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The Effects of Certain Organic Compounds On Plant Growth

Coumarin, Vanillin, Pyridine, Quinoline, Dihydroxystearic Acid, Pyrogallol, Etc.

By

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THE EFFECTS OF CERTAIN ORGANIC COMPOUNDS ON PLANT GROWTH

By

M. J. Funchess, Associate Agriculturist.

Introduction.

The causes of fertility or infertility of soils are usually explained by soil chemists and physicists in terms of plant food, or physical condition of soils. Unproductive soils are either deficient in some element, or elements, needed for plant growth, or they are in a bad physical condition, according to these old and rather generally accepted views. Such unfavorable conditions may be remedied by the application of manures and fertilizers, thereby supplying the deficient elements; or through the amelioration of the soil by the use of lime, by the addition of organic matter, and by thorough pulverization with tillage implements.

In comparatively recent years, a quite different view of the causes of infertility has been developed in the United States by the Bureau of Soils of the United States Department of Agriculture. According to this very advanced theory, infertility is frequently due to the presence in soils of substances which are injurious to plants, rather than to deficiencies of plant food. These harmful substances are root excretions, or are due to the products resulting from organic decomposition within the soil. To restore such soils to fertility, the injurious compounds must in some way be removed or rendered harmless. In support of this position, quite a large amount of experimental work has been reported.* The bulk of such experimental evidence, however, has been obtained from solution cultures, using wheat seedlings as the plant indicator, the plants being allowed to grow for only short periods. The methods used by the Bureau of Soils are fully described in several of its bulletins.

Object of The Experiments.

The work herein reported was undertaken in order to determine, if possible, whether the results obtained

* See especially bulletins No. 23, 28, 36, 40, 47, 53, 70, 77 and 87, of the Bur. of Soils, U. S. Dept. of Agr.

with soil cultures would parallel the results obtained with solution cultures. It is well known that for many organic substances, the powers of absorption and adsorption possessed by soil are high; it is also well known that in unsterilized soil numerous complex chemical and biochemical reactions may occur, while such reactions in solutions, are largely absent and occur slowly when at all. It seemed logical, therefore, to expect differences between the results obtained by the two methods, because of the greater absorptive, chemical, and biochemical action of soil.

In order to make such comparisons, the writer planned a series of experiments in the fall of 1913, and had the experiments conducted by a number of students, who used the data so obtained as a thesis for the B. S. degree. The results so obtained are incorporated in this publication, together with data subsequently obtained by the writer. The data obtained from the solution culture work were parallel with those reported by the Bureau of Soils, and were discontinued after the first set of trials was completed; however, the results of the soil culture experiments did not accord with those of the solution cultures. For this reason all of our later work was done with soil as the medium in which the plants were grown.

The Methods Used.

All of the data given were obtained from experiments conducted in the greenhouse, the plants being grown in either 2-gallon or 4-gallon pots. In all cases where the 2-gallon pots were used, each pot contained 20 pounds of air dry, screened soil; while the 4-gallon pots contained 40 pounds of air dry, screened soil. The special treatments, as well as the fertilizer treatments, were applied as follows: about an inch of soil was removed from the pot to be treated, and the materials added; then the soil in the pots was well stirred so as to thoroughly mix the added materials with the upper half of the soil in the pots. After this mixing, the soil that had been removed was returned to the pot. The special substances or compounds were usually added at the rates of 100, 250, 500, and 1000 parts per million of dry soil. In the later work, the smaller ratios were omitted, since the apparent effects of the small quantities were rather slight.

Based on the 40 pounds of soil per large pot, 18 grams of material is approximately equal to 1000 parts per million of soil, 9 grams, to 500 parts, and so on. For the small pots containing only 20 pounds of soil, half of these quantities were used so as to get the same ratios that were used for the large pots. In all cases, the crops were planted on the same day that the various treatments were applied. From time to time, the pots were watered with tap water so as to maintain a sufficient supply; but no attempt was made to maintain a definite weight in the several pots.

Special Chemicals Used.

All of the special reagents used in this work were prepared by E. Merck & Co., with the exception of pyridine and dihydroxystearic acid, which were Kahlbaum products. The required amounts of all compounds were weighed out on chemical balances, for the experiments conducted the first year; however, only the solid compounds were weighed, for the work of the second year, because of the difficulty involved in weighing exact quantities of liquids. The liquids were measured, rather than weighed, one cubic centimeter being assumed to weigh one gram; this assumption is not exact, though it is sufficiently close for the purposes of the work in hand.

Soils Tested.

Four different soils were used in the experiments which were begun in 1913. The heaviest of the four, classed as Cecil clay by the Bureau of Soils, is a rather heavy, sticky, red clay. The area from which our supply came had not been in cultivation for a year or two, and had grown up in lespedeza, weeds, and a few small bushes. The lightest and poorest, classed as Cecil sand, is a very poor, open, dry sandy soil. Our supply came from a field which had grown a very poor crop of corn during the summer of 1913. Two samples of Norfolk sandy loam were used; one was taken from a rather poor field about a mile south of the Experiment Station farm, while the other was obtained from the most productive part of the Experiment Station farm. The soil samples were spread in a thin layer on a concrete floor and stirred frequently until they became well dried. After the drying, samples of 20 pounds, or 40 pounds, as the size of the pot required, were weighed into the pots, and the pots transferred to the greenhouse.

For the work which began in the fall of 1914, a fresh sample of soil was collected from the same field from which the poor sample of Norfolk sandy loam had been taken the previous year.

Crops Grown.

Oats were grown on all pots during the fall and winter of each of the two years when these experiments were in progress. The oats were allowed to grow until quite an advanced stage was reached, when the crop was harvested and weighed. After the oat crop was taken off, corn was planted on all pots in the first year of the work; while the corn or peas followed the oats of the second year. The corn was grown until tassels were showing, or until the corn was well advanced. A good idea of the stage of growth reached in each case can be had from the photographs. All crop weights given are in grams. For further details, see the tables and discussion accompanying the tables.

Results of Pot Experiments With Cullers Field Soil.

In table I the results obtained on Cullers Field soil are given. The plants were grown in 2-gallon stoneware pots, each pot containing 20 pounds of soil. Oats were planted in the fall of 1913, and harvested in the early spring of 1914, just after the plants had fully headed out. After the oat crop was harvested, 9 grams of acid phosphate were added to each pot which had not received phosphate treatment for the oats, and each planted to corn. The corn crop was harvested just as the most forward plants were beginning to tassel. The air dry weights of the two crops, and the combined weights are given in the table. In the last column of the table, the results are shown in a relative way, the unfertilized yield being taken as 100.

Table I. Effect of fertilizers, lime, carbon black, pyrogallol, coumarin, vanillin, pyridine and quinoline on crop yields in Cullers Field soil. Crops grown in 2-gallon pots in the greenhouse, 1913-1914.

KIND OF TREATMENT	Grams	Weight of air-dry oats. First crop	Weight of air-dry corn. Second crop	Combined weight of two crops	Relative yields, unfertilized yield 100%
	gr'ms	gr'ms	gr'ms	gr'ms	gr'ms
Check, no treatment	-----	7.6	8.3	15.9	100
Nitrate of Soda	9.0	30.8	18.3	49.1	308
Kainit	9.9	16.0	10.4	26.4	172
Acid Phosphate	9.0	41.9	11.8	53.7	337
Nitrate, Kainit, Phosphate, each	9.0	79.5	21.3	100.0	634
Calcium Carbonate	9.0	7.6	11.3	18.9	119
Carbon Black	9.0	5.6	9.0	14.6	91
Pyrogallol	9.0	13.0	8.6	21.6	135
Pyrogallol	4.5	6.4	9.6	16.0	100
Pyrogallol	2.25	5.7	10.5	16.2	102
Pyrogallol	0.9	17.2	8.7	25.9	162
Coumarin	9.0	4.8	12.2	17.0	107
Coumarin	4.5	6.2	lost	?	?
Coumarin	2.25	22.9	12.7	35.6	224
Coumarin	0.9	10.0	10.2	20.2	127
Vanillin	9.0	4.8	12.0	16.8	105
Vanillin	4.5	5.7	8.5	14.2	89
Vanillin	2.25	6.7	lost	?	?
Vanillin	0.9	6.9	11.7	18.6	117
Pyridine	9.0	25.7	17.1	42.8	269
Pyridine	4.5	30.6	13.0	43.6	274
Pyridine	2.25	26.4	9.9	36.3	228
Pyridine	0.9	30.5	12.3	42.8	269
Quinoline	9.0	27.7	25.6	63.3	335
Quinoline	4.5	30.8	11.2	41.0	258
Quinoline	2.25	5.8	11.7	17.5	110
Quinoline	0.9	11.5	12.6	24.1	151

Under the conditions of these tests, this Norfolk sandy loam soil responded well to nitrate of soda and acid phosphate, when oats was the crop grown; kainit was much less beneficial, while lime was not effective. The crop of corn following the oats was most benefited by the residue from the nitrate and from the complete fertilizer. The natural productive power of this soil is very low, as shown by the yields of the two crops.

