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HAWAII AGRICULTURAL EXPERIMENT STATION,

J. M. WESTGATE, Agronomist in Charge.

Bulletin No. 43.

CHEMICAL STUDIES OF THE EFFICIENCY OF LEGUMES AS GREEN MANURES IN HAWAII.

BY

ALICE R. THOMPSON,

Assistant Chemist.

UNDER THE SUPERVISION OF

STATES RELATIONS SERVICE,
Office of Experiment Stations,

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LETTER OF TRANSMITTAL.

HAWAII AGRICULTURAL EXPERIMENT STATION,
Honolulu, Hawaii, April 27, 1916.

SIR: I have the honor to submit herewith and to recommend for publication as Bulletin No. 43 of the Hawaii Agricultural Experiment Station a manuscript entitled "Chemical Studies of the Efficiency of Legumes as Green Manures in Hawaii," by Alice R. Thompson, assistant chemist of this station. There are a number of different species of legumes available for utilization as green manure in maintaining the fertility and humus content of Hawaiian soils. The data herewith presented indicate the results of the first year's experiments to determine the relative efficiency of the different species on different soil types.

Respectfully,

J. M. WESTGATE,
Agronomist in Charge.

Dr. A. C. TRUE,
Director States Relations Service,
U. S. Department of Agriculture, Washington, D. C.

Publication recommended.
A. C. TRUE, *Director.*

Publication authorized.
D. F. HOUSTON,
Secretary of Agriculture.

CHEMICAL STUDIES OF LEGUMES AS GREEN MANURES IN HAWAII.[1]

CONTENTS.

INTRODUCTION.

Probably one of the most important problems in national conservation is the maintenance of soil fertility. The best solution of this problem at present seems to be rotation of crops combined with plowing under of green-manuring legumes and the application of mineral fertilizers when necessary. The soils of Hawaii, derived from basaltic lava, are of a heavy clay type, and under the present agricultural practice of taking off the heavy crop produced by the liberal application of mineral fertilizers, they soon fall into a bad physical condition, with poor drainage and poor aeration.

Owing to the use of much of the available arable land for the production of sugar cane, systematic rotation of crops is not likely to be practiced in Hawaii for some time to come, but green manuring already is finding rather extensive application. The rôle of legumes in assimilating atmospheric nitrogen by the aid of the bacteria in their root nodules and the improvement in the physical condition of the soil when green plants are plowed under are well known and need not be further considered.

Numerous varieties of legumes, both native and introduced, are found in Hawaii. The experiments herein reported upon were inaugurated in order to determine the comparative value for soil improvement of the different species and varieties of certain well-known field legumes and the more common legumes growing as weeds on these islands. The data presented in this bulletin represent the results of the first year's work along this line.

[1] The writer wishes to express her appreciation of the valuable suggestions made by Mr. William T. McGeorge, formerly chemist of this station, and Mr. M. O. Johnson, chemist, in regard to this work. Mr. C. A. Sahr, assistant agronomist, also gave helpful advice and assistance.

EXPERIMENTS, SERIES I.

For the experiments in growing the legumes two types of soil from the island of Oahu were used, one from the station grounds near Honolulu, a brown calcareous soil, rich in plant food and peculiar for its high magnesia content, the other obtained from Kunia near the Waianae Range, a red, apparently acid soil, low in phosphate and lime and of poor texture. The chemical analyses of these soils are given in Table I.

TABLE I.—*Chemical composition of two types of soils.*[1]

Constituent.	Station.	Kunia.	Constituent.	Station.	Kunia.
	Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
Water	10.39	4.97	Lime (CaO)	1.630	0.180
Volatile matter	9.72	14.36	Magnesia (MgO)	10.140	.290
Insoluble residue	36.18	38.45	Potash (K_2O)	.900	.290
Ferric oxid (Fe_2O_3)	14.96	24.09	Soda (Na_2O)	.760	.250
Alumina (Al_2O_3)	14 99	16.90	Phosphoric acid (P_2O_5)	.410	.060
Titanium dioxid (TiO_2)	.19	.40	Sulphur trioxid (SO_3)	.010	.080
Manganese oxid (Mn_3O_4)	.31	.09	Nitrogen	.147	.263

[1] The analyses of Hawaiian soils often total more than 100 per cent. This is probably due to the fact that the iron is present to a greater or less extent as ferrous iron, but is calculated as ferric iron.

Tin cans holding about 2 kilograms of soil were used for the pot experiments. For the experiment with station soil 132 pots were filled from a stock of this soil which had been mixed and passed through a coarse wire mesh to remove all the larger roots and stones. The soil contained some black gravel or volcanic ash with some magnetic iron. About 2 kilograms of soil was apportioned to each pot. The filled pots were placed on a table in the open air and were labeled as they stood, four in a row, by number according to the number of the row, and by letters A, B, C, and D, respectively, in each row. There were thus 33 rows of pots. The four pots in row No. 1 were kept as checks, and in each of the other 32 rows of pots was planted a different variety of legume. Pots filled with the red soil from Kunia were marked and placed on another table and labeled in like manner. Legume seeds of different varieties were planted in December, 1914, care being taken to count the number of seeds added to each pot. The results of determinations of the nitrogen contained in each variety of seeds and some other data are given in Table II.

TABLE II.—*Weights and water and nitrogen contents of legume seeds.*

Row No.[1]	Variety.	Weight of 1 seed.	Moisture content.	Nitrogen content of of 1 seed.	
				Weight.	Per cent.
		Grams.	*Per cent.*	*Grams.*	
2	Soy bean (*Glycine hispida*), Virginia	0.0873	9.89	0.00495	5.67
3	*Sesbania ægyptiaca*	.0174	10.69	.00087	4.97
4	Kulthi (*Dolichos biflorus*)	.0357	11.94	.00127	3.57
5	Oregon vetch (*Vicia sativa*)	.0588	12.34	.00234	3.98
6	Soy bean (*Glycine hispida*), Ototan	.0831	9.42	.00448	5.39
7	Cowpea (*Vigna unguiculata*), Taylor	.2646	11.64	.00913	3.45
8	Velvet bean (*Stizolobium pachylobium*)	1.5043	11.72	.06799	4.52
9	Lyon bean (*Stizolobium niveum*)	1.2432	11.84	.05656	4.55
10	Cowpea (*Vigna unguiculata*), mixed varieties	.1549	11.65	.00617	3.98
11	Florida velvet bean (*Stizolobium deeringianum*)	.6428	10.76	.02365	3.68
12	Sunn hemp (*Crotalaria juncea*)	.0388	11.51	.00225	5.80
13	Soy bean (*Glycine hispida*), Riceland	.1121	9.72	.00706	6.30
14	Florida beggar weed (*Desmodium tortuosum*)	.0020	10.76	.00010	5.06
15	Mung bean (*Phaseolus mungo*)	.0402	11.61	.00167	4.15
16	Black cowpea (*Vigna unguiculata*)	.2451	11.93	.00971	3.96
17	*Crotalaria incana*	.0075	....	.00037	4.92
18	Mauritius bean (*Stizolobium aterrimum*)	1.4705	12.22	.06970	4.74
19	*Crotalaria saltiana*	.0052	10.83	.00024	4.56
20	Cowpea (*Vigna unguiculata*), Red Ripper	.2352	12.38	.00910	3.87
21	Cowpea (*Vigna unguiculata*), Brabham	.1293	12.79	.00498	3.85
22	Soy bean (*Glycine hispida*), Barchet	.1119	9.90	.00775	6.93
23	Cowpea (*Vigna unguiculata*), Whippoorwill	.1467	12.15	.00560	3.82
24	Hairy vetch (*Vicia villosa*)	.0258	12.59	.00114	4.41
25	Jack bean (*Canavali ensiformis*)	1.2006	12.48	.04754	3.96
26	German lupine (*Lupinus hartwegii*)	.0159	10.39	.00092	5.78
27	*Phaseolus semierectus*	.0090	10.72	.00032	3.55
28	Soy bean (*Glycine hispida*), Wilson	.1217	10.53	.00677	5.56
29	Alfalfa (*Medicago sativa*), Peruvian	.0019	10.34	.00011	5.75
30	Spanish clover (*Desmodium uncinatum*)	.0030	16.35	.00014	4.64
31	*Cassia chamæcrista*	.0044	....	.00020	4.55
32	*Indigofera anil*	.0039	....	.00016	4.10
33	Sensitive plant (*Mimosa pudica*)	.0049	....	.00021	4.34

[1] These numbers are used in subsequent tables and serve to identify the kind of legume in each case.

The pots were protected from birds by means of wire netting until the plants were well grown. As the season was rather cold and rainy, the first series of plants did not have the most favorable conditions, but they made a fair growth. As the plants reached a certain degree of maturity (early bloom) they were taken to the laboratory, where, after careful removal of the soil, the foliage and roots were separated from each other and weighed. The plants from two pots of each row were air-dried, weighed again, and analyzed for nitrogen. The plants from the remaining two pots of each row were weighed, cut up, and mixed with the soil of the pots in which they were grown, and these were returned to the table in the open air to weather.

AMMONIA, NITRATE, AND NITRITE NITROGEN IN THE SOILS USED IN SERIES I.

As considerable interest centers about the conditions of the nitrogen in soil under growing plants, determinations were made of the total nitrogen and of the ammonia, nitrate, and nitrite nitrogen in the original soils, the check soils, and the soils from which the growing plants had been removed. A comparison of the check pots growing no plants and the pots containing legumes showed the relative gain or loss of these forms of nitrogen due to the action of the roots in the soil.

