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The effect of nitrate of soda applications on fruit bud formation in the strawberry,

Ralph Albert Van Meter
University of Massachusetts Amherst

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by

Ralph A. Van Meter

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The research work reported here was planned and carried through as foundation work for later and more extensive studies on the fruiting habits of the strawberry as they are affected by nutritional conditions. It formed a fundamentally important part of the general problem, however, and will be considered here as a complete research unit without further reference to studies, based on these results, which are under way.

Even when the stand of plants is comparable, strawberry yields may vary from three thousand quarts per acre to as high as ten thousand quarts. Unquestionably moisture is a tremendous factor in causing these variations, but next to moisture the supply of plant food at critical periods must play a very important part.

Given a satisfactory stand of plants, the yield depends upon the number and size of the berries bourne by each plant. The number of berries depends in turn upon the number of fruit

buds formed and the number of the resulting flowers that mature fruit. Fruit bud formation, then, is a matter of first importance.

The elements of fertility commonly limiting plant growth and development are nitrogen, phosphorus, and potassium, of which nitrogen is most often the limiting factor, because of the physical and chemical properties which it exhibits in the soil, and because of the intimate part which it plays in the metabolism of the plant.

Fruit bud formation is now known to be conditioned upon the accumulation of carbohydrate materials within the plant in the presence of a favorable nitrogen supply. (9). The formation and to some extent the subsequent behavior of fruit buds of the strawberry have been shown to be dependent upon nutritional conditions in the plant at the time of fruit bud formation (6, 10, 18). Carbohydrate accumulation, moreover, related closely to leaf area and the diversion of carbohydrate materials by growth processes, must be affected also by the nitrogen supply.

Nitrogen, therefore, would seem to be the element of fertility most intimately connected with fruit bud formation. This situation suggests the possibility of influencing fruit bud formation to a marked degree by manipulating the nitrogen supply at a critical period, and that is the field into which this experiment is projected.

Review of Literature

The results of fertilizer experiments with strawberries have usually been concerned with gross yields only, and the effects of applications of fertilizers containing nitrogen have been variable to the point of contradiction. The idea is encountered again and again that the spring of the fruiting year is the best time to fertilizer strawberries. Fletcher (5) states that a spring top-dressing of nitrate of soda frequently results in gains of 500 to 1000 quarts per acre, but Chandler (3) in Missouri, reported that nitrogen applied in spring in the form of either sodium nitrate or dried blood gave very injurious re-

sults, increasing the growth of weeds and resulting in soft, poorly colored fruit.

Brown (2) at the Hood River Station in Oregon found that heavy spring applications of nitrogen resulted in increased yields. White (18) found that a top-dressing in spring of 200 pounds of nitrate of soda per acre, on a sandy loam soil in New Jersey, resulted in definite increases. White (18) and Brown (2) attributed increased yields from spring applications of nitrogen to increased size of the fruit rather than to an increase in their number. Chandler (3) also noted an increase in the size of the fruit, but a decrease in number from failure of some blossoms to set fruit.

Gardner (6) in Missouri reported little influence on yield of spring applications of fertilizers and concluded that "maximum production of flower clusters, flowers and berries was associated with those summer and fall treatments that led to the greatest accumulation of starch and

total carbohydrates at the time of fruit bud differentiation", and that "treatments which would increase production through modifying fertility .... should be given during the summer and fall months."

Baker (1) in Indiana, found it a profitable practice to apply 500 pounds of a 2-12-6 fertilizer in the spring of the fruiting year. He applied a complete fertilizer low in nitrogen to large field plots during the summer before fruiting and concluded that "applications of 2-12-6 fertilizer at 500 pounds per acre during the summer before fruiting apparently cannot be depended upon to increase yields."

Baker (1) again, applied ammonium sulphate at the rate of 50 pounds per acre and found that it "produced profitable increases in yield of strawberries on.............soils of average fertility or below", and noted that "the average increase produced on such soils by sulphate of ammonia was nearly twice that produced by a 2-12-6 fertilizer applied in the spring of the fruiting year."

Some experimental work has been done on fertilization with nitrogen during the growing season of the year preceding the harvest. Chandler (3) found in Missouri that when sodium nitrate was applied in early summer of the year previous to fruiting, no damage was done nor was there any great benefit. Dried blood, however, when applied at that time in quantity, was injurious.

Fall fertilization was attempted in Maryland by Close (4) who applied commercial fertilizer at mulching time. Yields were reduced but the reduction might have been caused by improper mulching, since the check plots were not mulched. Brown (2) did some experimental work on an old bed in Oregon, in which he checked the application of fertilizers after harvest against applications at blossom time in the year following. The yields consistently favored late summer applications.

Loree (10), working with potted Senator Dunlap plants, in Michigan blow sand, found the greatest number of flower clusters on plants

fertilized with nitrogen and phosphorus in spring and summer of the first year or in spring and summer of the first year and a third time in the spring of the fruiting year. Nitrogen increased the yield in every instance, either alone or in combination with potash or phosphoric acid, but the yield of the summer-fertilized plants was greater than the yield of those fertilized in spring.

Loree found also that 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 content was associated with low yields, high nitrogen content with high yields. The most productive plants had a high content of both nitrogen and carbohydrates.

