RESPONSES OF THE CUTHBERT RASPBERRY
TO MINERAL TREATMENTS

by

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Table of Contents.

	Page
Introduction	1
Review of Literature	2
Materials and Methods	4
Results	10
(a) Observations on Sand Cultures..	10
(b) Laboratory Data	15
Discussion	25
Summary	31
Literature Cited	32
Acknowledgments	34

RESPONSES OF THE CUTHBERT RASPBERRY TO MINERAL TREATMENTS

Introduction

In the Fraser Valley of British Columbia many plantations once producing vigorous raspberry plants have suffered a gradual weakening and decline in health. Thus plants are now smaller and less productive than they should be according to past standards. Usually no pathological symptoms are noted, although the land has been planted to raspberries continuously in many cases from ten to fifty years. From these facts and earlier work on this problem (9,10), it seems very probable that the trouble is a nutritional one; therefore, it was decided to study some factors affecting the nutrition of the raspberry plant.

It was decided to grow the plants in well washed sand and supply food elements in solution: because the soil is such a complex body and provides so many unknown and variable factors that it is difficult to study responses of the plant to treatments in this medium, (27).

Now, it is established that the following elements are necessary for plant growth: nitrogen, phosphorus, potash, calcium, sulphur, magnesium, iron, boron, manganese, and zinc, and probably others such as copper. Hence, deficiencies of the elements nitrogen, phosphorus, potassium, calcium, and sulphur, were studied and compared with plants which received all the necessary nutrients.

For vigorous plant growth it is important to have a balance in the necessary food elements, because a large quantity of one nutrient in relation to the others may prove harmful to the plant. Also, the lack of one nutrient may cause a virtual excess of some other element and produce poor plants. Therefore, studies were made on the effects of heavy applications of one element in relation to other nutrients, and "excess" quantities of nitrogen, phosphorus, potassium, and calcium were used in treating some plants.

In recent years many of the so-called deficiency diseases have been found to be caused by lack of the micro or trace elements. Thus, the use of boron, manganese, and zinc was included in these studies.

Occasionally soil substances may be toxic or inhibit plant growth. Aluminum is known to be harmful in acid soils, and since the soils of the raspberry growing areas in the Fraser Valley are acid, and frequently very acid (9), it was decided to study the effects of aluminum on the growth of the raspberry plant.

By the use of sand cultures to grow raspberries with various nutrient treatments, it was expected to fulfill two objects: firstly, to study the effects of essential mineral elements on the growth of the raspberry plant; secondly, to produce under known and controlled conditions, a plant condition similar to that found in the unthrifty field plantings.

Review of Literature

In the latter half of the nineteenth century, Sachs, Knop, Nobbe, Pfeffer, and others did a great deal of work to determine what elements were essential to plant growth. Their work showed that carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, and iron are essential to plant life. Since then workers like Brenchley (1), and McHargue (17) have demonstrated the essential nature of the micro elements, boron, manganese, zinc, and copper. This work was accomplished or proved by the use of sand and water cultures.

The present day technique of using sand cultures and nutrient solutions has been developed by Hoagland, Shive, and others (13, 27). The symptoms of deficiencies and excesses of these plant food elements as shown by various parts of the plant have been studied and recorded for many species (3, 4, 6, 12, 19, 28).

Much literature has been published in an attempt to make laboratory determinations give an expression of the responses noted in the field. One of the most favoured has been the so-called carbohydrate nitrogen ratio as originally formulated by Kraus and Kraybill (14), when working with tomatoes, showing the relative proportion of carbohydrates to nitrogen to be a significant factor in determining vegetative and reproductive activities. This work has been developed by many workers, and evidently a narrow ratio, or low carbohydates in proportion to nitrogen is conducive to vegetative growth, whereas a wide ratio, high carbohydrate content in relation to nitrogen, is conducive to fruiting.

Apparently there is no literature in the above works dealing with the raspberry. Publications on this crop deal largely with the cultural aspects.

In 1937, Harris (9) named eight factors as being the causes of raspberry failures on some plantings in the Fraser Valley. These were: (1) a nitrogen deficiency, (2) a lime deficiency, (3) a phosphorus deficiency, (4) a potassium deficiency, (5) soils being too acid, (6) an unbalanced supply of plant nutrients, (7) the exhaustive first year effects of cover cropping on poor or impoverished soils, and (8) "wet feet" or root injury due to an excess of water in the soil. Other work (9) stated that the decline was initially due to loss of organic matter with its resultant effects of allowing leaching and undesirable soil conditions to develop. Thus starvation produces weakened plants.