The total nitrogen was determined in 20 grams of air-dried soil by the Kjeldahl-Gunning method modified for nitrates by addition of salicylic acid and sodium thiosulphate. Ammonia was determined by direct distillation of 100 grams of fresh soil with 500 cubic centimeters water and 20 grams magnesia. Nitrate and nitrite were determined by rubbing 100 or 200 grams fresh soil with 500 cubic centimeters water, allowing to stand 20 minutes, adding calcium sulphate [1] to coagulate the clay, and filtering. The nitrates in the filtrate were determined by the phenoldisulphonic method, the nitrites by the colorimetric method of Peter Griess.

The station soil was easily rubbed up with water, but the Kunia soil resisted rubbing to some extent. Since the results are relative, however, it was deemed best to make the nitrate determination within the hour on the soil from which the plants had been removed rather than to dry the soil for fine grinding and risk the changes due to oxidation. Determinations of the moisture content of the soil were always made. The results are given in Table III, the numbers corresponding to the number of each row and the variety of legume. The original station soil contained 21 parts per million ammonia nitrogen, 18.9 parts per million nitrate nitrogen, and 0.038 parts per million nitrite nitrogen. In the original Kunia soil were found 34.8 parts per million ammonia nitrogen, 99.6 parts per million nitrate nitrogen, and 0.062 parts per million nitrite nitrogen.

It is to be noted that, with but one or two exceptions, the nitrates in the soil under growing plants were considerably less than the nitrates in the check pots. It is apparent that there was some loss of nitrate due to drainage, as the nitrate in the original Kunia soil is greater than that in the check soil. But in comparison with the soil growing plants, the check soils always contained much more nitrate. That the loss of nitrates under growing plants is most probably not due to drainage is shown in Table V, where the soil from which the plants were removed equals or surpasses the check in nitrate content. The striking decrease of nitrates in the soil under growing plants indicates that the legumes have either absorbed the nitrates of the soil or exerted a depressing influence on the nitrification of the soil organic matter.

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[1] W. P. Kelly, Jour. Amer. Chem. Soc., 35 (1913), No. 6, pp. 775–779.

TABLE III.—*Comparison of ammonia, nitrate, and nitrite nitrogen in check soils with that in soils on which legumes had been grown (Series I).*

[Parts per million on water-free basis.]

Pot No.	Station soil.			Kunia soil.		
	Ammonia nitrogen.	Nitrate nitrogen.	Nitrite nitrogen.	Ammonia nitrogen.	Nitrate nitrogen.	Nitrite nitrogen.
Check A	27.9	15.9	0.006	25.3	79.1	0.035
Check B	26.4	14.5	.009	30.9	53.4	.023
Check C	28.9	18.9	.008	....	50.0	.041
Check D	18.0	15.1	.023	22.9	47.1	.038
Average of checks	25.3	16.1	.011	26.36	57.4	.34
2–A, soy bean	....	....	....	....	2.9	.006
2–B, soy bean	....	....	....	46.6	2.2	.017
3–A, Sesbania	20.1	1.4	.025	36.9	.4	.025
3–B, Sesbania	30.2	2.1	.015	35.2	.6	.031
4–A, Kulthi	23.4	.7	0	....	....	....
4–B, Kulthi	19.4	1.4	.017	....	....	....
5–A, Oregon vetch	18.2	.9	.023	40.1	.8	.032
5–B, Oregon vetch	20.9	1.8	.024	38.3	.7	.033
6–A, soy bean	19.9	1.5	.024	36.6	4.6	.016
6–B, soy bean	26.4	.7	0	40.9	.7	.016
7–A, cowpea	27.6	1.6	.014	36.5	1.1	.008
7–B, cowpea	25.6	1.6	.016	34.7	.7	.007
8–A, velvet bean	18.2	1.1	.027	17.4	1.4	.014
8–B, velvet bean	13.8	2.2	.031	32.5	1.1	.011
9–A, Lyon bean	13.6	1.2	.022	....	....	....
9–B, Lyon bean	21.8	1.4	.020	....	....	....
10–A, cowpea	25.5	.7	.016	38.7	1.8	.015
10–B, cowpea	20.4	.7	.016	35.0	1.7	.011
11–A, Florida velvet bean	15.2	1.3	.041	....	....	....
11–B, Florida velvet bean	15.1	1.6	.033	....	....	....
12–A, Sunn hemp	22.1	5.4	....	29.8	4.7	.031
12–B, Sunn hemp	18.5	5.8	....	41.5	3.8	.032
13–A, soy bean	27.0	1.8	.004	32.8	3.3	.032
13–B, soy bean	18.7	1.9	.004	41.6	3.2	.024
14–A, Florida beggar weed	21.4	1.8	.008	....	1.4	.006
14–B, Florida beggar weed	18.9	2.2	.016	....	....	....
15–A, Mung bean	23.8	1.4	.004	35.9	5.2	.007
15–B, Mung bean	23.9	....	.004	31.6	1.1	.009
16–A, black cowpea	17.1	.7	0	45.0	1.1	.011
16–B, black cowpea	32.7	1.2	.011	36.9	1.3	.008
17–A, Crotalaria	25.5	1.5	.030	....	1.4	.015
17–B, Crotalaria	19.1	1.4	.008	26.4	1.2	....
18–A, Mauritius bean	14.2	1.5	.015	32.9	1.4	.016
18–B, Mauritius bean	18.8	1.3	.028	39.7	2.1	.013
19–A, Crotalaria	21.4	1.5	.020	32.9	1.5	.015
19–B, Crotalaria	21.9	1.1	.022	31.5	1.5	.014
20–A, cowpea	19.2	1.6	.010	38.9	1.1	.015
20–B, cowpea	22.1	1.8	.011	33.9	1.5	.015
21–A, cowpea	20.5	.7	.015	39.1	3.5	.022
21–B, cowpea	25.8	1.9	.011	40.2	3.5	.029
22–A, soy bean	30.6	1.8	.009	38.3	1.1	.008
22–B, soy bean	22.1	2.3	0	39.1	1.1	.012
23–A, cowpea	22.3	2.2	.023	42.7	1.7	.015
23–B, cowpea	25.4	1.8	.011	....	.5	.017
24–A, hairy vetch	....	....	....	37.7	.6	.016
24–B, hairy vetch	....	....	....	31.2	.5	.025
25–A, jack bean	8.6	1.4	.019	27.7	1.1	....
25–B, jack bean	13.9	1.4	.014	....	....	....
26–A, German lupine	28.3	2.6	0	50.0	6.0	.003
26–B, German lupine	29.2	3.0	0	41.9	1.1	.012
27–A, Phaseolus	19.9	1.8	.004	32.2	14.2	.008
27–B, Phaseolus	17.0	.7	.016	36.4	8.8	.016
29–A, alfalfa	17.1	1.7	.022	....	....	....
29–B, alfalfa	18.0	1.1	.011	....	....	....
30–A, Spanish clover	23.5	1.3	.008	33.5	3.1	.013
30–B, Spanish clover	19.1	.6	.007	....	....	....
31–A, Cassia	16.0	1.1	.011	27.5	1.1	.022
31–B, Cassia	24.4	1.3	.007	24.1	.8	.022
32–A, Indigofera	11.9	1.4	.064	27.9	1.2	.040
32–B, Indigofera	....	....	....	25.9	.7	.052

A number of investigators have noted the decrease of nitrates in soils under leguminous crops. Lyon and Bizzell[1] believe that the decrease is due to absorption of nitrates by the legumes, and not to inhibition of nitrification, as the soil separated from the legumes showed considerable nitrifying power. The same authors show that nitrates under growing maize, oats, and potatoes may be increased in comparison with fallow soil held as a check, thus demonstrating a stimulating effect of these plant roots on nitrification.

As a field of various legumes was being cultivated on the station grounds, the writer determined the nitrates in samples of soil removed from near the roots of these plants with the following results:

TABLE IV.—*Ammonia and nitrate nitrogen in field soil samples.*

[Parts per million on water-free basis.]

Plat.	Ammonia nitrogen.	Nitrate nitrogen.	Plat.	Ammonia nitrogen.	Nitrate nitrogen.
Check plat 1	19.1	45.9	Velvet bean	15.2	13.1
Check plat 2	13.1	53.2	Crotalaria	25.2	21.6
Check plat 3	19.2	54.4	Cowpea	20.6	24.2
Jack bean	20.8	20.6	Kulthi	13.9	29.8
German lupine	13.4	28.8			

Even here there is shown a decrease of nitrate under the legumes. In pot experiments the roots are in touch with all of the soil, and their action in a small space shows a greater effect than under field conditions, where the roots of plants growing in rows draw on a much larger supply of soil. The pot experiments may, therefore, emphasize the root action as compared with that occurring under normal field conditions. On the other hand, the drainage in pot soil is probably greater than in field soil.

It will be seen in Table III that the ammonia content varied considerably and that the quantities of nitrite nitrogen were quite small. The ammonia values obtained are, of course, never exact, owing to the breaking down of amids in the soil on distillation.

The pots in which the legumes had been cut and turned under were allowed to stand several weeks under atmospheric conditions, being watered daily. The soil in pots from which the plants had been removed was allowed to weather.

In Table V is shown the ammonia and nitrate nitrogen determined in these soils and calculated on a water-free basis.

These results indicate that in most cases where the legumes turned under represented a considerable weight of material the nitrates were very much increased in the soil. In the soils from which the plants had been removed, and which had shown the decrease of

[1] New York Cornell Sta. Mem. 1 (1913), p. 81.

nitrate, the nitrate on standing had accumulated sufficiently to equal or surpass that in the check pots. This is of interest, as it indicates that the decrease of nitrates under growing plants is not due to drainage but to the influence of the plants. It also seems that nitrification is not inhibited in these soils by the action of the plant roots.

TABLE V.—*Comparison of ammonia and nitrate nitrogen in soil with legumes turned under with that in soil from which legumes had been removed.*

[Parts per million on water-free basis.]