Macoun (11)(12), working in the field with a fertile soil at Ottawa, Canada, applied nitrate of soda at different times during the first growing season and obtained an increase in all the nitrated series, which became progressively more

marked as the applications approached the period of fruit bud differentiation. He concluded: "Applications of nitrate of soda, even on land where nitrogen is not a limiting factor from a vegetative response standpoint, when made about September 15 causes a marked increase the following year."

Wentworth (12) fertilized strawberries in the field in New Hampshire with nitrate of soda in one-third installments; May 26, August 18, and in the following spring about three days before the first blossoms appeared. The yield was significantly decreased in seven plots out of eight.

Wentworth (17) also applied nitrate of soda to Howard 17 plants immediately after planting. The result was a decrease in yield as compared to plots that received no nitrate. He concluded that commercial fertilizers, particularly when used to supplement stable manure, were of no value and in fact probably harmful.

Whitehouse (19), in Maryland, made nutritional studies with Premier in quartz sand and found that fruitfulness in the strawberry

plant is correlated with a balance between nitrogenous and carbohydrate materials at time of fruit bud differentiation. The highest carbohydrate and lowest nitrogen content, or an abnormally high carbohydrate-nitrogen ratio, resulted in a weakly vegetative type of growth and a reduction in number of blossoms formed.

Lowest carbohydrate and highest nitrogen content, or an abnormally low carbohydrate-nitrogen ratio, resulted in a strongly vegetative growth and in a reduction in number of blossoms. An increase in blossom formation was associated with a carbohydrate-nitrogen ratio intermediate between that of the high nitrogen and no nitrogen plots.

Shoemaker (15) in Ohio applied sulfate of ammonia at planting, one month later, and on August 15, during the first summer after planting. All applications increased the yields and the increases were progressively greater the later the applications were made.

The time of fruit bud differentiation in the strawberry has received considerable attention.

Thirty years ago Goff (7) in Wisconsin reported that the initial stage of blossom bud differentiation in the strawberry occurred about September 20. Ruef and Richey, (14) found the first signs of flower bud formation in early September in Iowa. They found also that late-rooting runner plants did not, in some instances, show signs of bud formation until December, while other runner plants were intermediate in time of bud differentiation.

Richey and Schilletter (13) in Iowa found evidences of differentiation in first and second runner plants on September 10, but none on mother plants. They concluded that the age of the plant, its position in the runner series, and its leaf area were associated with the degree of floral development at different periods. Lack of moisture and low temperature seemed to hasten flower bud formation noticeably.

Hill and Davis (8) found the first sign of flower bud differentiation in the strawberry on September 19, at Ottawa, Canada. All runner plants four weeks old or older seemed to show signs of

beginning differentiation at the same time. They concluded: "There is apparently a critical seasonal period before which the stimulus for flower bud formation is lacking, independent of the age of the runners."

Despite more or less contradictory evidence, some interesting inferences may be drawn from the literature of strawberry fertilization: Spring fertilization, when it increases yields at all, probably does it by stimulating the plants to produce fruits of greater size and affects fruit bud formation little if any. High-nitrogen fertilizers seem to be most effective. Fruit bud formation must be affected, if at all, by treatment during the summer and fall.

On non-fertile soils and perhaps on some fairly good ones, repeated applications of a nitrogen bearing fertilizer may be expected to increase fruit bud formation. Applications in late summer have usually given greater increases in yields than those made early. Both early and late applications have seemed to be injurious at times.

Fruit bud formation in the strawberry takes place in the fall, and maximum fruit bud formation is associated with a proper relationship between carbohydrates and nitrogen at the time of, or immediately preceding, fruit bud formation.

Statement of the Problem

The object of this investigation has been to determine the effect on fruit bud formation in the strawberry of applications of nitrate of soda at different times during the growing period following planting.

Method of Procedure

Forty-five plots were planted to Howard 17 (Premier) strawberries in the spring of 1928. This made possible nine treatments, each replicated five times. The following chart will make the plan of arrangement clear.

North

Series	E	6	8	2	4	9	7	3	1	5
"	D	3	9	7	5	6	1	8	4	2
"	C	8	4	1	3	2	7	9	5	6
"	B	9	7	5	6	8	4	2	1	3
"	A	1	2	3	4	5	6	7	8	9

South

1. No nitrates
2. Nitrate of soda at planting time - May 11
3. Nitrate of soda when well established - June 13
4. Nitrate of soda before fruit bud formation - July 2
5. Nitrate of soda on August 6
6. Nitrate of soda on August 20
7. Nitrate of soda on September 5
8. Nitrate of soda on September 15
9. Nitrate of soda on October 4

Key to Fertilizer Treatments

0	3	28	0
0	2	29	0
0	1	30	0
0	0	0	0

0	0	0	0
0	15	16	0
0	14	17	0
0	13	18	0
0	12	19	0
0	11	20	0
0	10	21	0
0	9	22	0
0	8	23	0
0	7	24	0
0	6	25	0
0	5	26	0
0	4	27	0
0	3	28	0
0	2	29	0
0	1	30	0
0	0	0	0

Plan of Arrangement of Each Plot

Guard rows were planted between parallel plots and guard plants between abutting plots. Each plot contained 30 plants in two rows of 15 plants each and the plants were numbered one to 30. The above diagram shows the plan of each plot, O representing a guard plant.

