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TB 1199 (1959) USDA TECHNICAL BULLETINS UPDATA
SOIL FERTILITY STUDIES IN LYSIMETERS CONTAINING LAKELAND SAND
ALLISON, F.E. ; ROLLER, E.M. ; ADAMS, J.E. 1 OF 1

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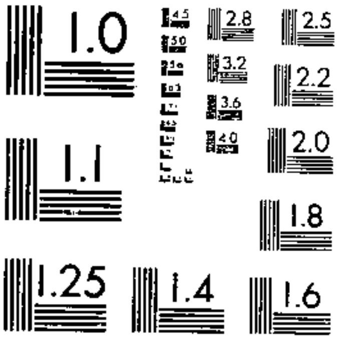

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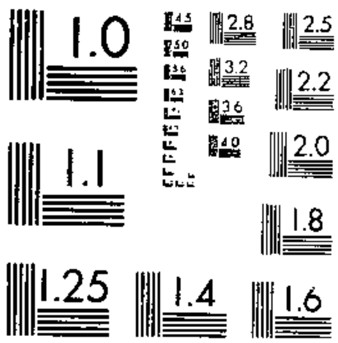

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Soil Fertility Studies in Lysimeters Containing Lakeland Sand

Technical Bulletin No. 1199

Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE
In Cooperation With
South Carolina Agricultural Experiment Station

The studies reported in this bulletin were made at the Sandhill Experiment Station, near Columbia, S. C., during 1932–45. The experiments were planned to obtain practical information on a problem sandy soil located near Columbia. Data were obtained during 1932–38 on rates of loss of plant nutrients and carbon in the sandy soil under various cropping conditions, especially following the addition of green manures, animal manures, and fertilizers. The experiments on the use of green manures in cotton production (1938–45 tests) were designed as a followup of the earlier experiments. A much wider variety of green manuring systems was used in the rotations with cotton.

A general lack of good information on the use of cover crops and on leaching losses of plant nutrients on sandy Coastal Plain soils made it practicable to publish the results of the above-listed studies. The desirability of using cover crops as a conservation practice on sandy Coastal Plain soils depends in part on their nutrient and moisture interrelations. Leaching losses, particularly of nitrogen applied off-season, is of real concern in the South. The information given in this bulletin not only will serve as a guide in the development of improved cover crop practices, but it will also give insight to nutrient movement in sandy soils, which is a key to developing sounder fertilizer practices. The results are believed to be applicable to other similar soils if allowance is made for climatic differences. It is necessary to bear in mind that the fertilizer rates used, especially in the earlier experiment, although normal for the time when the experiment was started, are low by 1958 standards.

Washington, D. C. **Issued May 1959**

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price 25 cents

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Soil Fertility Studies in Lysimeters Containing Lakeland Sand[1]

By F. E. Allison, principal soil scientist; E. M. Roller, formerly associate chemist; and J. E. Adams, formerly associate soil technologist, *United States Department of Agriculture*[2]

INTRODUCTION

Very sandy soils are frequently considered as problem soils, and may even be classed as marginal. Their low productivity is due chiefly to their deficient supply of plant nutrients, which are commonly found largely in the colloidal clay and organic fraction of soils. In addition, sandy soils are not retentive of water and are usually very droughty. Such soils are low in organic matter, which not only supplies available nutrients and holds water but assures an active biological population. Even if abundant amounts of plant residues are supplied regularly, soil organic matter will not be maintained at nearly so high a level in a sandy soil as in a clay or loam soil. With limited quantities of inorganic colloid present, the formation of organic-inorganic complexes, which are important constituents of the finer textured soils, is correspondingly limited.

Sandy soils are not wholly without merit, however, and have several advantages over clays. Sandy soils have excellent aeration, good drainage, and provide ease of root penetration. In addition, plowing and cultivation may be done at any time without danger of harmful effects. For crops such as melons and many vegetables, sandy soils are ideal. Some deep-rooted crops, such as alfalfa, also make excellent growths on very sandy soils if moisture is not too deficient and the necessary nutrients are supplied as needed. For most general farm crops, sandy soils are likely to be unsatisfactory or at least of limited value under most climatic conditions. For cotton or other long-season summer crops, very sandy soils present a problem of considerable magnitude to the grower.

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[1] This study was made in cooperation with the South Carolina Agricultural Experiment Station.

[2] The experimental plan was drawn up by Oswald Schreiner, J. J. Skinner, and Roland McKee, of the former Bureau of Plant Industry, U. S. Department of Agriculture; the experiments were conducted by J. E. Adams, E. M. Roller, Nelson McKaig, Jr., and A. B. Bowen, also from the former Bureau; and the mechanical and chemical analyses of soil were made under the direction of L. T. Alexander, U. S. Soil Conservation Service. The experimental data were assembled by F. E. Allison, Soil and Water Conservation Research Division, Agricultural Research Service. E. M. Roller died January 1, 1955.

NUTRIENT LOSSES, ORGANIC MATTER CHANGES, AND EVAPOTRANSPIRATION UNDER VARIOUS MANURING AND CROPPING SYSTEMS, 1932-38[3]

The experiments reported for 1932-38 were planned to obtain data on rates of loss of plant nutrients and carbon under various cropping conditions on Lakeland sand, especially following the addition of green manures, animal manures, and fertilizers.

EXPERIMENTAL PLAN

Description of Lysimeters

The lysimeters used are described briefly elsewhere.[4] They were installed at the Sandhill Experiment Station, Columbia, S. C., in 1932. The complete installation included 24 cylindrical steel tanks, 63 inches in diameter (1/2000 acre) and 48 inches in depth. They were buried in soil to within 4 inches of the top. The arrangement of these

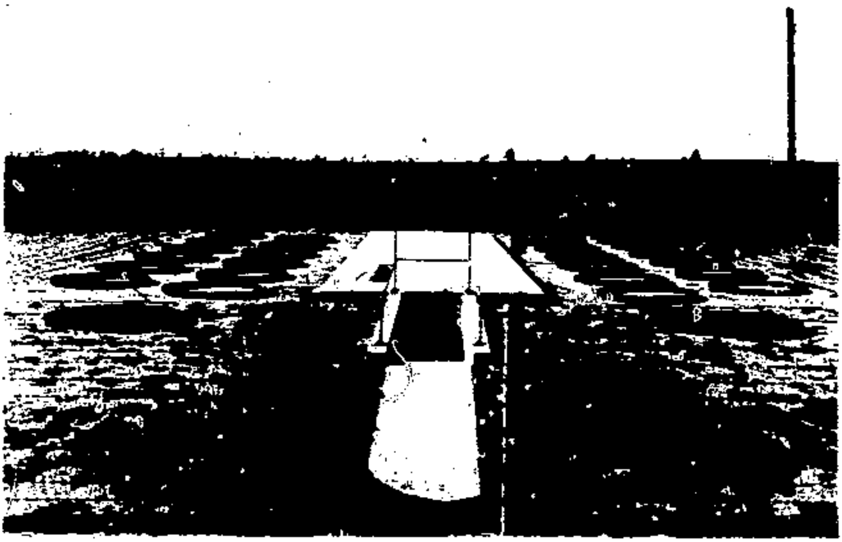

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FIGURE 1.—Enclosure showing arrangement of lysimeters.

24 lysimeters is shown in figure 1. A view of some of the lysimeters in the process of being installed is shown in figure 2. In this figure the steel tank in the foreground is inverted. Each of these tanks was connected by means of a block-tin tube (shown in fig. 2) with a steel receptacle 20 inches in diameter and 40 inches in depth into which the leachates from the soil tanks could drain. These receiving tanks, which were located below the soil tanks, are shown in figure 3. The

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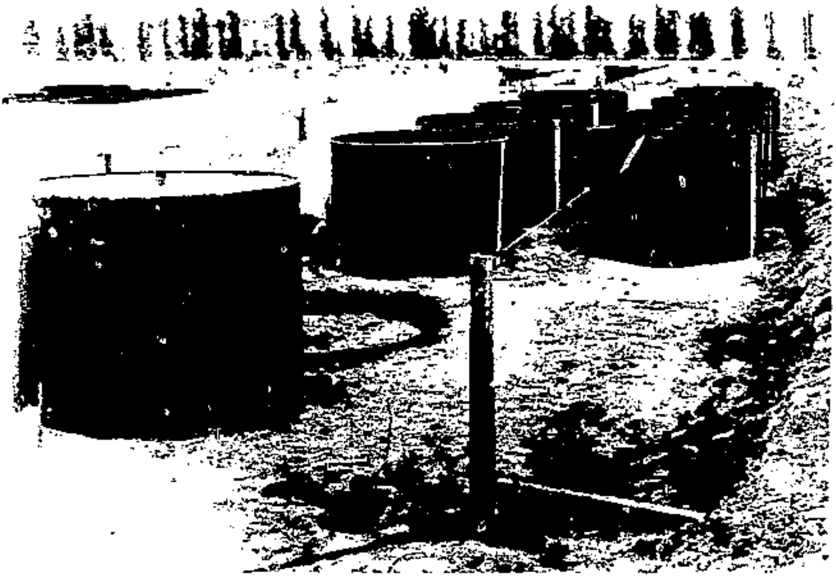
[3] This section was prepared by F. E. Allison, E. M. Roller, and J. E. Adams.

[4] ADAMS, J. E. GREEN MANURING AND FERTILIZER STUDIES IN LYSIMETERS. S. C. Agr. Expt. Sta. Ann. Rpt. 46: 154-156, illus. 1933.



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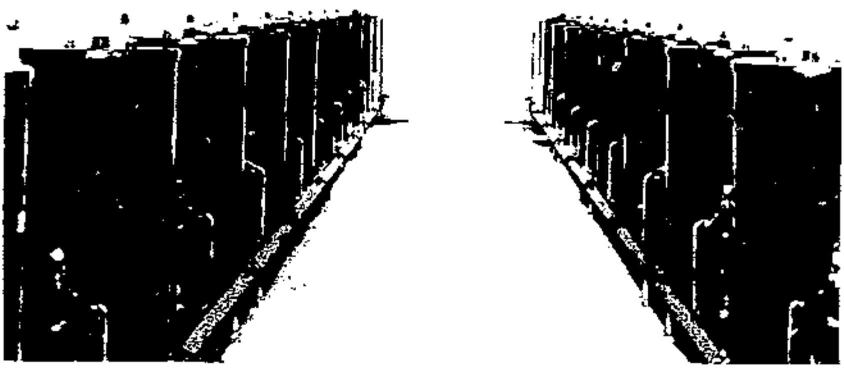

[illegible]

... soil tanks ... [illegible] ... coated with ... [illegible]

[illegible]

lysimeters, obtained from a wooded area on the experiment station grounds, was excavated by layers representing the natural formation, i. e., 0 to 10, 10 to 20, 20 to 40, and 40 to 43 inches. Each layer was thoroughly mixed on a platform and placed in the tanks in the same order as it was in the field. After filling, the soils were allowed to settle from July 1932, until the beginning of the cropping season of 1933.

Two shallow tanks of the same diameter as the soil tanks, and located near them, were used to measure the rainfall.

The Soil

The soil used in the lysimeters is described as a Lakeland sand by the United States Soil Conservation Service. Mechanical analyses of soil samples taken from different parts of the horizon are given in

TABLE 1.—*Mechanical analysis of Lakeland sand from Sandhill Experiment Station, Columbia, S. C.*

Depth, inches	Horizon	Particle-size distribution (in mm.)									
		Very coarse sand, 2–1	Coarse sand, 1–0.5	Medium sand, 0.5–0.25	Fine sand, 0.25–0.10	Very fine sand, 0.10–0.05	Silt, 0.05–0.002	Clay			
								<0.002	0.2–0.02	0.02–0.002	>2
SOIL SAMPLES FROM NATURAL HORIZON											
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0-3	A1	5.4	31.8	21.3	21.5	6.3	8.5	2.2	19.8	5.0	0
3-11	A21	5.9	30.4	19.9	23.9	8.3	8.6	3.0	23.1	5.6	0
11-18	A22	5.3	32.2	21.0	23.4	7.2	7.8	3.1	20.6	5.2	0
18-28	B2	5.8	30.9	20.0	23.3	7.1	7.9	5.0	20.6	4.5	0
28-39	B2	5.9	31.4	20.7	23.7	7.1	7.2	4.0	20.7	4.6	0
39-52	C1	5.2	29.4	21.5	27.6	7.9	5.2	3.2	23.2	2.9	0
52-62	C1	7.7	30.5	20.8	25.7	6.8	4.9	3.6	20.8	2.9	0
62-70	C2	9.1	32.1	20.5	24.4	6.4	4.4	3.1	19.5	2.6	0
SOIL SAMPLES TAKEN IN 1932 AS LYSIMETERS WERE FILLED											
0-10		5.6	34.0	20.2	23.0	6.6	7.4	3.2	20.0	4.7	0
10-20		5.7	35.9	21.2	21.3	5.8	6.7	3.4	17.5	4.5	0
20-40		4.8	30.8	21.8	24.4	7.9	6.8	4.4	20.4	4.6	0
40-43		9.5	35.0	20.1	21.0	5.7	5.5	3.2	17.1	3.7	0

TABLE 2.—*Chemical data on Lakeland sand from Sandhill Experiment Station, Columbia, S. C.*

Depth, inches	Horizon	pH	Organic matter			Extractable cations, meq./100 gm. soil						Base saturation
			Organic carbon	Nitrogen	C/N ratio	Ca	Mg	H	Na	K	Sum	
SOIL SAMPLES FROM NATURAL HORIZON												
			Percent	*Percent*								*Percent*
0-3	A1	4.9	1.47	0.016	32.0	0.3	<0.1	3.6	<0.1	<0.1	3.9	8
3-11	A21	5.3	.51	.017	30.0	<.1	<.1	1.7	<.1	<.1	1.7	<1
11-18	A22	5.4	.17			.1	<.1	1.0	<.1	<.1	1.1	9
18-28	B2	5.6	.10			.3	<.1	1.0	<.1	<.1	1.3	23
28-39	B2	5.9	.05			.2	.1	.8	<.1	<.1	1.1	27
39-52	C1	5.5	.03			<.1	.1	.6	<.1	<.1	.7	14
52-62	C1	5.7	.09			<.1	.2	.8	<.1	<.1	1.0	20
62-70	C2	5.3	.03			<.1	.2	.8	<.1	<.1	1.0	20
SOIL SAMPLES TAKEN IN 1932 AS LYSIMETERS WERE FILLED												
0-10		5.2	0.66	0.022	30.0	0.2	<0.1	1.1	<0.1	<0.1	1.3	15
10-20		5.5	.25	.010	25.0	.1	<.1	.8	.1	<.1	1.0	20
20-40		5.5	.05			.2	<.1	1.0	<.1	<.1	1.2	17
40-43		5.6	.09			<.1	<.1	0.8	.1	<.1	.9	11

table 1, and certain chemical data on these soils in table 2. These tables also give corresponding data on the 4 layers of soil taken at the time of filling the lysimeters. Very little difference in the mechanical nature of the soil occurs down to a depth of 6 feet. The data in table 1 emphasize the extremely sandy nature of the soil; the average clay content of the whole horizon was only a little more than 3 percent, and the total clay and silt was only 10 percent. This scarcity of fine particles explains the lack of development of a markedly differentiated profile. Since the soil was taken from a wooded area, there was a considerable accumulation of organic matter in the upper part of the A horizon but very little below the 18-inch depth. The wide carbon-nitrogen ratio of 30 to 1 in the surface 10 inches is owing chiefly to the presence of considerable elemental carbon that had accumulated as a result of the burning of forests in the unknown past. The extreme deficiency of the soil in nitrogen also limits the decomposition of the woody, highly carbonaceous, residues that are returned to the soil annually in forested areas and tend to accumulate at or near the surface. When placed in the lysimeters the soil in the 0 to 40-inch layer (see table 2) had a pH of 5.2 to 5.5 and was very deficient in all of the important soil bases.

Cropping and Fertilization

The cropping system for the 5-year experimental period for both summer and winter crops is shown for each of the lysimeters in table 3; the fertilizer and manure additions are given in table 4. None of the treatments was replicated. Since the crop and fertilizer treat-

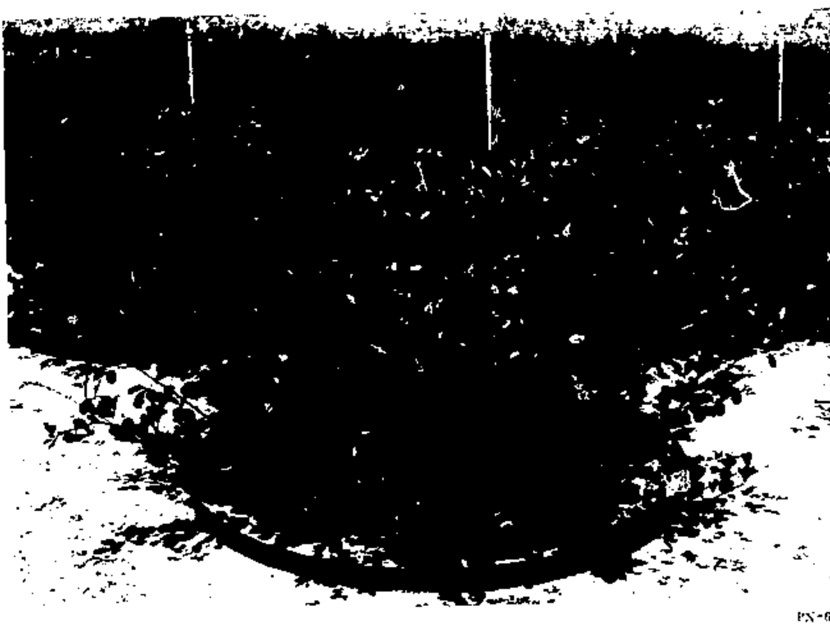

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FIGURE 4.—*Crotalaria mucronata (striata)* growing on lysimeters. Photograph taken in July.

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ments included a large number of variables, a summary of the main subjects upon which information was desired is given below.

Crotalaria (fig. 4) was grown on nine tanks. This portion of the experiment was designed to give information on the conservation of organic matter where crotalaria was turned as a green manure, where it was incorporated with the soil as a mature plant, and where the mature plants were used as a mulch. These three management practices were repeated with rye used as a winter cover. The use of mature crotalaria as a mulch with and without rye and of crotalaria harvested yearly was designed to give an index of the extent to which this crop serves as a soil-builder, and of the capacity of the soil to retain organic matter. Two additional tanks (Nos. 17 and 18), not cropped during the first 2 years, received an amount of fresh cow manure that furnished approximately the same quantity of nitrogen as added in the crotalaria. One of these tanks was cropped to rye each winter, whereas the other was left bare.

TABLE 3.—*The cropping system at the Sandhill Experiment Station, 1933–37*

Lysimeter No.	Summer crops [1]		Winter crops [2]		
	1933–34	1935–37	1933	1934	1935–37
1	Crotalaria, turned green.	Millet cut	None	None	None.
2	Crotalaria, turned mature.	do	do	do	Do.
3	Crotalaria, mulched	do	do	do	Do.
4	Crotalaria, turned green.	do	Rye, turned	Rye, harvested.	Do.
5	Crotalaria, turned mature.	do	do	do	Do.
6	Crotalaria, mulched	do	do	do	Do.
7	Cowpeas, turned mature.	do	None	None	Do.
8	do	do	Rye, turned	Rye, harvested.	Do.
9	Corn-crotalaria, mulched.	do	None	None	Do.
10	do	do	Rye, turned	Rye, harvested.	Do.
11	Crotalaria, mulched	Crotalaria, mulched.	None	None	Do.
12	do	do	Rye, turned	Rye, harvested.	Rye, turned.[3]
13	Crotalaria, harvested.	Crotalaria, harvested.	None	None	None.
14	None	None	do	do	Do.
15	Corn stover, turned	Millet, cut	do	do	Do.
16	None	None	do	do	Do.
17	do	Millet, cut	do	do	Do.
18	do	do	Rye, turned	Rye, harvested.	Do.
19	Millet, cut	do	Mixture, turned.	Mixture, harvested.	Mixture, harvested.
20	do	do	do	do	Do.
21	do	do	do	do	Do.
22	do	do	do	do	Do.
23	Cowpeas, turned mature.	do	Rye, turned	Rye, harvested.	None.
24	do	do	do	do	Do.

[1] *Crotalaria mucronata (striata)* was used throughout the experiment. All millet was cut 3 to 5 times each season and removed.
[2] The green manure mixture grown in lysimeters 19 to 22 consisted of rye, oats, barley, and vetch.
[3] Harvested the last year of the experiment.