It is interesting to note that the application of such materials as lime, carbon black, and pyrogallol have been of little or no benefit to this soil; it is also very interesting that coumarin and vanillin, both of which are very toxic to plants in water cultures, have not been more highly injurious to corn and oats grown in soil. It is true that the oat crop following immediately after the application of these compounds has been somewhat injured; but it is also true that the corn crop following several months after the treatments, has not only not been injured, but has, apparently, been slightly improved. The combined weight of the two crops from the several pots treated with vanillin and coumarin is in most cases greater than the combined weight of the crops from the untreated pots.

The results from the use of pyridine and quinoline, both of which are nitrogenous compounds, were entirely unexpected. In water cultures, these substances are almost always toxic to plants; but in soil cultures, both of the compounds have considerably increased the crop yields. The combined crops obtained from pyridine and the quinoline treated pots are very much larger than those obtained from the checks; indeed, nitrate of soda has been but little more effective than have these two organic "toxins."

Results of Pot Experiments With Cecil Clay Soil.

Table II shows the results obtained from Cecil clay soil. This test was conducted in 2-gallon pots, each pot containing 20 pounds of the screened soil. The first crop grown was oats, which crop was planted in the fall of 1913. When the oats were fully headed out the following spring, the crop was harvested, allowed to become thoroughly air dry, and weighed. All pots which had not received acid phosphate in the treatments given the oat crop, were given 9 grams of acid phosphate and planted to corn, in the spring of 1914. The corn was harvested when the largest plants were beginning to show tassels, and weighed, after it had become thoroughly air dry. The table of results follows:

Table II. Effect of fertilizers, lime, carbon black, pyrogallol and coumarin on crop yields in Cecil clay soil. Crops grown in the greenhouse, 1913-1914.

KIND OF TREATMENT	Amount of treatment, grams	Grams of air-dry oats. First crop	Grams of air-dry corn. Second crop	Combined weight of two crops	Relative yields, unfertilized yield 100%
Check, no treatment	-----	16.5	8.5	25.0	100
Nitrate of Soda	9.0	10.6	10.8	21.4	85
Kainit	9.0	8.5	7.6	16.1	64
Acid Phosphate	9.0	44.7	10.2	54.9	219
Nitrate, Acid Phosphate and Kainit	9.0	124.3	8.6	132.9	531
Calcium Carbonate	9.0	7.0	9.1	16.1	64
Carbon Black	9.0	12.4	10.5	22.9	93
Pyrogallol	9.0	7.7	8.9	16.6	66
Pyrogallol	4.5	9.9	12.9	22.8	91
Pyrogallol	2.25	6.4	9.8	16.2	64
Pyrogallol	0.9	6.1	10.2	16.3	65
Coumarin	9.0	5.6	9.6	15.2	61
Coumarin	4.5	5.6	9.4	15.0	60
Coumarin	2.25	11.5	9.5	21.0	84

The results obtained in this test are rather peculiar, and are difficult to explain. None of the treatments, excepting the acid phosphate and the complete fertilizer, was beneficial to oats. The differences in the corn yields from the several treatments are not great enough to warrant any conclusions.

One striking point brought out in this test was the very marked effect of phosphate on the growth and stooling of oats during the first few weeks of growth of the plants. Had the test been terminated at the end of the first month, the results obtained, using air dry weight as a criterion, would have shown that phosphate was even more beneficial than was the complete fertilizer. The plants on the phosphate-treated pot made a very vigorous early growth, and the amount of stooling was greatly in excess of that on any other pot. After about the first month, however, the plants began to turn yellow and show dead leaves at the bottom. On the other hand, the plants on the pot with complete fertilizer continued to grow rapidly and never lost color. The great need of phosphate is indicated by the yield obtained from the pot treated with nitrate of soda alone.

Attention is called to the fact that kainit, lime, carbon black, pyrogallol and coumarin were apparently injurious to oats, and without effect on corn. Neither crop was increased by the addition of such corrective agents as corbon black and pyrogallol. The evidence seems to show that this soil is poor because of a specific lack of available plant nutrients, rather than because of the presence of compounds toxic to the crops grown.

Results of Pot Experiments in Norfolk Sandy Loam From College Farm.

The yields obtained from soil collected from the Experiment Station farm are reported in table III. In this test, the plants were grown in 4-gallon pots, each pot containing 40 pounds of the screened soil. A crop of oats was grown during the fall and winter months, and was harvested when the plants were in full head. The pots which had not received phosphate in the treatment given the oats were then treated with a full dose of phosphate, i. e., 18 grams. Corn was planted in all pots and allowed to grow until tassels were beginning to show on most plants, when the crop was harvested, dried and weighed.

Table III. Effect of fertilizers, lime, carbon black, pyrogallol, and pyridine on crop yields in College Farm soil. Crops grown in 4-gallon pots in the greenhouse, 1913-1914.

KIND OF TREATMENT	Amount of treatment, grams	Grams of air-dry oats. First crop	Grams of air-dry corn. Second crop	Combined weight of two crops	Relative yield, unfertilized yield 100%
Check, no treatment	-----	30.7	19.1	49.8	100
Nitrate of Soda	18.0	191.0	16.9	207.9	418
Acid Phosphate	18.0	156.5	15.6	172.1	345
Kainit	18.0	27.1	24.6	81.7	164
Nitrate, Phosphate, Kainit, each	18.0	120.0	19.4	139.4	280
Calcium Carbonate	18.0	38.9	21.1	60.0	120
Carbon Black	18.0	41.0	16.9	57.9	116
Pyrogallol	18.0	19.7	19.1	38.8	78
Pyrogallol	9.0	31.8	16.8	48.6	99
Pyrogallol	4.5	48.5	18.6	67.1	134
Pyrogallol	1.8	49.0	19.3	68.3	136
Pyridine	18.0	138.9	19.3	158.2	317
Pyridine	9.0	141.8	14.2	156.0	313
Pyridine	4.5	106.0	20.2	126.2	255
Pyridine	1.9	52.7	19.5	72.2	145

Nitrogen and phosphorus were both very effective on the oat crop, while kainit and lime were only slightly beneficial. For some unaccountable reason, the plants on the pot with complete fertilizer made a poor growth from the beginning, and it is possible that some error was made in applying the treatments, but no source of error could be discovered. In two cases, light applications of pyrogallol appeared to have slightly benefitted the oats, but there was no corresponding benefit to corn; and it is doubtful whether this slight increase in the oat crop is due to any action of the pyrogallol. It is probable that small differences are due to slight inequalities in the fertility of the potted soil, rather than to any helpful action of the material added.

A most interesting result of the work with this soil is that pyridine is nearly as effective in increasing the oat crop as is nitrate of soda. Reference to the last column of the table shows at a glance that this compound very greatly increased the crop, rather than causing any injury, as would have been expected from water cultures.

None of the various treatments affected the corn crop following the oats.

RESULTS OF POT EXPERIMENTS ON CECIL SAND.

The Cecil sand used in the experiments of 1913-1914 was the poorest of the four soils used in the work. Apparently, this soil was so deficient in nitrogen, phosphorus and potash that only the complete fertilized pot made a very satisfactory growth. Carbon black seemed to be of some benefit to the oats, but did not increase the crop of corn following. Nor was pyrogallol of benefit to either of the crops. On the other hand, instead of being harmful, quinoline more than doubled the yield of the crops, where the larger quantities of the compound were used; and, as was the case with pyridine, was nearly as effective as nitrate of soda.

In the following table will be found the results obtained with Cecil sand:

Table IV. Effect of fertilizers, lime, carbon black, pyrogallol and quinoline on crop yields in Cecil sand. Crops grown in 4-gallon pots in the greenhouse, 1913-1914.

KIND OF TREATMENT	Amount of treatment, grams	Grams of air-dry oats. First crop	Grams of air-dry corn. Second crop	Combined weight of two crops	Relative yield, unfertilized yield 100%
Check. no treatment	-----	16.5	13.5	30.0	100
Nitrate of Soda	18.0	54.6	28.4	83.0	276
Kainit	18.0	33.9	13.6	47.5	158
Acid Phosphate	18.0	89.2	7.2	96.4	321
Nitrate, Phosphate, Kainit, each	18.0	190.9	46.1	237.0	790
Calcium Carbonate	18.0	24.7	11.1	35.8	119
Carbon Black	18.0	35.6	11.2	46.8	156
Pyrogallol	18.0	16.5	11.2	27.7	92
Pyrogallol	9.0	20.8	11.7	32.5	108
Pyrogallol	4.5	16.2	12.3	28.5	95
Pyrogallol	1.8	22.6	11.1	33.7	112
Quinoline	18.0	31.4	44.5	75.9	253
Quinoline	9.0	60.4	23.4	83.8	279
Quinoline	4.5	49.5	10.0	59.5	198
Quinoline	1.8	36.2	10.5	46.7	156

The oat crop was harvested when the plants were out in full head, allowed to become thoroughly air dry, and was then weighed.

