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EFFECTS OF FERTILIZERS AND ROTATION ON EARLINESS AND TOTAL YIELDS OF TOMATOES

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ABSTRACT

This is a report of 6 years' results of an experiment comparing 18 fertilizer combinations for tomatoes in a single crop system and in a 4-year rotation. Each treatment was replicated three times and results were measured by the differences in field yields of tomatoes. The effect of each treatment was determined by comparing its yield with the yield of check plats on each side. The significance of differences in yields was determined by Bessel's method. Crop response to each treatment was measured in its effect on early, mid-season, and total yields.

Phosphorus was of greatest importance in increasing both the early and total yields of tomatoes. Nitrogen was second in importance and potash was third. The best results were obtained using a complete fertilizer high in phosphorus. The tomatoes responded profitably to liberal applications of fertilizer.

Rotation was very important in maintaining tomato yields. Moderately high analysis fertilizer compared favorably with a very concentrated form. Manure proved an excellent fertilizer for tomatoes. The best results, especially for early yields, were obtained by supplementing the manure with commercial fertilizer high in phosphorus.

Seasonal conditions and time of transplanting proved to be important factors in total yields and early yields, respectively.

PLAN OF EXPERIMENT

This is a report of an experiment started in 1927 and gives the results of 6 years' tests. The experiment was designed to determine the effect on the earliness and total yields of tomatoes of nitrogen, phosphorus, and potassium fertilizers singly and in various combinations when applied to the soil under usual farming conditions. It also gives a comparison of yields of tomatoes grown continuously on the same land for 7 years with the yields of tomatoes in a 4-year rotation, using 18 fertilizer combinations in each case.

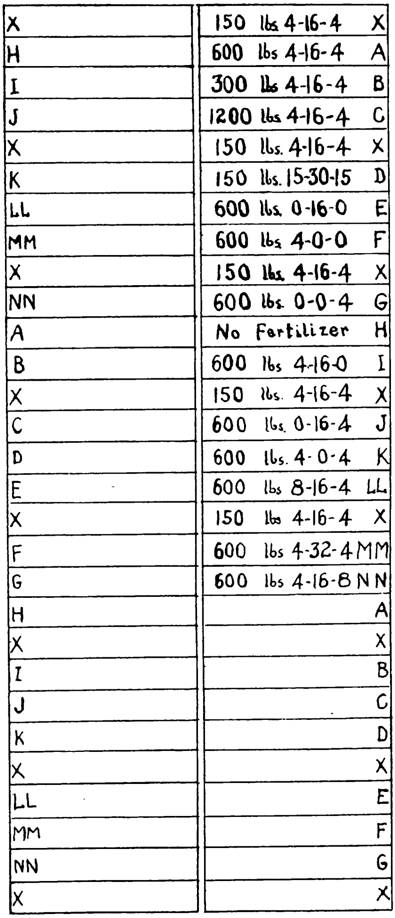

FIG. 1.—DIAGRAM SHOWING THE ARRANGEMENT OF THE FERTILIZER PLATS.

Special thought and effort were given to the arrangement of the plats, to plat technic, and to replication of treatments so as to make the results reliable and to prevent the drawing of erroneous conclusions. Each fertilizer treatment was applied in triplicate in both the rotated and continuous series. The replications of each fertilizer treatment were distributed as widely as possible over each field. Every fourth plat was a check plat. The effect of each fertilizer treatment was measured by the gains or losses in yield as compared with the yield of the check plats on each side of the treatment. This arrangement prevents drawing erroneous conclusions that might occur from any inequalities of the soil which would give a more favorable location to certain treatments. The plats were long and narrow so that soil differences, which are bound to occur in any field, would be sampled by the check plats as well as the different fertilizer treatments. The plats were permanently marked and each treatment was applied to the same plat each year so that any cumulative effect of the fertilizers would be obtained. In the rotated tomatoes a 4-year rotation was used, each crop in the rotation being grown each year. The same fertilizer treatments were applied to the same location in each of the four fields each year. Fig. 1 is a diagram of the arrangement of the plats in each of the five fields.

The fertilizer treatments were as follows:

A. 600 lbs. 4–16–4
B. 300 lbs. 4–16–4
C. 1,200 lbs. 4–16–4
D. 150 lbs. Nitrophoska (16–32–16)
E. 600 lbs. 0–16–0
F. 600 lbs. 4–0–0
G. 600 lbs. 0–0–4
H. No fertilizer
I. 600 lbs. 4–16–0
J. 600 lbs. 0–16–4
K. 600 lbs. 4–0–4
L. 600 lbs. 2–16–4
LL. 600 lbs. 8–16–4
M. 600 lbs. 4–8–4
MM. 600 lbs. 4–32–4
N. 600 lbs. 4–16–2
NN. 600 lbs. 4–16–8
X. 150 lbs. 4–16–4

The check treatment marked "X" on the diagram was applied to every fourth plat, making 16 plats in each field. It will be seen from the above list that the basic treatment was 600 pounds per acre of 4–16–4 fertilizer, and that the other treatments, except D, are variations of the separate ingredients of this basic treatment.

As originally laid out, the series contained the L, M, and N treatments. After observing the differences in yield secured for 2 years, it seemed evident that changes of only 2 per cent in the amount of an ingredient when applied at the rate of 600 pounds per acre could hardly be expected to make significant changes in yield that could be definitely attributed to the fertilizer. A variation of 2 per cent in the fertilizer means only 12 pounds difference in the plant food applied per acre at the 600-pound rate. Accordingly, in 1929, the L, M, and N treatments were discontinued and the LL, MM, and NN treatments substituted. In other words, instead of using half of each ingredient of the basic treatment, double the amount of each ingredient was substituted. It was thought that this change would give a better opportunity for studying the specific effect on yield of each fertilizer element.

It should be pointed out that the C treatment (1,200 pounds 4–16–4) could be expressed as 600 pounds of 8–32–8. Likewise, the B treatment 300 pounds of 4–16–4) could be expressed on the 600 pound basis as 2–8–2. In some of the tables these treatments are expressed in these terms in order to emphasize the comparison of equivalent amounts of separate ingredients.

As the experiment continued, it became evident that the tomatoes grown continuously on the same ground were suffering from lack of organic matter. It was decided, therefore, to see if the addition of organic matter in the form of well-rotted manure would build the soil up to its original state of fertility so that it would compare favorably with the tomatoes grown in rotation. Accordingly, in 1932, in the continuous series only, the F treatment (600 pounds 4–0–0) and the G treatment (600 pounds 0–0–4) were discontinued. It was clearly evident that these treatments were not effective and that the productive capacity of these plats was very seriously depleted. In their place two new treatments were substituted. In the plats formerly receiving the F treatment, well-rotted manure was applied at the rate of 20 tons per acre; and in the plats formerly receiving the G treatment, a new treatment was substituted consisting of 20 tons of well-rotted manure plus 600 pounds of 4–16–4 fertilizer per acre. It is the intention to continue these manure treatments in the future, using only 10 tons of manure in each case per acre each year. The heavier application was used the first year in order to build up the organic matter quickly.

The reason for using 4–16–4 as the basic fertilizer treatment was that other experiments in New York,[1] New Hampshire,[2] Missouri,[3] Indiana,[4] and Pennsylvania[5] have all shown that phosphorus is the principal limiting element in tomato production. Consequently, it seemed reasonable to expect that a complete fertilizer high in phosphorus would give the best results on tomatoes. Furthermore, on most soils in New York, phosphorus is most likely to be the principal limiting element.

To determine just what proportion would prove best, the ingredients were varied as previously described. All of the fertilizer

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[1]Work, Paul. Tomato fertilizer experiments in Chautauqua County, New York. *Cornell University Agr. Exp. Sta. Bul. No. 467. 1928.*

[2]Hepler, J. R., and Kraybill, H. R. Effect of phosphorus upon the yield and time of maturity of the tomato. *New Hampshire Agr. Exp. Sta. Tech. Bul. No. 28. 1925.*

[3]Rosa, J. T., Jr. Better methods of tomato production. *Missouri Agr. Exp. Sta. Bul. No. 194. 1922.*

[4]Brown, H. D. Canning factory tomatoes. *Purdue University Agr. Exp. Sta. Bul. No. 259. 1922.*

[5]Mack, W. B. Fertilization of truck crops in rotation. *Pennsylvania Agr. Exp. Sta. Bul. No. 210. 1927.*

mixtures were home mixed in order to use the same ingredients thruout. In every case the nitrogen was obtained half from nitrate of soda and half from ammonium sulfate. The phosphorus was derived from 16 per cent and 20 per cent superphosphate, and the potash was derived from muriate of potash, except in 1931 when sulfate of potash was used. It is thus seen that all the fertilizer materials used supply readily available plant food and are the forms easily obtainable by farmers. In fact, they are the usual ingredients of commercially mixed fertilizers.

The one exception in regard to kind of ingredients is treatment D in which the commercial product "Nitrophoska" was used. This is a very concentrated fertilizer which at the time of its introduction was listed as having an analysis of 16–32–16. Since 1928 the analysis has been 15–30–15 and a compensating increase in amount used in treatment D was made. Because of its very high analysis it was used at the rate of 150 pounds per acre, which gave an equivalent amount of nitrogen and potash, tho only half as much phosphorus, as the basic (A) treatment. This rate gave exactly the same amount of nitrogen, phosphorus, and potassium as the M treatment. It also had the same amount of phosphorus but twice as much nitrogen and potassium as the B treatment. It thus provided some excellent comparisons of ordinarily high analysis fertilizers with a very concentrated fertilizer. No other attempt was made to compare the *form* of each fertilizing element, but merely the *effect* of that element which would give results that would be generally applicable to field conditions in the growing of tomatoes.

The fertilizers were all applied broadcast by hand and were spread uniformly over each plat a few days before the tomato plants were transplanted to the field. The fertilizers were worked into the soil with a spring-tooth harrow drawn lengthwise of the plats.

The size of each fertilized plat was 16 x 76½ feet. The area from which the crops were harvested on each plat was 12 x 72½ feet, which is exactly 1/50 acre. There was a margin of 4 feet between plats to prevent any effect of fertilizers from adjacent plats being carried across during plowing and cultivation of the fields. All plowing was done across the plats so as not to leave dead furrows or back furrows in any plat. Harrowing and discing were done lengthwise of the plats so as not to carry the fertilizers from one plat to another.

The soil on which these experiments were conducted is Ontario loam, a rather heavy and stony soil. It was derived from the weathering of glacial till. Soils similar to this in type and fertilizer requirements form a major part of the farm lands of western New York. This particular soil is neutral to slightly alkaline, having a pH varying from 7 to 7.4.

The farm on which the experiments were conducted had been a tenant farm for a number of years previous to the start of this experiment and was devoted to the growing of general farm crops. Several years previous to that it had been used for growing nursery stock. No livestock feeding was practised, and consequently very little manure was returned to the soil and the farm was certainly not above the average in fertility at the time the experiments began.

The plats were laid out and the fields established in 1926, at which time a uniform fertilizer treatment of 300 pounds per acre of 4–16–4 was applied to all fields so as to gain an idea of the uniformity of the soil in the different areas. Consequently, the 1932 crop was the seventh produced on these fields, tho the differential treatments did not start until 1927 and only the 6 years' results beginning then are given in this bulletin.

The 4-year rotation used in this experiment is as follows: Tomatoes first year; snap beans second year, followed by a rye cover crop; beets third year, followed by a rye cover crop; and peas fourth year, followed by a sweet clover cover crop. The first two years the sweet clover was seeded in the peas, but better results have been obtained by harvesting the peas and refitting the soil and sowing the sweet clover separately. An excellent growth of sweet clover results in this way, which is knee high before frost occurs. This sweet clover is plowed under the next spring for tomatoes. It will be seen that this 4-year rotation contains four cash crops and a legume cover crop, as well as rye cover crops. The first 4 years tomatoes of both the rotated and continuous series were plowed under in the fall and the land left in this condition over winter to reduce the amount of plant diseases that might be carried over. However, the field planted to tomatoes continuously showed such marked effects from lack of organic matter that beginning in 1931 both the continuous and rotated tomatoes were disced under as soon as harvesting ended and the fields sown to a cover crop of rye.

The John Baer tomato was used thruout the experiments. Seed was sown each year on March 25, and when the seedlings were about 2 weeks old they were pricked off into flats which measured 14½ x 22 inches. One hundred and eight seedlings were set per flat. The plants were grown in these flats in cold frames until time to transplant them to the field. The date of transplanting to the field varied considerably different years. The entire series of both continuous and rotated tomatoes were transplanted to the field in 2 days each year, the plant setters working across the plats so that there would be no variation in the way the plants were set on each area. The transplanting dates were as follows: June 1, 1927; June 4, 1928; May 31, 1929; June 3, 1930; June 5, 1931; and May 24, 1932. The plants were set in the field in rows 4½ feet apart with the plants 4 feet apart in the row. The cultural practises were identical for the tomatoes grown continuously on the same field and those grown in rotation.