The plants were set 18 inches apart in the rows, and the rows were spaced at intervals of 36 inches. Each plot of 30 plants covered 144 square feet.

One pound of nitrate of soda was applied to each plot at the time specified. This was the equivalent of 302.5 pounds per acre — a heavy application. Since the first concern was time of application rather than the most economical amount, the attempt was made to provide all the nitrogen the plants could use, and still avoid any possible toxic effects. Incidentally, plot B 4 was given, by mistake, a second full application on August 6. The 605 pounds per acre apparently were not at all harmful, to plant growth, but they may have reduced the yield slightly.

The nitrate was applied to the plot rows only. It was applied by hand and scattered uniformly on the ground between and around plants in the rows with care to keep it off the leaves and crowns. The strip fertilized was about 18 inches wide.

To make sure that phosphorus or potassium should not become limiting factors, 200 pounds of superphosphate and 50 pounds of muriate of potash were broadcast over the whole field (about 1/3 of an acre) and harrowed in before the plants were set. Here, again, the attempt was made to insure an abundance of these elements, with no concern for specific amounts.

Previous Treatment of the Land

This land has been cropped for many years. There was no thought of using it for experimental purposes until the year in which the experiment started, but it is possible to record the treatments which the land received for four years preceding the beginning of this experimental work. Since this experiment deals with nitrogen, and

since the effect of nitrogen applications do not last as long as those of other elements, it seemed that nitrogen applied in 1924 should have little effect on the results of differential treatment in 1928.

In 1924 an application of poultry manure was plowed in and the field was set to strawberries — the variety trial plots of the College.

In 1925 the strawberry plantation was renovated in July, soon after the harvest season, and nitrate of soda was applied at the rate of 300 to 400 pounds per acre.

In 1926, after the second strawberry crop was harvested, the land was plowed, manured, and seeded to millet.

In 1927 the field was plowed in spring and seeded to oats and grass, without fertilizer. The grass mixture used was alsike, red clover, timothy, and red top. Later, the oats were cut and removed.

In the spring of 1928 the grass was plowed down and this experiment was started.

The repeated applications of plant food and the plowing down of organic materials would indicate that good farm practice had been followed and that the land was not depleted of fertility at the beginning of the experiment. This was, indeed, the situation. Later there were no signs of nitrogen starvation on the check plots which received no nitrogen while the experiment was under way.

The Soil

The soil is a medium loam with a gravelly subsoil. Just off the south end of the plots is an excavation from which gravel has been removed for years for filling and road making on the campus. The gravel is not pure, containing some loam, and the top soil is a fairly good loam, but the soil as a whole is not highly drouth resistent, particularly at the south end of the plots. The summer of 1928 was moist and no serious ill effects of the underlying gravel were apparent, but at harvest time in 1929 the plots in Series A showed some

characteristic drouth effects, and the plants on the lower ground were somewhat more vigorous throughout.

The southeast corner of the experimental area was driest when the land was plowed, and moisture increased with fair regularity to the north end. The soil in the northeast corner seemed to contain the most moisture at that time. There was a medium stand of young clover on the higher and drier ground, decreasing toward the northeast corner, where the land was mossy and sour looking.

Soil Acidity

pH values, or the reaction of the soil with respect to hydrogen ion concentration ($pH = \log \frac{1}{H^+}$), were determined from soil samples taken August 9. The results will be found in Table 1. The quinhydrone electrometric method of determining pH values was used.

Table 1. pH values of Soil
in the Experimental Plots

	Sample	pH
Check plot	A1	5.6
" "	B1	5.8
" "	C1	6.1
" "	D1	6.1
" "	E1	6.5
Composite sample	T2	6.5
" "	T3	6.2
" "	T4	6.3
" "	T5	6.2
" "	T6	6.3
" "	T7	6.2
" "	T8	6.3
" "	T9	6.3

A1, B1, C1, D1, and E1 were check plots and they are recorded separately to indicate the reaction of the untreated land. T2, T3, etc. were determined from composite samples taken from all the plots receiving Treatment 2, Treatment 3, etc.

These determinations show a fairly uniform condition of acidity throughout the experimental area. Since the strawberry is not highly sensitive to soil acidity and is often grown successfully on soils lower in pH values than any here recorded, it is assumed that acidity was not an important factor in causing variations in these plots.

Notes on Procedure

The land was fitted on May 9 and the experimental plots were set to strawberries on May 10. The plants were purchased from George Rennie of Andover, Massachusetts, a strawberry nurseryman who was instructed to select them carefully for uniformity and evidently did so. The time of shipping was arranged by wire so they would not arrive before the land was ready and they were set promptly under unusually good conditions.

These precautions in shipping seemed advisable because the strawberry plant is very susceptible to injury by drying, having fully developed leaves at the time of transplanting, and is likely to be injured when planting is delayed and the plants are held in storage.

The first nitrate applications were made on May 11, the day after planting. On May 14 the plants were checked over carefully to note any apparent failures in transplanting. The plants were rechecked at intervals during the summer and plants which were abnormal were noted and later thrown out in checking results.