Eighteen grams of phosphate were added to each pot which had not received phosphate in the treatments given the oats, and all were then planted to corn.

The corn crop grew until the largest plants were beginning to show tassels, when the corn was cut, air dried in the greenhouse, and weighed.

Conclusions From The First Year's Work.

The following conclusions seem to be justified, based on the experiments conducted during the fall, winter and spring of 1913-1914:

1. That the poor soils experimented upon were not benefited by the application of such substances as carbon black, pyrogallol, or calcium carbonate.
2. That coumarin and vanillin, when added to soil, were toxic to plants only when used in large amounts, and when these large amounts were added to the soil at time of seeding.
3. That nitrogenous compounds like pyridine and quinoline were beneficial, rather than harmful, as has been found to be true by means of water cultures.
4. That four or five months after the addition of coumarin and vanillin to a soil, no toxic effect on corn was apparent.
5. That plants must be grown for longer periods than two or three weeks, in fertility work, if true conclusions are to be reached.
6. That these conclusions were borne out in all of the four widely different types of soil used in this work.

Experiments Conducted in 1914-1915.

One of the experiments conducted during the second year was designed to show whether or not repeated applications of toxic compounds to soils would finally result in marked injury to plant growth. To study this point a number of pots used in the work of the first year were carried into the work of the second year with the same treatments, and the same crops as were used in the beginning of the work. The data so obtained are given in Table V. All of the data concerning these pots during the first year, may be found by reference to Table I.

During the summer of 1914, the pots were left dry and undisturbed in the greenhouse. In the fall of this year. these pots were treated as shown in the first column of

Table V, and planted to oats. After the oat harvest, each pot was treated as shown in the third column, and planted to corn. In the fourth column, the combined crop weights are given; and in the last column will be found the relative combined yields, based on the untreated pots as 100.

Table V. Effect of repeated treatments with fertilizers, pyridine, quinoline, vanillin, pyrogallol and coumarin on crop yields in Cullers Field soil. Crops grown in 2-gallon pots in the green house, 1914-1915.

KIND AND AMOUNT OF TREATMENT TO OATS	Green weight of oats grams	Kind and amt. of treatment to corn	Green weight of corn grams	Combined wg't. of two crops	Relative yields unfertilized, yield 100 %
Check—no treatment	14		19	33	100
Kainit, 4.5 grams	19	K*	26	45	136
Nitrate of soda, 4.5 grams	110	N.	43	153	463
Kainit and phosphate	18	K. & P.	27	45	136
K., P. & N.	234	K., P. & N	289	523	1585
Pyridine, 4.5 cc	43	K. & P.	89	132	400
Pyridine, 9.0 cc	67	K. & P.	228	295	894
Quinoline, 4.5 cc	36	K. & P.	121	156	472
Quinoline, 9.0 cc	61	K. & P.	183	244	739
Vanillin, 4.5 grams	9	K. & P.	40	49	148
Vanillin, 9.0 grams	8	K. & P.	35	43	130
Pyrogallol, 4.5 grams	14	K. & P.	27	41	124
Pyrogallol, 9.0 grams	12	K. & P.	28	40	121
Coumarin, 4.5 grams	8	K. & P.	38	46	139

* "K" means 4.5 grams of kainit; "N" means 4.5. grams of nitrate; "P" means 4.5 grams of phosphate.

The repeated application of toxic compounds like vanillin and coumarin proved to be more injurious for oats than was the first application; on the other hand, the repeated application of pyrogallol had practically no effect on the yields of either of the two crops. The oat crop followed immediately after the various treatments had been applied to the pots; and the yields of this crop seem to have been reduced somewhat by the presence of vanillin and coumarin. But the corn crop, which followed several months after the addition of these toxic compounds, was apparently benefited to a slight degree by their presence, or rather, by their addition to the soil at the time of planting the previous crop. A study of the combined yields obtained shows that the smallest total yield was obtained from the untreated pot; on this basis of comparison, the presence of pyrogallol, vanillin and coumarin influenced the crop yields but little. It does not appear from this work that either vanillin or coumarin is injurious to crops unless applied in very large quantities just before the crop is planted. Further, it does not appear that pyrogallol has any beneficial effect on the yields obtained under the conditions of these experiments.

The results obtained from the use of the nitrogenous compounds, pyridine and quinoline, are in strict accord with those obtained the first year. Instead of being harmful, as they are in water cultures, these substances have proved to be beneficial; and the benefit is roughly proportional to the amounts of the materials applied. The crop of oats obtained from the pots which had received 9 cc of these compounds was about four times as great as that from the untreated pot. When potassium and phosphorus were added to the pyridine and quinoline treated pots, the yields were roughly ten times as great as that of the check, and from six to eight times as great as that from the pot receiving potassium and phosphorus only. There is no evidence from this experiment that there is any cumulative injury resulting from the addition of such compounds to the soil in which plants are grown; as a matter of fact, there appears to be slightly less injury from the second dose of vanillin and coumarin than there was from the first dose.

Are fertilizers valuable because they carry plant food, or are they effective because they serve as an antidote or to decompose toxic compounds? Is there a plentiful supply of available phosphorus and potassium in soils at all times? A little light is shed on these questions by the data in the above table. For example, compare the untreated pot yields with those with the pot treated with kainit and phosphate; by this comparison, phosphorus and potassium are not much needed. But if a comparison is made between the pot with nitrate and with complete fertilized pot, it will be seen that the effect of the phosphorus and potassium has been very great. By this method of comparison, two values of quite different magnitude may be obtained for the phosphate-potassium combination. In the same way, two very different values may be obtained for the nitrate of soda. The difference between the total yield of the untreated pot and the nitrate pot is 120 grams; but the difference between the phosphate-kainit pot and the complete fertilized pot is 478 grams. Apparently this soil is inadequately supplied with either nitrogen or the mineral nutrients, if large crop yields are to be considered. On the other hand, if these fertilizers owe their effectiveness to their action on toxic compounds existing in the soil, then it takes a complete fertilizer to get the desired results on this soil.

The deficiency of mineral elements may be shown by another set of comparisons. Nitrate of soda alone is much more effective than either pyridine or quinoline alone, when used for oats; but when the mineral elements are added to pyridine and quinoline, while the nitrate is repeated, then for the second crop the residues from these two nitrogenous toxins become more effective than nitrate, in promoting the growth of a crop of corn following the oats. In other words, one application of pyridine and quinoline, along with the minerals, is more effective than is two applications of nitrate of soda.

In the light of these comparisons, and in the light of the fact that neither lime, carbon black, nor pyrogallol increased the productiveness of this soil, the conclusion seems justified that *this poor soil* is unproductive, not so much because of the presence in it of toxic compounds, but because of an *actual deficiency of available plant foods.*

Comparisons similar to those above may be made from most of the data presented in the other tables in this publication.

Results of Pot Tests Conducted on Norfolk Sandy Loam Soil From "Cullers Field."

In the experiments conducted during the fall and winter of 1913-1914, the various materials used were applied alone to the four soils used in the work. As this early work developed, it became clear that a complete fertilizer was needed to obtain large yields, no matter what type of soil was being studied. Lime, kainit, and acid phosphate, either singly or in combination, increased the yields of oats and corn very little. But when nitrate of soda was added to the mineral fertilizers, abundant growths were easily obtained. It also developed that pyridine and quinoline were not only not toxic, but were beneficial when applied to either oats or corn; and that the benefit was greater when used in connection with phosphate and potash than when used alone. Therefore, the bulk of the work done the second year aimed to show the effect on plant growth of the various compounds at hand, when used alone and also in connection with various fertilizer combinations. A lack of greenhouse space and of pots made it necessary for us to confine the study to one soil. The soil chosen was the poorer grade of Norfolk sandy loam designated "Cullers Field" soil in the foregoing pages. The fresh sample used was collected, dried and potted in the manner already described.

Table VI. Effect of fertilizers, lime, coumarin, vanillin, pyrogallol and carbon black on crop yields in Cullers Field soil. Crops grown in 2-gallon pots in the greenhouse, 1914-1915.

