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A STUDY OF THE PHYSICAL AND CHEMICAL PROPERTIES OF THE SOIL

AS INFLUENCED BY COWPEA CULTURE

by

Carlos Amie Le Clair, B. S. (Agriculture)

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A STUDY OF THE PHYSICAL AND CHEMICAL PROPERTIES OF SOIL AS INFLUENCED BY COWPEA CULTURE

INTRODUCTION

In the past twenty-five years much experimental work has been done with cowpeas, in relation to cultural methods, fertilization, and variety tests, but practically nothing has been written with regard to the direct effect of the plant upon the soil. It has been supposed that the peas are beneficial to a companion crop as, for example, corn. Some have expressed the belief that cowpeas are capable of producing a loosening effect upon the soil. Still others claim that the continuous cropping of land to this plant alone, or as a catch crop with wheat, results in an effect deleterious to the best growth of either wheat or peas. As to actual experimental data on these subjects, however, nothing authentic has been discovered.

WORK OF OTHER INVESTIGATORS

An exhaustive study of research literature revealed that previous work along these particular lines has been exceedingly limited. The following experiments bear only indirectly on the work of this thesis but are undoubtedly worthy of consideration. The historical data is grouped in three divisions. The first includes references dealing with the problem of nitric nitrogen in the soil, the second with the effect of shade upon the soil and the third with the effect of continuous cropping.

HISTORICAL

Nitric Nitrogen in the Soil

F. Philz, (Ztschr. Landw. Versuchsw. Ost., 14 (1911), No. 10, pp. 1150-1210), found that the nitrogen production in the soil, per unit area, was greater where legumes and cereals were grown together on the same plot than was the sum of the nitrogen production by the crops when grown alone on separate plots.

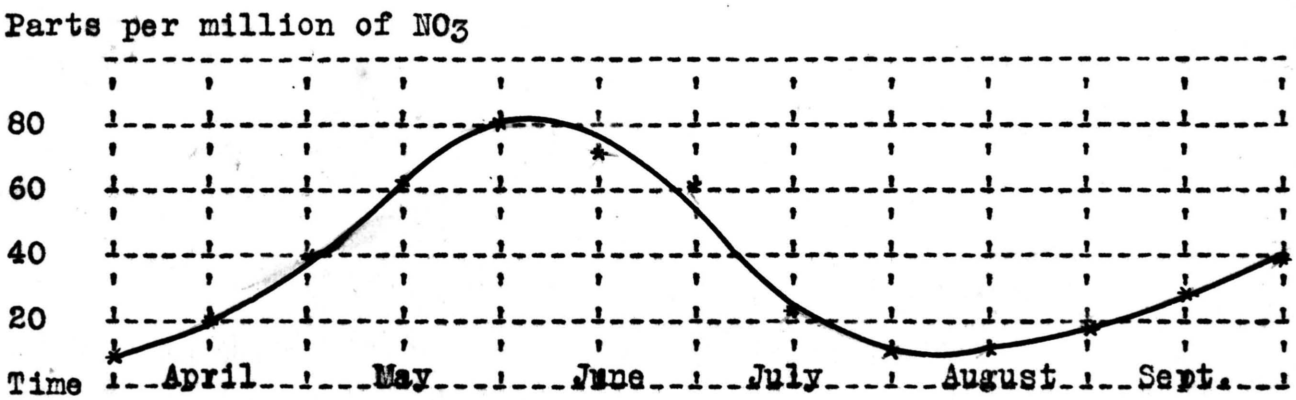
T. L. Lyon and J. A. Bizzell, (Journal Franklin Inst., 171 (1911), Nos. 1, pp. 1-16; 2, pp. 205-220, dgms 4), found that during the most active growing period of the corn crop nitrates were higher under corn than in cultivated soil bearing no crop. This phenômena was explained by the fact that nitrification is stimulated by some processes connected with the active growth and absorbing functions of the plants. Nitrates did not increase in cropped plots at the end of the season as they did in uncropped plots. On uncropped soil an increase of moisture in September was accompanied by a marked increase in nitrate accumulation.

R. Stewart and J. E. Graves, (Bulletins 106 and 110 of the Utah Station, on "The Production and Movement of Nitric Nitrogen"), found after extensive study, that there exists a pronounced variation in nitric nitrogen content of soils from foot to foot during the season due to water movement, variation in nitrification, feeding of plants and the fixation of nitric nitrogen in the form of insoluble protein by

micro organisms.

In cropped land there was always less nitrogen in the soil during the fall than in the spring. In fallow soils, on the other hand, more nitrogen was found in the fall than in the spring. Alfalfa left less nitrogen in the soil in the nitric form than did either oats or potatoes.

F. H. King of the Wisconsin Station measured the nitrates under corn at frequent intervals throughout the season and produced the following curve.



Effect of Shading on Soil

A. Buehler, (Ciel et Terre, March 1896, XVII, p. 22), reports having carried on an experiment on four broad plots of ground. One was exposed to sun and wind, the others were shaded in varying amounts by horizontal wooden trellises placed around each plot 40 centimeters above the ground. The trellises were so arranged as to cut off ¼, ½, and ¾ of the sunlight from respective screened plots.

Data at the end of the experiment showed that at mid day the shaded plots had a lower temperature than the open plot by from 2-10 degrees Centigrade. However, the cooling

by night under the shaded plot was very slight, being under 2 degrees Centigrade which explains the effectiveness of a wind break in preventing injury by frost. In rainy weather the variation of temperature either by day or by night was much smaller.

The relative evaporation from plots throughout the test was as follows:

Treatment	Per cent Evaporation
No shade.	.100
$\frac{1}{4}$ "	84
$\frac{1}{2}$ "	71
$\frac{3}{4}$ "	62

E. Wollney, (Der Einfluss Pflanzendecke und Beschattung, page 165), reports that the shade of crops on land has little or no tendency to increase the looseness of a soil, but his data shows that a crop on the land, be it cereal or legume, partially prevents the land from becoming compact. He has proven that not alone is this effect due to elimination of the effects of beating rains and sunlight thereafter, but to a greatly increased bacterial activity on cropped land. The bacteria thrive better in the moderate shade afforded by the plants, produce more humus and thus improve the soil structure. The author gives definite experimental data to substantiate his conclusions.

Effect of Continuous Cropping

The United States Department of Agriculture, Bureau of Soils, has shown in bulletin 40, page 36, that excreta of

wheat is harmful to succeeding crops of the same plant and that cowpeas following wheat are also somewhat toxic to the wheat and much more so to more nearly related plants. Of course, these conclusions were drawn from plant house tests which were conducted as follows:

The wheat seedlings were grown in sterile quartz sand or water culture and, after running a series of days or weeks the crop was harvested, when wheat or cowpeas were again planted in the same culture jar or flask. The growth of seedlings so treated as compared with others grown in non-toxic distilled water was the basis for their comparison. As an index to plant growth, they measured daily transpiration which they found amounted to from two to ten times the weight of the seedling. After growing a number of seedlings under such conditions the extract remaining in the culture bottle or pot is distilled and further cultures made of the distillate and of the residue. By determining whether the plants show stunting either in the distillate or the residue, the volatile or non-volatile character of the deleterious body is learned. In this way they have succeeded in isolating and identifying many toxic bodies among which di-hydroxy-stearic acid and Picoline carboxylic acid may be mentioned. That toxic bodies are most all of an organic nature, may be shown by evaporating the soil extract to dryness and igniting. The residue when again taken up with water no longer retains its deleterious effect. Absorbent materials such as carbon black, ferric hydrate, $CaSO_4$, and $CaCO_3$ have the ability to remove toxic bodies from solution. It was

further discovered that a soil found to be toxic was more deleterious to plants grown upon it than an extract of some. This is explained by the supposition that, as toxic bodies are not readily soluble, there would be a much greater amount ready for action in the soil than in its extract. That the toxicity of the soils tested was not due to their acidity was shown by the fact that non-toxic water made equally acid with mineral acids had no bad effects upon the plants grown in it.

C. E. Thorne, Ohio Station, (Bulletin No. 176), working in conjunction with the United States Bureau of Soils, found that while every soil they examined which exhibited toxic properties was acid in nature, all acid soils were not toxic.

H. J. Wheeler and J. F. Breazel, Rhode Island Station, (18th Annual Report, pages 286-323), checks identically with the findings of the Ohio Station.

T. Lyttleton Lyon and James A. Bizzell, Cornell Station (Bulletin No. 326), in a study of water soluble matter in soils sterilized and reinoculated, report that of two soils studied in the laboratory, soil (2) was very poor in spite of the fact that it contained as much organic matter and nutrient materials as did soil (1) which was remarkably good. The inability of the former soil to rid itself of toxic material formed by the steaming process of this experiment indicates that a similar condition causes its sterility in the field.

SCOPE OF PROBLEMS

The soil of the Station fields, upon which all experiments were run, analyzed as a silt loam. (See table A below.) The surface from 0"-8" is a gray to brownish silt loam, from below the surface 8"-24" it grades heavier and is dark red in color, and from 24"-48" it becomes more granular, contains some sand and is of a light yellowish tinge.

TABLE A

MECHANICAL ANALYSIS OF SOIL

0" TO 8" OF EXPERIMENTAL PLOTS

Volatile Matter	Fine Gravel	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Silt	Clay	
%	%	%	%	%	%	%	%	
4.91	.26	.37	.77	10.77	29.37	49.55	8.88	99.97

The main lines of investigation in this thesis were a study of the physical and chemical effects of cowpeas upon a soil when grown alone, when grown as a companion crop with corn and when grown as a catch crop after wheat. In addition to the direct study of the main problems, extensive observations were also made of the moisture contents of all plots and the relation of precipitation to crop removal. In conjunction with Mr. P. L. Gainey, working in Soil Bacteriology, much data was secured relative to the bacterial flora under the various treatments.

All the problems above mentioned suggested themselves through numerous inquiries made by farmers and by general observations on experiment station fields. Time and

again it has been reported that land seeded to cowpeas was much looser in the fall than adjacent plots not planted to peas. Also that, because of the extreme looseness of the soil after cowpeas, wheat following does not do well. Some have said that cowpeas, as a companion with corn, will benefit the latter; while others report that the corn yield is cut by the dual cropping system. Then, too, the question arose as to whether it made any difference in yield of either crop if the cowpeas were drilled in the row with the corn, or planted in between the rows at the last cultivation. Lastly, as to the advisability of the common practice of continuous cropping of land to a rotation of wheat and cowpeas, little was definitely known save that where such a system is in vogue signs of a cowpea sickness is apparent in some places.

OBJECT

Because of the apparent lack of data on these subjects of importance, this thesis was begun in September 1911.

PLAN OF THE WORK

From September 1911 until the Spring of 1912, the work consisted mainly in formulating plans and making preliminary tests for a basis upon which to lay the final scope of the work. The work eventually decided upon, as indicated in the introduction, was the physical and chemical properties of the soil as influenced by cowpea culture. This will be described in three parts as follows: Part I, Effect

of cowpeas as a companion crop with corn; Part II, Effect of cowpeas on soil structure; Part III, Effect of continuous use of cowpeas following wheat.

PART I.