TABLE 4.—*Fertilizer and manure treatments at the Sandhill Experiment Station, 1933–37*

Lysimeter No.	Kind of treatment [1]	Amount per acre and year
1–3	Nitrogen in crotalaria turned under	72.0 lb. N and 81.4 lb. N, resp., 1933 and 1934.
4–6	do	72.0 lb. N and 86.6 lb N, resp., 1933 and 1934.
7	Nitrogen in cowpeas turned under	26.1 lb. N, annually, 1933 and 1934.
8	do	31.7 lb. N, annually, 1933 and 1934.
9–10	Sodium nitrate added as side dressing to corn. Nitrogen added in crotalaria not determined.	75 lb. and 150 lb., resp., 1933 and 1934.
11	Nitrogen in crotalaria, mulched	72.0, 81.4, 142.8, 119.2, and 89.7 lb., resp., for 1933, 1934, 1935, 1936, 1937.
12	do	72.0, 86.6, 137.8, 97.0, and 95.5 lb., resp., for 1933, 1934, 1935, 1936, and 1937.
13	Nitrogen removed in crotalaria hay crop	72.0, 77.4, 129.4, 81.4, and 55.2 lb. N removed, resp., 1933, 1934, 1935, 1936, 1937.
14	No additional fertilizer	
15	Sodium nitrate added as side dressing to corn.	75 lb. and 150 lb., resp., 1933 and 1934.
16	No fertilizer	
17–18	Fresh cow manure added in fall	11.8 tons (72.0 lb. N) and 14.0 tons (81.4 lb. N), resp., 1933 and 1934.
19	Fresh cow manure added	17.8 tons (145.0 lb. N), spring 1933. 11.5 tons (84.4 lb. N), summer 1934. 5.0 tons (28.9 lb. N), fall 1934. 5.0 tons (30.5 lb. N), spring 1935. 5.0 tons (34.8 lb. N), fall 1935. 5.0 tons (38.0 lb. N), spring 1936. 5.0 tons (31.2 lb. N), fall 1936. 5.0 tons (38.4 lb. N), spring 1937. 5.0 tons (36.1 lb. N), fall 1937.
	Sodium nitrate added	100 lb., summer 1934, and 50 lb., winter 1934.
20	Similar to lysimeter 19, except manure mixed with oat straw.	Total nitrogen added same as for lysimeter 19.
21	Similar to lysimeter 19, except manure was semideep stall manure with oat straw used as bedding material.	Do.
22	Similar to lysimeter 19, except manure was deep stall manure.	Do.
23	Nitrogen in cowpeas turned under	43.8 lb. N annually, 1933 and 1934.
	Dolomitic limestone applied	1,200 lb. in 1933.
24	Nitrogen in cowpeas turned under	42.9 lb. N annually, 1933 and 1934.
	Dolomitic limestone applied	1,200 lb. in 1933.
	Muriate potash applied	100 lb. in 1933.

[1] 400 pounds of 4–8–4 fertilizer added annually each spring to all lysimeters except No. 16 for the 5 years and to Nos. 17 and 18 for 1933 and 1934. An additional 400-pound application was made to fall crops on lysimeters Nos. 19 to 22 for each year, 1934 to 1937.

Cowpeas were grown on four tanks in order to compare a common summer legume with crotalaria. The soil in two of the tanks was not limed, whereas the other two received 1,200 pounds per acre of dolomitic limestone. One tank that was not limed had a winter rye cover, but both tanks that were limed were planted to rye. One of these lysimeters received an application of 100 pounds of muriate of potash in addition to the basic fertilizer treatment, in order to overcome any potash deficiency induced or intensified by the use of limestone.

The series included both a fertilized and an unfertilized uncropped soil. The basic treatment (see table 4) was 400 pounds of a 4–8–4 fertilizer added annually.

Corn was grown on three tanks for the 2 years. Two of these were interplanted with crotalaria at the last cultivation, and one of these corn-crotalaria tanks also had rye as a winter cover.

Four lysimeters were used to study four types of manure produced at the dairy: (*a*) fresh solid manure without litter; (*b*) fresh manure plus oats straw corresponding to that obtained in the daily cleaning of the rest stalls; (*c*) manure collected in the semideep (8–10 inches) stall method where sufficient litter was added to keep the animals clean; and (*d*) deep stall manure. These four tanks were cropped to pearl millet during the summer and to a mixed crop of rye, oats, barley, and vetch during the winter. The millet was clipped and removed periodically in order to simulate grazing conditions.

Methods of Analysis

The methods of analysis used were for the most part the ones used by the Association of Official Agricultural Chemists (A. O. A. C.).[5]

Organic nitrogen was determined by the Kjeldahl method, using a salt mixture consisting of Na_2SO_4, $FeSO_4$, and $CuSO_4$. Where total nitrogen, including nitrates, was desired the salicylic acid modification was used. Nitrates were determined by the phenoldisulfonic acid method.

Carbon was oxidized by boiling in concentrated H_2SO_4 and $K_2Cr_2O_7$ for 30 to 40 minutes, collecting the carbon dioxide in alkali, and titrating according to the method of Adams.[6]

Potassium was precipitated as K_2PtCl_6, the precipitate dissolved in HCl, reduced with magnesia, filtered, washed, and ignited, and the platinum weighed.

Calcium was precipitated as CaC_2O_4, H_2SO_4 added, and titrated with standard $KMnO_4$.

Magnesium was precipitated as $MgNH_4PO_4$, the precipitate washed, ignited, and weighed as magnesium pyrophosphate.

Phosphorus was determined volumetrically by the molybdate method.

The methods used for manganese, sulfur, and chlorine were the official A. O. A. C. methods.

Soil reaction, expressed as pH, was determined by the potentiometric method of Snyder.[7]

RESULTS

Crop Yields and Nitrogen Contents

The dry weights of the summer and winter crops, and the nitrogen removed in the crops, are given in tables 5 and 6, respectively.

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[5] Association of Official Agricultural Chemists. official and tentative methods of analysis of the association of official agricultural chemists. Ed. 3. 593 pp., illus. 1925.

[6] Adams, J. E. determination of total carbon in soils by the wet oxidation method. Indus. and Engin. Chem., Analyt. Ed. 6: 277–279, illus. 1934.

[7] Snyder, E. F. methods for determining the hydrogen-ion concentration of soils. U. S. Dept. Agr. Cir. 56, 29 pp., illus. 1928.

TABLE 5.—*Crop yields as tons of dry matter in the tops per acre, Sandhill Experiment Station, 1933–38*

Lysimeter No.	Summer crops								Winter crops					
	Kind of crop, 1933–34	Years		Kind of crop 1935–37	Years				Kind of crop	Years				
		1933[1]	1934[2]		1935	1936	1937	Total		1933–34	1934–35	1935–36	1936–37	1937–38
1	Crotalaria	1.30	1.46	Millet	0.97	0.64	0.67	2.28	None					
2	do	1.30	1.63	do	1.25	.71	.72	2.68	do					
3	do	1.30	1.56	do	1.27	.70	.70	2.67	do					
4	do	1.30	1.58	do	1.20	.81	.74	2.75	Rye	[3]	0.36			
5	do	1.30	1.60	do	1.47	.81	.83	3.11	do	[3]	.30			
6	do	1.30	1.60	do	1.44	.74	.81	2.99	do	[3]	.22			
7	Cowpeas		.67	do	.55	.54	.54	1.93	None					
8	do		.77	do	.91	.72	.66	2.29	Rye		.30			
9	Corn (grain).		.40	do	.90	.55	.55	2.09	None					
10	do		.60	do	1.00	.59	.57	2.16	Rye	[3]	.73			
11	Crotalaria	1.30	1.53	Crotalaria	3.05	2.15	1.95	7.15	None					
12	do	1.30	1.60	do	3.16	2.05	2.01	7.22	Rye	[3]	.25	0.66	0.81	0.51
13	do	1.30	1.66	do	2.74	1.54	1.14	5.42	None					
14	None			None					do					
15	Corn (grain).		.50	Millet	.60	.49	.50	1.59	do					
16	None			None					do					
17	do			Millet	1.29	.62	.59	2.50	do					
18	do			do	1.25	.75	.70	2.70	Rye	[3]	.30			
19	Millet	1.34	1.83	do	1.53	1.26	1.54	4.33	Mixture[4]	[3]	.62	.83	1.13	1.23
20	do	1.32	1.79	do	1.96	1.44	2.00	5.40	do.[4]	[3]	.65	1.04	1.11	1.58
21	do	1.81	2.11	do	2.05	1.80	1.80	5.74	do.[4]	[3]	.79	1.05	1.42	1.79
22	do	1.38	1.45	do	1.53	1.36	1.86	4.75	do.[4]	[3]	.67	1.00	1.18	1.21
23	Cowpeas		1.40	do	1.26	.88	.74	2.88	Rye	[3]	.52			
24	do		1.33	do	1.18	.91	.80	2.89	do	[3]	.53			

[1] The weight of crotalaria was determined for lysimeter 13 only; the values for the other lysimeters for the year 1933 were assumed to be the same.
[2] The weights of cowpeas and corn given in this column are totals for 1933 and 1934.
[3] Not determined.
[4] The mixture consisted of rye, oats, barley, and vetch.

The effect of 2 successive crops of crotalaria used as a green manure on the growth and nitrogen content of millet during the following 3 years was determined in lysimeters 1 to 6. In general, the recovery of nitrogen in the crops closely paralleled the dry weights of the millet. When the crotalaria was turned under green, the yields of millet were somewhat less than where it was allowed to grow to maturity. This was probably owing chiefly to the larger quantity of nitrogen fixed by the longer growing crotalaria. The nitrogen in the mature plants would also be held to a slightly greater extent against leaching. No appreciable difference between the results was obtained where the mature crotalaria was turned into the soil and where it was left as a surface mulch. The use of a winter cover crop of rye was beneficial for all three systems of utilization of the summer green manure crop. The rye reduced the leaching of nitrate nitrogen during the winter season, and this nitrogen was later released through decay to the millet.

Where cow manure was added to lysimeters 17 and 18 in such quantity as to supply approximately the same amount of nitrogen as fixed by the young crotalaria (lysimeter 1), the yields were not greatly different from those obtained where the nitrogen source was green crotalaria. The results from lysimeters 17 and 18 are not, however, strictly comparable with those obtained where crotalaria was grown, because no nitrogen additions as complete fertilizer were made to these lysimeters during the first 2 years. This deficit amounted to 32 pounds of nitrogen. Furthermore, both lysimeters were uncropped during the first 2 summers of the experiment, thus allowing considerable loss of nitrogen through leaching.

TABLE 6.—*Nitrogen removed in crops as pounds per acre, Sandhill Experiment Station, 1933–38*

Lysimeter No.	Crops [1]	1933–34 Summer	1933–34 Winter	1934–35 Summer	1934–35 Winter	1935–36 Summer	1935–36 Winter	1936–37 Summer	1936–37 Winter	1937–38 Summer	1937–38 Winter	Total for 5 years
1	Crotalaria and millet	0	0	0	0	21.8	0	17.1	0	19.4	0	58.3
2	do	0	0	0	0	31.2	0	19.3	0	21.2	0	71.7
3	do	0	0	0	0	29.5	0	19.4	0	21.0	0	69.9
4	Crotalaria, millet, and rye.	0	0	0	[2] 1.3	27.4	0	22.4	0	21.5	0	72.6
5	do	0	0	0	[2] 1.6	35.8	0	22.7	0	24.6	0	84.7
6	do	0	0	0	[2] 1.2	33.4	0	22.1	0	24.5	0	81.2
7	Cowpeas and millet	0	0	0	0	20.0	0	14.1	0	15.9	0	50.0
8	Cowpeas, millet, and rye.	0	0	0	[2] 1.3	20.0	0	18.5	0	19.5	0	59.3
9	Corn, crotalaria, and millet.	------	0	[3] 36.6	0	25.3	0	15.1	0	16.4	0	93.4
10	Corn, crotalaria, millet, and rye.	------	0	[3] 40.1	[2] 1.1	25.4	0	17.3	0	17.3	0	101.2
11	Crotalaria	0	0	0	0	[2] 8.9	0	0	0	0	0	8.9
12	Crotalaria and rye	0	0	0	[2] 1.9	[2] 9.0	[2] 2.1	0	[2] 1.3	0	13.7	28.6
13	Crotalaria	72.0	0	77.4	0	129.4	0	81.4	0	55.2	0	415.4
14	None	0	0	0	0	0	0	0	0	0	0	0
15	Corn and millet	------	0	[3] 40.4	0	14.8	0	12.8	0	13.9	0	81.9
16	None	0	0	0	0	0	0	0	0	0	0	0
17	Millet	0	0	0	0	28.4	0	16.9	0	17.1	0	62.4
18	Millet and rye	0	0	0	[2] 1.3	25.6	0	19.0	0	19.3	0	65.2
19	Millet and mixture	23.5	0	47.1	27.8	40.3	21.3	40.2	22.1	47.7	17.8	287.8
20	do	25.0	0	43.9	37.3	48.4	18.6	37.0	41.3	50.5	21.2	323.2
21	do	37.2	0	53.8	45.3	47.3	27.1	49.2	36.9	45.6	27.7	370.1
22	do	25.4	0	36.2	32.6	37.7	25.8	36.2	26.2	51.3	19.0	290.4
23	Cowpeas, millet, and rye.	0	0	0	[2] 1.7	27.9	0	23.2	0	22.0	0	74.8
24	do	0	0	0	[2] 1.8	25.8	0	22.3	0	20.9	0	70.8

[1] See table 3 for details of cropping system.
[2] Includes only the nitrogen in the plant samples taken for analysis.
[3] Total nitrogen removed in 1933 and 1934 in grain. Separate values for the 2 years are not available.

The yields of millet from lysimeters 7 and 8, where cowpeas were turned under as a green manure, were much smaller than from the corresponding soils (lysimeters 2 and 5) where crotalaria was grown. This was obviously due to the much smaller quantity of nitrogen fixed by the 2 crops of cowpeas. In lysimeters 23 and 24, where dolomite was added, the cowpeas made a better growth and fixed more nitrogen. This better green crop produced larger yields of millet during the following 3 years. Potassium, supplied as muriate of potash, in addition to that supplied annually in the 4–8–4 fertilizer was without effect. In this sandy soil the main factor, other than water, that determined yields was apparently the quantity of nitrogen available for use at the time the crop needed it. When the green crop was turned under, the data (tables 5 and 6) show that although the main benefit was to the first crop, there were still appreciable benefits to the second and third crops.

The value of the green manures, especially crotalaria, to the crops that followed, is shown by comparison of the 3-year millet yields (1935–37) from these lysimeters with the corresponding yields where corn was grown (lysimeter 15) during the initial 2-year period. Cowpeas (lysimeter 7) increased the yields of millet by about 21 percent and crotalaria (lysimeters 1 to 3) by 60 percent. The inclusion of a rye cover crop increased these percentages to about 44 and 85, respectively. These differences were obtained regardless of the fact that corn received sidedressings of 37 pounds of nitrogen as sodium nitrate that were not given to the 2 legume crops during the initial 2-year period. Where corn was interplanted with crotalaria, the subsequent millet crops were nearly a third larger. These results again emphasize the importance of available nitrogen in crop production on this sandy soil.

In two lysimeters crotalaria was grown each summer for 5 years and returned to the soil as a mulch. In one of these (lysimeter 12) a rye cover crop was used, whereas in the other (lysimeter 11) the soil was left bare. The crotalaria yields averaged 2 tons of dry matter per acre per year for both treatments. In a third lysimeter (No. 13) where crotalaria was cut and removed, the average yield was 1.7 tons. Since the crotalaria could obtain its nitrogen from the air, it is likely that the lower yield on lysimeter 13 was due chiefly to the removal of essential mineral nutrients. Although the crotalaria yields (table 5) on the 3 lysimeters were identical for the first 2 years, they were markedly less during subsequent years where the crop was removed (lysimeter 13) than where it was returned as a mulch (lysimeters 11 and 12).

The dry weights and nitrogen contents of the millet and winter cover crops fertilized with four kinds of manure (lysimeters 19 to 22) show that semideep stall manure produced the greatest returns, whereas fresh manure and deep stall manures gave the poorest results. Yields were closely correlated with the nitrogen contents of the crops. The highest yields and nitrogen recoveries, obtained with the semideep stall manure, were about 20 percent greater than those for the fresh manure and deep stall manure. In evaluating these data it should be remembered that, although the same quantity of nitrogen was added to each of the four lysimeters, the comparisons are a little confused by the inclusion of vetch in the winter cover crop mixture. Data to be presented later (see table 13) show that a considerable portion of the nitrogen added in the four manures remained in the soil at the end of the experiment. The differences in retained nitrogen between manures were small. Furthermore, little nitrogen was lost, as will be shown later (see table 12) through leaching. In view of these facts and the lack of knowledge of the carbon-nitrogen ratios of the added manures, it is impossible to account with certainty for the differences obtained. They were likely determined by the quantity of nitrogen fixed by the vetch, by the amount lost through volatilization, by rate of release of nitrogen from the manures, and by the presence or absence of an adequate crop to utilize it as released.

Effect of Crop on Quantity of Leachate

The rainfall during the 5-year experimental period is given in inches by months and years in table 7. The quantity of water that percolated through the various lysimeters is shown in table 8. Calculations made from the data in these two tables show that an average

TABLE 7.—*Rainfall during the 5-year experimental period at Sandhill Experiment Station, 1933–38*

Month	1933	1934	1935	1936	1937	1938	Average
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
January		1.08	1.36	7.23	5.34	1.41	3.26
February		3.52	2.27	4.05	4.17	.64	2.93
March		3.66	1.84	5.06	2.94	1.01	2.92
April		2.36	3.85	10.26	6.35	6.35	5.83
May	3.70	4.58	1.14	.19	1.82		2.29
June	2.49	1.92	2.85	2.18	8.39		3.57
July	4.09	3.18	5.04	3.83	4.56		4.26
August	3.83	6.11	7.20	4.60	7.60		5.87
September	1.68	4.20	5.54	2.05	1.90		3.07
October	1.15	2.81	.99	8.70	2.39		3.21
November	.42	3.42	2.92	2.90	3.03		2.54
December	.83	3.40	2.24	4.45	2.45		2.67
Total for years and average annual rainfall	18.79	40.24	37.24	55.50	50.04	9.41	42.44

TABLE 8.—*Quantities of percolate expressed as inches per unit surface of lysimeters, Sandhill Experiment Station, 1933–38*

Lysimeter No.	Crops grown and rainfall	1933–34		1934–35		1935–36		1936–37		1937–38		1933–38	
		Apr. 4, 1933, to Oct. 26, 1933	Oct. 27, 1933, to Apr. 9, 1934	Apr. 10, 1934, to Oct. 1, 1934	Oct. 2, 1934, to Apr. 4, 1935	Apr. 5, 1935, to Oct. 2, 1935	Oct. 3, 1935, to Apr. 14, 1936	Apr. 15, 1936, to Oct. 15, 1936	Oct. 16, 1936, to Apr. 8, 1937	Apr. 9, 1937, to Oct. 4, 1937	Oct. 5, 1937, to Apr. 16, 1938	Total for 5 years	Percentage of total rainfall [1]
1	Crotalaria and millet.	5.52	2.74	5.95	9.07	9.69	26.85	6.95	17.36	14.86	10.24	109.23	51.2
2	do	4.65	1.45	5.82	7.00	8.66	26.18	6.47	17.32	14.55	10.05	102.24	47.5
3	do	5.04	1.96	5.83	7.91	8.56	26.50	6.57	17.55	14.61	10.05	104.58	48.6
4	Crotalaria, millet, and rye.	5.00	.71	5.85	5.69	8.59	26.12	6.46	17.38	14.16	9.91	99.89	46.8
5	do	5.14	.16	5.66	5.06	7.46	26.46	5.88	17.22	14.28	10.05	97.37	45.3
6	do	5.18	.51	5.78	5.42	7.76	26.21	6.19	17.38	14.22	9.86	98.51	45.8
7	Cowpeas and millet.	4.13	2.85	7.47	10.68	10.14	26.20	7.14	17.14	14.82	9.82	110.39	51.7
8	Cowpeas, millet, and rye.	3.52	1.43	6.93	8.11	9.88	26.03	6.66	17.28	14.49	9.85	104.18	48.8
9	Corn, crotalaria, and millet.	4.64	2.03	8.45	6.27	8.89	26.44	7.00	17.27	14.80	9.67	105.46	49.4
10	Corn, crotalaria, millet, and rye.	4.24	1.38	8.03	4.07	8.92	25.68	6.75	16.94	14.23	9.53	100.67	47.2
11	Crotalaria	4.91	2.00	5.95	7.94	3.61	22.86	2.87	10.92	8.01	7.61	82.68	38.3
12	Crotalaria and rye.	4.70	.49	5.71	5.33	2.85	20.96	3.12	15.17	8.23	6.07	72.63	33.6
13	Crotalaria	4.95	.87	6.01	7.34	4.24	22.93	3.60	17.37	10.26	9.11	86.68	40.1
14	None	8.42	3.90	13.47	10.35	15.01	26.24	11.02	17.38	18.09	9.88	133.76	62.7
15	Corn and millet	4.47	3.51	9.20	10.61	10.88	25.76	7.35	17.02	14.64	9.47	113.00	53.0
16	None	8.50	3.78	13.99	10.42	15.38	26.00	11.23	16.73	17.21	9.44	132.68	62.2
17	Millet	8.28	4.13	13.70	10.67	9.00	25.63	7.20	16.76	14.54	9.60	119.60	56.1
18	Millet and rye	8.15	1.07	13.80	7.65	9.08	25.81	6.21	16.87	13.48	9.03	111.15	52.1
19	Millet and mixed crops.	2.83	3.70	7.88	8.03	7.17	22.35	5.62	14.08	11.89	5.84	89.39	41.9
20	do	3.40	3.84	8.10	8.01	6.40	22.09	5.28	14.00	10.67	5.49	87.28	41.0
21	do	2.54	3.77	8.02	7.67	6.23	21.79	5.20	13.13	11.52	5.43	85.30	40.0
22	do	2.86	3.91	8.17	8.02	7.23	22.32	4.96	13.84	11.67	5.90	88.88	41.7
23	Cowpeas, millet, and rye.	3.39	.87	5.98	7.22	8.70	25.79	6.14	16.74	13.84	9.34	98.01	46.0
24	do	3.52	.74	6.44	7.77	8.93	25.81	6.02	17.10	13.54	9.77	99.64	46.7
Rainfall inches		18.56	10.11	21.76	17.30	23.42	32.53	20.51	24.38	27.55	17.23	213.35	...