Materials and Methods

Raspberry plants of the Cuthbert variety were obtained and passed by Government officials as healthy stock. These were grown in fresh water, pure quartz sand, held in 12-inch clay flower pots. Sixty such pots were divided into fifteen groups of four, and each group received a different nutrient solution. The fifteen treatments were:

1. Complete nutrient solution
2. Nitrogen deficient nutrient solution
3. Phosphorus deficient nutrient solution
4. Potassium deficient nutrient solution
5. Calcium deficient nutrient solution
6. Sulphur deficient nutrient solution
7. Complete nutrient solution plus excess nitrogen
8. Complete nutrient solution plus excess phosphorus

9. Complete nutrient solution plus excess potassium

10. Complete nutrient solution plus excess calcium

11. Complete nutrient solution plus 5 p.p.m. boron, 2 p.p.m. manganese, 1 p.p.m. zinc

12. Complete nutrient solution plus 5 p.p.m. boron

13. Complete nutrient solution plus 2 p.p.m. manganese

14. Complete nutrient solution plus 10 p.p.m. aluminum

The above fifteen nutrient solutions were based on Hoagland's Complete Nutrient Solution (13) which has a concentration of approximately 2000 p.p.m.

In preparing the nutrient solutions, stock solutions were made up by dissolving the following weights of chemicals individually and making the volume up to 2 litres:

1. Complete Nutrients

(a) (134 g. KNO_3
(200 g. $MgSO_4 \cdot 7\ H_2O$

(b) 416 g. $Ca(NO_3)_2 \cdot 4\ H_2O$

(c) 100 g. KH_2PO_4

2. Nitrogen Deficient Solution

(d) (100 g. KCl
(200 g. $MgSO_4 \cdot 7H_2O$

(e) 176 g. $CaCl_2$

(c) 100 g. KH_2PO_4

3. Phosphorus Deficient Solution

(a) (134 g. KNO_2
(200 g. $MgsO_4 \cdot 7\ H_2O$

(b) 416 g. $Ca(NO_3)_2 \cdot 4\ H_2O$

(f) 55 g. KCl

4. Potassium Deficient Solution

(g) (114 g. $NaNO_3$
(200 g. $MgSO_4.7\ H_2O$

(b) 416 g. $Ca(NO_3)_2.\ 4\ H_2O$

(h) 100 g. NaH_2PO_4

5. Calcium Deficient Solution

(a) (134 g. KNO_3
(200 g. $MgSO_4.7\ H_2O$

(i) 150 g. $NaNO_3$

(c) 100 g. KH_2PO_4

6. Sulphate Deficient Solution

(j) (134 g. KNO_3
(164.9 g. $MgCl_2.\ 4\ H_2O$

(b) 416 g. $Ca(NO_3)2.\ 4\ H_2O$

(c) 100 g. KH_2PO_4

(A bracket indicates that the chemicals grouped together are included in the same 2-litre stock.)

Those series receiving an excess or luxury feeding of nitrogen, phosphorus, potassium, and calcium received five times the normal amount of each of these individual nutrients in their respective diets. The same stocks as for full nutrients in Solution 1 were used plus these stocks:

7. Excess Nitrogen

(k) 1649 g. $NaNO_3$ made up to 2 litres.

8. Excess Phosphorus

(l) 406 g. $NaH_2PO_4.H_2O$ made up to 2 litres.

9. Excess Potassium

(m) 613 g. KCl made up to 2 litres.

10. Excess Calcium

(n) 782.5 g. $CaCl_2$ made up to 2 litres.

Those groups receiving the micro elements, boron, manganese and zinc, were given full nutrient solution plus these elements in the respective concentrations of 5 p.p.m., and 1 p.p.m. The stock solutions were made using the following quantities of materials made up to 2 litres:

11. Complete Nutrients plus Boron, Manganese, and Zinc

(o) 18.32 g. H_3BO_3 (Boron) made up to 2 litres.

(p) 4.6 g. $MnCl_2 . 4H_2O$ (Manganese) made up to 2 litres.

(q) 1.34 g. $ZnCl_2$ (Zinc) made up to 2 litres.

12. Complete Nutrient Solution plus Boron Stock.

13. Complete Nutrient Solution plus Manganese Stock.

14. Complete nutrient Solution plus Zinc Stock.

15. Complete Nutrient Solution plus 10 p.p.m. Aluminum.

(r) 56.2 g. $Al_2(SO_4)_3 . K_2SO_4 . 24\ H_2O$ made up to 2 litres.

These stocks were diluted before being fed to the plants. The following quantities of stock solutions were diluted to 4 litres in accordance with the preceding list of stocks used to prepare each of the fifteen nutrient treatments.

22 c.c. of stock solutions (a), (d), (g), (j)

26 c.c. of stock solutions (b), (e), (i)

12 c.c. of stock solutions (c), (f), (h), (l)

100 c.c. of stock solution (k)

18.5 c.c. of stock solution (m)

26.0 c.c. of stock solution (n)

12.5 c.c. of stock solutions (o), (p), (q).