Station soil.			Kunia soil.		
Pot No.	Ammonia nitrogen.	Nitrate nitrogen.	Pot No.	Ammonia nitrogen.	Nitrate nitrogen.
8-C [1]	....	177.5	8-C [1]	27.1	25.8
8-A	....	15.9	8-D [1]	19.9	24.4
9-C [1]	10.5	118.3	8-A	20.9	15.7
9-D [1]	16.5	66.1	8-B	19.5	12.1
9-A	13.5	18.6	9-C [1]	....	17.0
9-B	....	11.4	9-D [1]	....	13.9
17-C [1]	....	14.3	10-C [1]	....	33.3
17-A	....	15.5	10-D [1]	....	15.5
18-C [1]	10.1	169.5	11-C [1]	....	18.3
18-D [1]	14.7	56.7	11-D [1]	....	13.6
18-A	12.4	18.9	16-C [1]	....	17.0
18-B	14.2	20.8	16-A	....	16.1
19-C [1]	....	40.8	18-C [1]	21.1	30.8
19-A	....	11.0	18-D [1]	19.7	24.4
29-C [1]	....	35.9	18-A	23.8	10.2
29-A	....	10.8	18-B	19.7	11.9
31-C [1]	....	23.7	19-C [1]	....	10.2
31-A	....	12.1	19-A	....	9.8
Check	....	7.73	23-C [1]	....	20.9
			31-A	....	11.5
			Check	....	7.7

[1] Legumes turned under with the soil.

AMMONIFICATION AND NITRIFICATION IN SOILS USED IN SERIES I.

An experiment carried out with several samples of these soils, to determine the ammonifying and nitrifying action of the soil organisms on dried blood, indicates that when this material decomposes in the soil nitrogen may be largely lost as nitrates.

One hundred grams of soil was apportioned to a beaker, water added to make the moisture content about equal to two-thirds the soil water capacity, 2 grams of finely ground dried blood mixed with the soil, and the sample placed in a dark closet for incubation. Each soil examined was represented by two beakers prepared as above, and at the end of a week the ammonia was determined in one beaker of each lot. No noticeable difference was found in the results obtained from the check soils and those from which growing legumes had been removed. In general, the ammonia nitrogen in each beaker of soil was found to be about 0.14 gram in the station soil and and 0.12 gram in the Kunia soil. At the end of three weeks' incubation nitrates were determined in the remaining soils, and here again no great difference was found between the check soils and the planted soils. The nitrate nitrogen developed in each beaker amounted to about 0.05 gram in the station soil and about 0.03 gram in the Kunia soil.

The dried blood contained 13.1 per cent of nitrogen. Therefore, in 2 grams of this material added to each beaker, there was 0.262 gram of nitrogen. In the station check soil, before the addition of organic matter, there was 0.0030 gram of nitrate nitrogen, while in the planted soils there was about 0.0001 gram nitrate nitrogen. In all the station soils the ammonia nitrogen at the start was about 0.0015 gram. If the increase of ammonia and nitrate nitrogen is assumed to be due to the nitrogen added in the dried blood, the ammonia nitrogen split off from the organic matter is equal to about one-half the total organic nitrogen added and the nitrate nitrogen to about one-fifth. This shows the tendency of organic matter to decompose largely into soluble nitrogen salts, and it is natural to suppose that the same thing occurs in soils in which legumes are plowed under. It must be remembered, however, that the experiment with dried blood was made under especially stimulating conditions, and the further ammonification and nitrification of organic nitrogen already in the soil was not taken into account, this, it was presumed, having probably reached the maximum in the weeks of weathering in the pots under moist conditions.

A nitrification experiment was carried out in the same manner, mixing in each beaker of 100 grams of soil 20 grams of cowpea stems and leaves freshly cut up. Checks of 100 grams of soil were maintained without the addition of organic matter. At the end of three weeks, the nitrates were determined in the soil. The check soil contained 11 parts of nitrate nitrogen per million, while the soils in which the cowpeas had decomposed contained 250 parts of nitrate nitrogen per million. The 20 grams of cowpeas contained 0.1024 gram of nitrogen, and the nitrates developed from the cowpeas amounted to 239 parts per million. Hence, in 100 grams of soil there would be 0.0239 gram of nitrogen. That is, about one-fifth of the organic nitrogen of cowpeas was changed into soluble nitrates in the three weeks' period.

EXPERIMENT, SERIES II.

A second series of plants was started in April, when the weather was warmer. In this experiment all the seeds were germinated on wet cotton instead of in pots, and three sprouted seeds were added to each pot. In this way no nitrogen was added to the soil in the form of dead seeds, and it was noted that the seeds of the leguminous weeds, which are often difficult to start in cultivated soil, germinated very readily on the wet cotton.

In this series the same lot of Kunia soil was used, but 9 grams of calcium carbonate was added to each pot to correct acidity. A new stock of the station soil was used in the second series, but in other respects the second series resembled the first.

As the season was favorable to plant growth, good yields were obtained, the plants being analyzed and turned under, as in Series I.

In Table VI are presented a few of the determinations made of the nitrate, nitrite, and ammonia nitrogen in the soil from which legumes had been removed in Series II. These results confirm those in Series I.

TABLE VI.—*Ammonia, nitrate, and nitrite nitrogen in soil on which legumes had been grown (Series II).*

[Parts per million.]

Station soil.				Kunia soil.			
Pot No.	Ammonia nitrogen.	Nitrate nitrogen.	Nitrite nitrogen.	Pot No.	Ammonia nitrogen.	Nitrate nitrogen.	Nitrite nitrogen.
Original soil	26.3	39.5	0.038	Original soil	52.2	83.3	0.082
Check	23.2	13.2	.018	Check	29.5	40.2	0
Do	16.6	12.6	.026	Do	....	44.1	.054
Do	22.1	19.1	.028	6-A	29.8	1.2	.012
Do	21.7	43.4	....	6-B	26.3	1.3	.013
4-A	....	2.1	.035	12-A	29.8	1.5	0
4-B	....	1.9	.034	12-B	27.2	1.3	0
5-A	31.3	3.7	.018	14-A	24.7	1.3	0
7-A	22.7	1.9	.021	14-B	24.4	1.8	0
7-B	21.3	1.9	.022	15-A	19.0	1.2	.004
12-A	....	1.8	.033	15-B	35.7	1.1	.004
12-B	23.9	1.9	.037	22-A	31.3	1.2	.012
14-A	....	1.8	.058	22-B	32.0	1.5	.012
15-A	....	2.0	.033				
16-A	22.0	1.9	.075				
17-A	23.4	2.1	.022				
17-B	22.8	1.9	.021				
19-A	20.0	1.9	.018				
21-A	....	2.3	.033				
23-A	24.5	2.0	....				
24-A	27.8	1.9	.008				
26-A	25.4	2.3	.022				
27-A	18.4	1.1	.018				
29-A	23.4	2.0	....				
31-C	23.7	1.6	....				

COMPOSITION OF LEGUMES.

In order to determine the gain of nitrogen due to the assimilation of atmospheric nitrogen by the leguminous crops, the nitrogen was determined in the plants grown to maturity in the pots described above, and in the soil before and after growth of the crop.

In field practice the whole plant may be turned under as a nitrogen fertilizer, or the above-ground parts may be removed as feed for farm animals, leaving only the roots and stubble to decompose in the soil. In this investigation, since it was desirable to obtain results comparable with farm practice, the nitrogen was determined in the above-ground portion and roots separately, and the nitrogen in the total plant calculated from the data thus obtained.

In the two series of pot experiments it was soon noted that with few exceptions the plants grown on the Kunia soil did not make as good growth as those grown on the station soil. The weight of fresh material of the Kunia plants was less than that of the station plants, and the former legumes in many cases were unhealthy in appearance and occasionally had a yellowish color. As stated above, lime was added to the Kunia soil in the second series, but even this did not in many cases raise the plant weight and nitrogen content to those of the station soil plants.

In examining the roots for nodules it was noticed that the station soil plants had developed healthy nodules, but the plants in the first series from the Kunia soil had developed no nodules at all or only a few small ones. In the second series, in which lime had been added to the Kunia soil, the plants developed nodules in almost every case, but the nodules were generally not so numerous nor so healthy in appearance as those in the plants grown on the station soil. No inoculation of the soils was attempted, as the Hawaiian soils usually contain the bacteria requisite for developing legume nodules. This is very apparent in the station soil, where each variety of legume grown developed an abundance of nodules.

Notes were taken of the size and shape of the nodules. A number of varieties of legumes like the cowpea and soy bean developed spherical pealike nodules. The velvet bean and German lupine developed large bunches of nodules. The wild crotalarias had coral-shaped nodules on their roots, while those on the sensitive plant were so minute as to be discernible only on close examination.

Nitrogen was determined in the legumes by the Kjeldahl-Gunning method, modified for the possible nitrates present in the sample by the addition of salicylic acid and sodium thiosulphate.

Contradictory results have been obtained by various investigators with regard to the presence of nitrate nitrogen in legumes. King and Whitson [1] showed the presence of considerable nitrate in the samples examined by them, but Whiting [2] obtained only negative results in his tests for nitrates. In this laboratory the method of King and Whitson was used, but on adding disulphonic acid to the purified and evaporated filtrate, considerable discoloration took place, due probably to the charring of plant sugars. Time was not taken to determine nitrates by the method of Schloesing and Grandeau, but, as noted above, the total nitrogen determined was always modified for nitrates, as the legumes may develop nitrates under varying circumstances.

The digestion of the samples was carried on three hours after the solution had become colorless, in order to make certain that complete oxidation had taken place. One and one-half grams of sample was used except where the quantity of material at hand was small, as in the case of the roots of some varieties. Duplicate analyses were made on each air-dried sample, and the majority of duplicates agreed to within 0.05 per cent, others agreeing to within 0.10 per cent.

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[1] Wisconsin Sta. Bul. 93 (1902).

[2] Illinois Sta. Bul. 179 (1915), p. 528.

