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Fertilizers Required by Cotton as Determined by the Analysis of the Plant.

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FERTILIZER REQUIREMENTS OF COTTON.

AS DETERMINED BY THE ANALYSIS OF THE PLANT.

No question, perhaps, so nearly concerns the grower of cotton as that of fertilization. The small margin for profit in its cultivation makes it imperative that the southern farmer, who chooses to depend well nigh exclusively on the great staple for his livelihood, should cultivate it at the smallest possible cost. An indiscriminate and unintelligent use of fertilizers must be discarded, then, as early as possible, and the farmer should seek to inform himself as to what his soil needs in order to make it highly productive. Much that is valuable has been published on this subject, and many reliable experiments performed which seem to solve the question pretty effectually as far as the particular soils under consideration are concerned. By the application of various fertilizers in varying proportions the experimenter has been able to say that his soil needs this and that constituent in this and that amount, but he solves the question with any great degree of certainty *only* with reference to his own soil and those which resemble it in kind and climatic conditions. What is needed in South Carolina or Texas, for instance, may not be needed in Alabama, and what an east Alabama soil may be deficient in, may be found in sufficiency in a western Alabama soil. The great desideratum, therefore, is to find some method of determining soil requirements which admits of general application, or which may be readily and cheaply applied in individual cases. With the hope of being able, if possible, to make some small contribution toward the solution of this great problem, the work detailed in this bulletin was undertaken.

For the purposes of the experiments herein described two plots of ground were selected, whose soils are of the same general type, but are widely different in point of fertility. The soil of the Drake field is too poor for the profitable culture of cotton, while that of the Station garden has, by proper management, been brought into a high state of cultivation. The field plot stood idle the previous year, while the garden produced two crops. The last crop was a winter grass which was harvested just prior to breaking the soil for these experiments. In the preparation of this land all the stubble and roots, as far as possible, were removed by the rake after the ground was thoroughly broken up. Each piece of ground was divided into ten small plots, each 10x10 feet, and lying end to end. The garden strip was so located that there was a slight drainage in a transverse direction. In the Drake field, however, the peculiar conditions of the surface were such that, to secure uniformity of soil, the strip had to be so located that the drainage would be lengthwise, plot 1 being the higher. In all cases a space four feet wide was left between the plots. Three of the plots in each strip were left unfertilized, while to the other seven the three fertilizing constituents were applied, singly and in combination, as is set forth in Table I. In the final preparation of the soil and in the planting and cultivation of the cotton, all plots were treated alike.

The first set of samples for analysis were taken during the first week in June, when the plants were in the early flowering stage. The second set were drawn about the 1st of September, when the last blossoms were falling off, and the early bolls were beginning to open. The entire stalk above ground was taken, air dried, and prepared for analysis in the usual way.

It is proper to state here that all the field work for these experiments was done for the writer under the supervision of Mr. James Clayton, formerly assistant horticulturist of the station, to whom acknowledgments are due for valuable and painstaking services.

In Table I will be found the percentages of potash, phosphoric acid, and nitrogen in the plant in the flowering stage. The figures given are the means of a number of determinations, and are calculated to the dry substance, the moisture of each sample having been carefully determined in the usual way, by separated heatings and weighings until no further loss of weight occurred. In the same Table will be found the weight in ounces of the seed cotton gathered from each plot.

To make the results comparable the number of stalks in each plot were counted and the actual weights obtained were reduced to a uniform stand. It should be stated further that the stalks were not as thick in the plots as is usual, and none of them were located near the edge of the plots, the purpose being to allow the roots to have the full benefit of the fertilizers used.

TABLE I.

COTTON PLANT IN FLOWERING STAGE.

A glance at the figures in Table No. 1 will reveal several noteworthy facts. In the first place it will be observed that there is considerable divergence between the maximum and minimum percentages of two of the constituents. That the composition of the cotton plant, therefore, in relation to these ingredients at least, is subject to perceptible variation, cannot be doubted. For instance, the maximum percentage of potash in the Drake field is 50.8 % higher, and in the garden, 21.1 % higher, than the minimum in the same soil; while the maximum in the garden exceeds the minimum in the field by 98 %. The maximum of nitrogen in the field is 17 %, and in the garden 25.8%, higher than the minimum in the same soil; and the maximum in the garden, 28.2 %

Table I.

