AN ABSTRACT OF THE THESIS OF

George M. Scott for the degree of Master of Science in Horticulture presented on June 19, 1984.

Title: Strawberry Fruit Quality as Affected by Soil pH, Phosphorus, Spring Applied Nitrogen, and Time of Harvest.

Abstract approved: [signature]

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Strawberry cvs. Totem, Hood, Benton, and Olympus were grown in a Willamette silt loam at soil pH's of 5.6, 5.9, 6.2 and 6.4; Totem and Hood with and without spring applied N, Benton and Olympus with and without preplant banded P. Berry samples from early, mid-season and late harvests were analyzed for Brix, pH, firmness and anthocyanin.

Totem and Hood quality parameters were not significantly different among soil pH treatments. Fruit pH and Brix of Hood were significantly increased 3.1% and 4.6%, respectively, by spring applied N. Totem showed an overall decrease in firmness (measured by resistance to puncture) from 2.55 to 2.45 Newtons during the season. Fruit pH decreased from 3.5 to 3.3. Brix increased from 6.9 to 10.3%. Anthocyanin concentration increased from 41.0 to 43.3 mg/100 g fruit. Drip loss decreased from 62.3% to 42.9%. Berry size decreased from 13.8 to 11.6 g/berry. Hood showed an increase in firmness as the season progressed from 1.64 to 1.95 Newtons. Fruit pH decreased from 3.7 to 3.4. Brix increased from 7.4 to 9.2%. Anthocyanin concentration decreased from 56.0 to 44.9 mg/100 g fruit. Changes in drip loss were not significant. Berry size decreased from 14.6 to 11.7 g/berry.

Olympus responded to soil pH differences producing berries 5.5% firmer at pH 6.4, compared to pH 5.6, 5.9, and 6.2. Neither Benton nor Olympus showed differences in yield with soil pH levels. Firmness of Benton berries was 3.6% greater with added phosphorus but Olympus firmness was 4.5% less. Increased anthocyanin (from 31.7 to 32.8 mg/100 g fruit) and fruit pH (from 3.2 to 3.3) were also observed from phosphorus treatment of Olympus. Firmness of Olympus berries decreased from 2.36 to 2.01 Newtons as the season progressed. Fruit pH decreased from 3.3 to 3.2. Brix increased from 6.7 to 8.3%. Anthocyanin concentration decreased significantly mid-season dropping from 32.3 to 31.6 and increasing to 32.2 mg/100 g at the end of the season. Drip loss increased from 56.2 to 64.4%. Olympus berry size decreased from 11.9 to 10.2 g/berry. Benton berries increased in firmness through the season from 1.68 to 1.97 Newtons. Fruit pH decreased from 3.4 to 3.3. Brix increased from 7.9 to 10.3%. Anthocyanin concentration decreased from 31.49 to 28.10 mg/100 g fruit. Drip loss did not change signficantly, maintaining 64% throughout the season. Berry size decreased from 14.8 to 11.1 g/berry..

Strawberry Fruit Quality as Affected by Soil pH, Phosphorus, Spring Applied Nitrogen, and Time of Harvest

by

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REVIEW OF LITERATURE

Influences of Maturity

Brix

Soluble sugars increase steadily during development and ripening of strawberry (56). Spayed and Morris reported an increase in Brix of 5.0 to 7.2 from the immature green to the ripe stage (47). Maximum sugar content is obtained with ripe fruit (38) but does not increase during senesence and may even decrease (12). Several workers have reported means for Brix ranging from 5.5% to 11.6% for ripe berries of several cultivars (12, 15, 38, 41, 45, 56).

pH

Changes in pH in a ripening strawberry are not as distinct as are the changes in Brix. Both increases and decreases in pH have been observed (12, 41, 45, 56). Spayed and Morris (47) reported a rise in pH of 3.3 to 3.5 from the inception to the ripe stage. Reported means for juice pH range from 3.00 to 3.81 for several cultivars evaluated (45, 55, 58).

Anthocyanin

Dramatic increases in anthocyanin (acn) concentration are seen 35 days after petal fall (56). Woodward (56) observed that at least 75% of the acn in strawberry fruit is produced within a 7 day period prior to ripening, measuring a change in acn content from 5 to 80 g acn/g fresh weight during this period (56). Chlorophyll concentration declines rapidly until 28 to 35 days after petal fall. Carotenoid content falls less rapidly and both chlorophyll and carotenoid pigments reach very low levels in ripe fruits (< 5 g/g fresh wt.).

Firmness

Firmness (measured by puncture and shear press) decreases steadily as the fruit matures from the white stage until ripe (3, 12, 45). Sistrunk and Moore reported differences in shear-press measurements of 108 to 74 lb between "light" and "dark" berries (45).

The Influence of Time of Harvest

Brix

An average increase in Brix of 9% was observed in berries ripening at different times throughout the season (27, 41, 43, 44). Yet results from Sistrunk and Moore (45) showed Brix to decrease 6% in their work with several cultivars.

pH

Sistrunk and Moore (45), working in Arkansas, observed an increase in pH from 3.28 to 3.31 over the season while Shoemaker and Greve (41), in Ohio, found that pH decreased mid-season then rose to higher pH at the end of the season than was observed at the first picking.

Anthocyanin

Results of work by Sistrunk and Moore (45) show a decrease of 12% in color rating of strawberry fruit as the season progressed. In another study (44) they reported that a delay in harvest increased redness and darkness of frozen strawberries. Berries harvested later in the season received better color ratings than did fruit harvested early.

Firmness

Berry firmness throughout the season is quite variable and generally inconsistent (10, 27, 41, 42, 43, 45). Cochran and Webster (10) and Sistrunk (43) found fruit to be approximately 24% softer in the latter part of the season.

The Influence of Fertilizer

Brix

Haut (22) found slightly higher (4.2%) total sugars in berries from lower N treatments compared to 4.0% for higher N. Martin Del Molino (33) and Shoemaker and Greve (41) found supporting results. But Sistrunk (43) and Degman (15) reported increases in Brix of 12% from N and K treatments. Kimbrough (27) reported similar results with generally higher reducing sugars (3.45 to 3.61% fresh wt.) with N, P, and K compared to a control of 3.27.

pH

Shoemaker and Greve (41) found that the pH of juice from N plots were consistently higher than from check plots. Nitrogen treated berries were, on the average, 2.4% less acid throughout the entire picking season.

Firmness

Most workers report no significant differences in berry firmness associated with different fertilizer treatments. Haut (22) speculates that any obvious differences in firmness may be a result of differences in fruit temperature at testing, and not related to fertilizer treatments. Sistrunk (66) and others (41, 52) report firmness of fresh fruit from plots which received spring N to be 3% softer, but the differences were not statistically significant. Although firmness of fresh fruit is a good criterion for judging firmness of the frozen/thawed fruit, differences due to fertilizer treatment are more difficult to detect on the fresh fruit than on the frozen/thawed fruit (66).

Overholser and Claypool (36) found that berries from check plots gave 12% higher firmness readings. Using N, P, or extra N treatments in any combination resulted in softer fruit, particularly the extra N.

Darrow (13) noted little difference in berry firmness between different fertilizer plots. Although finding no statistically significant results, he observed that nearly all complete fertilizer plots showed greater firmness than the control. In addition, where leaf growth was least the berries were firmest (2.1% firmer than control), and where leaf growth was greatest the berries were softest (2.3% softer than control).

Yield

Waltman (52) reported that with seven cultivars, all but one showed a reduction in yield from spring application of N when compared to unfertilized plants. The average reduction in yield was 26.7%. He also observed a 29.8% reduction in yield with a split application of N. Only N applied in the fall was found to be beneficial. Waltmans research also showed that a N application of 60 lb/acre gave highest yields. Higher application (100 and 140 lb/acre) caused excessive plant growth and lower yield.

Work done by Kirsch (28) showed that N increased yields 11% only when P was not applied, and P increased yields 14% only when N was not applied. The increase in yield when both P and N were applied was not as great as the additive increase in yield when each was applied without the other. Kirsch also saw a consistent tendency for spring and split (fall and spring) applications of N to decrease yields. Yet, at another location, he observed that N increased yield regardless of time of application (28).