When the dilution was made just before feeding, iron was added at the rate of 1 c.c. of 1 per cent ferric tartrate solution per litre of nutrient solution.

The raspberries were set in the sand with one young sucker cane per pot. Each group of four pots was placed in a square hole in the earth so that about an inch of each pot was above ground level. The hole was cribbed to keep soil away from the pots, and a heavy layer of excelsior had been put on the bottom of the hole to prevent any contact between the pots and soil. The spaces between pots, and pots and cribbing, were filled with shavings. Thus evaporating surface was cut down and no soil touched the pots.

Plants were set in the pots of sand on May 12, 1937, and left for one week to start root development. Feeding was started May 18, 1937. The plants were fed twice weekly until June 21, 1937. At that time the plants were making vigorous growth and it was decided to feed them three times each week. They were watered whenever the feeding did not supply adequate water.

Daily observations were made on the development of the plants.

The plants were fed until the middle of October, and as the season was very mild and some growth was still being made, they were left until November 1, 1937, before samples for analysis were taken. Two representative plants from each group were taken into the laboratory for analysis except in the case of the nitrogen and phosphorus deficient groups.

These latter groups produced such small plants that four had to be used to provide sufficient material for the laboratory determinations.

Final observations on the plants including examination of the roots were made, and then the roots and aerial parts were separated. The roots were washed free of sand, and the fresh weights of roots and aerial parts were measured. Leaves and stems were separated and respective fresh weights determined. Then dry weights of roots, stems and leaves were obtained by drying to constant weight in an electric oven at 80° C. Since the stems and roots were thick, after 24 hours in the oven, each lot was ground, re-weighed, and put back to dry to constant weight. All material brought into the laboratory was dried, and after grinding was used for further analyses. The root samples were found to contain considerable fine grains of sand, hence this material was not used for further analytical work.

The ash weights or mineral content was determined on leaves and canes by heating 10-gram aliquots in a Muffle furnace at 600° C. for one hour.

Aliquots of stems and leaves were analyzed for reducing sugars, sucrose, starch, and total nitrogen. Reducing sugars and sucrose were determined by the Lane and Eynon method, starch by the hydrochloric acid method, and nitrogen by the Kjeldahl method (22).

Results

A. OBSERVATIONS ON SAND CULTURES

There was a marked difference in the response of the raspberry plants according to their nutrient treatment. The following descriptions of each group are condensed from the season's observations.

1. Complete Nutrient Solution.- This group produced normal, vigorous growth all season. At the end of the season the canes were about five and one half feet tall and heavily branched. The leaves were a healthy, dark green colour all through the season. When the roots were examined, they were found to be very well developed with abundant fibrous roots and many root hairs. In every regard, this group could be considered healthy, normal, vigorous, raspberry plants, and is used as the check in comparisons made in following observations.

2. Nitrogen Deficient Solution.- This group was the poorest in the whole series all season. These plants made no perceptible gain in growth after the end of June. In July, the whole leaf surface was distinctly yellow, and the bright red of the anthocyanin pigments was very marked. By August almost the entire leaf surface was bright red with the mid-rib and large veins showing yellow. In September defoliation began and continued rapidly, although remaining groups retained their leaves and many continued making new growth. The largest leaves only attained a size about one-quarter of that of average leaves on the complete nutrient solution plant.

At the end of the season, the canes were from 6 to 12 inches high. Also, the roots were very scanty and consisted of a few long stringy, thin ones.

3. Phosphorus Deficient Solution.- Next to the nitrogen deficient plants, this group was the poorest in the series. Early in the season, fairly rapid growth took place, but not as much as made by the check. By July the leaves were showing a marked dark colour of a bronzed purple hue. Growth ceased in August and the purpling of the leaves became more intense and began to show on the canes. At the end of the season the plants were stunted compared to the check, and the height of the canes averaged about 2 feet. The canes were very thin, weak-looking, and an extremely dark reddish purple colour. The leaves were a very dark green overlayed with a dark bronze-purple colour, and only about one-half or less the size of those of the check plants. Also, the roots were small, stunted, and generally poorly developed compared to those of the check.

4. Potassium Deficient Solution.- This group made slower growth than the check, but the general appearance was normal. By July some of the lower leaves showed a yellowing and dying around leaf margins and these lower leaves were the only ones which showed potassium deficiency symptoms. The tops continued making apparently normal growth although it was not as vigorous as that made by checks. At the end of the season the plants were smaller than the checks, as the canes were about 4 feet high, and lower leaves showed deficiency symptoms, but otherwise the plants appeared normal.

The roots were relatively well developed compared to those of the checks, and showed exceptional development of root hairs.