The plants were considerably crowded in the flats and were suffering somewhat from lack of plant food by the time they were transplanted to the field. This is the usual practise in growing tomatoes for the canning factory, and for that reason this method was used so as to make the results applicable to any grower of canning crops tomatoes. However, these results would apply equally well to market gardeners except that under the better plant growing conditions practised by most market gardeners they can reasonably expect heavier earlier yields than are reported here.

STATISTICAL METHODS

The differences in yields from various fertilizer treatments have been analyzed statistically, using Bessel's formula.[6] In this statistical analysis the significance of the differences between treatments was measured by the gains or losses in each treatment as compared with the pair of checks on each side of the treatment. The results of the statistical analyses are given in the following tables under the column entitled "Odds." If the odds are greater than 30 to 1, the differences are considered significant. That is, in comparing two treatments it is reasonably certain that when the odds are greater than 30 to 1 the differences in yield are not due to any

[6]Fisher, R. A. Statistical Methods for Research Workers. *Edinburgh: Oliver & Boyd. Ed. 4. 1932.*

chance variation in the soil or other factors, such as injury from insects or diseases, etc., but are due to the differences resulting from the fertilizer treatments.

The effect of each fertilizer treatment was determined for tomatoes grown continuously on the same field for 7 years, and also for tomatoes grown in the 4-year rotation previously described. The yields have been tabulated and statistically analyzed from three standpoints, namely, extra early yields (to August 31), early canning yields (to September 10), and total yields. All comparisons of the effects of fertilizers will be discussed from these three points of view.

The results with tomatoes grown in rotation and tomatoes grown each year on the same land have been analyzed separately and the yield records and comparisons recorded separately. In general, the effects of each variation in fertilizer treatment were similar in both the rotated and continuous tomato series. In the few cases where the results are not similar they will be discussed separately. Otherwise in *the following discussion of results only the yields of the rotated series will be mentioned because rotation should be practised in tomato growing.*

A larger number of comparisons showed significant differences in yields in the rotated series than in the continuous series. This is because the limiting effect of continuous cropping sometimes overshadowed other factors affecting yields and thus masked the full effect of the fertilizer differences. This is well illustrated in Table 4 where 11 comparisons in the rotated series showed significant differences, but only four of these same comparisons in the continuous series gave significant differences.

DISCUSSION OF RESULTS

FIELD RECORDS

In Tables 1 and 2 are given the complete yearly average yield records on an acre basis of each fertilizer treatment for the rotated and continuous tomatoes, respectively. The extra early yields (to August 31) and the yields to September 10, as well as the total yields, are given. Market gardeners are interested principally in extra early yields for which the highest returns are secured. Every year there is a drastic drop in the market price of tomatoes about September 1,

TABLE 1.—SUMMARY OF YIELDS OF ROTATED TOMATOES.

YEAR	A. 600 lbs. 4–16–4	B. 300 lbs. 4–16–4	C. 1,200 lbs. 4–16–4	D. 150 lbs. 16–32–16	E. 600 lbs. 0–16–0	F. 600 lbs. 4–0–0	G. 600 lbs. 0–0–4	H. No fertilizer	I. 600 lbs. 4–16–0	J. 600 lbs. 0–16–4	K. 600 lbs. 4–0–4	L. 600 lbs. 2–16–4	LL. 600 lbs. 8–16–4	M. 600 lbs. 4–8–4	MM. 600 lbs. 4–32–4	N. 600 lbs. 4–16–2	NN. 600 lbs. 4–16–8	X. 150 lbs. 4–16–4 Av. 16 chks.
									Yields to Aug. 31, Pounds per Acre									
1927	1,188	835	1,280	988	960	685	595	630	1,240	830	603	1,125	—	992	—	995	—	738
1928	1,202	953	1,316	950	730	603	789	550	950	750	585	967	—	1,246	—	1,185	—	750
1929	1,085	920	1,728	1,321	854	705	514	510	851	932	461	—	1,270	—	1,105	—	1,055	716
1931	965	760	1,090	645	681	758	580	583	905	790	744	—	1,052	—	1,009	—	799	694
1932	4,464	3,315	4,847	2,993	2,830	2,593	2,560	2,240	3,650	3,390	2,785	—	5,280	—	4,090	—	3,840	2,793
5-year av.	1,781	1,357	2,052	1,379	1,211	1,069	1,008	905	1,519	1,338	1,036	—	—	—	—	—	—	1,138
Av. '27, '28	1,195	894	1,298	969	845	644	692	590	1,095	790	594	1,046	—	1,119	—	1,090	—	744
Av. '29, '31, '32	2,171	1,665	2,555	1,653	1,455	1,352	1,218	1,111	1,802	1,704	1,330	—	2,534	—	2,068	—	1,898	1,401
									Yields to Sept. 10, Pounds per Acre									
1927	3,372	2,720	4,325	2,820	2,870	1,775	1,670	2,020	1,375	2,670	2,022	3,020	—	2,725	—	2,922	—	2,422
1928	4,340	3,090	3,790	3,240	2,490	2,141	3,042	1,795	3,590	3,341	2,140	3,645	—	3,835	—	3,690	—	2,391
1929	5,215	4,663	6,865	5,060	3,065	3,013	3,160	2,315	4,018	3,463	2,860	—	5,168	—	5,210	—	5,355	3,563
1931	6,906	5,910	8,710	6,005	5,256	4,505	4,055	3,605	5,508	4,357	4,905	—	7,350	—	7,305	—	5,410	4,656
1932	19,630	15,925	23,930	14,278	13,330	12,130	12,880	12,178	16,475	17,530	13,080	—	23,330	—	19,130	—	17,728	13,428
5-year av.	7,893	6,462	9,524	6,281	5,402	4,713	4,961	4,383	6,193	6,272	5,001	—	—	—	—	—	—	5,292
Av. '27, '28	3,856	2,905	4,058	3,030	2,680	1,958	2,356	1,908	2,483	3,006	2,081	3,333	—	3,280	—	3,306	—	2,407
Av. '29, '31, '32	10,584	8,833	13,168	8,448	7,217	6,549	6,698	6,033	8,667	8,450	6,948	—	11,949	—	10,548	—	9,498	7,216
									Total Yields, Tons per Acre									
1927	15.91	13.26	17.58	14.06	13.98	11.93	11.23	9.81	15.11	13.58	11.96	15.21	—	14.56	—	14.98	—	12.61
1928	10.72	8.59	11.37	9.19	7.42	5.87	6.12	6.97	9.14	10.64	7.44	9.64	—	9.74	—	10.29	—	7.24
1929	8.43	7.90	10.10	8.95	7.55	6.43	5.43	5.25	7.55	6.68	6.18	—	9.78	—	9.60	—	8.55	6.40
1931	14.16	11.51	15.53	14.71	12.18	9.61	9.16	9.91	12.30	10.23	10.43	—	13.13	—	13.63	—	12.71	10.51
1932	24.01	21.46	25.61	21.21	20.93	20.41	20.61	19.63	22.56	23.41	20.11	—	25.23	—	23.91	—	22.98	20.16
5-year av.	14.63	12.53	16.03	13.62	12.41	10.86	10.51	10.31	13.33	12.91	11.26	—	—	—	—	—	—	11.38
Av. '27, '28	13.31	10.93	14.48	11.63	10.70	8.90	8.68	8.39	12.13	12.11	9.70	12.43	—	12.15	—	12.64	—	9.96
Av. '29, '31, '32	15.53	13.63	17.01	14.96	13.55	12.15	11.73	11.61	14.13	13.43	12.24	—	16.05	—	15.71	—	14.76	12.35

TABLE 2.—SUMMARY OF YIELDS OF CONTINUOUS TOMATOES.

YEAR	A. 600 lbs. 4–16–4	B. 300 lbs. 4–16–4	C. 1,200 lbs. 4–16–4	D. 150 lbs. 16–32–16	E. 600 lbs. 0–16–0	F. 600 lbs. 4–0–0	G. 600 lbs. 0–0–4	H. No fertilizer	I. 600 lbs. 4–16–0	J. 600 lbs. 0–16–4	K. 600 lbs. 4–0–4	L. 600 lbs. 2–16–4	LL. 600 lbs. 8–16–4	M. 600 lbs. 4–8–4	MM. 600 lbs. 4–32–4	N. 600 lbs. 4–16–2	NN. 600 lbs. 4–16–8	X. 150 lbs. 4–16–4 Av. 16 chks.
Yields to Aug. 31, Pounds per Acre																		
1927	1,125	660	1,272	890	890	828	835	690	975	940	760	1,275	—	1,240	—	1,340	—	775
1928	645	610	875	645	695	378	625	510	525	710	575	560	—	645	—	695	—	560
1929	1,475	1,240	2,190	1,640	1,240	1,025	910	910	1,460	1,475	1,090	—	2,310	—	2,360	—	2,375	1,125
1930	1,969	1,434	2,454	1,619	1,819	854	1,004	1,019	2,254	1,834	954	—	2,319	—	2,304	—	2,320	1,319
1931	536	534	719	504	534	404	354	269	504	504	554	—	769	—	619	—	584	419
1932	2,797	1,682	4,197	1,582	1,732	2,747*	3,132†	1,162	2,282	2,397	1,562	—	3,582	—	2,962	—	3,047	1,547
6-year av	1,425	1,027	1,951	1,147	1,152	—	—	760	1,333	1,310	916	—	—	—	—	—	—	958
5-year av. (omit '30)	1,316	945	1,851	1,052	1,018	—	—	708	1,149	1,205	908	—	—	—	—	—	—	885
Av. '29, '30, '31, '32	1,694	1,223	2,390	1,336	1,331	—	—	840	1,625	1,552	1,040	—	2,245	—	2,061	—	2,082	1,103
Av. '27, '28	885	635	1,074	768	793	603	730	600	750	825	668	918	—	943	—	1,018	—	668
5-year av. (omit '32)	1,150	896	1,502	1,060	1,036	697	746	680	1,144	1,093	787	—	—	—	—	—	—	840
Yields to Sept. 10, Pounds per Acre																		
1927	3,494	2,760	4,044	3,255	3,260	2,460	2,860	2,526	3,460	3,065	2,262	4,120	—	3,615	—	4,910	—	2,760
1928	4,252	3,235	4,852	3,535	3,639	2,585	2,935	2,568	3,240	3,535	3,037	3,635	—	3,730	—	4,185	—	3,085
1929	5,403	4,319	8,136	4,469	3,865	3,771	3,669	3,269	5,464	5,569	3,370	—	6,515	—	7,120	—	6.470	3,969
1930	4,948	3,750	6,415	3,481	4,335	2,131	2,275	2,497	5,482	4,231	2,280	—	6,035	—	6,280	—	5,830	3,131
1931	4,228	3,060	5,112	3,178	2,982	3,026	2,378	2,378	4,278	3,178	3,529	—	4,828	—	4,328	—	4,278	2,728
1932	10,181	7,549	14,097	5,445	6,749	12,297*	14,747†	4,163	8,597	6,397	5,097	—	11,847	—	10,547	—	10,847	5,347
6-year av	5,417	4,107	7,109	3,892	4,134	—	—	2,891	5,084	4,292	3,258	—	—	—	—	—	—	3,501
5-year av. (omit '30)	5,512	4,183	7,248	3,983	4,093	—	—	2,983	5,013	4,308	3,453	—	—	—	—	—	—	3,578
Av. '29, '30, '31, '32	6,185	4,665	8,435	4,140	4,480	—	—	3,065	5,955	4,790	3,565	—	7,300	—	7,065	—	6,850	3,790
Av. '27, '28	3,872	2,997	4,449	3,397	3,448	2,522	2,894	2,545	3,350	3,297	2,648	3,870	—	3,672	—	4,547	—	2,922
5-year av. (omit '32)	4,460	3,422	5,715	3,882	3,612	2,792	2,820	2,642	4,382	3,872	2,892	—	—	—	—	—	—	3,132

Total Yields, Tons per Acre

1927	15.95	13.15	17.85	14.07	13.43	12.13	13.51	11.53	16.30	15.93	12.58	17.60	—	15.55	—	17.53	—	13.50
1928	9.86	7.48	12.11	9.03	8.81	5.73	7.23	6.38	8.38	8.98	6.68	9.43	—	7.71	—	9.56	—	7.16
1929	6.07	5.32	8.29	5.67	5.44	5.22	5.09	4.59	6.79	6.67	4.09	—	7.89	—	7.24	—	6.77	5.19
1930	4.95	4.27	5.32	4.32	4.65	3.50	3.82	3.45	5.27	4.99	3.27	—	5.77	—	6.27	—	5.20	3.87
1931	3.35	3.30	4.02	3.10	3.15	2.80	2.52	2.52	3.72	3.15	3.17	—	3.82	—	3.80	—	3.60	2.72
1932	10.81	9.60	13.82	8.50	10.08	14.11*	14.51†	6.45	10.38	9.63	7.58	—	12.30	—	11.70	—	12.05	8.10
6-year av.	8.50	7.19	10.24	7.45	7.59	—	—	5.82	8.47	8.22	6.23	—	—	—	—	—	—	6.76
5-year av. (omit '30)	9.21	7.77	11.22	8.01	8.18	6.64	7.27	6.29	9.17	8.87	6.82	—	—	—	—	—	—	7.33
Av. last 4 year	6.29	5.69	7.87	5.39	5.89	—	—	4.23	6.54	6.11	4.53	—	7.45	—	7.25	—	6.90	4.97
Av. '27, '28	12.90	10.32	14.98	11.55	11.11	8.93	10.38	8.95	12.34	12.45	9.63	13.52	—	11.63	—	13.54	—	10.33
5-year av. (omit '32)	8.03	6.70	9.52	7.24	7.09	5.87	6.43	5.67	8.09	7.94	5.96	—	—	—	—	—	—	6.49

*20 tons of manure applied to this plat in 1932. (See page 6.)

