cm size classes as independent variables. The partial regression coefficients obtained for the different variables indicated that canes smaller than 1.0 cm in diameter made negative, but non-significant, contributions to yield. The coefficients for the size classes greater than 1.0 cm in diameter were all positive and significant ($p < 0.05$). By combining the larger canes into a single variable a simple predictor of yield was obtained. For the two years the equations were respectively: $Y = 3.047+0.502X$ ($r = 0.602$, $df=79$, $p < 0.01$) and $Y = 2.275+0.614X$ ($r = 0.588$, $df=79$, $p < 0.01$), where "X" is the number of canes larger than 1.0 cm in diameter and "Y" is yield in Kg. Making such a distinction on the basis of size seems reasonable because 1.0 cm is approximately the diameter at which canes begin to produce fruit. Throughout this analysis the component "canes" will refer to the number of canes greater than 1.0 cm in diameter.

The "W" statistic of Hardwick and Andrews (8) was calculated for each cultivar as a function of the variance-covariance matrix. This value quantified the overall relationship among components. Since no attempt was made to influence yield by applying treatments, it was not possible to use their tables to estimate confidence limits for the values of "W".

Path coefficients were calculated as a measure of the interrelationships among yield components (5, 6, 10, 12). To achieve additivity of the components, the data was logarithmically transformed and standardized to zero mean and unit variance (3). The data were analyzed using multiple regression to obtain standardized partial regression coefficients or path coefficients. The multiple regression equations were constructed in such a way that the coefficients obtained were valid according to the path diagram in Figure 1. In this diagram, yield is represented as the result of its components, berry weight, number of berries per cane and number of canes per bush. Unresolved variability for berries per cane and berry weight are represented by U_1 and U_2 respectively.

Results and Discussion

The cultivars varied significantly in their yield components (Table 1). Among the cultivars grown at Grand Junction, the number of producing canes per bush varied from 6.5 for 'Earliblue' to 11.1 for 'Blueray'. Berries per cane ranged from 274.3 for 'Spartan' to 626.1 for 'Northland'. 'Rubel' had the smallest mean berry weight at 1.41 grams, while 'Spartan' had the highest mean at 2.85 grams. 'Elliot' was the highest yielding cultivar with 10.43 Kg/bush and

Figure 1. Path diagram illustrating the relationships among yield and the components of yield assumed in this study.

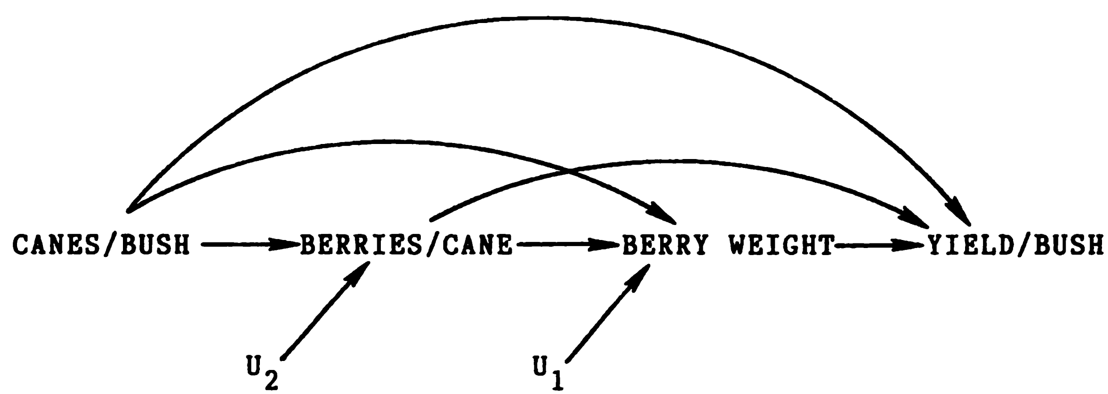

Figure 1

Table 1. Yield component means and degrees of component interaction (W) for 9 cultivars from research plots at Grand Junction Michigan and 3 commercial plantings of "Jersey".