SPECIAL TREATMENT	Fertilizer elements applied	Green weight of oats, grams	Green weight of corn, grams	Combined weight of crops	Relative yields complete fertilized yields 100%	Relative yields unfertilized, yields 100%
Check—no treatment	----------	12	16	28	--	100
None	K*	26	--	--	--	--
None	K. & P.	16	--	--	--	--
Cal. carbonate, 9.0 grams	K. & P.	17	--	--	--	--
None	K., P. & N	234	241	475	100	1696
Cal. carbonate, 9.0 grams	K., P. & N	300	275	565	121	2053
Coumarin, 9.0 grams	----------	4	--	--	--	--
" 4.5 "	----------	3	--	--	--	--
" 9.0 "	K. & P.	8	--	--	--	--
" 4.5 "	K. & P.	8	--	--	--	--
" 9.0 "	K., P. & N	101	346	447	94	1596
" 4.5 "	K., P. & N	144	245	389	82	1389
Vanillin, 9.0 "	----------	4	--	--	--	--
" 4.5 "	----------	7	--	--	--	--
" 9.0 "	K. & P.	5	--	--	--	--
" 4.5 "	K. & P.	8	--	--	--	--
" 9.0 "	K., P. & N	142	247	289	82	1389
" 4.5 "	K., P. & N	159	220	379	80	1353
Pyrogallol, 9.0 grams	----------	11	--	--	--	--
" 4 5 "	----------	11	--	--	--	--
" 9.0 "	K. & P.	16	--	--	--	--
" 4.5 "	K. & P.	17	--	--	--	--
" 9.0 "	K., P. & N	232	252	484	102	1714
" 4 5 "	K., P. & N	221	175	396	80	1396
Carbon black, 9.0 grams	----------	11	--	--	--	--
" " 9.0 "	K. & P.	23	--	--	--	--
" " 9.0 "	K., P. & N	215	168	373	78	1332

"K" means 4.5 grams of kainit; "N" means 4.5 grams of nitrate of soda; "P" means 4.5 grams of acid phosphate.

In Table VI are reported the yields obtained when coumarin, vanillin, pyrogallol and carbon black were used alone and in connection with fertilizer combinations. The green weight of the oat crop is shown in the third column of the table. A study of the results shows that both coumarin and vanillin have materially reduced the oat crop, whether used alone, or with kainit and phosphate, or with a complete fertilizer. Both of these compounds are very toxic to plants in water cultures, even when used in comparatively small amounts. In the work here reported, large proportions are used, based on the dry soil, and not on the water that the soil could hold. Nine grams per pot of twenty pounds of soil is approximately equivalent to 1000 parts per million of soil. Therefore, the concentration of the solutions in which the oat crop started growth was very much greater than 1000 parts per million, if the compound was soluble in water, and if the soil did not remove the material from solution by absorption. It appears remarkable, then, that the oat crop, which was planted on the same day that the treatments were applied, did not show even greater injury from the vanillin and coumarin. On the other hand, neither pyrogallol nor carbon black appears to have influenced the yields of oats to a noticeable degree. In view of the fact that both of these substances have been shown to exert a great beneficial influence on plants grown in poor soil extracts, it might be expected that a similar influence might be shown when they are added to the poor soil itself, rather than to the poor soil extracts.

After the oat harvest, corn was planted in those pots which had received a complete fertilizer in the oat treatments. In each of these pots, the fertilizer treatment was repeated for the corn, but no further addition of the special treatments was given. The other pots which had been in the oat test were planted to cowpeas, and the results of this test will be given separately. In the fourth column of the table will be found the corn yields. These results are very interesting. The pots which had received 9 grams of vanillin or coumarin in connection with a complete fertilizer, produced much lighter yields of oats than did the pot which received a complete fertilizer alone; but the crop of corn following after the oats appears not to have been injured by the vanillin at all; the effect of the coumarin appears to have been slightly beneficial. Pyrogallol was without effect and carbon black slightly reduced the yield of corn. The results here presented show that this poor soil cannot be much improved in fertility by the use of such materials as pyrogallol or carbon black, neither of which carries plant food. If this soil is poor because of the presence of toxic bodies, then these bodies are of such nature that the above compounds fail to affect them, i. e., neither adsorbing nor reducing agents alters the productive capacity of the soil. The results show, also, that the fertility of this soil is not much reduced by the addition of large quantities of compounds known to be toxic to plants in solution cultures, except when a crop is grown immediately after the addition of such compounds. This would indicate that these particular compounds undergo some change in the soil which renders them inert or actually beneficial.

As has already been noted, the early experiments conducted at this Experiment Station showed that pyridine and quinoline when applied to the soil, were beneficial to both oats and corn. The experiments conducted in 1914-1915 included pyridine, quinoline, nucleic acid, asparagine and naphthylamine, all of which are nitrogenous compounds. These were used in two ratios, the heavier ratio being 1000 parts per million of dry soil, and the lighter being 500 parts per million. The compounds were used without, and in connection with potassium and phosphorus. The results obtained with oats and corn are given in Table VII. All of the pots which were not plantcd to oats were planted to cowpeas instead; the results obtained with the peas are given elsewhere.

A study of the data obtained with the oat crop shows that the earlier experiments with pyridine and quinoline are fully substantiated. Nine c. c. of pyridine alone increased the oat crop materially; and with potash and phosphorus, the effect of such application is considerably greater than the effect of a complete fertilizer, with nitrate of soda as the source of nitrogen. The yields obtained from the quinoline treated pots are similar to those from the pyridine treated pots, though not quite so great. The fact that larger yields are obtained from the larger amounts of these two compounds shows that, *when these nitrogenous toxins are used in the soil,* and not in water cultures, *they lose their toxic properties entirely, and become highly beneficial.* Nor can it be argued that the addition of phosphorus and potassium increases the yield by exerting an antitoxic effect on these substances, because a similar increase in yield is obtained by adding these mineral elements to nitrate of soda, asparagine, and nucleic acid; neither of these latter materials is toxic to plants.

Table VII. Effect of fertilizers, nucleic acid, naphthylamine, asparagine, pyridine and quinoline on crop yields in Cullers Field soil. Crops grown in 2-gallon pots in the greenhouse, 1914-1915.

SPECIAL TREATMENT	Fertilizer elements applied	Green weight of oats, grams	Green weight of corn, grams	Combined wg't. of two crops	Relative yields fertilized yield 100%	Relative yields unfertilized yield 100%
Check—no treatment	----------	12	16	28	--	----
None	K*	26	--	--	--	----
None	K. & P.	16	--	--	--	----
Cal. carbonate, 9 grams	K. & P.	17	--	--	--	----
None	K., P. & N	234	241	475	100	1696
Nucleic acid, 9 grams	----------	202	111	313	66	1117
" " 9 "	K. & P.	328	72	400	84	1428
Asparagine, 9 grams	----------	117	181	298	62	1064
" 9 "	K. & P.	325	137	462	97	1650
Napthylamine, 9 grams	----------	24	89	113	24	403
" 9 "	K. & P.	38	73	111	23	396
Pyridine, 9 c. c	----------	96	200	296	62	1057
" 4.5 c. c	----------	87	--	--	--	----
" 9 c. c	K. & P.	305	77	382	80	1364
" 4.5 c. c	K. & P.	217	--	--	--	----
Quinoline, 9 c. c	----------	44	331	365	77	1303
" 4.5 c. c	----------	67	--	--	--	----
" 9 c. c	K. & P.	206	100	306	64	1092
" 4.5 c. c	K. & P.	137	--	--	--	----

* "K" means 4.5 grams of kainit; "P" means 4.5 grams of acid phosphate; "N" means 4.5 grams of nitrate of soda.

Naphthylamine proved to be of slight benefit to the crop of oats, and moderately helpful to the crop of corn following. Apparently it is decomposed very slowly in the soil, and is helpful only when decomposition takes place.

Asparagine and nucleic acid increased the oat crop to a remarkable degree, when used in connection with potassium and phosphorus; without the minerals, the effectiveness of both is reduced, though the absence of these mineral elements is much more evident with the asparagine treatment than with the nucleic acid treatment. A possible explanation of this difference between the yields obtained from these substances may be found in the difference in the composition of the compounds themselves. Asparagine contains no phosphorus, while the nucleic acid does; and the phosphoric acid of the nucleic acid is set free during the decomposition of the compound in the soil. Since this is true, the absence of phosphorus in the treatment given would be more noticeable in the asparagine treated pots than in the nucleic acid treated pots.