†20 tons of manure and 600 lbs. of 4–16–4 applied to this plat in 1932. (See page 6.)

and the most profitable tomatoes for the market gardener are obtained prior to that date. For that reason the yields to August 31 have been tabulated and analyzed separately.

In connection with the yield records to August 31, it should be pointed out that market gardeners could reasonably expect to obtain higher yields than are reported here, for two reasons. In the first place, the market gardener would use earlier plants. That is, his plants would be planted earlier, spaced further apart when pricked off, and would be transplanted to the field at least a week or 10 days earlier than were the tomatoes in this experiment which were grown as canning crop tomatoes. Heavier yields to August 31 would also have been obtained if the tomatoes had been harvested for the fresh market which requires firmer, less mature tomatoes. The tomatoes in this experiment were all harvested at fancy canning stage, or fully "red ripe", which would delay the harvest date from 4 to 6 days, as compared with market tomatoes.

Yields to September 10 are also tabulated separately because from a canner's standpoint these are early tomatoes which would precede the peak load at the cannery and thus utilize the facilities of the factory to better advantage.

CLIMATE AND YIELDS

From Tables 1 and 2 it will be readily seen that there were large variations in the total yields of each treatment in the different years. There were also wide differences in the yields to August 31 and to September 10, but the differences in the early yields did not vary in the same order or magnitude as the total yields. The variation in total yields between different years was due chiefly to variations in climatic conditions, particularly moisture supply and length of frost-free growing period.

Reviewing the seasons in detail, 1927 and 1932 were especially favorable for tomato growing. Both had long, frost-free periods, fairly well distributed rainfall, and produced large total yields. The highest yield of the rotated series was obtained in 1932, and the highest yield in the continuous series was obtained in 1927. The growing season of 1928 was average, having no unusual climatic conditions. In 1929, an extremely early frost (September 19) reduced the total yield. In 1930, a severe drouth greatly reduced the total yield. The severity of the drouth increased as the season progressed, and consequently, its effects were not so apparent in the early yields. The season of 1931 was also very dry with reduced total yields, altho the early yields were not much affected. It should be noted that these dry seasons reduced the yields on the continuous tomatoes particularly, while the tomatoes grown in rotation were not so seriously affected. Probably this was due to the serious depletion of the organic matter in the soil due to continuous cropping.

EARLY TRANSPLANTING IMPORTANT FOR EARLY YIELDS

An important factor affecting early yields was the time of transplanting the tomatoes to the field. The largest early yields of each fertilizer treatment in both the continuous and rotated tomatoes, were obtained in 1932, the year when the tomatoes were transplanted to the fields the earliest. The tomatoes were set in the field May 24th that year, a week earlier than in any other year in the experiment. The large increase in early yields in 1932 is outstanding. On the other extreme, the smallest early yields were obtained thruout each series in 1931. This was the year the tomatoes were set out the latest (June 5). The correlation between early transplanting to the field and large early yields is very marked. Differences in climatic conditions in the different seasons undoubtedly had some effect on the magnitude of the early yields. Certainly one of the principal factors affecting earliness of harvesting was the earliness of transplanting the tomatoes to the field.

ROTATION INCREASES YIELDS OF TOMATOES

In some of the tomato canning sections of the State there is a tendency among growers to select land particularly suited to tomatoes and to grow tomatoes continuously on that land for a number of years without rotation. For that reason when this experiment was laid out, a field especially suitable for tomatoes was selected, and tomatoes have been grown continuously on this field for 7 years. The entire fertilizer series was laid out in this field, as indicated in Fig. 1. At the same time a 4-year rotation was established, using four fields so that each crop in the rotation would be grown each year. The fertilizer plats were also laid out in each of these fields, as indicated in Fig. 1, so that the same fertilizer was applied to the same plat every year, and the crops rotated on that plat.

In 1930, through a laborer's error, the tomato plants intended for the rotated series were lost just before transplanting time. Since plants from an outside source would not be comparable with the ones set in the continuous tomato field, no tomatoes were grown in the rotation in 1930 and sweet corn was substituted that year in the rotation.

From an examination of Tables 1, 2, and 3, it will be seen that the field selected for continuous tomatoes was evidently more productive than the fields used in the rotation at the beginning of the experiment. For the first 2 years the continuous tomatoes out-yielded the ones grown in rotation. Following that, however, the effects of continuous cropping began to be apparent and the yields rapidly declined in the continuous series. At the same time the benefits of the rotation became apparent as the soil was improved by the cover crops, particularly by the sweet clover crop, and the yields of the rotated tomatoes gradually improved, as shown in Table 3.

The benefits of this rotation are well illustrated by comparing the difference in yields of the rotated and continuous tomatoes in 1927 with the difference in 1931. In 1927, the continuous series out-yielded the tomatoes in rotation. As previously mentioned this was probably because the field selected for continuous cropping happened to be superior to the field used for the rotated tomatoes at the time the experiment began. These same two fields came into direct comparison again in 1931 as the 4-year rotation began its second cycle, bringing tomatoes back to the first field. The contrast in yields in 1931 is very striking. This time the rotated field which had produced a different cash crop each year yielded approximately four times as much as the field cropped continuously with tomatoes.

This is further illustrated by comparing the differences in yields in 1928 and in 1932. In 1928, the continuous field slightly outyielded field No. 2 in the rotation. In the course of the rotation, tomatoes were again planted in field No. 2 in 1932. This time the rotated field produced approximately three times as much as the field cropped continuously with tomatoes.

The great advantage of rotation is again shown by comparing the 5-year average yield, 10.31 tons, from the unfertilized tomatoes (H) in rotation with the yield of 9.21 tons from continuous tomatoes receiving 600 pounds per acre annually of 4–16–4 fertilizer (A). This rotation with its cover crops and green manure crop of sweet clover maintained the productive capacity of the soil better than

TABLE 3.—EFFECT OF ROTATION AND OF INCREASING AMOUNTS OF 4-16-4 FERTILIZER ON YIELDS OF TOMATOES.

YEAR	CONTINUOUS TOMATOES					TOMATOES IN 4-YEAR ROTATION				
	(H) None	(X) 150 lbs.	(B) 300 lbs.	(A) 600 lbs.	(C) 1,200 lbs.	(H) None	(X) 150 lbs.	(B) 300 lbs.	(A) 600 lbs.	(C) 1,200 lbs.
					Total Yields*					
1927	11.53	13.50	13.15	15.95	17.85	9.81	12.61	13.26	15.91	17.58
1928	6.38	7.16	7.48	9.86	12.11	6.97	7.24	8.59	10.72	11.37
1929	4.59	5.19	5.32	6.07	8.29	5.25	6.40	7.90	8.43	10.10
1930	3.45	3.87	4.27	4.95	5.32	—‡	—	—	—	—
1931	2.52	2.72	3.29	3.35	4.02	9.91	10.51	11.51	14.16	15.53
1932	6.45	8.10	9.60	10.81	13.82	19.63	20.16	21.46	24.01	25.61
6-year av.	5.82	6.76	7.19	8.50	10.24	—‡	—	—	—	—
5-year av. (omit '30)	6.29	7.33	7.77	9.21	11.22	10.31	11.38	12.54	14.65	16.04
Gain over corresponding treatment due to rotation, 5-year av.						4.02	4.05	4.77	5.44	4.82
					Yields to Sept. 10†					
1927	2,526	2,760	2,760	3,494	4,044	2,020	2,422	2,720	3,372	4,325
1928	2,568	3,085	3,235	4,252	4,852	1,795	2,391	3,090	4,340	3,790
1929	3,269	3,969	4,319	5,403	8,136	2,315	3,563	4,663	5,215	6,865
1930	2,497	3,131	3,750	4,948	6,415	—‡	—	—	—	—
1931	2,378	2,728	3,060	4,228	5,112	3,605	4,656	5,910	6,906	8,710
1923	4,163	5,347	7,549	10,181	14,097	12,178	13,428	15,925	19,630	23,930
6-year av.	2,891	3,501	4,107	5,417	7,109	—‡	—	—	—	—
5-year av. (omit '30)	2,983	3,578	4,183	5,512	7,248	4,383	5,292	6,462	7,893	9,524
Gain over corresponding treatment due to rotation, 5-year av.						1,400	1,714	2,279	2,381	2,276
					Yields to Aug. 31†					
1927	690	775	660	1,125	1,272	630	738	835	1,188	1,280
1928	510	560	610	645	875	550	750	953	1,202	1,316
1929	910	1,125	1,240	1,475	2,190	510	716	920	1,085	1,728
1930	1,019	1,319	1,434	1,969	2,454	—‡	—	—	—	—
1931	269	419	534	536	719	583	694	760	965	1,090
1932	1,162	1,547	1,682	2,797	4,197	2,240	2,793	3,315	4,464	4,847
6-year av.	760	958	1,027	1,425	1,951	—‡	—	—	—	—
5-year av. (omit '30)	708	885	945	1,316	1,851	905	1,138	1,357	1,781	2,052
Gain over corresponding treatment due to rotation, 5-year av.						193	253	412	465	201

*Tons per acre. †Pounds per acre. ‡Not grown.

annual applications of 600 pounds of 4–16–4 fertilizer without rotation. This is probably due principally to the loss of organic matter, which is replenished in the rotation cropping system.

Other differences due to continuous cropping that cannot be shown in tables soon became apparent. During the last 2 years the continuous series produced smaller plants and much smaller total yields. The physical condition of the soil in the continuous series

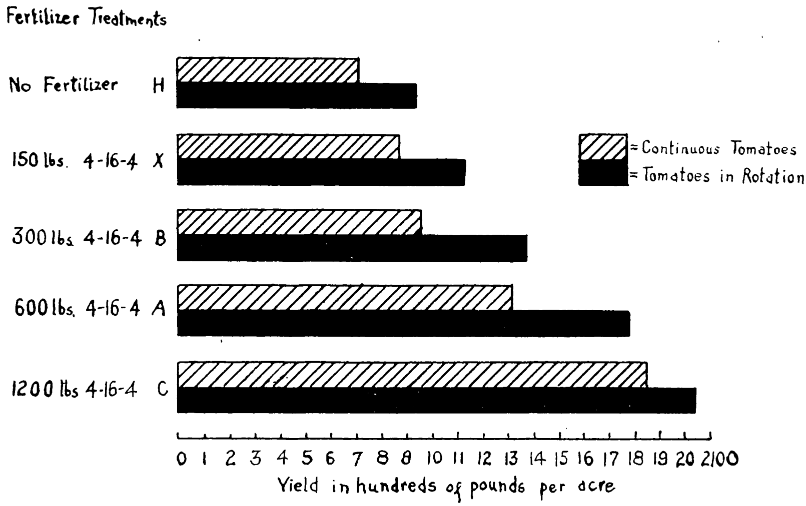

FIG. 2.—EFFECT OF ROTATION AND OF INCREASING AMOUNTS OF 4–16–4 FERTILIZER ON EARLY YIELDS (TO AUGUST 31) OF TOMATOES, 5-YEAR AVERAGE.

steadily deteriorated. Each year it showed an increasing tendency to puddle and was much harder to work. This was particularly noticeable at transplanting time when the soil in the rotated series was loose and friable while in the continuous series it was very hard. There was also a very noticeable reduction in the number of weeds in the continuous field as compared with the rotated fields.

Rotation does not seem to be such an important factor in increasing early yields of tomatoes. This is particularly true where a higher fertility level has been maintained by heavy fertilization. This is graphically illustrated in Fig. 2. However, there was some increase in early yields due to the rotation. The first three years continuous tomatoes produced better early yields due to more favorable soil conditions, but this was overcome as the benefits of rotation became apparent, so that for the average of the entire period the rotated tomatoes produced more early tomatoes than those grown continuously on the same land.