[1] A total of 1.78 inches of irrigation water was added to each of lysimeters 2, 3, 5, 6, 11, 12, and 13 during September and October 1933, and 0.88 inch was added to each of lysimeters 11, 12, and 13 in August 1935. In calculating the percentage of rainfall recovered in the percolates, these additions are included.

of 47.4 percent of the rain that fell on the 24 lysimeters leached through the soils. The largest amount of percolate—62.5 percent—was collected from the two uncropped lysimeters, and the least amount, 33.6 percent, from lysimeter 12, which grew a very heavy crop of crotalaria each summer and had a rye cover during the winters. The intermediate values for the other treatments were inversely related to the size of the crops grown.

Crop Yields and Evapotranspiration

The water losses by evapotranspiration (evaporation from soil plus transpiration) from the various lysimeters, together with the crop yields, are shown in table 9. The results of calculations of the efficiency of water use in terms of production of units of dry matter are also given.

TABLE 9.—*The use of water by crops grown in rotation in lysimeters for 5 years, Sandhill Experiment Station, 1933–38*

Lysimeter No.	Average dry matter produced per year	Average evapotranspiration per year			
		Water per year	Dry matter per inch	Water per 1,000 pounds dry matter	Water per pound of dry matter
	Pounds per acre	*Inches*	*Pounds*	*Inches*	*Pounds*
1	2,016	20.8	96.9	10.32	2,336
2	2,244	22.2	101.1	9.89	2,240
3	2,212	21.8	101.5	9.86	2,231
4	2,540	22.7	111.9	8.94	2,023
5	2,644	23.2	114.0	8.77	1,987
6	2,532	23.0	110.1	9.08	2,057
7	1,040	20.6	50.5	19.81	4,485
8	1,464	21.8	67.2	14.86	3,371
9	1,156	21.6	53.5	18.69	4,230
10	1,928	22.5	86.0	11.67	2,642
11	3,992	26.1	153.0	6.54	1,480
12	5,040	28.1	179.4	5.58	1,262
13	3,352	25.3	132.5	7.55	1,709
14	0	15.9			
15	1,036	20.1	51.5	19.40	4,393
16	0	16.1			
17	1,000	18.8	53.2	18.80	4,256
18	1,328	20.4	64.7	15.45	3,499
19	4,772	24.8	192.4	5.20	1,177
20	5,452	25.2	216.4	4.62	1,046
21	6,200	25.6	242.2	4.13	935
22	4,924	24.9	197.8	5.06	1,145
23	2,128	23.1	92.1	10.86	2,458
24	2,112	22.7	93.0	10.75	2,433
Weighted average			147.5	8.27	1,872

When the pounds of dry matter produced in the tops are plotted against evapotranspiration, as in figure 5, a straight line with a correlation coefficient of 0.886 is obtained. This line intercepts the X-axis at a point nearly corresponding to the water loss from a bare soil. If the yields from lysimeters 19 to 22, inclusive, which received much larger additions of nutrients, are eliminated, then the correlation coefficient is 0.957. The maximum evapotranspiration was about 28 inches of water per year from cropped soil, whereas the loss from bare soil was 16 inches.

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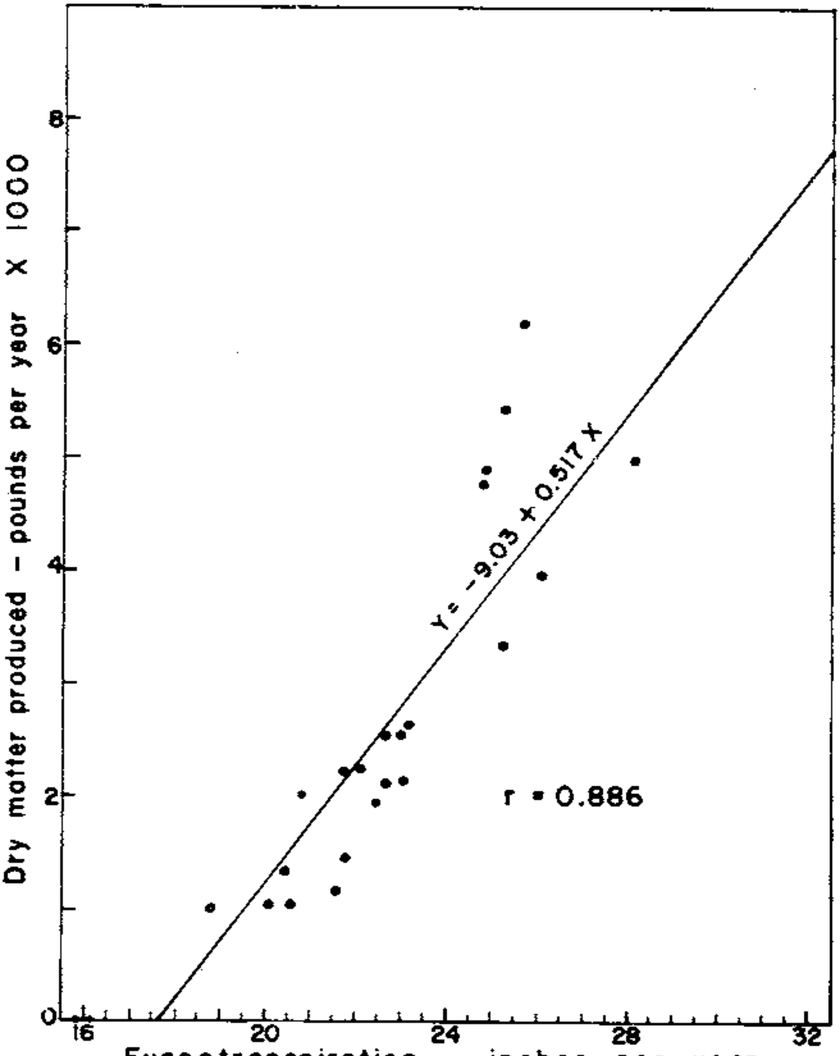

FIGURE 5.—The relationship between crop yields and evapotranspiration.

The total evapotranspiration (table 9, col. 6) ranged from 935 to 4,485 pounds of water per pound of dry matter produced, with an average value of 1,872 pounds. Cropping systems that left the soil bare for a minimum part of the time and produced the largest yields required the least water per unit of crop produced.

The economics of water use is better shown if crop yields are plotted against the efficiency of water use, as is done in figure 6. This plot gives a straight line with a correlation coefficient of 0.995. The more dry matter produced per unit area, or per inch of rainfall, the greater is the efficiency of use. This holds true regardless of kind of crop or rotation used.

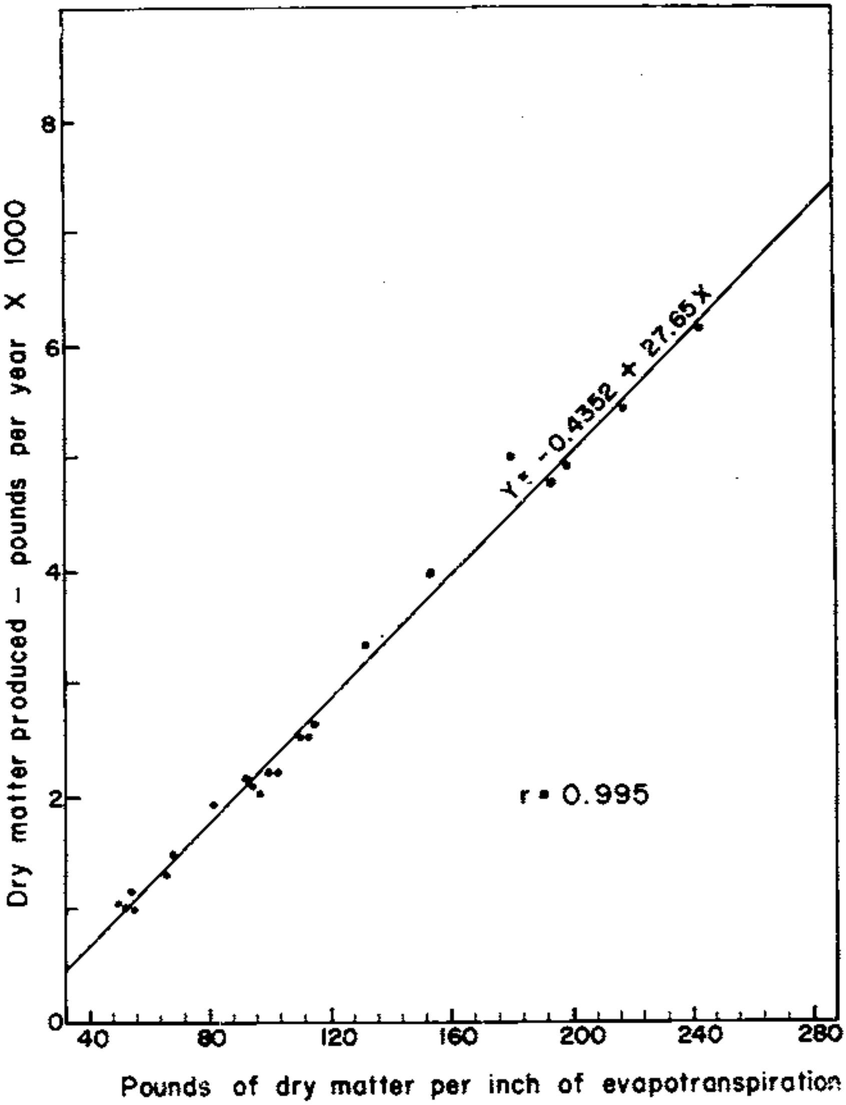

FIGURE 6.—The relationship between crop yields and efficiency of water use.

The 16-inch loss of water from an uncropped soil (table 9 and fig. 5) constitutes in net effect an overhead loss; it is the minimum loss that occurs under any condition. As crop growth proceeds from the seedling stage until near maturity the loss of water by evaporation from the soil surface gradually decreases, owing chiefly to increased soil water tension, shading, and mulching effects of the crop. During the same time, however, this loss is more than offset by increasing transpiration that tends to parallel crop growth. During the entire growth period of the crop the water loss by evaporation can be expected to be about one-half as great as the loss by transpiration.

In making use of these evapotranspiration results,[5] it is well to remember that lysimeter data of the type reported here cannot be expected to agree exactly with those obtained in the field. Under both conditions water losses by evapotranspiration are determined chiefly by the available moisture supply and the amount of radiant energy that strikes the plant. At certain times crops growing in the field, especially if deep rooted, may have more moisture available than if growing in the limited amount of soil in a lysimeter. In very dry years this difference may be important. There are other times, however, when lysimeter soils, due to the broken soil column and lack of downward capillary pull, may supply more water to the crop than would a corresponding field soil. The very sandy soil used in the present experiments, together with the depth of lysimeter, should have minimized these factors.

Secondary factors affecting evapotranspiration include wind velocity, relative humidity, air temperature, and density of vegetation. In the lysimeter experiments no crops were grown on the area in their immediate vicinity, and hence some of the energy that fell on this area was reflected against the vegetation in the lysimeters, or helped to warm the soils. Furthermore, the exposed isolated plants also intercepted more wind than they would have if growing in the field. The larger plants may also have received a little more light than would normally have fallen on the surfaces of the lysimeter, but this is offset in part at least by the greater amount of rain that such plants would intercept. All these effects are not believed to have affected appreciably the main conclusions to be drawn from the experiment. Certainly, in any general evaluation of the data, consideration should be given to the high accuracy with which water use can be measured in lysimeters in contrast to the lack of accuracy with which it can be measured in field experiments.

These studies, which show that high efficiency of water use is dependent upon high crop yields, also by inference show that any factor that increases these yields, such as fertilizers, a more fertile soil, better soil tilth, more available soil moisture, higher yielding types of crops, and better varieties, would be expected to increase the efficiency of water use. The type of crop grown and the rotation used are of minor importance except as these affect the total production of dry matter. A cropping system that keeps a growing crop on the soil for as large a percentage of the time as feasible would also favor the more economic use of the water.

These findings, when applied to irrigation farming, suggest that it would be inadvisable to bring new lands under irrigation unless they are capable of producing bumper crops. Furthermore, if water is limited, it would be better to irrigate a limited acreage adequately than to use the same water sparingly on a much larger area.

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[5] Allison, F. E., Roller, E. M., and Raney, W. A. THE RELATIONSHIP BETWEEN EVAPOTRANSPIRATION AND YIELDS OF CROPS GROWN IN LYSIMETERS RECEIVING NATURAL RAINFALL. Agron. Jour. 50:506–511. 1958.

Nitrogen in Leachates

The losses of nitrate nitrogen from the soils by leaching during the 5-year period of the experiment, shown in table 10, ranged for the various treatments from an extremely high value of 178 pounds to a low value of 10 pounds per acre. Although there was some relationship between rainfall and the quantity of nitrate in the percolates, this was not the most important factor. Loss was determined primarily by the quantity of nitrate in the soil at the time that leaching occurred, which was in turn determined by the quantity of nitrogen recently added in the various forms and by the extent to which the cropping treatments succeeded in removing the nitrates as formed.

TABLE 10.—*Nitrate nitrogen in percolates expressed as pounds per acre, Sandhill Experiment Station, 1933–38*

Lysimeter No.	Crops grown and rainfall	1933–34		1934–35		1935–36		1936–37		1937–38		Total
		May 10 to Oct. 26	Oct. 27 to Apr. 9	Apr. 10 to Oct. 1	Oct. 2 to Apr. 4	Apr. 5 to Oct. 2	Oct. 3 to Apr. 14	Apr. 15 to Oct. 15	Oct. 16 to Apr. 8	Apr. 9 to Oct. 4	Oct. 5 to Apr. 15	
1	Crotalaria and millet	11.8	2.4	26.3	43.5	3.3	7.5	0	2.9	0.1	4.0	101.8
2	do	7.4	.8	21.8	35.5	9.3	8.7	0	3.5	.1	5.3	92.4
3	do	9.3	1.4	17.6	21.0	7.4	7.9	0	3.5	.1	3.5	71.7
4	Crotalaria, millet, and rye.	9.3	.1	4.2	9.4	0	9.7	0	4.8	.1	4.8	42.4
5	do	6.0	.1	8.1	2.7	0	14.5	.1	5.1	.1	6.7	43.4
6	do	6.1	.1	5.9	1.3	0	13.4	0	3.9	.1	6.0	39.8
7	Cowpeas and millet	2.8	1.6	16.8	30.1	2.5	4.7	0	1.3	.1	2.4	62.3
8	Cowpeas, millet, and rye	2.2	0	3.1	7.0	.1	6.4	0	2.2	.1	3.5	24.6
9	Corn, crotalaria, and millet.	4.7	.2	7.7	1.7	2.3	5.1	.1	2.3	.1	2.5	26.7
10	Corn, crotalaria, millet, and rye.	3.1	0	6.6	.6	.2	7.9	0	2.2	.1	3.6	24.3
11	Crotalaria	4.5	2.1	16.2	15.2	8.1	44.8	1.1	37.4	20.1	28.6	178.1
12	Crotalaria and rye	5.0	.1	8.4	.9	.1	14.3	1.2	13.0	16.9	18.2	78.1
13	Crotalaria	4.9	.1	6.9	13.2	5.0	21.1	.5	17.8	19.3	17.5	107.2
14	None	27.1	16.7	32.3	11.7	26.0	8.1	17.7	7.0	22.6	8.9	178.1
15	Corn and millet	4.5	3.5	9.1	4.3	1.0	3.9	0	1.3	.1	1.2	28.9
16	None	18.1	9.7	21.8	10.2	21.7	7.9	14.0	6.7	14.4	7.6	132.1
17	Millet	16.4	13.0	30.1	34.3	2.8	7.9	.1	3.1	.1	1.6	100.4
18	Millet and rye	14.7	0	27.3	9.8	0	5.5	0	2.6	.1	.5	60.5
19	Millet and mixed crops	.3	0	8.1	.1	0	.1	.2	1.5	.1	1.9	12.4
20	do	1.0	0	6.6	.1	0	.1	.1	.5	.1	2.0	10.5
21	do	1.8	0	6.6	.1	0	.1	.1	2.3	.1	2.9	14.0
22	do	1.5	0	6.8	.1	0	.1	0	1.3	.1	1.4	11.3
23	Cowpeas, millet, and rye	.6	0	4.6	6.0	0	5.6	0	2.0	.1	1.5	20.4
24	do	2.1	0	3.8	7.0	0	5.9	0	1.3	.1	2.3	22.5
Rainfall, inches		16.12	10.11	21.76	17.30	23.42	32.53	20.51	24.38	27.55	17.23	210.9

Analyses for nitrates in the upper 4.5 inches of soil were made at irregular but frequent intervals during the 5-year experimental period. Part of these results is given in table 11; in figure 7 the data for four of the lysimeters are plotted in detail. For ready comparison the monthly rainfall figures are shown just below the soil nitrate graphs. These charts emphasize the rapidity with which nitrate was formed from organic nitrogen sources and accumulated when the soil temperature and moisture were satisfactory, and when there was no crop and inadequate rain to remove the nitrate. The graphs also show how quickly a moderately sized rain lowers the nitrate level in the surface soil to near zero. A vigorously growing crop will also prevent nitrate

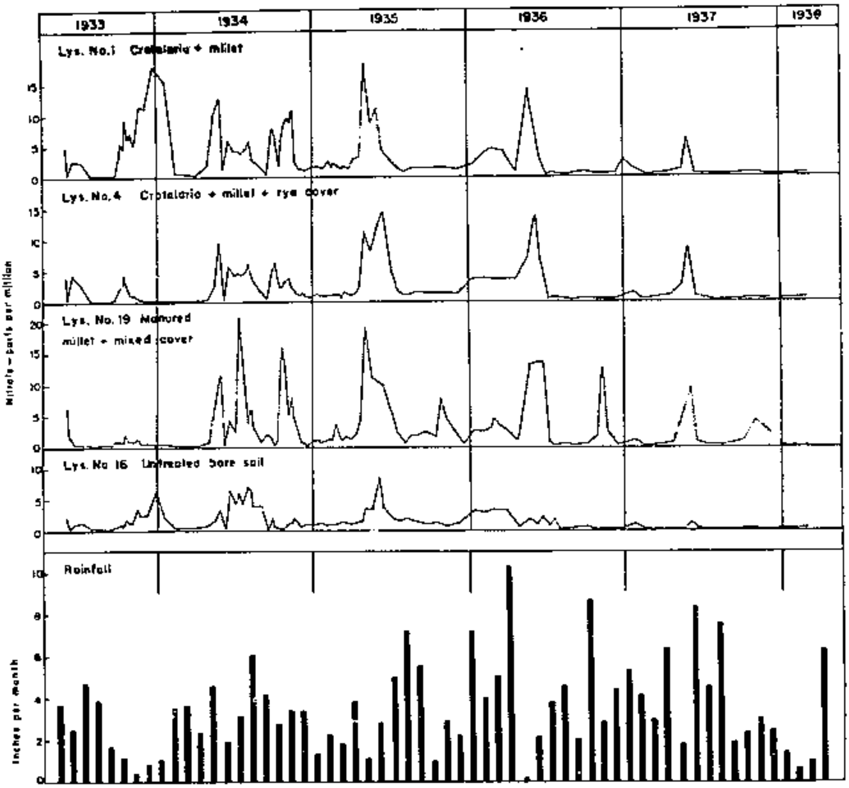

FIGURE 7.—Changes in nitrate nitrogen content of the surface soils in four selected lysimeters during the 5-year period of the experiment.

accumulation; in fact, on Lakeland sand the only practical way to prevent large losses of nitrogen by leaching following fertilization is to grow such a crop.