Cultivar	W	Canes per Bush	Berries per Cane	Berry Weight	Yield per Bush
Berkeley	.175	7.5ab[z]	492.1abcde	2.57ab	8.71ab
Bluecrop	.545	9.5ab	345.5bcde	2.36abc	7.53ab
Blueray	.281	11.1a	296.4de	2.78a	8.66ab
Earliblue	.284	6.5b	554.1abcd	1.96c	6.40b
Elliot	.362	9.2ab	583.6abc	2.08bc	10.43a
Jersey	.190	9.7ab	334.3cde	1.92cd	5.48b
Northland	.237	7.3b	626.1a	2.05c	7.31ab
Rubel	.175	8.9ab	600.6ab	1.41d	6.23b
Spartan	.680	9.4ab	274.3e	2.85a	7.25ab
total[y]	.308	8.8	456.3	2.22	7.56
Jersey[x]	.257	21.3	257.2	1.15	5.11

[z]Means followed by the same letter are not significantly different at the $P < 0.05$ level by Duncans multiple range test.

[y]All data pooled except for that from the commercial "Jersey".

[x]Data from commercial plantings for 3 years.

'Jersey' had the lowest yield, 5.48 Kg/bush. The number of productive canes in the commercially grown 'Jersey' was much higher than those in the cultivar trials, while the number of berries per cane, berry weight and yield were all lower.

Since berry number per cane was calculated from berry weight and total yield, it was not possible to estimate the significance of the path coefficients between yield and berry number per cane, individual berry weight and canes per bush. However, canes per bush and berries per cane appeared to be more important in determining yield than was berry weight. The effects of cane number and berries per cane on yield were consistently higher, and often much higher than the effect of berry weight (Table 2).

The direct effects of berry weight and berries per cane on yield were very similar between the commercially grown 'Jersey'and those in the cultivar trial, although the direct effect of cane number on yield was much lower in the commercial planting. The lower correlation between cane number and yield in the commercial 'Jersey' indicated that the bushes may have been approaching or beyond the density of maximum production (2).

Berries per cane had a negative direct effect on berry weight in all cultivars, but the effect was significant in only four. In 'Earliblue' and 'Blueray', the direct effect of number of canes on berry weight was negative and significant, indicating compensation. This effect was positive and

Table 2. Correlation and path coefficients (p) of 9 cultivars from a cultivar trial at Grand Junction, Michigan and 3 commercial plantings of "Jersey". Subscripts are defined as follows: 1 = Yield. 2 = Berry Weight. 3 = Berries/cane. 4 = Canes/Bush.

	r_{12}	r_{13}	r_{14}	r_{23}	r_{24}	p_{21}	p_{31}	p_{41}	p_{32}	p_{42}	p_{43}[z]	U_1	U_2
Berkeley	.457	.466	.226	-.114	.082	.510	1.167	.970	-.106	.011	-.669[y]	.994	.743
Bluecrop	-.201	.731	.829	-.500	-.123	.207	.652	.681	-.499	.009	.266	.867	.974
Blueray	-.499	.555	.778	-.597	-.400	.354	.795	.944	-.610	-.419	-.031	.678	.999
Earliblue	-.458	.911	.405	-.467	-.667	.420	1.050	.582	-.405	-.627	.099	.646	.949
Elliot	.292	.395	.741	-.457	.207	.471	.740	.769	-.434	.134	-.169	.885	.985
Jersey	.042	.350	.603	-.580	.203	.463	1.075	1.000	-.615	-.078	-.456	.798	.890
Northland	.304	.130	.794	-.684	.596	.221	.790	1.047	-.517	.344	-.487	.726	.873
Rubel	.079	.452	.441	-.235	-.125	.469	1.099	1.057	-.402	-.329	-.508	.893	.861
Spartan	.199	.582	.931	-.456	.344	.138	.455	.767	-.585	.497	.261	.698	.965
total[x]	.083	.478	.685	-.480	.072	.429	.843	.819	-.484	-.023	-.195	.876	.981
Jersey[w]	.057	.806	.144	-.243	-.115	.393	1.109	.582	-.324	-.230	-.355	.932	.935

[z] $r_{34} = p_{43}$.

[y] Values underlined are significant at the $P < 0.05$ level or higher.

[x] All data pooled except for that from the commercial "Jersey".

[w] Data from commercial plantings for 3 years.

significant in 'Spartan' which implies that both number of canes and berry weight were responding in the same way to environmental variability.

The correlation between yield and cane number was positive for all cultivars. This correlation was significant for all cultivars except 'Earliblue', 'Berkeley' and 'Rubel'. The values for 'Berkeley' and 'Rubel' were reduced by the large negative indirect path through berry number. The low correlation for 'Earliblue' was due to the low direct effect of cane number on yield.