TOMATOES RESPOND PROFITABLY TO LIBERAL FERTILIZATION

Comparing the effect of increasing amounts of fertilizer, it is readily apparent that each increase in the amount of fertilizer re-

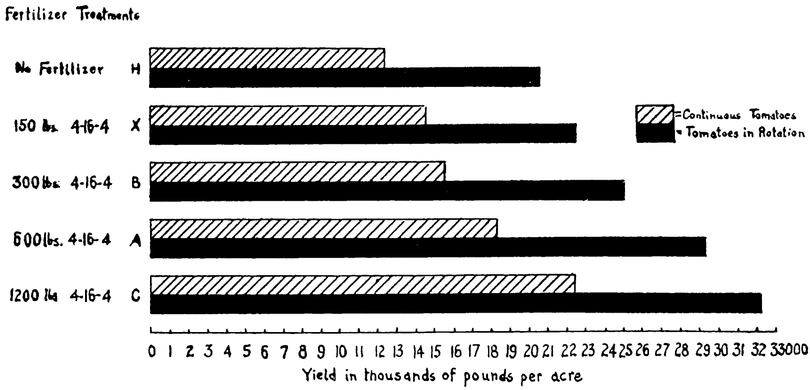

FIG. 3.—EFFECT OF ROTATION AND OF INCREASING AMOUNTS OF 4–16–4 FERTILIZER ON TOTAL YIELDS OF TOMATOES, 5-YEAR AVERAGE.

sulted in an increase in total yields. These results are given in Table 3 and are graphically illustrated in Fig. 3. Each increase in the amount of fertilizer used gave an increase in total yields, and also greatly increased the early yields. The heaviest rate of fertilization (1,200 pounds per acre) produced more than double the early yield from unfertilized plats. The effect of readily available fertilizer on increasing the early yields was very marked thruout the entire series, as shown in Table 3 and Fig. 2.

THE ECONOMICS OF FERTILIZING TOMATOES

The costs of growing tomatoes are rather high. Many of these costs are the same whether the yield is large or small. For example, the cost of the plants, transplanting, cultivating, and use of land and tools are all fixed costs regardless of the yield. Consequently, increasing the yield per acre without an equal increase in costs will reduce the net cost of tomatoes per ton. It is apparent from these results that liberal fertilization is an economical way to increase yields, because tomatoes respond very markedly to liberal fertilization. The increase in yield will more than repay the cost of fertilization.

Considering first total yields (Table 3), the unfertilized area in the rotated series produced 10.31 tons of tomatoes per acre for a 5-year average. When 150 pounds of 4–16–4 fertilizer, costing $2.50, were applied, the average yield per acre was 11.38 tons, or a gain of 1.07 tons due to this amount of fertilizer.

Doubling this original increment of fertilizer increased the cost $2.50 per acre. With the rotated tomatoes this gave a total yield of 12.54 tons, or an added gain of 1.16 tons for this additional expenditure of $2.50 for fertilizer. Again doubling the fertilizer application, at an additional cost of $5.00 per acre, the rotated tomatoes at this fertilizer rate produced 14.65 tons, or a gain of 2.11 tons due to the additional fertilizer. When the fertilizer rate was again doubled to 1,200 pounds per acre, at an added cost of $10.00 per acre, the rotated tomatoes produced a total yield of 16.04 tons or an increase of 1.39 tons for this last $10.00 worth of fertilizer. It is readily apparent from these figures that each additional increment of fertilizer resulted in an increase in yield more than sufficient to pay the cost of the fertilizer. Liberal fertilization not only increased the yield, but also tended to increase the size of the fruits, thus reducing picking costs and also increasing the proportion of U. S. No. 1 tomatoes which greatly increased the returns on a graded basis.

From a market gardener's standpoint it would be of especial interest to note the increase in early yields of tomatoes due to the more liberal fertilization (Table 3). Taking the yields to August 31, the $2.50 spent for the first increment of 150 pounds of 4–16–4 fertilizer produced an average increase per acre of 233 pounds per acre, as shown in comparing X with H. Doubling the fertilizer application resulted in an additional increase of 219 pounds per acre, giving an early yield of 1,357 pounds of tomatoes (treatment B). Again doubling the fertilizer application to 600 pounds increased the early yields an additional 424 pounds per acre to 1,781 pounds (treatment A). Doubling the fertilizer again resulted in an additional increase of 271 pounds to a total early yield of 2,052 pounds for the C treatment. Since the average price received by market gardeners for tomatoes up to August 31 is in excess of 1 cent per pound, it is apparent that each increasing amount of fertilizer resulted in sufficient gains to more than pay for the fertilizer from the standpoint of early yields alone. As previously mentioned, market gardeners could reasonably expect heavier early yields than are recorded here, which emphasizes further the value of liberal fertilization in increasing the yields of early tomatoes.

Prices of fertilizers vary in different years, but the prices given above are about an average for the period covered by this experiment. Prices of tomatoes, both on the canning factory and fresh market basis, likewise vary with different seasons, consequently no definite value for the increased yield of tomatoes is given, but a grower can readily apply prices he secures to these yield records to get an idea of the most economical rate of fertilization.

AVAILABLE PHOSPHORUS HAS MARKED EFFECT ON YIELDS

Striking differences in total yields were obtained by varying the amount of readily available phosphorus in the fertilizer used. The results show clearly that phosphorus is the most important fertilizer element in increasing tomato yields on soils of this type. The fertilizer treatments showing the effect of phosphorus on total yields are presented in Table 4 in which the average yields are shown together with the results of statistical analyses giving the significance of the differences in yields.

In examining the average yields in Table 4, it may be confusing at first glance to note that in the second line the average yield of the A treatment (4–16–4) is given as 14.63 tons, whereas the average yield of this same treatment is given as 13.31 tons in the fourth line. The reason for this difference is found in the column headed "Number of years". In the second line the 5-year average yield is given, while in the fourth line is given the 2-year average. The 2-year average was given in the latter case because it was used in comparison with the M treatment (4–8–4) which was only applied in 1927 and 1928. Consequently any comparisons with that treatment should only include the average yields for those 2 years, because, as noted on page 14, climatic conditions in different seasons greatly modify the yields.

Phosphorus applied alone gave a significant increase in yield over nitrogen alone, potash alone, and over nitrogen and potash

TABLE 4.—COMPARISON OF FERTILIZER TREATMENTS SHOWING THE EFFECT OF PHOSPHORUS ON TOTAL YIELDS OF TOMATOES.

FERTILIZER TREATMENTS AT RATE OF 600 LBS. PER ACRE, COMPARING I WITH II		TOMATOES IN ROTATION				CONTINUOUS TOMATOES			
		No. of years	Av. yields in tons per acre		Odds	No. of Years	Av. yields in tons per acre		Odds
I	II		I	II			I	II	
E(0–16–0)	H (No fertilizer)	5	12.41	10.31	9,999 to 1*	6	7.59	5.82	9,999 to 1*
A (4–16–4)	K (4–0–4)	5	14.63	11.26	9,999 to 1*	6	8.50	6.23	9,999 to 1*
M (4–8–4)	K (4–0–4)	2	12.15	9.70	9,999 to 1*	2	11.63	9.63	93 to 1*
A (4–16–4)	M (4–8–4)	2	13.31	12.15	9,999 to 1*	2	12.90	11.63	10 to 1
A (4–16–4)	MM (4–32–4)	3	15.53	15.71	1 to 1	4	6.29	7.25	1 to 5
C (8–32–8)	MM (4–32–4)	3	17.01	15.71	65 to 1*	4	7.87	7.25	1 to 1
M (4–8–4)	B (2–8–2)	2	12.15	10.93	168 to 1*	2	11.63	10.32	8 to 1
A (4–16–4)	I (4–16–0)	5	14.63	13.33	888 to 1*	6	8.50	8.47	1 to 1
A (4–16–4)	J (0–16–4)	5	14.63	12.91	27 to 1	6	8.50	8.22	1 to 1
I (4–16–0)	E (0–16–0)	5	13.33	12.41	101 to 1*	6	8.47	7.59	23 to 1
J (0–16–4)	E (0–16–0)	5	12.91	12.41	1 to 1	6	8.22	7.59	6 to 1
A (4–16–4)	E (0–16–0)	5	14.63	12.41	9,999 to 1*	6	8.50	7.59	11 to 1
E (0–16–0)	K (4–0–4)	5	12.41	11.26	1,214 to 1*	6	7.59	6.23	1,650 to 1*
K (4–0–4)	H (No fertilizer)	5	11.26	10.31	35 to 1*	6	6.23	5.82	3 to 1

*Odds indicate differences are significant.

together. Treatment E (phosphorus alone) gave an average yield of 12.41 tons, but treatment K (nitrogen and potash) produced only 11.26 tons. A complete fertilizer high in phosphorus, such as treatment A (4–16–4), produced 14.63 tons, an increase of 3.37 tons per acre over the same amount of fertilizer containing nitrogen and potash but lacking phosphorus, treatment K (4–0–4). Also, a fertilizer ratio of 4–8–4 gave a significant increase in yield,

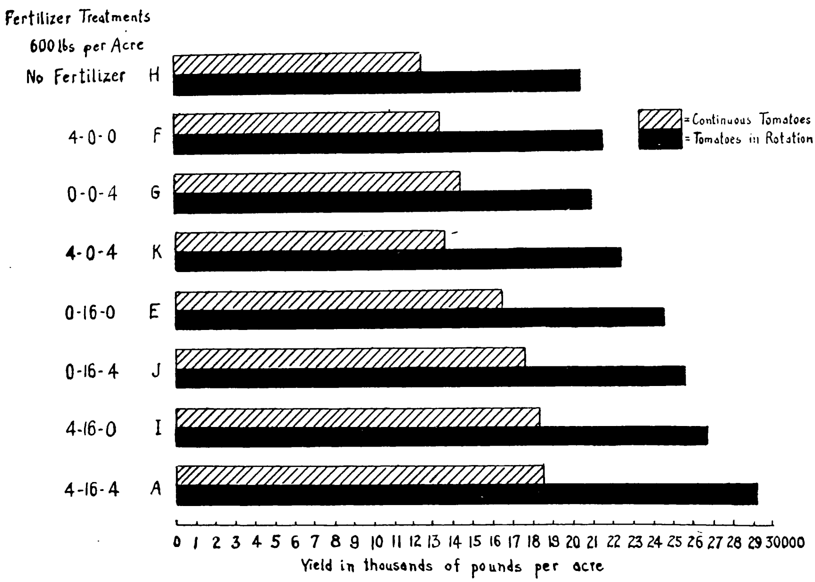

FIG. 4.—COMPARATIVE EFFECTS OF NITROGEN, PHOSPHORUS, AND POTASSIUM ON TOTAL YIELDS OF TOMATOES, 5-YEAR AVERAGE.

2.45 tons, over the same amount of fertilizer lacking phosphorus. This is shown in comparing M (4–8–4) which produced 12.15 tons and K (4–0–4) which yielded only 9.7 tons.

When the phosphorus deficiency was corrected by liberal phosphorus fertilization, then nitrogen and potash became limiting factors in the yield of tomatoes. This is graphically illustrated in Fig. 4.

Phosphorus alone (E treatment, 600 pounds 0–16–0) produced 12.41 tons of tomatoes per acre, a gain of 2.1 tons due to this fertilizer as compared with no fertilizer (H treatment). Adding nitrogen with the phosphorus (I treatment, 4–16–0) produced 13.33 tons of tomatoes, an additional gain of 0.92 ton due to the nitrogen. Adding potash to the phosphorus (J treatment, 0–16–4) produced an average gain of 0.5 ton which the statistical analysis shows was not significant. This is because the variations in yield in this treatment were rather large and a large probable error makes the significance of the average gain questionable.

If an element such as potassium is second or third in fertilizing importance, adding that element alone may not show any increase in yields. However, if the other elements, such as nitrogen and phosphorus, are added so as to correct their deficiencies, then potassium might become the element limiting additional yields and added potassium would increase the yields. This is shown in Table 4 comparing A (4–16–4) which produced 14.63 tons with I (4–16–0) which produced 13.33 tons, a significant gain of 1.3 tons due to the use of potash.

Adding both nitrogen and potassium to phosphorus produced the best gains. This is shown in comparing the yield of 14.63 tons from treatment A (4–16–4) with the yield of 12.41 tons from treatment E (0–16–0). In other words, the best results were obtained from a complete fertilizer high in phosphorus.