Hartman, White-Stevens and Hoffman (20) found that fertilizing strawberries with urea at 52 lb/acre was definitely disadvantageous and as a result, yields were reduced by 19% when compared to a control.

The Influence of Liming and Soil pH

Growth and Yield

Lime can be injurious if used in amounts sufficient to bring the soil to neutrality (32). In New York lime hindered runner formation in most cases and on certain soils growth was reduced and yields were correspondingly smaller following lime application (28). Responses to lime are strongly influenced by other soil additions such as organic matter, P and K.

Kirsch (28) noted that the magnitude of response to P was influenced by lime treatment. The yield-depressing effect of lime was barely significant where P was not applied, depressing yield by 9%, but highly significant where P was applied, depressing yield by 16%. This P-lime interaction was not observed, however, in a similar experiment at a different location.

Beneficial results were reported from the use of hydrated lime in Rhode Island. Baker and Mortensen (2) found that yield of Grade-1 plants was significantly improved 25% and that maximum plant yield was obtained by liming to reach a soil pH between 5.2 and 5.5 (2). Berry yields, however, were not significantly affected.

Linneberry et al. (31) found that one ton of limestone per acre on new land significantly increased yield by 33% over no limestone. This increased the soil pH from 4.42 to 4.75. Two tons did not increase yield over one ton, increasing pH from 4.75 to 5.30. They suggested that since the limestone was applied in a zone 5-6 inches deep, one ton satisfied the requirements of strawberries in that zone for that year. Since Ca is rather immobile, the effects of limestone were confined to a 5-6 inch root zone. Below the 6-inch depth, the pH was 4.42, and there was no root penetration into this zone. This substantiates the findings of Linneberry which indicate that strawberries will not live in a medium below a pH of 4.5 (31).

Each soil has its own optimum pH for best growth of strawberry. Cooper and Vaile (11) found the growth of strawberry plants in two very acid soils to be favorably affected by the addition of lime, resulting in a pH of 5.2 and 6.4 as the soil pH for best growth in two respective soils.

Hester (23) reported that the lowest soil pH for good strawberry growth was pH 4.6, 4.9, and 5.8 for three respective soils. He also noted that the point at which good growth was markedly retarded was directly correlated with the appearance of Al in the drainage water. The addition of organic matter, in the form of peat moss, suppressed Al solubility at low pH values and enabled crops to grow more satisfactorily than in untreated soils.

Lime studies in Arkansas (34) showed a significant reduction in yields if the pH was below 6.0. But similar work in Michigan, in a field ranging in pH from 4.9 to 6.2, showed no significant relation between soil pH and yield.

Brooks (8), in Florida, found optimum soil pH for strawberry growth was approximately 5.5. Good growth was observed between pH 5.0 and 6.0. And, typically, optimum pH varied considerably from field to field, according to the amount of organic matter present.

Other Factors Influencing Fruit Quality

Berry size, temperature, weather and location have all been observed to influence strawberry fruit quality. Small berries have a higher dry weight, and this correlates with high firmness (13, 19). Darrow (13) noted the difference in firmness tests of small and medium sized berries to be consistent and sufficient to be significant. Others (10, 40, 45) feel that the humidity or rainfall at or just prior to picking has much to do with the firmness of the berry. Haut (22) suggests that differences in berry temperature may be responsible for differences in firmness tests. Kirsch (28) observed several differences in berry size, soluble solids, and moisture content measurements between locations and cultivars.

STRAWBERRY FRUIT QUALITY AND YIELD AS AFFECTED BY SOIL pH AND SPRING APPLIED NITROGEN

Abstract

Strawberry cvs. Totem and Hood were grown in a Willamette silt loam at soil pH's 5.5, 6.0, 6.3 and 6.5, with and without spring applied N. Analyses of firmness, pH, Brix and anthocyanin concentration were made from samples of three harvests. None of these quality parameters measured in either cultivar were significantly different among soil pH treatments. Spring applied N increased fruit pH by 3% and increased Brix by 4.6% when compared to a control. Totem showed an overall decrease in firmness (measured by resistance to puncture) from 2.55 to 2.45 Newtons during the season. Fruit pH decreased from 3.5 to 3.3. Brix increased from 6.9 to 10.3%. Anthocyanin concentration increased from 41.0 to 43.3 mg/100 g fruit. Drip loss decreased from 62.3% to 42.9%. Berry size decreased from 13.8 to 11.6 g/berry. Hood showed an increase in firmness as the season progressed from 1.64 to 1.95 Newtons. Fruit pH decreased from 3.7 to 3.4. Brix increased from 7.4 to 9.2%. Anthocyanin concentration decreased from 56.0 to 44.9 mg/100 g fruit. Changes in drip loss were not significant. Berry size decreased from 14.6 to 11.7 g/berry. Yield was not significantly affected by soil pH or spring applied N.

Introduction

Most soil pH and fertility studies were conducted years ago and on cultivars that are no longer in production (1, 4, 7, 8). Few of those older studies were performed in Oregon. Many did not address the question of their effects on fruit texture and color (1, 7, 9, 15), two major concerns of strawberry processors.

The superior quality of Oregon's strawberries is largely attributed to the cultivars grown and the mild marine-like climate of the Willamette Valley. The effects of cultural practices and local microclimate on quality components of processed fruit are not well defined. The purpose of this study was to measure the effect of soil pH (5.3 to 6.7), with and without spring applied nitrogen, on quality and yield of 'Totem' and 'Hood' cultivars.

Materials and Methods

Totem and Hood strawberries were grown in a split-plot split-block arrangement with four soil pH levels, with and without spring applied nitrogen. The experiment was conducted at the North Willamette Experiment Station during 1983 and included four replications.

Soil pH and Nitrogen

Soil pH was altered by using one sulfur treatment and two lime treatments. Plots were established in 1969 using elemental S at 2.25 MT/ha and agricultural limestone flour (95% $CaCO_3$ equivalent, less than 0.7% $MgCO_3$) at 0, 9.0, and 18.0 MT/ha. Plots were maintained using vegetable trials until May 6, 1982 when this current strawberry project was planted. Plots consisted of a 13.7 meter row with only the center 7.6 meters planted with 20 plants at 38 cm spacings. Plots were split to receive either a spring N (Urea, 38% N) application of 34 kg N/ha on April 15, just prior to full bloom, or to receive no spring N.

Soil pH was measured from four combined samples taken on the last day of June from within each row using a 15 cm soil probe. Twenty grams of soil were mixed with 40 ml distilled water and allowed to sit for 15 min. The soil was again stirred and after sitting another 15 min. the pH was measured using a Beckman glass electrode pH meter.

Sampling

Berry samples were taken three times during the season at 7-10 day intervals beginning June 3. Ten berries from each treatment were selected for uniform color and size. The fresh weight of the sample was used to determine mean berry weight.

Firmness

Firmness of the fresh berries was tested immediately after picking using a U.C. Davis penetrometer with a 0.5 cm plunger tip. Four measurements were made on the shoulder of each of five berries, two measurements with skin intact and two with skin removed. These measurements are reported as skin firmness and flesh firmness, respectively. The berries were then frozen for further analysis.

Drip Loss

Five uncapped uniform berries from each plot were individually quick frozen (IQF). These IQF berries were stored in a commercial freezer locker and transferred to OSU Food Science Department and held at -20°F prior to analysis. Each IQF sample was weighed then placed in a funnel over a graduated cylinder to thaw. A piece of screen placed under the berries prevented the funnel from being plugged. After ten hours the berries were again weighed and the ml of dripped juice recorded.

The berries and juice from the drip loss were added to the thawed samples used in the fresh firmness measurements and were blended for 15s in a 250 ml beaker using a hand-held Bamix blender (ESGE AG, 9501 Mettlen, Switzerland).

Brix

Soluble solids of the homogenate was determined using a hand held ATAGO refractometer.

Berry pH

The pH of the homogenate were measured directly using a glass electrode pH meter.

Anthocyanin

From the stirred homogenate, 1.0 g was weighed into a centrifuge tube and blended for 10s in 25.0 ml acid-ethanol (15:85; 1.5 N HCL:95% ETOH). After centrifuging at 2500 Xg for 20 min., 3.0 ml supernate was mixed with 10 ml of solvent (acid-ethanol). The absorbance of this solution was measured at 515 nm (wavelength of maximum absorption of pelargonidin-3-glucoside pigment) in a single beam spectrophotometer.