In Part I, the relation of cowpeas in corn to soil moisture and nitrate content, a uniform, level piece of land was laid out in three 1/26 acre plots. (See Fig. I, Part I, page 16). Plots number I and II were drilled to yellow dent corn after carefully preparing the soil, while plot number III was drilled to the same amount of corn together with black cowpeas in the proportion of two parts of corn to three parts of peas. The season was late this year for Missouri and the crop was not put in until May 25th, 1912. On May 29th, 1912, all plots were harrowed. Later the corn and peas were replanted so that as near a perfect stand as possible was secured. The weeds were scrupulously removed from time to time by frequent cultivations and even hand hoeings. Whenever this was done, all plots were worked on the same day and treated identically the same. At the last cultivation of corn, the same amount of peas as used on plot III were planted in plot II between rows of corn. This was accomplished by using a one horse wheat drill with every other tube closed. Thus there were three rows of peas between every two rows of corn. The empty drill was run through the other plots at this time so as to eliminate error through its mulch effect. The peas planted with the corn on plot III had not spread enough to be injured by this treatment.

Nitrate and moisture determinations were made at the following periods:

(a) At planting time.

(b) At last cultivation.

(c) At tasseling time.

(d) At harvest time.

Observations were made from time to time as to the maturity of the corn on all plots and the yield of same was secured at the end of the season.

PART II.

On June 17th, 1912, another uniform strip of land which had been in small grain the previous year was selected and divided into five 1/62 acre plots. (See Fig. I, Part II, Page 25) Plots I and II were scraped with a hoe to make them free of weeds and debris. Plots III, IV and V were carefully spaded to a depth of eight inches. A series of samples for moisture and nitrate analysis were taken over the entire area to a depth of three feet, at this time. Just before planting to peas, compactness tests were made with an especially devised instrument (See Fig. III, Part II, page 28) on plots plowed and unplowed. On June 8th, 1912, plots II and III were drilled to black cowpeas and artificial shade was arranged on plot IV (See Fig. II, Part II, page 26). The three plots uncropped were kept free of weeds from time to time by scraping them off with a hoe but no further cultivation was given. At the close of the growing season, compactness of all plots was again measured and another series

of soil samples secured for nitrate, moisture, and bacterial studies.

PART III

For this experiment, two adjacent plots were secured, one of which had been cropped to wheat followed by a fall catch crop of cowpeas for a series of twelve years, the other to a rotation of corn, oats, wheat and legume for a similar length of time. (See Fig. I, Part III, page 40.) The former will be called plot "A" and the latter plot "B" in the course of this discussion. Both plots were in wheat when first samples of soil for moisture and other studies were taken, June 8th, 1912. It was the plan of the experiment to take samples respectively for special analysis of moisture, nitrate and bacterial count at the following periods:

(a) In the spring.
(b) At wheat harvest.
(c) In the late fall.

Unfortunately a complete analysis of this soil at the beginning of the experiment, eight years ago, was not available but nevertheless, assuming that both plots were identical at that time, it was planned to compare the present supply of plant food. Thus it was hoped might be determined the cause for the continually poorer crops on the continuously cropped plot. Treatment was made of the soil from each plot in pot culture as was the extract of the same studied in water culture experiments. As yet, however, work has not

progressed sufficiently in this line to warrant more than a brief discussion in this thesis.

PRELIMINARY DATA.

Before deciding upon the number of cores it would be necessary to take from each plot to warrant an authentic analysis representative of the soil under consideration, nitrate determinations of many individual borings were made. It was found that the average analysis of at least six borings gave a result within the limit of experimental error for the method used. In addition to this, a composite sample was made of the six cores, which gave on analysis, as seen in the following table, a result as accurate as that obtained by averaging the individual analysis. Hence, all future data reported for chemical analysis will be from a composite of from six to eight samples taken from each plot.

(See Table I, page 13)

TABLE I

NITRATES IN PARTS PER MILLION OF OVEN DRY SOIL

PLOT	1st Ft.	2nd Ft.	3rd Ft.	PLOT	1st Ft.	2nd Ft.	3rd Ft.
A^1	3.56	4.67	4.16	B^1	6.26	5.09	2.50
A^2	15.00	6.00	2.56	B^2	4.17	3.63	3.32
A^3	3.59	4.32	3.12	B^3	3.01	2.91	3.24
A^4	7.61	6.65	4.51	B^4	6.03	2.19	3.28
A^5	5.89	2.46	2.21	B^5	2.42	2.32	2.31
A^6	2.69	2.94	2.76	B^6	8.20	4.89	4.72
A Average	6.39	4.50	3.22	B Average	5.00	4.21	3.24
A composite	6.73	3.95	3.07	B Composite	5.12	3.50	3.25
*A Final	6.56	4.22	3.14	B Final	5.06	3.85	3.24

*Average of individual and composite analysis.

The individual samples from which the above tabulated data was secured and, in fact, all the samples secured in this entire work were taken four feet deep with an inch and a half soil auger. The soil from each foot was placed in a separate container and taken to the laboratory. For chemical analysis the soil was at once dried in the oven at 50 degrees Centigrade so as to prevent continuance of bacterial activity, ground in a mortar and sent through a 60 mesh sieve. A composite was made by carefully mixing on a rubber cloth and finally riffling.

In order to still further insure the representativeness of the samples from a given plot, the following plan was devised to distribute the borings, with especial reference to

corn plots. (See Fig. A below.)

Fig. A

45 ft.	Eliminated		10 ft. Eliminated
Row 1		*	
" 2		*	
" 3		*	
" 4		*	
" 5		*	
" 6		*	
" 7		* *	

*Showing where samples were taken

Originally it was planned to secure samples only to the third foot because of the tenacity of the heavy clay subsoil below, but later in the season it was found possible to obtain an additional foot.

<u>Official methods</u> were followed in all analytical work except where otherwise stated.

In like manner the number of cores necessary to make a representative moisture determination was ascertained. The same general scheme as shown in Fig. A above was used when securing moisture samples, taking care, of course, not to let two borings come too close to each other. Moisture samples were placed in tared metal cans and taken to the laboratory as soon as possible. A net weight was at once secured and then the covers removed and the samples dried in an oven at 105 degrees Centigrade until constant weight was obtained.

Table II below gives the data obtained on June 14th, 1912, on a test plot of average size used.

TABLE II

* PER CENT OF MOISTURE OVER ALL PLATS.

Depth	Core I	Core II	Core III	Core IV	Core V	Core VI	Core VII	Aver.
	%	%	%	%	%	%	%	%
1st Ft.	25.1	20.3	24.5	25.1	26.4	23.4	22.2	23.8
2nd Ft.	30.1	29.8	30.9	30.5	30.0	30.3	29.9	30.2
3rd Ft.	27.1	27.1	28.5	27.0	27.0	27.2	24.8	27.1

*Per cent of moisture always reported on the oven dry basis.

A study of this table reveals the fact that six or more samples of the first foot, five or more of the second and four or more of the third or fourth foot when averaged together give, within one per cent error, the amount of moisture in the soil at the respective depth. Upon this basis of calculation all future moisture data will be reported.

Experimental work upon a shade device for Plot IV, Fig. I, Part II, revealed the fact that a window screen tightly stretched over a frame and covered with a thin grade of black cheese cloth, would per mit rain to pass through without much hinderance but shut out the direct rays of the sun, thus providing the desired screen effect.

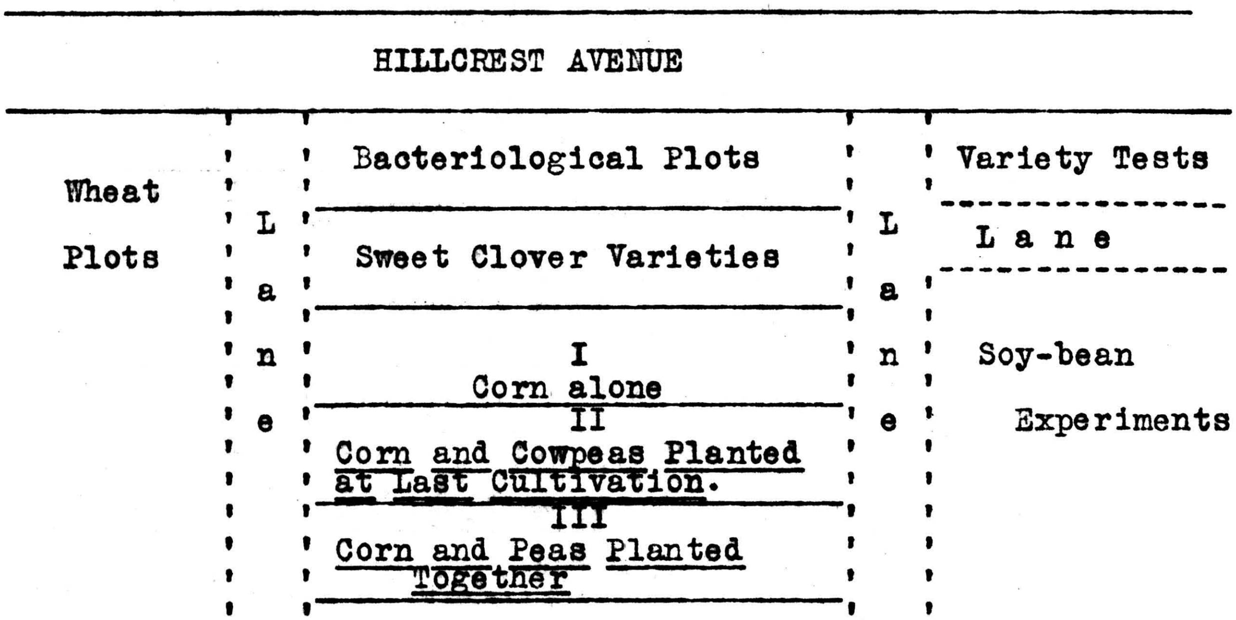
EXPERIMENTAL DATA

PART I

EFFECT UPON SOIL WHERE COWPEAS ARE GROWN AS A COMPANION CROP WITH CORN

Fig. I.

Showing location and arrangement of plots in Part I.



In the work with the inter-relationship of cowpeas and corn, it was found that at last cultivation the NO_3 content for the first three feet had greatly increased over what it was at the beginning of the experiment on June 20th, 1912. (Compare Tables IA and IB)

TABLE IA.

