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Effects of Boron Nutrition upon Strawberry Yield Components

B.V. Neilson and G.W. Eaton

Department of Plant Science, University of British Columbia, Vancouver, B.C., Canada V6T 1W5

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Abstract. **Plants of everbearing strawberry (*Fragaria* X *ananassa* Duch. 'Quinault') were grown in solution culture with 0.01, 0.05, 0.25, and 1.25 ppm boron. Fruit developed abnormally on deficient plants, but there was no reduction in fruit weight. Where boron was insufficient, flower number per leaf, fruit set, or fruit enlargement limited yield but where boron was intermediate, leaf numbers limited yield. No single component limited yield at the highest level of boron.**

Table 1. Modified Hoagland and Arnon nutrient solution with boron treatments.

Macronutrients	Concn (m moles/liter)
$NH_4H_2PO_4$	1.0
KNO_3	6.0
$Ca(NO_3)_2 : 4H_2O$	4.0
$MgSO_4 : 7H_2O)$	2.0
NaCl	0.2
Micronutrients	(ppm)
Sequestrine (10% Fe)	1.0
$MnCl_2 : 4H_2O)$	0.25
$CuCl_2 : 7H_2)$	0.01
$NaMoO_4 : 2H_2O$	0.025
$ZnSO_4 : 7H_2O$	0.025
Treatment levels	
H_3BO_3	0.01
	0.05
	0.25
	1.25

Heavy leaching by coastal rains has made many of the coarse, sandy soils of the Pacific Northwest boron-deficient (12). Deficiency symptoms in strawberry are reduced vegetative growth and misshapen or "cat-faced" fruit, which is due to poor achene development and subsequently reduced tissue enlargement (8).

Excessive borax applications to the soil can produce toxic effects in the strawberry (10). Therefore, the effects of both boron deficiency and toxicity on the morphological components contributing to yield are of interest.

In a recent study, the number of crowns per hectare accounted for 50% of the yield variability in the strawberry 'Cambridge Favourite'. This model was concerned with yield per unit land area and did not explore the interactions of yield on a per plant basis. Components measured were crown number, truss number, berry number, and berry weight (11).

Yield component models were developed in the present study which expressed yield of the everbearing 'Quinault' on a per plant basis. The action of the components in shorter models under 4 levels of boron treatment was examined.

The experiment was a randomized, complete-block design with 12 blocks and 4 treatments and was conducted from May 14 to July 31, 1981 (77 days) in a greenhouse. One-year-old crowns were grown hydroponically in Hoagland and Arnon's nutrient solution (9) (Table 1). Boron treatment levels chosen were 1/25 and 1/5, one and 5 times the recommended rate of 0.25 ppm boron, reflecting a broad range of treatments (Table 1).

As berries ripened (75% red), they were harvested and weighed and achenes were counted. Leaf areas were determined electronically with a LI-COR model 3100 area meter.

The measured attributes and yield components (Table 2) were examined for treatment effect by analysis of variance (ANOVA). No significant treatment effect was detected. However, fruit grown at reduced boron levels frequently showed loosely attached achenes and "cat-facing", both symptoms of boron deficiency (8). Symptoms appeared on the aggregate fruit first because it requires more boron than the rest of the plant (3).

Sequential yield component analysis (SYCA) provides a measure of the contribution to yield made by morphological plant characteristics (5). These characteristics or their ratios represent yield components such as leaf number (L/P), fruit set (B/F), and berry weight per developed achene (Y/DA) (Table 2), which can be used to form a multiplicative model. Taking the natural logarithm of these ratios provides a model which is linear and additive, enabling regression analysis (6). Calculating the increase in R^2 contributed by each component as it is added to a multiple regression provides an estimate of the contribution of each variable to yield variability. Such increments in R^2 are additive and correspond to contributions of orthogonal independent variables.

Forward SYCA measures the independent contribution of a component to yield, possibly through effects upon later components, but after the effects of preceding components have been considered (4). The sequence is determined by the ontogenetic appearance of the components. The increase in R^2 added by the latest component measures its contribution to yield, and the successive estimates adding to unity or 100%, since all variability is accounted for.