A comparison of the nitrate nitrogen removed in the percolates (table 10) with the total nitrogen content of the same percolates (table 12) shows that, on the average, 85.2 percent of the nitrogen in the leachates was nitrate nitrogen. During the summer of 1934 and the following winter it was observed that quantities of organic matter varying from near zero to the equivalent of 11 pounds of nitrogen per acre were found in the leachates from the various cylinders. The total organic matter collected during this period is given in table 12. At other times during the experimental period no more than traces of organic matter were observed in the percolates. This tendency for some organic matter to leach through the 43-inch columns of sand probably largely accounts for the nonnitrate nitrogen in the percolates. It is also possible that some of the 15-percent difference between the results in tables 10 and 12 may be due to variations in analytical results by the 2 methods used.

Table 11.—*Nitrate nitrogen contents of soils in lysimeters as parts per million of dry soil in upper 4.5 inches, Sandhill Experiment Station, 1933–38*

Lysimeter No.	Crops grown	1933 May 25	1933 July 5	1933 Sept. 13	1933 Oct. 16	1933 Nov. 20	1933 Dec. 27	1934 Feb. 13	1934 May 1	1934 May 28	1934 June 7	1934 June 18	1934 July 11	1934 Aug. 1	1934 Aug. 20	1934 Sept. 24	1934 Oct. 8	1934 Oct. 29	1934 Nov. 19	1934 Dec. 31	1935 Jan. 29	1935 Feb. 25	1935 Mar. 18	1935 Apr. 15	1935 May 20
1	Crotalaria and millet	4.8	2.5	0.2	0.1	11.3	17.6	0.7	2.0	12.5	1.5	5.9	4.4	4.8	1.8	5.7	4.7	8.7	11.1	1.6	1.5	2.4	1.8	2.8	8.7
2	do	2.8	2.5	.1	----	.5	1.0	.5	1.1	2.5	.7	6.8	4.5	4.7	2.2	.9	.6	8.5	10.4	1.2	2.5	2.4	1.8	2.1	34.8
3	do	4.2	1.8	.2	----	.3	.5	.3	2.2	10.2	.6	8.0	4.5	5.6	2.7	.7	1.2	5.3	7.9	1.4	3.1	2.3	2.5	2.4	10.0
4	Crotalaria, millet, and rye	3.8	2.7	.2	3.7	.3	.2	.2	.4	9.4	.5	5.7	4.6	4.9	1.7	2.6	6.6	3.2	2.2	1.0	1.0	1.2	1.6	1.3	8.2
5	do	3.5	2.3	.2	--	.5	.5	.2	1.0	12.0	1.0	7.4	4.4	5.2	1.5	.5	1.0	2.7	3.4	1.0	1.0	1.0	1.5	1.4	21.1
6	do	3.1	2.6	.2	--	.5	.3	.2	1.3	10.0	.7	9.5	4.2	4.4	1.8	.2	.6	1.6	1.3	1.0	1.0	1.4	1.6	1.3	12.1
7	Cowpeas and millet	2.7	2.2	.4	3.7	6.5	11.9	.4	1.9	12.2	.5	5.6	4.1	5.0	3.1	5.5	10.3	3.5	4.3	1.3	1.9	1.8	1.9	1.3	18.6
8	Cowpeas, millet, and rye	4.3	3.8	.3	2.4	.2	.3	.2	.4	8.3	.4	5.6	3.6	4.8	3.1	5.7	11.1	2.5	2.5	1.1	1.0	1.0	1.4	1.0	11.8
9	Corn, crotalaria, and millet	4.1	1.3	.3	.3	.3	.3	.2	1.8	8.2	.5	6.0	4.0	5.4	2.2	2.1	.8	.4	.8	1.1	2.5	2.1	3.1	2.6	7.3
10	Corn, crotalaria, millet, and rye.	4.1	1.2	.3	.3	.3	.2	.3	1.3	6.8	.6	5.8	4.0	5.9	3.3	1.9	.9	.6	.7	1.0	1.4	1.1	1.6	1.7	12.1
11	Crotalaria	3.5	2.4	.1	----	.3	.7	.2	2.7	12.0	.9	7.4	4.2	5.1	1.7	1.3	.9	3.0	4.9	1.4	2.3	2.4	2.1	2.3	13.8
12	Crotalaria and rye	4.4	2.0	.2	----	.3	.3	.2	1.0	13.2	.5	8.0	4.5	5.3	1.1	.3	.3	2.1	2.2	1.0	1.5	.9	1.5	2.3	12.1
13	Crotalaria	3.7	2.2	.2	----	.5	.3	.3	.6	8.9	.2	7.8	4.1	4.6	3.1	1.6	.3	2.0	4.0	1.1	1.8	1.5	1.6	1.8	10.0
14	None	4.7	2.1	.5	2.0	3.1	2.6	.3	1.0	15.9	.3	6.9	6.2	7.5	2.8	2.0	1.0	.6	2.1	1.1	1.1	1.1	1.6	1.5	4.2
15	Corn and millet	3.3	.9	.3	2.7	.9	2.3	.2	.9	4.0	.2	6.0	4.4	5.6	3.0	2.4	.6	1.8	1.8	1.0	1.0	1.1	1.6	1.4	9.1
16	None	2.1	1.1	.4	2.0	2.5	6.3	.4	.8	3.4	.3	6.3	5.9	7.1	3.9	2.1	.3	1.0	1.9	1.0	1.0	1.1	1.5	1.1	3.5
17	Millet	2.0	1.0	.4	--	3.4	6.3	.5	3.2	.4	.7	7.7	17.0	23.5	2.7	2.9	2.0	5.7	9.3	1.3	1.5	1.3	1.8	2.6	10.3
18	Millet and rye	2.1	.9	.4	--	.6	.2	.3	.3	1.5	.3	9.4	28.1	23.9	2.2	2.9	2.6	1.4	1.4	1.0	.8	1.0	1.5	1.0	8.9
19	Millet and mixed crops	6.3	.2	.3	2.0	.5	.3	.3	.7	11.6	.4	4.4	20.5	4.0	.8	1.7	1.0	12.1	4.7	1.0	.8	3.9	1.6	1.9	11.1
20	do	2.9	1.0	.3	4.5	.6	.3	.3	1.3	15.2	.5	4.9	20.5	2.8	.7	1.7	1.1	11.6	6.3	.9	.9	9.0	1.5	2.3	30.4
21	do	9.1	.6	.4	4.5	.9	.3	.3	1.8	14.9	1.0	5.1	20.5	4.3	.6	3.4	1.5	24.6	7.4	1.0	.9	7.6	1.5	1.8	11.4
22	do	4.4	.4	.4	3.9	.5	.3	.3	2.1	7.8	.3	5.0	20.5	3.9	1.3	1.9	1.2	31.4	6.8	.9	.9	3.2	1.6	1.3	14.3
23	Cowpeas, millet, and rye	3.6	3.8	.3	4.4	.3	.3	.3	.2	14.7	.3	5.6	3.7	4.4	1.4	4.0	18.2	3.3	2.5	1.1	1.0	1.1	1.6	1.2	8.0
24	do	3.5	2.3	.3	3.9	.3	.3	.3	.8	10.0	.3	5.6	3.2	3.8	1.5	2.7	13.1	4.0	3.5	1.2	1.2	1.1	1.5	1.3	14.5

TABLE 11.—*Nitrate nitrogen contents of soils in lysimeters as parts per million of dry soil in upper 4.5 inches, Sandhill Experiment Station, 1933–38*—Continued

Lysimeter No.	Crops grown	Years																							
		1935						1936											1937						1938
		June 16	July 22	Aug. 22	Oct. 19	Nov. 12	Dec. 9	Jan. 13	Mar. 2	Mar. 30	Apr. 27	May 25	June 22	July 20	Aug. 17	Oct. 5	Nov. 9	Dec. 14	Feb. 15	Apr. 20	May 17	June 1	July 6	Oct. 6	Nov. 27	Mar. 3
1	Crotalaria and millet	4.5	1.5	1.4	1.5	1.5	1.1	2.9	4.5	4.0	0.8	13.8	2.6	0.6	0.4	0.6	0.3	0.2	0.3	0.6	1.0	6.3	0.3	0.3	0.2	0.4
2	do	5.7	1.8	1.2	1.5	1.4	1.1	3.2	3.8	3.9	1.1	5.1	6.7	.5	.3	.5	.4	.2	.3	.7	2.2	13.8	.3	.3	.2	.5
3	do	6.9	1.8	1.1	1.3	1.4	1.4	3.2	3.8	3.3	.9	6.5	5.1	.5	.3	.4	.5	.2	.2	.7	2.2	8.9	.3	.3	.2	.3
4	Crotalaria, millet, and rye.	14.3	1.7	1.1	1.4	1.3	1.1	3.6	3.6	3.6	.8	7.0	6.3	.5	.4	.3	.4	.2	.3	.9	2.6	8.5	.3	.3	.2	.4
5	do	6.9	1.9	1.2	1.3	1.3	1.1	3.3	3.8	3.3	1.3	6.5	6.0	.5	.4	.4	.3	.2	.3	1.1	3.3	11.0	.3	.4	.2	.4
6	do	7.7	1.6	1.5	1.4	1.4	1.5	3.3	4.0	3.6	1.4	7.8	4.9	.4	.4	.5	.3	.2	.2	.9	1.7	10.5	.3	.3	.2	.5
7	Cowpeas and millet	4.4	1.4	1.3	1.5	1.3	1.8	3.6	3.6	3.3	.7	4.9	2.3	.5	.4	.4	.3	.2	.2	.7	1.7	9.8	.2	.3	.2	.3
8	Cowpeas, millet, and rye.	5.1	1.5	1.3	1.4	1.2	1.0	3.5	3.7	3.4	.7	15.4	10.5	.3	.4	.5	.2	.2	.2	.5	2.6	10.1	.2	.4	.2	.3
9	Corn, crotalaria, and millet.	5.4	1.7	1.5	1.4	1.2	1.0	3.0	3.2	3.4	.7	5.3	1.7	.4	.4	.4	.2	.2	.2	.6	1.6	6.8	.3	.3	.2	.4
10	Corn, crotalaria, millet, and rye.	5.3	1.5	1.4	1.3	1.4	1.0	3.5	3.8	3.3	.9	5.3	4.7	.4	.4	.4	.2	.2	.2	.6	2.4	5.5	.3	.2	.2	.3
11	Crotalaria	14.3	1.3	1.5	1.3	2.1	5.0	3.2	4.4	3.7	2.0	8.7	7.7	7.1	.4	.7	7.1	.7	.2	2.6	2.9	14.8	.9	1.2	1.6	3.9
12	Crotalaria and rye	15.4	1.5	1.4	1.3	3.6	1.3	3.3	3.6	3.1	2.0	10.5	28.6	20.0	1.7	.8	5.6	.6	.3	1.2	3.6	25.0	1.1	1.0	1.5	.7
13	Crotalaria	10.0	1.5	1.4	1.3	1.3	2.7	3.2	4.3	3.3	1.1	5.0	7.1	6.3	.8	.6	3.4	.4	.3	.8	2.0	10.0	1.2	.5	.2	.6
14	None	7.1	1.7	1.3	1.8	1.1	2.5	3.5	4.2	3.4	.6	20.0	4.1	1.2	.5	.7	.2	.1	.3	.4	1.1	8.0	.5	.2	.2	.4
15	Corn and millet	4.0	1.5	1.2	1.2	1.1	1.5	3.3	3.8	3.4	.7	9.1	3.0	.3	.3	.3	.2	.2	.2	.5	1.2	6.5	.3	.2	.2	.3
16	None	3.5	1.6	1.6	1.3	.9	1.3	3.2	3.4	3.3	.7	2.0	2.3	1.9	.3	.6	.2	.1	.2	.3	.2	1.3	.3	.3	.2	.4
17	Millet	3.4	1.5	1.2	1.2	1.2	1.3	3.1	3.7	3.6	1.0	4.5	7.4	.3	.4	.4	.3	.2	.2	.5	2.7	4.1	.3	.3	.2	.6
18	Millet and rye	3.1	1.5	1.1	1.2	1.1	1.3	2.9	3.7	3.3	.8	9.5	7.1	.3	.4	.3	.3	.2	.2	.7	2.0	5.1	.3	.3	.2	.4
19	Millet and mixed crops	10.0	2.0	1.9	1.7	4.7	1.6	2.7	4.5	3.1	1.1	13.3	13.8	.4	.7	.6	12.5	.4	.2	.8	5.6	9.5	.3	1.1	2.8	.2
20	do	11.8	1.6	1.4	1.0	5.1	1.5	2.7	3.0	3.3	1.0	10.0	13.3	.5	.8	.5	10.0	.3	.2	3.3	6.3	12.5	.3	.4	2.6	.2
21	do	12.5	1.6	1.4	1.9	6.1	1.6	3.2	3.4	3.1	1.4	17.4	17.4	.8	1.1	.5	12.5	.4	.2	2.1	4.0	10.0	.3	.5	2.3	.4
22	do	11.1	1.8	1.3	2.6	4.5	1.5	2.9	3.1	3.2	1.7	14.3	10.8	.5	.8	.5	8.9	.4	.2	1.0	7.1	11.1	.3	.4	1.5	.4
23	Cowpeas, millet, and rye.	4.2	1.7	1.3	1.4	.9	1.7	3.2	3.5	3.6	.9	8.2	4.3	.4	.6	.3	.2	.2	.2	.4	3.3	10.0	.3	.3	.3	.4
24	do	6.3	1.7	1.3	1.2	1.1	1.7	3.3	3.6	4.4	.9	10.0	3.8	.4	.5	.3	.2	.2	.2	.5	2.6	8.0	.3	.3	.3	.4

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TABLE 12.—*Total nitrogen for 1933–38 and organic matter for 1934–35, as pounds per acre, in percolates of lysimeters, Sandhill Experiment Station*

Lysimeter No.	Crops grown	Total nitrogen for successive seasons											Organic matter 1934–35 [1]		
		1933–34		1934–35		1935–36		1936–37		1937–38		Total for 5 years	Summer	Winter	Total
		Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter				
		Lb./a.	*Lb./a.*	*Lb./a.*	*Lb./a.*	*Lb./a.*	*Lb./a.*	*Lb./a.*	*Lb./a.*	*Lb./a.*	*Lb./a.*	*Lb./a.*	*Lb./a.*	*Lb./a.*	*Lb./a.*
1	Crotalaria and millet	11.8	4.7	26.1	48.5	5.1	8.2	0.2	4.2	0.5	4.4	113.7	28.6	86.9	115.5
2	do	7.4	1.6	19.0	30.7	10.9	10.0	.2	4.6	2.0	5.9	101.3	9.9	60.8	70.7
3	do	9.4	2.0	17.7	25.7	7.6	9.1	.3	5.1	1.9	4.2	83.0	6.1	47.4	53.5
4	Crotalaria, millet, and rye	9.3	.2	5.5	11.5	.5	11.2	.2	7.4	2.4	5.4	53.6	7.5	.8	8.3
5	do	6.5	.2	10.6	3.4	.5	15.8	.3	7.4	1.4	7.5	53.6	6.6	9.6	16.2
6	do	5.9	.3	9.8	1.8	.5	14.1	.2	5.9	1.0	6.8	40.3	5.0	9.4	14.4
7	Cowpeas and millet	2.9	4.4	15.2	30.1	3.9	5.4	.3	2.9	.5	2.7	77.3	9.8	70.2	80.0
8	Cowpeas, millet, and rye	2.2	.3	4.0	9.0	.3	6.7	.5	3.4	.4	4.0	30.8	8.7	7.2	15.9
9	Corn, crotalaria, and millet	5.0	.6	9.3	2.4	3.5	5.7	.3	3.7	.3	2.7	33.5	7.0	1.2	8.2
10	Corn, crotalaria, millet, and rye.	3.2	.2	8.1	1.1	.4	8.5	.3	3.7	.3	4.1	29.9	7.3	1.2	8.5
11	Crotalaria	3.7	1.8	18.8	18.1	10.1	50.6	1.5	47.3	22.1	31.7	205.7	5.3	4.6	9.9
12	Crotalaria and rye	5.1	.2	10.6	1.4	.4	16.7	1.6	16.3	18.3	20.0	90.6	6.4	10.2	10.6
13	Crotalaria	5.4	.2	8.4	15.2	6.6	24.5	.8	22.2	21.6	18.5	123.4	12.3	2.2	14.5
14	None	27.6	14.9	31.4	13.9	31.6	9.7	20.3	10.0	26.7	9.5	195.6	56.7	135.3	192.0
15	Corn and millet	5.0	1.4	10.7	5.3	1.9	4.9	.1	2.5	.8	1.3	33.9	11.1	13.5	24.6
16	None	18.4	10.6	25.6	13.7	27.2	8.8	17.5	8.7	15.3	8.1	153.9	59.2	4.5	63.7
17	Millet	16.6	12.3	28.7	40.7	3.7	9.2	.3	4.3	.5	1.9	118.2	16.6	29.7	46.3
18	Millet and rye	14.7	.2	32.4	12.5	.2	6.8	.1	3.7	.3	.9	71.8	15.5	29.4	44.9
19	Millet and mixed crops	.5	.1	9.4	.5	.4	.6	.6	2.9	.2	2.3	17.5	12.7	11.8	24.5
20	do	1.8	.3	8.9	.3	.4	.6	.3	1.2	.7	2.4	16.9	7.0	13.6	20.6
21	do	.4	.1	11.9	.4	.4	.5	.5	4.0	.4	3.4	22.0	14.0	10.2	24.2
22	do	.3	.1	9.0	.5	.4	.8	.3	2.6	.4	1.7	16.1	9.5	11.6	21.1
23	Cowpeas, millet, and rye	.9	.1	6.3	8.9	.4	6.7	.3	3.2	.4	2.0	20.2	15.7	18.1	33.8
24	do	2.7	.1	6.1	11.2	.5	7.2	.2	2.1	.3	2.7	33.1	6.8	11.3	18.1

[1] Organic matter was visible in the percolates only during this period.

Changes in Soil Nitrogen and Carbon

Changes in the organic nitrogen contents for successive years of the upper 4.5 inches of soil in the 24 lysimeters are given in table 13, and for the carbon contents in table 14. All the lysimeters except the two uncropped ones showed at least some gain in both soil nitrogen and carbon as a result of the various fertilizer and cropping treatments. The average gain in carbon was 1,170 pounds per acre 4.5 inches of soil during the 5-year period; the largest gains (average=2,373 pounds) occurred where animal manures were added annually and where crotalaria was grown continuously without removal of the crop. The corresponding average value for the remaining 16 cropped soils was 718 pounds. On the average, for every gain of 10 pounds of carbon there was a corresponding gain of nearly 1 pound of nitrogen. The carbon-nitrogen ratio of the organic matter formed during the experiment in the 4 lysimeters that received annual applications of animal manures averaged 10.9, whereas the ratio for the remaining 18 cropped lysimeters was 9.4. Where the larger gains occurred, the ratios were fairly constant for the various lysimeters, but the figures ranged rather widely for the smaller gains, since at this level the analytical errors became more important.

TABLE 13.—*Changes in organic nitrogen in upper 4.5 inch layer of soil, Sandhill Experiment Station, 1933–38*

Lysimeter No.	Crops grown	Percentage of nitrogen in soil at yearly periods						Gain (or loss) in 5 years	
		1933	1934	1935	1936	1937	1938	Percent	Pounds per acre [1]
1	Crotalaria and millet	0.0240	0.0243	0.0290	0.0257	0.0282	0.0273	0.0033	49.5
2	do	.0220	.0258	.0268	.0271	.0270	.0284	.0064	96.0
3	do	.0220	.0247	.0265	.0294	.0281	.0289	.0069	103.5
4	Crotalaria, millet, and rye	.0220	.0283	.0273	.0289	.0293	.0292	.0072	108.0
5	do	.0220	.0237	.0295	.0307	.0313	.0305	.0085	127.5
6	do	.0230	.0232	.0322	.0298	.0297	.0287	.0057	85.5
7	Cowpeas and millet	.0220	.0241	.0238	.0259	.0245	.0238	.0018	27.0
8	Cowpeas, millet, and rye	.0220	.0227	.0248	.0265	.0258	.0268	.0048	72.0
9	Corn, crotalaria, and millet	.0210	.0225	.0243	.0270	.0266	.0249	.0039	58.5
10	Corn, crotalaria, millet, and rye.	.0220	.0224	.0235	.0248	.0267	.0265	.0045	67.5
11	Crotalaria	.0220	.0214	.0285	.0321	.0345	.0383	.0163	244.5
12	Crotalaria and rye	.0210	.0223	.0283	.0337	.0348	.0370	.0160	240.0
13	Crotalaria	.0220	.0222	.0235	.0259	.0272	.0246	.0026	39.0
14	None	.0220	.0212	.0218	.0208	.0206	.0185	−.0035	−52.5
15	Corn and millet	.0220	.0225	.0223	.0246	.0247	.0228	.0008	12.0
16	None	.0220	.0220	.0210	.0217	.0205	.0201	−.0019	−28.5
17	Millet	.0210	.0249	.0250	.0268	.0267	.0265	.0055	82.5
18	Millet and rye	.0220	.0242	.0238	.0288	.0282	.0262	.0042	63.0
19	Millet and mixed crops	.0220	.0250	.0285	.0316	.0340	.0362	.0142	213.0
20	do	.0220	.0265	.0335	.0338	.0358	.0370	.0150	225.0
21	do	.0220	.0264	.0328	.0342	.0364	.0362	.0142	213.0
22	do	.0210	.0249	.0315	.0330	.0348	.0370	.0160	240.0
23	Cowpeas, millet, and rye	.0210	.0228	.0260	.0270	.0289	.0287	.0077	115.5
24	do	.0210	.0228	.0280	.0276	.0285	.0287	.0077	115.5

[1] Calculations are based on 1,500,000 pounds of soil.