The general care given the plants approximated good cultural treatment. The soil was cultivated and that next to the plants was hoed as often as was necessary to keep down weeds and grass, and the plots were kept clean and in good order.

The first blossoms were removed on May 26 and blossoms were removed thereafter as they appeared.

Runner plants were placed around the parent plants at intervals of six inches to study the effect of time of rooting to nitrogen response. This proved impracticable and was finally abandoned. Data were secured from the parent plants only, but each was surrounded by

runner plants at a uniform distance, placed in accordance with the following diagram:

```
(2)   (1) - (2)
 l     l
(1) -  M  - (1)
       l     l
(2) - (1)   (2)
```

Plan of Runner Arrangement

M represents the mother plant. The numbers refer to the first and second runner plants set on each of the four runners retained. All other runners and runner plants were removed.

The plots and guard rows were mulched with oat straw about December 1. The mulch was approximately two inches thick after settling and was somewhat heavier than that used generally by strawberry growers. This mulch was removed from the plants in spring when the plants began to grow and most of it was removed from the field to facilitate the making of observations.

Observations

The check on number of fruit buds formed was made at harvest time in 1929. The berries were

graded into sizes and counted as they were picked, and blossoms failing to set fruit were noted. These records were made separately for each of the 1350 plants in the experimental plots.

In addition soil nitrate and soil moisture determinations were made at intervals of about two weeks, as recorded later. Soil samples for these determinations were taken as follows: Standard soil augurs were used and 14 samples were taken from each plot. These were taken in the rows from between the plants. Samples from the five check plots were taken separately, but samples from the five plots under each of the other treatments were mixed carefully into a composite sample for that treatment. In this way, with a minimum of determinations, the variations in nitrates and moisture on the untreated soil could be recorded, along with the behavior of soil nitrates in each series of the plots under differential treatment.

PRESENTATION OF DATA

Influence of Treatments on Vegetative Growth

The summer of 1928 in general was favorable to plant growth and the treatments made no noticeable difference in the way in which the plants developed. As the drier part of the summer came on the plants in Series A and to a lesser extent those in B began to lag somewhat in growth and they appeared less vigorous. The plots on the south end also produced fewer runners and set fewer runner plants.

This appeared uniform for all treatments, however, and beyond question was a moisture relationship rather than one of nitrates.

Influence of Treatments on the Number of Fruit Buds Formed

Table 2 shows the number of fruit buds formed on each plot as revealed by the berries produced. In every series of treatments except Series A the trend is clearly toward increased production for the later applications. The yields

Table 2. Yields by Plots

Plot	Treatment	No. Plants	No. Berries	No. of berries per plant
Series A 1	No nitrates	25	924	37
2	Nitrated May 11	30	1144	38.1
3	" June 13	27	1099	40.7
4	" July 2	30	1133	37.8
5	" Aug. 6	26	1110	42.7
6	" Aug. 20	26	778	29.9
7	" Sept. 5	27	938	34.7
8	" Sept. 15	23	767	33.3
9	" Oct. 4	24	806	33.6
Series B 1	No nitrates	28	1069	38.1
2	Nitrated May 11	27	931	36.2
3	" June 13	27	1172	43.4
4	" July 2	29	1015	35.
5	" Aug. 6	27	1024	38.
6	" Aug. 20	26	1102	40.4
7	" Sept. 5	28	1132	40.4
8	" Sept. 15	28	1049	37.5
9	" Oct. 4	26	1160	44.6
Series C 1	No nitrates	28	1110	39.7
2	Nitrated May 11	29	1296	44.7
3	" June 13	29	1329	45.8
4	" July 2	29	1493	51.5
5	" Aug. 6	26	1084	41.7
6	" Aug. 20	27	1218	45.1
7	" Sept. 5	30	1315	43.8
8	" Sept. 15	26	1300	50.
9	" Oct. 4	24	1104	46.

Table 2. Yields by Plots - continued

Plot		Treatment		No. Plants	No. Berries	No. of berries per plant
Series D	1	No nitrates		26	1287	46.
	2	Nitrated	May 11	28	1308	46.7
	3	"	June 13	23	950	41.3
	4	"	July 2	28	1262	45.1
	5	"	Aug. 6	23	1081	47.
	6	"	Aug. 20	26	1249	48.
	7	"	Sept. 5	24	1203	50.1
	8	"	Sept. 15	27	1381	51.2
	9	"	Oct. 4	21	1037	49.4
Series E	1	No nitrates		30	1195	39.8
	2	Nitrated	May 11	23	969	42.1
	3	"	June 13	28	1323	47.3
	4	"	July 2	28	1183	42.3
	5	"	Aug. 6	28	1142	40.8
	6	Thrown out*				
	7	Nitrated	Sept. 5	27	1323	49.
	8	"	Sept. 15	28	1324	47.3
	9	"	Oct. 4	29	1519	52.4

* Because of an error in date of applying nitrate to this plot, it seemed advisable to omit the results from calculations.

in Series A indicate an effect on fruit bud formation from early nitrate applications greater than that secured from other series -- great enough in fact to reverse the trend of results as clearly exhibited by every other series.