The correlation between berries per cane and yield was positive in all cases, but in general it was not as high as that between cane number and yield. This correlation was highest for 'Earliblue' because of the large direct effect of berry number per cane on yield and the relatively small negative indirect effects.

The correlation between berry weight and yield was quite variable, ranging from 0.45 for 'Berkeley' to -0.50 for 'Blueray'. The variability in this correlation appears to be due to the highly variable indirect paths through berry number per cane, and through cane number.

"W" values for most of the cultivars were below 0.5, indicating that they had a reduced ability to respond to favorable environmental conditions because an increase in one yield component was partially offset by a decrease in another yield component. Either the maximum yield potential of the cultivars was reached or some environmental resource was limiting. It is not known which resource could have been limiting - the planting was irrigated and fertilized regularly.

The "W" values for 'Bluecrop' and 'Spartan' were above 0.5 indicating additivity among the yield comoponents. It is interesting that these genotypes are now the most widely planted mid- and early-season cultivars in Michigan.

Conclusions

When evaluating the performance of highbush blueberry cultivars, researchers have generally recorded data on yield and berry size. By making use of one more easily obtainable datum, canes per bush, it was possible to identify significant compensatory interactions among components and to demonstrate variability among cultivars for such interactions. For example, cane number per bush and individual berry weight were negatively associated in 'Earliblue' and 'Blueray', but not 'Spartan'. The correlation between berry weight and yield ranged from 0.45 in 'Berkeley' to -0.50 in 'Blueray'. The consideration of component interactions may allow for the more accurate identification of desirable genotypes.

Literature Cited

1. Adams, M. W. 1967. Basis of component compensation in crop plants with special reference to the field bean, Phaseolus vulgaris. Crop Sci. 7:505-510.
2. Bunting, E. S. 1973. Plant density and yield of grain maize in England. J. Agric. Sci. 81:455-463.
3. Driscoll, M. F. and G. H. Abel. 1976. A correct logarithmic transformation for standardizing multiplicative trait variables. Crop Sci. 16:301-303.
4. Engledow, F. L. and S. M. Wadham. 1923 Investigations on yield in the cereals. Part I. J. agric. Sci. 13:390-439.
5. Hancock, J. F., J. H. Siefker and N. L. Schulte. 1983. Cultivar variation in yield components of strawberries. HortScience. 18(3):312-313.
6. Hancock, J. F., M. P. Pritts and J. H. Siefker. Yield components of strawberries maintained in ribbons and matted rows. Crop Res.(Hort. Res.) 1984. 24:37-43.
7. Johnston, S., J. Moulton and J. Hull Jr. 1969. Essentials of blueberry culture. Mich. St. Univ. Coop. Ext. Bul. E-590.
8. Hardwick, R. C. and D. J. Andrews. 1980. Genotypic and environmental variation in crop yield. A method of estimating the interdependance of the components of yield. Eyphytica. 29:177-188.

9. Leng, E. R. 1963. Component analysis in inheritance studies of grain yield in maize. Crop Sci. 3(1):187-190.

10. Li, C.C. 1975. Path Analysis - a primer. Pacific Grove: The Boxwood Press.

11. Rasmusson, D. C. and R. Q. Cannell. Selection for grain yield and components of yield in barley. Crop Sci. 10: 51-54.

12 Wright, S. 1934. The Method of Path Coefficients. Ann. Math. Stat. 5:161-215.

CHAPTER 4

PRUNING, PRODUCTIVITY AND VEGETATIVE GROWTH IN THE HIGHBUSH BLUEBERRY *VACCINIUM CORYMBOSUM* L.

Abstract

Bushes of _Vaccinium corymbosum_ (L.) 'Jersey' were pruned by removing 20 - 40% of either large, mature canes or young, medium sized canes. There were no significant differences in yield per plant, berry number per plant or individual berry weight between the treatments removing different sized canes. However, the proportion of basal area removed was negatively correlated ($P < 0.05$) with yield per plant in the first year due to reductions in berry number. This negative effect diminished over the next two years. Pruning had a significant positive effect on individual berry weight in the first and third years, and new cane production was significantly associated with the number of canes removed.

