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INTRODUCTION

With the exception of moisture there is, perhaps, no factor which more often limits fruit production by the strawberry plant than the supply of nitrogen and mineral nutrients in the soil. A soil may possess all the physical qualities which make it suitable for the strawberry, but unless there are proper amounts of the essential elements readily available for the plants the results in growth and fruit production are likely to be unsatisfactory. The nutrient requirements of the strawberry are not well understood. The limited data which are available are conflicting and the recommendations for the use of fertilizers equally contradictory. Commercial fertilizers are applied with little definite knowledge of the results that may be expected from the use of different amounts, different combinations, or different times of application. The interpretation of the results of fertilizer experiments have been based almost entirely upon the yield and grade of fruit. Very little attention has been given to the nutritive conditions within the plant and their relationship to the various manifestations of growth such as runner production, crown development, number of flower clusters, the flowering and the setting of the fruit. Few carefully conducted experiments have been made to control experimental conditions so as to measure accurately the various responses of the strawberry plant to known variations in the supply of available nutrients in the soil. Consequently, though the yield of fruit is the ultimate test of the value of any fertilization program the results obtained in terms of yield only are empirical and of limited range of applicability.

Analyses of the fruit indicate that the amount of nutrients removed from the soil by the strawberry when compared with some other crops is relatively small. For instance, Van Slyke (12) in New York calculated that a crop of 5,000 quarts per acre will remove from the soil approximately 7.5 pounds of nitrogen, 3 pounds of phosphoric acid and 12 pounds of potash. However, the total intake, or the amounts of these constituents which are actually removed from the soil by the plants in the production of a crop of fruit is much larger than these figures indicate, for the soil must provide, in addition to the elements which are required by the fruit, a liberal supply of the constituents which are necessary for the growth and development of vegetative tissues.

A study of the literature shows that the response of the strawberry to fertilizer treatments has been extremely variable and that there are many

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conflicting opinions regarding the kind and amounts of materials carrying the limiting elements which may be profitably employed. There is also a considerable diversity of opinion regarding the influence of nutritive conditions in the soil, as affected by fertilizer applications, at different seasons. Fletcher (6) emphasizes the importance of a large amount of available plant nutrients in the "short time between the blossom and the ripe fruit." He states (7) that "gains of 500 to 1,000 quarts an acre from a spring dressing of nitrate of soda are not infrequent." White (14) in New Jersey reported an increase of 31 per cent in yield from a spring dressing of 200 pounds of nitrate of soda. The soil was a sandy loam and had not previously been fertilized with nitrogen though well supplied with potash and phosphoric acid. A similar application (15) of nitrate of soda to plants which were well fertilized with complete fertilizer a year before, when they were set, gave an increase of only 18 per cent. The gains in yield were due to an increase in the size of the fruit and apparently not to any increase in numbers. Brown (3) at the Hood River Station in Oregon found that heavy applications of nitrogen greatly increased the yield but that the results from the use of either potash or phosphoric acid alone were disappointing. Highest yields were secured when heavy applications of sodium nitrate were made, one-half in early spring and the other half at blossoming time. On the other hand, at the Woburn Experimental Farms (2) in England, where liquid dressings of manure and commercial fertilizers were applied to strawberry plants during the fruiting season, the dressings had a retarding influence on the ripening of the fruit, but otherwise had no appreciable effect on the crop. Chandler (4) in Missouri found that nitrogen either in the form of sodium nitrate or dried blood applied in the spring before the crop was harvested gave injurious results in every case. They caused excessive weed growth and greatly reduced the crop. The berries were larger but fewer in number, and they were soft and of poor color and quality. Gardner (8) in Missouri found little, if any, effect upon yield from applications of fertilizer in the spring of the fruiting year. He states, "When moisture and temperature are not limiting factors the number of flower clusters, number of flowers and size of berries are dependent on nutritive conditions within the plant the preceding fall and winter, and they are practically independent of soil fertility conditions during the spring and at the time of fruiting."

Few experiments have been reported which furnish definite data on the effect of fertilizers when applied in the spring a year before the harvesting of the crop. Bailey (1) in summarizing the results of a series of cooperative experiments conducted on various types of soil in Oswego County, New York, reported that the use of both potash and phosphoric acid was beneficial, but with commercial nitrogen the increase in returns failed to repay the outlay. The fertilizers were applied to young plantations after the first tillage and after the plants bloomed, but a year before any records were taken on the crop. The use of potash and phosphoric acid increased productiveness, and the berries were firmer and better colored. When nitrogenous fertilizers were used there was too much plant growth and an inferior quality of fruit. Chandler (4) found that when sodium nitrate or dried blood was applied in small quantities during the early summer one year before the crop was harvested they did not cause excessive plant or weed growth the following spring. However, when dried blood was applied in large quantities, even a year before the crop was harvested, it tended to cause excessive plant growth, to reduce the yield, and to cause the berries to wilt worse during droughts at picking time.

Experimental data on the influence of summer and fall applications of fertilizers in the nutrition of the strawberry are also meager. Bailey (1) reports that in one of the tests in Oswego County, New York, the fertilizer was not applied until August. The fertilizers were sodium nitrate and acid phosphate, and the plot yielded almost 1,000 quarts less per acre than the plots which were fertilized with potash in combination with nitrate of soda or potash alone. He attributes the small yield, in part, to the lateness of the fertilizer application. Close (5) in Maryland applied commercial fertilizer to strawberry beds in the fall at the time when they were ordinarily mulched. The yields from the fall fertilized plots were smaller than from the check plot which received no fertilizer or mulch. Brown (3) in Oregon conducted some experiments on an old bed to determine the value of applications made after the harvesting season as compared with similar applications made at blossoming time. The yields though small consistently favored late summer applications.

STATEMENT OF PROBLEM

The objects of this investigation have been to determine (1) the particular nutritive conditions which are most favorable for fruit bud formation and the development of the fruit in the strawberry; and (2) the influence of certain nutrient materials, particularly those containing nitrogen, phosphoric acid and potash, on the growth and the nutritive conditions in the plant when applied at different times of the year.

MATERIALS AND METHODS

Young runner plants were dug from a bed of Senator Dunlap strawberries early in the spring of 1923 and planted in six inch pots. These were first set on boards which were laid on the bottom of a shallow trench, and then surrounded with ordinary garden soil. Later this soil was covered with sand to prevent it from getting into the pots. The soil used for growing the plants during the experiment was a very light sand, intended to provide a medium which would offer favorable physical conditions for growth but at the same time one very low in plant nutrients. The composition of the soil is shown by the following analysis:

Moisture	0.16 per cent
Loss on ignition	0.36 per cent
Phosphorus pentoxide (P_2O_5)	0.04 per cent
Sodium oxide (Na_2O)	1.07 per cent
Potassium oxide (K_2O)	1.29 per cent
Silicon dioxide (SiO_2)	86.75 per cent
Calcium oxide (CaO)	0.98 per cent
Magnesium oxide (MgO)	0.90 per cent
Iron and aluminum oxides (Fe_2O_3 and Al_2O_3)	9.29 per cent
Titanium dioxide (TiO_2)	trace
Manganous oxide (MnO)	trace
Sulphate (SO_3)	bare trace
Nitrogen (N)	0.02 per cent

When the plants had become established in the pots they were divided into lots of thirty-five each and treated with fertilizers according to the outline in Table 1. With the exception of Lot 18 the nutrient elements were applied in the form of commercial ammonium sulphate containing 20.75 per cent nitrogen, acid phosphate containing 16 per cent P_2O_5 and potassium chloride containing 50 per cent K_2O. In Lot 18 chemically pure monocalcium phosphate and commercial sodium nitrate were used. The fertilizer applications were calculated on the basis of an application of 200 pounds of ammonium sulphate, 400 pounds of acid phosphate and 150 pounds of potassium chloride per acre, assuming the plants to be grown under field conditions in hills 15x30 inches apart. During the first season the spring applications of acid phosphate and potassium chloride were made on May 10 and the summer applications on August 1. In the case of the nitrogen-carrying fertilizers applications of one gram per plant were made once each month to avoid excessive concentration in the soil and consequent injury to the plants. Those for the spring period were made on May 10, June 1, and July 1 and those for the summer period on August 1, September 1, and October 1. When fertilizers were applied in the spring of the second year a single application was made soon after the plants started to grow (about May 1).