The Kjeldahl digestions were made over asbestos mats in which a medium-sized hole allowed the flame to play upon the flask without touching the glass above the acid. Also, enough sulphuric acid was always used with the potassium sulphate so that on cooling after digestion the sample remained in a fluid condition, as it was observed that loss of ammonia took place if the mass fused. Check tests were made with standard ammonium chlorid, and the results obtained agreed very closely with the calculated results. Blank tests were made for each new series of reagents and usually required 0.2 cubic centimeter of fifth-normal standard acid.

It was found necessary to grind the samples of legumes exceedingly fine to get good duplicates. The first samples, which had been only air-dried and which were difficult to grind, gave poor results. On drying in the oven and then grinding, the results agreed usually to within 0.05 per cent.

In Tables VII and VIII are given the average nitrogen values obtained from the above-ground parts and roots of the plants grown in Series I and Series II in the two lots of soil.

TABLE VII.—*Nitrogen in above-ground parts of legumes.*

[Water-free basis.]

Row No.	Variety.	Station soil.				Kunia soil.			
		Series I.		Series II.		Series I.		Series II.	
		A	B	A	B	A	B	A	B
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
2	Soy bean, Virginia	......	......	1.73	1.52	4.03	3.52	......	......
3	*Sesbania ægyptiaca*	1.81	2.35	.92	1.01	1.28	1.26	0.89	0.88
4	Kulthi	3.59	2.88	3.34	3.11	1.44	......	......	......
5	Oregon vetch	2.73	2.74	1.95	2.35	2.15	1.91	......	......
6	Soy bean, Otootan	2.23	3.88	......	......	2.34	2.02	2.41	1.95
7	Cowpea, Taylor	2.53	2.41	2.93	2.58	1.85	1.77	2.76	2.77
8	Velvet bean	2.15	2.56	2.43	2.59	1.84	1.98	1.98	1.82
9	Lyon bean	2.45	2.39	2.20	2.19	......	......	......	......
10	Cowpea, mixed varieties	2.47	2.28	2.78	2.69	1.97	1.85	2.05	......
11	Florida velvet bean	2.00	2.25	2.54	2.49	......	......	1.95	3.05
12	Sunn hemp	3.73	3.65	2.78	2.69	1.91	2.29	1.99	2.13
13	Soy bean, Riceland	3.50	3.71	2.38	2.10	2.84	2.57	......	......
14	Florida beggar weed	2.72	2.97	2.58	2.59	2.08	......	1.69	2.16
15	Mung bean	2.99	3.02	3.30	2.82	1.77	1.79	1.89	1.65
16	Black cowpea	2.66	2.34	3.07	3.07	2.28	1.98	......	......
17	*Crotalaria incana*	3.62	3.41	3.25	3.16	2.82	2.32	2.40	2.25
18	Mauritius bean	2.59	2.32	2.33	2.45	2.06	2.06	1.74	1.66
19	*Crotalaria saltiana*	3.62	3.55	3.22	3.24	3.16	3.09	3.07	2.82
20	Cowpea, Red Ripper	2.82	2.84	2.97	3.08	1.59	1.92	......	......
21	Cowpea, Brabham	2.32	2.66	3.16	3.30	1.96	2.34	......	......
22	Soy bean, Barchet	4.27	......	3.08	2.46	1.75	1.78	2.08	1.81
23	Cowpea, Whippoorwill	3.01	3.28	2.42	2.80	1.58	2.17	......	......
24	Hairy vetch	......	......	2.01	1.62	1.67	3.36	......	......
25A	Jack bean (without pods)	2.76	2.51	2.18	1.79	1.10	1.64	1.28	1.40
25B	Jack bean (with pods)	2.66	2.69	2.71	2.51	2.24	2.27	3.33	3.09
26	German lupine	3.06	2.72	2.03	2.19	1.43	1.59	......	......
27	*Phaseolus semierectus*	3.00	2.91	3.40	3.50	1.71	2.51	......	......
29	Alfalfa, Peruvian	3.64	3.79	2.37	1.92	......	......	2.50	2.33
30	Spanish clover	3.56	3.37	2.65	2.45	2.01	2.47	......	......
31	*Cassia chamæcrista*	3.17	2.96	3.09	2.71	2.21	1.99	1.73	1.83
32	*Indigofera anil*	3.14	2.92	3.26	3.20	1.61	2.23	2.61	2.12
33	Sensitive plant	.93	.91	.99	1.41	.88	1.34	1.03	.81

78760°—17——3

TABLE VIII.—*Nitrogen in roots of legumes.*

[Water-free basis.]

Row No.	Variety.	Station soil.				Kunia soil.			
		Series I.		Series II.		Series I.		Series II.	
		A	B	A	B	A	B	A	B
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
2	Soy bean, Virginia	......	......	1.04	1.07	1.89	1.71	......	......
3	*Sesbania ægyptiaca*	2.12	2.33	.85	1.02	1.12	1.08	0.81	0.89
4	Kulthi	2.50	2.18	2.21	2.42	......	1.50	......	......
5	Oregon vetch	2.20	2.30	1.44	1.94	1.30	1.78	......	......
6	Soy bean, Otootan	1.91	1.77	1.98	......	1.99	1.37	1.51	1.13
7	Cowpea, Taylor	1.53	1.54	2.09	......	1.71	1.60	1.40	1.53
8	Velvet bean	2.16	1.86	1.86	1.57	1.63	1.44	1.18	1.34
9	Lyon bean	1.90	2.51	1.91	1.65	......	......	1.19	1.20
10	Cowpea, mixed varieties	1.74	1.83	1.91	1.98	1.63	1.45	1.51	1.62
11	Florida velvet bean	1.35	1.94	1.50	2.11	......	......	1.46	1.60
12	Sunn hemp	1.11	.77	1.81	1.47	1.50	1.49	1.02	1.33
13	Soy bean, Riceland	1.97	1.99	1.11	1.01	1.42	1.72	......	......
14	Florida beggar weed	1.71	1.53	1.98	1.86	1.34	......	1.28	......
15	Mung bean	1.65	1.61	2.22	1.91	1.87	1.73	1.33	1.01
16	Black cowpea	1.84	1.45	2.53	2.26	1.49	1.28	......	......
17	*Crotalaria incana*	1.65	1.74	2.01	1.94	2.06	1.69	1.44	1.33
18	Mauritius bean	2.21	2.19	1.92	2.35	1.31	1.57	1.51	1.42
19	*Crotalaria saltiana*	2.29	2.42	1.99	2.00	1.60	1.90	1.49	1.47
20	Cowpea, Red Ripper	1.81	1.82	2.37	2.19	1.79	1.64	......	......
21	Cowpea, Brabham	1.38	1.68	2.14	2.03	1.76	1.68	......	......
22	Soy bean, Barchet	1.69	......	2.05	1.63	1.15	1.17	1.40	1.30
23	Cowpea, Whippoorwill	2.16	1.88	1.57	1.64	1.40	1.58	......	......
24	Hairy vetch	......	......	1.42	1.60	1.30	2.07	......	......
25	Jack bean	1.62	1.90	1.82	1.79	1.11	1.30	1.04	.95
26	German lupine	2.14	2.25	2.01	2.01	.93	1.04	......	......
27	*Phaseolus semierectus*	1.44	2.16	2.19	2.42	1.11	1.51	......	......
29	Alfalfa, Peruvian	2.36	2.25	1.11	.89	1.06	1.30	1.34	1.35
30	Spanish clover	1.88	1.91	1.70	1.69	1.19	1.36	......	......
31	*Cassia chamæcrista*	1.72	1.81	1.69	1.58	1.35	1.20	......	1.27
32	*Indigofera anil*	2.19	2.39	2.27	2.38	1.42	1.55	2.32	1.84
33	Sensitive plant	.79	.68	1.12	1.27	.74	.54	.69	.69

On examining these results it will be noted that the plants grown in the station soil usually contained a higher percentage of nitrogen in the water-free material than the plants grown in the Kunia soil. This is probably due to the fact that the plants in the first series on the Kunia soil developed few nodules or none at all, and were thus unable to assimilate as much atmospheric nitrogen as the series of plants on station soil. In the series in which lime was added to the Kunia soil, the nitrogen content was raised in some instances. As shown in Table VII, the percentage of nitrogen in the foliage of the Kunia series of velvet beans and cowpeas is less than that in the plants grown on station soil. The jack-bean percentage is also less, but is increased by the addition of lime. The wild crotalaria (No. 17), grown in the Kunia soil, contains less nitrogen than the station pot plants, but crotalaria No. 19 has about the same percentage in both soils. The German lupine made especially poor growth in the Kunia soil and contained less nitrogen than in the station soil. *Phaseolus semierectus*, Spanish clover (*Desmodium uncinatum*) *Cassia chamæcrista*, and *Indigofera anil* all show a smaller percentage of nitrogen in the Kunia series than in the station series.

As may be seen from Table VIII, the cowpea and velvet bean roots of the Kunia series have the same nitrogen content as those of the station series, or only slightly less, while roots of crotalarias (Nos. 17

and 19), jack bean, Phaseolus (No. 27), and Indigofera grown on the Kunia soil have a consistently lower percentage of nitrogen.

The nitrogen percentage of the roots does not vary so greatly as does the foliage value.

In most instances the nitrogen content of the roots is considerably smaller than that of the foliage, which is worthy of note in view of the fact that legumes assimilate their nitrogen through the roots and not through the foliage.

A comparison of the results from station soil in Tables VII and VIII shows that the nitrogen of the water-free roots of velvet bean equals that of the foliage in some cases. This is probably due to the large bunches of nodules on the roots of the velvet bean. The same is true of the German lupine, which also developed nodules in large bunches.

In the Kunia plants of velvet bean and German lupine the roots have a smaller nitrogen content than that of the foliage, due probably to the fact that they did not develop as healthy nodules as did the station-soil plants. For the other varieties in which the nodules were small, the tables show less nitrogen in the dried roots than in the dried foliage.