PARTS PER MILLION OF NO_3 PER GRAM OF DRY SOIL

June 20th, 1912. Beginning of Experiment

Treatment	1st Ft.	2nd Ft.	3rd Ft.
All plots	9.11	5.59	5.25

TABLE IB

PARTS PER MILLION OF NO_3 PER GRAM OF DRY SOIL

July 11, 1912 — At Last Cultivation

Treatment	1st Ft.	2nd Ft.	3rd Ft.
Corn Alone	12.2	16.6	7.85
Corn with Cowpeas At Last Cultivation	12.7	18.0	9.34
Corn with Cowpeas Planted Together	15.3	13.2	9.80

From these tables it is evident that nitrification has increased in all plots quite uniformly and, although there is a slight variation, we can say it is well within the limit of experimental error. The increased amount of NO_3 in the soil on July 11, 1912, must be solely because of cultivation and increased bacterial activity due to seasonal stimulus. This conclusion is upheld by the findings of F. H. King with regard to nitrates under corn as previously sighted. (See, Work of Other Investigators, under Historical Data, page 3)

TABLE II

PARTS PER MILLION OF NO_3 PER GRAM OF DRY SOIL

August 2, 1912 — At Tasseling

Treatment	1st Ft.	2nd Ft.	3rd Ft.	4th Ft.
Corn Alone	11.08	9.87	10.9	9.75
Corn with Cowpeas At Last Cultivation	11.72	15.31	26.2	9.60
Corn with Cowpeas Planted Together	8.26	13.11	9.6	6.38

Here we see a complicatinn of data which is somewhat difficult to explain. However, the plot to corn and

cowpeas at last cultivation, in pounds per acre top three feet of soil, has most nitrates; corn sown alone ranks next and corn and cowpeas planted together last. By comparing data of Table II with nitrate analysis for June 20th, considering of course only the first three feet of soil, it is seen that under all treatments there is more NO_3 in the soil in all plots at this time than was the case in the spring. Comparing what was present in the soil at last cultivation (Table IB) with the amount present to date, it is seen that there are less nitrates present on all plots. In that the nitric nitrogen content of the fourth foot is seemingly constant, it may be therefore concluded that the plots are exhausting the available nitrogen supply at this period of heavy growth. The peas had just begun to make growth and were not supplying nitrogen for themselves as yet as the amount left in the soil reveals.

TABLE III

PARTS PER MILLION OF NO_3 PER GRAM OF DRY SOIL

November 12, 1912 At Harvest

Treatment	1st Ft.	2nd Ft.	3rd Ft.	4th Ft.
Corn Alone	9.54	6.09	6.86	4.38
Corn and Cowpeas at Last Cultivation	10.45	7.50	4.88	3.61
Corn and Cowpeas Planted Together	8.91	8.81	5.999	4.21

Comparing the different treatments one with the other at harvest time, it is found that practically the same amount of nitrogen is left in the soil in every case. However, on November 12th, there are less nitrates present than at tasseling time or at last cultivation. At some time between August 2d and harvest of crop the removal of nitrates in the soil may have exceeded the production of same by bacteria. Table III then probably represents a point where the production is again on the increase over the removal by vegetation and leaching. The periods of nitrate study were too greatly separated by time intervals to plot a curve which could be compared with the observations of seasonal change of nitrate content of soil under corn shown by King (See Historical Data). Yet, for the most part it will be seen from the above comparisons that, for the plot planted to corn alone at least, there is a striking agreement with previous findings.

Figuring that the first foot of this soil under consideration over an acre weighs 3,000,000, the second foot 3,500,000, and the third foot 4,000,000 pounds and that there is no appreciable withdrawel of nitric nitrogen from below the third foot on the soils studied, the following table is presented for consideration.

TABLE IV

POUNDS OF NITROGEN (NITRIC) IN

TOP ACRE THREE FEET OF SOIL

Date	Treatment	Pounds of Available Nitrogen
June 20/12	Over all plots	13.46
Nov. 12/12	Corn alone	17.46
Nov. 12/12	Corn with cowpeas at last cultivation	17.34
Nov. 12/12	Corn with cowpeas planted together	18.35

Table IV reveals the fact that the cowpeas in the corn did not use any more of the available nitrogen than did the corn alone. In fact, even more nitrogen seemed to be left in the soil where peas were planted with the corn at planting time than under any other treatment. In order to check this finding, nitrate determinations will be made again in the spring (1913) on each plot to determine which treatment offers most available nitrogen to the crop following.

Now by turning to a consideration of the water content of the same plots and comparing with samples taken in the same way at the various periods, the following tables are produced.

TABLE V

PER CENT OF WATER IN SOIL

June 20, 1912 At Beginning of Experiment

Treatment	1st Ft.	2nd Ft.	3rd Ft.
Over all Plots	26.2%	29.3%	26.5%

TABLE VI

PER CENT OF WATER IN SOIL

July 11th, 1912 At Last Cultivation

Treatment	1st Ft.	2nd Ft.	3rd Ft.
Corn Alone	19.7%	23.8%	17.9%
Corn and Cowpeas at last Cultivation	19.8%	28.7%	20.8%
Corn and Cowpeas planted together	17.5%	20.5%	16.9%

Here it will be seen that the cowpeas with corn at planting time have used considerably more water than the plot to corn alone up to July 11th, 1912, but the water has been removed from all depths considered so that the general relation in the respective depths under the corn and peas remains

much as it was at the beginning of the experiment. The spring was very dry this year and this together with the fact that the cowpeas were drawing heavily on the soil moisture at this time accounts for the results in the above table.

Cowpeas were planted in plot Number II at this time and the continued drought as shown in Table IX, page 23, resulted in a slight set back to the peas planted at last cultivation. They did survive however, and made almost a perfect stand. The peas on Plot III seemed to have made normal growth in spite of the dry weather, for on August 1, 1912, they almost completely covered the space between the rows. Absolutely no stunting effect of the corn was observed under any treatment. Nevertheless, the corn planted alone seemed to be maturing somewhat earlier. Moisture in the soil at tasseling time is tabulated in Table VII.

TABLE VII

PER CENT OF MOISTURE IN THE SOIL

August 1st, 1912			At Tasseling	
Treatment	1st Ft.	2nd Ft.	3rd Ft.	4th Ft.
Corn Alone (I)	11.6%	14.8%	11.9%	15.6%
Corn Planted with Cowpeas at last Cul.	12.7%	12.8%	18.2%	17.2%
Corn Planted with Cowpeas at Planting	11.0%	17.5%	17.4%	19.5%

Thus on the whole, to date, when only the first three feet of soil in each plot is considered, it is seen that the plot to corn alone conserved least moisture, corn with cowpeas at last cultivation next, and corn and cowpeas planted together most. It is also evident that the plot to peas at last cultivation is using most of its water supply from the second foot

of soil wherein the young cowpea roots at this time are just getting a foot hold. Nevertheless, when we consider the amount of water used down to four feet it would seem that cowpeas are, by reason of their shading effect or otherwise, leaving more water in the soil. With the amount of water left in the soil at this time by corn planted alone taken as 100, the ration stands for the other plots as follows:

Corn and cowpeas planted at last cultivation....115
" " " " together...............131

This data is further evidenced by the fact that the corn on the plots to cowpeas showed no tendency to fire, while where corn was planted alone the lower leaves, at least three, had already turned yellow and dry. From what has been previously said, we could not attribute this phenomena to the difference in nitrate content of the soil under each treatment, so it must be due to moisture differences or to other variable factors.

TABLE VIII

PER CENT OF MOISTURE IN SOIL

November 12th, 1912. At Harvest

Treatment	1st Ft.	2nd Ft.	3rd Ft.	4th Ft.
Corn Alone	25.87%	26.70%	19.70%	20.40%
Corn with Cowpeas Planted at Last Cultivation	26.30%	23.20%	18.10%	17.40%
Corn with Cowpeas Planted Together	23.40%	26.20%	19.40%	17.30%

Again, considering only the first three feet of soil, we can see by a comparison of the above table with that of Table V, page 20, taken at the planting time, that, through the season as a whole corn alone is only slightly less exhaustive

of soil moisture than where corn and cowpeas are planted either together at planting time, or corn with cowpeas at the last cultivation.

To represent even more vividly the fluctuation of soil moisture content throughout the season under the various treatments we present the following tables.

TABLE IX

*TONS OF WATER IN TOP THREE FEET OF SOIL DURING GROWING SEASON

DATE	TREATMENT			
	Corn Alone	Corn-Cowpeas Last Cultiv.	Corn-Cowpeas Together	
	Tons Water in Soil	Tons Water in Soil	Tons Water in Soil	Tons Water Added by Rainfall
June 20, '12	1453	1453	1453	176.1
to				
July 11, '12	1048	1058	1165	74.1
to				
August 2, '12	661	773	819	1169.7
to				
November 12, '12	1248	1162	1147	
Water Used by Crop Plus Surface Evaporation	1607	1693	1708	

* From U. S. Weather Bureau observations.

TABLE X

*TONS OF WATER USED UNDER VARIOUS TREATMENTS DURING SEASON

DATE	TREATMENT		
	Corn Alone	Corn-Cowpeas Last Cultiv.	Corn-Cowpeas Together
	Tons Water Used	Tons Water Used	Tons Water Used
June 20th to July 11th, 1912	580	571	464
July 11th to Aug. 2nd, 1912	461	360	420
Aug. 2nd to Nov. 12th, 1912	582	780	841

*Calculated from data of Table IX and including total amount of water used by the crop and lost through surface evaporation.

A study of Table IX reveals the fact that the entire season corn, considered as a whole, with peas planted as a companion crop are, as was stated before, slightly more exhaustive of soil moisture than corn alone. Table X, however, shows that the effect of the companion crop must be to prevent evaporation of water from the soil by the close mat of vegetative growth it produced, because, regardless of the fact that there was more dry matter produced on the land cropped to corn and cowpeas as compared to corn alone, up to August 2d, less water was used under the former treatment. This resulted in more water being left available to the corn plant during the mid-summer semi-drought period when the crop was in greatest need of it. (See, water used August 2d to November 12th, 1912, under respective treatments.)

TABLE XI

YIELD OF CORN IN BUSHELS PER ACRE UNDER VARIOUS TREATMENTS.

	TREATMENT		
	Corn Alone	Corn and Cowpeas at Last Cultivation	Corn and Cowpeas Together
Number of Bushels	48.2	52.1	45.8

From Table XI it is seen that the yield of corn when corrected to stand is only slightly different under the treatments used. A check was not run on soil variation in this field, but aside from such probable source of error, it would be safe to say that this year, on Station plots, a companion crop of cowpeas in corn did not have a consistent effect of reducing the quantity and quality of the corn yield. Furthermore, a study of the nitrate and moisture content of the plots made at periods throughout the season, as before

described, show that any bad effect the cowpea may have in reducing corn yields must find its origin in some other phenomena than a removal of either moisture or nitrates.

PART II

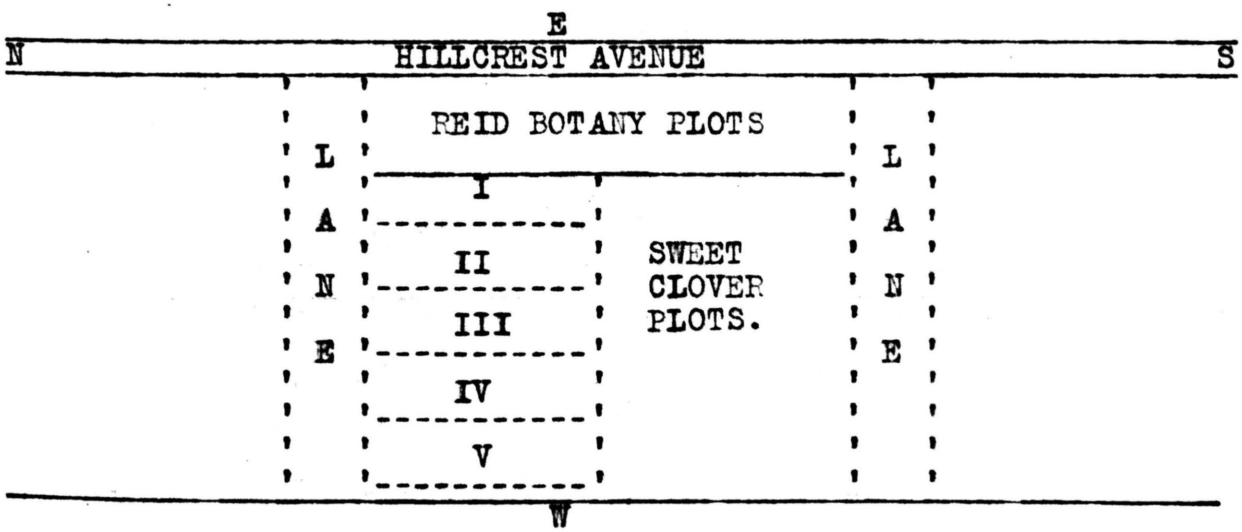
TO DETERMINE THE CAUSE OF SOIL FRIABILITY UNDER COWPEAS

PLAN OF PLOTS

PLOT I D	PLOT II E	PLOT III F	PLOT IV G	PLOT V H
Unplowed, no crop, kept clean	Unplowed Cowpeas	Plowed Cowpeas	Plowed, no Cowpeas, Shade	Plowed, no Cowpeas, kept Clean

LOCATION OF PLOTS

Fig. I.