Table 1.—Outline of Treatments Used in Strawberry Nutrition Experiment

Lot No.	Fertilizer.	Total amount applied per plant.	Time of application.
1	No fertilizer		
2	Ammonium Sulphate	3 grams	Spring
3	Ammonium Sulphate	3 grams	Summer
4	Ammonium Sulphate	6 grams	Spring and summer
5	Ammonium Sulphate	3 grams	Spring
	Acid Phosphate	15 grams	Summer
6	Acid Phosphate	15 grams	Spring
7	Acid Phosphate	15 grams	Summer
8	Acid Phosphate	15 grams	Spring
	Ammonium Sulphate	3 grams	Summer
9	Acid Phosphate	15 grams	Summer
	Ammonium Sulphate	2 grams	Spring (2nd year)
10	Ammonium Sulphate	3 grams	Spring
	Acid Phosphate	15 grams	Spring
11	Ammonium Sulphate	3 grams	Summer
	Acid Phosphate	15 grams	Summer
12	Ammonium Sulphate	6 grams	½ spring, ½ summer
	Acid Phosphate	15 grams	
13	Ammonium Sulphate	8 grams	⅓ spring, ⅓ summer, ⅓ following spring
	Acid Phosphate	15 grams	
14	Ammonium Sulphate	3 grams	Spring
	Acid Phosphate	15 grams	Spring
	Potassium Muriate	5 grams	Spring
15	Ammonium Sulphate	3 grams	Summer
	Acid Phosphate	15 grams	Summer
	Potassium Muriate	5 grams	Summer
16	Ammonium Sulphate	6 grams	½ spring, ½ summer
	Acid Phosphate	15 grams	
	Potassium Muriate	5 grams	
17	Ammonium Sulphate	8 grams	⅓ spring, ⅓ summer, ⅓ following spring.
	Acid Phosphate	15 grams	
	Potassium Muriate	5 grams	
18	Sodium Nitrate	8 grams	⅓ spring, ⅓ summer, ⅓ following spring
	Mono Calcium Phosphate	4 grams	
	Potassium Muriate	5 grams	

So far as possible, uniform conditions favorable for the growth of the plants were maintained during the course of the experiment. Water was supplied whenever necessary by means of an overhead system of irrigation and the foliage kept in a healthy condition by spraying with bordeaux mixture. There was some root growth outside of the pots but usually the boards underneath prevented any penetration into the soil in which the pots were plunged. The pots were lifted occasionally and any roots found protruding from them were removed.

All runners were removed as they appeared throughout the season and the number and total length of those from each lot of plants recorded. On August 1 and on October 26 three representative plants were selected from each of the lots which had previously received different treatments. These were washed, the fresh weights of the tops and roots determined, and afterward dried and saved for dry weight, free reducing sugars, sucrose, starch, total polysaccharides, nitrogen and mineral determinations.

When the plant samples were collected samples of the soil in which they were grown were taken for hydrogen-ion determinations. These were made colorometrically against standard buffer solutions. The untreated soil showed a pH of 7.5, indicating a slight degree of alkalinity, and apparently it remained unchanged throughout the season. The use of fertilizers resulted in some modification of the pH, but the differences were small and there was no indication that the variations in hydrogen-ion concentration in the soil had any definite influence on the behavior of the plants in this experiment.

During the winter the plants were protected with several inches of straw. All were left under natural out-door conditions until spring. During the spring and summer of the fruiting year records were taken of the number of flower clusters, number of flowers per cluster, and the number and weight of the berries from each individual plant. Moisture determinations of the berries were made and the fruit dried and saved for analysis. Records were made also of the number of abortive pistils and fully developed akenes per berry for each of the different lots. After all the fruit was harvested three representative plants were collected from each lot and the fresh and the dry weights determined and recorded.

The determinations of nitrogen and mineral content of the plants, as well as the hydrogen-ion determinations of the soil, were made by the Chemistry Section of this Station. All carbohydrate determinations were made in the research laboratory of the horticultural department. The Allihn method (10), with slight modification, was employed in making all the carbohydrate determinations. Digestion with diastase (13) preceded the hydrolysis of the starch. The results of all chemical analyses were calculated on the basis of oven-dry material.

PRESENTATION OF DATA

The Influence of Nutrients Applied During the Spring and Summer on Vegetative Growth.—When the plants were dug from the field in the spring care was taken to select those which were nearly the same in size and vigor. At the end of the third week differences in the character of the plants were noticeable, particularly in the lots to which nitrogen had been applied. At the end of the spring period (August 1) these differences were very pronounced.

Results Attending Spring Applications.—The data in Table 2 show the average total fresh and dry weights of the plants which were collected from the various lots on August 1 and on October 26. The average fresh weight of the unfertilized plants on August 1 was 21 gms.; that of those which were fertilized with nitrogen alone 36 gms.; a gain of 70 per cent over the unfertilized plants during the spring period. In the lots which were fertilized with nitrogen and phosphoric acid the average weight was 45.7 grams or a gain of nearly 118 per cent. The gain in weight from the use of nitrogen and phosphoric acid with potash in combination was slightly less. Phosphoric acid alone did not increase the growth appreciably over that of the unfertilized plants.

Table 2.—Effect of Spring and Summer Applications of Fertilizer on the Size of the Strawberry Plant

Lot No.	Treatment.	Total average weight per plant, Aug. 1. (gms.)		Total average weight per plant, Oct. 26. (gms.)		Increase Aug. 1 to Oct. 26. (gms.)	
		Fresh.	Dry.	Fresh.	Dry.	Fresh.	Dry.
1	Unfertilized	21.0	6.32	20.14	6.01	−.86	−.31
2	N spring	36.0	10.4	38.0	11.4	2.0	1.0
10	NP spring	45.73	14.5	49.1	15.29	3.36	.8
14	NPK spring	42.43	13.37	54.38	15.78	11.94	2.4
6	P Spring	21.4	6.48	18.82	5.8	−2.58	−.68
3	N summer	21.0	6.32	44.07	12.65	23.06	2.25
11	NP summer	21.0	6.32	49.92	13.9	28.92	7.57
15	NPK summer	21.0	6.32	56.5	15.87	35.5	9.54
7	P summer	21.0	6.32	20.23	5.65	−.77	−.67
4	N spring-summer	36.0	10.4	58.7	18.79	22.7	8.39
12	NP spring-summer	45.73	14.5	76.3	22.86	31.56	8.36
16	NPK spring-summer	42.43	13.37	60.23	18.69	17.79	5.32
18	NPK-S spring-summer	34.23	9.71	51.0	15.45	16.76	5.74
5	N spring, P summer	36.0	10.4	51.8	16.03	15.8	5.63
8	P spring, N summer	21.4	6.48	42.7	12.3	21.3	5.8

During the summer period there were slight increases in the fresh and dry weights of the plants which were fertilized with nitrogen alone or in combination. However, the general effect of withholding nitrogen after August 1 was an almost immediate check in the growth of the crowns. For example in Lots 2 and 10 the increases in fresh weight per plant after August 1 were only 2 gms. and 3.36 gms. respectively. In the unfertilized and in the acid phosphate-fertilized lots there were decreases in weight after August 1 due to a failure of the plants to produce new growth and the loss of some of the older leaves in the fall.

Results Attending Summer Applications.—The effect of nitrogenous fertilizers on the growth of the plants in Lots 3, 11, and 15 which had received no previous fertilizer treatment during the spring period was almost immediate. The leaves changed from a light green to a dark green color and the plants grew vigorously until the close of the season. The plants were slightly larger at the close of the season than those which received similar treatments during the spring period only. Phosphoric acid alone failed to produce any effect on vegetative growth, but when used in combination with nitrogen or with nitrogen and potash the growth was greater than with the use of nitrogen alone.

Results Attending Spring and Summer Applications.—Plants which were treated with fertilizers containing nitrogen during both the spring and summer periods were invariably larger at the close of the season than those which were treated during the spring period or the summer period only. Those which were treated with nitrogen and phosphoric acid were

Table 3.—Record of Number and Length of Runners Removed (Length recorded in inches)