In Table IX is given the percentage of nitrogen in the whole water-free plant as calculated from the figures in the preceding tables and from the weight of plant and roots as noted after drying.

TABLE IX.—*Nitrogen in the whole plant of different legumes.*

[Water-free basis.]

Row No.	Variety.	Station soil.				Kunia soil.			
		Series I.		Series II.		Series I.		Series II.	
		A	B	A	B	A	B	A	B
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
2	Soy bean, Virginia	......	......	1.57	1.44	3.39	3.04	......	......
3	*Sesbania ægyptiaca*	1.90	1.72	.89	1.02	1.24	1.21	0.858	0.89
4	Kulthi	3.46	2.79	3.22	3.00	......	1.45	......	......
5	Oregon vetch	2.51	2.56	1.62	2.21	1.49	1.82	......	......
6	Soy bean, Otootan	2.11	3.25	......	......	2.29	1.88	2.14	1.71
7	Cowpea, Taylor	2.37	2.25	......	2.49	1.82	1.73	2.44	2.59
8	Velvet bean	2.17	2.38	2.32	2.45	1.76	1.74	1.58	1.57
9	Lyon bean	2.31	2.41	2.17	2.07	......	......	......	......
10	Cowpea, mixed varieties	2.34	2.21	2.63	2.57	1.87	1.72	1.93	......
11	Florida velvet bean	1.84	2.19	2.38	2.46	......	......	1.73	2.34
12	Sunn hemp	2.81	2.11	2.56	2.46	1.82	2.14	1.65	1.91
13	Soy bean, Riceland	2.98	3.10	2.09	1.81	2.47	5.29	......	......
14	Florida beggar weed	2.47	2.64	2.42	2.40	1.77	......	......	1.87
15	Mung bean	2.73	2.78	3.16	2.72	1.79	1.79	1.81	1.57
16	Black cowpea	2.51	2.07	2.99	2.92	2.02	1.72	......	......
17	*Crotalaria incana*	3.11	2.97	2.90	2.86	2.53	2.06	1.92	1.76
18	Mauritius bean	2.51	2.30	2.21	2.43	......	1.90	1.64	1.59
19	*Crotalaria saltiana*	3.26	3.32	2.89	2.99	2.65	2.77	2.51	2.36
20	Cowpea, Red Ripper	2.61	2.63	2.88	2.95	1.63	1.83	......	......
21	Cowpea, Brabham	2.51	3.05	3.56	3.61	2.28	2.72	......	......
22	Soy bean, Barchet	3.46	......	2.67	2.04	1.62	1.65	1.87	1.64
23	Cowpea, Whippoorwill	2.83	2.96	2.26	2.58	1.52	2.01	......	......
24	Hairy vetch	......	......	1.80	1.61	1.46	2.84	......	......
25	Jack bean	2.54	2.55	2.42	2.09	1.77	1.72	2.51	2.09
26	German lupine	2.91	2.62	2.02	2.13	1.35	1.51	......	......
27	*Phaseolus semierectus*	2.38	2.72	3.06	3.23	1.46	2.19	......	......
29	Alfalfa, Peruvian	2.80	2.86	1.49	1.15	......	......	1.66	1.73
30	Spanish clover	2.94	2.79	2.24	2.11	1.68	1.98	......	......
31	*Cassia chamæcrista*	2.75	2.66	2.72	2.42	1.88	1.71	1.54	1.63
32	*Indigofera anil*	2.81	2.77	2.91	2.89	1.53	1.97	2.51	2.04
33	Sensitive plant	.87	.76	1.06	1.34	.81	.84	.84	.74

A few varieties of plants made poor growth in the pots. The vetches and several of the soy beans made such poor growth that they were probably abnormal in nitrogen content, but on the whole the nitrogen content of plants of the same variety grown on the same soil agrees very well.

In the calculation of total weights on a water-free basis, plants of the Kunia series again appear deficient in nitrogen. Liming the Kunia soil increased the nitrogen content of the jack bean and cowpea (No. 7), but not the velvet bean. Apparently no other variety, except Indigofera, was affected by liming. The legumes especially high in nitrogen are the crotalarias (Nos. 17 and 19). The sensitive plant contains least nitrogen.

In Table X is given the nitrogen calculated as percentage of fresh material.

TABLE X.—*Nitrogen in the whole plant of different legumes.*

[Fresh material.]

Row No.	Variety.	Station soil.				Kunia soil.			
		Series I.		Series II.		Series I.		Series II.	
		A	B	A	B	A	B	A	B
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
2	Soy bean, Virginia	......	......	0.369	0.315	0.885	0.808	......	......
3	*Sesbania ægyptiaca*	0.451	0.452	.269	.245	.373	.375	0.289	0.307
4	Kulthi	.588	.584	.545	.560	......	.342	......	......
5	Oregon vetch	.489	.489	.339	.646	.234	.289	......	......
6	Soy bean, Ototan	.437	.801	......	......	.587	.518	.513	.396
7	Cowpea, Taylor	.500	.573	......	.462	.474	.402	.691	.814
8	Velvet bean	.518	.548	.544	.528	.433	.417	.506	.478
9	Lyon bean	.567	.558	.555	.521	......	......	......	......
10	Cowpea, mixed varieties	.560	.490	.495	.448	.427	.390	.473	......
11	Florida velvet bean	.527	.599	.571	.584	......	......	.459	.649
12	Sunn hemp	.522	.413	.655	.687	.503	.493	.484	.558
13	Soy bean, Riceland	.542	.666	.496	.417	.716	1.813	......	......
14	Florida beggar weed	.633	.733	.696	.623	.508	......	......	.503
15	Mung bean	.507	.492	.815	.708	.527	.562	.407	.443
16	Black cowpea	.589	.499	.561	.563	.457	.387	......	......
17	*Crotalaria incana*	.857	.772	.634	.689	.647	.675	.555	.543
18	Mauritius bean	.579	.594	.536	.519	......	.482	.416	.407
19	*Crotalaria saltiana*	.873	1.012	.913	.767	.938	.817	.844	.815
20	Cowpea, Red Ripper	.573	.552	.461	.429	.399	.466	......	......
21	Cowpea, Brabham	.495	.537	.533	.594	.326	.469	......	......
22	Soy bean, Barchet	.809	......	.580	.500	.441	.449	.413	.382
23	Cowpea, Whippoorwill	.578	.562	.433	.574	.355	.364	......	......
24	Hairy vetch	......	......	.392	.303	.260	.533	......	......
25	Jack bean	.670	.623	.995	.653	.595	.417	1.084	.886
26	German lupine	.355	.344	.377	.381	.240	.290	......	......
27	*Phaseolus semierectus*	.480	.659	.687	.755	.330	.380	......	......
29	Alfalfa, Peruvian	.941	.889	.486	.412	......	......	.478	.572
30	Spanish clover	.617	.627	.478	.525	.510	.543	......	......
31	*Cassia chamæcrista*	.909	.799	.804	.737	.620	.590	.521	.577
32	*Indigofera anil*	.983	1.034	.913	.982	......	.640	.843	.697
33	Sensitive plant	.271	.249	.282	.297	.321	.253	.265	.234

Crotalaria (Nos. 17 and 19), soy bean (No. 22), Cassia, and Indigofera contain most nitrogen. German lupine and sensitive plant contain least nitrogen.

The total percentages of moisture in the fresh plants are given in Table XI.

TABLE XI.—*Moisture in the whole plant.*

[Fresh material.]

Row No.	Variety.	Station soil.				Kunia soil.			
		Series I.		Series II.		Series I.		Series II.	
		A	B	A	B	A	B	A	B
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
2	Soy bean, Virginia	......	......	76.5	78.1	73.8	73.7	......	......
3	*Sesbania ægyptiaca*	76.4	73.7	70.0	76.0	70.0	69.2	66.3	64.0
4	Kulthi	83.3	79.2	83.0	81.3	......	76.3	......	......
5	Oregon vetch	77.8	80.8	79.1	70.7	84.3	83.5	......	......
6	Soy bean, Otootan	79.3	75.5	......	......	74.4	72.5	75.9	76.9
7	Cowpea, Taylor	78.8	74.7	81.3	81.6	77.0	76.7	71.7	68.7
8	Velvet bean	76.4	76.9	76.6	78.5	75.5	76.1	68.0	68.7
9	Lyon bean	75.4	76.7	74.5	74.6	......	......	68.2	69.2
10	Cowpea, mixed varieties	76.0	77.8	81.4	82.5	77.3	77.3	75.5	75.4
11	Florida velvet bean	71.4	72.6	75.9	76.1	......	......	73.3	72.2
12	Sunn hemp	81.4	80.3	74.3	72.2	72.4	77.0	70.6	70.7
13	Soy bean, Riceland	81.9	78.5	76.0	76.5	71.1	65.7	......	......
14	Florida beggar weed	74.5	72.2	71.2	74.0	71.3	......	77.0	73.0
15	Mung bean	81.5	82.3	74.2	74.0	70.5	68.6	77.2	71.8
16	Black cowpea	76.5	76.0	81.2	80.9	77.4	77.8	......	......
17	*Crotalaria incana*	72.5	74.1	78.1	76.2	74.5	67.3	71.4	69.5
18	Mauritius bean	76.7	74.3	76.3	78.7	78.8	74.7	74.9	74.3
19	*Crotalaria saltiana*	78.8	76.6	75.8	79.6	73.8	77.3	74.8	74.3
20	Cowpea, Red Ripper	78.1	78.8	84.1	85.4	75.6	74.7	......	......
21	Cowpea, Brabham	77.5	78.4	82.2	80.9	83.4	78.8	......	......
22	Soy bean, Barchet	76.7	......	78.2	75.4	72.7	72.7	78.0	76.7
23	Cowpea, Whippoorwill	79.5	81.0	80.9	77.7	76.7	82.0	......	......
24	Hairy vetch	......	......	78.2	81.3	82.2	81.2	......	......
25	Jack bean	73.7	75.4	58.8	68.8	66.3	75.9	56.9	57.5
26	German lupine	87.7	86.7	81.3	82.0	82.3	80.9	......	......
27	*Phaseolus semierectus*	79.8	75.9	77.5	76.6	77.6	82.5	......	......
29	Alfalfa, Peruvian	66.4	68.8	66.7	64.2	......	......	71.3	67.2
30	Spanish clover	61.7	60.4	78.7	75.2	57.2	52.8	......	......
31	*Cassia chamæcrista*	67.1	70.1	70.5	69.6	67.2	65.4	66.1	64.5
32	*Indigofera anil*	65.1	62.7	68.7	66.1	......	67.7	66.4	65.8
33	Sensitive plant	68.8	67.4	73.3	77.9	60.4	70.1	68.4	68.2

Table XII shows the weight in grams of nitrogen found in the whole plant of each pot and the proportion of nitrogen in the above-ground parts and roots.