In regard to the actual amount and the best ratio of phosphorus to the other fertilizer elements to use for tomatoes, it is evident that when the proportion of phosphorus was four times as great as the amount of nitrogen and of potassium, then additional phosphorus was not effective in increasing yields. This is shown in Table 4 in comparing treatment A (4–16–4) with treatment MM (4–32–4). Altho the MM treatment produced 15.71 tons of tomatoes as compared with 15.53 tons from the A treatment, the difference was not significant statistically. On the other hand, increasing the nitrogen and potash to maintain the 1–4–1 ratio when the phosphorus was increased gave a very significant increase in yields over the yield obtained when only the amount of phosphorus was increased. This is shown by comparing the yield of 17.01 tons from treatment C (8–32–8) with the yield of 15.71 tons from treatment MM (4–32–4). This shows a very significant gain of 1.3 tons in favor of the 1–4–1 ratio as compared with the higher (1–8–1) ratio of phosphorus.

That the proportion of phosphorus should be high in relation to the other elements is shown in comparing treatment A (4–16–4) with treatment M (4–8–4). In this case the higher ratio of phosphorus (4–16–4) resulted in an average yield of 13.31 tons of tomatoes with a significant gain of 1.16 tons over the lower ratio of phosphorus (4–8–4) which produced only 12.15 tons.

This is contradicted, on the other hand, in the comparison between treatment M (4–8–4) with treatment B (2–8–2). This comparison indicates that the lower ratio of phosphorus is better. Considering these contradictory indications, one could compromise and recommend a ratio half way between 1–4–1 and 1–2–1. No doubt a ratio of 1–3–1 as represented in a 4–12–4 fertilizer would be very satisfactory. The weight of the evidence indicates that a relatively large amount of available phosphorus in the fertilizer will give the best results. This is shown by the fact that adding 96 pounds per acre of actual phosphoric acid (P_2O_5) as in the A treatment (600 pounds of 4–16–4) gave significantly larger yields than were obtained when only 48 pounds of P_2O_5 were added per acre as in the M treatment (600 pounds of 4–8–4). This clearly shows that large amounts of available phosphorus are needed for the best yields of tomatoes. The actual amount of phosphorus applied may be obtained either in heavy applications of a low phosphorus ratio or by smaller applications of a high phosphorus fertilizer.

Adding 48 pounds per acre of actual phosphoric acid (P_2O_5) was apparently sufficient to overcome the phosphorus deficiency in the soil to such an extent that nitrogen and potash became somewhat limiting factors. This is shown in comparing treatment M (600 pounds of 4–8–4) with treatment B (300 pounds of 4–16–4). Both treatments contained 48 pounds of actual phosphoric acid (P_2O_5). But the M treatment, containing twice as much nitrogen and potash, produced 12.15 tons of tomatoes, a significant gain of 1.22 tons over the yield of the B treatment, 10.93 tons. The results clearly indicate that after the phosphorus deficiency has been remedied the addition of nitrogen and potash will give significant increases in yield.

PHOSPHORUS STIMULATES EARLY YIELDS

A comparison of fertilizer treatments showing the effect of phosphorus on early yields is given in Table 5 which records the yields to August 31, and in Table 6 which gives the yields to September 10. The importance of phosphorus in stimulating earliness of maturity is graphically illustrated in Fig. 5. Referring to Table 5, it will be seen that phosphorus alone, treatment E (0–16–0), produced 1,211 pounds of tomatoes per acre to August 31 as compared with 905 pounds produced where no fertilizer was used (H treatment). The significance of this gain is shown in the overwhelming odds in favor of the phosphorus treatment. On the other hand,

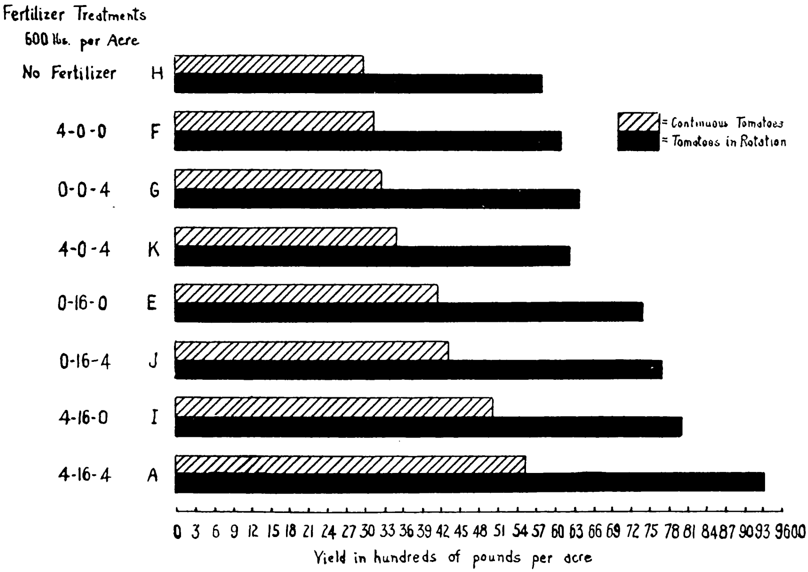

FIG. 5.—COMPARATIVE EFFECTS OF NITROGEN, PHOSPHORUS, AND POTASSIUM FERTILIZERS ON EARLY YIELDS (TO SEPTEMBER 10) OF TOMATOES, 5-YEAR AVERAGE.

nitrogen and potash, K treatment (4–0–4), produced only 1,036 pounds as compared with 905 pounds produced where no fertilizer was used, a gain which was not significant statistically.

The importance of phosphorus in stimulating earliness of maturity is emphasized by comparing a fertilizer containing nitrogen, phosphorus, and potash, treatment A (4–16–4), with the same amount of fertilizer lacking phosphorus, treatment K (4–0–4). With phosphorus, a yield of 1,781 pounds was produced and where phosphorus was omitted the yield was 1,036 pounds, a very significant increase of 745 pounds due to the use of phosphorus.

Apparently 8 per cent of phosphorus, or more specifically, 48 pounds per acre of actual phosphoric acid (P_2O_5), was sufficient greatly to stimulate earliness of maturity. This is shown in the 2-year average comparing the M treatment (4–8–4) which produced

TABLE 5.—COMPARISON OF FERTILIZER TREATMENTS SHOWING THE EFFECT OF PHOSPHORUS ON EXTRA EARLY YIELDS (TO AUGUST 31) OF TOMATOES.

Fertilizer treatments at rate of 600 lbs. per acre, comparing I with II		Tomatoes in rotation				Continuous tomatoes			
		No. of years	Av. yields in lbs. per acre		Odds	No. of years	Av. yields in lbs. per acre		Odds
I	II		I	II			I	II	
E (0–16–0)	H (No fertilizer)	5	1,211	905	1,214 to 1*	6	1,152	760	9,999 to 1*
A (4–16–4)	K (4–0–4)	5	1,781	1,036	292 to 1*	6	1,425	916	168 to 1*
M (4–8–4)	K (4–0–4)	2	1,119	594	9,999 to 1*	2	943	668	8 to 1
A (4–16–4)	M (4–8–4)	2	1,195	1,119	1 to 1	2	885	943	1 to 1
A (4–16–4)	MM (4–32–4)	3	2,171	2,068	1 to 1	4	1,694	2,061	1 to 3
C (8–32–8)	MM (4–32–4)	3	2,555	2,068	2 to 1	4	2,390	2,061	1 to 1
M (4–8–4)	B (2–8–2)	2	1,119	894	5 to 1	2	943	635	8 to 1
A (4–16–4)	I (4–16–0)	5	1,781	1,519	2 to 1	6	1,425	1,333	1 to 1
A (4–16–4)	J (0–16–4)	5	1,781	1,338	10 to 1	6	1,425	1,310	5 to 1
I (4–16–0)	E (0–16–0)	5	1,519	1,211	12 to 1	6	1,333	1,152	3 to 1
J (0–16–4)	E (0–16–0)	5	1,338	1,211	2 to 1	6	1,310	1,152	1 to 1
A (4–16–4)	E (0–16–0)	5	1,781	1,211	31 to 1*	6	1,425	1,152	6 to 1
E (0–16–0)	K (4–0–4)	5	1,211	1,036	172 to 1*	6	1,152	916	79 to 1*
K (4–0–4)	H (No fertilizer)	5	1,036	905	5 to 1	6	916	760	15 to 1

*Odds indicate that differences are significant.

TABLE 6.—COMPARISON OF DIFFERENT FERTILIZER TREATMENTS SHOWING THE EFFECT OF PHOSPHORUS ON EARLY YIELDS (TO SEPTEMBER 10) OF TOMATOES.

Fertilizer treatments at rate of 600 lbs. per acre, comparing I with II		Tomatoes in rotation				Continuous tomatoes			
		No. of years	Av. yields in lbs. per acre		Odds	No. of years	Av. yields in lbs. per acre		Odds
I	II		I	II			I	II	
E (0–16–0)	H (No fertilizer)	5	5,402	4,383	9,999 to 1*	6	4,134	2,891	9,999 to 1*
A (4–16–4)	K (4–0–4)	5	7,893	5,001	734 to 1*	6	5,417	3,258	1,100 to 1*
M (4–8–4)	K (4–0–4)	2	3,280	2,081	25 to 1	2	3,673	2,647	9,999 to 1*
A (4–16–4)	M (4–8–4)	2	3,856	3,280	1 to 1	2	3,872	3,673	2 to 1
A (4–16–4)	MM (4–32–4)	3	10,584	10,548	1 to 1	4	6,185	7,065	1 to 1
C (8–32–8)	MM (4–32–4)	3	13,168	10,548	2 to 1	4	8,435	7,065	2 to 1
M (4–8–4)	B (2–8–2)	2	3,280	2,905	1 to 1	2	3,673	2,997	2 to 1
A (4–16–4)	I (4–16–0)	5	7,893	6,193	4 to 1	6	5,417	5,084	1 to 1
A (4–16–4)	J (0–16–4)	5	7,893	6,272	8 to 1	6	5,417	4,292	12 to 1
I (4–16–0)	E (0–16–0)	5	6,193	5,402	30 to 1*	6	5,084	4,134	15 to 1
J (0–16–4)	E (0–16–0)	5	6,272	5,402	8 to 1	6	4,292	4,134	1 to 1
A (4–16–4)	E (0–16–0)	5	7,893	5,402	68 to 1*	6	5,417	4.134	20 to 1
E (0–16–0)	K (4–0–4)	5	5,402	5,001	407 to 1*	6	4,134	3,258	111 to 1*
K (4–0–4)	H (No fertilizer)	5	5,001	4,383	9 to 1	6	3,258	2,891	5 to 1

*Odds indicate that differences are significant.

1,119 pounds of early tomatoes per acre and the K treatment (4–0–4) which produced only 594 pounds in the 2-year average. In this, the gain was 525 pounds due to this amount of phosphorus. In the comparison between the A treatment (4–16–4) and the M treatment (4–8–4) in which there was a difference in yield of tomatoes of only 76 pounds which was not significant, 48 pounds of P_2O_5 again seems sufficient. Thirty-two per cent phosphorus gave no advantage over 16 per cent phosphorus when only 4 per cent of nitrogen and 4 per cent of potassium were used. This is shown in the comparison of the A treatment (4–16–4) with the MM treatment (4–32–4) in which there was a slightly greater yield from the smaller amount of phosphorus. Doubling the nitrogen and potash so as to give 8 per cent of each with the 32 per cent of phosphorus, or a 1–4–1 ratio, produced an increase in yield which was not statistically significant. This was shown in comparing the C treatment (8–32–8) with the MM treatment (4–32–4).

That phosphorus is the first fertilizer element limiting earliness of maturity is shown by the fact that phosphorus alone, E treatment (0–16–0), produced 1,211 pounds per acre, a significant gain of 175 pounds over the 1,036 pounds produced by fertilizer containing nitrogen and potash together, K treatment (4–0–4). This is further emphasized by the fact that nitrogen or potassium alone or in combination produced no significant increases over no fertilizer, while phosphorus alone produced a great increase as previously mentioned.

When sufficient phosphorus is applied to remedy the phosphorus deficiency, then nitrogen and potash become factors limiting earliness. Increased yields were obtained from a complete fertilizer high in phosphorus. This is shown by comparing the A treatment (4–16–4) which produced 1,781 pounds with the E treatment (0–16–0) which produced only 1,211 pounds. In this case a gain of 570 pounds of early tomatoes resulted from the addition of nitrogen and potash after the phosphorus deficiency had been met.

It is interesting to note that adding nitrogen to the phosphorus as in the I treatment (4–16–0) produced a small gain over phosphorus alone, E treatment (0–16–0), but that this gain was not statistically significant. Furthermore, adding potash to the phosphorus, as in the J treatment (0–16–4), produced only a slight gain over phosphorus alone, E treatment (0–16–0), and again the increase was not significant. However, when nitrogen and potash together were added to phosphorus, a significant gain of 570 pounds was obtained over phosphorus alone. This is shown in comparing the A treatment (4–16–4) with the E treatment (0–16–0).