Introduction

Pruning is assumed to increase berry size and maintain long term productivity in the highbush blueberry (1,6,10). While pruning necessarily involves the removal of some bearing wood, this loss is thought to be compensated for by the increased productivity of the remaining wood. Unfortunately, there are only a few quantitative studies that substantiate these ideas. Johnston (6) performed pruning trials over 2 years on plantings of blueberry bushes taken from the wild. Moderately pruned bushes produced more fruit than either unpruned or heavily pruned bushes, but this effect could not be ascribed to pruning alone because competing trees and shrubs had been removed from the pruned plots but not from the unpruned, check plots. Brightwell and Johnston (1) found that mean yields in 10 year old bushes were lower for pruned than unpruned bushes, even though berry size increased with the severity of pruning. Howell et al. (5) observed that when large, unthrifty bushes were sawed off at ground level their yields surpassed those of unpruned controls by the third season of harvest.

The influence of pruning appears to be regulated by cane age and density. Shutak and Marucci (10) claim that cane productivity begins to decline after 6 years because older canes do not produce vigorous shoots, so berry size is reduced. Pritts and Hancock (9) determined that productivity in unpruned wild highbush blueberries peaked when the plants were approximately 20 years of age.

In this study, the effect of pruning was evaluated by removing varying amounts of different sized canes from unpruned 15-year-old 'Jersey' plants. Yield per bush, fruit number per bush, individual fruit weight and cane production per bush were measured.

Materials and Methods

Two adjacent rows of "Jersey" were studied at the Horticultural Research Center, Michigan State University, East Lansing. Bush spacing was 1 meter within rows and 3 meters between rows. The rows were divided transversely into 3 blocks, each containing 6 plots of 3 bushes. Bush size was estimated by measuring the diameter of all canes at 10 cm above the ground, calculating the cross sectional areas and summing them.

Several pruning treatments were applied: 1) no cane removal. 2) removal of the largest canes until 20% of the total base area had been removed. 3) as in treatment 2 but continuing until 40% of the total base area had been removed. 4) removal of canes 1 cm in diameter, followed by sucessively larger canes, until 20% of the total base area had been removed. 5) as in number 4 but continuing until 40% of the basal area was eliminated. 6) treatments 2 and 4 together amounting to a total of 40% of the basal area of the bush. Canes were cut as low to the ground as possible in the second and third weeks of May, 1981. The number of canes and the basal area remaining after pruning were recorded. Canes less than 1 cm in diameter were not removed because they made up only a small proportion of the basal area of the bushes and were considered unlikely to be exerting a major influence on yield (11).

In 1981, 1982 and 1983 the fruit was hand harvested and the gross weight was recorded for each bush. Two pickings were sufficient to obtain all but a negligible portion of the fruit. At each picking, a sample of at least 150 berries was taken from each bush. These samples were weighed and counted, and individual berry weights were calculated for each bush as the weighted average of the berry weights from the two pickings. Berry numbers per bush were estimated by dividing the yield of each bush by its individual berry weight.

In November 1983, canes were again measured and the increase in the basal area of each bush was calculated. The number of new canes produced was determined by subtracting the number remaining after pruning from the number present at the end of the experiment.

An analysis of covariance for yield, berry number and weight was performed on the data for each year using total base area as a concomitant variable. In addition, path coefficients (3,4,7,12) were calculated to determine the direct and indirect effects of bush size and pruning on yield per bush, berry number per bush and individual berry weight. Path coefficients were calculated using logarithmically transformed data (2).

The path diagram used is depicted in Figure 1. It assumes that berry number per bush is determined at an earlier developmental stage than is individual berry weight, so berry number can affect berry weight but berry weight cannot affect berry number. Because berry number was estimated from individual berry weight and yield per bush, tests of significance could not be used on the direct effect of berry number or berry weight on yield. However, the path coefficients

Figure 1. Path diagram outlining the relationships among yield, berry weight, berry number, basal area before pruning and proportion of basal area remaining after pruning.