COTTON PLANT IN FLOWERING STAGE.

Plots.	FERTILIZERS USED.	Drake Field.				Station Garden.			
		Per cent. Potash.	Per cent. Phosphoric Acid.	Per cent. Nitrogen.	Oz. Seed Cotton.	Per cent. Potash.	Per cent. Phosphoric Acid.	Per cent. Nitrogen.	Oz. Seed Cotton.
1	None	2.154	0.839	3.390	3.75	3.444	0.861	3.455	35.63
2	Nitrate Soda	....	0.863	3.906	10.	3.287	0.829	3.976	73.43
3	Kainit.	2.751	......	3.382	11.88	3.320	0.958	3.717	117.14
4	Acid Phosphate	....	0.781	3.837	34.	3.227	0.914	3.896	124.29
5	None	2.034	0.934	3.488	9.29	3.178	0.862	3.825	130.83
6	Nitrate Soda and Kainit	2.137	0.627	3.855	30.	2.981	0.805	3.831	120.
7	Nitrate Soda and Acid Phosphate	1.823	0.699	3.685	23.21	3.199	0.854	4.225	96.25
8	Kainit and Acid Phosphate	1.997	0.919	3.967	29.17	3.102	0.797	3.873	132.86
9	Nitrate Soda, Kainit, Acid Phosp.	2.547	0.830	3.645	37.50	3.611	0.860	4.347	145.34
10	None	2.238	0.886	3.645	12.50	3.106	0.805	4.149	141.25

higher than the minimum in the field. The *relative* variations between the extremes of phosphoric acid are greater than those in the case of nitrogen, but the absolute variations are small, and may possibly be traceable to accidental causes. It may not be amiss to state just here that a great deal of time and care were spent in the analytical work, that no errors might creep in to vitiate the results, and hence it can be confidently affirmed that the results given may be relied on. It is believed, however, that some individual stalks have exhibited peculiarities of composition, and such peculiarities might have been eliminated, perhaps, had a larger number of plants from each plot been available for analysis.

In the second place, we note that the character of the soil exercises a perceptible influence on the composition of the plant, at least as far as potash and nitrogen are concerned. Taking the means of the percentages of potash in the three unfertilized plots of each soil separately, we find that this mean in the garden soil is 51.4 % higher than the corresponding mean in the field soil. Making the same estimates for nitrogen, we find that the garden soil exceeds the field soil in this ingredient by 8.6 %. Here, as before, we cannot affirm any positive rule concerning phosphoric acid.

The original purpose of these investigations was to find out what effect, if any, the addition of fertilizing constituents to the soil would have on the relative proportions of these constituents in the plants themselves. With this purpose before us let us examine Table I in detail. In the results from the Drake field soil, we see that the highest percentage of potash is in plot 3, and the next highest in plot 9, to both of which plots potash was added. On the other hand, the second lowest percentage is in plot 8, which also was fertilized with potash. It will be noticed that this plot seems eccentric in another particular—in that it contains the highest percentage of nitrogen, when no nitrogen was applied to it. With this exception, the highest percentage of nitrogen is found in plot 3 which has nitrogen fertilization, and the lowest percentage where nitrogen was used, is higher than the average of those where no nitrogen was added, even when the high percentage of plot 8 is included in the estimate. As has already been noted, the variation in phosphoric acid seems to obey no rule, the percentages in the two soils being practically the same.

In the beginning of this discussion it was stated that the garden soil was in a high state of cultivation to begin with, and it was to be expected, that the influence of fertilizers here, both on the composition of the plant and on the yield of seed cotton, would be less strongly marked than in the poorer soil. While this is the case, it is, also, true that by fertilization with potash and nitrogen the percentages of these constituents even here are increased. This is notably true in plot 9, where all three fertilizers were applied and where are found the highest percentages of these ingredients.

The average effect of fertilization on the percentages of the fertilizing constituents in the plants may best be seen by reference to Table II. By the term "fertilization" in this table is to be understood the use of the particular ingredient in question, without reference to the other ingredients. Thus when percentages of potash are considered, fertilization with potash without reference to phosphoric acid or nitrogen is solely considered.

Table II.