Accurate values for the percentages of carbon added to the various lysimeters that were still present at the end of the experimental period cannot be given, since the carbon contents of the added organic materials are not known. Apparently the gains in soil carbon, where green manures and crop residues were added, are closely correlated with the quantity of carbon added. In this respect, the manure additions are in a different class. This carbon represents much more resistant material, since it is the carbon left after much decomposition has already occurred. Futhermore, the yearly additions of carbon to lysimeters 19 to 22 were greater than to the others with the possible exception of Nos. 11 and 12.

TABLE 14.—*Changes in carbon contents of upper 4.5 inch layer of soil, Sandhill Experiment Station, 1933–38*

Lysimeter No.	Crops grown	Percentage of carbon in soil at yearly periods						Gain (or loss) in 5 years		C/N ratios	
		1933	1934	1935	1936	1937	1938	Percent	Pounds per acre[1]	1933	1938
1	Crotalaria and millet	0.584	0.581	0.595	0.612	0.624	0.630	0.046	690	24.3	23.1
2	do	.569	.591	.589	.605	.610	.612	.043	645	25.9	21.5
3	do	.598	.579	.573	.653	.618	.638	.040	600	27.2	22.1
4	Crotalaria, millet, and rye	.577	.586	.619	.653	.646	.660	.083	1,245	26.2	22.6
5	do	.587	.570	.604	.657	.656	.670	.083	1,245	26.7	22.0
6	do	.582	.607	.640	.655	.647	.652	.070	1,050	25.3	22.7
7	Cowpeas and millet	.580	.507	.602	.604	.611	.609	.029	435	26.4	25.6
8	Cowpeas, millet, and rye	.589	.583	.572	.625	.620	.638	.049	735	26.8	23.8
9	Corn, crotalaria, and millet.	.584	.592	.583	.607	.627	.636	.052	780	27.8	25.5
10	Corn, crotalaria, millet, and rye.	.591	.548	.600	.602	.636	.656	.065	975	26.9	24.8
11	Crotalaria	.567	.566	.619	.617	.687	.700	.133	1,995	25.8	18.3
12	Crotalaria and rye	.557	.588	.600	.673	.700	.724	.167	2,505	26.5	10.6
13	Crotalaria	.596	.552	.573	.583	.609	.603	.007	105	27.1	24.5
14	None	.582	.571	.574	.572	.557	.553	−.029	−435	26.5	29.9
15	Corn and millet	.596	.591	.611	.584	.604	.605	.009	135	27.1	26.5
16	None	.588	.585	.584	.549	.565	.578	−.010	−150	26.7	28.8
17	Millet	.588	.604	.628	.625	.611	.616	.028	420	28.0	23.2
18	Millet and rye	.592	.615	.615	.618	.643	.647	.055	825	26.9	24.7
19	Millet and mixed crops	.590	.595	.670	.698	.713	.729	.139	2,085	26.8	20.1
20	do	.586	.631	.707	.714	.750	.756	.170	2,550	26.6	20.4
21	do	.572	.638	.687	.715	.750	.748	.176	2,640	26.0	20.7
22	do	.588	.629	.705	.716	.739	.752	.164	2,460	28.0	20.3
23	Cowpeas, millet, and rye	.596	.567	.614	.640	.644	.653	.057	855	28.4	22.8
24	do	.580	.575	.651	.629	.628	.630	.050	750	27.6	22.0

[1] Calculations are based on 1,500,000 pounds of soil.
[2] Nitrogen given in table 12.

The increases in soil organic matter obtained in these studies may seem small but the increases are actually as large as could be expected, considering that there was little inorganic colloid present to hold the carbon compounds and soil aeration and climate favored biological activity. Undoubtedly the initial low organic matter level of the soil was an important factor favoring carbon retention. This level was very stable, as shown by the small loss of carbon from the two uncropped soils after removal to the lysimeters. If an attempt were made to raise the organic matter content to higher levels, increasing resistance to such a buildup would be expected. Even in much finer textured soils, maintained under similar conditions, marked increases in carbon are seldom observed.

Nitrogen Balance Sheet

Accurate nitrogen balance data cannot be given for most of the lysimeters, because legumes were grown for at least a part of the time in all but 3 of the 22 cropped lysimeters. The exact amount of nitrogen fixed by the legumes is not known. The above-ground parts of the crops were analyzed, however, and from these data a fairly accurate value can be given for the quantity of atmospheric

TABLE 15.—*Nitrogen balance sheet expressed as pounds per acre*[1] *during the 5-year period (1933–38), Sandhill Experiment Station*

Lysimeter No.	Crops grown	Nitrogen additions						Nitrogen removed			Soil nitrogen gain or loss	Total nitrogen recovered	Net gain or loss in nitrogen
		Fertilizer	Animal manure	Rain and seed	Total, except legumes	Legumes	Total, all nitrogen	Crop	Percolate	Total			
1	Crotalaria and millet	80.0	0	30	110.0	153.4	263.4	58.3	113.7	172.0	+49.5	221.5	−41.9
2	do	80.0	0	30	110.0	153.4	263.4	71.7	101.3	173.0	+96.0	269.0	+5.6
3	do	80.0	0	30	110.0	153.4	263.4	69.9	83.0	152.9	+103.5	256.4	−7.0
4	Crotalaria, millet, and rye	80.0	0	35	115.0	158.6	273.6	72.6	53.6	126.2	+108.0	234.2	−39.4
5	do	80.0	0	35	115.0	158.6	273.6	84.7	53.6	138.3	+127.5	265.8	−7.8
6	do	80.0	0	35	115.0	158.6	273.6	81.2	46.3	127.5	+85.5	213.0	−60.6
7	Cowpeas and millet	80.0	0	30	110.0	52.1	162.1	50.0	77.3	127.3	+27.0	154.3	−7.8
8	Cowpeas, millet, and rye	80.0	0	35	115.0	63.4	178.4	59.3	30.8	90.1	+72.0	162.1	−16.3
9	Corn, crotalaria, and millet	117.0	0	30	147.0	(2)	147.0	93.4	33.5	126.9	+58.5	185.4	+38.4
10	Corn, crotalaria, millet, and rye	117.0	0	35	152.0	(2)	152.0	101.1	29.9	131.0	+67.5	198.5	+46.5
11	Crotalaria	80.0	0	30	110.0	491.3	601.3	[3] 8.9	205.7	214.6	+244.5	459.1	−142.2
12	Crotalaria and rye	80.0	0	35	115.0	488.9	603.9	[3] 28.0	90.6	118.6	+240.0	358.6	−245.3
13	Crotalaria	80.0	0	35	115.0	[4] 0	115.0	415.4	123.4	538.8	+39.0	577.8	+462.8
14	None	80.0	0	25	105.0	0	105.0	0	195.6	195.6	−52.5	143.1	+38.1
15	Corn and millet	117.0	0	30	147.0	0	147.0	81.9	33.9	115.8	+12.0	127.8	−19.2
16	None	0	0	25	25.0	0	25.0	0	153.9	153.9	−28.5	125.4	+100.4
17	Millet	48.0	153.4	28	229.4	0	229.4	62.4	118.2	180.6	+82.5	263.1	+33.7
18	Millet and rye	48.0	153.4	33	234.4	0	234.4	65.2	71.8	137.0	+63.0	200.0	−34.4
19	Millet and mixed crops	168.8	475.3	35	679.1	(2)	679.1	287.8	17.5	305.3	+213.0	518.3	−160.8
20	do	168.8	475.3	35	679.1	(2)	679.1	323.2	16.9	340.1	+225.0	565.1	−114.0
21	do	168.8	475.3	35	679.1	(2)	679.1	370.1	22.0	392.1	+213.0	605.1	−74.0
22	do	168.8	475.3	35	679.1	(2)	679.1	290.4	16.1	306.5	+240.0	546.5	−132.6
23	Cowpeas, millet, and rye	80.0	0	35	115.0	87.6	202.6	74.8	29.2	104.0	+115.5	219.5	+16.9
24	do	80.0	0	35	115.0	85.9	200.9	70.8	33.1	103.9	+115.5	219.4	+18.5

[1] Calculations based on 1,500,000 pounds of soil.
[2] Not determined.
[3] Includes only the nitrogen in the plant sample removed for analysis.
[4] Crop removed.

nitrogen that was fixed and returned to the lysimeters. The nitrogen balance data, which are reported in table 15, seem to show that the nitrogen in the legume tops represents rather closely the amount that was fixed by these plants. The plants obtained little nitrogen from the soil because of the low percentage present. The nitrogen taken from the soil, and not from the air, happens to correspond closely with that in the roots of the crotalaria and cowpeas.

The net nitrogen gain or loss figures for the 24 lysimeters are given in table 15. In arriving at these figures it was assumed that all of the nitrogen in the harvested parts of the legume crops came from the air, except where mixed legumes and nonlegumes were grown. In these mixtures no determinations were made of the nitrogen in the legumes, and the figures in the last column of table 15 make no allowance for such fixation. The nitrogen gain or loss figures for lysimeters 1 to 8 and for 23 and 24, where the nitrogen in the tops was considered in arriving at the balance, are surprisingly near zero in each of the 10 lysimeters. The extreme variations are between +18.5 and −60.6 pounds of nitrogen per acre with an average value of −14.0 pounds. If the many obvious sources of error in arriving at net values, the uncertainty as to the exact portion of the legume nitrogen that came from the air, and the lack of replication are considered, all the results are within experimental error. Certainly, there is no evidence for appreciable losses of nitrogen from these 10 lysimeters by volatilization.

Where corn was grown for 2 years, followed by millet for 3 summers (lysimeter 15), the net nitrogen loss for the period was 19.2 pounds per acre. Under similar conditions, where crotalaria was sown in the corn for 2 seasons, the nitrogen balance figures show a gain of 38.4 pounds without winter cover (lysimeter 9) and 46.5 pounds with rye cover (lysimeter 10). In arriving at these net gains the unknown amount of nitrogen fixed by the crotalaria was not considered; in fact, these gains, if real, probably represent the approximate amount of nitrogen fixed during the 2 seasons by the late-sown companion crop.

The nitrogen balance value obtained where crotalaria was grown for 5 years and harvested (lysimeter 13) was +462.8 pounds. Most or all of this gain is the result of symbiotic nitrogen fixation, and, doubtless, would have been considerably greater if more nutrients other than nitrogen had been added.

Where crotalaria was grown for 5 years, with or without a rye cover crop and the crotalaria returned to the soil (lysimeters 12 and 11), the nitrogen balance figures were −245.3 and −142.2 pounds per acre if all the nitrogen in the tops and none of that in the roots are considered as fixed from the air and included in the calculations. Two main explanations for the negative values seem to be involved. First, the crops on these two lysimeters were not harvested but returned to the soil each year. This return of so much nitrogenous plant material would be expected to increase crop yields and at the same time decrease nitrogen fixation. Table 15 shows that the nitrogen in the tops from the 2 crotalaria-mulched soils was an average of 75 pounds greater than from the tops grown on the soil from which the crop was removed (lysimeter 13). Nitrogen fixation figures are not available, but the fixation in lysimeters 11 and 12 was almost certainly considerably below that occurring in the latter. If this is true, then the large negative values for lysimeters 11 and 12 are not real; they are large because much of the nitrogen in the legume tops actually came from the decomposing crotalaria instead of from the air, as the table indicates. A second possibility is that a considerable loss of gaseous nitrogen from these soils occurred. Since the legume tops decomposed on the soil surface some gaseous losses, chiefly as ammonia, would be expected. Although both of these two possibilities probably contributed to the negative nitrogen balance values for lysimeters 11 and 12, the first was probably the more important.

The addition of fresh manure for 2 years to fallow soils, followed by the growth of millet during the succeeding 3 years without a winter cover crop (lysimeter 17), resulted in a positive nitrogen balance of 33.7 pounds per acre over the 5-year period. In a similarly treated soil, except for the addition of a rye cover crop (lysimeter 18), the net balance was −34.4 pounds. Both values are doubtless within experimental error.

Where four types of manure were applied twice a year over the 5-year period and the soils cropped to millet during the summer and to a legume-nonlegume mixture during the winter (lysimeters 19 to 22), the loss of nitrogen averaged 120 pounds. The losses from the 4 lysimeters ranged from 74 to 161 pounds per acre. These are minimum values, since no allowance is made for any fixation during the winter by the vetch growing in the rye–oats–barley–vetch cover. This fixation is not believed to have been large. The data seem to show rather positively that some gaseous losses of nitrogen occurred from this soil where manure was added each year. Although these losses were greatest where fresh manure was added and least where semideep stall manure was used, it is possible that the differences between manures may not be significant. In the interpretation of these results it is necessary to remember that each of these 4 lysimeters received 144 pounds of nitrogen in the form of a 4–8–4 commercial fertilizer and about 25 pounds of nitrogen as sodium nitrate during the experimental period. From published results,[9] the unaccounted-for losses of nitrogen could have been either as ammonia, nitrogen gas, or oxides of nitrogen. The chief loss was probably as ammonia, but some reduction of nitrate, added or formed in the soil, may have occurred.

The nitrogen balance results for the two uncropped tanks (Nos. 14 and 16) show unaccounted-for gains rather than losses. In the soil of lysimeter 14, where 16 pounds of fertilizer nitrogen was added annually during the experiment, the nitrogen found in the leachate exceeded by 38 pounds the sum of the nitrogen added in the fertilizer and rain and released from the soil. This positive value may indicate some nonsymbiotic nitrogen fixation, but more likely is experimental error. Lysimeter 16, which contained untreated soil, showed a nitrogen gain of 100 pounds per acre. The extremely small amount of available energy materials present would seem to rule out bacterial fixation of nitrogen. If the gain of 100 pounds is significant, the most likely explanation is that the nitrogen was fixed by blue-green algae. Recent researches have shown that these chloro-

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[9] ALLISON, F. E. THE ENIGMA OF SOIL NITROGEN BALANCE SHEETS. Adv. in Agron. 7: 213–250, illus. 1955.

phyll-containing micro-organisms are of considerable importance under some field conditions, especially in rice paddies.

Potassium in Leachates

In the search for the best fertilizing and cropping practices for very sandy soils, it is essential that information be obtained on the rates and extent of loss of all the more important plant nutrients under a variety of cropping conditions. The contents of potassium in the leachates from the various lysimeters are given in table 16.

TABLE 16.—*Potassium contents of percolates as pounds of K_2O per acre, Sandhill Experiment Station, 1933–38*

Lysimeter No.	Crops grown	Total lb. K_2O added as KCl (1933-38)	1933-34		1934-35		1935-36		1936-37		1937-38		Total for 5 years
			May 6 to Oct. 26	Oct. 27 to Apr. 9	Apr. 10 to Oct. 1	Oct. 2 to Apr. 4	Apr. 5 to Oct. 2	Oct. 3 to Apr. 14	Apr. 15 to Oct. 15	Oct. 16 to Apr. 8	Apr. 9 to Oct. 4	Oct. 5 to Apr. 15	
1	Crotalaria and millet	80	3.7	1.5	3.1	3.1	1.5	2.7	1.6	2.3	2.2	0.6	22.3
2	do	80	2.3	1.4	2.4	2.8	1.6	1.7	1.2	2.0	2.0	.6	18.0
3	do	80	2.5	1.5	2.2	1.8	1.3	1.7	1.0	2.0	1.8	.6	16.4
4	Crotalaria, millet, and rye	80	2.0	.7	2.2	5.8	1.5	2.3	1.0	2.0	1.9	.5	19.9
5	do	80	2.4	.2	2.9	5.2	1.5	2.1	1.0	2.1	1.5	.6	19.5
6	do	80	1.7	.7	2.8	4.8	1.1	2.0	1.0	2.0	1.7	.9	18.7
7	Cowpeas and millet	80	1.5	.9	1.9	1.9	2.0	3.2	1.5	2.4	2.0	1.0	18.3
8	Cowpeas, millet, and rye	80	.8	.5	2.2	4.8	1.7	1.9	1.2	2.0	1.6	1.4	18.1
9	Corn, crotalaria, and millet	80	1.5	1.1	2.1	10.3	1.4	.9	1.1	1.7	1.4	.7	22.2
10	Corn, crotalaria, millet, and rye	80	1.0	1.0	2.5	7.1	1.3	1.2	1.2	1.7	1.3	.7	19.3
11	Crotalaria	80	1.5	1.2	2.4	4.1	1.1	4.4	1.4	9.9	1.4	4.6	32.0
12	Crotalaria and rye	80	1.7	.6	2.2	5.0	1.0	3.0	1.3	2.9	12.8	1.1	31.6
13	Crotalaria	80	2.0	.9	2.2	2.9	1.1	2.5	1.0	2.0	1.4	.6	16.6
14	None	80	8.1	3.4	13.7	17.5	15.0	12.0	9.7	7.7	12.7	5.1	105.8
15	Corn and millet	80	2.0	.9	1.7	11.7	2.0	.9	1.4	1.4	1.6	.7	24.3
16	None	0	6.6	2.7	10.2	8.0	12.4	8.5	7.0	5.1	6.4	2.5	69.4
17	Millet	[1] 48	6.0	3.0	11.0	10.5	3.0	2.6	1.7	1.7	2.6	2.1	44.5
18	Millet and rye	[1] 48	4.8	.9	8.8	4.0	2.3	2.7	1.2	1.4	1.5	1.1	28.7
19	Millet and mixed crops	[1] 144	.9	.8	2.3	5.5	1.5	1.7	1.4	1.8	1.4	5.5	22.8
20	do	[1] 144	.8	2.3	5.2	13.3	2.5	4.3	3.8	6.5	5.6	7.6	51.9
21	do	[1] 144	1.5	1.9	5.1	12.6	4.2	10.6	7.7	13.4	15.3	9.8	82.1
22	do	[1] 144	.9	1.3	2.8	5.6	4.2	2.2	1.5	2.0	1.9	6.8	29.2
23	Cowpeas, millet, and rye	80	.6	.4	1.0	4.0	1.4	1.9	1.2	1.6	1.7	2.2	16.0
24	do	143	.8	.5	1.6	2.0	2.3	4.2	1.8	3.2	2.9	3.7	23.0

[1] Additional potash, not determined, was added in the animal manures.

The potash content of the leachate from the unfertilized fallow soil (lysimeter 16) was 69 pounds K_2O per acre for the 5-year period; where 80 pounds was added as fertilizer (lysimeter 14) the leachate contained 106 pounds of potash. Among the other 22 leachates from cropped soils only one (lysimeter 21) had a potassium content greater than that from the unfertilized fallow soil, and this one received considerably more potash in the form of 4–8–4 fertilizer and an undetermined amount in the cow manure added semiannually during the experimental period. The average K_2O content of the leachates from the 15 cropped lysimeters that received 80 pounds of potash as complete fertilizer and no animal manure was 21 pounds. The data in table 16, taken as a whole, emphasize that potash was lost from this sandy soil very readily in the absence of a crop. The various cropping treatments reduced the leaching losses by 80 percent. Winter cover crops had little effect, because the summer crops had apparently left little soluble potassium in the soil. If fall applications of potash had been made, it is likely that winter cover crops would have markedly reduced the potassium contents of the percolates.

The leaching losses where manure was added were usually somewhat greater than where no manure was applied, both because more potash was added and also because fall applications of manure were made. The leaching data for potassium bear a close resemblance to those for nitrogen in the sense that where either element was present in a soluble form it was removed readily by rains. Obviously this can best be prevented by keeping the soil cropped as much of the time as possible and by avoiding applications at a time when the vegetation is not adequate to assimilate it.