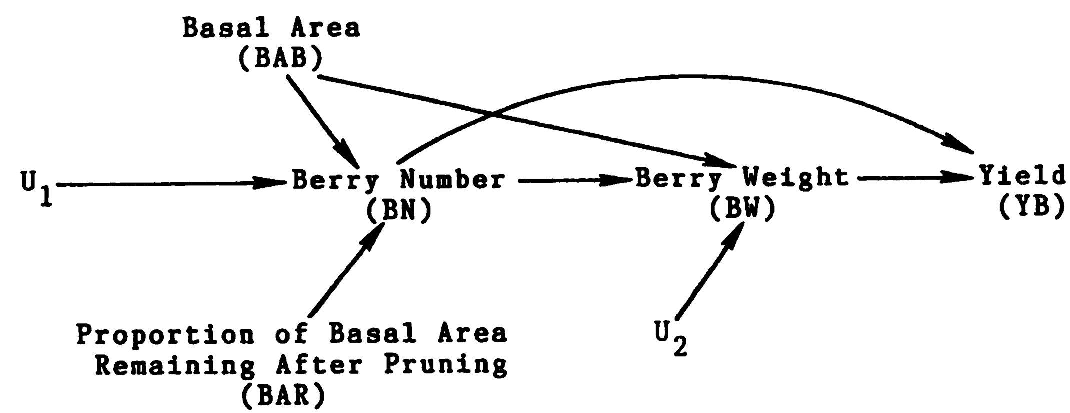
Basal Area
(BAB)
U_1
Berry Number
(BN)
Berry Weight
(BW)
Yield
(YB)
Proportion of Basal Area
Remaining After Pruning
(BAR)
U_2

Figure 1

between these variables still gave a valid estimate of the degree of relationship.

Results and Discussion

There was substantial variation among years in individual berry weight, berry number per bush and yield (Table 1). Individual fruit weight was highest in 1982, while yield and fruit number per bush were greatest in 1983.

Berry number was a more important determinant of yield than was berry weight. The path coefficients from berry number to yield were consistently near 1.0, while the path coefficients from berry weight to yield were 64-88% lower (Table 2). Pruning reduced yield in the first harvest season, as indicated by the significant positive correlation between yield and the proportion of basal area remaining after pruning (Table 1). Yields were not significantly correlated with degree of pruning in 1982 or 1983.

There were no significant differences in yield per bush, berry number per bush, or individual berry weight between the treatments removing different sized canes. This suggests that the total quantity of pruning was more important than the sizes of canes removed. It may be that our oldest canes were more vigorous than Marucci and Shutak imply, "Jersey" canes may age more slowly than the average. It is also possible that canes of an intermediate size are the most productive. The largest and smallest canes could then be

Table 1. Means of unpruned bushes across years.

Year	Individual berry weight (g/berry)	Berry number per bush	Yield per bush
1981	0.786	5187.8	3890.4
1982	1.191	1848.3	2178.3
1983	0.749	8029.4	6098.8

Table 2. Path and correlation coefficients between yield components of 'Jersey' bushes at East Lansing, Michigan. Basal area before pruning (BAB), Percent of basal area remaining after pruning (BAR), Individual berry weight (BW), Berry number per plant (BN), Yield per bush (YB). Unexplained variability in berry number and berry weight is represented by U_1 and U_2, respectively.

Correlation Coefficients	1981	1982	1983
BAR vs. BW	-0.32*	0.17	-0.44**
BAR vs. YB	0.28*	0.20	0.19
BAB vs. YB	0.74**	0.69**	0.77
BAB vs. BW	-0.13	0.04	-0.20
BN vs. YB	0.95**	0.99**	0.99**
Path Coefficients			
BAR to BW	-0.06	0.23	-0.41**
BAR to BN	0.34**	0.18	0.27
BAB to BW	0.40**	0.28	-0.11
BAB to BN	0.70**	0.70**	0.77**
BN to BW	-0.76**	-0.35	-0.12
BN to YB	1.11	1.00	1.05
BW to YB	0.30	0.12	0.19
U_1	0.79	0.74	0.75
U_2	0.70	0.73	0.64

* Significantly different from 0 at the 5% level of probability.

** Significantly different from 0 at the 1% level of probability.

reasonably equivalent in productivity.

Pruning reduced berry number per bush in the first year, as indicated by the significant correlation between berry number and the proportion of basal area remaining after pruning (Table 1). This relationship weakened in 1981 and 1982 and was not statistically significant. The values for U_1 listed in Table 1 indicate that about half of the variability in berry number in each year could not be accounted for by bush size and pruning severity.

Individual berry weight was increased by pruning in 1981 and 1983 as indicated by the significant negative correlation between berry weight and the proportion of the bush remaining after pruning. In 1982, all treatments had similarly sized large fruit. Berry numbers may have been too low in 1982 to affect berry weight.