The plots in Series A, however, were numbered in order from left to right and that threw the early applications to the left end of the series and the later treatments to the right. The right end is the driest part of the area under experimentation and moisture rather than nitrates was undoubtedly the limiting factor. In no other series was this arrangement followed.

Table 3, summarizing the yields by treatments, shows more plainly the trend toward increased production following the later applications. Series A has been omitted here and in succeeding averages because it obviously has nothing to contribute toward the solution of the problem, and when averaged in with other plots it tends to obscure the results secured there.

Table 3. Yields by Treatments

(Series A omitted)

	Treatments	No. Plants	No. Berries	Average no. of berries per plant
1.	Check. No application	114	4661	40.9
2.	Nitrate at planting time	107	4554	42.6
3.	Nitrate 1 month later - June 13	107	4774	44.6
4.	Nitrate July 3	114	4953	43.4
5.	Nitrate Aug. 6	104	4331	41.6
6.	Nitrate Aug. 20	79	3569	45.2
7.	Nitrate Sept. 5	109	4973	46.5
8.	Nitrate Sept. 15	109	5054	46.4
9.	Nitrate Oct. 4	100	4820	48.2

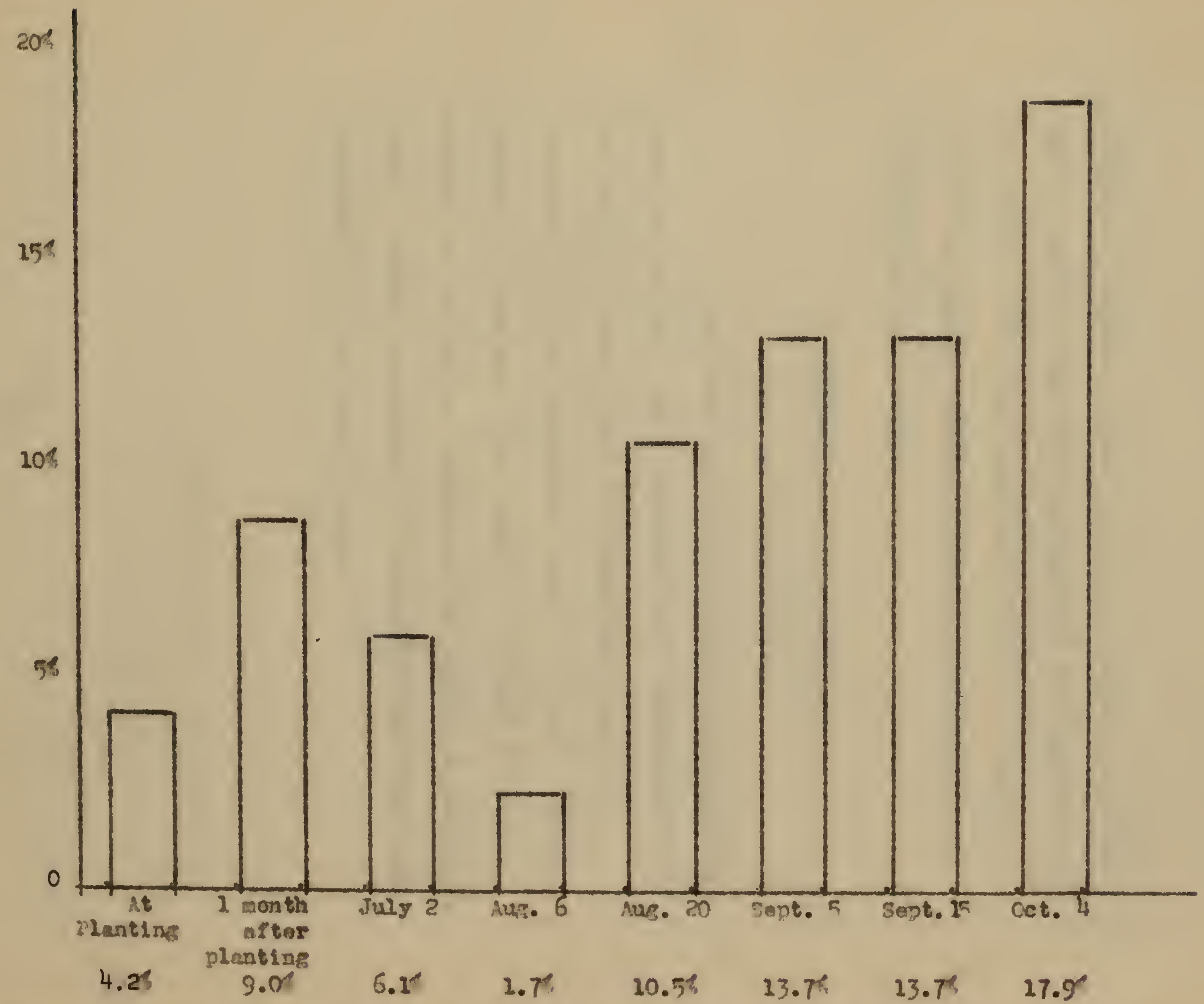
These increases in yields of treated plots over check plots are shown more clearly in Table 4, where percentage increases are given in the first column and in the second, the increase in quarts when these percentages are applied to a basic crop of 4000 quarts per acre. This assumed

yield without fertilizers is not unreasonable on this land, for the same variety on a nearby plot has yielded in excess of 10,000 quarts per acre.