TABLE XII.—*Nitrogen in above-ground parts, roots, and whole plant from each pot.*

Row No.	Variety.	Station soil.				Kunia soil.			
		Series I.		Series II.		Series I.		Series II.	
		A	B	A	B	A	B	A	B
2	Soy bean, Virginia:	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
	Foliage	......	......	0.123	0.106	0.117	0.116	......	......
	Roots	......	......	.023	.016	.022	.019	......	......
	Total plants	......	......	.146	.122	.139	.135	......	......
3	*Sesbania ægyptiaca:*								
	Foliage	0.185	0.154	.083	.080	.114	.107	0.198	0.141
	Roots	.091	.121	.052	.045	.036	.030	.117	.085
	Total plants	.276	.275	.135	.125	.150	.137	.315	.226
4	Kulthi:								
	Foliage	.176	.248	.274	.327	......	.088	......	......
	Roots	.018	.026	.027	.051	......	.012	......	......
	Total plants	.194	.274	.301	.378	......	.100	......	......
5	Oregon vetch:								
	Foliage	.052	.041	.047	.068	.043	.036	......	......
	Roots	.026	.023	.060	.025	.094	.068	......	......
	Total plants	.078	.064	.107	.093	.137	.104	......	......

TABLE XII.—*Nitrogen in above-ground parts, roots, and whole plant from each pot*—Continued.

Row No.	Variety.	Station soil.				Kunia soil.			
		Series I.		Series II.		Series I.		Series II.	
		A	B	A	B	A	B	A	B
		Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
6	Soy bean, Ototan:								
	Foliage	0.129	0.353			0.094	0.109	0.157	0.125
	Roots	.053	.067			.014	.019	.042	.029
	Total plants	.182	.420			.108	.128	.199	.154
7	Cowpea, Taylor:								
	Foliage	.658	.663	.609	.534	.226	.204	.312	.338
	Roots	.080	.092		.096	.074	.064	.049	.032
	Total plants	.738	.755		.630	.300	.268	.361	.370
8	Velvet bean:								
	Foliage	1.072	.957	1.001	.958	.291	.315	.709	.451
	Roots	.311	.244	.171	.089	.158	.171	.409	.342
	Total plants	1.383	1.201	1.172	1.047	.449	.486	1.118	.793
9	Lyon bean:								
	Foliage	.833	.903	.902	.865				
	Roots	.224	.203	.095	.184				
	Total plants	1.057	1.106	.997	1.049				
10	Cowpea, mixed varieties:								
	Foliage	.783	.497	.751	.621	.266	.237	.324	
	Roots	.118	.075	.105	.087	.070	.088	.063	.044
	Total plants	.901	.572	.856	.708	.336	.325	.387	
11	Florida velvet bean:								
	Foliage	.511	.592	.559	.615			.367	.464
	Roots	.123	.116	.060	.046			.231	.237
	Total plants	.634	.708	.619	.661			.598	.701
12	Sunn hemp:								
	Foliage	.280	.241	.336	.336	.101	.092	.105	.096
	Roots	.046	.059	.063	.043	.023	.015	.030	.024
	Total plants	.326	.300	.399	.379	.124	.107	.135	.120
13	Soy bean, Riceland:								
	Foliage	.347	.304	.190	.126	.116	.123		
	Roots	.100	.090	.026	.022	.020	.189		
	Total plants	.447	.394	.216	.148	.136	.312		
14	Florida beggar weed:								
	Foliage	.199	.175	.250	.259	.060		.061	.065
	Roots	.041	.028	.069	.065	.025			.019
	Total plants	.240	.203	.319	.324	.085			.084
15	Mung bean:								
	Foliage	.326	.417	.452	.457	.103	.095	.119	.096
	Roots	.043	.045	.047	.038	.013	.014	.013	.009
	Total plants	.369	.462	.499	.495	.116	.109	.132	.105
16	Black cowpea:								
	Foliage	.734	.782	.602	.611	.249	.214		
	Roots	.112	.218	.089	.102	.082	.178		
	Total plants	.846	1.000	.691	.713	.331	.292		
17	*Crotalaria incana:*								
	Foliage	.326	.252	.314	.322	.227	.213	.259	.252
	Roots	.053	.045	.074	.062	.099	.106	.151	.162
	Total plants	.379	.297	.388	.384	.326	.319	.410	.414
18	Mauritius bean:								
	Foliage	.930	.933	.867	.845		.346	.334	.369
	Roots	.223	.151	.161	.188	.059	.127	.231	.139
	Total plants	1.153	1.084	1.028	1.033		.473	.565	.508
19	*Crotalaria saltiana:*								
	Foliage	.286	.405	.335	.191	.231	.179	.221	.223
	Roots	.066	.070	.078	.030	.058	.040	.060	.062
	Total plants	.352	.475	.413	.221	.289	.219	.281	.285
20	Cowpea, Red Ripper:								
	Foliage	.671	.517	.603	.582	.178	.207		
	Roots	.112	.082	.090	.068	.054	.075		
	Total plants	.783	.599	.693	.650	.232	.282		
21	Cowpea, Brabham:								
	Foliage	.631	.556	.566	.627	.178	.206		
	Roots	.051	.081	.071	.059	.030	.034		
	Total plants	.682	.637	.637	.686	.208	.240		
22	Soy bean, Barchet:								
	Foliage	.192		.213	.135	.107	.096	.123	.107
	Roots	.033		.094	.093	.021	.016	.038	.036
	Total plants	.225		.307	.228	.128	.112	.161	.143
23	Cowpea, Whippoorwill:								
	Foliage	.789	.804	.883	.633	.177	.226		
	Roots	.149	.137	.127	.085	.071	.062		
	Total plants	.938	.941	1.010	.718	.248	.288		
24	Hairy vetch:								
	Foliage			.084	.063	.053	.161		
	Roots			.031	.032	.049	.064		
	Total plants			.115	.095	.102	.225		

TABLE XII.—*Nitrogen in above-ground parts, roots, and whole plant from each pot*—Continued.

Row No.	Variety.	Station soil.				Kunia soil.			
		Series I.		Series II.		Series I.		Series II.	
		A	B	A	B	A	B	A	B
		Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
25	Jack bean:								
	Foliage	0.952	0.532	0.530	0.576	0.088	0.285	0.081	0.091
	Pods	.255	.616	.867	.708	.455	.184	.766	.473
	Roots	.154	.072	.107	.095	.070	.090	.078	.090
	Total plants	1.361	1.220	1.504	1.379	.613	.559	.925	.654
26	German lupine:								
	Foliage	.355	.324	.199	.208	.047	.068	......	......
	Roots	.049	.072	.060	.086	.007	.006	......	......
	Total plants	.404	.396	.259	.294	.054	.074	......	......
27	*Phaseolus semierectus:*								
	Foliage	.240	.279	.592	.518	.087	.073	......	......
	Roots	.076	.065	.147	.116	.039	.021	......	......
	Total plants	.316	.344	.739	.634	.126	.094	......	......
29	Alfalfa, Peruvian:								
	Foliage	.237	.406	.128	.100	......	......	.115	.117
	Roots	.306	.365	.140	.140	......	......	.161	.107
	Total plants	.543	.771	.268	.240	......	......	.276	.224
30	Spanish clover:								
	Foliage	.128	.138	.087	.074	.054	.074	......	......
	Roots	.038	.052	.043	.044	.020	.033	......	......
	Total plants	.166	.190	.130	.118	.074	.107	......	......
31	*Cassia chamæcrista:*								
	Foliage	.222	.314	.315	.482	.126	.153	.218	.254
	Roots	.048	.069	.061	.095	.047	.050	.114	.137
	Total plants	.270	.383	.376	.577	.173	.203	.332	.391
32	*Indigofera anil:*								
	Foliage	.283	.642	.274	.253	.084	.087	.248	.191
	Roots	.105	.210	.102	.117	.060	.039	.111	.074
	Total plants	.388	.852	.376	.370	.144	.126	.359	.265
33	Sensitive plant:								
	Foliage	.050	.056	.038	.051	.043	.072	.052	.039
	Roots	.036	.067	.036	.055	.041	.049	.047	.055
	Total plants	.086	.123	.074	.106	.084	.121	.099	.094

EXPERIMENT, SERIES III.

Since the weight of nitrogen per pot in a number of the small varieties was not sufficient to show plainly the gain due to assimilation of atmospheric nitrogen, a third crop of legumes was grown and the nitrogen determined in the whole plants. In this planting a larger number of plants per pot was grown in order to increase the total plant material and weight of nitrogen. The legumes grown in the third experiment were planted in the pots of the second series in which the plants had been turned under. The third series was modified by the addition of sodium phosphate to the Kunia soil, which had been limed in the second series. Since this soil was very low in phosphate, it was hoped that the addition of this element would improve the crops. However, the legumes in the Kunia series did no better than before and were, as usual, inferior in size to the plants grown on station soil. It is possible that a larger addition of lime to this red soil might have given better results. The third Kunia crop was not harvested, as it showed no improvement over the previous lot.