5. Calcium Deficient Solution.- This group made normal vigorous growth until August and then did not continue quite so rapidly or vigorously as the checks. In July some lower leaves began to show yellow streaking and mottling, and this condition developed over more leaves as the season advanced.

At the end of the season these plants were almost as large as the checks, and leaves were the same size as those on the checks, but the foliage of the whole plant was a lighter green than the checks. Lower leaves were distinctly mottled and streaked with yellow. The root system was excellent with a strong development of fibrous roots.

6. Sulphate Deficient Solution.- In the early part of the season, these plants presented a normal appearance but made weaker and slower growth than the checks. In August the plants were growing very slowly, and the foliage began to turn a light green. At the end of the season very marked deficiency symptoms were showing. Leaves were smaller than those of the checks, and were mottled yellow and green. The mottling was very fine, thus it gave a general appearance of a uniform light yellow green colour. The canes were also a very light yellow-green and averaged about 4 feet in height. The root systems were well developed with abundant fibrous roots.

7. Excess Nitrogen Solution.- These plants grew at the same rate as the checks, and the leaves and stems were

about the same size as those of the checks. The only apparent difference was the very rich, darker green colour of the leaves compared to those of check plants, and this increased colour was noted during the whole growing period. The roots were very succulent and fleshy, also not very extensive. There were practically no rootlets.

8. <u>Excess Phosphorus Solution.</u>- This group was outstandingly the best in the series during the whole season. From June till the end of the season the plants were taller and made more growth than any other group. Growth was normal. The size and colour of leaves was the same as for the checks. The canes were about 7 feet high, thus being taller than the checks. There was more heavy branching on the canes and growth from the crown than for any other group. The root system was exceptionally well developed, each system being larger than those in any other group. Fibrous roots were so abundant that the root system appeared the most dense in the entire series.

9. <u>Excess Potassium Solution.</u>- All through the growing season, the plants in this group were apparently the same as the checks in size and colour of canes and leaves. The roots were well developed and about the same size as those of the checks but more fleshy and succulent than all other groups except that receiving excess nitrogen.

10. <u>Excess Calcium Solution.</u>- The plants in this group grew normally in the early part of the season. In August growth slowed down materially, and lower leaves showed brown, dead margins giving the appearance of a "scorch". The

plants made very small increases in growth for the rest of the season and at the last examination, they appeared stunted in comparison to the checks. The foliage was a lighter green than that of the checks, and more leaves had dead, brown margins. The root systems were relatively well developed, and had many fleshy, succulent roots similar to those of the excess potassium plants.

11. Complete Nutrient Solution, plus Boron, Manganese, and Zinc.- This group of plants was practically identical with the check plants. The plants grew vigorously all season. The roots, however, did not appear as dense and well developed as those of the check plants.

12. Complete Nutrient Solution, plus Boron.- This group was also very similar to the checks. In July and August, the plants made very rapid, vigorous growth and were second only to the excess phosphorous plants. However, by September increase in growth was slow, and at the final examination they were apparently the same as the check plants in regard to height, amount and colour of foliage. The roots were dense and well developed, being similar to those of the checks.

13. Complete Nutrient Solution, plus Manganese.- This group was apparently the same as the checks with regard to size and colour of canes and leaves. The roots, however, were scanty with more fleshy, succulent roots and fewer fibrous ones than the check plants.

14. Complete Nutrient Solution, plus Zinc.- This group was also the same as the checks in appearance of canes,

leaves and roots.

15. <u>Complete Nutrient Solution, plus Aluminum.</u>- This group was also the same as the checks in appearance of canes, leaves and roots.

The deficiency symptoms exhibited by raspberry plants lacking nitrogen, phosphorus, potassium, calcium, and sulphur are typical of symptoms of such deficiencies as described by other workers (3, 4, 6, 19).

B. LABORATORY DATA

The fresh weights of roots and aerial parts, and the root shoot ratio are given in Table I. The root shoot ratio was determined by dividing the weight of shoots by that of the roots.

The most noticeable point in Table I is that the excess phosphorus plants had the largest weight of cane and leaf, and is an excellent third in regard to weight of roots. The root shoot ratio however does not illustrate this difference.

TABLE I.

Fresh Weights of Roots and Shoots, and the Root Shoot Ratio.