Referring to Table 6, it will be seen that comparing the same fertilizer combinations shows the same treatments to be significantly superior in increasing the yields to September 10 as in increasing the yields to August 31 (Table 5). Only one additional comparison shows a significant difference in the yields to September 10. This is the comparison of the I treatment (4–16–0) which produced 6,193 pounds, a significant gain of 791 pounds over the E treatment (0–16–0). In the extra early yields, given in Table 5, the I treatment was not quite significantly better than the E treatment, altho there was considerable gain due to the nitrogen.

NITROGEN INCREASES YIELDS WHEN USED WITH PHOSPHORUS

The effect of nitrogen on total yields of tomatoes is shown in Table 7. It will be seen from this table that nitrogen alone, F treatment (4–0–0) failed to produce a significant increase in yield over no fertilizer (H). Adding potash with the nitrogen also failed to produce a significant increase in yield, but when phosphorus was added with nitrogen, the yields increased greatly.

As previously pointed out, phosphorus is the first limiting fertilizer element in tomato production. For that reason, the effect of nitrogen fertilizers is masked until the phosphorus deficiency has been remedied. When phosphorus was supplied, nitrogen produced a significant increase in yield. This is shown in comparing the I treatment (4–16–0) which produced 13.33 tons with the E treatment (0–16–0) which produced 12.41 tons, showing a gain of 0.92 ton of tomatoes due to the nitrogen.

It appears from the data that 2 per cent nitrogen was not sufficient. This is shown in comparing the A treatment (4–16–4) with the L treatment (2–16–4) in which a significant gain of 0.88 ton resulted from the increased amount of nitrogen. From the average yields it would seem that 8 per cent of nitrogen would be better than 4 per cent when used with 16 per cent phosphorus and 4 per cent potash. This is shown in comparing the LL treatment (8–16–4) with the A treatment (4–16–4). It is shown again in comparing the LL treatment (8–16–4) with the J treatment

TABLE 7.—COMPARISON OF FERTILIZER TREATMENTS SHOWING THE EFFECT OF NITROGEN ON TOTAL YIELDS OF TOMATOES.

Fertilizer treatments at rate of 600 lbs. per acre, comparing I with II		Tomatoes in rotation				Continuous tomatoes			
		No. of years	Av. yields in tons per acre		Odds	No. of years	Av. yields in tons per acre		Odds
I	II		I	II			I	II	
F (4–0–0)	H (No fertilizer)	5	10.86	10.31	2 to 1	5	5.87	5.67	657 to 1*
A (4–16–4)	J (0–16–4)	5	14.63	12.91	27 to 1	6	8.50	8.22	1 to 1
A (4–16–4)	L (2–16–4)	2	13.31	12.43	426 to 1*	2	12.90	13.52	1 to 1
A (4–16–4)	LL (8–16–4)	3	15.53	16.05	1 to 1	4	6.29	7.45	1 to 5
C (8–32–8)	LL (8–16–4)	3	17.01	16.05	3 to 1	4	7.87	7.45	1 to 1
L (2–16–4)	B (2–8–2)	2	12.43	10.93	9,999 to 1*	2	13.52	10.32	1,041 to 1*
I (4–16–0)	F (4–0–0)	5	13.33	10.86	9,999 to 1*	5	8.09	5.87	9,999 to 1*
K (4–0–4)	F (4–0–0)	5	11.26	10.86	7 to 1	5	5.96	5.87	1 to 1
I (4–16–0)	E (0–16–0)	5	13.33	12.41	101 to 1*	6	8.47	7.59	23 to 1
LL (8–16–4)	J (0–16–4)	3	16.05	13.45	22 to 1	4	7.45	6.11	16 to 1

*Odds indicate that differences are significant.

(0–16–4). Yet in spite of the large average gains due to the additional nitrogen, when analyzed statistically, these gains do not appear to be significant. The reason for the low ratio of odds when there seems to be such a large difference in average yields is due to the marked influence of climatic conditions on the response of the crop to readily available nitrogen fertilizers. On account of this influence of climatic conditions there were wide variations in the gains from the application of nitrogen in different seasons. These variations resulted in a larger probable error when the gains were averaged, and this reduced the odds. It is perfectly certain that the addition of readily available nitrogen in the fertilizer will increase the yields of tomatoes, but the amount of nitrogen that will give the best increase may vary with different seasons.

CLIMATIC CONDITIONS INFLUENCE EFFECT OF NITROGEN ON EARLY YIELDS

Variations in climatic conditions in different years are more likely to influence the response of plants to nitrogen fertilizers than their response to phosphorus or potassium fertilizers. This is because temperature and soil moisture affect the rate of nitrification in the soil, and this in turn affects the amount of nitrogen available to the crop. In the lower temperature of a cool season there would be less nitrogen available from the soil. Under these conditions there would be a greater crop response from the addition of fertilizers containing nitrogen in a readily available form. Furthermore, in an exceedingly dry season there would likely be a greater crop response from the application of readily available nitrogen because low soil moisture reduces the rate of nitrification in the soil. Under these conditions the application of a fertilizer containing nitrogen in readily available form would increase the crop response to nitrogen. For these reasons the variation in climatic conditions in the different seasons has a more marked effect on the crop response to nitrogen. The availability of phosphorus and also of potash are not so readily affected by climatic conditions.

Since climatic conditions thus affect the crop response to nitrogen fertilizers, there is a wider variation in the gains due to the nitrate treatments in the different seasons. In the statistical analyses this increases the probable error and reduces the odds, which indicate the significance of the treatment.

Table 8 gives a comparison of the fertilizer treatments showing the effect of nitrogen on extra early yields of tomatoes (to August 31) and Table 9 shows a similar comparison in the yields to September 10. Referring to Table 8, it is apparent that nitrogen alone, F treatment (4–0–0), with an average yield of 1,069 pounds gave an increase over no fertilizer of 165 pounds per acre to August 31, but the increase was not statistically significant. By comparing the I treatment (4–16–0) with the F treatment (4–0–0) it is evident that phosphorus is the principal fertilizing element limiting early yields. Therefore, the extent of the crop response to nitrogen fertilizer is likely to be masked until the phosphorus deficiency has been remedied. Comparing the I treatment (4–16–0) with the E treatment (0–16–0), there was a gain in the extra early crop of tomatoes of 308 pounds per acre due to the nitrogen, altho this gain was not statistically significant. Comparing the A treatment (4–16–4) with the J treatment (0–16–4), there was a gain of 443 pounds of extra early tomatoes per acre due to the nitrogen. Comparing LL (8–16–4) with J (0–16–4), there was a gain of 830 pounds of early tomatoes due to the nitrogen. This was only a 3-year average and the statistical analysis indicates that the gains are not significant. But as pointed out before, the seasonal differences and the few comparisons (only 3 years) account for this lack of significance. This is shown by referring to Table 1 in which it will be seen that there was an increase in yield every year, due to the application of nitrogen.

Because nitrogen is known to stimulate vegetative growth of the plant, there is a common belief among farmers that nitrogen fertilizer would produce excessive leaf growth at the expense of fruit and would tend to delay maturity of tomatoes. The yield records in Tables 1 and 2 and the comparisons in Tables 8 and 9 show conclusively that the nitrogen fertilizers at the rates applied resulted in no delay in maturity, but on the contrary, tended to increase the yields of early tomatoes. Larger plants with larger early yields and larger total yields were produced where nitrogen fertilizer was applied.

In Table 9 are presented comparisons of fertilizer treatments showing the effect of readily available nitrogen fertilizer on the yields of tomatoes to September 10. An increase in yield resulted in every comparison in which the nitrogen was increased, but the

TABLE 8.—COMPARISON OF FERTILIZER TREATMENTS SHOWING THE EFFECT OF NITROGEN ON EXTRA EARLY YIELDS (TO AUGUST 31) OF TOMATOES.

FERTILIZER TREATMENTS AT RATE OF 600 LBS. PER ACRE, COMPARING I WITH II		TOMATOES IN ROTATION				CONTINUOUS TOMATOES			
		No. of years	Av. yields in lbs. per acre		Odds	No. of years	Av. yields in lbs. per acre		Odds
I	II		I	II			I	II	
F (4–0–0)	H (No fertilizer)	5	1,069	905	5 to 1	5	697	680	1 to 1
A (4–16–4)	J (0–16–4)	5	1,781	1,338	10 to 1	6	1,425	1,310	5 to 1
A (4–16–4)	L (2–16–4)	2	1,195	1,046	14 to 1	2	885	918	1 to 1
A (4–16–4)	LL (8–16–4)	3	2,171	2,534	1 to 1	4	1,694	2,245	1 to 5
C (8–32–8)	LL (8–16–4)	3	2,555	2,534	1 to 1	4	2,390	2,245	1 to 1
L (2–16–4)	B (2–8–2)	2	1,046	894	5 to 1	2	918	635	2 to 1
I (4–16–0)	F (4–0–0)	5	1,519	1,069	436 to 1*	5	1,144	697	48 to 1*
K (4–0–4)	F (4–0–0)	5	1,036	1,069	1 to 1	5	787	697	1 to 1
I (4–16–0)	E (0–16–0)	5	1,519	1,211	12 to 1	6	1,333	1,152	3 to 1
LL (8–16–4)	J (0–16–4)	3	2,534	1,704	4 to 1	4	2,245	1,552	13 to 1

*Odds indicate that differences are significant.

TABLE 9.—COMPARISON OF FERTILIZER TREATMENTS SHOWING THE EFFECT OF NITROGEN ON EARLY YIELDS (TO SEPTEMBER 10) OF TOMATOES.

Fertilizer treatments at rate of 600 lbs. per acre, comparing I with II		Tomatoes in rotation				Continuous tomatoes			
		No. of years	Av. yields in lbs. per acre		Odds	No. of years	Av. yields in lbs. per acre		Odds
I	II		I	II			I	II	
K (4–0–4)	H (No fertilizer)	5	5,001	4,383	4 to 1	6	3,258	2,891	1 to 1
A (4–16–4)	J (0–16–4)	5	7,893	6,272	8 to 1	6	5,417	4,292	12 to 1
A (4–16–4)	L (2–16–4)	2	3,856	3,333	2 to 1	2	3,872	3,870	1 to 1
A (4–16–4)	LL (8–16–4)	3	10,584	11,949	1 to 1	4	6,185	7,300	1 to 2
C (8–32–8)	LL (8–16–4)	3	13,168	11,949	2 to 1	4	8,435	7,300	1 to 1
L (2–16–4)	B (2–8–2)	2	3,333	2,905	3 to 1	2	3,870	2,997	3 to 1
I (4–16–0)	F (4–0–0)	5	6,193	4,713	8,505 to 1*	5	4,382	2,792	3,704 to 1*
K (4–0–4)	F (4–0–0)	5	5,001	4,713	1 to 1	5	2,892	2,792	1 to 1
LL (8–16–4)	J (0–16–4)	3	11,949	8,450	3 to 1	4	7,300	4,790	69 to 1*
I (4–16–0)	E (0–16–0)	5	6,193	5,402	30 to 1*	6	5,084	4,134	15 to 1

*Odds indicate that differences are significant.

gains in yields were not statistically significant except in one case. Comparing the I treatment (4–16–0) which produced 6,193 pounds with the E treatment (0–16–0) which produced 5,402 pounds, there is an average gain of 791 pounds per acre due to the nitrogen fertilizer. This gain is statistically significant.

It should be noted that the use of nitrogen fertilizers resulted in substantial increases in the yields of the rotated tomatoes. This might seem surprising at first thought because a legume green manure crop (sweet clover) rich in nitrogen is plowed under in preparing the land for the rotated tomatoes. Each year the sweet clover is plowed under about 2 weeks previous to the time the tomatoes are to be transplanted to the field. It has been shown by other experiments[7] that when organic matter begins to decompose in the soil, the bacteria causing this decomposition use large amounts of nitrogen from the soil solution at that time. This results in a competition between these bacteria and the growing crop for the available nitrogen in the soil solution. Altho the incorporation of the legume with the soil actually increases the total nitrogen content of the soil, the amount of nitrogen available to the growing crop is reduced during the early stages of decomposition by the soil bacteria. Eventually, this nitrogen becomes available to the crop, but in the meantime the application of nitrogen fertilizer in readily available form will increase the supply for the growing crop. Consequently, it frequently happens that the application of readily available nitrogen fertilizer when plowing under a green manure or cover crop will increase the early yields for the succeeding crop. That this is good fertilizer practise is shown by the yield records of the rotated tomatoes in Tables 8 and 9.