Calcium and Magnesium in Leachates

The calcium contents of the leachates from the various lysimeters are given in table 17 and the magnesium contents in table 18. The data for the two elements, when related to the treatments, bear a close resemblance, as would be expected, except that soils normally contain more calcium than magnesium and this is reflected in the

TABLE 17.—*Calcium contents of percolates as pounds CaO per acre, Sandhill Experiment Station, 1933–38*

Lysimeter No.	Crops grown	1933-34		1934-35		1935-36		1936-37		1937-38		Total for 5 years
		May 6 to Oct. 26	Oct. 27 to Apr. 9	Apr. 10 to Oct. 1	Oct. 2 to Apr. 4	Apr. 5 to Oct. 2	Oct. 3 to Apr. 14	Apr. 15 to Oct. 15	Oct. 16 to Apr. 8	Apr. 9 to Oct. 4	Oct. 5 to Apr. 15	
1	Crotalaria and millet	7.0	4.2	21.9	44.0	22.8	52.4	9.3	23.3	22.2	13.1	222.0
2	do	6.5	3.1	12.3	31.4	23.6	53.1	7.7	25.8	26.6	14.8	204.9
3	do	5.5	3.7	12.4	17.2	21.5	51.2	8.6	26.4	26.1	15.7	188.3
4	Crotalaria, millet, and rye.	4.5	1.0	5.9	11.6	13.2	40.0	6.8	23.6	26.1	14.1	146.8
5	do	4.6	.5	9.0	4.9	9.1	41.5	6.2	25.8	21.6	16.2	139.4
6	do	3.9	1.0	7.7	3.8	10.1	41.8	6.3	23.0	20.9	16.2	134.7
7	Cowpeas and millet	3.3	5.0	14.1	26.2	17.0	45.7	9.1	21.5	19.1	11.7	172.7
8	Cowpeas, millet, and rye.	2.6	1.5	7.7	9.0	11.5	27.0	6.8	19.6	16.2	11.1	113.0
9	Corn, crotalaria, and millet.	3.5	2.0	7.4	8.3	8.9	26.0	5.9	14.0	27.6	5.7	109.3
10	Corn, crotalaria, millet, and rye.	2.5	1.3	7.3	5.3	8.1	24.9	5.0	14.9	22.3	8.6	100.2
11	Crotalaria	4.2	3.2	11.6	16.4	5.0	89.9	6.4	80.8	31.2	45.7	294.1
12	Crotalaria and rye	4.7	1.1	8.2	3.4	2.8	38.7	4.0	34.8	33.3	27.3	150.2
13	Crotalaria	6.1	1.4	5.7	12.2	8.2	47.0	5.9	38.6	36.4	20.4	190.9
14	None	21.4	12.3	20.7	24.0	46.8	46.6	32.8	28.3	45.4	19.0	306.3
15	Corn and millet	4.3	2.8	7.3	10.6	9.0	20.2	5.5	11.8	9.7	7.8	89.0
16	None	15.7	9.2	18.8	14.7	23.2	20.5	20.9	15.0	20.9	12.8	171.7
17	Millet	13.7	11.4	26.9	39.0	7.9	28.8	7.7	17.4	12.9	8.4	176.1
18	Millet and rye	9.7	.7	26.6	15.9	6.6	27.9	6.0	16.5	17.0	7.0	133.9
19	Millet and mixed crops	1.4	2.8	8.4	4.4	6.9	28.4	6.6	10.7	33.2	8.2	120.0
20	do	1.4	6.3	9.0	8.9	8.9	26.6	8.0	17.4	27.6	8.7	122.8
21	do	1.5	5.2	14.5	9.6	10.0	28.1	7.2	17.7	33.2	7.6	134.6
22	do	1.7	3.8	8.6	5.8	8.4	31.3	7.2	20.4	38.0	9.8	135.0
23	Cowpeas, millet, and rye.[1]	1.9	1.4	6.1	11.0	11.8	40.3	6.1	18.0	15.1	9.7	121.4
24	do[1]	3.6	3.3	9.9	21.7	16.0	45.7	6.7	16.7	18.2	9.7	155.5

[1] In 1933 an application of 1,200 pounds per acre of dolomitic limestone was made to these lysimeters.

quantities present in the leachates. The largest quantities of both elements leached from the soil were from the fertilized fallow soil, but these quantities were only slightly more than where crotalaria was grown without winter cover and returned as a mulch. Winter cover crops usually decreased the losses of both elements. Undoubtedly, crops tend to reduce losses in the drainage waters through their assimilation or transformation of the soluble salts of these elements, especially the nitrates. Such compounds as calcium nitrate may be assimilated completely, or only the nitrate ion may be utilized, leaving at least a part of the calcium to form carbonates, sulfates, or other less soluble salts, or the calcium may enter the exchange complex.

TABLE 18.—*Magnesium contents of percolates as pounds MgO per acre, Sandhill Experiment Station, 1933–38*

Lysimeter No.	Crops grown	1933–34		1934–35		1935–36		1936–37		1937–38		Total for 5 years
		May 6 to Oct. 26	Oct. 27 to Apr. 9	Apr. 10 to Oct. 1	Oct. 2 to Apr. 4	Apr. 5 to Oct. 2	Oct. 3 to Apr. 14	Apr. 15 to Oct. 15	Oct. 16 to Apr. 8	Apr. 9 to Oct. 4	Oct. 5 to Apr. 16	
1	Crotalaria and millet	8.4	3.5	19.4	21.1	6.4	15.0	2.5	5.5	2.2	2.2	86.2
2	do	4.5	2.8	12.2	19.8	8.9	15.2	2.0	6.0	2.5	2.2	76.1
3	do	5.7	3.1	13.0	11.3	9.0	17.7	2.3	5.8	2.5	2.6	73.6
4	Crotalaria, millet, and rye.	5.2	.7	7.6	9.7	7.5	20.7	2.9	7.3	3.3	3.2	68.1
5	do	6.3	.4	9.5	3.8	5.5	23.1	2.6	7.0	3.0	2.9	64.9
6	do	5.4	.8	9.0	3.6	6.1	22.2	2.8	7.9	2.8	3.3	63.9
7	Cowpeas and millet	5.5	3.9	15.4	17.1	6.5	16.0	2.6	5.7	2.2	2.8	77.9
8	Cowpeas, millet, and rye.	4.4	1.0	8.3	8.2	7.9	19.9	3.2	7.1	2.9	3.3	66.2
9	Corn, crotalaria, and millet.	5.9	1.1	8.7	7.4	6.2	14.0	3.2	5.4	2.2	2.4	56.5
10	Corn, crotalaria, millet, and rye.	5.2	.8	8.2	5.2	6.0	16.7	3.2	6.4	2.2	3.1	57.0
11	Crotalaria	5.9	2.7	10.7	12.4	7.0	29.2	1.3	13.2	5.5	7.1	95.0
12	Crotalaria and rye	4.9	.9	9.6	3.8	2.0	27.6	2.0	11.2	4.9	5.1	72.0
13	Crotalaria	5.6	1.1	7.1	12.2	5.7	24.4	1.6	8.2	5.0	4.1	75.0
14	None	22.2	9.3	22.3	13.9	15.5	10.2	4.9	3.5	4.7	2.8	109.3
15	Corn and millet	5.3	1.5	5.9	9.9	6.6	12.5	2.4	5.0	3.1	2.6	58.0
16	None	14.8	6.8	17.1	10.0	10.5	9.0	6.8	5.8	4.8	3.2	88.8
17	Millet	13.7	8.8	23.3	21.1	3.1	10.0	2.3	5.0	3.9	3.6	94.8
18	Millet and rye	10.6	.3	25.1	10.0	3.3	12.5	2.1	5.8	2.6	2.7	75.0
19	Millet and mixed crops	3.2	1.0	9.2	4.8	5.7	10.6	2.6	7.1	3.5	2.4	59.1
20	do	3.0	4.5	9.8	7.1	6.7	16.0	3.5	6.6	4.2	2.8	64.2
21	do	3.2	3.4	15.4	8.0	7.4	17.2	2.7	5.6	3.6	2.5	69.0
22	do	4.0	2.4	9.5	5.0	6.7	18.9	2.7	7.2	4.0	2.5	62.9
23	Cowpeas, millet, and rye.[1]	4.1	1.1	6.3	8.3	8.6	20.5	2.8	8.2	4.4	4.7	69.0
24	do[1]	4.1	3.2	11.4	17.3	10.1	21.3	2.4	8.1	3.9	4.9	86.7

[1] In 1933 an application of 1,200 pounds per acre of dolomitic limestone was made to these lysimeters.

Sodium in Leachates

The quantity of sodium in the leachates from the various lysimeters is reported in table 19. Where no fertilizer was added and no crop was grown (lysimeter 16), 35.6 pounds of Na_2O was present in the

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percolates. Addition of the usual 400 pounds per acre of 4–8–4 fertilizer annually increased the sodium value in the absence of a crop (lysimeter 14) to 98.5 pounds. The leachates from all the other lysimeters that received the same quantity of fertilizer but were variously cropped, gave values that were near but slightly below this figure. Larger quantities of sodium in other leachates are due either to additions of complete fertilizer containing sodium, to fertilization with sodium nitrate, or to additions of animal manures. The crops had little effect on the values obtained.

Manganese in Leachates

Manganese was determined in the various leachates, even though these values are of minor interest in the present study. They are reported in table 20. The highest value, 2.9 pounds Mn_3O_4 for the 5-year period, was obtained in the percolate from the fertilized fallow. Under similar conditions, where no fertilizer was added, the quantity was 1.85 pounds. The leachates from the fertilized cropped soils contained an average of 1.2 pounds of Mn_3O_4, which is a reduction of 59 percent caused by the crops.

TABLE 19.—*Sodium contents of percolates as pounds Na_2O per acre, Sandhill Experiment Station, 1933–38*

Lysimeter No.	Crops grown	1933–34		1934–35		1935–36		1936–37		1937–38		Total for 5 years
		May 9 to Oct. 26	Oct. 27 to Apr. 9	Apr. 10 to Oct. 1	Oct. 2 to Apr. 4	Apr. 5 to Oct. 2	Oct. 3 to Apr. 14	Apr. 15 to Oct. 15	Oct. 16 to Apr. 8	Apr. 9 to Oct. 4	Oct. 5 to Apr. 15	
1	Crotalaria and millet	14.5	7.6	11.8	10.1	8.0	5.0	4.1	8.7	5.7	4.4	79.9
2	do	13.0	4.6	12.8	11.2	7.0	6.9	3.6	9.1	4.8	4.8	77.8
3	do	12.8	6.0	15.1	9.2	7.2	7.8	3.0	10.1	5.8	3.7	80.7
4	Crotalaria, millet, and rye	16.0	1.7	12.1	9.6	9.7	14.0	3.2	10.2	4.8	4.1	85.4
5	do	9.4	5.2	16.0	8.7	8.5	14.0	3.5	10.6	4.1	3.6	83.6
6	do	11.0	1.6	15.5	9.0	7.7	13.1	3.3	10.4	5.4	5.0	82.0
7	Cowpeas and millet	11.8	5.7	14.0	9.5	9.5	6.1	3.5	10.2	4.9	3.8	79.0
8	Cowpeas, millet, and rye	13.2	1.7	11.9	11.2	12.1	7.2	3.4	10.4	3.8	4.7	79.6
9	Corn, crotalaria, and millet	15.3	4.8	24.5	19.1	27.0	18.5	6.2	10.1	8.4	3.3	137.2
10	Corn, crotalaria, millet, and rye	14.6	3.0	29.1	17.0	25.5	22.7	5.9	12.4	5.2	4.2	139.6
11	Crotalaria	10.5	6.4	13.2	9.8	2.9	16.7	1.0	18.4	7.9	7.5	94.3
12	Crotalaria and rye	9.6	1.5	13.9	9.8	2.2	20.9	1.3	15.5	4.2	6.2	85.1
13	Crotalaria	14.3	2.4	13.0	15.0	3.2	17.8	1.8	18.9	6.9	4.4	97.7
14	None	23.5	8.6	16.9	3.4	11.8	4.0	9.6	8.0	11.5	1.2	98.5
15	Corn and millet	11.1	4.4	26.5	25.1	20.4	25.4	5.5	15.4	7.0	3.1	144.2
16	None	16.1	2.2	3.3	1.0	3.9	1.9	2.1	2.4	1.5	.3	35.6
17	Millet	15.4	1.9	12.2	8.0	9.9	14.7	4.1	11.7	5.8	3.6	87.3
18	Millet and rye	14.3	.8	12.8	3.1	10.2	19.1	2.8	11.2	4.9	3.3	82.5
19	Millet and mixed crops	10.6	3.7	20.9	21.5	37.1	38.1	8.4	30.2	13.1	5.6	189.2
20	do	12.3	0.9	26.3	23.0	43.5	49.7	11.8	37.9	16.1	8.6	230.1
21	do	18.0	8.0	39.2	29.4	53.1	54.7	10.6	41.2	19.8	7.0	281.0
22	do	13.6	5.0	29.1	21.0	46.0	41.6	8.2	28.5	16.0	4.7	214.6
23	Cowpeas, millet, and rye	11.5	4.5	9.0	10.2	13.8	13.2	3.8	11.1	6.5	3.2	86.8
24	do	17.1	3.1	12.7	15.0	12.3	11.0	2.7	11.2	6.1	3.1	91.3

TABLE 20.—*Manganese contents of percolates as pounds Mn_3O_4 per acre, Sandhill Experiment Station, 1933–38*

Lysimeter No.	Crops grown	1933–34		1934–35		1935–36		1936–37		1937–38		Total for 5 years
		May 6 to Oct. 26	Oct. 27 to Apr. 9	Apr. 10 to Oct. 1	Oct. 2 to Apr. 4	Apr. 5 to Oct. 2	Oct. 3 to Apr. 14	Apr. 15 to Oct. 15	Oct. 16 to Apr. 8	Apr. 9 to Oct. 4	Oct. 5 to Apr. 16	
1	Crotalaria and millet	0.18	0.08	0.21	0.29	0.13	0.25	0.04	0.06	0.17	0.03	1.44
2	do	.12	.12	.13	.32	.19	.21	.02	.05	.14	.03	1.33
3	do	.06	.15	.23	.18	.17	.22	.03	.07	.17	.03	1.31
4	Crotalaria, millet, and rye	.09	.03	.17	.13	.08	.15	.02	.06	.12	.03	.88
5	do	.10	.02	.21	.07	.08	.21	.03	.10	.15	.05	1.02
6	do	.12	.06	.18	.05	.08	.21	.02	.07	.13	.05	.97
7	Cowpeas and millet	.05	.10	.12	.27	.15	.34	.05	.07	.18	.04	1.37
8	Cowpeas, millet, and rye	.05	.04	.08	.09	.11	.26	.03	.05	.15	.04	.93
9	Corn, crotalaria, and millet	.06	.03	.04	.07	.09	.15	.03	.04	.12	.03	.66
10	Corn, crotalaria, millet, and rye	.06	.02	.05	.05	.04	.14	.03	.04	.13	.04	.60
11	Crotalaria	.06	.11	.18	.09	.09	.79	.04	.69	.33	.21	2.59
12	Crotalaria and rye	.05	.04	.16	.05	.02	.54	.03	.17	.54	.08	1.68
13	Crotalaria	.13	.07	.12	.15	.07	.61	.05	.25	.58	.14	2.17
14	None	.47	.25	.26	.21	.31	.47	.20	.12	.60	.08	2.96
15	Corn and millet	.08	.06	.06	.12	.06	.15	.02	.04	.11	.04	.74
16	None	.27	.16	.15	.19	.21	.27	.15	.11	.27	.07	1.65
17	Millet	.25	.22	.15	.46	.05	.25	.04	.07	.12	.04	1.65
18	Millet and rye	.20	.01	.15	.15	.05	.24	.04	.06	.12	.04	1.07
19	Millet and mixed crops	0.	.04	.08	.04	.04	.16	.02	.07	.24	.04	.73
20	do	0	.09	.09	.05	.06	.20	.06	.09	.28	.04	.96
21	do	0	.10	.15	.07	.06	.21	.05	.10	.28	.06	1.06
22	do	0	.08	.09	.04	.05	.20	.04	.07	.20	.03	.80
23	Cowpeas, millet, and rye	0	.04	.07	.11	.06	.31	.03	.08	.15	.04	.92
24	do	0	.04	.11	.30	.12	.53	.04	.11	.25	.05	1.55

Phosphorus in Leachates

Analyses for phosphorus in the leachates, reported in table 21, show that even this very sandy soil released little of this element. The largest quantity, 2.1 pounds, was present in the percolate from the fertilized fallow; the value for the unfertilized fallow soil was 1.5 pounds P_2O_5. Cropping treatment had little effect, as all other values fell within the range of 0.9 to 1.7 pounds P_2O_5 for the 5-year period. It is fortunate that this very sandy soil retains phosphorus against leaching to almost the same extent as does a much finer textured soil.

Sulfur in Leachates

The sulfur contents of the various leachates are shown in table 22. The lowest amount, 124 pounds SO_3 per acre for 5 years, was in the leachate from the unfertilized fallow soil. The addition of 400 pounds per acre annually of 4–8–4 fertilizer raised this value to 269 pounds. The lysimeters (Nos. 19 to 22) that received additional complete fertilizer and also animal manures released an average of 408 pounds of SO_3 to the leachate. Crops usually decreased the sulfur content of the leachates only slightly.

TABLE 21.—*Phosphorus contents of percolates as pounds P_2O_5 per acre, Sandhill Experiment Station, 1933–38*

Lysimeter No.	Crops grown	Added as fertilizer, pounds P_2O_5	1933–34		1934–35		1935–36		1936–37		1937–38		Total for 5 years
			May 6 to Oct. 26	Oct. 27 to Apr. 9	Apr. 10 to Oct. 1	Oct. 2 to Apr. 4	Apr. 5 to Oct. 2	Oct. 3 to Apr. 14	Apr. 15 to Oct. 15	Oct. 16 to Apr. 8	Apr. 9 to Oct. 4	Oct. 5 to Apr. 15	
1	Crotalaria and millet	160	0.17	0.26	0.12	0.39	0.08	0.20	0.12	0.10	0.22	0.05	1.71
2	do	160	.22	.08	.11	.40	.10	.18	.09	.10	.20	.03	1.51
3	do	160	.09	.13	.12	.29	.06	.19	.09	.10	.19	.02	1.28
4	Crotalaria, millet, and rye	160	.10	.04	.12	.22	.05	.22	.08	.10	.20	.03	1.25
5	do	160	.15	.02	.11	.12	.04	.20	.04	.11	.18	.02	.99
6	do	160	.23	.06	.10	.09	.06	.19	.04	.10	.18	.02	1.07
7	Cowpeas and millet	160	.27	.27	.12	.24	.06	.14	.05	.10	.16	.03	1.44
8	Cowpeas, millet, and rye	160	.17	.12	.13	.15	.05	.16	.05	.09	.15	.06	1.13
9	Corn, crotalaria, and millet.	160	.29	.16	.10	.09	.05	.17	.05	.10	.21	.04	1.26
10	Corn, crotalaria, millet, and rye.	160	.25	.10	.11	.08	.07	.19	.05	.10	.19	.04	1.18
11	Crotalaria	160	.12	.21	.09	.16	.02	.18	.03	.13	.10	.02	1.06
12	Crotalaria and rye	160	.16	.05	.07	.12	.02	.23	.03	.09	.10	.02	.89
13	Crotalaria	160	.18	.08	.09	.15	.03	.17	.03	.11	.15	.02	1.01
14	None	160	.32	.38	.21	.30	.08	.21	.07	.10	.38	.04	2.09
15	Corn and millet	160	.18	.29	.10	.12	.06	.15	.05	.09	.16	.03	1.24
16	None	0	.17	.16	.18	.24	.08	.26	.05	.10	.22	.02	1.48
17	Millet	96	.16	.0	.17	.38	.04	.15	.04	.10	.16	.02	1.22
18	Millet and rye	96	.34	.09	.18	.16	.04	.23	.03	.10	.16	.03	1.36
19	Millet and mixed crops	288	.45	.27	.08	.09	.06	.14	.03	.10	.21	.04	1.47
20	do	288	.43	.32	.05	.07	.03	.19	.05	.10	.23	.04	1.51
21	do	288	.51	.27	.10	.05	.04	.13	.03	.07	.18	.06	1.44
22	do	288	.29	.28	.10	.05	.03	.15	.04	.13	.15	.04	1.26
23	Cowpeas, millet, and rye	160	.16	.10	.08	.16	.04	.16	.03	.10	.13	.03	.99
24	do	160	.33	.08	.08	.25	.04	.19	.03	.10	.13	.02	1.25

TABLE 22.—*Sulfur contents of percolates as pounds SO_3 per acre, Sandhill Experiment Station, 1933–38*