GROUP	No. of Plants	Fresh weight of shoots		Fresh weight of roots		Root Shoot -Ratio
		weight of 2	Average	weight of 2	Average	
		gm.	gm.	gm.	gm.	
1. Complete	2	356.0	178.0	279.8	139.9	1:1.27
2. -N	4	22.2	5.5	14.0	3.5	1:1.57
3. -P	4	111.0	27.7	50.7	12.7	1:2.18
4. -K	2	304.0	152.0	188.6	94.3	1:1.61
5. -Ca	2	352.0	176.0	127.0	63.5	1:2.78
6. $-SO_4$	2	138.0	79.0	100.7	50.4	1:1.46
7. +N	2	186.0	93.0	200.5	100.2	1:0.92
8. +P	2	446.0	223.0	255.5	127.8	1:1.74
9. +K	2	338.0	169.0	210.0	105.0	1:1.61
10. +Ca	2	228.0	114.0	175.0	87.5	1:1.30
11. Complete +B,Mn,Zn	2	218.0	109.0	283.7	141.9	1:0.77
12. " +B	2	352.0	176.0	216.0	108.0	1:1.63
13. " +Mn	2	217.0	108.5	150.3	75.2	1:1.44
14. " +Zn	2	305.0	152.5	175.4	87.7	1:1.74
15. " +Al	2	327.0	163.5	133.3	66.6	1:2.45

The dry weight determinations for the canes, leaves and roots are shown in Table II.

TABLE II.

Percentage Dry Weight of Leaves, Canes and Roots.

GROUP	Percentage dry weight		
	Leaves%	Canes%	Roots%
1. Complete	29.80	45.89	45.2
2. -N	-----	42.64	51.8
3. -P	38.29	47.83	44.5
4. -K	37.87	47.05	38.6
5. -Ca	38.13	47.19	46.8
6. $-SO_4$	38.44	47.07	44.8
7. +N	35.80	42.88	53.4
8. +P	31.99	41.68	45.5
9. +K	35.09	43.39	40.3
10. +Ca	32.89	41.29	46.2
11. Complete +B, Mn, Zn	35.54	46.21	46.5
12. Complete +B	37.09	45.12	42.5
13. Complete +Mn	36.65	45.40	41.8
14. Complete +Zn	33.33	44.75	41.5
15. Complete +Al	37.38	44.20	36.2

The above figures appear high for percentages dry weight on material from raspberry plants; however, the samples were gathered when carbohydrate reserves would be high after a season of active growth.

Rapid healthy growth is associated with low total solid and high water contents (7). In Table II, the percentage dry weight of leaves is low for the plants treated with complete nutrient solution, and excess phosphorus, with excess calcium and complete nutrient solution plus zinc also being low. Since the calcium excess plants were so obviously unhealthy, and probably had the entrance of many nutrients inhibited, it does not compare with others in this group. The percentage dry weight for canes shows plants treated with excess phosphorus, excess calcium, and nitrogen deficient to be the lowest. Of the normal vigorous plants desired by growers, the excess phosphorus is the only one entering this low percentage dry weight group.

The values for roots cannot be considered accurate because of the difficulty of removing sand especially from the well developed root systems.

The percentages of ash for the canes and leaves are given in Table III.

TABLE III.
Percentage Ash of Raspberry Leaves and Canes

GROUP	Canes		Leaves	
	% ash of dry weight	% ash of green weight	% ash of dry weight	% ash of green weight
	%	%	%	%
1. Complete	3.00	1.37	5.69	1.62
2. -N	4.60	1.96		
3. -P	2.22	1.08	5.52	2.11
4. -K	2.99	1.41	5.13	1.94
5. -Ca	1.83	0.86	4.75	1.81
6. $-SO_4$	3.76	1.77	6.09	2.34
7. +N	2.38	1.02	5.29	1.88
8. +p	2.43	1.01	6.26	2.00
9. +K	2.87	1.25	6.62	2.32
10. +Ca	2.95	1.22	6.86	2.25
11. Complete +B, Mn, Zn	2.10	0.98	4.94	1.76
12. Complete +B	2.16	0.97	5.59	2.07
13. Complete +Mn	2.60	1.18	5.24	1.92
14. Complete +Zn	2.30	1.03	6.13	2.04
15. Complete +Al	1.81	0.80	6.40	2.39

Apparently no consistent correlations between growth and percentage ash can be made from the above table.

The analyses of carbohydrates considered as available for the raspberry plant's life processes are shown in Tables IV. and V. Values for reducing sugars, sucrose, and starch are expressed in percentage of both green and dry weights.

(Insert Table IV.)

There are no apparently outstandingly uniform differences in these analyses for reducing sugars, sucrose and starch. The best growing plants were neither high nor low in defoliation, it is hardly to be expected that they would give indications of behaviour during rapid growing season.

(Insert Table V.)

The excess phosphorus plants have the highest percentage of reducing sugars. The poorest groups including the potassium deficient and other deficiency groups show the lowest percentages. It is noted that most groups of plants having high reducing sugar content have a low sucrose content. The starch figures show no consistency in that poor and desirable plants have similar values in these data.

The total carbohydrates including reducing sugars, sucrose, and starch, total nitrogen, and the carbohydrate-nitrogen (C/N) ratio for leaves and canes are shown in Tables VI. and VII., respectively.