The results obtained from the plants grown on station soil are given in Table XIII. It is noticeable that the crowding of the plants increased the yield of nitrogen.

TABLE XIII.—*Nitrogen in plants grown on station soil (Series III).*

Row No.	Variety.	Nitrogen in whole plant.				Weight of nitrogen per pot.	
		Water-free basis.		Fresh basis.			
		C	D	C	D	C	D
		Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Grams.*	*Grams.*
3	*Sesbania ægyptiaca*	0.91	1.08	0.245	0.269	0.153	0.149
4	Kulthi	2.21	....	.497	....	.678	....
7	Cowpea, Taylor	2.31	2.43	.469	.459	1.010	1.196
12	Sunn hemp	2.95	2.81	.672	.623	.584	.520
13	Soy bean, Riceland	2.53	3.20	.549	.690	.423	.510
14	Florida beggar weed	2.63	2.82	.701	.696	.494	.456
15	Mung bean	3.12	3.16	.561	.565	.671	.743
16	Black cowpea	2.50	2.47	.469	.461	1.130	1.044
17	*Crotalaria incana*	3.43	3.73	.612	.633	.607	.671
19	*Crotalaria saltiana*	3.43	3.45	.641	.607	1.090	.863
26	German lupine	....	2.11	....	.304	....	.363
27	*Phaseolus semierectus*	2.95	2.89	.529	.496	.620	.598
29	Alfalfa, Peruvian	2.75	2.78	.812	.683	.743	.728
30	Spanish clover	2.44	2.57	.571	.548	.371	.288
31	*Cassia chamæcrista*	2.66	2.69	.663	.649	.697	.753
32	*Indigofera anil*	2.78	2.58	.718	.691	.723	.671

GAIN OF NITROGEN DUE TO ATMOSPHERIC ASSIMILATION.

The weight of nitrogen in the plants of each pot having been obtained, the proportion of nitrogen due to atmospheric assimilation and that due to absorption of nitrogen from the soil itself were estimated.

It was necessary to know the loss or gain of nitrogen in the soils in which each legume was grown, and a very careful analysis was made of the original soil, the check soils, and the soils from which the mature plants were removed. Nitrogen in 20 grams of soil was determined as previously described and modification made for the presence of nitrates. By grinding each lot of soil from a pot, mixing very thoroughly, and quartering, samples were obtained in which triplicate nitrogen determinations agreed within a few thousandths of 1 per cent, and any difference amounting to over 0.01 per cent was believed to be a reliable indication of gain or loss. Determinations were made in triplicate for every sample examined and the average weight of nitrogen for every three determinations calculated.

All samples of soil were dried in the air at ordinary temperature, since it has been shown that in Hawaiian soils heated to high temperature the organic nitrogen changes into ammonia,[1] and it was feared that drying in the oven might cause loss of nitrogen as ammonia.

The soils in the check pots of the station soil Series II and III agree very closely in nitrogen content, and it is believed that any gain or loss of nitrogen in the pot soils in which legumes were grown is a comparable gain or loss, due to the growth of legumes.

[1] W. P. Kelley and Wm. T. McGeorge, Hawaii Sta. Bul. 30 (1913), p. 32.

The station soil used for Series II and III was a different lot from that used in Series I, and results for Series I and for Series II and III are not comparable. The fact that there was a gain of 0.10 per cent in the check pot soils of Series II and III over the original soils, the nitrogen content of which was 0.17 per cent, indicates a fixation of nitrogen due to bacteria in the soil. This gain of nitrogen was not due to nitrogen in the water added each day, as the checks of Series I for the station soil and the Kunia soil showed no gain. Lipman and Burgess[1] have shown by experiments a gain of nitrogen in soils due to fixation of nitrogen by bacteria equal to 0.10 per cent or more in one month, and these results indicate that certain samples of soil contain very active nitrogen-fixing bacteria.

In the Kunia soils there was a small loss of nitrogen in the check soils as compared with the original soil, and this is accounted for by the high content of nitrate nitrogen in the red soil when first obtained. On standing in the open air with daily watering for a number of months, the nitrates were finally very nearly drained away.

In determining the gain of nitrogen in the soils due to the fixation of atmospheric nitrogen by legumes, a comparison was made of the total nitrogen in the check pots with that in the pots in which the legumes had been grown. As there were four check pots in each series which received exactly the same treatment as the other pots as regards watering, exposure, etc., the results should be reliable.

In Table XIV is given the percentage of nitrogen in the pot soils of Series II from which the crops had been removed for analysis. A gain of nitrogen will be observed in those soils from which the matured crop had been removed. This may be due in part to the seeds added, but it is in excess of the nitrogen contained in the seeds. The gain of nitrogen determined in the plants is thus apparently due entirely to atmospheric assimilation, since the soils have sustained rather a gain than a loss.

Certain investigators[2] have stated that the roots of legumes excrete nitrogenous compounds. If this is so, the soil from which the plants have been removed after full growth should show a gain of nitrogen over the check soils. Part of the gain shown over that due to the nitrogen of seeds added may be due to root excretions, but it is just as probable that it is due to the decomposition of aging nodules and roots.

The combined results indicate that the total nitrogen in the plants is due to the assimilation of atmospheric nitrogen, as there was no loss of nitrogen in the soils from which the plants were removed.

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[1] Centbl. Bakt. [etc.], 2. Abt., 44 (1915), No. 17-23, pp. 481-511.
[2] J. G. Lipman, New Jersey Stas. Bul. 253 (1912), p. 25.

TABLE XIV.—*Nitrogen in soils and plants from pots of station soil (Series II).*

[Water-free basis.]

Pot No.	Nitrogen in soil.	Gain of nitrogen in soil.	Nitrogen due to seeds in total soil.	Weight of nitrogen in plants removed.	Pot No.	Nitrogen in soil.	Gain of nitrogen in soil.	Nitrogen due to seeds in total soil.	Weight of nitrogen in plants removed.
	Per cent.	*Per cent.*	*Per cent.*	*Grams.*		*Per cent.*	*Per cent.*	*Per cent.*	*Grams.*
Check A.	0.265	....	....	....	11-B.....	.301	.030	.003	.661
Check B.	.271	....	....	....	16-A.....	.278	.007	.002	.691
Check C.	.273	....	....	....	16-B.....	.282	.011	.001	.713
Check D.	.275	....	....	....	18-A.....	.296	.025	.011	1.028
2-A......	.273	0.002	0.001	0.146	18-B.....	.299	.028	.011	1.033
2-B......	.276	.005	.001	.122	20-A.....	.280	.009	.001	.693
5-A......	.276	.005	.0004	.107	20-B.....	.277	.006	.001	.650
5-B......	.278	.007	.0003	.093	21-A.....	.278	.007	.001	.637
7-A......	.286	.015	.001	....	21-B.....	.280	.009	.001	.686
7-B......	.281	.010	.001	.630	22-A.....	.281	.010	.002	.307
8-A......	.299	.028	.011	1.172	22-B.....	.282	.011	.001	.228
8-B......	.305	.034	.011	1.047	23-A.....	.281	.010	.001	1.010
9-A......	.296	.025	.008	.997	23-B.....	.304	.033	.001	.718
9-B......	.287	.016	.008	1.049	25-A.....	.290	.019	.007	1.504
10-A.....	.284	.005	.001	.856	25-B.....	.297	.026	.007	1.379
10-B.....	.279	.008	.001	.708	33-A.....	.309	.038	0	.074
11-A.....	.303	.032	.003	.619	33-B.....	.301	.030	0	.106

Table XV shows the results from station soil, Series III.

TABLE XV.—*Nitrogen in soils and plants from pots of station soil (Series III).*

[Water-free basis.]

Pot No.	Nitrogen in soil.	Gain of nitrogen in soil.	Nitrogen due to seeds in total soil.	Gain of nitrogen in soil over seed nitrogen.	Weight of nitrogen in plants turned under.	Weight of nitrogen in plants removed.	Gain of nitrogen due to plants of Series III.[1]
	Per cent.	*Per cent.*	*Per cent.*	*Gram.*	*Gram.*	*Grams.*	*Grams.*
Check A..............	0.265	....	....	....	....	....	....
Check B..............	.271	....	....	....	....	....	....
Check C..............	.273	....	....	....	....	....	....
Check D..............	.275	....	....	....	....	....	....
Average of checks.....	.271	....	....	....	....	....	....
3-C, Sesbania.........	.286	0.015	0.001	0.264	0.133	0.153	0.284
3-D, Sesbania.........	.284	.013	.001	.229	.149	.149	.229
4-C, Kulthi...........	.282	.011	.001	.196	.312	.678	.562
7-C, cowpea...........	.295	.024	.003	.397	.656	1.010	.751
7-D, cowpea...........	.297	.026	.004	.397	.765	1.196	.828
12-C, Sunn hemp......	.292	.021	.002	.354	.333	.584	.605
12-D, Sunn hemp......	.293	.022	.002	.383	.305	.520	.598
13-C, soy bean........	.289	.018	.004	.256	.174	.423	.505
13-D, soy bean........	.287	.016	.004	.235	.140	.510	.605
14-C, Florida beggar weed...............	.292	.021	0	.387	.293	.494	.588
14-D, Florida beggar weed...............	.288	.017	0	.324	.313	.456	.467
15-C, Mung bean.....	.292	.021	.002	.366	.639	.671	.398
15-D, Mung bean.....	.301	.030	.001	.540	.552	.743	.731
16-C, black cowpea...	.292	.021	.004	.309	.722	1.130	.717
16-D, black cowpea...	.292	.021	.004	.309	.810	1.044	.543
17-C, Crotalaria......	.282	.011	0	.197	.313	.607	.491
17-D, Crotalaria......	.282	.011	0	.215	.322	.671	.564
19-C, Crotalaria......	.288	.017	0	.333	.391	1.090	1.032
19-D, Crotalaria......	.297	.026	0	.455	.854	.863	.464
26-C, German lupine..	.274	.003	.001	....	....	....	....
26-D, German lupine.	.293	.022	.001	.424	.260	.363	.527
27-C, Phaseolus.......	.290	.019	0	.357	.643	.620	.334
27-D, Phaseolus......	.283	.012	0	.229	.632	.598	.195
29-C, alfalfa..........	.285	.014	0	.275	.249	.743	.669
29-D, alfalfa..........	.287	.016	0	.313	....	.728	....
30-C, Spanish clover..	.293	.022	0	.442	.208	.371	.605
30-D, Spanish clover..	.308	.037	0	.770	.218	.288	.840
31-C, Cassia..........	.319	.048	0	.854	.557	.697	.994
31-D, Cassia..........	.321	.050	0	.881	.654	.753	.980
32-C, Indigofera......	.303	.032	0.	.589	.352	.723	.959
32-D, Indigofera......	.319	.048	0	.806	.406	.671	1.071

[1] Obtained by subtracting nitrogen in plants turned under from the sum of nitrogen in soil and in plants removed.