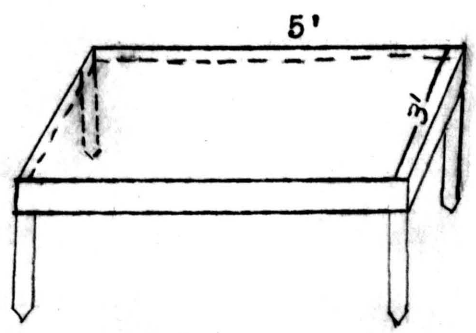
The plots were laid out on May 31st, 1912. Plots III, IV, and V were carefully spaded at this time. Plots I and II were scraped with a hoe to remove trash and weeds, but no further treatment was given. A week later, June 11th, 1912, plots II and III were drilled to Black cowpeas.

An ordinary wheat drill was used, putting the peas in eight inches apart at the rate of one and one-half bushels per acre. The drill was operated by pulling it at the end of a long rope so that the horses were not permitted to walk over the plots. On Saturday, June 9th, 1912, after planting, all plots were gently scraped with a hoe to give them an equal start.

The main point at issue was a study of the soil compactness and nitrate content of plots to the various treatments at the beginning and end of the growing season. An artificial shade was erected on Plot IV at a time when the cowpeas on Plots II and III were matting over the soil. The shade device was a frame made of 2"-4" lumber supported on legs made of the same material (See Fig. II). Over this, some galvanized screen was tightly stretched to serve as a support for a thin, black piece of cheese cloth, which was found efficient in shading the soil from the direct rays of the sun and only very slightly impeding the beating of the rain.

Fig. II

Showing the Construction of the Shade Device.



Compactness tests were made by counting the number of times a weighted ram had to be dropped from a specified height in order that a conical pin be driven a given distance in the soil. (See Fig. III.) Fifteen determinations of this character were made in each plot and the average of these taken as representative.

The first observations were made on June 19th, 1912, The soil was very friable at this time. Several showers had fallen since planting time and consequently the plots were in excellent tilth.

A definite system was followed in locating places for compactness determinations, just as described under methods of taking samples for analysis. This eliminated any chance of duplicating a measurement of a given spot, at later times. Tests were made at least eighteen inches apart to further avoid any influence due to overlapping. In manipulating the mechanical device (See Fig. III), auger plate "E" was placed squarely on the ground and pin "D" was set in the aperature. Sheat "F" was then slipped over "D" and ram "G" pressed on pin until it was driven into the soil sufficiently deep so that mark "B" on ram was even with the surface of sheath "H". The ram was raised each time to "A" and then dropped freely by its own weight (7445 grams). This operation was repeated, recording each drop, until point "C" on ram was even with upper surface of sheath at "H". Thus the pin was driven a distance of four and one-half inches in the ground each time a test was made. The number of drops necessary to produce this effect was the measure of the relative compactness of soil in respective plots.

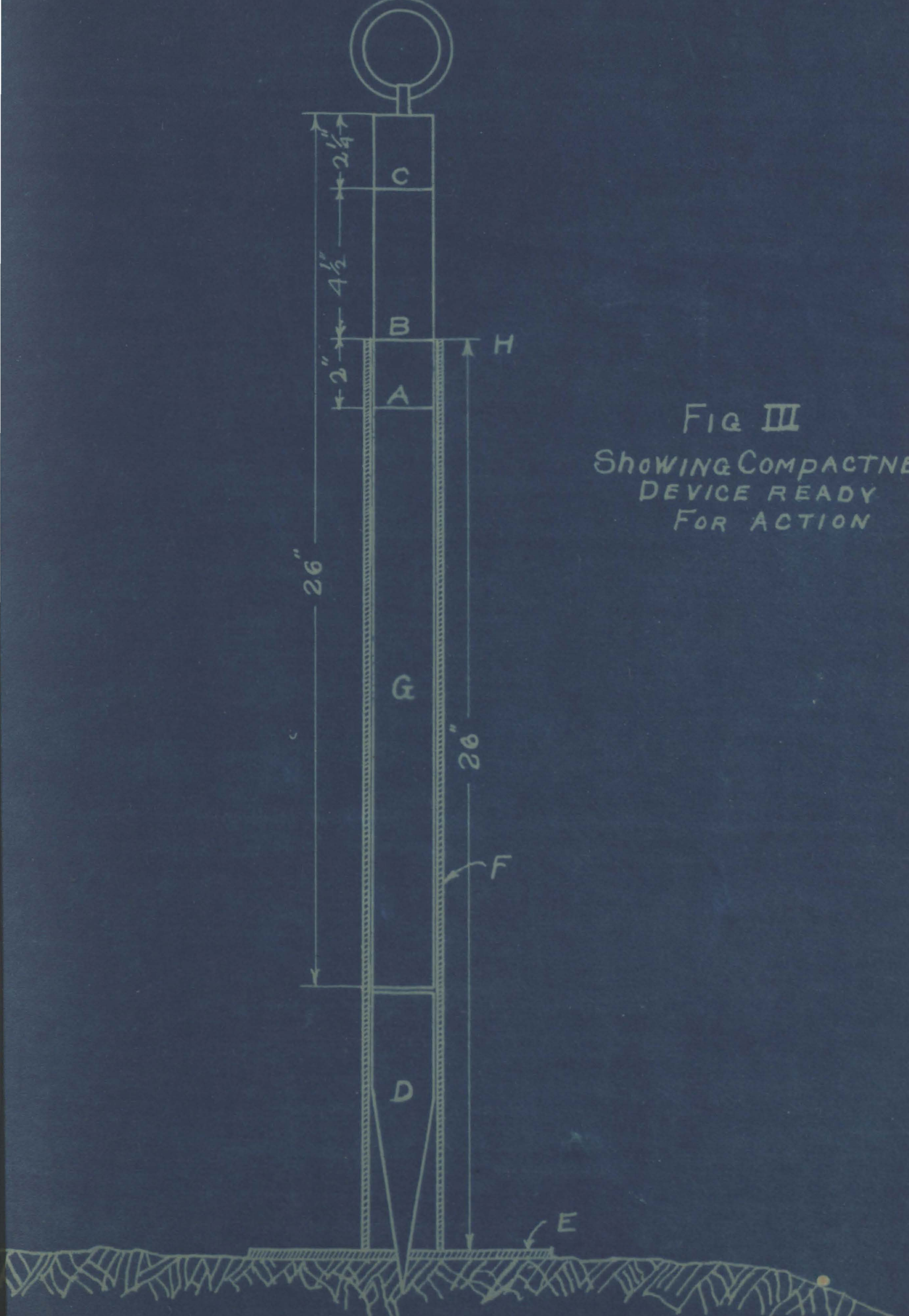


FIG III
SHOWING COMPACTNESS
DEVICE READY
FOR ACTION

TABLE I

RELATIVE COMPACTNESS OF SOIL AT THE BEGINNING OF THE EXPERIMENT

June 19, 1912.

Trial	Unplowed Clean	Unplowed Cowpeas	Plowed Cowpeas	Plowed Artificial Shade	Plowed Clean
1	17	8	3	2	3
2	22	7	6	3	3
3	18	9	3	2	4
4	12	8	3	4	3
5	13	14	3	4	3
6	12	12	3	3	2
7	12	13	4	3	4
8	10	11	6	3	2
9	13	9	3	4	2
10	11	13	4	3	3
11	10	15	3	4	2
12	12	10	3	3	3
13	16	9	6	5	1
14	11	7	3	5	2
15	12	7	5	4	2
Average	13.3	10.5	3.6	3.4	3.6

The fluctuation between readings as seen in Table I cannot be accounted for other than that it represents the normal variation of soil friability over large areas. Increasing the number of readings did not materially alter the average secured. So the authentic average compactness of the plowed and unplowed plots stand in the ratio of one to four at this time. Moisture determinations were made on the following day with no rain intervening and were as follows:

TABLE IIA

PER CENT OF MOISTURE IN SOIL AT TIME COMPACTNESS WAS MEASURED

	1st Ft.	2nd Ft.	3rd Ft.
Over All Plots	26.2%	26.5%	29.3%

On June 24th, 1912, all plots were lightly cultivated with a hoe in order to remove the weeds which had begun to

appear. At this time the peas were doing very well and stood about four inches high. Samples for nitrate analysis showed the soil to contain at the beginning of the experiment the amounts tabulated in Table IIB

TABLE IIB

PARTS PER MILLION OF NO_3 IN THE SOIL OF ALL PLOTS

JUNE 24th, 1912.

No. of Core	1st Ft.	2nd Ft.	3rd Ft.
13 C	6.14	3.21	5.11
14 C	6.93	6.13	2.37
15 C	6.46	3.51	3.27
16 C	7.26	3.20	3.66
17 C	12.25	3.76	3.05
18 C	3.93	3.25	4.78
19 C	9.15	4.05	2.09
20 C	5.86	3.69	4.35
21 C	7.43	3.37	2.26
22 C	9.30	3.76	2.58
Average	7.46	3.79	3.35
Composite	8.06	3.81	3.56
Final	7.76	3.80	3.45

As might naturally be expected there is most nitric nitrogen in the surface foot with a gradual decrease downward. The analysis of individual cores also substantiates the conclusion derived from preliminary tests, namely, that a thoroughly mixed composite is an authentic measure of the actual nitric nitrogen in the soil.

About a month after planting to cowpeas the photographs labeled Figures III and IV respectively were taken. They show the general plan of the experiment and the thriftiness of the peas at the early date of July 17th, 1912.


PLAT E
NOT PLOWED COW PEAS
PLAT D
NOT PLOWED CLEAN


PLOWED KEPT CLEAN
PLOWED ARTIFICIAL SHADE

Picture on preceding page, Fig. III, looking from right to left, shows unplowed plot kept clean, unplowed plot to peas and plowed plot to peas, respectively.

Picture on preceding page, Fig. IV, looking from right to left shows plowed plot kept clean and artificially shaded and plowed plot kept clean and not shaded.