TABLE IV.

Percentages of Reducing Sugars, Sucrose, and Starch in Raspberry Leaves.

GROUP	Reducing Sugars		Sucrose		Starch	
	% of green weight	% of dry weight	% of green weight	% of dry weight	% of green weight	% of dry weight
1. Complete	7.85	26.33	3.86	12.96	3.34	11.20
2. -N	----	-----	----	-----	----	-----
3. -P	6.10	16.30	1.83	4.90	5.16	13.79
4. -K	4.46	11.85	1.88	5.00	4.60	11.01
5. -Ca	6.26	16.50	3.48	9.13	5.00	13.09
6. $-SO_4$	6.48	16.90	4.07	10.50	4.54	11.80
7. +N	4.98	13.86	3.18	8.86	6.16	17.03
8. +P	6.41	19.92	1.27	3.86	4.85	15.10
9. +K	8.45	24.06	1.28	3.53	7.09	20.09
10. +Ca	8.85	26.89	1.71	5.20	7.17	21.80
11. Complete+B,Mn,Zn	9.84	27.71	2.24	6.33	5.72	16.18
12. Complete +B	6.28	16.92	1.24	3.33	5.76	15.49
13. Complete +Mn	7.87	21.42	1.08	2.93	6.79	18.56
14. Complete +Zn	7.04	21.13	0.24	0.73	6.42	19.26
15. Complete +Al	8.78	23.51	1.07	4.30	6.08	16.28

TABLE V.

Percentages of Reducing S ugars, Sucrose, and Starch in Raspberry Canes.

GROUP	Reducing Sugars		Sucrose		Starch	
	% of green weight	% of dry weight	% of green weight	% of dry weight	% of green weight	% of dry weight
1. Complete	7.07	15.40	0.64	1.40	13.21	28.81
2. -N	8.53	20.00	----	----	5.56	13.85
3. -P	6.31	13.20	5.64	1.18	10.42	21.84
4. -K	6.17	13.90	----	----	10.68	22.62
5. -Ca	6.56	13.86	1.67	3.33	10.12	21.20
6. -SO 4	7.38	15.65	1.48	3.13	10.60	22.23
7. +N	8.26	19.00	----	----	12.50	29.01
8. +P	8.56	22.50	----	----	9.31	22.25
9. +K	8.83	21.70	----	----	8.66	19.97
10. +Ca	6.74	16.27	----	----	9.15	22.21
11. Complete+B, -Mn, -Zn	7.06	15.52	1.38	3.00	9.34	21.12
12. Complete +B	8.55.	18.92	1.99	4.40	11.30	25.00
13. Complete +Mn	7.73	17.01	1.95	4.20	9.60	20.06
14. Complete +Zn	7.54	16.80	2.36	5.26	9.14	20.29
15. Complete +Al	8.32	18.80	1.56	3.53	9.06	20.24

TABLE VI.

Percentages of total Carbohydrate, and total Nitrogen, and The C/N Ratio of Raspberry Leaves on the Fresh Weight Basis.

SAMPLE	Total carbo-hydrates	Total nitrogen	C/N Ratio
Complete	15.05	4.12	3.66
-P	13.09	5.09	2.58
-K	10.94	4.06	2.70
-Ca	14.75	4.09	3.60
$-SO_4$	15.09	4.36	3.25
+N	14.32	4.67	3.06
+P	12.53	3.44	4.31
+K	16.82	4.29	3.91
+Ca	17.73	4.01	4.40
Complete +B, Mn, Zn	17.80	3.18	5.65
Complete +B	13.28	3.74	4.95
Complete +Mn	15.74	5.21	3.10
Complete +Zn	13.70	3.86	3.54
Complete +Al	15.93	4.32	3.69

In Table VI., the excess potassium, excess calcium, and complete nutrient plus boron, manganese and zinc plants have the highest percentages of total carbohydrates. The potassium deficient plants have the lowest total carbohydrate (24). The phosphorus deficient plants, excess nitrogen, and complete nutrients plus manganese, have the highest percentages of nitrogen. Besides highest total carbohydrates, the complete nutrients plus boron, manganese, and zinc, plants have the lowest total nitrogen content, thus giving this group the highest C/N ratio.

All deficient plants and the excess nitrogen plants have a low ratio.

TABLE VII.

Percentages of Total Carbohydrate, and Total Nitrogen, and The C/N Ratio of Raspberry Canes.