GENERAL SUMMARY.

	Drake Field.			Station Garden.		
	Fertilization.			Fertilization.		
	Without	With	% Increase by	Withoui	With	% Increase by
Potash............	2.062	2.356	14.25	3.240	3.254	0.43
Phosphoric Acid...	.828	.807	—2.53	.853	.856	0.35
Nitrogen...........	3.618	3.773	4.28	3.819	4.095	7.23

It will thus be seen that by fertilization with potash, the average percentage of that constituent in each soil is increased. This increase is large in the poor soil and small in the rich. Fertilization with nitrogen, also, has a well marked influence on the percentages of that constituent, as the above table shows.

The results that we have hitherto been considering were obtained from the analysis of the plant in the early flowering stage. It was deemed expedient to analyze the plant in a later stage, also, and so about three months after the first samples were taken, when the plant was full of unopened bolls, the second lot were drawn. One of the purposes of this investigation was to see if the percentages of potash, phosphoric acid, and nitrogen in the plant did not increase with the yield of cotton. This could hardly be otherwise, if the seed were ground up with the stalk, inasmuch as the seed are a reservoir, so to speak, in which these constituents accumulate. Hence it was thought best not to include the young, inmature seed in the sample for analysis, and they were accordingly rejected. The results of the analysis are given in Table III following, which is constructed after the model of Table I. Here, as in the other, the results are calculated to the dry substance.

Table III.

ANALYSIS OF PLANT IN THE BOLLING STAGE.

Plots.	FERTILIZERS USED.	Drake Field. Per cent. Potash.	Drake Field. Per cent. Phosphoric Acid.	Drake Field. Per cent. Nitrogen.	Drake Field. Oz. Seed Cotton.	Station Garden. Per cent. Potash.	Station Garden. Per cent. Phosphoric Acid.	Station Garden. Per cent. Nitrogen.	Station Garden. Oz. Seed Cotton.
5	None	1.256	.788	1.883	9.29	2.538	.758	2.352	130.83
6	Nitrate Soda and Kainit	2.123	.345	1.969	30.	2.026	.741	2.436	120.
7	Nitrate Soda and Phosphoric Acid.	1.051	.537	1.883	23.21	1.494	.688	2.064	96.25
8	Kainit and Phosphoric Acid	2.119	.488	1.841	29.17	2.751	.900	2.442	132.86
9	Nitrate Soda, Kainit, Phosp. Acid	2.562	.557	1.833	37.50	3.054	.696	2.339	145.34
10	None				12.50	2.683	.724	2.273	141.25

A conspicuous fact observable in the above table is that the figures here are smaller than the corresponding figures in the first table. This was to be expected. The plant at this stage of growth is nearing maturity, and the three important constituents are being rapidly stored up in the seed.

Studying the table in detail, we find that in the Drake field the lowest percentages of potash are in 5 and 7, where there was no potash fertilization, while the highest is in 9, where there is complete fertilization and where there is, also, the highest yield of cotton. As we shall see a little later, the average of the percentages of potash in plots in the field which have potash fertilization, is about the same as that in the richer soil of the garden. Singularly enough we have in 9 one of the lowest percentages of nitrogen, but the other two nitrogen-fertilized plots bring up the average, and with this constituent, as with potash, we have an increase of percentages due to fertilization. We must observe, however, the small variation between the maximum and minimum in this column.

Coming now to the garden plot we find that the average effect of potash fertilization is to increase the percentages of potash, while, on the other hand, nitrogen fertilization does not seem to have a like effect on the percentages of nitrogen. This would seem to indicate that the garden soil contains a deficiency of potash, but a sufficiency of nitrogen.

The results on phosphoric acid are worthy of special attention. With a single exception the percentages of this constituent in the Drake field in the bolling stage, are decidedly lower than the corresponding ones in the flowering stage, while no such marked change is observable in the garden percentages. It would seem, therefore, that there is a deficiency of available phosphoric acid in the Drake field, which was not shown by the analysis at the earlier stage, and further, that there is no such deficiency in the garden soil. The exceptional case referred to is in 5, where the percentage of phosphoric acid is only a little smaller than the average found in the earlier stage. This fact, taken in connection with that of a high percentage of nitrogen and a low yield of cotton, might suggest the possibility of a case of arrested development. It will be observed that with rare exceptions the percentages of all the constituents are higher in the garden than they are in the field, and from this the conclusion may be drawn that there is a deficiency of potash, phosphoric acid, and nitrogen in the field. The smaller yield of cotton in the field strengthens this conclusion.