Observations taken August 21st, 1912, showed the cowpeas on the plowed plot to be only a little heavier than those on the adjacent unplowed plot. Blossoms had already begun to appear, and runners measured from one to two feet in length. Some crab grass had sprung up but only few other weeds were noticed. The shades were in very good condition all through to date and the soil beneath seemed normal save that it was covered with a growth of green algae. This was also true of the soil under peas but to a less marked extent.

Great care was given to details such as freeing from weeds, renewing the covering of the shade device, etc., throughout the season. Just before frost, compactness tests were again made on all plots after removing the cowpea vines. The vines were cut with a scythe and the strip walked on by the operator was eliminated from the test areas. Data secured for October 15th, 1912, is represented in Table III for compactness and Table IV for moisture left in the soil.

TABLE III

COMPACTNESS OF PLOTS AS MEASURED

ON OCTOBER 15TH, 1912.

TREATMENT				
D Unplowed Clean	E Unplowed Cowpeas	F Plowed Cowpeas	G Plowed Shade	H Plowed Clean
20	18	4	6	5
19	12	5	6	6
17	19	3	5	7
18	11	3	6	6
20	14	5	6	6
24	17	3	6	5
20	14	4	6	5
20	15	3	5	5
19	17	3	5	7
22	17	5	5	6
16	15	4	7	8
16	15	5	6	5
23	15	3	6	5
19	13	4	7	6
19	18	5	7	5
20	16	3	6	7
21	16	4	6	7
18	15	5	6	8
19	11	5	5	6
AVERAGE				
19.4	15.4	4.0	5.9	6.0

The relative compactness as shown in Table III was duplicated, using a modification of the method which originated with E. Wollney, namely, the apparent specific gravity of the soil in each plot was determined. A metallic brass tube 7.8 centimeters in diameter was driven to a depth of 23.2 centimeters in the soil. The tube was then dug out and the contact below broken. Duplicate cores of soil from each plot were thus secured, taken to the laboratory, dried and weighed. The dry weight of the soil divided by the volume of the cylinder (1,465 cc.), is the apparent specific gravity and should be an index to friability. See data in Table IV below. Wollney compared porosity of cores similarly taken by measuring the relative amounts of water needed to fill the pore space, but the principle is the same in both cases.

TABLE IV

APPARENT SPECIFIC GRAVITY OF SOIL

UNDER VARIOUS TREATMENTS

Plot	Core #1 Wt. of soil	Core #2 Wt. of soil	Av. Wt. of Core	Apparent Specif. Grav.
Unplowed Clean	1957	1936	1946	1.33
Unplowed Cowpeas	1865	1884	1884	1.26
Plowed Cowpeas	1720	1739	1729	1.17
Plowed Shade	1740	1752	1746	1.18
Plowed Clean	1635	1742	1756	1.19

Checking the results found by the Wollney method with those shown in Table III the same ratio is found to hold in every case. This gives strong assurance that the use of the compactness device, by means of which the results of Table III were obtained, is an accurate method of measuring soil friability and, in that it is easily and rapidly made, a very desirable one.

TABLE V

PER CENT OF MOISTURE IN PLOTS

On October 15th, 1912

Treatment	1st Ft.	2nd Ft.	3rd Ft.	4th Ft.
Unplowed Clean	17.9%	29.4%	24.2%	22.5%
Unplowed Cowpeas	25.2%	28.1%	17.9%	13.6%
Plowed Cowpeas	21.7%	26.1%	16.5%	18.8%
Plowed Shade	19.2%	29.0%	25.9%	26.9%
Plowed Clean	11.2%	28.3%	27.9%	25.3%

A study of the moisture in the soil at the close of the experiment as shown by the above table, reveals, as would be expected, that the plots to cowpeas leave less moisture in the soil than do the plots uncropped and kept clean. Strange to say, however, this use of water is from below the second foot. Under cowpeas the surface foot as well as the second foot below contains as much water as is found in the uncropped plots for the same depth. It would seem, then, that the cowpea plant is a comparatively deep feeder and the shade of its leaves serves as a blanket to prevent evaporation. This conclusion is again borne out by a study of the moisture content of the soil under the artificial shade.

Now, since only the moisture in the first foot could possibly affect the degree of compactness, or looseness at any one time, a direct comparison of the data shown (Table III) with that secured at the beginning of the experiment (Table I), can be made, for, on October 15th, the moisture in the first foot of every plot, save five(V), was within the limit of variation where by preliminary tests effects due to water can be appreciated by our means of measurement. Therefore, disregarding water as a factor, it is apparent that cowpeas possibly have a tendency to maintain the friability of either plowed or unplowed land. The data, also, shows that the plowed plot artificially shaded was almost as compact as the adjacent plowed plot not shaded. This may be interpreted either, that the shade was inefficient or that the loosening of the soil is due to some other factor. From the conclusions of E. Wollney on this point and experimental data to be presented below, it seems probable that this

preservation of soil structure is due to increased bacterial activity resulting in the formation of humus. This was actually demonstrated by Wöllney.

The nitrate analysis of the plots at the close of the experiment together with bacterial count, nitrifying efficiency and ammonifying efficiency are given in Table VI below.

TABLE VI

NITRATE ANALYSIS - BACTERIAL COUNT - NITRIFYING AND AMMONIFYING EFFICIENCY OF SOIL ON OCTOBER 15th, 1912.

PARTS PER MILLION OF NO_3 IN THE SOIL

DEPTH	TREATMENT				
	Unplowed Clean	Unplowed Cowpeas	Plowed Cowpeas	Plowed Shaded	Plowed Clean
1st Ft.	16.93	9.76	17.833	5.06	40.91
2nd Ft.	5.88	4.42	7.08	11.55	10.30
3rd Ft.	6.31	9.18	4.08	18.42	10.20
4th Ft.	4.42	3.73	4.48	4.72	7.69
BACTERIA PER GRAM OF SOIL IN PLOTS					
1st Ft.	8,481,000	29,985,000	17,929,000	9,344,400	7,720,000
AMMONIFYING EFFICIENCY OF SOILS					
1st Ft.	197.19	166.20	177.50	163.80	167.20
NITRIFYING EFFICIENCY OF SOILS					
1st Ft.	73.50	65.40	99.25	124.25	- 5.50

The amounts of nitric nitrogen in the soil, as shown by data of Table VI, reveals the fact that at this season of the year all plots are going into winter with more available nitrogen in the soil than they contained in the early spring as shown in Table IIB. It is also seen that cultivated plots either cropped or uncropped are richer in nitric nitrogen at the end of the season than are the plots not plowed. The low nitrate content of the first foot of the plot artificially

shaded cannot be explained. Lastly, the results check with previous investigations in the fact that under even a legume treatment there exist less nitrates in the soil in the fall than under adjacent similarly treated fallowed plots. (See historical data.)

Although we have a wide range in the total bacterial count under the respective treatments, the only certain conclusion we can draw is that under cowpeas we have larger numbers of bacteria than where no crop is on the land. The ammonifying and nitrifying efficiency of these soils as affected by the summer's treatment seemed to have been considerably influenced by the varied conditions noted, but no correlations can be drawn. Thus, briefly summing up, it might be said that the maintenance of soil structure from spring to fall, by the growth of cowpeas on the land, is due partially to the shading effect of the foliage which even as the artificial shade resists the compacting effect of beating rains and baking sun. Besides this, there seems to be a marked correlation between the friability of the soil under peas and the bacterial flora present. Where present in largest numbers, they possibly bring about a greater production of active humus and so maintain the looseness of the soil.

PART III

THE EFFECT OF CONTINUOUS CROPPING OF WHEAT AND COWPEAS ON SOIL PRODUCTIVENESS

In the problem concerning the decreasing of wheat yields on a plot subjected to a cropping system of continuous wheat and cowpeas for a series of twelve years as compared to the yields of the same crops on adjacent plot with a rotation of corn, oats, wheat and a legume, work was commenced with the assumption that the phenomena was possibly due to a chemical difference in the plots. As stated under the discussion of the plan of this experiment, both plots were in wheat in the spring of 1912 when this study began. Unfortunately, the data on the wheat yields in years previous has been lost, but it may be said that, on the plot where cowpeas were put in immediately after the grain was cut and allowed to grow until time for wheat again to be sown in the fall, the yield on the continuously cropped plot was at first greater but in late years much less than the average of check plots for the respective years. Table I shows the yield in bushels per acre during the year 1912.

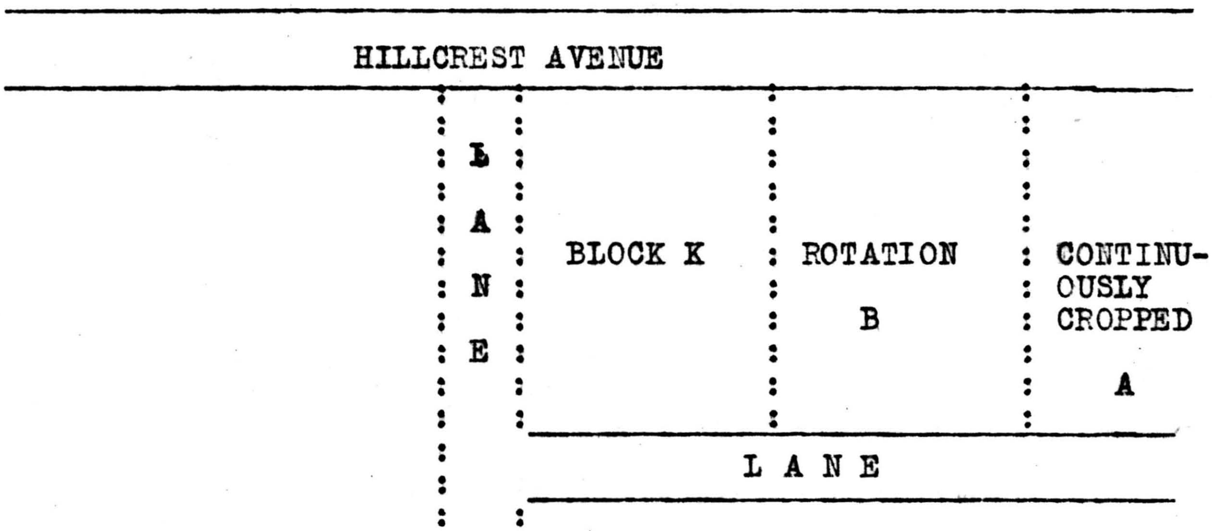
PART I

YIELD OF WHEAT PER BUSHEL ON PLOTS ROTATED AND CONTINUOUSLY CROPPED FOR THE YEAR 1911-12

Treatment	Continuously Cropped	Wheat in Rotation
Bushels per Acre	4.45	23.75

Fig. I

SHOWING LOCATION OF PLOTS ON STATION FARM



The results given in Table I seemed to show indications of soil sickness in the case of the continuously cropped plot. In that previous investigation has revealed that such conditions only exist in sour soils deficient in available plant food, an analysis was made to determine the lime requirement of both plots. Total organic matter and the closely correlated nitrogen supply, together with active humus and available phosphorus were the analyses deemed most liable to explain the phenomena of the recent low yield of the continuously cropped plot. Bacterial activity and the influence of bacteria on the available nitrogen supply, together with moisture fluctuations were studied by a series of analyses made at the following times:

(a) In early spring
(b) At wheat harvest
(c) In the late fall

Results are tabulated and discussed below.