SAMPLE	Total carbo-hydrates	Total nitrogen	C/N Ratio
Complete	20.92	3.29	6.14
-N	14.09	----*	----
-P	22.37	2.40	9.32
-K	16.85	2.23	7.55
-Ca	18.35	2.06	9.09
$-SO_4$	19.46	2.44	7.95
+N	20.76	3.17	6.54
+P	17.87	2.53	6.97
+K	17.49	2.79	6.28
+Ca	15.89	3.28	4.84
Complete +B, Mn, Zn	17.78	3.02	5.87
Complete +B	21.84	3.48	6.28
Complete +Mn	19.28	3.95	4.88
Complete +Zn	19.04	3.29	5.78
Complete +Al	18.90	3.43	5.50

* Sample too small for analysis.

In Table VII., the complete nutrient, phosphorus deficient, and complete nutrient plus boron, have the highest percentages of total carbohydrate. The nitrogen and potassium deficient plants have the lowest. The complete nutrient plus manganese plants have the highest percentage of total nitrogen, and the calcium deficient plants show the lowest. The excess calcium and the complete nutrient plus manganese plants have the lowest C/N ratio, and the deficiency groups have the highest.

DISCUSSION

Observations on the raspberry plants grown in sand cultures proved that they will grow satisfactorily if they can obtain the necessary nutrients. Also these same observations show the falseness of an idea prevalent among growers that the Cuthbert variety has degenerated. When able to obtain the essential food elements in adequate quantities, the Cuthbert variety will produce healthy plants.

The plants grown in the nitrogen, phosphorus, potassium, and sulphur deficient groups produced foliage symptoms similar to those found in many field plantings, presenting further evidence that decline of raspberry vigour is due to nutritional causes. Of those plants grown in the excess groups, the phosphorus plants demonstrated the need for an excellent supply of phosphorus. Evidently many farms do not supply this nutrient in adequate quantities.

It is reported that Fraser Valley soils are acid, and many are extremely acid (9). The raspberry thrives best in a soil of pH 5.2 to 6.8, according to Morgan. Thus a slightly acid soil is desirable. However, high acidity or low pH causes fixation of phosphorus (26, 30). Thus phosphatic fertilizers do not prove of much benefit. On distinctly acid soils in Quebec, it was found that surface applications of phosphatic fertilizers merely increased the readily soluble phosphorus in the surface one-half inch layer of soil (29). Hence, since Fraser Valley soils are acid, it is very possible that the plants do not have access to sufficient quantities of available phosphorus. The poor growth in the excess calcium series was possibly due to lack of adequate phosphorus, because this element is fixed as insoluble tricalcic-phosphate. Thus liming to correct acute soil acidity may reduce the availability of phosphorus as found in studies by Pierre and Browning (23).

There was no apparent benefit from the use of boron, manganese, and zinc in the one season's work. Since these elements are needed in such minute quantities, it is likely that the plants obtained enough from the sand or pot, and thus the growth of these particular groups this season does not preclude the possible need of such elements on soils cropped for a long period of time.

The group receiving aluminum showed no toxic effects. Since McLean and Gilbert reported plant growth to be depressed by concentrations of 3.5 p.p.m. of aluminum (18), it is evident that the toxicity of this element had been reduced. Since aluminum is precipitated by calcium and phosphorus (18, 30), the aluminum content must have been reduced from the toxic level of 15 p.p.m. to a non-injurious concentration by phosphorus and calcium in the nutrient solution.

Since the excess phosphorus plants produced the most desirable plants in this experiment, it was expected that this superiority would be shown in the laboratory work. These plants did produce the largest weight of leaves and canes by a considerable amount. The weight of roots was a little less than that for plants receiving a complete nutrient solution, and the same solution plus boron, manganese, and zinc. However, since phosphorus promotes root formation, especially fibrous roots (21), (25), these plants probably had a more efficient root system than any other group. The weight is likely to be too low in comparison to other plants because a greater proportion of fibrous roots would be lost when washing.

The root shoot ratios apparently show no consistently favorable data for the best series, but it is interesting to note that the phosphorus deficient plants have a smaller amount of shoot growth in relation to the roots than the excess phosphorus plants.

As noted before the most actively growing plants receiving adequate nutrients have a higher percentage of water or lower dry weights (7). The data show that the plants receiving complete nutrient solution, excess phosphorus, and excess calcium had the lowest dry weight for leaves. Davis (4) found excess calcium to increase dry matter in comparison to checks, hence the above data may be a result of a sampling error. However, since the type of plant produced with excess calcium is not desired, the favorable dry weight data are of no benefit. Since the percentage dry weight of the excess phosphorus and complete nutrient plants is so much lower than for other treatments, it appears a significant point in showing that these plants were superior to the others. In comparing data on the dry weights of canes, the excess phosphorus, excess calcium, and nitrogen deficient plants show the lowest percentage. Thus for the desired type of plants, once more the excess phosphorus plants are shown up favorably.