Table IV following, gives the summary of results contained in Table III, and is submitted without comment.

Table IV.

GENERAL SUMMARY.

	DRAKE FIELD FERTILIZATION.			STATION GARDEN. FERTILIZATION.		
	With out	With	% Increase by	Without	With	% Increase by
Potash	1.154	2.268	96.53	2.238	2.610	16.62
Phosphoric Acid	5.66	.527	—6.89	.741	.761	2.70
Nitrogen	1.862	1.895	1.77	2.356	2.280	—3.22

For convenience of comparison and study, it has been thought advisable to present Table V following, which is a consolidation of Tables I and III.

It will be seen from this table that the percentages of the constituents in the bolling stage are smaller in most instances than the corresponding percentages in the flowering stage. It will be convenient to refer to this decrease in values in per cents of those of the earlier stage. In the Drake field we find the decrease in potash in No. 6 to be 0.7 %, and in Nos. 8 and 9, there is an increase of 6.1% and 0.6 % respectively; while in the other two plots the decrease is 38.2 % and 42.3 %. It will be observed, also, that the largest yields of cotton are in plots 6, 8, and 9. From this it would seem that in the potash-fertilized plots there is a sufficiency of that constituent under the circumstances here existing. On the other hand, comparing the field and garden, we find that while the latter has much higher percentages of potash to begin with, it has at the same time larger per cents of decrease than the potash-fertilized plots in the field, ranging from 11.3 % in plot 8 to 53 % in plot 7. In other words, with a larger supply there is a smaller excess of potash over the demands for that constituent. Little can be learned from the figures relating to phosphoric acid. The decrease ranges from 0.8 % in plot 6 in the garden to 46.9 % in plot 8 in the field. The decrease in the values of nitrogen is uniformly high, showing the great demand for that valuable constituent. In the field the range is from 46 % in plot 5 to 53.6 % in plot 8, while in the garden it runs from 36.4 % in 6 to 51.1 % in 7.

A few words with reference to the yield of cotton in passing. A reference to Table I will show that in the unfertilized plots 1, 5, and 10 in each soil the yield is not the same, but is lowest in 1 and highest in 10. This suggest that all the plots are not uniformly fertile, but increase in fertility from 1 to 10. This lack of uniformity in natural fertility, will, of course, effect the results obtained by artificial fertilization, but the effect of the latter on the yield is noticeable, just as it was on the composition of the plant. By a study of Table V we find that where we have high percentages of two or more constituents in the flowering stage, and a relatively low decrease of those percentages in passing to the bolling stage, we have, generally speaking, a large yield. On the other hand, low, or even average, percentages in the early, and a large decrease of the same in the later stage, showing an insufficient supply from the soil, means a relatively low yield. The application of this rule,

Table V.

Plot	FERTILIZERS USED.	Drake Field. Potash Flower-ing	Drake Field. Potash Bolling	Drake Field. Phosphoric Acid Flower-ing	Drake Field. Phosphoric Acid Bolling	Drake Field. Nitrogen Flower-ing	Drake Field. Nitrogen Bolling	Drake Field. Seed cott'n	Station Garden. Potash Flower-ing	Station Garden. Potash Bolling	Station Garden. Phosphoric Acid Flower-ing	Station Garden. Phosphoric Acid Bolling	Station Garden. Nitrogen Flower-ing	Station Garden. Nitrogen Bolling	Station Garden. Seed cott'n
5	None	2.034	1.256	0.934	0.788	3.488	1.883	9.29	3.178	2.538	0.862	0.758	3.825	2.352	130.8
6	Nitrate and Kainit	2.137	2.123	0.627	0.345	3.855	1.969	30.	2.981	2.026	0.805	0.741	3.831	2.436	120.
7	Nitrate and Phos. Acid	1.823	1.051	0.699	0.537	3.685	1.883	23.21	3.199	1.494	0.854	0.688	4.225	2.064	96.3
8	Kainit and Phos. Acid	1.997	2.119	0.919	0.488	3.967	1.841	29.17	3.102	2.751	0.797	0.900	3.873	2.442	132.9
9	Nitrate, Kainit, Phos. Acid	2.547	2.562	0.830	0.557	3.645	1.833	37.50	3.611	3.054	0.860	0.696	4.347	2 339	145 3
10	None	......	......	......	......	......	......	......	3.106	2.683	0.805	0.724	4.149	2.273	141.3