Date	June 8		June 15		June 25		July 5		July 18		July 24		August 5		August 13		August 20		August 29		Sept. 5		Total	
Lot No.	No.	Length	No.	Length	No.	Length	No.	Length	No.	Length	No.	ngth	No.	Length	No.	Length	No.	Length	No.	Length	No.	Length	No.	Length
1	1	3	4	28	12	83	3	14	1	6	1	6	3	14	1	10	....	.....	1	10	....	....	27	176
2	....	....	6	26	10	53	16	76	42	268	22	120	50	242	48	270	25	101	30	135	2	13	251	1304
3	....	....	3	12	8	51	3	18	4	26	3	17	4	18	1	8	3	12	10	31	6	41	45	234
4	....	....	....	......	19	98	17	44	45	273	30	174	42	140	35	178	27	82	35	133	5	24	255	1148
5	....	....	7	37	9	60	17	56	31	214	23	130	56	253	31	179	24	80	23	77	3	17	224	1103
6	3	18	1	4	7	49	2	8	6	16	....	.....	3	11	3	24	....	.....	1	6	....	....	26	136
7	....	....	7	38	10	67	3	13	5	29	3	18	3	12	....	.....	3	14	1	3	....	....	35	194
8	1	3	1	3	5	29	1	4	3	26	1	5	5	22	....	.....	9	33	28	98	7	48	61	270
9	....	....	2	6.5	3	10	....	.....	2	8	....	.....	2	7	....	.....	....	.....	1	6.5	1	4	11	42
10	4	36	10	40	42	260	22	148	36	305	28	160	66	321	40	226	12	42	20	77	3	18	283	1633
11	3	6	3	15	6	49.5	1	3	1	4	....	.....	2	4.5	3	20	2	12	11	29	6	45.5	38	188.5
12	....	....	7	37	48	272	58	350	62	444	35	128	77	331	58	273	34	113	66	263	10	57	455	2288
13	5	27	11	50	39	227	59	302	58	388	45	178	74	368	66	360	34	108	59	239	6	35	456	2282
14	3	12	8	44	30	196	34	238	27	158	28	122	62	273	48	363	23	93	28	136	2	14	293	1649
15	....	....	5	43	6	51	1	16	1	9	....	.....	....	....	....	.....	1	3	....	....	2	19	16	140
16	6	42	16	80	40	248	40	227	36	256	36	181	70	386	43	279	23	80	28	111	6	45	344	1935
17	3	14	21	88	42	259	39	228	52	354	25	106	65	325	43	271	39	164	31	125	15	108	375	2042
18	....	....	8	42	25	122	28	124	58	370	19	91	57	276	48	284	20	68	13	65	1	10	277	1453

the largest and most vigorous of all. The average green weight of these plants on October 26 was 76.3 grams. Those fertilized with nitrogen alone weighed 58.7 grams and those fertilized with nitrogen, phosphoric acid and potash 60.23 grams. In Lot 18 nitrogen, phosphorus and potassium were applied in the same amounts as in Lot 16, but, as indicated in Table 1, the phosphorus was applied as chemically pure monocalcium phosphate and the nitrogen as commercial sodium nitrate. The treatment was designed to throw some light on the importance of sulphur in strawberry nutrition. Since no sulphur was added to the soil in the form of fertilizers and there was only a bare trace present in the soil, the amount available for the plants must have been extremely small. The plants grown under this treatment were not as large and vigorous as those which received a complete fertilizer treatment. The petioles were shorter and the plants more spreading in habit. During a portion of the season there was a characteristic crinkling of the leaves somewhat resembling the disease known in some of the southern states as "strawberry crimp." However, an analysis of the plants given later shows that the tissues contained nearly as much sulphur as those grown under any other treatment.

Table 4.—Summary of Runner Production

Lot No.	Treatment.	Total number runners removed.	Total length of runners removed (inches)	Total fresh wt. of runners (gms.)	Av. fresh wt. of plant Oct. 26. (gms.)	Av. fresh wt. of runners per plant. (gms.)
1	No fertilizer	27	176	10.2	20.14	.3
2	N spring	251	1,304	106.9	38.0	3.0
10	NP spring	283	1,633	132.2	49.1	3.8
14	NPK spring	293	1,649	140.0	54.38	4.0
6	P spring	26	136	9.5	18.82	2.8
3	N summer	45	234	22.4	44.07	.64
11	NP summer	38	188	17.4	49.92	.5
15	NPK summer	16	140	10.0	56.5	.3
7	P summer	35	194	13.3	20.23	.4
8	P spring, N summer	61	270	27.5	42.7	.8
5	N spring, P summer	224	1,103	90.4	51.8	2.6
4	N spring-summer	224	1,103	101.4	58.7	2.9
12	NP spring-summer	455	2,288	208.0	76.3	6.0
13	NP spring-summer	456	2,282	215.4	61.0	6.2
16	NPK spring-summer	344	1,935	191.5	60.23	5.5
17	NPK spring-summer	375	2,042	200.0	60.23	6.0
18	NPK-S spring-summer	277	1,453	138.0	51.0	4.0

The Effect of Fertilizer Treatments on Runner Production.—Records of the number and length of runners produced by each lot of plants are shown in Table 3. This table also affords some idea of the distribution of runner production throughout the season. A summary of the total number, length, and fresh weight of the runners, together with the average production per plant, is given in Table 4. The unfertilized plants produced only 27 runners with a total length of 176 inches and a total weight of 10.2 grams. About 75 per cent of these were produced during June. Spring applications of nitrogen either alone or in combination with phosphoric acid or potash greatly stimulated runner production and apparently at the expense of other parts of the plant, for runners were produced freely throughout the season even though no nitrogen was applied after July 1 and the growth of the tops was checked. Continued applications of nitrogen during the summer period, particularly when in combination with phosphoric acid and potash, stimulated still greater runner production. In Lot 13 the total number of runners produced was 456, with a total length of 2,282 inches and a total weight of 215.4 grams. When nitrogen was applied during the summer period only, fewer runners were produced though the total weight of the plants slightly exceeded that of the plants in the spring-treated lots. However, when the weight of runners is taken into account the total amount of vegetative growth produced per plant was nearly the same in the spring and the summer-treated lots.

Relation of Top and Root Development. — The growth of the tops and roots previous to August 1 in the plants of the unfertilized lot and of those which were treated with acid phosphate were nearly equal, but when the plants were treated with nitrogen the tops were much larger than the roots. (See Table 5.) When nitrogen was used alone the ratio of tops to roots was 3 to 2; when it was used in combination with phosphoric acid and potash, it was 2 to 1. The weights of the plants which were collected in October show that there were increases in the root growth in all the spring-fertilized lots and decreases in the weight of the tops. Very little top growth, except the production of runners, was made in these lots after August 1. Some of the outer leaves dried up and were lost, and this, with the larger number of runners produced, accounts for the loss in weight. The data show, however, that there was considerable growth of the roots after August 1 and that the amount of living tissue in the tops at the close of the growing season was less than in the roots. In the summer-treated lots which had not been treated with nutrients previous to August 1 the development of the roots was less in proportion to the amount of tops than in the spring-fertilized lots. In the lots which were treated with nutrients during both the spring and the summer periods, the tops were all larger than the roots. It will be noticed, however, that with nitrogen alone the weight of the tops did not greatly exceed that of the roots; with the addition of phosphoric acid and potash the proportion of tops was much larger. Apparently, the phosphoric acid or the potash, or perhaps both, promoted the development of larger crowns with relatively small root systems. The most important point to be oberved, however, is that when the supply of nutrients in the soil was small the plants developed extensive root systems with small crowns. On the other hand, with a moderate supply of readily available nutrients the roots systems were less extensive and the crowns proportionally larger.

The Influence of Fertilizer Treatments on Vegetative Growth During the Spring and Summer of the Fruiting Year. — Considerable differences were observed in the growth of the plants during the spring and summer of the second (fruiting) year. The unfertilized plants developed very little new foliage, and some of them only one or two very small flower clusters. The growth of the plants of the various lots which were fertilized during the preceding season was variable, but in general, the plants which were treated during the summer period with fertilizers containing nitrogen grew more vigorously than those which were similarly treated during the spring period only. Whenever nitrogen was applied in the spring of the fruiting year there was a quick response in vegetative growth, not only in the development of new foliage but in runner production. The response in new growth was much greater in the plants of Lot 9, which were grown under rather low nutritive conditions, than in those of Lots 13 and 17 which were well supplied with nitrogen and the mineral nutrients during the preceding season.

The Influence of Fertilizer Treatments on the Nitrogen, Mineral, and Carbohydrate Content of the Plants.—Still more significant perhaps

Table 5.—The Effect of Nutrients on Top and Root Development in the Strawberry Plant

Nutrients Applied	Av. dry wt. of tops and roots August 1 (gms.)			Av. dry wt. of tops and roots October 26 (gms.)								
				Spring Treatment			Summer Treatment			Spring and Summer Treatment		
	Tops	Roots	Ratio of Tops to Roots T/R	Tops	Roots	T/R	Tops	Roots	T/R	Tops	Roots	T/R
No Fertilizer..	3.27	2.95	1.11	1.82	4.19	.43	....	....	....	....	....	....
P........	3.5	2.98	1.17	1.96	3.85	.5	2.17	3.48	.6	9.72	9.07	1.07
N........	6.24	4.16	1.47	5.56	5.84	.93	6.94	5.71	1.2	12.3	10.56	1.16
NP.......	9.77	4.73	2.06	6.95	8.34	.83	7.02	6.88	1.02	11.2	7.21	1.55
NPK.....	9.08	4.29	2.11	7.66	8.12	.94	8.14	7.7	1.06	8.76	6.68	1.3
NPK(-S)..	6.34	3.37	1.88	....	....	....	....	....	....	....	....	....