The determination of acn content is based on Lambert-Beer's laws: $A = \epsilon CL$ (19). A = absorbance; ϵ = molar extinction coefficient; C = molar concentration; L = pathlength (cm). Concentration in mg/liter was determined by multiplying by the molecular weight (MW) of the pigment. (MW of PGD - 3 - glucoside is 433.2)

$$C_{(mg/l)} = \frac{A}{EL} \times MW \times 10^3$$

Multiplying C by the dilution factor (liters/g) converts units to mg Acn/g fruit (19). Results are reported per 100 g fruit.

Leaf Analysis

Leaf samples collected the last week in June were analyzed for N, P, K, and Ca at the Plant Analysis Lab, Department of Horticulture, Oregon State University.

Results and Discussion

Influence of Soil pH

Quality parameters in either Totem or Hood showed no significant differences among soil pH treatments. Few studies are reported of the influence of soil pH on strawberry quality. Most works report results of yield and growth. Yield of Totem increased from 3.9 to 4.9 T/A with a rise in soil pH, though not significantly. Lineberry (11) observed an increase in yield of 1,442 to 2,160 quarts per acre by increasing soil pH from 4.42 to 4.75.

Influence of Spring Nitrogen

Increases in fruit pH of .072 and .037 and in Brix of 0.3 were observed by spring N treatment of Hood (Figure 1.1 and 1.2). Similar responses to N were observed by Sistrunk (15), Degman (5), and Kimbrough (8) for Brix and Shoemaker and Greve (14) for berry pH.

Influence of Time of Harvest

Firmness, fruit pH, Brix, anthocyanin concentration, drip loss and berry size in both Totem and Hood showed significant differences ($P < 0.0001$) among harvests (Figures 1.3 and 1.4), except for drip loss in Hood.

Firmness of Totem and Hood did not follow the same trend over the season. Hood increased in firmness from 1.64 to 1.95 Newtons. Firmness of Totem decreased mid-season from 2.55 to 1.95 Newtons and rose to 2.45 at the last harvest. Similar results have been observed by others (3, 8, 15, 17). Fruit pH decreased in Totem from 3.5 to 3.3, and in Hood from 3.7 to 3.4. Sistrunk and Moore (17), working in Arkansas, observed an increase in pH from 3.28 to 3.31 over the season.

Brix increased in Totem from 6.9 to 10.3% and in Hood from 7.3 to 9.2%. Several researchers have found supporting results observing a rise in Brix of approximately 9% during the season (8, 14, 15). Yet results from Sistrunk and Moore (16) showed Brix to decrease by 6% in their work with several cultivars.

Anthocyanin concentration decreased steadily in Hood from 56.0 to 44.9 mg acn/100 g fruit. Anthocyanin in Totem increased mid-season from 41.0 to 47.6 and dropped to 43.3 mg acn/100 g fruit by the late harvest. Sistrunk and Moore report conflicting results in seasonal changes of strawberry color (15, 16). One study reported a 12% decrease in color ratings as the season progressed. In another study they reported that berries harvested later in the season received better color ratings than did fruit harvested earlier. (No association was made, however, between color rating and anthocyanin concentration.)

Drip loss of Totem decreased from 62% to 42% during the season. Drip loss in Hood increased slightly, but not significantly, from 61% to 62%.

Berry size decreased in Hood from 14.5 to 11.7 g/berry and in Totem from 13.8 to 11.6 g/berry.

In view of the significant affects of harvest time on quality, in the context of this experiment, time of harvest was the single most important independent factor influencing quality of strawberry.

Interactions

Several significant treatment interactions among treatments were seen with both Totem and Hood (Tables 1.1 and 1.2).

Totem

Totem berries had significantly firmer flesh in soil with pH 6.45 at first harvest. Later harvests had significantly softer fruit. This difference among firmness measurements accounted for 71% of the variation among soil pH treatments. Little work has been done on the effects of lime and soil pH on strawberry quality. Most work reported has dealt mainly with yield and growth response (2, 9, 10, 11).

Skin firmness was highest in the early harvest in soil with pH 6.45. While these berries gave the highest readings, comprising 36% of the variance, berries grown in soil at pH 6.00 gave the lowest readings, comprising 57% of the variance.

It is generally believed that the amount of juice that drips from a thawing berry has a negative correlation with berry firmness. Berries showing relatively low percent drip loss should be relatively firmer. Sistrunk and Moore (16), working with sugared fruit, found shear-press values to relate to drained weight in some cultivars. They report increasing percent drainage weight with decreases in shear-press readings and that these weights increased over the season.

Drip loss decreased at soil pH 5.55 at the end of the season, dripping 22% less than fruit from other treatments. Drip loss was also influenced by N, showing significant differences at all three harvests. In the first two harvests, N treated berries dripped less than check berries. The reverse occurred at the third harvest.

Hood

Skin firmness of Hood strawberries showed signficant differences between N treatments at soil pH 6.45. Check plot berries were firmer than N treated berries ($P < .05$). Differences in skin firmness were observed among soil pH treatments with berries receiving N, though not protected with a significant F value from analysis of variance.

Differences in acn concentration were observed among soil pH levels during mid-season. The highest concentration of acn was found in berries grown in soil pH 6.45, averaging a 16% increase over the other treatments.

Drip loss was significantly different between N treatments in the lowest pH soil (5.9). Berries receiving N dripped considerably more than check berries.

Three significant interactions were found in flesh firmness of Hood. Two involve N and soil pH. Differences among soil pH treatments within the N check plots were significant at the .05 level, the softest readings being from berries grown in soil of pH 6.30. The deviation of this treatment accounted for 61% of the variance among pH treatments. The second interaction was between N treatments of the same soil pH (6.30). Berries receiving N were considerably firmer ($P = .025$).

The third flesh firmness interaction was influenced by N and harvest. Differences occurred between N treatments in both the early and late harvests (significant at 0.05 and 0.025, respectively). Berries receiving N were firmer in the early harvest while berries receiving no N were firmer in the late harvest.

Simple correlation coefficients show significant association between skin firmness and flesh firmness for both Totem and Hood. Although the skin firmness is a good criterion for judging the firmness of the flesh, neither fresh firmness measurements were significantly associated with the firmness of the frozen berry (drip loss), except flesh firmness of Totem.

Correlation and analysis of variance of leaf analysis results for N,P,K, and Ca revealed no significant association with any quality parameters measured.

Neither Totem nor Hood responded to differences in soil pH in any significant manner. And only Hood was significantly affected by spring N, showing increased Brix and fruit pH. Notable changes in quality parameters occurred as the season progressed. Changes in quality affecting factors (berry size, temperature, humidity, rainfall, nutrient availability) also occur during the season and can significantly influence fruit quality. In retrospect, any or all of these factors could be responsible for quality changes over time. A non-statistical review of weather records found temperature, humidity, and rainfall patterns to be inconsistent with changes in quality parameters, particularly firmness. It is the authors opinion that berry size may be the most influential of them all. But time of harvest was used in this experiment, and as such was the most influencing factor affecting strawberry quality.