Table 4. Increases over Check Plots in Percentages and Calculated Increases in Quarts per Acre when applied to a 4000 Quart Crop

Treatments	Average no. of berries per plant	Percentage increase	Calculated increase in quarts
1. Checks	40.9	0	0
2. Nitrate at planting time	42.6	4.2	168
3. Nitrate 1 month later - June 13	44.6	9.0	360
4. Nitrate July 2	43.4	6.1	244
5. Nitrate Aug. 6	41.6	1.7	108
6. Nitrate Aug. 20	45.2	10.5	420
7. Nitrate Sept. 5	46.5	13.7	548
8. Nitrate Sept. 15	46.4	13.7	548
9. Nitrate Oct. 5	48.2	17.9	716

While early applications were effective in increasing yields very materially, the greatest increases were secured from applications after the



Percentage increase in yield of treated plots over checks, from nitrate of sodaapplied at different times

middle of August. Just why the smallest increase should result from the application of August 6 is not clear. The data available throw no light on it and no unusual circumstances surrounding this application were noted.

Influence of Treatments on Size of Strawberries

These increases following fertilization might be reduced very materially in importance if not entirely nullified in commercial value if they came at the expense of size of fruit. Variations in size are also closely related to variations in quality of strawberries within a variety. Table 5 shows the number of strawberries from each treatment in each size group.

Table 5. Proportion of Berries in each Size Group

Treatment	Above 20 gm. %	10 to 20 gm. %	3 to 10 gm. %	Below 3 gm. %	Blossoms not setting fruit %
1. Checks	3.8	12.3	58.1	25.8	.1
2. Nitrate at planting time	5.5	12.3	58.4	23.7	.3
3. Nitrate 1 month later - June 13	4.6	11.8	59.8	23.8	.3
4. Nitrate July 2	4.7	12.1	60.2	23.0	
5. Nitrate Aug. 6	4.9	12.1	60.2	22.8	.3
6. Nitrate Aug. 20	4.4	11.3	60.7	23.6	.2
7. Nitrate Sept. 5	5.0	12.6	58.7	23.7	.1
8. Nitrate Sept. 15	5.9	12.0	60.9	21.1	.4
9. Nitrate Oct. 4	5.7	11.9	57.3	25.1	.3

There may possibly be a very slight tendency shown here toward an increase in size from the last three applications. A few more of the strawberries from the plots receiving nitrate after September 1 were large enough to be placed in size one. However, the difference is so slight that it

cannot be considered significant. It will be taken as a lead, though, and checked carefully when more data are available.

The important thing shown by Table 5 is that increases in yield were not at the expense of size of fruit.

The Behavior of Soil Nitrates

To determine the period through which nitrates were actually available to the plants, it seemed advisable to take observations on the behavior of nitrates in the soil at frequent intervals throughout the duration of the experiment.

Table 6 details the results of these analyses. (The phenol disulphonic acid method of analysis was used). They show many inconsistencies and unexplainable variations, quite in line with the known behavior of soil nitrates under such conditions.

Soil nitrates in the check plots show, in general, points of maximum abundance about July 15 and August 15. Plots A1 and D1 were relatively

high in nitrates in mid-July, but in early September the nitrate almost disappeared from both plots. The great reduction of nitrates in September suggests the influence of the minor nitrogen cycle.

With the single exception of the plots under Treatment 6 (T6), soil nitrates increased very decidedly following the rather heavy applications. These increased amounts of nitrates had disappeared for the most part in three or four weeks.

It may be significant that the low-yielding check plots were in general low in soil nitrates in September, the period of maximum fruit bud formation, and the highest yielding plots T7, T8, and T9, were high in nitrates at about that time.

Three analyses were made at intervals of about two weeks in the spring of 1929 — the fruiting year. These show no variations that can be attributed to the applications of nitrate of soda during the preceding summer and autumn. The applications were heavy, but apparently the added nitrates had disappeared from the soil by spring, and they did not reappear before the harvest season. This, again, is quite in line with the known behavior of soil nitrates.