Table 6.—Percentage Composition of Strawberry Plants Collected October 26 (Oven dry material)

Lot No.	Treatment	Ash %	S %	N %	P_2O_5 %	K_2O %	Reducing sugars %	Sucrose %	Total sugars %	Starch %	Total polysaccharides %	Total carbohydrates %
	TOPS											
1	Unfertilized	....	.23	.82	.51	....	5.44	1.24	6.68	....	22.26	28.94
2	N spring	11.64	....	.97	.45	.87	7.6	3.92	11.52	1.32	10.98	22.5
10	NP spring	11.48	....	.71	.42	.99	9.76	1.4	11.16	....	16.04	27.2
14	NPK spring	11.88	....	.84	.48	.99	9.95	.7	10.65	....	12.70	23.35
6	P spring	16.16	.20	.86	.73	1.10	....	7.8	7.8	....	8.24	16.04
5	N spring, P summer	14.24	....	.66	.52	.98	10.13	1.2	11.33	.90	13.74	25.07
3	N summer	11.89	....	1.59	.49	1.10	9.1	.8	9.9	....	7.5	17.4
11	NP summer	9.40	....	2.02	.76	1.33	2.9	4.63	7.53	....	9.87	17.4
15	NPK summer	11.05	....	2.09	.84	1.50	7.49	4.78	12.17	.80	11.18	23.35
8	P spring, N summer	15.15	....	1.79	.67	1.11	2.61	8.11	10.72	....	11.26	21.98
4	N spring-summer	13.34	.26	1.55	.34	.98	6.66	3.09	9.75	1.03	11.64	21.39
12	NP spring-summer	10.88	.26	1.79	.66	1.00	5.4	4.9	10.3	1.0	10.29	20.59
16	NPK spring-summer	11.89	.22	1.63	.62	1.01	3.91	5.95	9.86	1.03	12.00	21.86
18	NPK-S spring-summer	12.86	.19	1.55	.65	1.25	4.33	7.72	12.05	.72	12.43	24.48
	ROOTS											
1	Unfertilized	27.21	.19	.69	.50	.87	5.17	1.97	7.14	....	15.34	22.48
4	N spring-summer	18.72	.21	1.64	.39	.86	5.72	.50	6.22	4.14	18.81	25.03
6	P spring	30.85	.24	.84	.87	1.06	5.27	1.06	6.33	....	14.67	21.0
12	NP spring-summer	19.18	.41	2.22	.69	1.03	8.79	.75	9.54	3.0	11.87	21.41
16	NPK spring-summer	13.89	.27	2.02	.67	1.01	....	....	....	....	....	....
18	NPK-S spring-summer	12.27	.19	1.72	.68	1.13	....	....	....	....	....	....

than the morphological characters which have been discussed were the differences in the nitrogen, mineral and carbohydrate content of the plants in the different lots. The analyses of the plants taken October 26 are shown in Tables 6 and 7. Some of the samples were too small to make all determinations, and for this reason the analyses in several cases, particularly for sulphur and starch, are incomplete. Only a few analyses of the roots are given. These show that the ash and starch content are larger in the roots than in the tops. There were some differences in the percentages of nitrogen and of carbohydrates other than starch, but the data in Table 7 show that, in general, the absolute amounts in proportion to the amount of dry matter were nearly the same. The percentage of ash in the tops varied from 9.4 in Lot 11 to 16.16 in Lot 6. It will be noticed, however, that the plants with the least ash contained larger amounts of nitrogen, phosphoric acid and potash than those with the highest ash content. The unfertilized plants and those which were treated in the spring period only with fertilizers containing nitrogen showed lower percentages of nitrogen, phosphoric acid and potash and a higher percentage of carbohydrates than those which were similarly treated during the summer period. The greatest differences were in the nitrogen content. When the nutrients were applied in the summer period only, the percentage of nitrogen was larger than when corresponding treatments were given during both the spring and summer periods. In the spring-treated lots the nitrogen ranged from 0.66 to 0.97; in the summer-treated lots from 1.59 to 2.02; and in the spring and summer-treated lots from 1.55 to 1.79 per cent. Reference to Table 7 shows, however, that the absolute amounts of nitrogen and carbohydrates per plant were the largest in Lots 4, 12 and 16, which were well supplied with nutrients during the entire season.

The analyses of the plants at the close of the spring period (August 1) are given in Table 8. A comparison of these analyses with those of the plants which were taken October 26 shows that considerable amounts of nitrogen and potash which had been absorbed by the plants during the early stages of growth were lost later in the season. The data show that in Lots 1 and 6 there was an increase in the percentages of nitrogen and phosphoric acid but a decrease in potash during the summer period. In Lots 2, 10 and 14 the phosphoric acid remained nearly constant but there were large decreases in nitrogen and potash. The total dry weights of the plants on August 1 and on October 26 were nearly the same; therefore, the loss in percentage cannot be accounted for by an increase in bulk or growth of plant. There were probably some losses of these elements from the crowns through runner production and the death of some of the outer leaves during the summer period. It is also conceivable that certain amounts may have been returned to the soil and that there were losses from the plants by leaching. A further comparision of the analyses in Tables 6 and 8 brings out still another interesting fact. The nitrogen-carbohydrate relationship within the plants on August 1 was nearly identical with that of the summer-treated plants on October 26. The response to this condition in the spring-treated plants, however, was manifested chiefly by a vigorous runner production and, as will be shown later, no fruit bud differentiation at the time and very little fruit bud differentiation in late fall; under similar conditions in the summer-treated plants there was less tendency for runner production and a greater response in fruit bud formation. The analyses of the spring-treated plants taken on October 26 show that there was a decrease in the percentage of nitrogen after August 1 and a slight increase in carbohydrate content. In

Table 7.—Absolute Amounts of Nitrogen, Minerals, and Carbohydrates per Plant in Strawberry Plants Collected October 26.

Lot No.	Av. dry wt. of tops per plant (gms.)	S (gms.)	N (gms.)	P_2O_5 (gms.)	K_2O (gms.)	Free reducing sugars (gms.)	Sucrose (gms.)	Total sugars (gms.)	Starch (gms.)	Polysaccharides (gms.)	Total carbohydrates (gms.)
	TOPS										
1	1.67	.004	.014	.009	....	.091	.021	.112	....	.372	.483
2	5.03	....	.049	.023	.044	.382	.197	.579	.066	.552	1.132
10	6.39	....	.045	.027	.063	.623	.089	.712	....	1.030	1.738
14	7.09	....	.060	.034	.070	.705	.050	.755	....	.900	1.655
6	1.82	.004	.016	.013	.020	....	.142	.142	....	.150	.292
5	7.26	....	.052	.038	.071	.735	.088	.823	.065	.998	1.820
3	6.43	....	.102	.032	.071	.585	.052	.637	....	.482	1.119
11	6.53	....	.132	.049	.087	.189	.303	.492	....	.644	1.136
15	7.47	....	.156	.063	.112	.559	.350	.909	.059	.835	1.744
8	5.83	....	.046	.039	.065	.152	.473	.625	....	.660	1.281
4	8.97	.023	.139	.031	.087	.597	.278	.875	.092	1.044	1.918
12	11.4	.030	.204	.075	.114	.615	.559	1.174	.114	1.170	2.347
16	10.36	.030	.169	.064	.105	.405	.616	1.021	.106	1.243	2.264
18	8.04	.015	.125	.053	.100	.348	.621	.969	.058	1.000	1.968
	ROOTS										
1	3.89	.0073	.0268	.0194	.0338	.201	.0766	.277	....	.596	.873
4	8.42	.0176	.138	.0328	.0656	.481	.043	.524	.348	1.583	2.107
6	3.61	.0086	.0303	.0314	.0382	.190	.038	.228	....	.529	.757
12	9.79	.03	.217	.0675	.1007	.860	.074	.934	.293	1.162	2.096

Table 8.—Nitrogen, Mineral and Carbohydrate Content of Strawberry Plants Collected August 1

Lot No.	Treatment	S %	N %	P_2O_5 %	K_2O %	Free reducing sugars %	Sucrose %	Total sugar %	Polysaccharides %	Total carbohydrates %
1	Unfertilized	.14	.69	.33	1.68	....	....	....	....	....
6	P spring	.17	.65	.46	1.60	....	....	....	....	....
2	N spring	.15	1.22	.48	1.66	5.57	2.59	8.16	12.19	20.35
10	NP spring	.25	1.38	.49	1.64	11.97	1.26	13.23	12.39	25.62
14	NPK spring	.16	1.35	.49	1.60	11.84	1.75	13.59	12.51	26.1
18	NPK (-S)	.19	1.52	.52	2.06	6.06	2.07	8.13	12.37	20.5

Lot 18 which received nitrogen during both the spring and summer period the percentages of nitrogen on August 1 and October 26 were nearly the same and there was a slight increase in the percentage of carbohydrates.