Corn was planted in a number of the pots after the oats were harvested. The pots were treated as follows for the corn: the check pot remained untreated; the pot which had received a complete fertilizer for the oats was given a complete fertilizer for the corn, the same quantities of phosphate, kainit and nitrate being used in each case; while all of the remaining pots received 4.5 grams each of kainit and acid phosphate. It is very interesting to note the effect of the addition of potassium and phosphorus to those pots which had previously received nitrogenous compounds alone to oats. Without the minerals, the oat plants could not make use of the nitrogenous materials, and hence, there was an accumulation of nitrogen in those pots in which the minerals were lacking. Now, when these pots were treated with potassium and phosphorus and planted to corn, the limiting factor was removed, and there resulted enormous growth of the corn plants. Without exception, the high yielding oat pots proved to be the low yielding corn pots, and vice versa. No evidence is obtained from this work to show that pyridine or quinoline is toxic to plants, when it is added to the soil in which the plants are grown. On the contrary, it is definitely shown that these two compounds are useful sources of nitrogen, when used in connection with mineral fertilizers.

The effect of dihydroxystearic acid on plant growth when it is added to soil is of special interest in view of the great amount of work that has been done with it in water cultures, and the conclusions that have been drawn from these water cultures. The presence of even minute quantities of dihydroxystearic acid in water cultures greatly reduced the growth of wheat seedlings; and since this toxic compound has been isolated from soils, the conclusions were drawn that the infertility of the soils from which this compound was isolated, was due to its presence. If this be true, then it should be possible to increase the infertility of a poor soil by adding to that soil large amounts of dihydroxystearic acid. In order to test this, a number of pots were treated as shown in the table below, and two crops grown, as in the case of the other experiments reported. The natural soil on which this test was made is infertile, apparently, because of a great deficiency of nitrogen, since neither phosphorus, nor potassium, nor lime, nor combinations of these increased the yields materially, while a complete fertilizer resulted in a most vigorous growth of plants, showing that it was the deficiency of nitrogen that caused the poor growth. Now, when dihydroxystearic acid is used alone or in combination with fertilizers and lime, the effect of the supposedly toxic compound is almost nil, as may readily be seen by a comparison of the yields reported in Table VIII. At no time during the progress of the work was there an apparent injury from this material although it has been shown to be decidedly toxic to plants, in solution cultures. A crop of corn followed after the oats, and growths obtained showed no indication of injury by dihydroxystearic acid. The corn received no second dose of the special treatment, but the fertilizer treatment given to the oats was repeated for the corn. Not all of the oat pots are represented in the fourth column of the table, for the reason that a number of pots carried peas instead of corn as the second crop; the cowpea results are given in a separate table. Apparently, the corn was slightly benefited by the previous application of dihydroxystearic acid; however, the difference between the yields from the pot with complete fertilizer and the pot with dihydroxystearic acid in addition to the complete fertilizer is most likely due to slight soil inequalities, or to unavoidable errors, rather than to any benefit derived from the special material added. Certainly, there is no indication that dihydroxystearic acid is injurious to corn or oats, under the conditions of this experiment. The tabulated results follow:

Table VIII. Effect of fertilizers, lime, and dihydroxystearic acid on crop yields in Cullers Field soil. Crops grown in 2-gallon pots in the greenhouse, 1914-1915.

SPECIAL TREATMENT	Fertilizer elements applied	Green weight of oats, grams	Green weight of corn, grams	Combined wg't. of two crops	Yield Check 100%
Check—no treatment	----------	12	16	28	100%
None	K*	26	--	--	----
None	K. & P.*	16	--	--	----
Cal. carbonate, 9 grams	K. & P.	17	--	--	----
None	K., P. & N	234	221	475	1696
Cal. carbonate, 9 grams	K., P. & N	300	275	575	2052
Dihydroxstearic acid, 9 grams	----------	12	16	28	100
" " 9 "	K.	13	16	29	103
" " 9 "	K. & P.	13	--	--	----
" " 9 "	K., P. & N	238	302	540	1928
Cal. carbonate, 9 grams	K., P. & N	242	--	--	--

* "K" means 4.5 grams of kainit; "P" means 4.5 grams of acid phosphate; "N" means 4.5 grams of nitrate of soda.

Probably the most interesting of all of our experiments is reported in Table IX. The three pots used contained the same soil that was used in the experiments of 1913-1914. The check pot had been a check pot in an experiment conducted the previous year; the second pot on the table received nine grams each of acid phosphate and kainit the previous year; and the third pot had received 18 grams of pyridine. Based on the 40 pounds of air dry soil per pot, the eighteen gram doses are equivalent to 1000 parts per million, and the nine gram doses, to 500 parts per million of dry soil. Since none of the toxins applied singly had killed either oats or corn, and pyridine and quinoline had been helpful, when applied singly, it was thought possible that a combination of all the toxic compounds at hand might prevent growth entirely. Further, these few pots were used in this way in the hope of getting an insight into the action of such combinations, so as to have a basis for some future work.

In considering the data obtained, it should be remembered that the last pot in the table had had a heavy application of pyridine in the experiments conducted previous to those here reported. During the two seasons in which these experiments were in progress, this third pot received a total of 81 grams of compounds which, in solution cultures, have been shown to be highly toxic to plants. And during the last season, this pot received 63 grams of toxic compounds, all of which were applied to the soil on the same day on which the oats were planted. If the soil used in this work weighed four million pounds to the acre, this 63 grams of toxins is equivalent to about seven thousand pounds per acre, based on the surface six inches. The phosphate and potash treatment which has been given the oats was repeated for the corn, but none of the special treatments were repeated.

By the time that the crop was two weeks old, the plants in the third pot began to take on a darker green color than those in the other two pots, and soon thereafter a vigorous stooling began. When the experiment was terminated, the plants of the third pot had stooled to such an extent that nearly the whole surface of the pot was covered with plant stems. A study of the photographs shown in Plate VIII will give a good idea of the appearance of the three pots just before harvest.

A crop of corn followed after the oats. As was the case with oats, the corn plants in the third pot made a better growth and had a darker green color than did those in the other two pots. These color and growth differences were noticeable by the time that the corn was a week old, and remained until the harvest of the crop. At no time was there the slightest indication of injury to either of the two crops by the enormously heavy applications of toxic compounds which had been made. Both the photographs and the crop weights give abundance of proof that the results obtained with soil cultures are radically different from those obtained with solution cultures. The weights of the green crops are presented in Table IX.

Table IX. Effect of a combination of toxic compounds on crop yields on College Farm soil. Crops grown in 4-gallon pots in the greenhouse, 1914-1915.

SPECIAL TREATMENT	Fertilizer elements applied	Green weight of oats, grams	Green weight of corn, grams	Combined wg't. of two crops	Check 100%
Check—no treatment	--------	48	45	93	100
Cal. carbonate, 36 grams	K. & P.	66	52	118	126
Cal. carbonate, 36 grams; pyridine, 18 c.c; quinoline. 18 c.c.; vanillin, 9 grams; coumarin, 9 grams; dihydroxystearic acid, 9 grams	K. & P.	446	564	1010	1086

* "K" means 4.5 grams of kainit; "P" means 4.5 grams of acid phosphate.

It is generally known that most of the poor sandy soils of the Southern states will produce very vigorous crops of cowpeas, even though they be so poor that they do not produce profitable crops of corn or cotton. Now, if the poor yields of corn or cotton obtained from such soils are due to the presence of toxic bodies in the soil, rather than to deficiencies of plant food, it would seem that cowpeas are not injured by the same compounds which do reduce the yields of the non-leguminous crops. It was decided to try to determine the effect on cowpea yields of certain of the compounds which had been used in the experiments already given. In the last column of Table X is shown the yields of cowpeas obtained when this crop was grown five months after the various toxic compounds had been added to the soil. Oats were grown immediately after the application of the special treatments had been given, and the oat yields are reproduced here for ease of comparison. The oats were harvested in the early spring before the plants were headed out; the pots were fertilized as shown in the fourth column, and peas planted. The weights given are for the stems and vines, excluding leaves and leaf stems. It was impossible to prevent leaf shedding in the greenhouse after the beginning of the hot weather of May and early June; and since some of the plants lost leaves more freely than did others, all leaves and leaf stems were discarded so as to get comparable weights. The plants growing in the coumarin treated pots began shedding first and lost leaves most freely of all the pots in the experiment. On the other hand, the plants following the pyridine and quinoline treatments made the best early growth of all the pots in the test, these showing a rich dark green color from the beginning. However, there were only slight differences in the appearances of the crops on the various pots at the time that the experiment was terminated, with the exception of the coumarin treated plants. Coumarin was apparently injurious to the peas, causing the plants to take on a mottled yellow and green color, and greatly increasing the tendency to shed leaves.

Table X. Effect of fertilizers, lime, carbon black, coumarin, vanillin, pyrogallol, pyridine, quinoline, and dihydroxystearic acid on crop yields in Cullers Field soil. Crops grown in 2-gallon pots in the greenhouse, 1914-1915.