TABLE II

LIME REQUIREMENTS OF PLOTS

BY THE HOPKINS TITRATION METHOD

Treatment	Pounds of Calcium Carbonate per Acre Required		
	1st Ft.	2nd Ft.	3rd Ft.
Wheat in Rotation	1,550	4,350	1,350
Wheat Continuous	930	4.537	1,425

From the above, it is seen that in the first three feet of soil, in the plots considered, the continuously cropped plot requires about 325 pounds of lime less than does the plot which has been in a good rotation. This is evidence beyond doubt that a difference of acidity cannot account for the great difference in yield as shown in Table I, page 39.

The plant food situation was then considered with special emphasis on the immediately available plant food constituents. Nitrate determinations were made just as the wheat began to appear with results as given below, together with bacterial count, nitrifying and ammonifying efficiencies.

TABLE III

BACTERIAL STUDIES AND PARTS PER MILLION OF

NITRATES IN THE SOIL

June 8th, 1912 At Beginning of Experiment

Treatment	Parts per Million of NO_3 in Soil		
	1st Ft.	2nd Ft.	3rd Ft.
Plot Continuously Cropped	6.56	4.22	3.14
Rotation Plot - Corn Oats, Wheat & Clover	5.06	3.85	3.24

BACTERIAL STUDIES

TREATMENT	FIRST FOOT OF SOIL		
	No. in Gram	Ammonifying Efficiency	Nitrifying Efficiency
Plot Continuously Cropped	7,642,900	348.89 ppm	74.60 ppm
Plot Rotated - Corn Oats, Wheat & Legume	7,290,000	264.61 ppm	148.11 ppm

When the wheat was harvested on both plots and just before the ground was plowed for cowpeas on the continuously cropped plot, samples were again taken and the nitrate analysis is given in Table IV below.

TABLE IV

PARTS PER MILLION OF NO_3 IN ONE GRAM OF DRY SOIL

July 16

TREATMENT	1st Ft.	2nd Ft.	3rd Ft.
Plot Continuously Cropped	4.59	7.08	3.17
Plot Rotated - Corn Oats, Wheat & Legume	6.00	5.91	3.39

In pounds per acre of nitric nitrogen, this table shows that the amount present in both plots to a depth of three feet is almost the same.

Comparing Tables III and IV, it is seen that in spite of the variation in nitrifying and ammonifying efficiencies as indicated by laboratory experiments, both plots contain the same amount of nitrates at the time of harvest. Although this may in part be due to the fact that the crop removal at the close of the period overshadowed the actual bacterial activity at this time, but there is no way of determining the correctness of this hypothesis.

The similarity that exists between the amount of nitric nitrogen in the third foot (see Table IV), together with the fact that less than four inches of rainfall fell during the lapse of observations (see Table V) would assure beyond doubt that nothing would have been gained at this time by studying the amounts of NO_3 at great depths.

TABLE V

INCHES OF RAINFALL AND DISTRIBUTION BETWEEN

JUNE 8th AND JULY 17th

Date June	9	10	11	12	13	14	15	16	17	18	19	20	21
Inches Rain	T#	0	0	0	.44	.37	.23	.42	.89	.14	0	0	0
Date June	22	23	24	25	26	27	28	29	30	July		1	2
Inches Rain	0	0	0	0	0	0	0	.08	T#			.20	0
Date July	3	4	5	6	7	8	9	10	11	12	13	14	15
Inches Rain	1.2	0	0	T#	0	0	0	T#	0	T#	0	0	0
Date July	16	17											
Inches Rain	.15	0											
Total Inches Rain	3.92												

#Trace

The cowpeas were permitted to grow as long as possible before harvesting and they were then cut, raked off to cure, and the ground again plowed for wheat. On November 12th, 1912, the wheat had grown to about three inches in height, and, as frost was expected at any time, the last set of samples for moisture and nitrate analysis were then taken.

TABLE VI

BACTERIAL STUDIES AND

PARTS PER MILLION OF NO_3 PER GRAM OF SOIL

ON NOVEMBER 12th, 1912

TREATMENT	1st Ft.	2nd Ft.	3rd Ft.	4th Ft.
Plot Continuously Cropped	8.05	7.45	5.26	4.49
Plot Rotated - corn, Oats, Wheat & Legume	9.21	7.55	7.35	7.34

TREATMENT	FIRST FOOT OF SOIL		
	No. in Gram Bacteria	Ammonifying Efficiency	Nitrifying Efficiency
Plot Continuously Cropped	98,990,000	218.19 ppm	43.750 ppm
Plot Rotated - Corn, Oats, Wheat & Legume	4,613,000	148.22 ppm	1.425 ppm

Table VI, again shows that in this treatment as in others described there exists an accumulation of nitrates in the soil as we approach the winter months. Cowpea plants following wheat, although probably not able to secure their complete nitrogen from the air, seem to decrease but little the winter store of nitric nitrogen. It is probable that the removal by the catch crop has a more favorable effect upon the production of nitrates than would be the case if the crop were not on the land and hence a balance in the soil is maintained. Then, too, must be considered the great increase in bacterial count under the plot seeded to peas. Thus the conclusion is necessarily drawn that their activity at this time was favorable to the making of plant food, other than nitrogen, available for the preceding crop. However, quoting from Mr. P. L. Gainey, to whom we are indebted for much assistance in securing this data, we can say "That all things considered, the fertility of the rotated plot as it

exceeds the one continuously cropped is not entirely due to bacterial activity."

Turning now to a study of water economy under the above treatment, we offer for consideration the data in Table VI.

TABLE VI

PER CENT OF MOISTURE IN SOIL

ON JUNE 8th, 1912

At Beginning of Experiment

TREATMENT	1st Ft.	2nd Ft.	3rd Ft.
Plot Continuously Cropped	10.2%	17.4%	16.3%
Plot Rotated - Corn, Oats, Wheat & Legume	13.0%	12.5%	14.8%

The above data shows that the plot in a rotation contains at the time observed considerably less water in the first three feet of soil than does the continuously cropped. This is probably due to the removal of water by the larger growth and better stand of wheat on the former plot or to a varied moisture content as the plots came out of winter. Considering, now, what the conditions are at harvest time a month and a half later see Table VII below.

TABLE VII

PER CENT OF MOISTURE IN THE SOIL

July 17th, 1912

At Harvest

TREATMENT	1st Ft.	2nd Ft.	3rd Ft.
Plot Continuously Cropped	7.5%	12.0%	13.5%
Plot Rotated - Corn, Oats, Wheat & Legume	11.9%	17.3%	14.4%

It is seen that the amount of moisture remaining in the soil at this time is reversed, being somewhat greater now in the rotated plot which produced the biggest yield of grain. This is accounted for by the fact that on the continuously cropped plot there was a rank growth of weeds which sapped the moisture to an even greater extent than did the good stand of grain.

TABLE VIII

PER CENT OF MOISTURE IN THE SOIL

NOVEMBER 12th, 1912

TREATMENT	1st Ft.	2nd Ft.	3rd Ft.	Late Fall 4th Ft.
Plot Continuously Cropped	22.0%	18.1%	14.2%	15.4%
Plot Rotated - Corn Oats, Wheat & Legume	21.3%	18.7%	18.3%	16.1%

From Table VIII, it is apparent that having a catch crop during this particular season and on this soil after wheat, is no more exhaustive of soil moisture than allowing the land to lie idle, as was the case in the rotation plot.

Finding that, from a bacteriological, acidity, and water supply standpoint, it was impossible to explain the difference in productiveness of these two plots, a comparison of the plant food supply was made. Unfortunately no analysis of the plots at the beginning of the experiment could be secured but the soil was sufficiently uniform to warrant like conditions at the outset. The soil is a silt loam and grades to clay below so that the potash factor is undoubtedly of no great import. Thus an analysis to determine the re-

moval of this element was not deemed necessary and only total loss on ignition (organic matter), humus (active), total nitrogen and available phosphorus (see Table IX below) was studied.

TABLE IX

TOTAL AND AVAILABLE PLANT FOOD IN SOIL

ELEMENT	TREATMENT					
	Continuously Cropped			Rotated - Corn, Oats, Wheat and Clover		
	1st Ft.			1st Ft.		
Loss on Ignition	4.09%			3.99%		
Humus (Active)	3.82%			3.97%		
Total Nitrogen	.113%			.100%		
Available Phosphorus#	1st Ft.	2nd Ft.	3rd Ft	1st Ft	2nd Ft.	3rd Ft.
	.00126%	.00874%	.00193%	.00135%	.00083%	000117%

Here again no positive results were obtained other than that the supply of plant food was not sufficiently different in the plots to conclusively account fot the infertility of the continuously cropped plot. The only other alternative that presented itself was a probable toxic body in the continuously cropped plot that may have accumulated from the excreta of the wheat or cowpea plants or by reason of the soil management practised.

To investigate this proposition, soil from the continuously cropped plot was secured to a depth of one foot. After drying and mixing thoroughly, the soil was digested with toxic free distilled water in the proportion of 6 parts of water to 5 of soil. The preparation of the toxic free water, as well as the general technique of this part of the work, was carried on under the various precautions suggested by the

#N/5 HCl method was employed to determine the available Phosphorus.

United States Bureau of Soils in Bulletins Numbers 22, 23, 28, 36, 47, and 53. The muddy extract was filtered through the ordinary filter paper and then again through a porous Brigg's filter to remove clay and bacteria. Only extract from the poor plot has been used up to the present and the following treatment was given. Glass bottles of two hundred and fifty cubic centimeter capacity were sterilized, covered with black paper, and fitted with parrafined corks. In duplicate sets of three each, the bottles were filled with distilled water (toxic free) plus a full nutrient ration (Tollen's) and soil extract plus full nutrient ration (Tollen's). To one series, we planted sterilized wheat seedlings and to the other cowpeas. Hydrogen peroxide was used as the sterilizing agency and the seeds were treated for one hours.