THE RELATION OF POTASH AND SUGARS

One of the general effects of the fertilizer treatments in this experiment was an increase in the amount of sugars and a decrease in polysaccharides. The unfertilized plants contained 6.68 per cent sugar and 22.26 per cent polysaccharides. With the exception of Lots 6 and 11 the amounts of sugar in the fertilized lots ranged from 9.75 to 12.17 per cent. Lot 3 was lowest in polysaccharides with 7.5 per cent, Lot 10 highest with 16.04 per cent. Spring-treated plants contained more free reducing sugars and less sucrose than the summer-treated plants. The data presented in Table 9 show that there is, apparently, some relationship between the intake of potash and the amount of sugars found in the plant. The potash content varied from 20 to 114 mgms. and the sugar content from 142 to 1174 mgms. per plant. The ratio of potash to sugars (S/K_2O) in the tops varied from 1.0:5.6 to 1.0:13.5. The average ratio was 1:8.7, the most common ratio about 1:10. In the roots the ratio was approximately 1:8. The data indicate that though there is no definite ratio of potash to sugars the amount of sugars produced is closely associated with the intake of potash.

Table 9.—The Ratio of Potash and Sugar in the Strawberry Plant

Lot No.	Dry wt. per plant (gms.)	Potash (K_2O)		Sugar.		Ratio of potash to sugars. S/K_2O.
		Per cent.	Mgms. per plant.	Per cent.	Mgms. per plant.	
	TOPS					
2	5.03	.87	43	11.52	579	13.5
3	6.43	1.10	70	9.9	637	9.9
4	8.97	.98	87	9.75	875	10.5
5	7.26	.98	71	11.33	823	11.7
6	1.82	1.10	20	7.8	142	7.1
8	5.83	1.11	65	10.72	625	9.6
10	6.39	.99	63	11.16	713	11.3
11	6.53	1.33	87	7.53	492	5.6
12	11.4	1.00	114	10.3	1,174	10.3
14	7.09	.99	70	10.65	755	7.08
15	7.47	1.50	112	12.17	909	8.1
16	10.36	1.01	105	9.86	1,021	9.7
18	8.04	1.25	100	12.05	968	9.7
	ROOTS					
1	3.89	.87	34	7.14	277	8
4	8.42	.86	65	6.22	524	8
6	3.65	1.06	38	6.33	228	6
12	9.79	1.03	100	9.54	934	9.3

The Total Intake of Nitrogen and Mineral Elements by the Strawberry Plant. — Calculations from the data in Table 6 show that the typical ash content of the plants at the termination of growth in the fall was approximately 12.4 per cent, and that the plants contained an average of 1.75 per cent nitrogen, .64 per cent phosphoric acid, and 1.16 per cent potash. Though these figures are not necessarily indicative of the requirements of the strawberry, they furnish a measure of the amounts of the various nutrients absorbed from the soil by the plants. Analyses of the berries indicate that the amounts of nitrogen, phosphoric acid, and potash present in the fruit are small and suggest that relatively the strawberry is not a soil-depleting crop. However, the data show that the amount of nutrients required by the plants during the period of vegetative growth is considerable.

The Influence of Fertilizer Treatments on the Flowering and Setting of Fruit. — Table 10 summarizes the data on flower production and the set of fruit in the different lots. The general effect of the fertilizers containing nitrogen has been an increase in the number of clusters per plant and in some cases a slight increase in the number of flowers per cluster. The average number of flower clusters per plant in the spring-fertilized lots ranged from 4.7 to 6.4, and in the summer-fertilized lots from 9.7 to 11.7. The average number of clusters per plant in the lots which received both spring and summer treatments was somewhat larger, ranging from 10.5 to 14.4, and there was a slightly larger number of flowers per cluster. The applications of fertilizers in the spring of the fruiting year had no effect on the number of clusters or the number of flowers per cluster.

Table 10.—The Influence of Fertilizer Treatments on Flowering and the Setting of Fruit in the Strawberry

Lot No.	Treatment.	Av. no. flower clusters per plant.	Av. no. flowers per cluster.	Total no. flowers setting fruit.	Per cent of flowers setting fruit.	Per cent of set matured.
1	Unfertilized	3.3	6	76	22.7	86.8
1A	Unfertilized 1st yr. N spring	4.0	7.2	57	40	84.2
2	N spring	6.4	6.5	208	30.8	83.1
10	NP spring	5.0	7.4	225	33.3	84.4
14	NPK spring	4.7	7.8	198	28.4	84.8
6	P spring	4.4	5.7	113	27.9	92.9
5	N spring, P summer	4.9	7.3	201	27.8	88.5
3	N summer	11.7	6.8	596	37.1	83.3
11	NP summer	9.7	9.1	648	38.4	76.3
15	NPK summer	10.3	7.4	740	46.0	83.5
8	P spring, N summer	11.3	7.5	626	36.8	83.5
7	P summer	3.8	6.6	141	27.0	89.3
9	P summer, N second spring	3.2	7.0	344	61.3	88.1
4	N spring-summer	12.2	7.1	717	39	76.5
12	NP spring-summer	14.4	8.8	910	40	75.1
13	NP spring-summer-spring	13.3	8.8	1,228	52	74.6
16	NPK spring-summer	11.7	8.2	685	37.6	81.9
17	NPK spring-summer-spring	10.5	9.1	1,091	47.3	81.4
18	NPK-S spring-summer-spring	7.6	8.9	563	43.3	88.4

The percentages of flowers which set fruit are also shown in Table 10. From these data it appears that the percentage of set may be influenced by nutritive conditions which exist in the plant, and to a considerable extent by nutritive conditions in the soil during the blooming season. Plants which had been fertilized during the spring period only did not set as many flowers as those which had been fertilized during the summer period. The average set of all spring (first year) fertilized lots was 29.6 per cent, of all summer-fertilized lots 37 per cent, and of those which had been fertilized during both the spring and the summer periods 39 per cent. Reference to Table 6 shows that the summer-fertilized plants had more reserve nitrogen in the tissues in the fall, which may account for the better set of fruit the following spring.

Applications of nitrogen in the spring of the fruiting year greatly increased the set of fruit, particularly with those plants which were grown under low nutritive conditions the preceding summer and fall. In Lot 1 (unfertilized), 22.7 per cent of the blossoms set fruit, while in those of the same lot which had received an application of sodium nitrate just before blossoming there was a 40 per cent set. In Lot 9, which had been treated with acid phosphate during the summer period and with nitrogen the following spring, 61.3 per cent of the blossoms set fruit while the set was only 27.6 per cent when no spring application of nitrogen was used.

The Influence of Fertilizer Treatments on the Total Yield and Size of Fruit. — Table 11 presents a summary of the average total yield and the number and weight of berries from the plants of the different lots. Nitrogen, when used alone or in combination with phosphorus and potash, in every instance greatly increased the yield. The yields due to the influence of spring applications of fertilizer the first year were doubled and in some cases trebled by the same treatment with fertilizers during the summer period. Fertilizers applied during both spring and summer periods in only one instance gave increased yields over those which were applied in the summer period only. The largest yields were secured from plants in Lots 13 and 17 which were fertilized during both the spring and summer periods and again in the spring of the fruiting year. Applications of nitrogen in the spring of the fruiting year increased the yields by inducing a better setting of the flowers and an increase in the size of the berries.