if it be a rule, to plot 5 Drake field may explain the low yield of cotton there, a deficiency both of potash and of nitrogen being manifest. Likewise in plot 7, Station garden, we find a large decrease in the percentages of all three constituents, although two of them have been added to the soil, and here, also, we find a relatively low yield.

In connection with this work, it has been thought well to make a complete analysis of the two soils. In view of the fact of their similarity geologically, both being classed as light sandy soils, and the additional fact that one is very poor and the other rich, a comparison of their chemical composition will be interesting.

CHEMICAL ANALYSIS OF SOILS.

	DRAKE FIELD.	STATION GARDEN.
Moisture	.650	.825
Insoluble Silica	94.790	93.097
Soluble Silica	.532	.560
Alumina	1.153	1.873
Oxide Iron	.850	1.093
Lime	.185	.260
Magnesia	.158	.122
Soda	.268	.315
Potash	.098	.087
Phosphoric Acid	.087	.064
Nitrogen	.069	.086
Organic Matter	1.550	2.195
Humus	.580	.863
Available Inorg. Matter	.647	.946
Humus Silica	.253	.353
Humus Phosphoric Acid	.020	.035

As will be observed, both soils have a high percentage of insoluble silica, that of the field exceeding that of the garden nearly two per cent. Oxide of iron in the hydrated condition is believed by some to increase in soils the absorptive power of gases, and particularly, of moisture. Both of our soils are low in this constituent, with the advantage in favor of the garden. Estimated in terms of the poorer soil, the garden soil is 28.6 % higher in oxide of iron than the other. If the minimum limit assigned to lime in light sandy soils by writers on this subject be correct, both of these have a sufficiency of this valuable constituent, the garden having 40.5 % more than the field. In both potash and phosphoric acid; on the other hand, the garden soil is poorer, about 1 % in the former and 26.4 % in latter. What has just been said applies to *total* phosphoric acid. The humus phosphoric acid, all of which is believed to be readily available to the plant, is 75 % higher in the garden than in the field. In total available inorganic matter—that which dissolves out with the humus—the garden soil is 46 % richer than the field soil.

It will thus be seen that the garden soil in the main is richer in the important inorganic constituents than the other soil; but it is believed that its superior fertility is chiefly due to its larger proportion of organic matter. In total organic matter it is 41.6 %; in humus, 48.8 %; and in total nitrogen, 24.8 % richer than the other.

CONCLUSIONS.

It is not safe to base conclusions on a single series of experiments. Further investigations may make it necessary to alter some of the opinions suggested in this paper, and some of these conclusions here may have to be withdrawn, but it is believed that the broadest conservatism will sanction the following conclusions from the results herein presented:

1. That the composition of the cotton plant in respect to potash, phosphoric acid, and nitrogen, is subject to decided variations under varying conditions.
2. That the nature of the soil exerts a considerable influence on the composition of the plant, a rich soil giving higher percentages of the three important constituents than a poor soil.
3. By fertilizing with either of the three constituents in soils not already containing a sufficiency of the same, it is possible to increase the percentage of that constituent in the cotton plant which is grown on such soil.
4. That humus in the soil is of great value, not only in supplying organic constituents, but, also, in holding inorganic constituents in most available conditions.

It is not claimed that the results herein described *demonstrate* the utility of this method as a means of determining soil requirements for cotton, but it is claimed that they are highly suggestive. If the normal composition of the healthy, thrifty plant under given soil conditions be known, we believe it possible to determine when a deficiency of any of the three constituents exists in a given soil. Systematic determinations, therefore, of the composition of the cotton plant under normal healthy conditions, together with determinations of the chemical composition and the physical properties of the producing soil, will furnish a basis, it is believed, for the establishment of a plan of investigation which will prove of great value to the agricultural interests of the South.