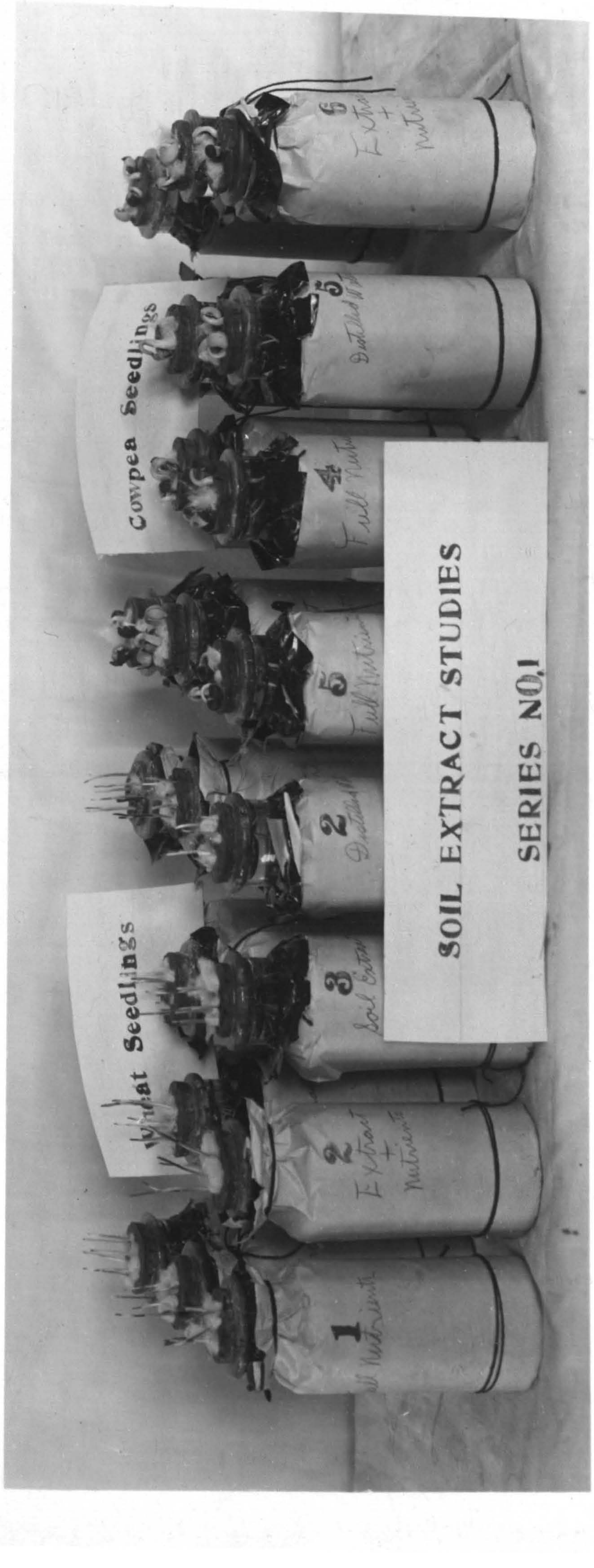
A perfect stand was secured in all of the cultures as may be seen by reference to photograph of plants just as the first observations were commenced. (See page 48 a)

TABLE X

TRANSPIRATION OF WHEAT AND COWPEA SEEDLINGS

WHEAT SEEDLINGS

DATE		TREATMENT	
		Full Nutrient	Extract Nutrient
		Wt. in Grams	Wt. in Grams
January 12, 1912	A	461.4	457.9
	B	460.4	460.0
	C	448.0	462.4
January 18, 1912	A	450.8	451.0
	B	451.6	442.2
	C	438.3	454.1
Water Transpired - Average for 6 Days		10.5	7.6


Wheat Seedlings
Cowpea Seedlings
SOIL EXTRACT STUDIES
SERIES NO 1

COWPEA SEEDLINGS

DATE		TREATMENT	
		Full Nutrient	Extract Nutrient
		Wt. in Grams	Wt. in Grams
January 12, 1912	D	453.7	450.4
	E	447.6	453.2
	F	465.0	462.3
January 18, 1912	D	445.9	442.8
	E	440.0	441.9
	F	456.6	452.7
Water Transpired - Average for 6 Days		7.9	8.5

From the data tabulated above it can be seen that there is very little difference between the checks as to water transpired. Therefore, assuming that the water transpired is an index to growth, it is a direct means of determining any deleterious effect the soil extract may have on the development of wheat, or cowpeas. The series was continued twenty-four days changing solutions in all bottles in the middle of the period in order to keep plant food supply as constant as possible and provide efficient aeration.

In that the variation noted under transpiration measurements might not be proportional to the actual growth of plants, it was arranged to harvest same at the end of the experiment. The green and dry weights are recorded in Table XI below.

TABLE XI

GREEN AND DRY WEIGHTS OF ROOTS AND TOPS OF PLANTS GROWN

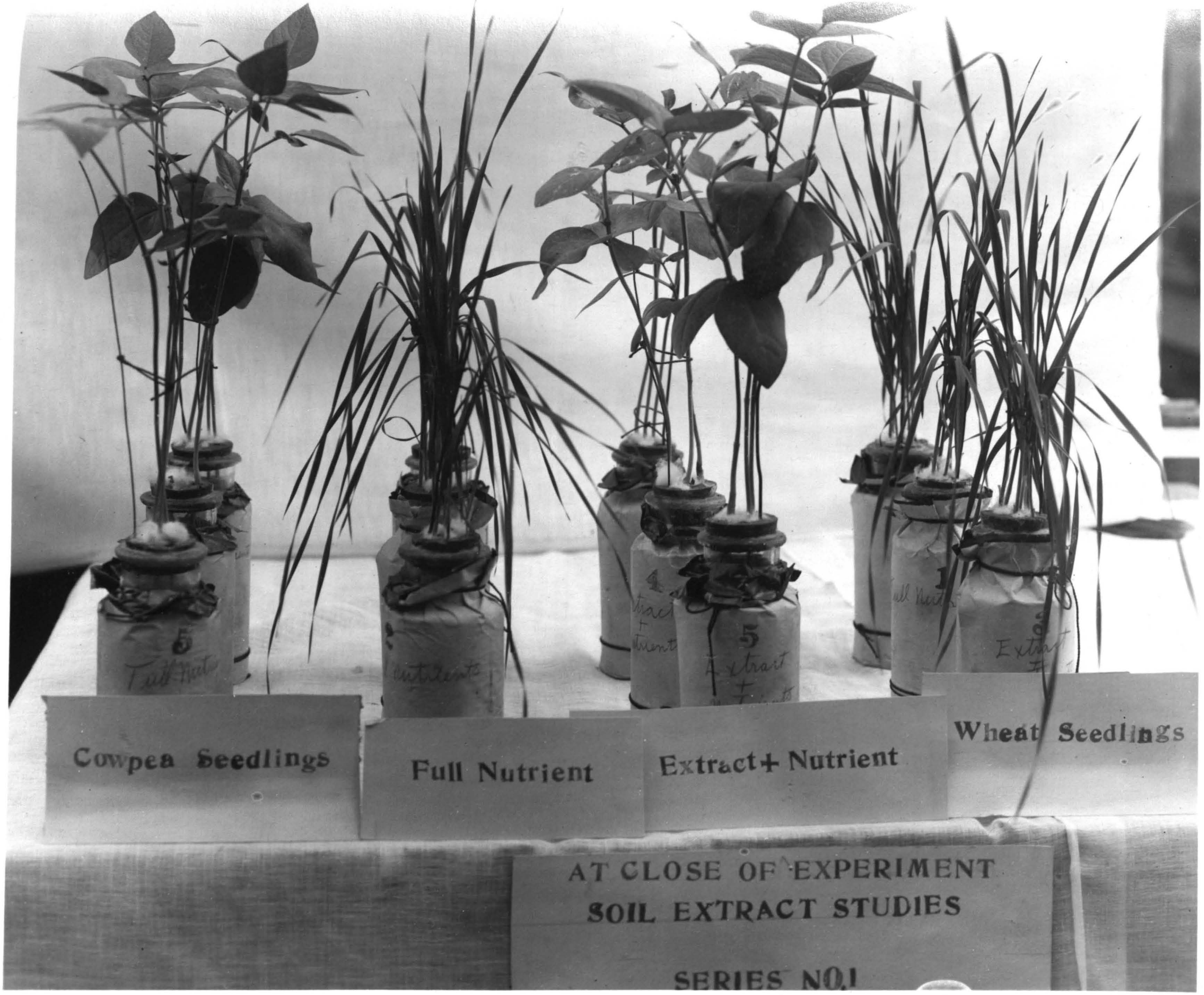
	Full Nutrient			Extract Full Nutrient			Full Nutrient			Extract Full Nutrient		
	WHEAT						COWPEAS					
	Wt. in Grams			Wt. in Grams			Wt. in Grams			Wt. in Grams		
	Green	Dry		Green	Dry		Green	Dry		Green	Dry	
	Tops	Tops	Roots	Tops	Tops	Roots	Tops	Tops	Roots	Tops	Tops	Roots
	3.4	.48	.122	1.7	.29	.1072	5.4	.448	.0782	6.9	.676	.1022
	3.6	.431	.131	1.8	.19	.1042	5.6	.54	.0976	7.1	.728	.1116
	3.3	.332	.113	1.8	.27	.0804	5.5	.58	.0780	7.0	.5042	.1060
Av.	3.4	.417	.112	1.7	.25	.0972	5.5	.52	.0812	7.0	.6364	.1016

Table XI shows that for both the green and the dry weight of tops, there is a distinct uniformity between the individuals of a given series. On the other hand, we see that the averages for various treatment are quite different. Dry weight of roots in every instance were directly proportional to the respective weight of tops even though observations made from time to time revealed the fact that the rootlets of the plants grown in soil extract were in every case more fibrous than those grown in distilled water. This was true even in the case of wheat where the soil extract had less weight of root than the full nutrient-distilled water.

TABLE XII

TOTAL AVERAGE TRANSPIRATION OF CULTURES FOR TWENTY-FOUR DAYS

WHEAT		COWPEAS	
Full Nutrient	Extract & Nutrient	Full Nutrient	Extract & Nutrient
Wt. in Grams	Wt. in Grams	Wt. in Gms	Wt. in Grams
187.8	169.6	178.6	233.1


Cowpea Seedlings
Full Nutrient
Extract + Nutrient
Wheat Seedlings
AT CLOSE OF EXPERIMENT
SOIL EXTRACT STUDIES
SERIES NO.1


SHOWING ROOT
DEVELOPMENT
Full Nutrient
Extract + Nutrient

Comparing results of transpiration measurements as shown in Table XII with dry weight of plants produced (see Table XI), it is seen that they check in direct proportion and we are lead to conclude from this data and physiological observations as seen by pictures on preceding pages that the extract from the soil of continually cropped plot is toxic to wheat seedlings. (See pages 51 and 52)

There is a possibility that the deleterious effect upon the wheat seedlings may have been due to the excess of mineral salts carried by the soil extract when reinforced with nutrient ration. However, in that the cowpea plants were not likewise affected, but as might be expected, actually stimulated by the additional food and, further, in that the United States Bureau of Soils has proven that few soil extracts contain enough mineral food in solution to be deleterious when so treated, the above source of error may be dispensed with. It was planned to repeat the experiment, adding to the full nutrient mineral salts equivalent to the amount in the original soil extract. Then all influencing factors other than soil toxicity will be eliminated.

Hence to clear up this doubtful question another series was arranged, similar to the first in all respects, save that the distilled water cultures with the full nutrient ration were reenforced by the extra amount of salts contained in the original soil extract. To supply this amount of salts as much soil extract as used in the "extract cultures" was evaportaed down to dryness and ignited. Thus all toxic

organic bodies were eliminated together with the volatil radicals including NO_3 which was combined with the mineral ash. The soil extract when evaporated was found to have 4.6 parts per million of NO_3 and this was supplied to the ash residue by addition of nitric acid equivalent to this amount. With toxic free distilled water reenforced with full nutrients the soil extract ash residue was taken up. Therefore the available plant food in the distilled water cultures was practically identical with that of the extract and nutrient cultures.

Growth measurement was measured by transpiration as in the first run and results are reported below in Table XIII.