Table 6. Nitrates in soil, expressed as p.p.m. NO_3 of dry soil weight

____ marks the first analysis after nitrate of soda was applied

Plot	1928 July 9	July 16	July 23	July 30	A Aug. 6	Aug. 13	Aug. 20	Aug. 27	Sept. 4	Sept. 10	Sept. 17	Sept. 24	Oct. 11	1929 June 1	June 14	June 28
A1	28.8	96.2	66.1	34.0	45.1	58.2	60.5	4.0	3.5	10.2	13.2	7.6	6.0	22.8	18.1	25.8
B1	97.5	137.0	84.2	48.0	40.9	220.0	62.2	Tr.	Tr.	22.8	20.0	13.5	29.9	24.7	34.0	39.6
C1	45.7	87.3	72.2	57.1	22.5	57.9	58.5	4.2	4.5	Tr.	Tr.	5.2	Tr.	11.5	12.8	17.1
D1	27.1	110.5	48.4	36.1	29.0	82.3	62.8	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	12.7	14.7	19.3
E1	70.1	69.5	74.0	36.4	22.4	72.1	78.4	20.8	11.9	Tr.	6.6	5.2	Tr.	12.8	15.8	15.9
T2	109.2	124.0	133.8	69.7	52.1	65.1	97.8	13.9	4.0	11.5	29.8	14.1	Tr	16.6	18.9	15.0
T3	146.2	273.5	201.7	92.4	74.7	98.1	98.7	12.9	4.8	9.8	34.6	6.1	9.6	16.1	15.3	27.8
T4	157.9	312.5	194.2	175.1	82.7	130.0	163.0	13.7	5.6	17.1	9.9	20.7	13.2	15.8	17.0	23.6
T5	43.9	70.0	72.0	85.3	37.2	161.6	137.0	36.4	4.4	43.9	29.4	27.0	37.2	16.7	19.3	26.0
T6	40.5	74.2	72.8	44.8	35.3	53.0	75.6	44.6	17.2	25.1	39.5	45.5	36.2	16.0	15.9	22.8
T7	78.7	82.0	67.4	49.3	38.0	53.1	50.1	8.6	4.6	141.0	40.2	217.5	171.0	19.7	17.2	21.4
T8	58.0	59.8	74.2	41.5	41.2	68.8	73.3	8.1	Tr.	12.1	60.2	235.5	220.0	19.7	25.0	25.3
T9	61.8	65.5	59.9	44.2	34.5	67.2	79.3	7.3	Tr.	13.8	122.8	22.5	183.0	17.7	16.0	23.5
B4*								57.8	20.4	45.0	19.3	48.3	79.0	15.8	17.4	22.6

* B4 was given, by mistake, an extra application of nitrate on August 6. Separate analyses of samples from this plot were made after August 27. After August 6, B4 was not averaged into T4.

Variations in Soil Moisture

Water plays such an important part in plant life that it might easily be possible for variations in soil moisture to offset entirely the effects of fertilizer treatments. It seemed advisable, therefore, to determine the moisture content of the soil samples taken for nitrate analyses. The results of these determinations are presented in Table 7.

These results show no significant variations in moisture content between the groups of plots under differential treatment. The differences are surprisingly small and they show no tendency toward uniform differences between groups of treated plots.

There is a consistent difference between plot 1 in Series A (A1) and plots 1 in the other series. This check plot is at the south end of the field and the behavior of plants in the whole of Series A indicates strongly that the soil underlying that end of the field was too dry for the satisfactory development of strawberry plants. Certainly moisture conditions in A1 were markedly different from moisture conditions in the other check plots.

Table 7. Variations in Soil Moisture, expressed as per cent of dry soil

Plot	1928 July 9	July 17	July 23	July 30	Aug. 6	Aug. 13	Aug. 20	Aug. 27	Sept. 4	Sept. 10	Sept. 17	Sept. 24	Oct. 11	1929 June 1	June 14	June 28
A1	28.8	29.3	31.5	31.0	31.8	30.1	29.4	29.8	32.3	29.8	29.2	28.4	30.0	31.2	26.3	27.3
B1	31.0	31.0	32.3	30.7	32.1	33.2	32.0	34.1	32.4	30.5	29.0	29.5	31.8	32.6	28.1	28.0
C1	28.7	30.5	30.7	31.1	29.6	31.3	29.4	33.9	33.2	31.0	29.8	30.5	30.6	31.2	26.8	28.5
D1	31.2	31.8	34.0	30.6	33.0	31.8	29.4	34.8	33.9	31.9	31.6	33.7	32.6	33.1	30.1	30.6
E1	38.4	33.5	37.2	36.4	36.4	26.8	35.0	40.4	38.7	36.7	36.5	36.0	35.6	37.7	36.1	35.8
T2	30.8	29.9	33.0	30.3	32.3	29.8	28.8	32.6	36.1	31.3	31.6	26.1	30.4	31.8	28.4	28.4
T3	30.4	29.3	33.4	31.1	32.2	30.3	29.7	33.4	33.5	31.4	27.8	30.9	30.5	28.5	26.1	29.1
T4	30.6	29.3	32.1	32.3	34.1	29.6	29.6	30.8	33.9	31.5	31.3	30.0	30.9	31.9	29.1	29.5
T5	30.1	30.7	33.9	32.3	34.1	29.0	32.5	35.2	35.5	31.9	31.9	31.4	30.6	30.0	29.1	29.0
T6	30.3	29.5	31.7	30.6	31.8	30.8	29.3	33.1	33.3	30.0	31.0	32.4	30.7	29.5	26.9	28.6
T7	30.7	30.8	33.8	30.7	31.4	27.3	29.4	30.8	31.5	35.2	29.8	27.0	28.1	28.7	25.2	27.6
T8	30.7	30.0	32.6	30.2	29.4	28.9	27.6	33.1	34.0	31.3	28.8	30.0	36.2	30.8	28.5	28.4
T9	31.3	30.3	32.3	31.6	32.0	31.1	29.9	30.9	34.5	31.3	31.1	30.9	27.9	31.3	27.6	29.0
							E4	31.5	28.8	28.4	31.5	30.9	29.4	31.2	27.4	27.1

Relation of Rains to Time of Application

In all the differential fertilization, the nitrate of soda was applied on top of the soil. While the fertilizer was readily soluble, there is some doubt as to whether it could penetrate the soil and become available to plants until carried down by rainfall. The date of the next rain following application, then, would become the time of effective fertilization. Table 8 gives the date of the first rainfall of .25 inch or more, following the application of nitrate to each group of plots.