SPECIAL TREATMENT	Fertilizer elements applied to oats	Green weight of oats, grams	Fertilizer elements applied to peas	Air-dry weight of cowpeas, grams
None	K*	26	K.	6.2
"	K. & P.*	16	K. & P.	6.1
Cal. carbonate, 9.0 grams	K. & P.	17	K. & P.	7.6
Coumarin, 9.0 grams		4		4.3
" 4.5 "		3		4.2
" 9.0 "	K. & P.	8	K. & P.	5.3
" 4.5 "	K. & P.	8	K. & P.	5.2
Vanillin, 9.0 grams		4		5.5
" 4.5 "		7		7.3
" 9.0 "	K. & P.	5	K. & P.	7.1
" 4.5 "	K. & P.	8	K. & P.	7.4
Pyrogallol, 9.0 grams		11		5.1
" 4.5 "		11		5.4
" 9.0 "	K. & P.	16	K. & P.	4.5
" 4.5 "	K. & P.	17	K. & P.	8.2
Carbon black, 9.0 grams		11		6.1
" " 9.0 "	K. & P.	23	K. & P.	6.0
Pyridine, 4.5 c. c		87		5.0
" 4.5 c. c	K. & P.	227	K. & P.	6.3
Qiunoline, 4.5 c. c		67	K. & P.	7.7
" 4.5 c. c	K. & P.	137	K. & P.	5.4
Dihydroxstearic acid, 9.0 grams	K. & P.	13	K. & P.	5.6

* "K" means 4.5 grams of kainit; "P" means 4.5 grams of acid phosphate.

The yields of cowpeas obtained are so variable that conclusions of any kind would be out of place, and unwarranted. However, the writer believes that of the compounds tested, coumarin was the only one that had a detrimental effect on the crop of peas, basing this judgment upon the general appearance of the crops produced by the several pots in the experiment. The rather erratic results obtained are believed to be due to the very high temperatures which existed in the greenhouse during the hot weather of May and early June.

General Discussion.

The data presented on the preceding pages of this publication are the results of experiments continuing over a period of two years. From the beginning of this work, the aim has been to parallel with soil cultures, the solution culture experiments reported by the Bureaus of Soils, as far as means and time would permit. A large proportion of the soils of Alabama are naturally poor, and require fertilization for high yields. In the light of the experiments of the Bureau, this infertility might be due to the presence in the soil of compounds which are toxic to plants; and the liberal use of fertilizers is necessary in order to overcome or to antidote these toxic substances. If this be true, then the fertility of a soil should be increased in proportion to the removal of the inhibiting materials, since all normal soils are supposed to contain at all times a sufficient supply of available plant nutrients.

It has been shown to be possible to remove the toxic properties of a poor soil extract by the use of absorbents like ferric hydrate, finely divided quartz, or carbon black. Pyrogallol has also been shown to be very effective in certain cases in reducing the toxicicity of such extracts. Logically, then, increased yields should be expected from poor soils which have been treated with carbon black, or pyrogallol, since the addition of these would remove the only cause of infertility, i. e., toxic compounds. In no case has this been found to be true, under the conditions of the tests herein reported. The addition of calcium carbonate proved to be of little benefit, showing that acidity was not the cause of the low yielding power of the soils used in this work.

On the other hand, the addition to soils of such toxic compounds as vanillin, coumarin, dihydroxystearic acid, pyridine or quinoline failed to greatly increase the infertility of the infertile soils used. To be sure, the application of such compounds in ratios as great as 1000 parts per million of dry soil decreased the yields in some cases, where the crop was planted on the same day that these heavy applications were made. But when these compounds had been in the soil for a few months, the evidence shows that little or no toxic effects were to be found. Indeed, the nitrogenous compounds had a beneficial effect in all cases reported, though there was evidence that these may be harmful for a short time after the applications are made. This constitutes good evidence that rapid chemical or biochemical transformation of these compounds into beneficial or inert forms occurs in unsterlized soils under the conditions of these experiments. Slight injury to oats was apparent in most of the heavy treatments of pyridine and quinoline during the first weeks of growth; but this injurious action disappeared, and the pots so treated usually produced crops which compared favorably with those produced by the nitrate treated pots.

It is interesting to note that, had these experiments been terminated when the plants were only 15 days old, a quite different set of conclusions would have been drawn from the work. Both pyridine and quinoline would have been found to be harmful, while it is likely that vanillin and coumarin would have been recorded not injurious. Neither of these latter showed injury to oats during the first few days of growth; only in the later stages could their effect be noted, and that effect was a simple retardation of growth. It is very evident, then, that plants must be grown for considerable periods of time, if erroneous conclusions are to be avoided.

The increased amount of stooling induced in oats by pyridine and to a less extent by quinoline, is worthy of attention. The pyridine treated pots could be picked very easily after the plants were about 40 days old, due to vigorous stooling produced. Reference to the photographs on Plate II quite clearly shows the great number of stems produced on the pyridine treated pots. This increased stooling caused by pyridine has been noted both years, and in all of the soils tested.

Since the beginning of the work here reported, several papers have been published giving the results of tests with toxins in soil cultures.

Fraps (1) concludes from tests on a number of Texas soils, that pyrogallol has no beneficial effects on plants when used in connection with soil cultures. He also studied the effect of vanillin, coumarin, and dihydroxystearic acid when added to soils, and found little or no injury to result therefrom.. It was found that vanillin and coumarin rapidly disappeared from the soils to which they had been applied.

Schreiner and Skinner (2) studied the toxic properties of salicylic aldehyde in soil, and found that even small quantities were harmful to plants. Six months after the application of salicylic aldehyde to field soils, enough of the compound still persisted to cause injury to growing plants.

Skinner (3) has reported pot experiments in which vanillin was added to three different soils on which wheat was grown. His results show that on soils of low fertility, vanillin was injurious; while on the fertile Hagerstown soil, no harmful effect resulted. In a field test at Arlington Farm, considerable injury to plants was caused by comparatively small amounts of vanillin; and the harmful effects of this compound persisted for six months, as shown by plant tests, and chemical examination of the soil for vanillin.

Upson and Powell (4) used vanillin in connection with soil cultures, and found little or no harmful effects on wheat, even with concentrations up to 1000 p. p. m. of soil. The toxic effect of salcylic aldehyde was found to be variable on different soils, but in all cases, the injury was considerably less than in solution cultures.

By means of soil cultures in pots, Davidson (5) studied the toxicity of coumarin and vanillin, finding that the germination of wheat was unimpaired, and the growth retarded but little. He concludes that "On the whole, it might be said that these experiments would hardly lend much support to the assumption that the presence in the soil of organic substances toxic in water cultures is a factor of considerable importance under field conditions, when the other factors of plant growth are normally good."

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(1) Texas Station Bulletin 174.
(2) Bul. 108, U. S. Dept. Agri.
(3) Bul. 164, U. S. Dept Agri.
(4) Jour. Ind. & Eng. Chem. 7:5.
(5) Jour, Am. Soc. Agronomy, 7:5

The experiments conducted by Fraps, by Upson and Powell, and by Davidson gave results which are in almost complete agreement with our work; while the tests by Schreiner and Skinner do not accord closely.

Where soil culture experiments fail to give concordant results, in all probability, such lack of agreement is due to the differences between the soil types used in the experiments.

It would seem clear that the soil toxin theory cannot apply to the soils used in these experiments. In each case, infertility of the check pots can be completely explained as being due to a lack of mineral nutrients. It is also evident from the data here presented that solution culture and soil culture experiments fail to agree. Consequently, the utmost caution should be observed in drawing conclusions in regard to the causes of soil fertility or infertility, from solution culture studies alone.

General Summary of All Experiments.

1. The first year's work is substantiated by the data obtained the second year.

2. Soils very deficient in nitrogen cannot be much benefited by the addition of lime, phosphorus and potassium. Nitrogen alone is much more effective than a combination of these three elements.

3. The addition of large amounts of coumarin and vanillin depresses the yield of oats, when the oats are planted immediately after the application of these compounds.

4. Fertilizers do not prevent the bad effects of coumarin and vanillin.

5. Lime, carbon black, and pyrogallol are of little or no benefit to plants, when they are added to soils used in these experiments.

6. Neither pyrogallol nor carbon black increased the effectiveness of fertilizers.

7. Pyridine and quinoline, both of which are nitrogenone compounds, have been found to be highly beneficial to both oats and corn in all soils tested.

8. The addition of potassium and phosphorus greatly increases the beneficial effects of pyridine and quinoline.

9. The action of potassium and phosphorus in increasing the effectiveness of pyridine and quinoline cannot be regarded as an antitoxic action. These two mineral elements greatly increased the effect of asparagine, nucleic acid, and nitrate of soda, none of which is toxic to plants.