As before mentioned, this crop was grown in certain of the pots of Series II in which the plants had been turned under. These pots had been allowed to weather several weeks before the new crop was planted and there was probably some loss of nitrogen by the leaching of nitrification products. The new crop also may have taken part of its nitrogen from the first crop before assimilating nitrogen from the air. The results shown in Table XV indicate considerable assimilation of atmospheric nitrogen, but on subtracting the nitrogen due to the first crop, from the total nitrogen gained, the second crop in several instances appears to have absorbed only a part of its nitrogen from the air. It is probable that the results in Table XV would have resembled those of Table XIV if no crop had been turned under before the planting of a second crop. As it is, the percentage of nitrogen due to the utilization of atmospheric nitrogen by the last crop can be obtained by dividing the gain of nitrogen determined for each pot by the total weight of nitrogen found in the plants grown in that pot.

In Table XVI are given the gains of nitrogen due to the assimilation of atmospheric nitrogen by the plants grown in the limed Kunia soil. In all cases there was a gain of nitrogen in the soil over that due to seeds added and the plant nitrogen thus indicates a gain from atmospheric nitrogen. Since the total gain of nitrogen per pot was less in the Kunia series than that in the station series, it is to be expected that less total nitrogen was usually gained from the air by the former series. Velvet bean No. 11 is an exception.

TABLE XVI.—*Nitrogen in soils and plants from pots of Kunia soil (Series II).*

[Water-free basis.]

Pot No.	Nitrogen in soil.	Gain of nitrogen in soil.	Nitrogen due to seeds in total soil.	Weight of nitrogen in plants removed.
	Per cent.	*Per cent.*	*Per cent.*	*Gram.*
Original soil	0.280			
Check B	.264			
Check C	.260			
Check D	.266			
Average of checks	.263			
3-A, Sesbania	.276	0.013	0	0.315
3-B, Sesbania	.276	.013	0	.226
7-A, cowpea	.271	.008	0.001	.361
7-B, cowpea	.268	.005	.001	.370
9-A, Lyon bean	.275	.012	.009	
9-B, Lyon bean	.280	.017	.009	
11-A, Florida velvet bean	.285	.022	.003	.598
11-B, Florida velvet bean	.273	.010	.003	.701
17-A, Crotalaria	.281	.018	0	.410
17-B, Crotalaria	.277	.014	0	.414
18-A, Mauritius bean	.284	.021	.010	.565
19-A, Crotalaria	.270	.007	0	.281
19-B, Crotalaria	.272	.005	0	.285
25-A, Jack bean	.268	.005	.007	.925
25-B, Jack bean	.271	.008	.007	.654
31-A, Cassia	.267	.004	0	.332
31-B, Cassia	.268	.005	0	.391

In Table XVII are given the gains of nitrogen in soils in which legumes had been grown and then turned under to decompose. Although all the varieties had been turned under in two pots in each row of four pots, it seemed necessary only to analyze those soils in which heavy weights of legumes had been grown and mixed with the soil, since the nitrogen of the small plants could not be very accurately determined when so diluted with the soil.

TABLE XVII.—*Nitrogen in soils of Series II in which the legumes were turned under for decomposition.*

Station soil.					Kunia soil.				
Pot No.	Nitrogen in soil.	Gain of nitrogen in soil.	Nitrogen due to seeds in soil.	Plant nitrogen turned under.	Pot No.	Nitrogen in soil.	Gain of nitrogen in soil.	Nitrogen due to seeds in soil.	Plant nitrogen turned under.
	Per cent.	*Gram.*	*Per cent.*	*Grams.*		*Per cent.*	*Gram.*	*Per cent.*	*Grams.*
Check A..	0.265	....	....	....	Check B .	0.264	....	....	....
Check B..	.271	....	....	....	Check C..	.260	....	....	....
Check C..	.273	....	....	....	Check D .	.266	....	....	....
Check D..	.275	....	....	....					
8-C......	.319	0.936	0.011	0.890	7-D......	.265	0.040	0.001	0.541
8-D......	.319	.946	.011	.919	8-C......	.298	.700	.011	.841
9-C......	.306	.662	.008	.656	8-D......	.301	.760	.011	.994
9-D......	.311	.579	.008	.909	9-C......	.277	.280	.009	....
10-C......	.287	.299	.001	.697	9-D......	.265	.040	.009	....
10-D......	.289	.335	.001	.848	10-C......	.262	.020	.001	.355
11-C......	.296	.500	.003	.532	10-D......	.271	.160	.001	.468
11-D......	.302	.623	.003	.622	11-C......	.287	.480	.003	.676
20-C......	.286	.276	.001	.449	11-D......	.279	.320	.003	.488
20-D......	.288	.316	.001	.538					
21-C......	.287	.299	.001	.692	18-C......	.299	.720	.011	.736
21-D......	.285	.265	.001	.726	18-D......	.299	.520	.011	.633
22-C......	.284	.243	.002	.254	25-C......	.283	.400	.007	1.231
22-D......	.283	.228	.001	.281	25-D......	.276	.260	.007	.640
23-C......	.282	.209	.001	.709					
23-D......	.291	.396	.002	.739					
25-C......	.312	.754	.007	1.961					
25-D......	.308	.725	.007	1.838					

On studying Table XVII, it is noticeable that practically all the nitrogen in the velvet bean (Nos. 8 and 11) and soy bean (No. 22) was retained in the station soil after decomposition of the legumes, but only about one-half or less of the nitrogen in the cowpeas (Nos. 10, 20, 21, and 23) and jack bean (No. 25) was recovered. In the Kunia soil, the velvet bean nitrogen is not so completely recovered, and a large percentage of nitrogen from the cowpeas was not recovered.

As stated in the first part of this bulletin, there is every indication that the organic nitrogen of these legumes is nitrified to a considerable extent, and the loss of nitrogen determined in those pots in which legumes were turned under and allowed to decompose is probably due to the drainage of nitrates formed from the organic nitrogen of the plants.

SUMMARY.

(1) The nitrate content of soils in which legumes are growing is low as compared with unplanted check soils, owing possibly to absorption of nitrates by the roots of the growing plants.

(2) Where a large amount of leguminous growth is turned under to decompose, the nitrate content of the soil usually is greatly increased.

(3) Legumes grown on station soil usually showed a higher percentage of nitrogen in the water-free material than those grown on Kunia soil. Liming in a few cases increased the nitrogen content and the nodule development of legumes on Kunia soil.

(4) The nitrogen content of the above-ground parts of legumes, although more variable than that of roots, was also usually greater, especially on the station soil, where only the velvet bean and German lupine gave the same value for plant and roots, owing possibly to the large bunches of nodules on their roots. This is noteworthy because of the fact that legumes assimilate nitrogen through their roots and not through their foliage.

(5) In calculations of nitrogen in the entire legume plant on water-free basis the plants grown on Kunia soil again appear deficient in this element. Liming increased the nitrogen content of the entire plant in case of the jack bean and cowpea, but not of the velvet bean. The crotalarias contained most nitrogen on both fresh and water-free basis. As green manure, *Sesbania ægyptiaca* and the velvet bean might be used successfully on Kunia soil if a lime dressing is employed.

(6) The results of analyses indicate that the nitrogen of leguminous plants is gained through atmospheric assimilation and not from the soil.

(7) When a legume is to be grown for turning under the roots only, the percentage of nitrogen in the roots and the weight of roots per acre should be considered. The varieties which gave the heaviest yield of root nitrogen per pot were the cowpea, velvet bean, jack bean, Mauritius bean, alfalfa, *Indigofera anil*, and *Phaseolus semierectus* grown on station soil.

(8) From the results obtained in beaker experiments, it appears that one-fifth of the total nitrate nitrogen of cowpeas is converted into soluble ammonia and nitrate salts in three weeks' time. In pot experiments, where the conditions more nearly represented those in the field, in the station soil pots one-half the nitrogen of decomposing cowpeas and jack beans was lost through weathering. In Kunia soil a loss of nitrogen was also observed in case of these legumes and also of velvet beans and soy beans, which showed no loss from weathering in station soil, probably because of their later maturity, and

consequently shorter period of weathering. It appears that in the field, with heavy rains or irrigation, considerable loss of nitrogen probably results through the leaching of soluble ammonia compounds and nitrates from decomposing legumes.

(9) It would be advisable, therefore, to follow the turning under of leguminous crops in field soil by the growth of a crop which would utilize the soluble nitrates and ammonia salts formed from the nitrogen of the legumes before they are lost by drainage.

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