Table 8. Time of First Rains
Following Fertilizer Applications

Treatment number	Date of Fertilization	Date of Next Rainfall of .25 inch or more
2	May 11	May 18
3	June 13	June 14
4	July 3	July 6 (.18 inch)
5	August 6	August 7
6	August 20	August 22 - 23
7	September 5	September 17
8	September 15	September 17
9	October 4	October 5

A quarter of an inch was assumed arbitrarily as the minimum amount of rainfall which, it seemed reasonable to suppose, would dissolve the nitrate and carry it down far enough to make it available to plants. The .18 inch on July 6 probably was enough to be at least partially effective.

If it is true that the nitrate did not become available until the first rain following application, then the first application was delayed a week before becoming available. It is difficult to see how this could make any appreciable difference in results.

The only delay which might possibly be important is that following the application on September 5. The delay of twelve days was sufficient to bring the application of September 5 into action at the same time as that of September 15. If these two identical treatments became available at the same time the results should be the same, within the limits of experimental error. Reference to Table 4 shows this to be the case.

Discussion

The soil involved in this experiment was quite fertile and results must be understood to apply to soils on a fairly high plane of fertility. The differential treatments made no noticeable difference in the appearance of the plants during the period of the experiment, but they did affect yields. It seems probable then that even where plants seem to develop normally yields may in some cases be increased by proper fertilization.

It is interesting to note that the plants in all plots, except those on the dry soil in Series A, were vigorous throughout the period of the experiment, regardless of treatment. There would seem to be little benefit to be expected then from applications made to stimulate plant growth early in the season on such soils. There seemed to be a point in vegetative development beyond which the plants could not be forced. Some limiting factor other than plant food became operative.

Of particular interest in this connection is plot B4. This plot received by mistake two applications of nitrate of soda and the combined amounts were equivalent to 644 pounds per acre. Yet these plants did not grow better than those in the plots receiving half that amount. The yield may have been reduced, for B4 yielded fewer berries than any other plot under Treatment 4. This brings forward the possibility that the amount of nitrate applied may be important as well as the time of application, an excess amount tending to depress fruit bud formation as surely as a lesser amount tends to stimulate it. This might possibly explain the results secured in New Hampshire (16), and some of the other conflicting testimony.

The data suggest that on poorer soils fertilization might be undertaken with two separate objectives in mind: In addition to early fertilization to stimulate plant growth and runner formation, late summer or fall fertilization to stimulate fruit bud formation might be advisable.

This is quite at variance with fertilization practice on the poorer soils of New England, where strawberries are ordinarily given an application of complete fertilizer in spring soon after planting to stimulate plant growth, and another application in the spring of the fruiting year. This latter application seems to be effective in increasing the size of the fruit and probably both applications are worth while on poor soils. The system would seem to leave a shortage of available nitrogen, however, in late summer and fall, just at the time when an abundance of nitrogen is needed to stimulate fruit bud formation. Observation leads to the belief that a shortage of nitrogen in the fall is a very common occurrence in strawberry culture everywhere.

Applications of nitrate of soda made as early as planting time stimulated fruit bud formation somewhat. Just how this came about is uncertain. Surplus nitrogen might have been stored in the plants until needed at the time of flower bud formation, or there may have been a certain

stimulation of vegetative growth early in the season which was not noticeable but which nevertheless brought about a more favorable nutritional condition in the plants at the time of fruit bud formation.

It is possible that early applications of nitrate of soda enabled some of the plots in Series A to withstand drouth conditions better. The plots nitrated early in the season outyielded those fertilized later, but moisture conditions were obviously wrong throughout that series and there may have been a little more moisture available in the plots giving the highest yields. Unfortunately the data do not indicate definitely the reason for the behavior of these plots.

It is clear that the applications most effective in promoting fruit bud formation were made toward the end of the season. It was at or near the period of fruit bud formation that an abundance of nitrogen was needed most. With slight changes this work is being continued and if future results support those reported here, we can recommend a fundamental change in the method of fertilizing strawberries.

Summary

1. Forty-five field plots were planted to strawberries in the spring of 1928 and given differential treatments with nitrate of soda to determine the effects on fruit bud formation of an abundant nitrogen supply at different times during the growing season.

2. The soil was a productive loam over a gravelly subsoil, which had been well farmed in recent years and was capable of producing fair crops without fertilization.

3. pH values averaged slightly above 6 and were not widely divergent.

4. The moisture content also was fairly uniform except in one replication, which was consistently dry.

5. Observations on fruit bud formation were made at harvest time by counting and classifying the berries and abortive blossoms.

6. All applications increased the number of fruit buds formed, over the number formed by the checks.

7. The most effective applications were made on September 5, September 15, and October 4. The applications of September 5 and 15 probably became effective together on September 17 when dissolved and carried down by rain.

8. Increases in yield were not at the expense of size. The treatments did not seem to affect size appreciably.

9. Soil nitrates were increased by the applications. These increases lasted about three or four weeks, then disappeared. The applications did not affect soil nitrates in the following spring.

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