In the first year, the increase in berry weight was largely due to the indirect path through berry number. That is, increased berry weight appeared to be related to the removal of fruit buds. Three years after pruning (1983), the increase in berry weight was largely due to the direct effect of pruning on berry weight, with only a minor contribution from the indirect path through berry number. This suggests that pruning promoted the production of more vigorous fruiting laterals.

Even though berry weight was strongly influenced by pruning severity, it was not correlated with total bush size in any year. The direct effect of basal area on berry weight was significant in 1981, but the effect of the indirect path through berry number acted to cancel it out. In 1983 both the direct and indirect effects were small. The values for U_2 indicate that slightly less than half of the variability for berry weight was not explained by bush size or severity of pruning.

New cane production was significantly associated with the number of canes removed (Figure 2). New canes are needed to replace old canes as they decline in vigor. However, too much pruning may over-stimulate new cane production and result in severe inter-cane competition and require extra pruning effort later. The length of this experiment was not sufficient to determine the level of pruning which is optimal for long term productivity. In particular, the contribution of new canes produced in response to pruning cannot be fully assessed until they reach maturity.

In conclusion, moderate pruning (20 - 40% of the basal area) appears to reduce yield in the first year, but it also increases fruit weight and may act to prevent an eventual decline in productivity by stimulating the production of new vigorous canes. Less severe levels of pruning need to be examined to determine if berry weights can be increased without decreasing yield.

Figure 2. Relationship between treatment mean number of canes removed and mean number of new canes produced. $Y = 1.19X + 1.68$ ($r=0.97$, $df=4$, $p<0.01$).

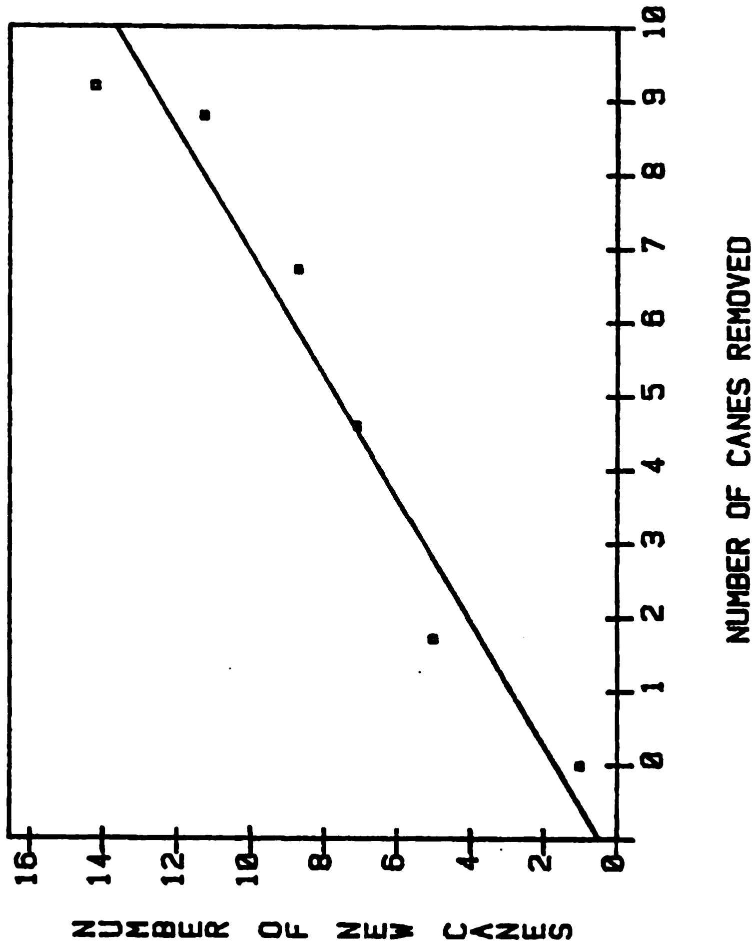
NUMBER OF NEW CANES
0
2
4
6
8
10
12
14
16
0
1
2
3
4
5
6
7
8
9
10
NUMBER OF CANES REMOVED

Figure 2

Literature Cited

1. Brightwell, W. T. and Johnston, S. 1944. Pruning the highbush blueberry. Mich. St. Coll. Tech. Bull. 192.

2. Driscoll, M. F. and G. H. Abel. 1976. A correct logarithmic transformation for standardizing multiplicative trait variables. Crop Sci. 16:301-303.