The components of yield also were forced into the equation one at each step in reverse sequence. This is backward SYCA and measures the contribution of each component including any influence upon it by previous components (4). Thus, backward SYCA provides a cumulative measure of contribution to yield variability by each component and by all the previous components acting through them. If R^2 is zero for any component in backward SYCA, then that component's contribution to yield must only be through its indirect effects upon later components (4).

Data were analyzed by partitioning variation in yield (fresh berry weight in grams) according to the following models: 1) RW + C/RW + L/C + LA/L + LW/LA + I/LW + F/I + B/F + TA/B + DA/TA + Y/DA = Y, (forward SYCA); and 2) Y/DA + DA/TA + TA/B + B/F + F/I + I/LW + LW/LA + LA/L + L/C + C/RW + RW = Y, (backward SYCA).

Table 2. Measured and calculated attributes of individual strawberry plants.

Symbol	Attribute
n	No. of plants
Measured	
RW	Root mass, dry wt (g)
C	Crown no.
L	Leaf no.
LA	Leaf area (cm^2)
LW	Leaf mass, dry wt (g)
I	Inflorescence no.
F	Flower no.
B	Berry no.
TA	Total achene no.
DA	Developed achene no.
Y	Yield, fresh fruit wt (g)
Calculated	
C/RW	Crown no. per g of root
L/C	Leaf no. per crown
LA/L	Mean leaf area
LW/LA	Leaf mass per unit area
I/LW	Inflorescence no. per unit of leaf mass
F/I	Flowers per inflorescence
B/F	Fruit set
TA/B	Total achenes per berry
DA/TA	Proportion of developed achenes
Y/DA	Fresh berry wt per developed achene
F/L	Flowers per leaf
DA/B	Developed achenes per berry

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Table 3. Coefficients of determination (100 R^2) for yield component analysis of the long model of strawberry yield with combined treatments, n = 45.

Dependent variable	Independent variable[z] RW	C/RW	L/C	LA/L	LW/LA	I/LW	F/I	B/F	TA/B	DA/TA	Y/DA	Total
Forward analysis												
C/RW	49** −											49
L/C	0 −	11* −										11
LA/L	20**	14* −	0 −									34
LW/LA	0 −	6 −	32** −	8 −								47
I/LW	20** −	10	2 −	4 −	10 −							46
F/I	6	8 −	0	1 −	2	0 −						18
B/F	8	2	11* −	0 −	1 −	5 −	0 −					27
TA/B	3 −	24** −	0 −	8	1 −	2 −	3 −	3 −				42
DA/TA	1 −	2	5	3	0	2 −	2 −	11*	0			25
Y/DA	1	1	6 −	3	0 −	0 −	0 −	21** −	1 −	57** −		88
Y	9	2	27**	9	2	3	7	20*	2	15*	4	100
Backward analysis												
Y	10	0	5	7	0	11	11	20*	0	7	29**	100

[z]Notation as in Table 2. The signs are those of corresponding regression coefficients. Negative signs indicate component compensation.
* = $P < 5\%$, ** = $P < 1\%$.

Table 4. Coefficients of determination (100 R^2) for the forward analysis of the shorter model of strawberry yield with combined and per treatment analysis.

Treatment	Dependent variable	Independent variable[z] L	F/L	B/F	DA/B	Y/DA	Total
0.01 ppm boron n = 12	F/L	1					1
	B/F	10 −	13 −				23
	DA/B	4	11 −	13 −			28
	Y/DA	12 −	6 −	6 −	57* −		81
	Y	33	41*	8	14	4	100
0.05 ppm boron n = 12	F/L	67** −					67
	B/F	38*	3				42
	DA/B	11 −	2 −	43*			56
	Y/DA	15 −	0 −	41* −	38 −		95
	Y	32	5	50*	11	2	100
0.25 ppm boron n = 12	F/L	1					1
	B/F	22	2 −				24
	DA/B	3	6 −	31 −			40
	Y/DA	20	2 −	4 −	36 −		61
	Y	61**	18	0	15	6	100
1.25 ppm boron n = 9	F/L	14					14
	B/F	39	0 −				39
	DA/B	3 −	51* −	10			64
	Y/DA	7	38 −	19 −	14		77
	Y	32	45	11	4	8	100
Combined n = 45	F/L	14* −					14
	B/F	18** −	3 −				21
	DA/B	3 −	3 −	8			14
	Y/DA	4 −	1 −	16** −	62** −		83
	Y	34**	16**	24**	19**	6	100

[z]Notation as in Table 2. The signs are those of corresponding regression coefficients. Negative signs indicate component compensation.
* = $P < 5\%$, ** = $P < 1\%$.