Lysimeter No.	Crops grown	1933–34		1934–35		1935–36		1936–37		1937–38		Total for 5 years
		May 6 to Oct. 26	Oct. 27 to Apr. 9	Apr. 10 to Oct. 1	Oct. 2 to Apr. 4	Apr. 5 to Oct. 2	Oct. 3 to Apr. 14	Apr. 15 to Oct. 15	Oct. 16 to Apr. 8	Apr. 9 to Oct. 4	Oct. 5 to Apr. 15	
1	Crotalaria and millet	3.9	2.4	3.5	13.4	40.5	85.8	18.1	38.8	33.5	21.0	260.9
2	do	4.4	1.3	5.1	6.8	32.8	84.1	16.9	40.0	32.6	21.3	245.9
3	do	4.8	1.9	5.9	8.5	34.5	86.2	16.9	41.6	34.8	22.7	257.8
4	Crotalaria, millet, and rye.	4.8	.6	12.3	9.7	39.8	80.7	15.2	37.7	32.3	23.0	256.1
5	do	3.9	.2	8.5	8.4	32.5	77.7	14.9	40.2	34.2	19.7	240.2
6	do	3.4	.6	8.8	0.0	33.5	76.9	15.0	30.7	33.6	21.9	242.4
7	Cowpeas and millet	4.0	1.8	7.8	14.9	36.1	87.6	17.8	44.1	34.9	22.4	271.4
8	Cowpeas, millet, and rye	3.0	1.5	10.1	17.2	40.4	78.5	16.1	41.4	32.0	20.8	261.0
9	Corn, crotalaria, and millet.	3.7	2.5	22.0	15.0	44.0	78.1	16.0	30.6	32.8	18.9	263.6
10	Corn, crotalaria, millet, and rye.	3.1	1.5	24.1	8.9	47.2	73.3	14.7	31.9	26.5	18.4	252.6
11	Crotalaria	4.1	1.7	5.1	12.6	9.8	60.4	7.0	29.8	17.4	11.1	159.0
12	Crotalaria and rye	3.3	.5	7.0	10.1	9.1	70.8	8.1	37.0	13.1	11.2	170.2
13	Crotalaria	5.3	1.2	8.0	13.0	9.0	70.3	7.8	32.4	16.5	14.6	179.0
14	None	4.7	1.8	14.1	17.2	44.9	84.3	18.4	36.0	30.8	16.4	268.6
15	Corn and millet	3.8	5.2	27.4	17.8	42.3	74.5	14.0	38.0	30.7	20.5	274.2
16	None	5.1	2.1	10.8	9.1	15.3	36.7	8.5	17.0	13.4	5.3	124.2
17	Millet	4.8	2.1	13.2	6.3	16.9	55.8	15.5	36.0	35.3	19.2	205.7
18	Millet and rye	4.8	1.5	9.7	8.5	17.0	61.5	13.2	35.5	28.9	19.0	203.5
19	Millet and mixed crops.	2.6	3.8	17.9	13.6	59.5	127.1	19.2	67.0	55.4	16.1	385.2
20	do	2.3	3.2	19.7	13.5	60.4	139.9	19.8	72.2	55.8	15.4	405.2
21	do	3.4	2.9	21.0	13.3	72.2	145.0	20.7	72.3	61.4	14.7	426.9
22	do	4.3	3.9	26.3	13.7	64.3	139.1	17.3	65.5	65.8	15.6	415.8
23	Cowpeas, millet, and rye.	4.3	.7	6.9	10.0	45.3	98.9	15.3	46.9	37.9	23.5	290.6
24	do	3.5	.4	4.8	13.1	48.7	101.3	14.6	48.6	36.7	18.4	290.1

Chlorine in Leachates

The chlorine contents of the leachates from the various lysimeters, shown in table 23, averaged about 150 pounds per acre for the experimental period. Most of the chlorides came from the soil, as shown by the value (141 pounds) for the untreated and uncropped lysimeter 16. Fertilization with 400 pounds of 4-8-4 fertilizer increased this quantity (lysimeter 14) to 183 pounds. Only three values higher than this were obtained; two of these were where larger additions of complete fertilizer were made together with manure, and the third was where muriate of potash was added. All cropping systems decreased the chlorine content of the leachates, but the effect was not marked for most lysimeters.

TABLE 23.—*Chlorine contents of percolates as pounds of Cl per acre, Sandhill Experiment Station, 1933–38*

Lysimeter No.	Crops grown	1933–34		1934–35		1935–36		1936–37		1937–38		Total for 4.5 years
		May 6 to Oct. 26	Oct. 27 to Apr. 9	Apr. 10 to Oct. 1	Oct. 2 to Apr. 4	Apr. 5 to Oct. 2	Oct. 3 to Apr. 14	Apr. 15 to Oct. 15	Oct. 16 to Apr. 8	Apr. 9 to Oct. 4	Oct. 5 to Apr. 15	
1	Crotalaria and millet	(1)	11.7	11.7	19.4	15.0	32.5	10.3	31.0	9.2	11.5	152.3
2	do	(1)	12.4	11.6	15.4	10.5	37.6	8.9	30.5	9.8	11.9	148.6
3	do	(1)	14.1	11.3	14.3	10.1	34.3	9.4	36.3	10.7	11.3	151.8
4	Crotalaria, millet, and rye.	(1)	5.3	12.2	13.0	15.0	34.6	9.2	36.4	10.4	10.6	146.7
5	do	(1)	1.6	15.5	9.7	8.8	33.5	8.4	40.3	9.7	10.8	141.3
6	do	(1)	4.7	15.7	10.5	8.3	34.7	9.2	49.0	11.2	10.6	153.9
7	Cowpeas and millet	(1)	12.8	14.7	19.8	16.3	29.5	12.7	16.3	11.7	9.4	143.2
8	Cowpeas, millet, and rye.	(1)	6.1	12.9	14.6	17.8	31.5	10.0	17.9	9.8	10.0	130.6
9	Corn, crotalaria, and millet.	(1)	7.8	16.4	13.1	15.3	32.8	12.1	17.4	9.2	9.8	133.9
10	Corn, crotalaria, millet, and rye.	(1)	6.2	16.7	9.9	16.6	30.4	12.4	14.7	11.2	10.2	128.3
11	Crotalaria	(1)	14.4	11.1	16.6	5.4	38.7	5.7	29.6	7.7	9.4	138.6
12	Crotalaria and rye	(1)	4.9	15.6	11.4	3.7	40.2	6.6	22.0	7.9	7.2	119.5
13	Crotalaria	(1)	6.5	19.5	15.3	6.9	31.6	8.6	22.3	9.8	8.2	128.7
14	None	20.0	7.9	31.1	17.5	34.7	23.6	22.7	18.9	17.3	9.5	183.2
15	Corn and millet	(1)	7.8	23.5	22.1	21.7	24.7	14.1	17.1	12.4	10.7	154.1
16	None	9.6	3.4	26.8	18.8	20.8	23.4	12.0	13.6	14.5	8.0	141.3
17	Millet	(1)	4.7	27.8	32.5	15.1	33.2	12.4	16.4	9.8	9.7	161.6
18	Millet and rye	(1)	.7	28.4	14.9	24.6	30.5	9.4	18.4	9.1	9.7	145.7
19	Millet and mixed crops	(1)	8.3	17.3	12.9	14.5	25.2	12.6	23.6	10.7	6.3	131.4
20	do	(1)	31.1	19.5	16.7	22.5	29.9	22.6	27.4	12.0	8.0	189.7
21	do	(1)	26.3	52.4	29.4	29.8	33.7	19.8	29.0	18.2	7.3	245.9
22	do	(1)	17.6	23.5	15.6	25.0	28.3	15.9	22.4	13.8	7.3	169.4
23	Cowpeas, millet, and rye.	3.8	5.7	14.7	17.3	19.8	34.1	10.6	19.2	7.8	8.9	138.1
24	do	4.0	14.8	45.5	53.6	25.9	36.3	10.4	20.1	9.2	12.1	227.9

[1] Not determined.

SUMMARY

Lysimeter studies are reported that were designed to obtain both fundamental and practical information on methods of crop production on a very sandy soil low in organic matter and water-holding capacity. Emphasis was placed on the determination of the value of green manures in comparison with animal manures in crop production and in soil organic matter maintenance. Leaching losses of several of the elements are also reported and nitrogen balance data calculated.

Where crotalaria was grown for 2 years and returned to the soil each year, the crops of millet that followed were markedly increased and the effect was in evidence for three successive millet crops. Crotalaria turned at maturity gave larger yields of millet than when crotalaria was turned early. The yields of millet were almost the same where the mature crotalaria was added to the soil as a mulch as where it was incorporated with it. A rye cover crop greatly decreased the losses through leaching and thereby increased yields. Cowpeas was much less effective as a green manure than was crotalaria. Fresh cow manure, added at such rate as to supply the same quantity of nitrogen as that fixed by crotalaria, gave about the same yield increase. Obviously, the main factor determining the millet yields was the amount of nitrogen available, which was determined by the quantity added or fixed and by the extent to which nitrogen was assimilated before being removed by leaching.

Where cow manure was applied regularly at equal nitrogen levels and the millet crop clipped frequently, the total tons (dry weight) of millet per acre for the 5-year period were: (1) 7.5 for fresh cow manure; (2) 8.6 for fresh cow manure plus oats straw; (3) 9.7 for semi-deep stall manure containing oat straw; and (4) 7.6 for deep stall manure containing pine needles. As these yields are directly correlated with the nitrogen contents of the crops and little loss occurred through leaching, it would appear that the differences between manures were due chiefly to the variations in loss of volatile forms of nitrogen.

The water lost by evaporation or evapotranspiration ranged from 16 inches from the uncropped soils to 28 inches from the soil planted to crotalaria and rye. The annual rainfall averaged 42.5 inches. A direct and high degree of correlation occurred between the dry weights of crops produced and evapotranspiration from these cropped soils. Likewise, the efficiency of water use was directly correlated with dry matter production. These relationships held for all cropping systems, showing that the type of crop grown was not important except as it affects the total dry matter produced. Water is also used more efficiently if the soil is kept covered with vegetation.

Losses of nitrate nitrogen in the leachates ranged from 11 to 178 pounds per acre for the 5-year period. Such losses were low where a crop was grown almost continuously on the soil, and high where the fertilization and cropping systems were such as to allow considerable nitrate formation without simultaneous crop utilization. About 15 percent of the nitrogen in the leachates was in forms other than nitrate.

Organic carbon and nitrogen were increased to at least a slight extent by all the 22 cropping treatments. The average increase in carbon during the 5-year period was 1,169 pounds per acre for the surface 4.5 inches of soil. The average increase in carbon for the 4 soils that received animal manures semiannually was 2,434 pounds;

for the two soils where crotalaria was returned as a mulch, 2,250 pounds; and for the remaining 16 cropped soils, 718 pounds. The gains in soil carbon where green crops and crop residues were added appeared to be correlated closely with the quantity of carbon added. The stage of maturity at which the green crop was added to the soil and the method of addition did not appreciably affect the organic matter buildup. Winter cover crops were beneficial, both in conserving nitrogen and in helping to raise the soil organic matter level. Increases in soil carbon were accompanied by increases in nitrogen in the approximate ratio of 1 part of nitrogen to 10 parts of carbon.

Crotalaria fixed about 75 to 90 pounds of nitrogen per acre annually, and cowpeas 40 pounds. The quantity fixed corresponded closely with the total nitrogen in the tops of the plants when grown under conditions of low available soil nitrogen.

Accurate nitrogen balance figures for the various lysimeters could not be calculated, because legumes were grown in all but three of the cropped lysimeters. The data indicate, however, that essentially all of the added nitrogen could be accounted for except where crotalaria was grown annually and returned as a mulch, and where animal manures were used. In the crotalaria lysimeters, either some gaseous losses of nitrogen occurred or the fixation by the legumes was less than estimated. Where animal manures were used, 10 to 20 percent of the added nitrogen evidently escaped as gas, probably ammonia.

Potassium was readily leached from fallow soils, but summer crops prevented much of the loss. Winter crops had little effect on the quantity of potassium leached, as summer crops had already removed most of the soluble potassium.

The quantities of sodium in the leachates were usually greater than that of potassium and were not greatly affected by the cropping treatments.

Calcium and magnesium losses from the soil, which were fairly large in the absence of a crop, were reduced by both summer and winter crops.

Manganese in the leachates ranged from 0.6 to 3.0 pounds Mn_3O_4 per acre for the 5-year period. In most cases cropping decreased the amounts in the leachates.

The loss of phosphorus through leaching was negligible, the maximum value for the experimental period being 2.1 pounds P_2O_5 per acre from the fertilized fallow soil.

Losses of sulfur ranged from 124 to 427 pounds SO_3 per acre for the 5-year period. These losses were determined more by the additions made than by the cropping treatment.

The chlorine contents of the leachates averaged about 150 pounds for the entire experiment. Crops usually reduced the losses, but not markedly.

USE OF GREEN MANURES IN COTTON PRODUCTION, WITH INFORMATION ON NUTRIENT LOSSES, SOIL ORGANIC MATTER CHANGES, AND EVAPOTRANSPIRATION, 1938–45 [10]

In the earlier experiment, the use of green manure crops, especially crotalaria, on Lakeland sand was very effective in increasing crop yields. The effects of such legume crops were caused chiefly by the nitrogen fixed by the legume rather than by the increase in soil organic matter. A rye winter cover crop was also effective in producing larger yields through the conservation of nitrogen that would otherwise have escaped in the drainage waters. Any cropping system that tended to reduce such nitrogen losses also brought about larger yields. The addition of summer green manures, winter cover crops, and animal manures resulted in some increases in soil organic matter, but these increases were apparently not sufficiently large to affect appreciably the physical properties of the soils or the crop yields other than through the additional nutrients supplied.

The experiments reported in this section were designed as a followup of the experiments reported in the preceding section. A much wider variety of green manuring systems was used in rotations that always contained cotton as the indicator crop. Yield data are supplemented by leaching data and soil analyses for carbon and nitrogen.

EXPERIMENTAL PLAN

Lysimeters and Soil

The 24 lysimeters used in these studies were the same as those used in the studies described in the earlier section (pp. 2 to 4). The lysimeters were located at the Sandhill Experiment Station near Columbia, S. C.

The soil was the same Lakeland sand that was placed in the lysimeters in 1932 and used for the first experiment. Mechanical and chemical analyses of this soil are given in tables 1 and 2. In preparing the soil for use in the second experiment it was removed from all lysimeters according to three horizons; namely, 0 to 10, 10 to 20, and 20 to 43 inches. The soil from any given horizon from all 24 lysimeters was placed in a single pile for mixing. Since a 2-inch settling had occurred subsequent to the original filling, sufficient new soil was obtained from the original location and added proportionately to each horizon to bring the total depth to 43 inches. After cleaning and painting the insides of the tanks with asphaltum paint, the mixed soil was placed in the lysimeters according to horizons. Before adding the soil, however, 37 pounds of coarse gravel was placed in the bottom of each tank over the drain, and above this 70 pounds of coarse sand,

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[10] This section was prepared by F. E. Allison and E. M. Roller.

as in the original installation. All these refilling operations took place in the latter part of May 1938, immediately after completion of the first experiment.

Cropping Systems

The crops grown in summer and winter on each of the lysimeters during the experimental period 1938–45 are given in table 24.

After filling the lysimeters, no crops were grown in 1938. During this period the leachates were collected and analyzed from time to time for salt concentration to note the degree of uniformity. All lysimeters were planted to cotton the second summer (1939) in order to get the soils in better condition for the experiment to follow and to obtain more information on the degree of uniformity of the soils in the various lysimeters. Owing to the extremely severe boll weevil injury to cotton in some lysimeters, however, it was impossible to obtain crop data on uniformity of the soil in the lysimeters.

A large number of crop combinations (table 24) involving the use of summer and winter green manure crops was used. During the main 6-year experimental period, the indicator crop, cotton, was grown in the various lysimeters from 1 to 6 seasons. One lysimeter was kept fallow for all but the last year. The treatments were not replicated.

Fertilization

The additions of all plant nutrients and lime to the lysimeters during the experimental period are given in table 25 in chronological order. It should be noted that in any one season all lysimeters received the same additions of inorganic nutrients. All crop residues were returned to the soils. With the exception of the cotton residues for the 1939 season, these were returned to the lysimeters on which they were grown. In the 1939 season the residues from all lysimeters were pooled and the same proportion returned to each lysimeter.

The total quantity of each of the main elements added is given by growth periods in table 26. Sufficient dolomitic limestone was added from time to time to keep the soil reaction between pH 6.0 and 6.5.

Methods of Analysis

The chemical methods used were the same as described in the earlier experiment, except that total carbon was determined by dry combustion rather than by the Adams wet-oxidation method.[11] Comparative analyses of the Lakeland sand gave values that were 6.8 percent higher with the dry combustion method than with the wet-oxidation procedure.

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[11] See footnote 6, p. 8.

TABLE 24.—*The cropping system for the 7-year experimental period, 1939–45, at the Sandhill Experiment Station*

Lysimeter No.	Summer Crops							Winter Crops	
	1939	1940	1941	1942	1943	1944	1945	1938–39	1939–1945
1	Cotton	*Crotalaria mucronata.*	Cotton	Cotton	*Crotalaria mucronata.*	Cotton	Cotton	Fallow	Rye.
2	do	do	do	do	do	do	do	do	Oats.
3	do	do	do	do	do	do	do	do	Vetch.
4	do	do	do	do	do	do	do	do	Peas.
5	do	do	do	do	do	do	do	do	Fallow.
6	do	do	do	do	do	do	do	do	Rye and vetch, mixed.
7	do	do	do	do	do	do	do	do	Peas and vetch, alt. years.
8	do	do	do	do	do	do	do	do	Rye and vetch, alt. years.
9	do	do	do	do	do	do	do	do	Rye with nitrogen.
10	do	do	do.[1]	do.[1]	do	do.[1]	do	do	Rye.
11	do	Soybeans	do	do	Soybeans	do	do	do	Do.
12	do	Velvetbeans	do	do	Velvetbeans	do	do	do	Do.
13	do	*Crotalaria spectabilis.*	do	do	*Crotalaria spectabilis.*	do	do	do	Do.
14	do	*Crotalaria intermedia.*	do	do	*Crotalaria intermedia.*	do	do	do	Do.
15	do	Millet [2]	do	do	Millet [2]	do	do	do	Do.
16	do	do.[3]	do	do	do.[3]	do	do	do	Do.
17	do	*Crotalaria mucronata.*	Soybeans	do	*Crotalaria mucronata.*	Soybeans	do	do	Do.
18	do	do	do	do	do	do	do	do	Rye and vetch, alt. years.
19	do	do	*Crotalaria mucronata.*	*Crotalaria mucronata.*	do	*Crotalaria mucronata.*	do	do	Rye.
20	do	*Crotalaria spectabilis.*	*Crotalaria spectabilis.*	*Crotalaria spectabilis.*	*Crotalaria spectabilis.*	*Crotalaria spectabilis.*	do	do	Do.
21	do	*Crotalaria mucronata.*	Soybeans	*Crotalaria mucronata.*	Soybeans	*Crotalaria mucronata.*	do	do	Do.
22	do	Millet	do	Millet	do	Millet	do	do	Do.
23	do	Cotton	Cotton	Cotton	Cotton	Cotton	do	do	Do.
24	do	Fallow	Fallow	Fallow	Fallow	Fallow	do	do	Fallow.

[1] *Crotalaria mucronata* allowed to volunteer in cotton.
[2] Turned at maturity.
[3] 2 crops of millet turned at an early growth stage.

TABLE 25.—*Fertilizers* [1] *and lime, as pounds per acre, added to the 24 lysimeters at the Sandhill Experiment Station during the period October 25, 1938, to September 27, 1945*

Date applied	Commercial fertilizer			Dolomitic limestone
	Amount	Material [2]	Lysimeters	
First winter and summer (1938-39):	*Pounds*			*Pounds*
Apr. 11 (1939)				1,000
Apr. 13	600	2-8-6	All	
May 16	50	Sodium nitrate	do	
June 2	67.5	Nitrate-ammonia (12 pounds N).	do	
July 6	67.5	do	do	
Second winter and summer (1939-40):				
Oct. 10	300	2-8-6	do	
Dec. 20	67.5	Nitrate-ammonia	do	
Feb. 29	67.5	do	do	
Apr. 6	135	do	No. 9	
Apr. 17	600	6-8-6	All, except No. 23	
	600	2-8-6	No. 23	
Apr. 24	135	Nitrate-ammonia	All, except No. 9	
May 23	67.5	do	No. 23	
June 26	67.5	do	do	
Third winter and summer (1940-41):				
Oct. 15	300	2-8-6	All	
Feb. 25	67.5	Nitrate-ammonia	do	
Apr. 1	135	do	No. 9	
Apr. 23	600	6-8-6	Nos. 17-22, 24	
	600	2-8-6	Nos. 1-16, 23	
	135	Nitrate-ammonia	All, except No. 9	
May 28	67.5	Nitrate-ammonia	Nos. 1-16, 23	
June 30	67.5	do	do	
Fourth winter and summer (1941-42):				
Oct. 7	300	2-8-6	All	
Feb. 23	135	Nitrate-ammonia	do	
Apr. 3	135	do	No. 9	
Apr. 14				1,000
Apr. 28	600	6-8-6	Nos. 19-22, 24	
	600	2-8-6	Nos. 1-18, 23	
	135	Nitrate-ammonia	All, except No. 9	
May 20	67.5	Nitrate-ammonia	Nos. 1-18, 23	
May 25	67.5	do	Nos. 1-18, 23	
May 30	67.5	do	All	
Fifth winter and summer (1942-43):				
Oct. 15	300	2-8-6	All	
Feb. 24	135	Nitrate-ammonia	do	
Mar. 26	135	do	No. 9	
Apr. 26	600	2-8-2	All	
	135	Nitrate-ammonia	All, except No. 9	
May 22	600	2-0-2	All	
May 29	600	2-0-2	do	
June 16	600	2-0-4	do	
Sixth winter and summer (1943-44):				
Sept. 18	360	Nitrate-ammonia	No. 16	
				733
Oct. 9	360	Nitrate-ammonia	All, except No. 16	
Oct. 16	300	2-8-6	All	
Feb. 29	180	Nitrate-ammonia	do	
Apr. 2	135	do	No. 9	
Apr. 18	600	2-8-2	All	
	135	Nitrate-ammonia	All, except No. 9	
May 22	135	do	All	
June 12	600	2-0-6	do	
June 28	600	2-0-3	do	

See footnotes at end of table.