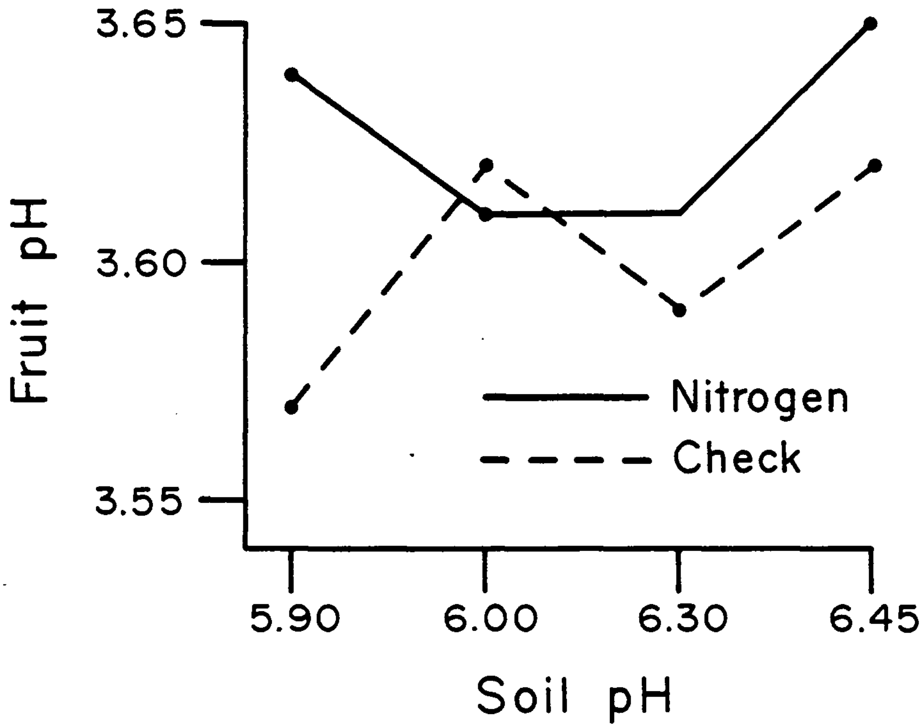

Figure 1.1. Changes in fruit pH of Hood strawberry as affected by soil pH and spring applied nitrogen.

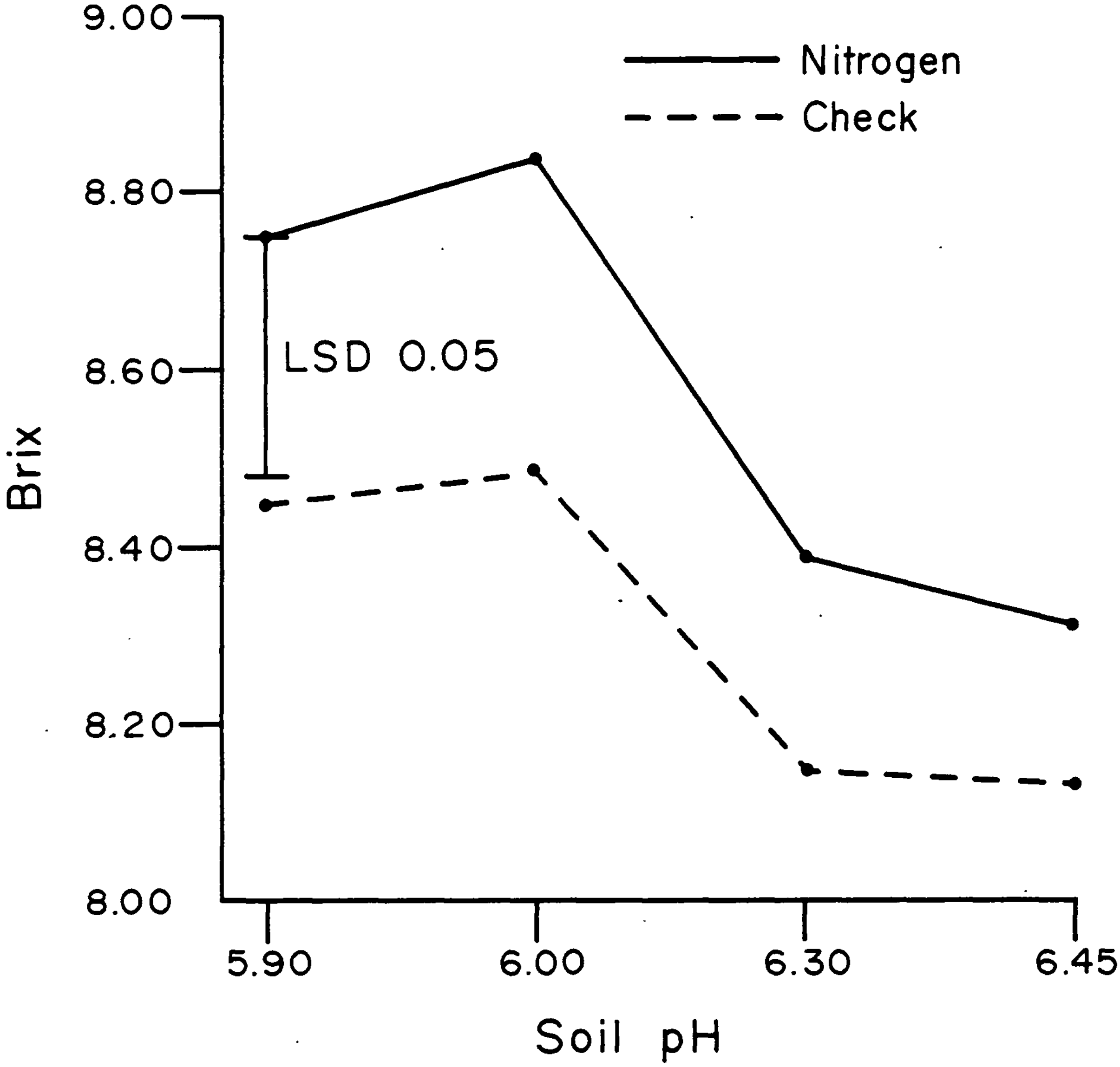

Figure 1.2. Changes in Brix of Hood strawberry as affected by soil pH and spring-applied nitrogen.

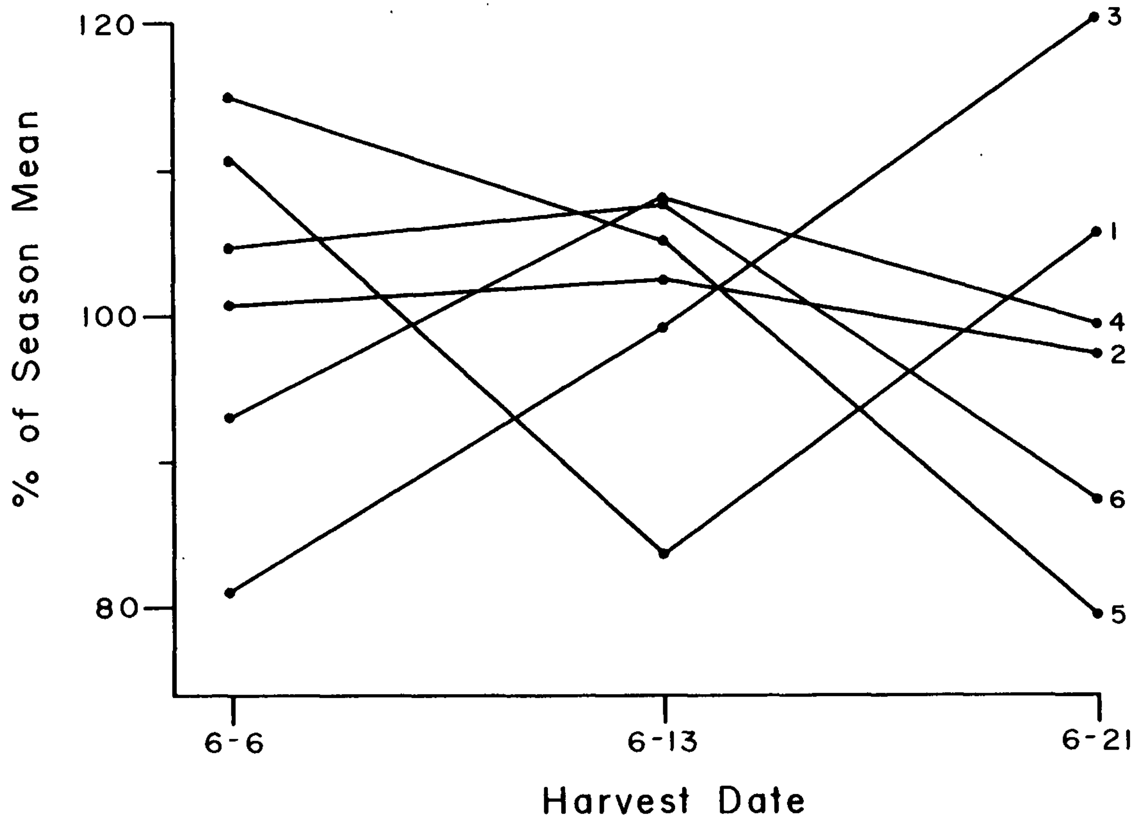

Figure 1.3. Seasonal changes in fruit quality of Totem strawberry for three harvests. 1=fresh firmness, 2=fruit pH, 3=Brix, 4=anthocyanin, 5=drip loss, 6=berry size.