10. Dihydroxystearic acid had absolutely no bad effect on either oats or corn. Larger yields of both crops were obtained in the presence of dihydroxystearic acid and a complete fertilizer, than with a complete fertilizer alone.

11. Naphthylamine, a nitrogenous compound, is slightly beneficial to oats and corn, but apparently it is changed very slowly in soils; and unless it is decomposed, it has no effect one way or another.

12. Asparagine and nucleic acid, neither of which is toxic to plants in solution cultures, proved to be very beneficial when used in soil cultures.

13. A normal soil can apparently dispose of enormous quantities of organic compounds through physical, chemical, and biochemical action.

14. The results obtained with soil cultures fail to agree with those obtained with solution cultures, when the aim is to show the toxicity or non-toxicity of chemical compounds.

15. Soil fertility problems cannot be solved by means of short time solution culture studies. Soil fertility studies with the soil left out, cannot be depended upon to answer correctly the complex questions involved in soil fertility work.

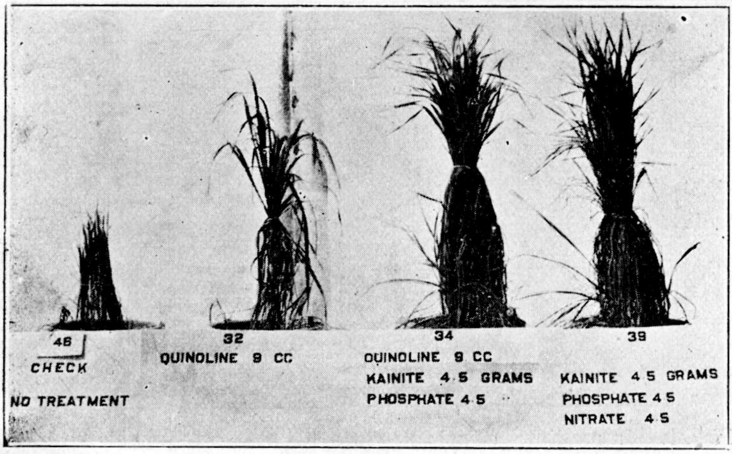

Fig. 1. Immediate effect of quinoline on oats when applied alone and in connection with fertilizers.

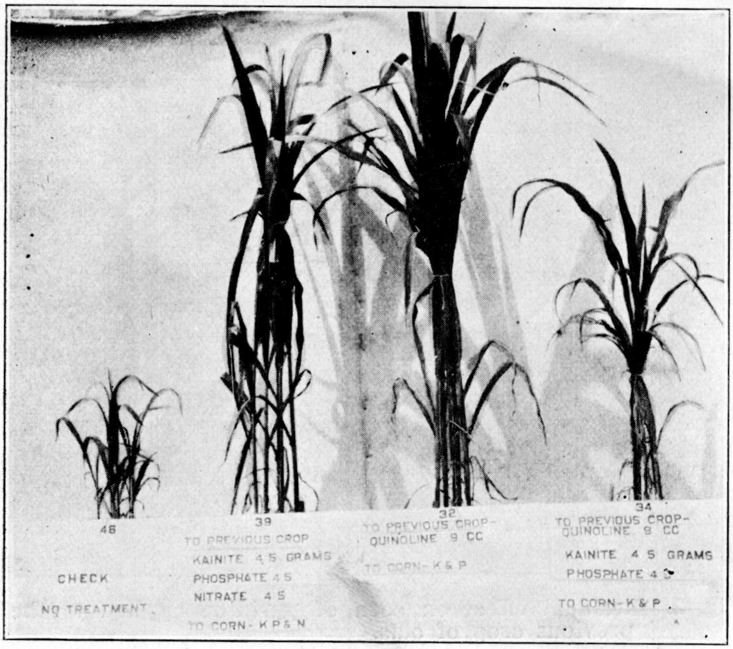

Fig. 2. Residual effect on corn of quinoline when applied to the previous crop of oats.

PLATE II.

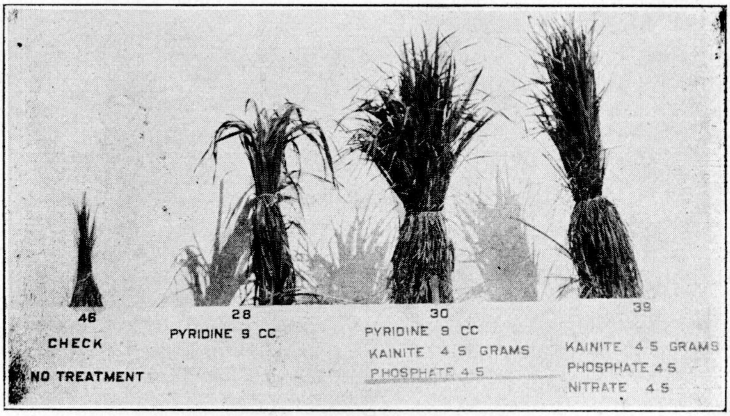

Fig. 1. Immediate effect on oats of pyridine applied alone and in connection with fertilizer.

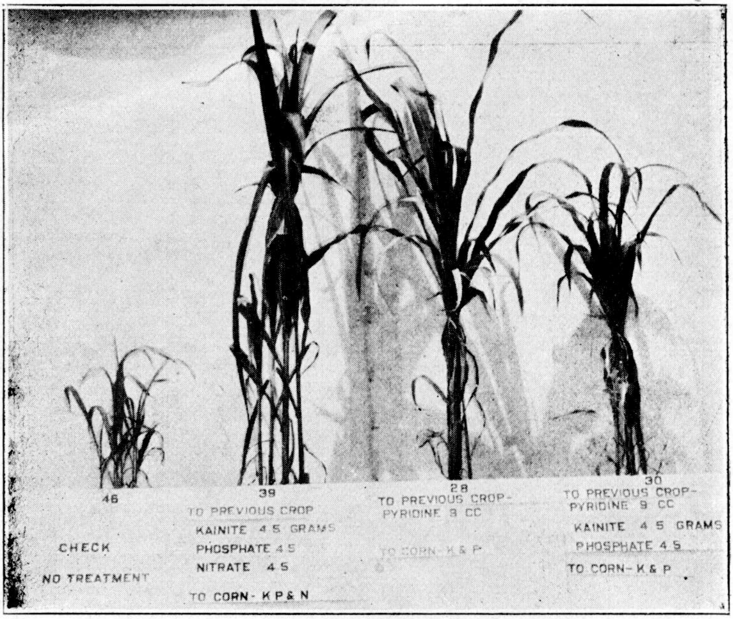

Fig. 2. Residual effect on corn of pyridine applied to the previous crop of oats.

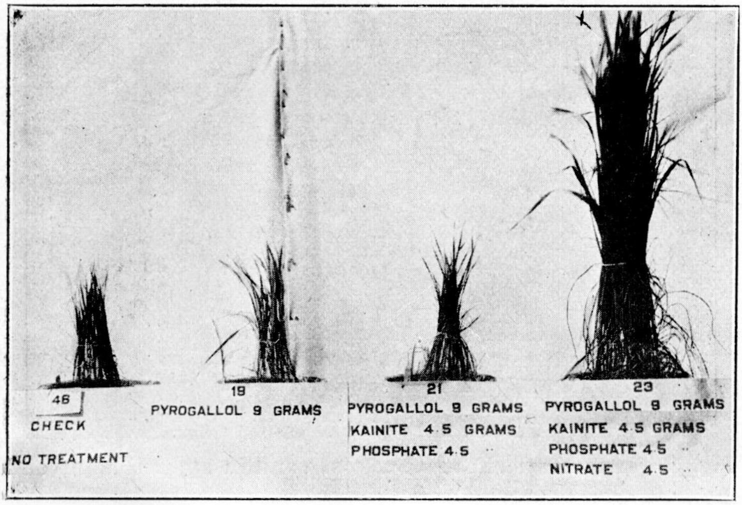

Fig. 1. Immediate effect on oats of pyrogallol applied alone and in connection with fertilizers.

Fig. 2. Residual effect on corn of pyrogallol and carbon black applied to the previous crop of oats.

(Plate III, fig. 2, pot No. 24, blurred line at bottom of the legend should read, "To corn, K. P. and N.)

PLATE IV.