Table 11.—Number and Size of Berries per Plant as Influenced by Different Fertilizer Treatments

Lot No.	Treatment.	Av. no. berries per plant.	Av. total wt. of berries per plant. (gms.)	Av. wt. per berry. (gms.)
1	Unfertilized	3.9	9.8	2.5
1A	Unfertilized (1st yr,), Nitrogen (2nd spring)	9.6	24.2	2.5
6	P spring	6.56	14.3	2.18
7	P summer	6.0	14.4	2.4
9	P summer, N 2nd spring	12.1	35.0	2.88
2	N spring	10.8	25.7	2.37
10	NP spring	10.6	22.6	2.14
14	NPK spring	8.74	20.8	2.26
5	N spring, P summer	8.9	20.6	2.3
3	N summer	24.8	53.5	2.2
11	NP summer	26.0	58.1	2.23
15	NPK summer	31.0	71.5	2.43
8	P spring, N summer	26.1	60.5	2.33
4	N spring-summer	26.1	53.2	2.04
12	NP spring-summer	38.0	74.7	1.97
13	NP spring-summer-spring	45.8	96.3	2.1
16	NPK spring-summer	29.63	67.1	2.26
17	NPK spring-summer-spring	37.0	91.3	2.46
18	NPK-S spring-summer-spring	26.2	54.7	2.09

In Table 12 data are arranged to show the number and size of the berries which ripened in different periods during the harvesting season. It will noticed that the berries which ripened in the first period (June 20-25) were the largest and that there was a decrease in size until at the end of the season many of them were very small. However, Valleau (11) has shown that there is a definite relationship between the position of the flower in the cluster and the size as well as the degree of setting of the fruit. With Senator Dunlap in particular, he found that though a very large percentage of the primary flowers set perfect fruit, there was a gradual decrease in the number of perfect fruits and the total number of berries set from the primary

Table 12.—The Influence of Fertilizer Treatments on the Number and Size of Berries at Different Periods During the Harvesting Season

Lot No.	Treatment.	Av. No. clusters per plant.	Berries harvested June 20 to 25.			Berries harvested June 27 to July 2.			Berries harvested July 2 to 10.		
			Av. no. berries per plant.	Av. total wt. berries per plant. (gms.)	Av. wt. of berry. (gms.)	Av. no. berries per plant.	Av. total wt. of berries per plant. (gms.)	Av. wt. of berry. (gms.)	Av. No. per plant. berries	Av. total wt. of berries per plant. (gms.)	Av. wt. of berry. (gms.)
1	Unfertilized	3.3	.6	2.7	4.5	1.4	3.8	2.7	2.0	3	1.51
1A	N spring, 2nd yr	4.0	2.0	9.2	4.6	4.4	9.6	2.2	3.2	5.4	1.7
6	P spring	4.4	1.5	4.2	3.0	2.1	5.4	2.4	3.0	5.0	1.63
7	P summer	3.8	1.86	6.1	3.2	2.0	4.0	2.0	2.2	4.3	1.95
9	P summer, N 2nd spring	3.2	2.9	11.7	4.1	6.1	17.3	2.8	3.1	5.9	1.9
2	N spring	6.4	2.9	10.5	3.65	4.2	9.5	2.26	3.7	5.7	1.54
10	NP spring	5.0	2.55	8.3	3.26	4.0	9.4	2.35	4.0	4.9	1.22
14	NPK spring	4.7	2.26	7.8	3.44	3.0	6.6	2.2	3.5	5.4	1.54
5	N spring, P summer	4.9	2.15	7.8	3.63	3.65	8.7	2.4	3.1	4.1	1.32
3	N summer	11.7	4.9	13.8	2.8	10.0	25.0	2.5	9.8	14.8	1.5
11	NP summer	9.7	5.0	16.0	2.8	10.7	28.0	2.6	10.3	16.1	1.56
15	NPK summer	10.3	3.3	11.1	3.4	13.0	37.6	2.9	13.2	23.0	1.75
8	P spring, N summer	11.3	5.0	16.0	3.2	11.6	32.0	2.7	9.4	13.4	1.42
4	N spring-summer	12.2	5.3	15.8	3.0	13.0	25.5	2.0	9.0	11.9	1.33
12	NP spring-summer	14.4	5.6	16.0	2.9	18.0	41.6	2.3	14.3	17.0	1.2
13	NP spring-summer-spring	13.3	7.65	24.0	3.14	25.5	57.2	2.24	12.7	15.0	1.2
16	NPK spring-summer	11.7	6.0	17.8	2.97	14.0	35.4	2.5	10.0	14.0	1.4
17	NP spring-summer-spring	10.5	7.0	23.0	3.30	18.7	51.0	2.7	11.4	18.0	1.6
18	NPK-S spring-summer-spring	7.6	4.8	13.7	2.85	10.0	24.7	2.47	11.4	16.5	1.45

to the last flowers which opened in the cluster. The data in Table 12 show that the number of early berries depends more on the number of flower clusters than any other factor. Nitrogen applied in the spring of the fruiting year slightly increased the number as shown in Lots 1A, 9, 13 and 17, probably by a better setting of the primary flowers. The early berries were usually larger when they were few in number. In Lots 1, 2, 10 and 14, which bore a small number of clusters, the berries were larger than those from the summer-treated plants in Lots 3, 11 and 15, which bore a large number of clusters.

In the second period (June 27 to July 2) a larger number of berries in proportion to the number of clusters was harvested from the summer-fertilized plants and the fruit was larger in size. Nitrogen applied in the spring before fruiting was most effective during this period. Apparently it influenced a much larger setting of the secondary and tertiary flowers in the clusters, for 3.8 clusters per plant in Lot 7 ripened only 2 berries with an average weight of 2 grams each while 3.2 clusters in Lot 9 ripened 6.1 berries with an average weight of 2.8 grams each. Corresponding increases in the number and size of berries during this period may be shown by a comparison of Lots 12 and 13 and of Lots 16 and 17.

In the third period, which included the last four pickings, nearly all the fruit was small. However, the size of berry in Lots 7, 9 and 15 held up well to the end of the season. The number of berries ripened in this period was about equal to the number ripened in the second except in Lots 4, 12, 13, 16 and 17, which ripened about fifty per cent of the entire crop during the second period.

The Relation of Nitrogen and Carbohydrates to Fruit Bud Formation and Yield in the Strawberry Plant. — The results of recent investigations indicate that the proportion of nitrogen and carbohydrates existing in the plant at certain times of the year bears an important relationship to fruit bud differentiation and to blossom and fruit production the following spring and summer. Kraus and Kraybill (9) in their studies of the response in vegetative growth and fruit setting of the tomato concluded that "fruitfulness is associated neither with highest nitrates nor highest carbohydrates but with a condition of balance between them. Fertilizers containing available nitrogen are mainly effective in producing vegetative response. They may either increase or decrease fruitfulness according to the relative available carbohydrate supply."

Extreme ranges in the nitrogen and carbohydrate content were produced by the treatments given the plants in these experiments: (1) a low nitrogen content with high carbohydrates; (2) a low nitrogen content with low carbohydrates; (3) a high nitrogen content with low carbohydrates; and (4) a high nitrogen content with high carbohydrates.

Lots 1 and 6 both have a low nitrogen content, but the carbohydrate content is high in Lot 1 and low in Lot 6. The number of clusters and the total yield of fruit in Lot 6 was larger than in Lot 1. However, it is evident that high carbohydrates alone was not responsible for the relatively low yield in Lot 1, for other lots nearly as high in carbohydrates yielded well. Nevertheless the combination of high carbohydrates with low nitrogen has apparently inhibited fruit bud formation, for Lots 5, 10 and 14 were all low in nitrogen and high in carbohydrates and their relative production as measured by number of clusters and yield of fruit in proportion to their size is even less than in Lot 1. In Lot 6 which was fertilized with acid phosphate the plants contained larger amounts of phosphoric acid, potash,

Table 13.—Nitrogen and Carbohydrates and their Relation to Fruit Bud Formation and Yield in the Strawberry Plant

Lot No.	Dry wt. of tops per plant. (gms.)	Nitrogen.		Total carboyhdrates.		Av. no. clusters per plant.	Av. no. clusters per gm. dry wt. of plant.	Av. no. berries per plant.	Av. total wt. of berries per plant. (gms.)	Av. total wt. of berries per gm. dry wt. of plant.
		Per cent.	Mgms. per plant.	Per cent.	Mgms. per plant.					
1	1.67	.82	14	28.94	483	3.3	2.0	3.9	9.8	5.27
6	1.82	.86	16	16.04	292	4.4	2.4	6.56	14.3	7.85
2	5.03	.97	49	22.5	1,132	6.4	1.27	10.8	25.7	5.1
8	5.83	1.79	104	21.98	1,281	11.3	2.0	26.1	60.5	10.4
10	6.39	.71	45	27.19	1,738	5.0	.8	10.6	22.6	3.5
3	6.43	1.59	102	17.4	1,119	11.7	1.8	24.8	53.5	8.3
11	6.53	2.02	132	17.4	1,136	9.7	1.5	26.0	58.1	8.8
14	7.09	.84	60	23.35	1,655	4.7	.66	8.74	20.8	2.9
5	7.26	.66	52	25.07	1,820	4.9	.67	8.9	20.6	2.8
15	7.47	2.09	156	23.35	1,744	10.3	1.38	31.0	71.5	9.6
18	8.04	1.55	125	24.48	1,968	7.6	.94	26.2	54.7	6.8
4	8.97	1.55	139	21.39	1,918	12.2	1.36	26.1	53.2	6.0
16	10.36	1.63	139	21.86	2,264	11.7	1.13	29.6	67.1	6.5
12	11.4	1.79	204	20.59	2,347	14.4	1.26	38.0	74.7	6.6

and sugars than those in Lot 1, and it is possible that these factors may have had some influence on the formation of fruit buds.