Table 5. Coefficients of determination (100 R^2) for the forward analysis of the shorter model of final strawberry yield with combined and per treatment analysis.

Treatment (ppm boron)	n	Independent variable[z] L	F/L	B/F	DA/B	Y/DA	Total
Combined	45	34**	16**	24*	19*	6	100
0.01	12	33	41*	8	14	4	100
0.05	12	32	5	50*	11	2	100
0.25	12	61*	18	0	15	6	100
1.25	9	32	45	11	4	8	100

[z]Notation as in Table 2. Values are rounded to integers.
* = $P < 5\%$, ** = $P < 1\%$.

When 2 components are correlated negatively, compensation exists between them. Significant compensations between vegetative components occurred in the forward SYCA: between root mass (RW) and crown number per gram of roots (C/RW); between crown number per gram of roots and both leaf number per crown (L/C) and mean leaf area (LA/L); as well as between leaf number (L) and leaf mass per unit area (LW/LA) (Table 3).

Compensation between vegetative and reproductive structures occurred between the following components: root mass and inflorescence number per leaf mass (I/LW); and between crown number per gram of roots and total achenes per berry (TA/B) (Table 3). Thus, some vegetative structures appeared to have been produced at the expense of reproductive ones.

No component made a significant contribution to flowers per inflorescence (F/I) (Table 3). The number of flowers per inflorescence may have been determined by factors not represented in the model.

Crown number per gram of roots was correlated negatively with total achenes per berry (Table 3). Total achenes per berry is determined at the time of flower initiation and could be affected by the number of meristematic areas (crowns) that will initiate inflorescences (1). The negative association implied that competition among meristems limited formation of achenes.

B/F makes a positive contribution to achene development (DA/TA). Both of these components were correlated negatively with Y/DA. Therefore, increased fruit set results in more berries on the inflorescence, which may be responsible for less tissue enlargement per achene.

Because of the form of the models for an individual observation, and despite compensation, all components are necessarily correlated positively with yield of fresh fruit (Y) in the final analysis of yield but only 3 components made significant contributions to yield variability. L/C was the most important vegetative characteristic contributing to final Y in the forward analysis. It accounted for 30% of yield variability (Table 3). Fruit set and the number of developed achenes per berry also were important contributors to yield (Table 3).

In the backward SYCA, B/F and Y/DA made positive contributions to yield (Table 3) and previous components acted through them. Y/DA has been reported to be influenced by berry position on the inflorescence, tending to decrease as inflorescence position progresses from primary to quaternary (7). The role of Y/DA in the backward analysis indicates that the ability of an achene to stimulate tissue enlargement was more important than the number of achenes doing so on a given berry. Other researchers have found potential achene spacing to be a characteristic of a cultivar (2). There are less receptacle cells available for enlargement and lower auxin levels in berries lower on an inflorescence (2).

To examine each treatment separately, a

Table 6. Coefficients of determination (100 R^2) for the backward analysis of the shorter model of final strawberry yield with combined and per treatment analysis.

Treatment (ppm boron)	n	Independent variable^z L	F/L	B/F	DA/B	Y/DA	Total
Combined	45	25**	21**	21**	6	28**	100
0.01	12	33	62*	2	0	3	100
0.05	12	5	1	20	0	73**	100
0.25	12	13	48	13	16	10	100
1.25	9	11	12	31	33	13	100

^{z}Notation as in Table 2. Values rounded to integers.
* = $P < 5\%$, ** = $P < 1\%$.

shorter model was constructed. This model included those 5 components which contributed significantly to final yield in the long model (Table 2, 3, 4): 1) L + F/L + B/F + DA/B + Y/DA = Y, (forward SYCA); and 2) Y/DA + DA/B + B/F + F/L + L = Y, (backward SYCA).