No correlation between growth and percentage ash could be found. The worst plants appeared almost at extremes of high and low ash contents. The varying degrees of maturity as caused by the nutrient treatments may cause these data to be insignificant, since the amounts of minerals taken up by plants varies according to the stage of growth (2, 16). Also it is possible that there is an optimum percentage of minerals such as the value for the excess phosphorus plants which will produce the most desirable plants.

Since carbohydrates are the means of storing energy in a plant, it is expected that plants with the greatest carbohydrate reserves will have the largest store of energy, and only vigorously growing plants can build up such a supply. The data in Table IV. give the percentages of the carbohydrate fractions in the leaves sampled in this work. Some facts such as lack of potassium producing low carbohydrate content are shown (24). Since, however, the carbohydrate content of the leaf is so variable, depending not only on nutritional differences in metabolism but also on time of day of sampling (20), stage of maturity, and the fact that these samples could not be collected simultaneously, the data cannot be judged on a comparative basis.

The results in Table V. showing the carbohydrate fractions of the canes may be similarly regarded as not comparative for judgment. However, the carbohydrate content is more likely to be stable in this part of the plant according to Hicks (11). In that light, the excess phosphorus plants showing the highest percentage of reducing sugars may be a significant point in favour of this group of plants. The figures for starch seem to be too similar to allow much interpretation, and evidently the values for total available carbohydrate show more significance.

Total carbohydrate available to plant life processes and total nitrogen content of plant tissues have been used in an attempt to evaluate growth responses since the initial work of Fischer (5). It is customary to express these values in the C/N ratio as done by Kraus and Kraybill in their work with the tomato (14). Kraybill et al (15) found that it made no significant difference to the picture whether the ratio is expressed on a fresh or dry weight basis. The data on the C/N ratio of raspberry leaves and canes are presented so as to compare with this previous work. It has been noted which groups of plants had the highest and lowest C/N ratios. It is interesting to note that in the nitrogen, phosphorus, potassium, calcium, and sulphur deficient groups, that the leaves have the lowest ratios and the canes have the highest ratios in comparison to the other plants.

Hicks (11) in studying the C/N ratio found considerable variations of the ratio in different organs of the plant. He found that the carbohydrate content did not vary in the stem, however, the nitrogen did vary and more was present in the younger tissue. Also, the ratio varied a great deal within the leaves. Thus it is to be expected that the canes of the raspberry plant would be less likely to be influenced and varied by such factors as differences in stage of growth as the leaves. In considering the C/N ratios in the canes, the deficiency groups show high ratios, and this is to be expected (14) as Kraus and Kraybill found high C/N ratios accompanied by a weak vegetative condition. Also, an exceedingly low C/N ratio accompanies a weakly vegetative condition (14), and this probably accounts for the excess calcium plants having the lowest ratio as they were adequately supplied with nutrients, yet were poor plants in comparison to the checks. The complete nutrient plus manganese plants show the second lowest ratio, and as these plants appeared equally as good as the checks, it is possible that an experimental error in sampling for analyses may account for this situation, or it may be at the extreme end of optimum C/N ratios for raspberry plants for making satisfactory growth.

Gurjar (8) found that the C/N ratio of the tomato varied from extremes of 19 to 2, but that the fruit was borne when the ratios were between 4 and 6. Thus it seems likely that the raspberry has a similar optimum ratio.

The excess phosphorus plants did not appear luxuriantly vegetative, and from the first year appearances, it was judged that such plants would produce the desired type of crop. The C/N ratio of 6.97 is well between the extremes of 4.84 for the excess calcium plants and 9.31 for the phosphorus deficient plants. Thus it seems probable that this ratio of 6.97 may be in the optimum C/N ratio range for raspberry plants. All series which made good growth--complete nutrient, excess nitrogen, phosphorus, potassium, complete nutrients plus boron, manganese and zinc, and complete nutrient plus boron and zinc alone, respectively--have ratios between 5.78 and 6.97, which may be within or close to what would be the optimum range of C/N ratios for raspberry plants.

The laboratory work does not apparently show the excess phosphorus plants to be abnormal in any way, but rather makes them appear superior. Hence, the red raspberry needs a plentiful supply of phosphorus, and some, if not most of the trouble with Fraser Valley raspberry plantings can be overcome when a means of supplying the plants with plenty of phosphorus is found.

SUMMARY

Raspberry plants of the Cuthbert variety were grown in sand cultures with fifteen different nutrient treatments. Observations on these plants were recorded.

Plants showing symptoms of nitrogen, phosphorus, potassium, and sulphur deficiencies were similar to plants in many commercial plantings.

A liberal supply of phosphorus produced excellent plants showing that the raspberry will grow if given sufficient nutrients and also the Cuthbert variety has not degenerated.

Laboratory work further showed that the excess phosphorus plants were superior. Hence the problem resolves itself into finding a means of supplying adequate phosphorus to the raspberry plant.

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