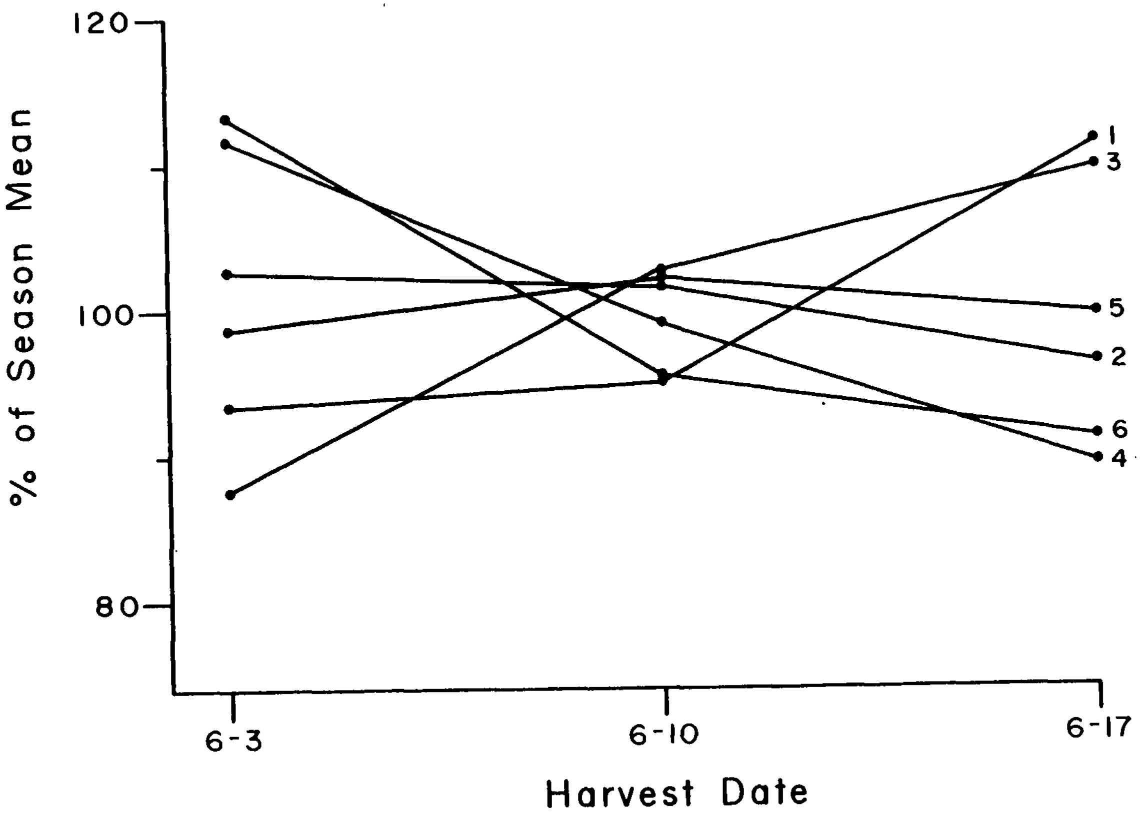

Figure 1.4. Seasonal changes in fruit quality of Hood strawberry for three harvests. 1=fresh firmness, 2=fruit pH, 3=Brix, 4=anthocyanin, 5=drip loss, 6=berry size.

Table 1.1. Interactions on fruit quality of Totem strawberry.

Quality Parameter	Interacting Treatment		Soil pH 5.55	6.00	6.30	6.45
Brix	Harvest	1	6.70	7.22	7.00	6.90
(% soluble solids)		2	8.60	8.70	8.30	8.35
		3*	10.55	10.02	10.77	9.90
			LSD .01=.68, sx=.1808, cv=.0596			
Skin firmness	Harvest	1*	2.64	2.41	2.57	2.73
(Newtons)		2	1.93	2.05	2.01	1.77
		3	2.47	2.58	2.38	2.35
			LSD .05=.255, sx=.0797, cv=.0961			
Flesh firmness	Harvest	1*	1.82	1.75	1.79	2.03
(Newtons)		2	1.36	1.44	1.33	1.23
		3	1.55	1.58	1.47	1.50
			LSD .05=.184, sx=.065, cv=.1235			
Drip loss	Harvest	1	64.4	62.0	62.1	60.7
(%)		2	57.5	56.6	56.5	56.3
		3*	35.6	46.1	45.8	44.2
			LSD .01=6.70, sx=1.78, cv=.0936			
			Harvest 1	2	3	
Drip loss	Spring N		57.8*	55.6*	46.3*	
(%)	Check		62.3	62.2	39.9	
			LSD .01=4.75, sx=1.26, cv=.0937			

* Indicates treatment with protected F value.
sx = standard error of mean.
cv = coefficient of variation.

Table 1.2. Interactions on fruit quality of Hood strawberry.

Quality Parameter	Interacting Treatment		Soil pH 5.90	6.00	6.30	6.45
Anthocyanin (mg/100 g)	Harvest	1	52.78	58.48	57.06	55.63
		2*	48.50	42.22	49.93	55.63
		3	44.22	45.65	42.22	45.65
		LSD	.05=6.31, sx=3.15, cv=.126			
Drip loss (%)	Spring N		63.13*	61.53	59.94	62.16
	Check		59.15	63.06	61.82	63.51
		LSD	.05=3.44, sx=1.11, cv=.0625			
Skin firmness (Newtons)	Spring N		1.71	1.79	1.81	1.68*
	Check		1.73	1.75	1.73	1.80
		LSD	.05=.099, sx=.0321, cv=.0635			
Flesh firmness (Newtons)	Spring N		1.14	1.14	1.17*	1.11
	Check*		1.19	1.15	1.09	1.15
		LSD	.05=.0652, sx=.0212, cv=.0639			
			Harvest 1	2	3	
Flesh firmness (Newtons)	Spring N		.970*	1.34	1.33*	
	Check		.899	1.14	1.41	
		LSD	.05=.0702, sx=.0248, cv=.0841			

* Indicates treatment with protected F value.
sx = standard error of mean.
cv = coefficient of variation.

Table 1.3. Range, mean, and standard deviation of fruit quality parameters of Totem and Hood strawberries.

Parameter	Range	Mean	Std. Dev.
Totem			
Skin firmness (Newton)	1.63 - 3.10	2.32	0.353
Flesh firmness (Newton)	.985 - 2.47	1.57	0.281
Fruit pH	3.31 - 3.74	3.48	0.091
Brix (% sol. solids)	6.20 - 11.6	8.58	1.48
Anthocyanin (mg/100g)	32.6 - 53.7	43.9	4.74
Berry size (g)	6.40 - 18.7	13.2	2.13
Drip loss (%)	26.7 - 74.0	54.0	10.0
Hood			
Skin firmness (Newton)	1.28 - 2.36	1.75	0.232
Flesh firmness (Newton)	.637 - 1.66	1.14	0.201
Fruit pH	3.34 - 3.88	3.61	0.125
Brix (% sol. solids)	6.60 - 10.6	8.43	0.939
Anthocyanin (mg/100g)	37.6 - 73.9	55.1	7.31
Berry size (g)	9.0 - 20.0	12.8	2.16
Drip loss (%)	50.2 - 70.8	61.7	4.14

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STRAWBERRY FRUIT QUALITY AND YIELD AS AFFECTED BY SOIL pH, PHOSPHORUS, AND TIME OF HARVEST

Abstract

Strawberry cultivars Benton and Olympus were grown in a Willamette silt loam at soil pH's 5.6, 5.9, 6.2 and 6.4, with and without preplant banded phosphorus. Olympus produced berries 5% firmer at soil pH 6.4, compared to pH 5.6 and 5.9. Berries grown at pH 6.2 were, comparatively, 4% softer. Neither cultivar showed differences in yield among soil pH levels. Firmness of Benton berries increased 3.6% with added phosphorus but in Olympus, firmness decreased 4.5%. Increasing levels of anthocyanin and fruit pH were also observed from phosphorus treatment of Olympus.