Lots 2 and 8 both had a moderately high carbohydrate content but there was twice as much nitrogen in Lot 8 as in Lot 2. Here the nitrogen content would appear to be the limiting factor in fruit production, for in Lot 2 with 0.97 per cent nitrogen there were 6.4 clusters and the total yield was 25.7 grams per plant, while in Lot 8 with 1.79 per cent nitrogen the number of clusters was 11.3 and the yield of fruit 60.5 grams per plant.

The data from Lots 3, 10 and 11 also suggest that nitrogen was the governing factor in fruit production, for in Lot 10 which had a low nitrogen content—0.71 per cent—and a high carbohydrate content, the number of clusters and the total yield of fruit was less than one-half that from Lots 3 and 11 which had a high percentage of nitrogen and a comparatively low carbohydrate content.

Similar comparisons may be made with the remaining groups. It will be noticed that the carbohydrate content was moderately high in all the lots in these groups, but that there were extremes in the nitrogen content. Low nitrogen content in Lots 5 and 14 was associated with low yields. On the other hand, high nitrogen with high carbohydrates as in Lot 15 was associated with high yields. In general, the data show clearly the importance of nitrogen in the nutrition of the strawberry. A large accumulation of carbohydrates is desirable, but a relatively large amount of nitrogen is very important for fruit bud differentiation and the development of the fruit the following spring.

Equally clear is the fact that fruit bud differentiation is limited by some factor or factors other than a certain proportion of nitrogen and carbohydrates in the plant. It has been pointed out that though in this experiment extreme ranges have been produced both in the nitrogen and in the carbohydrate content in the various lots of plants at the time of fruit bud differentiation, some fruit bud formation has always taken place—better in some lots than in others—but nevertheless it has never been entirely inhibited. Furthermore, in the discussion of the data presented in Table 7, it has been shown that the nitrogen-carbohydrate content of the spring-fertilized plants on August 1 was very similar to that of the summer-fertilized plants on October 26. Sometime after August 1, the nitrogen-carbohydrate relationship of the summer-fertilized plants must have become identical with that of the spring-fertilized plants earlier in the season. The response to this condition in the spring-fertilized plants was a vigorous runner production. On the other hand, when this condition obtained in the summer-fertilized plants it did not start a vigorous runner production, but led to fruit bud formation.

The data show, however, that though fruit bud formation has not been entirely inhibited by the extremes in the nitrogen and in the carbohydrate content of the various lots of plants, there are certain nutritive conditions which are more favorable than others for it during late summer and fall when normally it is taking place. Extreme variations in the nitrogen content have had a greater effect than extremes in carbohydrate content. High carbohydrates with low nitrogen had an inhibiting effect. Low nitrogen has always been associated with low yields; high nitrogen with high yields. The best condition in the plant at the time of fruit bud differentiation was a high nitrogen content associated with a moderately high, or a high percentage of carbohydrates.

The Influence of Fertilizer Treatments on Pistil Abortion.—Gardner

(8) has shown that the number of pistils per flower and the setting of the individual pistils bears an important relationship to the size of the fruit, and that the nutritive conditions in the plant during the fall, particularly at the time of fruit bud differentiation, has considerable influence on the setting of the pistils the following spring. No attempt has been made in this investigation to study this relation other than to determine the influence of the different treatments on this factor in the development of the fruit. Counts were made of the number of akenes and of the aborted pistils in berries from each of the different lots. Some of the berries were collected early in the season and some from the midseason crop. None of the small late berries were saved for this purpose. The data are presented in Table 11. The differences in the number of pistils per berry were not as large as might be expected considering the wide range of the treatments. In general the number of pistils was larger in the berries from the plants which had received summer treatments than from those of the spring-treated lots, but the differences are not sufficiently consistent to warrant any definite conclusions. Furthermore, there is no evidence that there has been any definite influence of the different treatments, on the setting of the individual pistils.

Table 14.—The Influence of Fertilizer Treatments on Pistil Abortion

Lot No.	Treatment.	Av. total no. of pistils per berry.	Av. no. of akenes.	Av. no. aborted pistils.	Per cent of pistils aborting.
1	Unfertilized	217	197	20	9.2
2	N spring	243	212	31	12.7
10	NP spring	158	137	21	13.3
14	NPK spring	223	197	26	11.6
5	N spring, P summer	247	223	24	9.7
6	P spring	233	215	18	7.7
3	N summer	235	208	27	11.5
11	NP Summer	238	213	25	10.5
15	NPK summer	261	226	35	13.4
8	P spring, N summer	253	221	32	12.6
7	P summer	204	183	21	10.3
4	N spring-summer	242	204	38	15.7
12	NP spring-summer	228	210	18	8.0
16	NPK spring-summer	253	230	23	9.1
18	NPK-S spring-summer	213	171	42	19.7
9	P summer, N following spring	192	170	22	11.5
13	NP spring-summer-spring	268	244	24	8.2
17	NPK spring-summer-spring	266	224	22	8.2

The Moisture Content of Berry as Influenced by Fertilizer Treatments.—In the field experiments which have been reported from different sections of the country, frequent mention has been made of the effect of fertilizers on the texture and quality of the fruit. Chandler (4), in particular, reported that whenever nitrogen was applied in the spring before the crop was harvested it tended to make the berries soft and of poor color and quality. Somewhat similar results are reported by Bailey (1) from the use of nitrogenous fertilizers when applied in the spring a year before the crop was harvested. Brown (3) found that when the weather was extremely warm during a large portion of the season the plants which had received heavy applications of nitrogen produced berries that were inclined to be soft and that plants receiving sulphate of potash produced somewhat firmer but not more attractive berries. However, in the years when there was a long cool picking season there was practically no difference in the firmness, size, and appearance of the fruit.

Moisture determinations were made for three samples of fruit which were taken at different times during the harvesting period, from each of the different lots of plants in this experiment.

Table 15.—Moisture Content of Berries as Influenced by Fertilizer Treatments.

Lot No.	Treatment.	Wt. of H_2O per gm. of dry matter.			Av. wt. of H_2O per gm. dry matter.
		Sample 1.	Sample 2.	Sample 3.	
1	Unfertilized	9.1	7.6	8.85	8.52
2	N spring	9.7	8.25	8.77	8.91
10	NP spring	9.7	8.15	8.6	8.82
14	NPK spring	8.7	7.4	9.0	8.03
6	P spring	10.3	7.2	7.84	8.44
3	N summer	10.7	8.86	9.04	9.53
11	NP summer	10.2	8.2	9.5	9.3
15	NPK summer	11.0	8.44	9.3	9.58
7	P summer	9.56	7.3	8.6	8.49
4	N spring-summer	10.7	8.6	9.8	9.53
12	NP spring-summer	12.1	9.0	8.8	9.97
16	NPK spring-summer	10.9	8.87	9.6	9.79
5	N spring, P summer	9.7	7.6	7.61	8.3
8	P spring, N summer	9.17	8.7	8.8	8.89
9	P summer, following spring	8.9	7.33	6.6	7.61
13	NP spring-summer-spring	10.6	8.3	8.0	8.93
17	NPK spring-summer-spring	10.4	7.9	8.6	8.97
18	NPK-S spring-summer-spring	10.3	9.3	9.4	9.7

Berries from the unfertilized plants and those which were treated with acid phosphate alone showed a lower moisture content than those from the other fertilized lots. Plants which had been fertilized with nitrogen during the summer period produced berries with a higher moisture content than those which had been similarly treated during the spring period only. However, there was practically no difference in the appearance and texture of the fruit at the time of harvesting. Acid phosphate and potash when used in combination with nitrogen had no effect on total moisture content. The use of fertilizers applied in the spring of the fruiting year, as shown in Lots 9, 13 and 17, did not result in any increase in moisture content though the berries were somewhat larger than those from the plants which were not fertilized at that time.

DISCUSSION

Though strawberries are actually planted in soils of practically every kind, they are seldom grown in a medium that is of lower productivity than the one used in this experiment—a dune or "blow" sand. The evidence indicates that even such a soil will provide the strawberry plant with an ample supply of most of the essential nutrient elements. Applications of fertilizers carrying nutrient elements other than nitrogen would seem to be of little value, though perhaps in some cases phosphorus-containing materials may be of some use. On the other hand, the data show that a deficiency in available nitrogen at any period during the growing season profoundly influences the growth and development of the plant and bservation leads to the belief that such deficiencies are of common occurrence in strawberry production. Furthermore, surpluses over and above amounts actually required often lead to an undue amount of runner production. From a practical standpoint, then, nitrogen is the nutrient element to which the grower needs to give the most of his attention.