POTASH INCREASES YIELDS WHEN USED WITH NITROGEN AND PHOSPHORUS

Table 10 gives comparisons showing the effect of potassium fertilizers on total yields of tomatoes. From this table it will be seen that potassium alone, G treatment (0–0–4), failed to produce a significant increase in yield over no fertilizer. When phosphorus and nitrogen were supplied in sufficient quantities so as not to be limiting factors, there was a marked response from potassium.

[7]Collison, R. C., and Conn, H. J. The effect of straw on plant growth *New York State Agr. Exp. Sta. Tech. Bul. No. 114. 1925.*

TABLE 10.—COMPARISON OF FERTILIZER TREATMENTS SHOWING THE EFFECT OF POTASH ON TOTAL YIELDS OF TOMATOES.

Fertilizer treatments at rate of 600 lbs. per acre, comparing I with II		Tomatoes in rotation				Continuous tomatoes			
		No. of years	Av. yields in tons per acre		Odds	No. of years	Av. yields in tons per acre		Odds
I	II		I	II			I	II	
G (0–0–4)	H (No fertilizer)	5	10.51	10.31	1 to 1	5	6.43	5.67	69 to 1*
A (4–16–4)	I (4–16–0)	5	14.63	13.33	888 to 1*	6	8.50	8.47	1 to 1
A (4–16–4)	N (4–16–2)	2	13.31	12.64	18 to 1	2	12.90	13.54	1 to 1
N (4–16–2)	B (2–8–2)	2	12.64	10.93	2,467 to 1*	2	13.54	10.32	4,776 to 1*
A (4–16–4)	NN (4–16–8)	3	15.53	14.76	4 to 1	4	6.29	6.90	1 to 1
C (8–32–8)	NN (4–16–8)	3	17.01	14.76	9,999 to 1*	4	7.87	6.90	2 to 1
K (4–0–4)	G (0–0–4)	5	11.26	10.51	48 to 1*	5	5.96	6.43	1 to 11
J (0–16–4)	G (0–0–4)	5	12.91	10.51	256 to 1*	5	7.94	6.43	9,999 to 1*

*Odds indicate that differences are significant.

This is shown in comparing treatment A (4–16–4), which produced an average yield of 14.63 tons, with treatment I (4–16–0), which produced an average yield of 13.33 tons. This shows a significant gain of 1.3 tons due to the potassium fertilizer.

The average yields indicate that 4 per cent of potash is better than 2 per cent. Treatment A (4–16–4) gave an average yield of 0.67 ton more than treatment N (4–16–2), but the odds indicate that this gain was not significant.

Altho potash increased the yield of tomatoes when applied with nitrogen and phosphorus, the records indicate that a small amount of potash is sufficient to satisfy the crop needs. This is shown in comparing treatment N (4–16–2) with treatment B (2–8–2). This shows a significant gain of 1.71 tons in favor of the higher ratio of nitrogen and phosphorus to potassium. That a low ratio of potash is sufficient is again shown in comparing A treatment (4–16–4) with NN treatment (4–16–8). The average yield was actually less where the larger amount of potassium was used, but the differences were not significant. Again the advantage of a low ratio of potash is shown in comparing treatment C (8–32–8) with treatment NN (4–16–8). Increasing the amount of nitrogen and phosphorus in relation to the potassium, resulted in a very large increase in yield and a very significant gain in favor of the higher proportion of the other elements.

Potassium fertilizer was much more effective when used with nitrogen and phosphorus together. For example, potash with nitrogen, K treatment (4–0–4), produced 11.26 tons of tomatoes, a gain of 0.75 ton over potash alone, G treatment (0–0–4). This gain was statistically significant but potash with nitrogen was not significantly better than nitrogen alone. This is shown (Table 7) in comparing treatment K (4–0–4) with treatment F (4–0–0), and indicates that potassium is secondary to nitrogen in importance.

Phosphorus with potassium, J treatment (0–16–4), produced a significant gain of 2.4 tons over potassium alone, G treatment (0–0–4), but potassium with phosphorus was not significantly better than phosphorus alone, indicating that potassium was secondary to phosphorus as a limiting fertilizer element. This is shown (Table 4) in comparing treatment E (0–16–0) with treatment J (0–16–4), which was not significantly better.

However, nitrogen plus phosphorus without potassium did not produce as good yields as the combination containing all three elements. This is shown in comparing treatment A (4–16–4) with treatment I (4–16–0) in which there is a significant gain of 1.3 tons due to the addition of potash. These results clearly indicate that a potassium fertilizer was not a factor limiting tomato yields until the soil deficiencies of both phosphorus and nitrogen had been remedied. The conclusion, therefore, is that potassium is third in importance as a necessary fertilizer element for tomatoes.

The effect of potassium in the rotated series as compared with the continuous series is shown in the results from potassium fertilizer alone, G treatment (0–0–4), compared with results from no fertilizer (treatment H). In the rotated tomatoes there was a slight but not significant gain due to the potassium fertilizer. The continuous tomatoes showed an entirely different result. The average yield of continuous tomatoes was 5.67 tons with the H treatment (no fertilizer). The average yield from potash fertilizer alone (G treatment, 0–0–4) was 6.43 tons, a significant gain of 0.76 ton due to the potash fertilizer.

This greater response from potassium fertilizer in the continuous tomato series is to be expected and may be explained by the beneficial effect of sweet clover in the rotation. Soils of the type used in this experiment and upland soils generally are fairly well supplied with potash which is more or less available for crop growth. Sweet clover has a tendency to render soil potash more available to the succeeding crop by increasing the carbon dioxide content of the soil, and thus dissolving more of the soil potassium and making it more available for plant use.[8] The tomatoes grown in rotation followed sweet clover each year and therefore probably had available a greater supply of potassium from the soil. The continuous tomatoes, without this assistance from sweet clover, consequently showed a greater response to readily available potash fertilizer.

The tendency of the potash to give greater response in the continuous series is again shown in comparing treatment A (4–16–4) with treatment NN (4–16–8). In the continuous tomatoes there was an average gain of 0.61 ton in favor of the larger amount of potassium, altho the gain was not statistically significant, while in the rotation there was no increased yield of tomatoes from the addi-

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[8]Headden, W. P. Effects of clover and alfalfa in rotation, II. *Colorado Agr. Exp. Sta. Bul. No. 362. 1930.*

tional potash fertilizer. The results, however, are somewhat contradictory, because in comparing treatment A (4–16–4) with treatment I (4–16–0) in the continuous tomato series there will be found only 0.03 ton difference in average yields, which was not significant, while in the rotated series there was a significant gain due to the potash fertilizer. The only explanation of these contradictory results is that nitrogen and phosphorus, particularly the latter, were such overwhelmingly limiting factors in tomato yield that where they were liberally supplied they sometimes overshadowed the effect of potassium.

The effect of potash fertilizers on early yields is shown in Table 11. It will be seen from this table that almost identical results were obtained in the early yields as with the total yields, and that potash played a minor rôle in increasing the yields of early tomatoes. No significant differences in gains due to the potash treatments were obtained. The average yield records, however, indicate an advantage in using potash in connection with nitrogen and phosphorus, but that potash alone was not effective. It is clearly evident that with early yields as well as with total yields potash is third in importance as a limiting factor in tomato production, and that to obtain the best results it should be used in a rather low ratio in connection with nitrogen and phosphorus.

CONCENTRATED FERTILIZERS VS. MODERATELY HIGH ANALYSIS MIXTURES

Thus far in this discussion all comparisons have been between fertilizer combinations in which only the amount or ratio of the several ingredients has been varied. The same form of phosphorus (superphosphate) was used thruout; likewise the same forms of nitrogen, namely, 50 per cent from nitrate of soda and 50 per cent from ammonium sulfate. Similarly, the same form of potash (muriate of potash) was used in each comparison.

In Table 12 a comparison is made between different forms of fertilizer. The forms of nitrogen, phosphorus, and potash previously mentioned were combined in a high analysis fertilizer mixture and compared with a very concentrated fertilizer in which the nitrogen, phosphorus, and potash were combined in different chemical forms from that previously mentioned. The very concentrated form of fertilizer used was a commercial product called "Nitrophoska." It

Table 11.—Comparison of Fertilizer Treatments Showing the Effect of Potash on Early Yields (to September 10) of Tomatoes.

Fertilizer treatments at rate of 600 lbs. per acre, comparing I with II		Tomatoes in rotation				Continuous tomatoes			
		No. of years	Av. yields in lbs. per acre		Odds	No. of years	Av. yields in lbs. per acre		Odds
I	II		I	II			I	II	
G (0–0–4)	H (No fertilizer)	5	4,961	4,383	17 to 1	5	2,820	2,642	10 to 1
A (4–16–4)	I (4–16–0)	5	7,893	6,193	4 to 1	6	5,417	5,084	1 to 1
A (4–16–4)	N (4–16–2)	2	3,856	3,306	2 to 1	2	3,872	4,547	1 to 3
N (4–16–2)	B (2–8–2)	2	3.306	2,905	2 to 1	2	4,547	2,997	10 to 1
A (4–16–4)	NN (4–16–8)	3	10,584	9,498	1 to 1	4	6,185	6,850	1 to 1
C (8–32–8)	NN (4–16–8)	3	13,168	9,498	6 to 1	4	8,435	6,850	2 to 1
K (4–0–4)	G (0–0–4)	5	5,001	4,961	2 to 1	5	2,892	2,820	1 to 1
J (0–16–4)	G (0–0–4)	5	6,272	4,961	266 to 1*	5	3,872	2,820	9,999 to 1*

*Odds indicate that differences are significant.

was used in treatment D (16–32–16) thruout the experiment. The ratio of nitrogen, phosphorus, and potassium in this fertilizer was 1–2–1, respectively, and could not be varied. This was the same ratio as in the M treatment (4–8–4). Therefore, to get equivalent amounts of nitrogen, phosphorus, and potassium for comparison would require one-fourth as much Nitrophoska as of 4–8–4 (M treatment). For that reason 150 pounds of Nitrophoska (D treatment) was used in this experiment. As previously mentioned (page 7), the percentage of nitrogen, phosphorus, and potassium in Nitrophoska was reduced in later years by the manufacturer to 15–30–15 which maintained the same 1–2–1 ratio as before. Consequently, a compensating increase in the pounds of Nitrophoska used per acre was made so that the actual amount of nitrogen, phosphorus, and potash applied in treatment D was the same each year.

Unfortunately, from the standpoint of this comparison, the M treatment (4–8–4) was discontinued after 2 years. The 2 years' comparison, however, between the M treatment (600 pounds of 4–8–4) with the D treatment (150 pounds of 16–32–16) shows a slight advantage in average yields in favor of the 4–8–4 mixture. This advantage in average yields, as given in Table 12, is shown in the comparisons of total yields, extra early yields (to August 31), and in the yields to September 10. Yet in none of these comparisons was the advantage of the M treatment statistically significant, except in the continuous tomato series in the yields to September 10. In this case the increase in yield in favor of the M treatment (4–8–4) was statistically significant.

Two other fertilizer treatments are compared with Nitrophoska in Table 12. In the comparison between A (600 pounds 4–16–4) and D (150 pounds of 16–32–16), there was an average increase in total yields of 1.01 tons in favor of the A treatment for the rotated tomatoes and of 1.05 tons for the continuous treatment. The increased yields from the A treatment were statistically significant in both the rotated and continuous series. However, it should be noted in this comparison that, altho equivalent amounts of nitrogen and potash were used in both these fertilizer treatments, yet the A treatment (600 pounds of 4–16–4) contained twice as much available phosphorus as the D treatment (150 pounds 16–32–16). As previously pointed out (page 21), phosphorus is the principal fer-

TABLE 12.—COMPARISON OF EFFECT OF EQUIVALENT AMOUNTS OF NITROGEN, PHOSPHORUS, AND POTASH IN VERY CONCENTRATED AND IN HIGH ANALYSIS FERTILIZER MIXTURES ON YIELDS OF TOMATOES.

Fertilizer treatments, comparing I with II		Tomatoes in rotation				Continuous tomatoes			
		No. of years	Av. yields per acre		Odds	No. of years	Av. yields per acre		Odds
I	II		I	II			I	II	
Effects on Total Yields*									
A (600 lbs. 4–16–4)	D (150 lbs. 16–32–16)	5	14.63	13.62	1,506 to 1†	6	8.50	7.45	40 to 1†
D (150 lbs. 16–32–16)	B (300 lbs. 4–16–4)	5	13.62	12.53	35 to 1†	6	7.45	7.19	2 to 1
M (600 lbs. 4–8–4)	D (150 lbs. 16–32–16)	2	12.15	11.63	5 to 1	2	11.63	11.55	1 to 1
Effects on Early Yields (to Sept. 10)‡									
A (600 lbs. 4–16–4)	D (150 lbs. 16–32–16)	5	7,893	6,281	10 to 1	6	5,417	3,892	82 to 1†
D (150 lbs. 16–32–16)	B (300 lbs. 4–16–4)	5	6,281	6,462	1 to 1	6	3,892	4,107	1 to 1
M (600 lbs. 4–8–4)	D (150 lbs. 16–32–16)	2	3,280	3,030	1 to 1	2	3,672	3,397	132 to 1†
Effects on Extra Early Yields (to Aug. 31)‡									
A (600 lbs. 4–16–4)	D (150 lbs. 16–32–16)	5	1,781	1,379	6 to 1	6	1,425	1,147	6 to 1
D (150 lbs. 16–32–16)	B (300 lbs. 4–16–4)	5	1,379	1,357	1 to 1	6	1,147	1,027	9 to 1
M (600 lbs. 4–8–4)	D (150 lbs. 16–32–16)	2	1,119	969	3 to 1	2	943	768	2 to 1

*Tons per acre.