Firmness, fruit pH, Brix, anthocyanin, drip loss and berry size in both Olympus and Benton were significantly affected by time of harvest, except for drip loss in Benton. Firmness of Olympus berries decreased from 2.36 to 2.01 Newtons as the season progressed. Fruit pH decreased from 3.3 to 3.2. Brix increased from 6.7 to 8.3%. Anthocyanin concentration decreased significantly mid-season dropping from 32.3 to 31.6 and increasing to 32.2 mg/100 g at the end of the season. Drip loss increased from 56.2 to 64.4%. And berry size decreased from 11.9 to 10.2 g/berry. Benton berries increased in firmness through the season from 1.68 to 1.97 Newtons. Fruit pH decreased from 3.4 to 3.3. Brix increased from 7.9 to 10.3%. Anthocyanin concentration decreased from 31.49 to 28.10 mg/100 g fruit. Drip loss did not change significantly, maintaining 64% throughout the season. Berry size decreased from 14.8 to 11.1

g/berry. Neither Benton nor Olympus showed significant differences in yield from soil pH or preplant banded P.

Introduction

Quality components of strawberry are major concerns of fruit processors. Over 90% of Oregon's strawberries are processed and are recognized nationally as the hallmark of quality. The superior quality of Oregon's strawberries can be largely attributed to the cultivars and the mild climate of the Willamette Valley.

Most soil pH and fertility studies with strawberries were conducted years ago, in other states, and on cultivars no longer in production. Few of these studies have treated the effects of soil pH on fruit quality. Kirsch (8) in 1959, conducted lime and fertility trials in Oregon but did not evaluate fruit quality. The purpose of this study was to measure the effect of soil pH and phosphorus on quality and yield of Benton and Olympus strawberries.

Materials and Methods

Benton and Olympus strawberries were grown in four soil pH's of 5.6, 5.9, 6.2 and 6.4, with and without preplant banded phosphorus. Berries were sampled three times throughout the season at 7 to 10 day intervals beginning June 7.

Of the 20 plants per plot, the 10 most uniform, adjacent plants were used for sampling. The soil pH treatments, sampling methods and analysis procedures described on pages 9-11 were used. Phosphorus was applied, May 6, 1982 at 100.9 kg/Ha as 0-45-0 banded 10-12 cm below the soil surface directly in the row prior to planting.

Results and Discussion

The Effects of Soil pH

Only Olympus strawberries responded to differences in soil pH (Table 2.1). Berries sampled from soil pH 6.4 were significantly firmer (5.5%) than berries from soil pH 5.6 and 5.9. Berries grown at pH 6.2 gave comparably lower firmness measurements (4.5% softer). Although the changes in firmness were not consistent with changes in soil pH, they were significant ($p \leq .05$). Growth and yield have commonly been studied in relation to soil pH. Responses vary considerably depending of soil type and pH (3, 8). Few studies report any affect of soil pH on fruit quality.

Neither Olympus nor Benton showed significant differences in yield among soil pH levels. The results were inconsistent and followed no logical pattern. Although some workers have reported similar results (10), many have reported signficant decreases (10, 18) or increases in yield as well (1, 2, 7).

The Effects of Phosphorus

Benton and Olympus responded inversely to one another between phosphorus treatments with respect to skin firmness (Table 2.2). Firmness of Benton berries increased from 1.78 to 1.85 Newtons with added phosphorus. Firmness of Olympus decreased from 2.02 to 1.93 Newtons with the same treatment. Overholser and Claypool (11) found that using P resulted in softer fruit. Strawberries from their check plots were 5% firmer than berries from P plots. But Darrow (4) found little difference in berry firmness between different fertilizer plots. He attributed the slight differences he found to differences in berry size rather than fertilizer treatment.

To explain the firmness of Benton strawberries on this difference alone (Table 2.2) would be misleading. There were only slight differences in berry firmness between phosphorus treatments in the first two harvests (Fig. 2.1). The major difference occurred in the third harvest. The effect of this difference is shown in Table 2.2.

The Effects of Harvest Time

Firmness, fruit pH, drip loss and anthocyanin in both cultivars were significantly influenced by time of harvest, except drip loss in Benton (Figures 2.2 and 2.3). Firmness of Olympus decreased mid-season from 2.36 to 1.55 Newtons and then increased to 2.00 Newtons at the late harvest. Firmness of Benton increased steadily through the season from 1.68 to 1.97 Newtons. Although most reported results are variable and are generally inconsistent (2, 7, 12, 13, 14, 15), Cochran and Webster (2) and Sistrunk (14) found some fruit to be 24% softer in the later part of the season.

Fruit pH decreased in both Olympus (from 3.3 to 3.2) and Benton (from 3.4 to 3.3). Sistrunk and Moore (14), however, observed slight increase in pH from 3.28 to 3.31.

Brix of Olympus increased 19% during the season from 6.7 to 8.3%. Benton increased 23% from 7.9 to 10.3%. Seasonal increases in Brix are most common (7, 12, 14, 15) yet Sistrunk and Moore (14) observed a 6% decrease in Brix in some of their work.

Changes in anthocyanin concentration, though slight, were significant for both cultivars. Olympus decreased mid-season from 32.29 to 31.61 and increased again to 32.18 mg acn/100 g fruit by the season's end. Anthocyanin in Benton decreased steadily from 31.49 to

28.10 mg/100 g fruit.

Drip loss of Benton did not significantly change during the season, maintaining an average of 64%. Drip loss of Olympus fluctuated from 56% to 65% to 64% for the three harvests.

Interactions

The results of Olympus show significant soil pH and P interactions affecting Brix and anthocyanin (Figures 2.4 and 2.5). Berries from plants receiving banded phosphorus showed significant differences in Brix between soil pH levels. The largest difference occured at pH 6.20, which revealed a decrease in Brix of about 5%. Another significant interaction occurred between phosphorus treatments of the same soil pH. Eighty-five percent of the variation between phosphorus treatments can be accounted for by the difference in soil pH.

Changing patterns in anthocyanin (acn) throughout the season occurred between soil pH levels (Figure 2.5). Acn increased with subsequent harvests at the lower soil pH levels (5.65 and 5.95). At pH 6.20, acn dipped mid-season but increased again at the season's end. At pH 6.40, acn steadily decreased over the season.

Changes in quality parameters due to soil treatments were inconsistent and appear highly unpredictable. Only Olympus responded to changes in soil pH, and the response to phosphorus treatment of Benton and Olympus were opposite. To make soil treatment recommendations to growers, based on these results, would be difficult. Strawberry cultivars respond "individually" to various soil treatments. These responses not only vary among different soil types, but also vary considerably between different pH levels of the same soil.

The most notable quality changes were observed among harvests. Except for drip loss in Benton, all quality parameters changed significantly during the season. In light of these results, time of harvest is the most influencing independent factor affecting strawberry fruit quality.