3. Hancock, J. F., J. H. Siefker and N. L. Schulte. 1983. Cultivar variation in yield components of strawberries. HortScience 18(3):312-313.

4. Hancock, J. F., M. P. Pritts and J. H. Siefker. 1984. Yield components of strawberries maintained in ribbons and matted rows. Crop Res. (Hort. res.) 24:37-43.

5. Howell, G. S., C. M. Hansen, H. C. Bittenbender and S. S. Stackhouse. 1975. Rejuvenating Highbush Blueberries. J. Amer. Soc. Hort. Sci. 100(5):455-457.

6. Johnston, Stanley. 1934. The Cultivation of the Highbush Blueberry. Mich. St. Coll. Special Bull. 252.

7. Li, C.C., 1975. Path Analysis - a primer. Pacific Grove: The Boxwood Press.

8. Nie, Norman H., 1975, Statistical Package for the Social Sciences. McGraw-Hill. p.p. 383-397.

9. Pritts, Marvin P. and J. F. Hancock. 1985. Lifetime biomass partitioning and yield component relationships in the highbush blueberry, vaccinium corymbosum (Ericaceae). Submitted A. J. Botany.

10. Shutak, V. G. and P. E. Marucci. 1966. Plant and fruit development. Blueberry culture. Rutgers University, New Brunswick, N.J. pp. 179-198.

11. Siefker, J. H. and J. F. Hancock. 1985. Yield component interactions in cultivars of the highbush blueberry *Vaccinium corymbosum* L. Submitted, HortScience.

12. Wright, Sewall. 1921. Correlation and Causation. J. Agric.Res. 20:557-585.

CHAPTER FIVE

CONCLUSIONS

The stability analysis demonstrated that blueberry cultivars respond differently to environmental variation. These differences were manifest in the variation of the regression coefficients of cultivar mean on environmental mean and in the presence of significant deviations from regression. Such information could supplement mean yield and season of production as criteria in choosing cultivars for commercial planting. It could also aid in the selection of breeding material.

Stability analyses are, of course, most valid when carried out over a range of environmental conditions that is representative of the area in which the crop is to be grown. While the data analyzed here came from a single site, cooperative planning of yield trials and the sharing of data by investigators in different areas could be very useful in selecting cultivars.

The yield component analysis showed that the cultivars varied not only in their yield components but also in the relationships among yield components. Most interactions between components were compensatory, but in a few cases they were additive or neutral. This variability could be exploited in a breeding program by using a relative lack of compensatory interactions among the components of yield as a criteria for the selection of parents. The "W" statistic could be used as a quantitative summary of component interactions.

The primary yield components all had positive direct effects on yield. The number of berries per cane and number of canes per bush had the strongest effect, while berry weight had the weakest effect. This suggests that cultural practices should focus on increasing canes per bush or berries per cane. Increasing the canes per bush will probably be most successful in cultivars like "Bluecrop" and "Spartan" in which increasing cane number does not appear to reduce the number of berries per cane.

Pruning caused a decrease in yield by reducing the number of berries. To provide an economic justification for pruning we must assume that there is a long term increase in yield which will eventually compensate for the short term reduction. Canes produced in response to pruning, having grown and matured under conditions of reduced competition, may be more vigorous and productive. Much of the beneficial effect of pruning would not be observable until the young canes that remain after pruning and new canes produced in response to pruning had reached full productivity (5-6 years).

Berry weight did increase in response to pruning. In the first year the increase resulted from the reduction in berry number. In the next two years the increase was not a direct result of decreased berry number but may have been due to a general increase in bush vigor. Increased berry weight is desirable for the fresh market and may ultimately result in yield increases if berry number returns to pre-pruning levels without affecting berry weight.

In summary, increasing yield in the highbush blueberry is a complex process. It cannot be assumed that cultural or genetic manipulations of individual yield components will have proportional effects on yield, because a change in one component is likely to cause compensating changes in other components. By understanding such interactions it may be possible to minimize losses of yield due to necessary operations, such as pruning, or to maximize yield without seriously reducing berry weight. The increasing cost of labor dictates that effort be expended as effectively as possible.