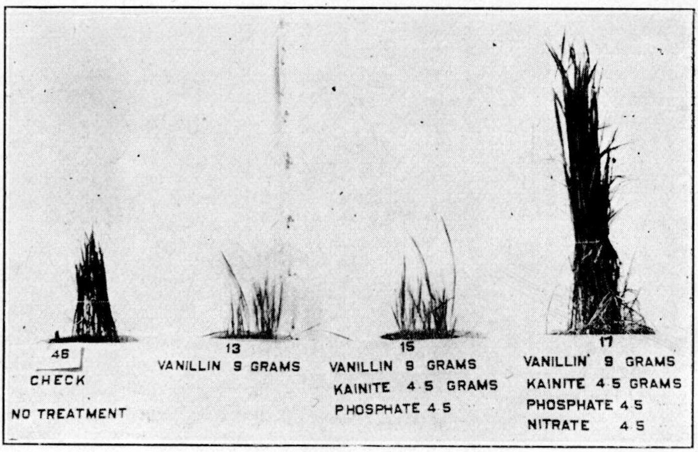

Fig. 1. Immediate effect on oats of vanillin applied alone and in connection with fertilizers.

Fig. 2. Residual effect on c rn of vanillin to the previous crop of oats.

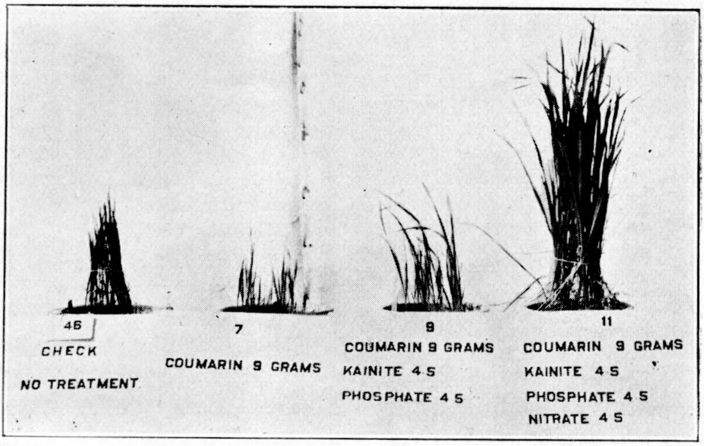

Fig. 1. Immediate effect of coumarin on oats when applied alone and in connection with fertilizers.

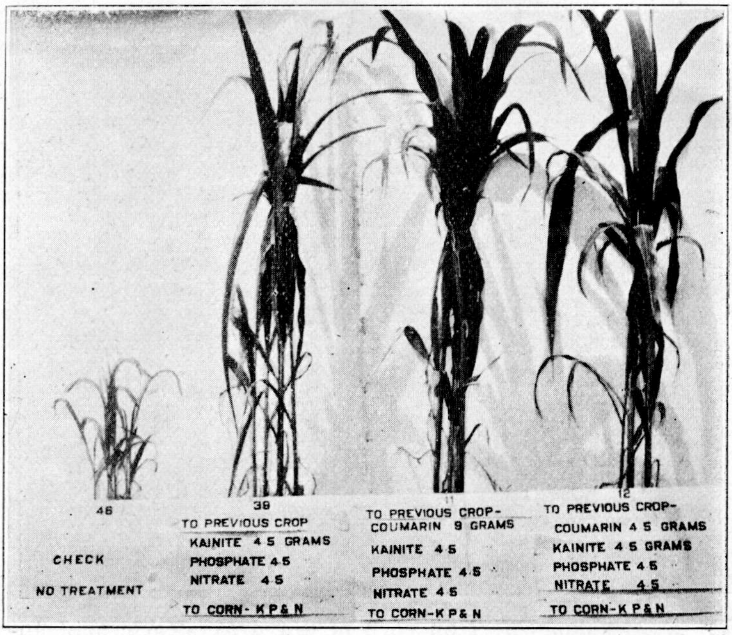

Fig. 2. Residual effect on corn of coumarin applied to the previous crop of oats.

PLATE VI.

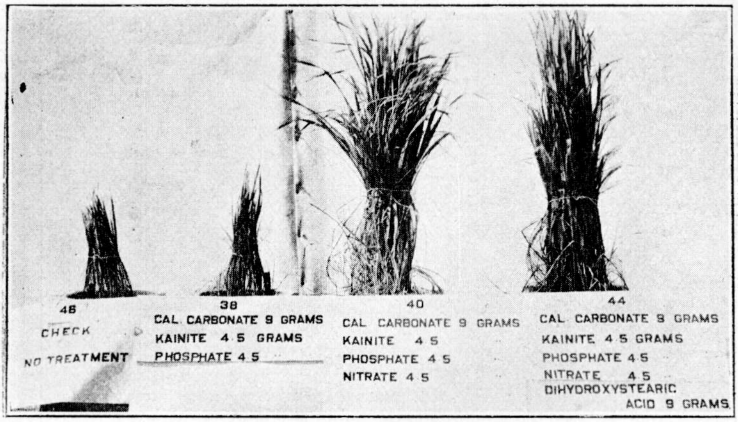

Fig. 1. Immediate effect of dihydroxystearic acid on oats when used in connection with a complete fertilizer.

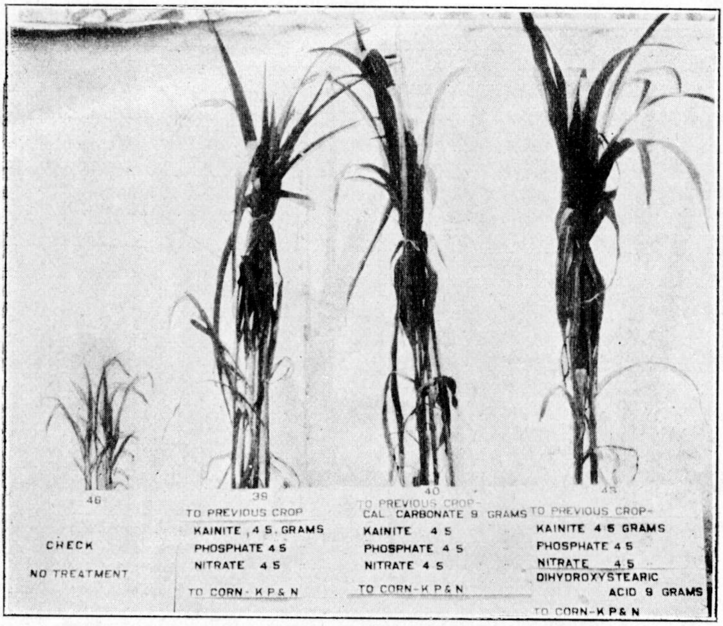

Fig. 2. Residual effect on corn of dihydroxystearic acid applied to previous crop of oats.

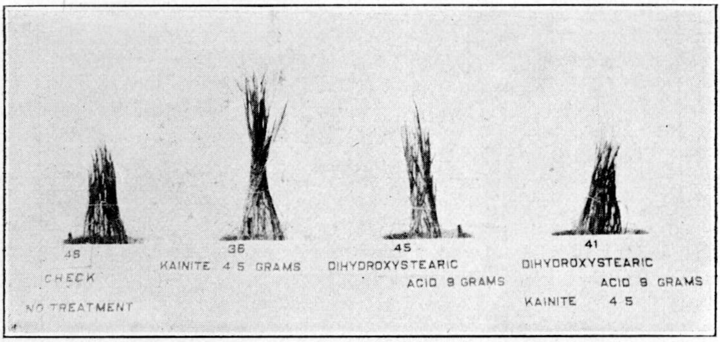

Fig. 1. Immediate effect of dihydroxystearic acid on oats when used alone and in connection with kainit.

Fig. 2. Residual effect on corn of dihydroxystearic acid applied to previous crop of oats.

PLATE VIII.

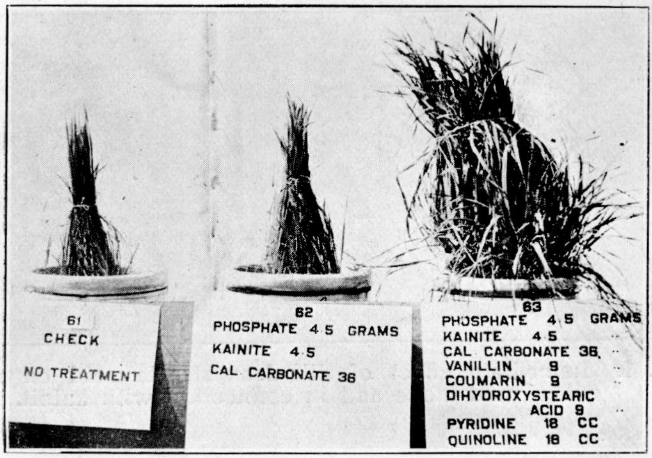

Fig. 1. Immediate effect on oats of a combination of organic compounds in connection with fertilizer and lime.

Fig. 2. Residual effects on corn of a combination of organic compounds applied to the previous crop of oats.