Plants grown with a limited supply of available nitrogen during the spring and early summer and with a more liberal supply later will produce crowns about as large as those in which these nutrient conditions are reversed, and they are much more productive. On light soils which are likely to be deficient in nitrogen, the application of quickly available nitrogenous fertilizers in the spring when the plants are set may stimulate a vigorous vegetative growth with an abundant runner production. This may result in a condition which will arrest the development of the crowns and reduce fruit bud formation. Therefore, such applications, if made at all, should be light in the case of those plantations intended for fruit production. In the case of plantations intended principally for plant or runner production more liberal spring applications are warranted. In many cases both spring and summer applications of nutrients may be necessary for the development of crowns of sufficient size for maximum fruit production and to obtain the best conditions for fruit bud differentiation. However, if only one application is to be given the summer treatment is preferable.

Fruit bud formation and total yield of fruit depend largely on nutritive conditions within the plant in late fall. More specifically, they seem to be associated with a rather high nitrogen and carboydrate content within the plant at that particular time. These in turn depend largely on soil nutrient conditions, particularly the supply of available nitrogen during the late summer and early fall. Without doubt, many soils that are being well cultivated naturally provide conditions that approach the optimum in this respect, and fertilizer applications would not be useful. They might even be harmful. On the other hand, it is evident that in many cases light or moderate summer and early fall applications of quickly available nitrogen-carrying fertilizers would be of value. No definite statement can be made that will enable the grower to decide exactly when or where fertilizer applications are reasonably sure to prove profitable nor can a definite statement be made as to how heavy such applications should be. However, observations on the appearance of the different lots under experimental study in this investigation, the data furnished by the analyses, and the later fruiting records, together with many field observations lead to the belief that any considerable purpling of the foliage in the summer or early fall, excluding that which is obviously caused by drouth or leaf spot, indicates a deficiency of available soil nitrogen that is very likely to interfere with fruit bud differentiation and correspondingly to reduce subsequent yield. This should be a signal for judicious applications of nitrogen-carrying fertilizer; better still, the grower should so handle his strawberry plantation as to prevent this condition from developing. It is, of course, possible that applications of amounts over and above those required to prevent such purpling may sometimes be desirable. Applications of nitrogen in the spring of the fruiting year may increase yields by inducing a better setting of the flowers and an increase in the size of the berries. However, the greatest response from an application at this time may be expected from those plants which have been grown under low nutritive conditions during the preceding summer and fall.

SUMMARY AND CONCLUSIONS

1. Large variations have occurred in the size of the plants as a result of receiving the various fertilizer treatments in this experiment. The summer-treated plants were slightly larger than the spring-treated plants. The largest plants were obtained when the nutrients were applied during both the spring and the summer periods.

2. Nitrogen has been the chief limiting element. It is an important factor in promoting vegetative growth and is particularly important at the time of fruit bud differentiation.

3. Phosphorus alone apparently has had no effect on vegetative growth. In combination with nitrogen it has promoted a larger vegetative growth and fruit production than was secured with nitrogen alone.

4. Plants treated with sodium nitrate, monocalcium phosphate and potash were not as large or as productive as those treated with ammonium sulphate, acid phosphate and potash.

5. Spring applications of nitrogen, alone or in combination with phosphoric acid or phosphoric acid and potash, caused a vigorous runner production. When equal amounts of the same nutrients were applied during the summer period, few runners were produced and there was a better development of the crowns.

6. With a limited supply of nutrients in the soil the roots were large in proportion to the tops. With a moderate supply of nutrients the root system was less extensive and the tops proportionally larger. When phosphoric acid and potash were used in combination with nitrogen the proportion of tops to roots was larger than when nitrogen was used alone.

7. Plants which had been treated with nitrogen during the previous summer period grew better in the spring of the fruiting year than the unfertilized, or the spring-treated (first year) plants. When nitrogen was applied in the spring of the fruiting year the response in vegetative growth was greater in plants grown under low nutritive conditions the preceding summer and fall.

8. The ash content of the roots was larger than that of the tops. There were some differences in the percentages of nitrogen and carbohydrates in the tops and roots, but the absolute amounts of the various constituents in proportion to the amount of dry matter were nearly the same.

9. The amount of ash in the tops varied from 9.4 to 16.16 per cent, but the plants with the lowest percentage of ash contained higher percentages of nitrogen, phosphoric acid and potash than those with the highest ash content.

10. The unfertilized plants and the spring-treated plants were lower in nitrogen, phosphoric acid and potash and higher in percentage of carbohydrates, than the summer-treated plants.

11. One of the effects of the fertilizer treatments was an increase in sugars and a decrease in polysaccharides. Spring-treated plants contained more free reducing sugars than the summer-treated plants. The amount of sugars in the plants appears to be closely associated with the potash content.

12. Calculations from the data of this experiment show that an acre of strawberry plants in hills 15 by 30 inches apart will produce, during the period of vegetative growth and fruit bud formation, approximately 2,500

pounds of dry matter which will contain 41.75 pounds of nitrogen, 16 pounds of phosphoric acid, 29 pounds of potash and 225 pounds of other mineral constituents.

13. The total number of flowers per plant as modified by fertilizer treatments is determined chiefly by the number of clusters, and to a very limited extent by the number of flowers per cluster. Fertilizers containing nitrogen increased the number of flower clusters per plant. The summer-treated plants produced nearly twice as many clusters as the spring-treated plants. A slightly larger number of clusters was borne by the spring and summer-treated plants. Applications of fertilizers in the spring of the fruiting year have no effect on the number of clusters or the number of flowers per cluster.

14. The proportion of flowers which set fruit was influenced to some extent by nutritive conditions which exist in the plant the preceding fall, and to a considerable extent by nutritive conditions in the soil at blooming time. Summer-treated plants, which contained more nitrogen at the termination of growth in the fall, set a larger percentage of blossoms than the spring-fertilized plants which were low in nitrogen. Applications of nitrogen in the spring of the fruiting year caused a better setting of the blossoms and an increase in the size of the berries.

15. Nitrogen alone or in combination with phosphoric acid and potash in every instance increased the total yield. The yield of the summer-fertilized plants was larger than that of the spring-fertilized plants. Largest yields were obtained from plants which were fertilized during both the spring and the summer periods and again in the spring of the fruiting year.

16. Fruit bud differentiation in the strawberry does not depend on a particular nitrogen-carbohydrate ratio in the plant. However, fruit buds were formed more readily when certain quantitative relationships of the nitrogen and carbohydrates existed at the time differentiation normally takes place.

17. Variations in the nitrogen content of the plants at the time of fruit bud differentiation had a greater effect on the yield of fruit than variations in carbohydrate content. Low nitrogen was associated with low yields, high nitrogen with high yields. Plants with a high nitrogen content and a high carbohydrate content were most productive.

18. The size of the crown is not an index of the fruitfulness of the strawberry plant. Total production is determined by the number of flower clusters and the number of blossoms which set and develop into fruits. These are determined chiefly by nutritive conditions within the plant at the time of fruit bud differentiation during the late summer and fall.

19. There is no indication that fertilizer treatments materially affected the moisture content, the texture, or the quality of the fruit.

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LITERATURE CITED

1. Bailey, L. H., Cornell Univ. Agr. Exp. Bul. 189. 1901.
2. Bedford, H. A. R., and Pickering, S. V. Woburn Exp. Farms Rept. 1900, pp. 83-92. (abs. from Exp. Sta. Rec. Vol. 12, p. 645. 1900-1901).
3. Brown, G. G., Oreg. Agr. Exp. Sta. Bul. 159. 1919.
4. Chandler, W. H., Mo. Agr. Exp. Sta. Bul. 113. 1913.
5. Close, C. P., Ballard, W. R., and White, T. H., Md. Agr. Exp. Sta. Bul. 124. 1907.
6. Fletcher, S. W., Strawberry Growing, p. 53. New York. 1917.
7. Ibid. p. 59.
8. Gardner, V. R., Mo. Agr. Exp. Sta. Res. Bul. 57. 1923.
9. Kraus, E. J., and Kraybill, H. R., Oreg. Agr. Exp. Sta. Bul. 149. 1918.
10. Methods of Analysis, A. O. A. C., p. 90. Washington, D. C. 1921.
11. Valleau, W. D., U. S. Dept. Agr. Jour. Agr. Res. XII:10. p. 613. 1918.
12. Van Slyke, L. L., Fertilizers and Crops, p. 694. New York. 1912.
13. Walton, G. P., and Coe, M. R., U. S. Dept. Agr. Jour. Agr. Res. XXIII:12, p. 995. 1923.
14. White, J. M., N. J. Agr. Exp. Sta. Rept., 1891, p. 141.
15. White, J. M., N. J. Agr. Exp. Sta. Rept., 1892, p. 127.