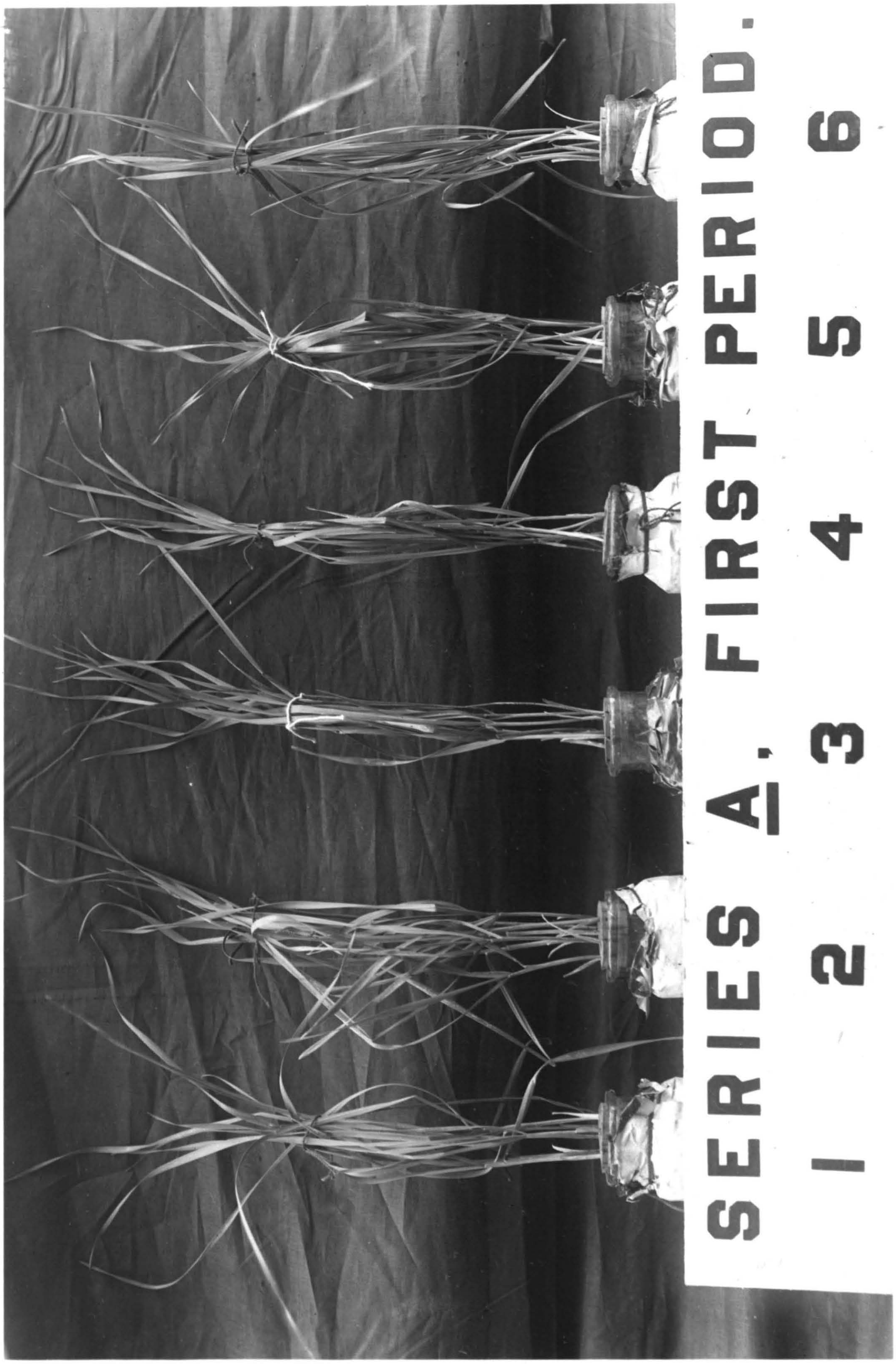
TABLE XIII

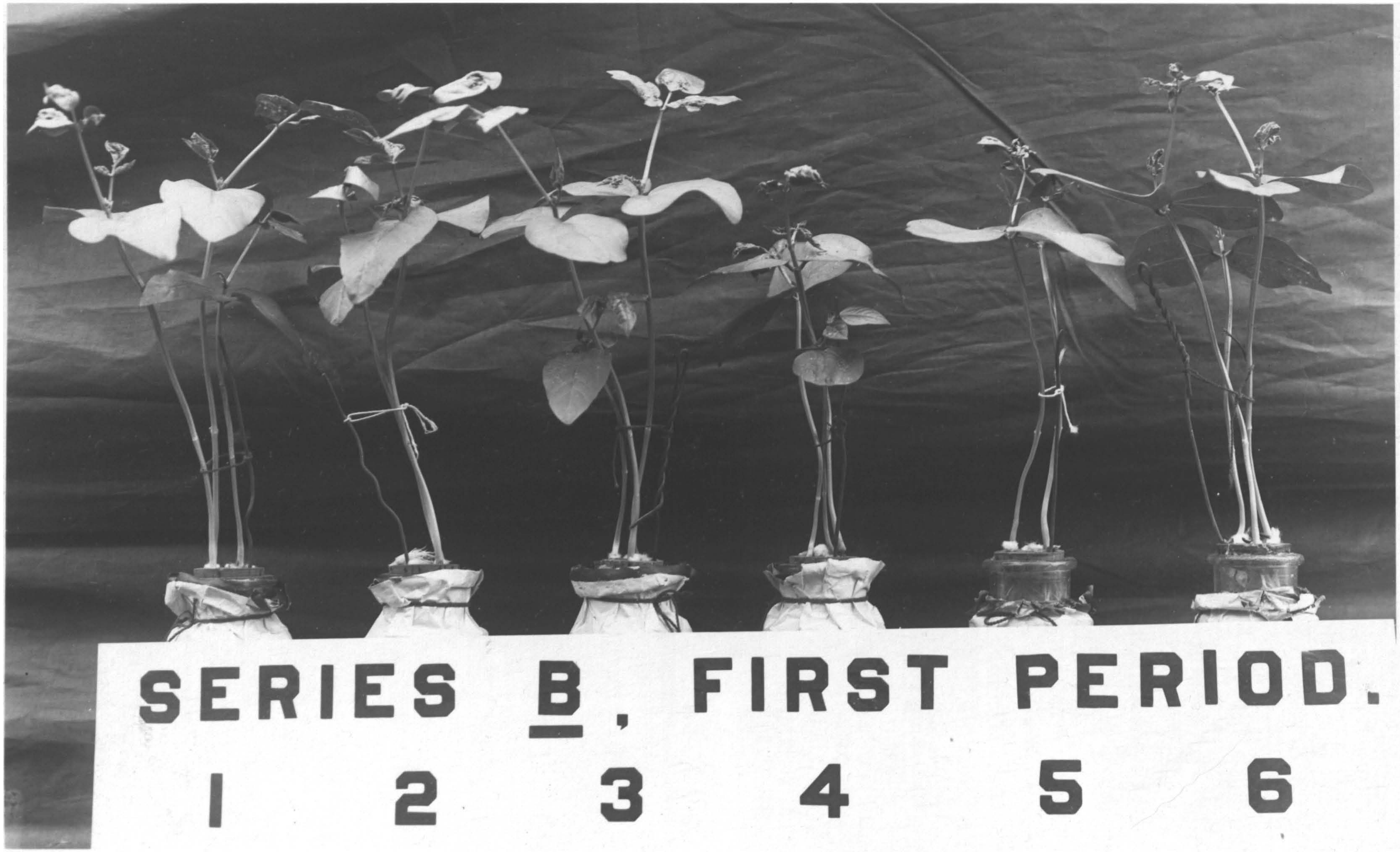
Transpiration of Water from Culture Bottles From Feb.27-Mar.7

No	Nutri. & Ash	Ex. & Nutri.	No	Nutri. & Ash	Ex. & Nutri.
1	68.0 Gms.	61.9 Gms.	1	22.7 Grams	22.0 Grams
2	68.5 "	63.0 "	2	22.9 "	22.2 "
3	67.5 "	63.2 "	3	22.7 "	22.1 "
Aver	68.0 "	62.7 "	Av.	22.8 "	22.1 "
	*WHEAT, SERIES A			COWPEAS, SERIES B	

From the average transpiration data as presented above it is seen that the previous suspicion as to the toxic properties of the continuously cropped plot is substantiated. The data shows that the soil extract from the poor plot is toxic to wheat seedlings. Further, that the cowpea seedlings are not so affected and that the difference noted in the previous run was probably due to a plant food variation in the distilled water and soil extract cultures.

*See pictures on pages 55 and 56.


SERIES A. FIRST PERIOD.
1 2 3 4 5 6


SERIES B, FIRST PERIOD.
1 2 3 4 5 6

This conclusion in the case of cowpeas, however, hardly checks with actual field observations for it has been noted that the peas never make a real thrifty growth of late years even though adjacent plots produce normally. Yet, the enhanced growth noted may be due not to deleterious bodies but to the small amount of available plant food and water left in the soil after the wheat is harvested.

Mr. P. L. Gainey, working with the soil from the same plots taken at the same time samples were secured for the preparation of soil extracts described above, prepared pot culture series. The soil was treated with .2% toluole in one series of pots and in another it was untreated. Oats was the crop grown and a noticeable increase of growth resulted where the soil from both plots was thus treated over that of the respective untreated checks. However, the beneficial effect of the toluole was even more marked in the case of the rotation plot soil than in the case of the continuously cropped. Investigation proved that in this treatment the toluole completely sterilized the soil so the beneficial effects are due rather to the correction of some soil condition rather than to a stimulus to bacterial activity. Why this effect should be more pronounced in the rotation soil than the other, is unexplainable save that it may be due to some characteristic of the plant grown, or to the fact that toluole removes some deleterious factor common to both plots. Future experiments with this in mind, using other plants, will be conducted with the hope of throwing more light upon this complex problem and of the identification of the deleterious body or bodies.

CONCLUSIONS.

PART I

1. The data seems to warrant the conclusion that a legume companion crop, such as cowpeas with corn, not only has no deleterious effects, but rather, has a stimulating effect upon the quantity of NO_3 produced during the growing season.

2. Cowpeas planted with corn, or at last cultivation seem to have a tendency to prevent surface evaporation, giving more water to the corn plant at a time when most needed. If the season as a whole be considered, however, the double crop leaves less water in the soil at the end of the growing season.

3. Where cowpeas were drilled with corn at planting time there is apparently as much available nitrogen in the soil at tasseling time, when corn and peas are making their greatest growth, as is the case under straight crop treatment.

4. The lack of firing of corn on plots seeded to cowpeas, as compared with corn alone, may be due to the greater amount of available moisture in the soil under the former cropping system.

PART II

1. That cowpeas tend to maintain the friability of loose and compact seed beds.

2. While cowpeas on the land take more water from the soil than evaporates from uncultivated adjacent plots, the removal of water is from below the second foot.

3. Land plowed and left uncropped, or plowed and seeded to cowpeas, will leave more nitrates in the soil at the end of the season than will unplowed land similarly treated.

PART III

1. Continuous cropping to wheat and cowpeas leaves the soil in such a condition that an extract of same is deleterious to wheat plants.

2. In so far as we have gone, investigations with regard to bacterial activity, acidity, moisture, plant food supply, and toxic properties of this particular soil have indicated that, while not any <u>one</u> of the factors is capable of producing the existing infertility of land continuously cropped to wheat and cowpeas, <u>some</u>, or all of the above factors working together may produce this effect.

This thesis is never to leave this room.
Neither is it to be checked out overnight.