†Odds indicate that differences are significant.

‡Pounds per acre.

tilizer element limiting tomato yields and an increase in yields occurred whenever more phosphorus was used.

In the comparisons between the D treatment (150 pounds 16–32–16) and the B treatment (300 pounds 4–16–4), the Nitrophoska gave a significant increase in total yields. For early tomatoes, however, the yields were about even. It should be noted in comparing the D and B treatments that equivalent amounts of available phosphorus were used in each case, but that there was twice as much nitrogen and potash in the 150 pounds of Nitrophoska as in the 300 pounds of 4–16–4.

The principal advantage claimed for the very concentrated fertilizer is the saving in freight rates and in cost of application because of the smaller quantity required. From the limited data available it seems that considered only from the standpoint of equivalent amounts of plant food the very concentrated form was not quite as effective as a moderately high analysis fertilizer for tomatoes. No attempt was made to compare the economics of using very concentrated and high analysis forms of fertilizers. This would involve the balancing of differences in yields with differences in freight rates, handling charges, etc. The latter factors would vary greatly in different regions and the results would not be applicable to other localities.

MANURE GREATLY INCREASES YIELDS OF TOMATOES

As mentioned on page 6, it was clearly evident that continuous cropping with tomatoes had seriously depleted the organic matter in the soil. To determine if this loss of organic matter was the principal cause of the reduced yields in continuous cropping, it was decided to add organic matter to certain plats in the continuous series to see if the productive capacity of this soil for tomatoes could be brought up to a par with that in rotation. Accordingly, in 1932 the former F (4–0–0) and G (0–0–4) treatments in the continuous series were discontinued. On the F plats 20 tons per acre of well-rotted manure were applied. This was called treatment Y. On the G plats the treatment was changed to 20 tons per acre of well-rotted manure plus 600 pounds of 4–16–4 fertilizer. This was called treatment Z. The commercial fertilizer added was the same as in the A treatment. In the future it is planned to use only 10 tons of manure per acre annually in the Y and Z treatments.

The results of the manure treatments are given in Table 13. By comparing these yields with the yields obtained in rotation (Table 1), it will be seen that even the poorest treatment in the rotation (H, no fertilizer) outyielded the manure treatments in the continuous tomatoes in 1932. Nevertheless, the manure treatments resulted in a tremendous increase in yields and produced larger total yields than any other fertilizer treatment in the continuous tomatoes. The F and G plats, which had formerly been next to the bottom in average yields, in one season were brought to the top of the list in production due to the use of manure as a fertilizer. It will be interesting to see if progressive increases in yield will result from the subsequent annual application of manure.

Referring to Table 13 in comparing the Y treatment (20 tons of manure) with the A treatment (600 pounds 4–16–4), it will be seen that the manure gave an increase in total yield of 3.3 tons, and that this large increase was overwhelmingly significant. In the yields to September 10 there was an average increase of 1.05 tons in favor of the manure treatment and this increase was also statistically significant. However, the extra early yields (to August 31) were about equal, altho in this case the manure treatment was not quite as good as the commercial fertilizer.

SUPPLEMENTING MANURE WITH 4–16–4 FERTILIZER INCREASES EARLY YIELDS

Comparing the Z treatment (20 tons of manure plus 600 pounds 4–16–4) with the A treatment (600 pounds 4–16–4), it will be seen from Table 13 that the manure treatment gave a tremendous increase in total yields and in yields to September 10, and that both increases were statistically significant. Also, in the extra early yields (to August 31), the manure treatment gave an average yield per acre of 3,192 pounds of tomatoes as compared with the 2,790 pounds produced by the A treatment. Altho this shows an increase in favor of the manure treatment, it was not statistically significant. From these comparisons it is evident that manure as a fertilizer was more effective later in the season.

It should be pointed out, however, that the manure was applied in the spring and plowed under with a good cover crop of rye. All this organic matter was turned under about 2 weeks before the tomatoes were transplanted to the field. It would require a much

TABLE 13.—COMPARISON OF EFFECTS OF MANURE AND OF COMMERCIAL FERTILIZERS ON EARLINESS AND TOTAL YIELDS OF TOMATOES, 1 YEAR ONLY.

Fertilizer treatments (acre basis), comparing I with II		Extra early yields (to Aug. 31)			Early yields (to Sept. 10)			Total yields		
		Lbs. per acre		Odds	Tons per acre		Odds	Tons per acre		Odds
I	II	I	II		I	II		I	II	
(Y) 20 tons manure	(A) 600 lbs. 4–16–4	2,747	2,790	1 to 1	6.15	5.10	34 to 1*	14.11	10.81	9,999 to 1*
(Z) 20 tons manure & 600 lbs. 4–16–4	(A) 600 lbs. 4–16–4	3,132	2,790	1 to 1	7.37	5.10	9,999 to 1*	14.51	10.81	9,999 to 1*
(Z) 20 tons manure & 600 lbs. 4–16–4	(Y) 20 tons manure	3,132	2,747	4 to 1	7.37	6.15	1,214 to 1*	14.51	14.11	1 to 1
(C) 1,200 lbs. 4–16–4	(Y) 20 tons manure	4,195	2,747	9,999 to 1*	7.05	6.15	13 to 1	13.82	14.11	1 to 1
(Z) 20 tons manure & 600 lbs. 4–16–4	(C) 1,200 lbs. 4–16–4	3,132	4,195	1 to 3,704*	7.37	7.05	1 to 1	14.51	13.82	1 to 1
(C) 1,200 lbs. 4–16–4	(A) 600 lbs. 4–16–4	4,195	2,790	175 to 1*	7.05	5.10	284 to 1*	13.82	10.81	59 to 1*

*Odds indicate differences are significant.

longer time for this organic material to become thoroly incorporated in the soil. This may account for the principal benefit of the manure late in the season, altho the big increase in yield to September 10 from the manure treatments certainly shows that the manure *did not* delay maturity.

Comparing the Z treatment (20 tons of manure plus 600 pounds 4–16–4) with the Y treatment (20 tons of manure) shows that manure was the principal factor in increasing yields, but the readily available commercial fertilizer with the manure gave an additional increase in yields. The commercial fertilizer stimulated earliness of maturity. In the yields to September 10 it resulted in an increase of 1.17 tons of tomatoes, which was statistically significant.

Comparing the manure treatment Y (20 tons) with the heaviest rate of application of commercial fertilizer (C treatment, 1,200 pounds 4–16–4) shows a very significant increase of 1,448 pounds of extra early tomatoes in favor of the C treatment. Comparing the yields to September 10, the C treatment still gave the larger yield, but considering the whole season the manure treatment outyielded the C treatment. The total yields were 14.11 tons for the manure treatment (Y) and 13.82 tons for the C treatment (1,200 pounds of 4–16–4). The difference in yields was not statistically significant.

Comparing the Z treatment (20 tons of manure plus 600 pounds 4–16–4) with the C treatment (1,200 pounds 4–16–4) shows a significant difference in extra early yields of 1,063 pounds in favor of the C treatment. By September 10 the Z treatment with a yield of 7.37 tons showed a gain of 0.32 ton over the C treatment. Averaging the total yields shows that the Z treatment (20 tons manure plus 600 pounds 4–16–4) with a yield of 14.51 tons produced 0.69 ton of tomatoes more than the C treatment (1,200 pounds 4–16–4), altho the gain was not statistically significant. Again this shows that the manure fertilizer was more effective later in the season. It also shows that liberal application of readily available plant food in commercial fertilizer greatly increases the early yields of tomatoes.

The increase in early and total yields of tomatoes from liberal application of readily available fertilizers is also shown in the last comparison in Table 13. In this case, treatment C with twice as much fertilizer as treatment A, yielded 4,195 pounds of extra early tomatoes (to August 31), while treatment A (600 pounds 4–16–4) produced only 2,790 pounds. This shows a very significant gain of 1,405 pounds of early fruit due to the increased amount of fertilizer. By September 10 the C treatment with a yield of 7.05 tons showed an increase of 1.95 tons of tomatoes more than the A treatment. In total yields the C treatment produced 13.82 tons which was a very significant gain of 3.01 tons more than was produced by the A treatment.

CONCLUSIONS AND RECOMMENDATIONS

Yields of tomatoes varied greatly in the different years of this experiment. These seasonal differences were due primarily to variations in temperature, rainfall, and frost-free periods. However, a good rotation and the proper use of fertilizers were important factors in maintaining high average yields of tomatoes.

A rotation for tomatoes should include a legume crop every 4 years. Cover crops also should be turned under whenever possible to help maintain the organic matter content of the soil. A good rotation is essential for a permanent system of truck farming or of canning crops production. The following 4-year rotation proved very satisfactory and has maintained the yields of tomatoes: First year, tomatoes followed by rye cover crop; second year, snap beans followed by rye cover crop; third year, beets; and fourth year, cannery peas followed by a sweet clover cover crop. A cover crop of rye may also follow the beets the third year, but its use would depend on whether spring or fall plowing is preferred for the peas. The sweet clover following the peas is turned under the following spring for tomatoes. This rotation provides a cash crop every year, a legume green manure crop, and two or three cover crops of rye. Sweet corn, cabbage, or many other crops might be substituted for any of the crops in this rotation.

Phosphorus is the principal limiting element in tomato growing on most soils. Applying readily available phosphorus fertilizer results in a very marked increase in early yields and in total yields of tomatoes. Nitrogen appears to be second in importance in increasing yields of tomatoes. A profitable increase in yield may be expected where readily available nitrogen is applied in connection with phosphorus fertilizers. Nitrogen fertilizers applied in reasonable amounts will not retard maturity but will stimulate the early growth and maturity of the crop. On most soils potash is most likely to be third in importance as a limiting fertilizer element in tomato production. Consequently, the best results from potash fertilizers can only be obtained when nitrogen and phosphorus have been added in sufficient quantities to correct the limiting effect of these elements. Under these circumstances, however, potash may be used profitably on tomatoes.

A complete fertilizer high in phosphorus gave the best results in this experiment, and is generally recommended. A 4–16–4 formula proved very satisfactory. The results of these fertilizer tests comparing differing amounts of nitrogen, phosphorus, and potassium gave a fairly definite idea of the best proportion of these three fertilizer elements for tomatoes on most soils. Under most circumstances a fertilizer well adapted for tomatoes should contain from 4 to 8 per cent of readily available nitrogen, 12 to 16 per cent of readily available phosphorus, and 4 to 8 per cent of readily available potassium. Fertilizer combinations within these limits would undoubtedly give excellent results with tomatoes on all the important soils in this State. In general, a 4–16–4 or a 4–12–4 ratio is recommended.

Tomatoes respond profitably to liberal fertilization. At least 1,200 pounds per acre of 4–16–4 or a similar high analysis fertilizer is recommended for market garden tomatoes. Liberal fertilization has a very marked effect in increasing early yields, which are the most profitable to market gardeners. From 600 to 1,200 pounds per acre of 4–16–4 or a high analysis fertilizer closely approximating this ratio is recommended for tomatoes for canning factories. Increased yields resulting from the use of fertilizer will lower the cost per ton in growing tomatoes. A grower with limited funds for fertilizer will probably obtain a larger net return by reducing his acreage, if necessary, and applying an adequate amount of fertilizer per acre.

Early yields of tomatoes and also total yields are markedly affected by the time of transplanting. In general, the earlier tomatoes can be transplanted to the field without danger of frosts, the earlier will be the harvest and the larger the total yields.

The limited data available indicate that from the standpoint of equivalent amounts of plant food a moderately high analysis fertilizer is slightly better than a very concentrated form of fertilizer.

However, the use of very concentrated fertilizers results in some saving in freight and handling costs and this factor should be taken into consideration in determining the value of these very concentrated fertilizers.

Manure is an excellent fertilizer for tomatoes. It should be well rotted and should be plowed under at least 2 weeks before time to set the tomatoes in the field. Supplementing manure with a complete fertilizer high in phosphorus or with a fertilizer containing readily available phosphorus alone is recommended. This will give additional increases in yields, more particularly in early yields.