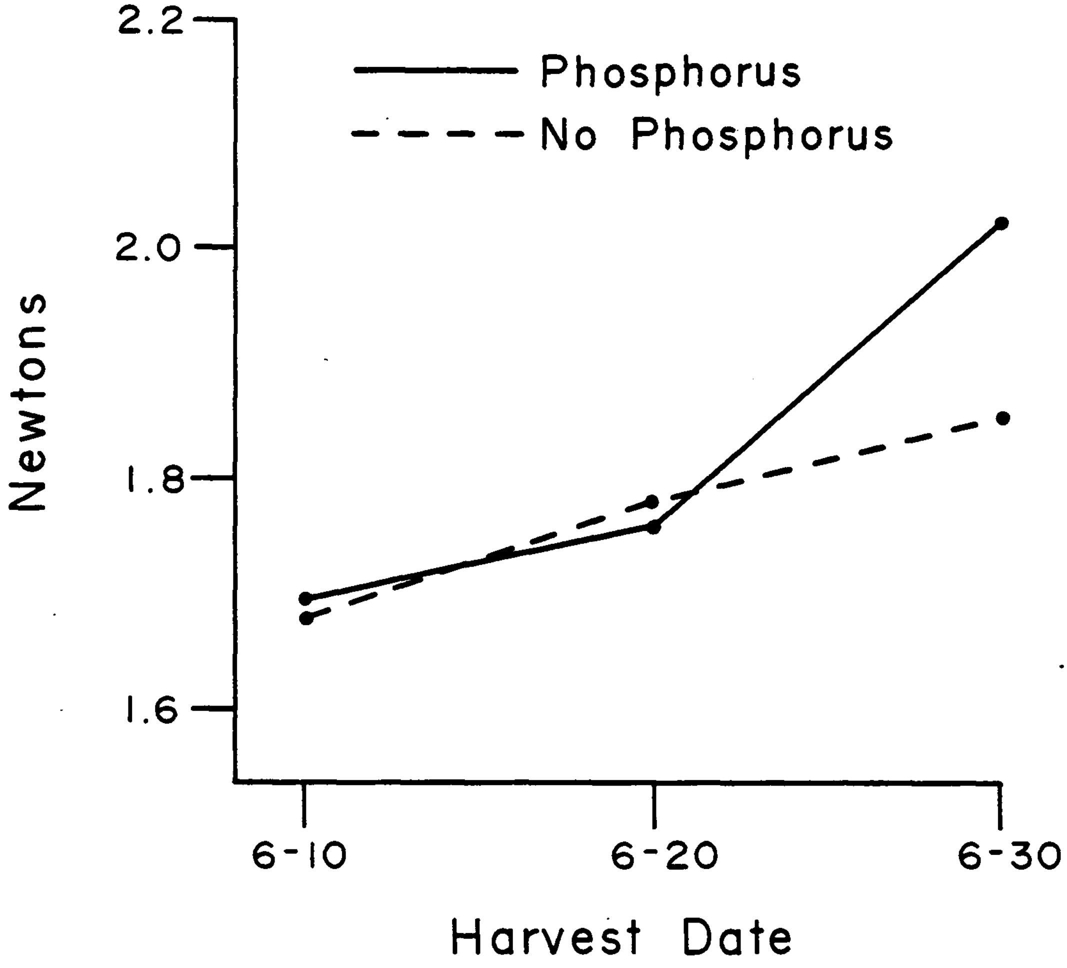

Figure 2.1. The influence of phosphorus and harvest date on firmness of Olympus strawberry.

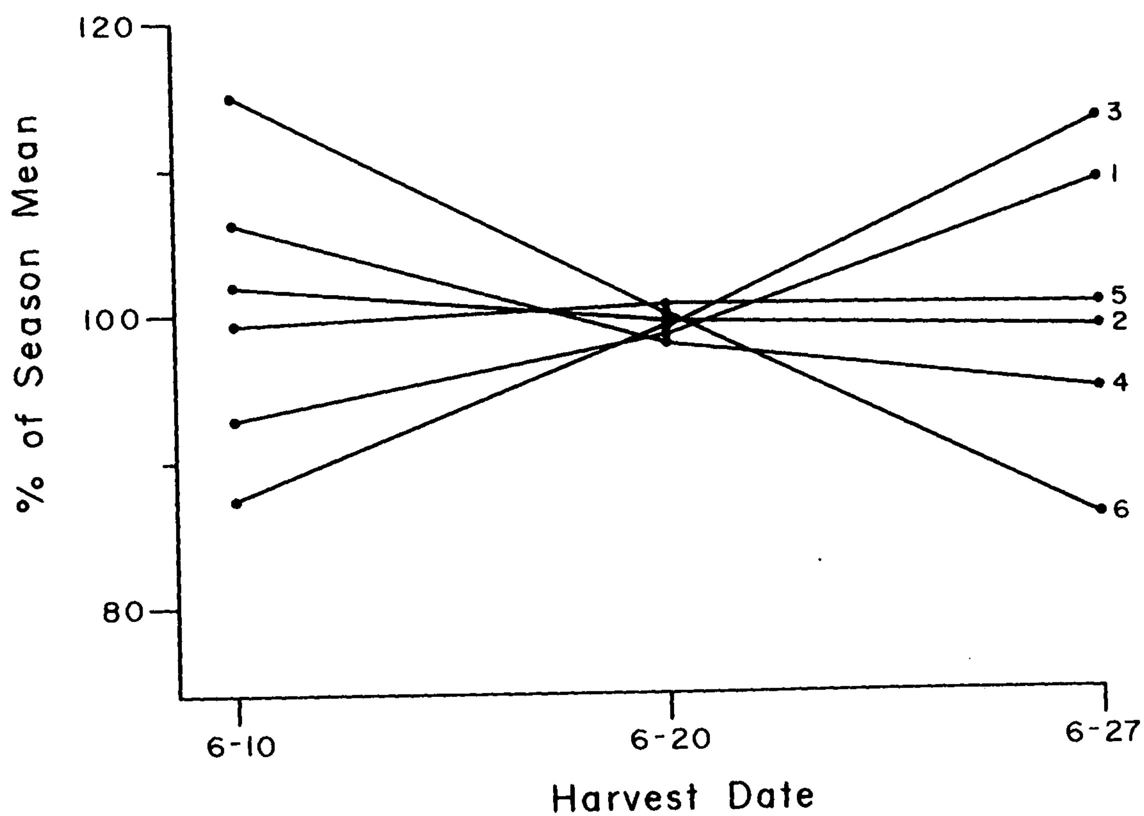

Figure 2.2. Seasonal changes in fruit quality of Benton strawberry for three harvests. 1=fresh firmness, 2=fruit pH, 3=Brix, 4=anthocyanin, 5=drip loss, 6=berry size.

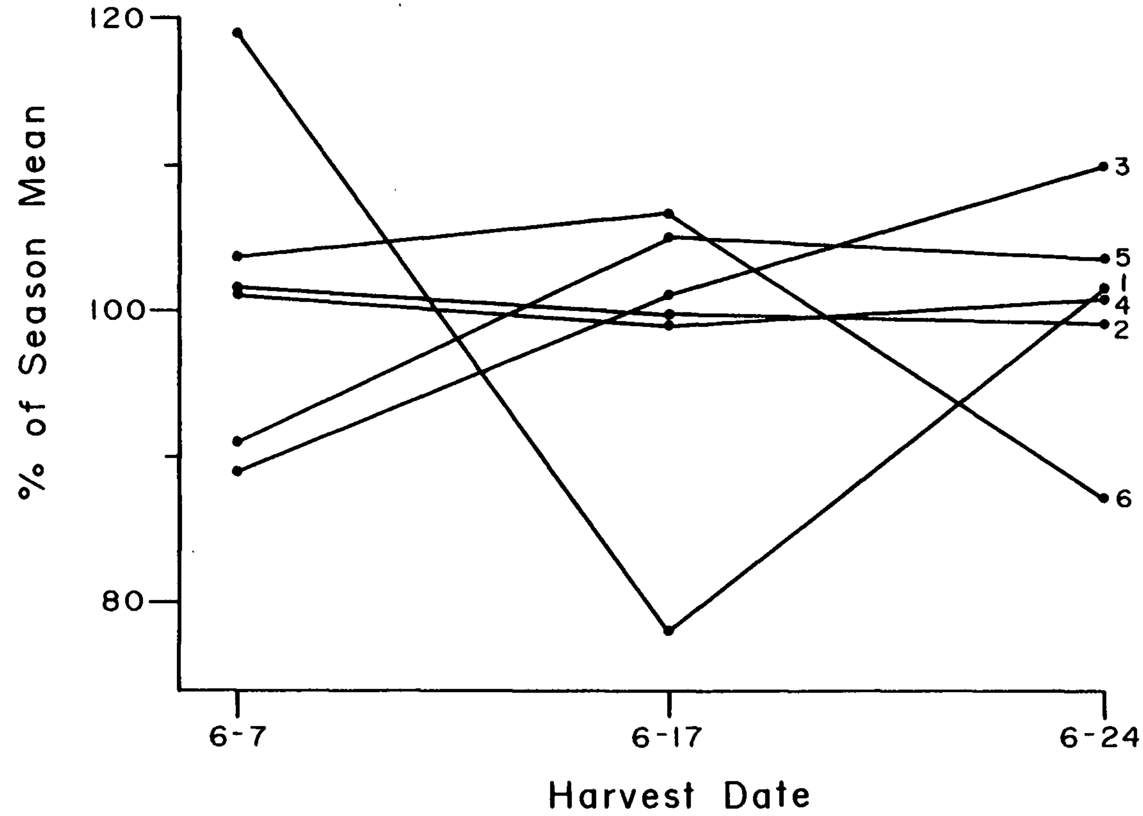

Figure 2.3. Seasonal changes in fruit quality of Olympus strawberry for three harvests. 1=fresh firmness, 2=fruit pH, 3= Brix, 4=anthocyanin, 5=drip loss, 6=berry size.