Some differences in contributions to Y were realized when treatments were considered separately. In both the forward and backward SYCA at 0.01 ppm boron, flowers per leaf (F/L) was the most important contributor to yield variation (Table 5, 6). Since plants with greater flowering tended to have greater yield and the effect of flowering was not compensated by other components, other plants could have had greater yield if they had more flowers. Thus, yield was limited most by insufficient flowering.

B/F and tissue enlargement per achene (Y/DA) made a positive contribution to yield variation (Table 5, 6) at 0.05 ppm boron. Yield was limited by fruit set in the forward SYCA and fruit enlargement in the backward SYCA.

L/P made a positive contribution in the forward regression (Table 5, 6), but no single component contributed to yield in the backward SYCA with 0.25 ppm boron (Table 6). As vegetative growth was the limiting factor, the boron level of 0.25 ppm was adequate to support reproductive growth.

No single component made a significant contribution to yield with 1.25 ppm boron, in either the forward or backward SYCA (Table 5, 6). Three plants died in this treatment, decreasing the degrees of freedom for error and increasing the coefficient of determination required for significance to 50%.

In summary (Table 5), boron deficiency was most strongly manifested in the reproductive structures, making these the components which limited yield at low boron levels. With intermediate boron, however, leaf number rather than reproductive vigor limited yield. No single component at higher boron levels was limiting to yield. We found no differences in mean Y between treatments but deficient plants produced unattractive berries with loosely attached achenes. Thus, boron deficiency affected fruit quality before it affected fruit yield. Fruit enlargement due to tissue growth per achene was the most important contributor to yield. This characteristic depends upon both cultivar and berry position (2, 7).

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Time of Pruning and Bloom Date in Cultivated Highbush Blueberry

R.E. Gough
Department of Plant Science, University of Rhode Island, Kingston, RI 02881

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Abstract. **Mature bushes of several cultivars of highbush blueberry (*Vaccinium corymbosum* L.) were left unpruned or pruned on September 16, November 15, and February 15 in each of 3 years. Plants left unpruned usually reached full bloom first. Plants pruned in September usually attained full bloom last, while those pruned in February bloomed earliest, shortly after those that were not pruned. Pruning resulted in an average delay in full bloom of from 0–5 days.**

Brierley (2) working with apples, and Gladwin (3) with grapes, reported that there was little or no effect of pruning time on subsequent growth of the plant. However, Bioletti (1) reported that vinifera grape vines pruned immediately after leaf-fall started growth about 4 days earlier in the spring than those pruned in mid-winter. Those pruned in late spring were delayed about 6 days. The later that the vines were pruned, the later vegetative growth and blossoming developed. The observed delay in growth was considered of commercial importance for reducing frost damage in California.

The highbush blueberry sometimes sustains frost damage during bloom. This study was initiated to determine the effect of time of pruning on time of bloom of the cultivated highbush blueberry.

This study was conducted over a 3-year period at the Rhode Island Agricultural Experiment Station plots at East Farm, in Kingston, using 'Earliblue', 'Collins', 'Blueray', and 'Bluecrop' in 1979–1980; 'Bluetta', 'Collins', 'Bluecrop', and 'Darrow' in 1980–1981; and 'Bluecrop', 'Darrow', and 'Lateblue' in 1981–1982. All plants in all years were pruned according to standard practice (4).

In all years, 3 plants of each cultivar were pruned in mid-September, 3 in mid-November, and 3 in mid-February. These dates roughly corresponded to those of rapid flower-bud formation, leaf discoloration and abscission, and completion of rest requirement, respectively. The date at which plants of each treatment reached full bloom each year was determined. Full bloom here is defined as the stage at which the first corollas begin to fall. All plants were grown on a Bridgehampton fine sandy loam soil at a pH of 5.0 under a sawdust mulch and received an annual application of 1 kg of 5N-4.3P-3.8K.

Plant response to pruning varied among

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