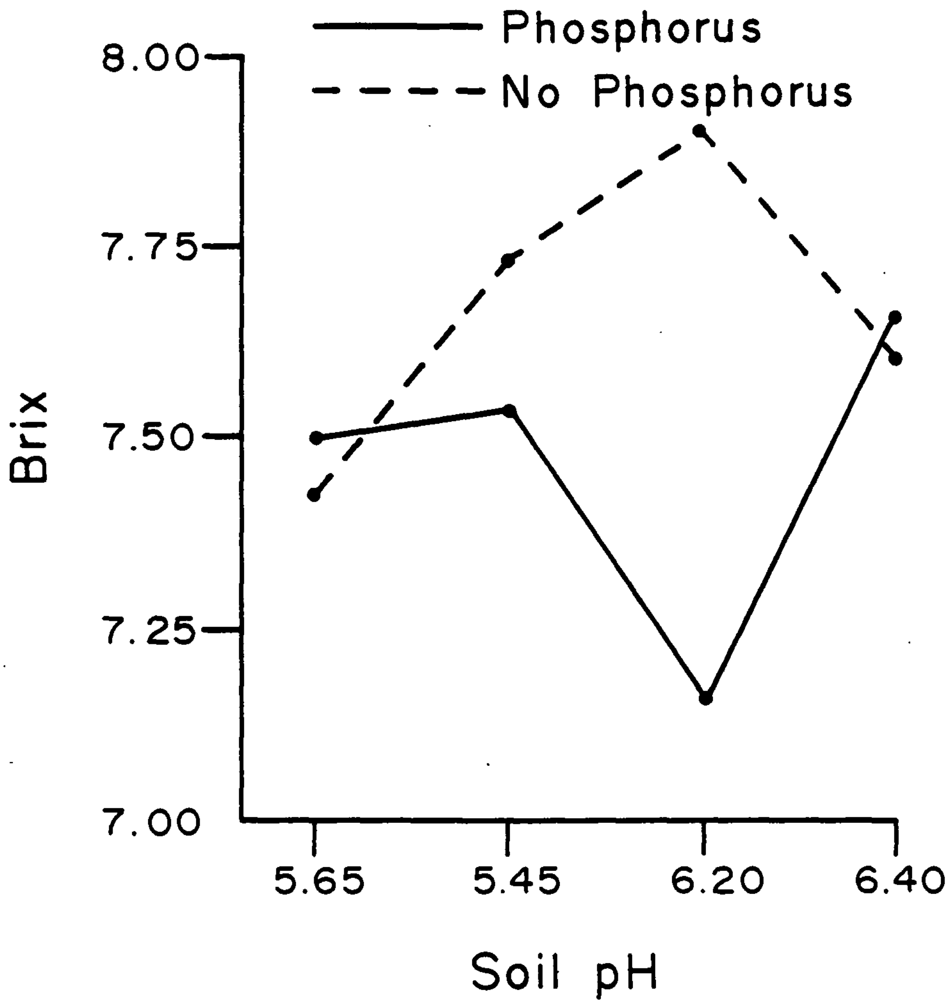

Figure 2.4. Effects of soil pH and phosphorus on Brix of Olympus strawberry.

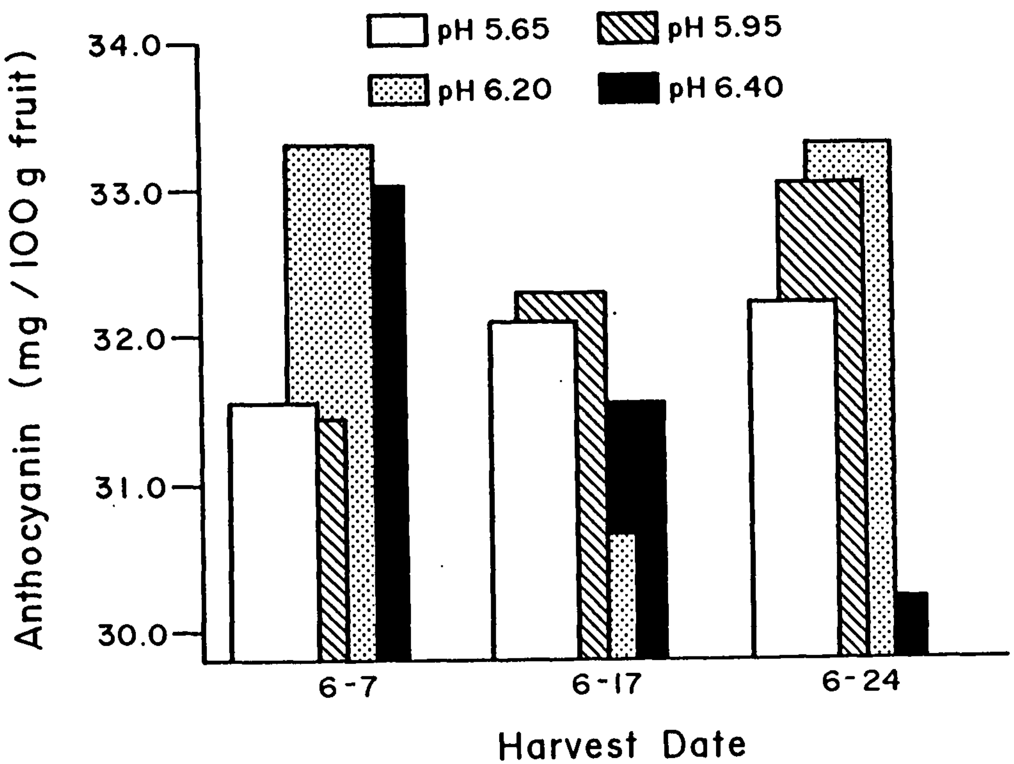

Figure 2.5. Soil pH and harvest date interaction on anthocyanin concentration of Olympus strawberry.

Table 2.1. The effects of soil pH on firmness of Olympus and Benton strawberry.

Olympus	Soil pH	5.65	5.95	6.20	6.40
	Fresh firmness	1.98	1.99	1.91	2.10[z]
Benton	Soil pH	5.55	5.90	6.20	6.45
	Fresh firmness	1.80	1.87	1.75	1.82[y]

[z] LSD .05 = 0.11, sx = .037, cv = .0187
[y] no significant differences between treatments.

Table 2.2. The effects of phosphorus on fresh firmness of Benton and Olympus strawberries.

	No phosphorus	Banded phosphorus
	(Newtons)	
Benton	1.786	1.853*
Olympus	2.022	1.932*

* Significant difference between treatments at 5% level.

Table 2.3. The effect of phosphorus on fruit pH and anthocyanin of Olympus strawberry.

	No phosphorus	Banded phosphorus
Fruit pH	3.2	3.3*
Anthocyanin (mg/100g fruit)	31.72	32.41*

* Significant differences between treatments at 5% level.

Table 2.4 Range, mean, and standard deviation of fruit quality parameters of Benton and Olympus strawberries.

Parameter	Range	Mean	St. Dev.
Benton			
Skin firmness	1.16 - 2.74	1.81	.244
Flesh firmness	0.85 - 1.32	1.06	.107
Fruit pH	3.16 - 3.78	3.36	.081
Brix	6.70 -12.6	9.08	1.18
Anthocyanin	24.6 - 39.5	29.7	2.97
Size	6.50 -24.5	15.8	4.67
Drip loss (%)	52.72 -70.44	64.35	3.41
Olympus			
Skin firmness	1.23 - 2.94	1.98	.424
Flesh firmness	0.73 - 2.27	1.32	.362
Fruit pH	3.12 - 3.48	3.29	.073
Brix	5.40 - 9.40	7.56	.821
Anthocyanin	27.0 - 38.0	31.9	2.44
Size	7.70 -17.1	11.4	1.79
Drip loss (%)	40.1 - 74.7	61.9	5.69

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