TABLE 25.—*Fertilizers*[1] *and lime, as pounds per acre, added to the 24 lysimeters at the Sandhill Experiment Station during the period October 25, 1938, to September 27, 1945*—Continued

Date applied	Commercial fertilizer			Dolomitic limestone
	Amount	Material [2]	Lysimeters	
Seventh winter and summer (1944–45):	*Pounds*			*Pounds*
Oct. 25	300	2-8-6	All	
Mar. 3	200	Sodium nitrate	do	
Apr. 3	135	Nitrate-ammonia	No. 9	
				1,000
Apr. 21	135	Nitrate-ammonia	All, except No. 9	
Apr. 27	600	2-8-5 [3]	All	
May 22	150	Sodium nitrate	do	
June 7	150	do	do	
June 29	600	4-0-6	do	

[1] All cotton residues, including the seed, were returned to the soil each year in September or October.
[2] All formulas refer to nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O), in this order. Nitrate-ammonia consisted of equal parts of nitrogen supplied as sodium nitrate and ammonium sulfate. The same combination was used in the mixed fertilizers except for the application made on Apr. 27, 1945.
[3] All nitrogen as sodium nitrate.

TABLE 26.—*Additions of plant nutrients,*[1] *expressed as pounds per acre, to the lysimeters, Sandhill Experiment Station, 1938–45*

Season	N	P_2O_5	K_2O	CaO	MgO
Winter, 1938-39	0	0	0	0	0
Summer, 1939	44	48	36	365	218
Winter, 1939-40	30	24	18	31	0
Summer, 1940	60	48	36	62	0
Winter, 1940-41	18	24	18	31	0
Summer, 1941	60	48	36	62	0
Winter, 1941-42	30	24	18	31	0
Summer, 1942	72	48	36	365	218
Winter, 1942-43	30	24	18	31	0
Summer, 1943	72	48	60	62	0
Winter, 1943-44	102	24	18	253	160
Summer, 1944	84	48	66	62	0
Winter, 1944-45	38	24	18	31	0
Summer, 1945	108	48	66	365	218
Total	748	480	444	1,751	814

[1] Composition of materials:
N as 20 percent ammonium nitrate or 16 percent sodium nitrate;
P_2O_5 as 18 percent superphosphate;
K_2O as 50 percent muriate of potash;
CaO as 23.8 percent superphosphate and 30.3 percent dolomitic limestone;
MgO as 21.8 percent dolomitic limestone.

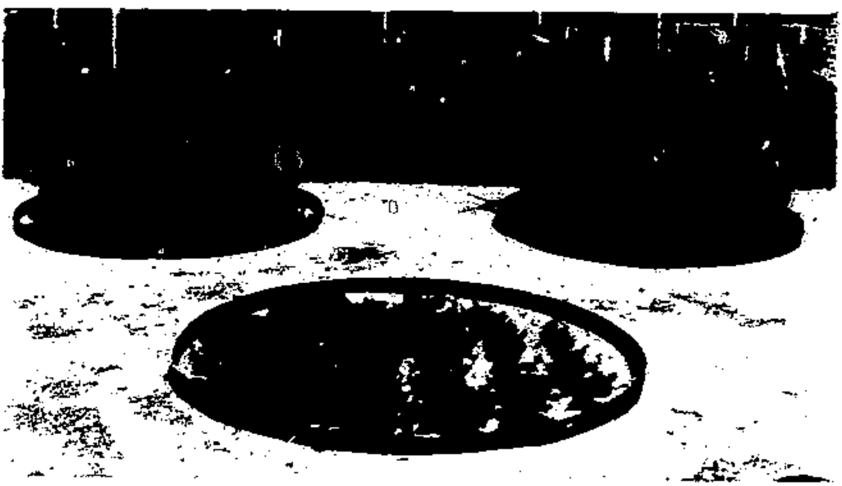
RESULTS

Crop Yields

The yields of the winter crops for the entire experiment are shown in table 27. Figures 8 to 13 show the growth of some of these crops, as well as the layout of the lysimeters.

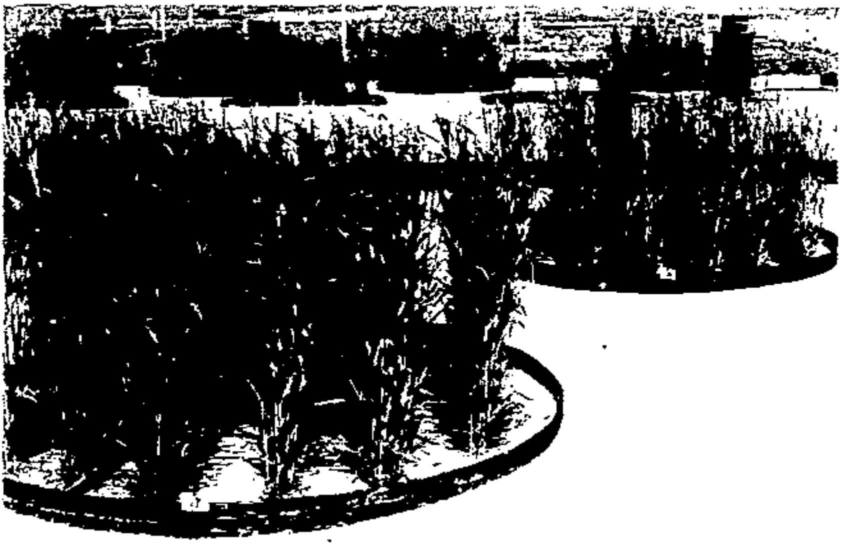
TABLE 27.—*Yields of winter crops expressed as pounds of dry matter per acre, Sandhill Experiment Station, 1939–45*

Lysimeter No.	Kind of crop	1939–40	1940–41	1941–42	1942–43	1943–44	1944–45	Total, 1939–45
		Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1	Rye	1,785	2,743	3,390	999	4,294	2,217	15,428
2	Oats	520	1,782	2,050	547	2,525	1,122	8,555
3	Vetch	1,124	567	310	588	246	632	3,467
4	Peas	262	828	588	338	586	960	3,562
5	Fallow	0	0	0	0	0	0	0
6	Rye and vetch, mixed	1,821	2,555	3,275	1,169	3,254	2,458	14,532
7	Peas and vetch, alternate years	153	828	994	542	586	632	3,735
8	Rye and vetch, alternate years	1,907	1,308	3,211	939	3,932	967	12,264
9	Rye with nitrogen	1,954	2,642	3,345	926	4,384	2,169	15,420
10	Rye	1,989	2,591	3,211	1,702	4,339	2,555	16,387
11	do	1,988	2,436	3,211	851	4,430	2,169	15,087
12	do	2,167	2,388	3,345	1,036	4,475	2,458	15,869
13	do	2,070	2,083	2,944	814	4,565	2,314	14,790
14	do	1,877	3,150	3,434	1,036	4,475	2,121	16,093
15	do	1,831	699	2,542	888	3,341	2,217	11,518
16	do	1,910	932	2,944	962	3,155	1,928	11,831
17	do	1,970	2,642	3,070	1,036	4,475	3,711	17,804
18	Rye and vetch, alternate years	2,081	1,600	3,523	939	4,430	930	12,993
19	Rye	1,781	2,704	4,728	2,257	4,610	3,760	19,930
20	do	1,810	2,286	3,390	2,072	4,475	2,747	16,780
21	do	1,700	2,845	3,925	2,295	4,610	3,519	18,894
22	do	1,782	792	3,523	703	3,573	1,446	11,819
23	do	1,811	1,778	3,077	926	3,706	1,763	13,061
24	Fallow	0	0	0	0	0	0	0



PN-921

FIGURE 8.—Austrian Winter peas on lysimeter 7 in foreground and rye in the background. Photographed March 20, 1942.

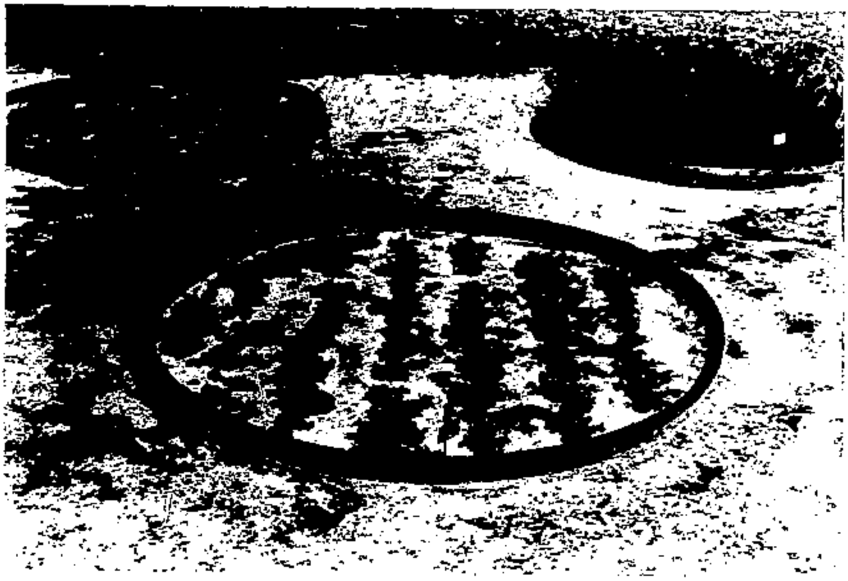


PN-622

FIGURE 9.—Rye on lysimeters 17 and 18. Photographed March 20, 1942.

PN-623

FIGURE 10.—Oats on lysimeter 2. Photographed March 13, 1944.



PN-634

FIGURE 11.—Vetch on lysimeter 3 in foreground, peas on lysimeter 4 in the left rear, and oats on lysimeter 2 in the right rear. Photographed March 13, 1944.

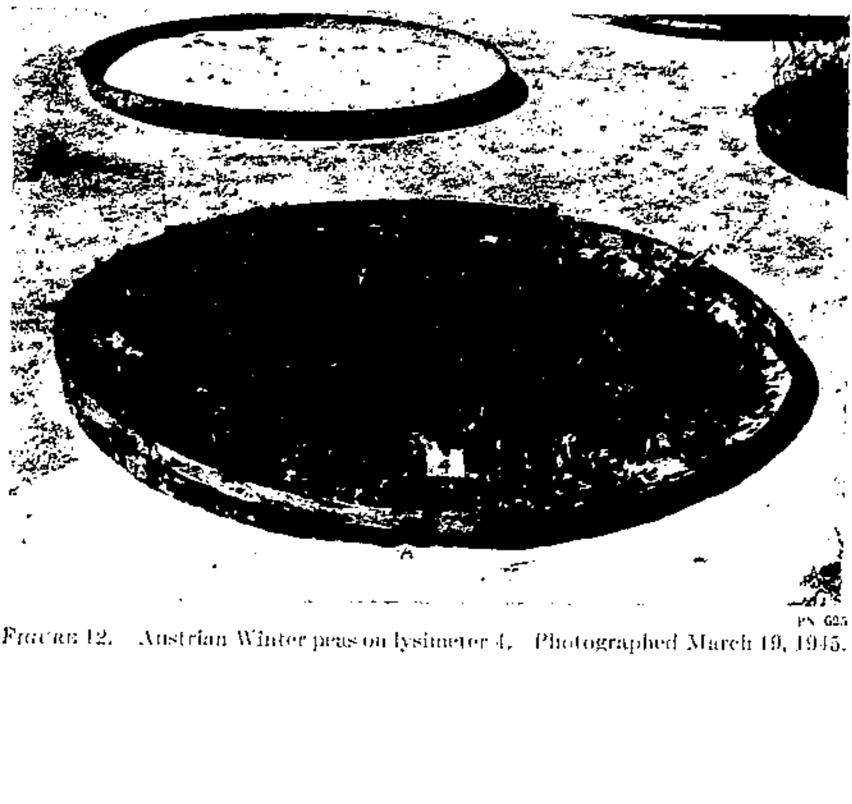


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FIGURE 12. Austrian Winter peas on lysimeter 4. Photographed March 19, 1945.

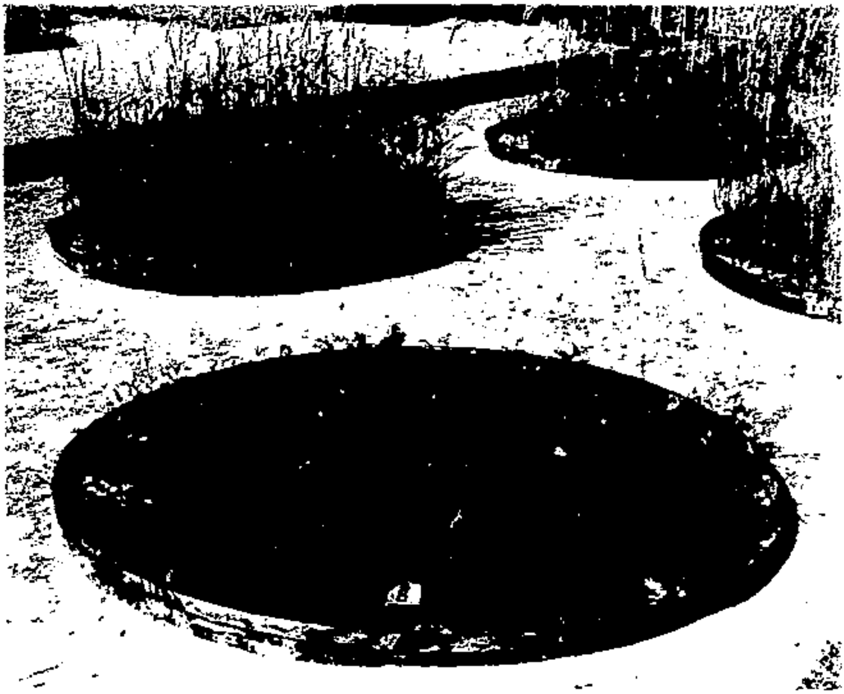

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FIGURE 13.—Vetch on lysimeter 8 in foreground and rye in the background. Photographed March 19, 1945.

The yields of the summer crops for the 6 years of the experiment, beginning in 1940, are given in table 28. Figures 14 to 16 show the appearance of some of these crops.

The cotton for the year 1939 was not harvested, because of very severe boll weevil injury, but the plants were cut green, dried, mixed, and an equal portion of the total returned to each lysimeter. For the same reason, the seed cotton was not harvested in 1941 but the plants were cut, dried, weighed, and returned to the soil of the lysimeter where grown. For ease of comparison, some of the data in table 28 are rearranged in table 29 to show more directly the effect of the cropping systems on the yields of cotton, the indicator crop.

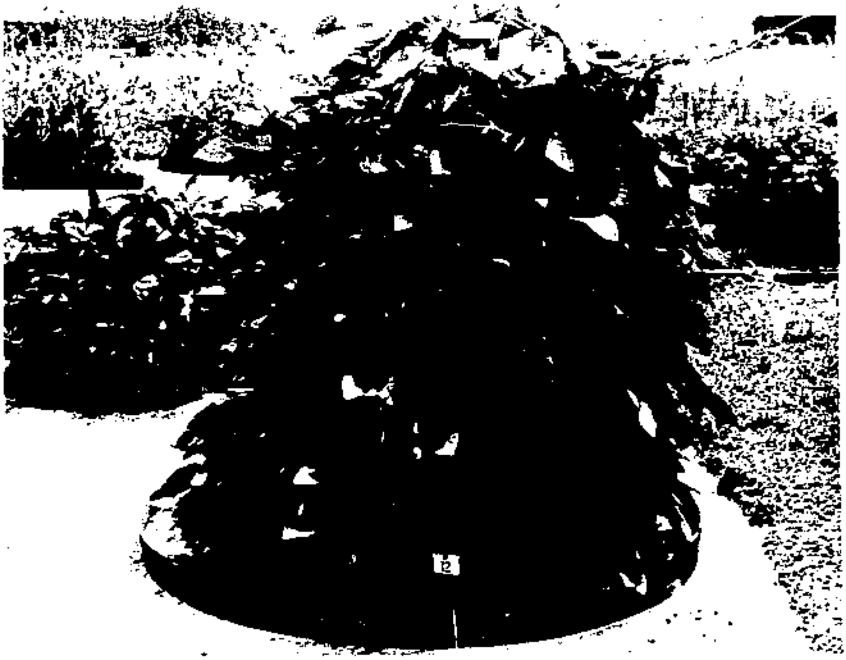

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FIGURE 14.—Velvetbeans on lysimeter 12. Photographed July 19, 1943.

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FIGURE 15.—*Crotalaria mucronata* (*striata*) on lysimeter 19. Photographed July 19, 1943.

TABLE 28.—*Yields of summer crops [1] expressed as pounds of dry matter per acre, Sandhill Experiment Station, 1939–45*

Lysimeter No.	1939 Crop	1939 Residue [2]	1939 Seed cot.	1940 Crop	1940 Residue	1940 Seed cot.	1941 Crop	1941 Residue	1941 Seed cot.	1942 Crop	1942 Residue	1942 Seed cot.
1	Cot.	1,461	(6)	C. m.	6,962	------	Cot.	1,566	(6)	Cot.	1,184	1,317
2	Cot.	1,461	(6)	C. m.	7,284	------	Cot.	1,392	(6)	Cot.	1,133	732
3	Cot.	1,461	(6)	C. m.	6,671	------	Cot.	754	(6)	Cot.	567	466
4	Cot.	1,461	(6)	C. m.	7,152	------	Cot.	696	(6)	Cot.	465	371
5	Cot.	1,461	(6)	C. m.	6,490	------	Cot.	986	(6)	Cot.	454	345
6	Cot.	1,461	(6)	C. m.	7,041	------	Cot.	1,334	(6)	Cot.	1,600	1,026
7	Cot.	1,461	(6)	C. m.	6,561	------	Cot.	986	(6)	Cot.	423	428
8	Cot.	1,461	(6)	C. m.	7,063	------	Cot.	696	(6)	Cot.	1,093	717
9	Cot.	1,461	(6)	C. m.	7,059	------	Cot.	1,508	(6)	Cot.	1,475	1,226
10	Cot.	1,461	(6)	C. m.	7,972	------	Cot.	1,102	(6)	Cot.	1,660	1,176
11	Cot.	1,461	(6)	Soy.	4,665	------	Cot.	1,276	(6)	Cot.	1,290	1,197
12	Cot.	1,461	(6)	V. b.	7,932	------	Cot.	1,508	(6)	Cot.	1,500	1,324
13	Cot.	1,461	(6)	C. s.	5,732	------	Cot.	1,334	(6)	Cot.	1,347	1,215
14	Cot.	1,461	(6)	C. i.	6,556	------	Cot.	1,392	(6)	Cot.	1,376	1,475
15	Cot.	1,461	(6)	Mil.	6,384	------	Cot.	1,508	(6)	Cot.	1,508	1,432
16	Cot.	1,461	(6)	Mil.	6,050	------	Cot.	1,508	(6)	Cot.	1,289	1,185
17	Cot.	1,461	(6)	C. m.	7,720	------	Soy.	3,044	------	Cot.	1,327	1,411
18	Cot.	1,461	(6)	C. m.	7,183	------	Soy.	2,136	------	Cot.	1,295	1,340
19	Cot.	1,461	(6)	C. m.	7,870	------	C. m.	5,351	------	C. m.	8,556	------
20	Cot.	1,461	(6)	C. s.	5,798	------	C. s.	2,540	------	C. s.	7,295	------
21	Cot.	1,461	(6)	C. m.	7,474	------	Soy.	3,007	------	C. m.	8,435	------
22	Cot.	1,461	(6)	Mil.	6,451	------	Soy.	3,318	------	Mil.	7,704	------
23	Cot.	1,461	(6)	Cot.	3,779	(6)	Cot.	1,392	(6)	Cot.	1,600	1,400
24	Cot.	1,461	(6)	0	------	------	0	------		0	------	------

Lysimeter No.	1943 Crop	1943 Residue	1943 Seed cot.	1944 Crop	1944 Residue	1944 Seed cot.	1945 Crop	1945 Residue	1945 Seed cot.	1939–45 Total summer crop residues [3]	1939–45 Total seed cotton [4]	1939–45 Total summer and winter residues [5]
1	C. m.	8,236	------	Cot.	1,910	2,371	Cot.	2,634	3,878	23,953	7,566 (3)	39,381
2	C. m.	7,502	------	Cot.	1,274	2,451	Cot.	2,112	3,648	22,158	6,831 (3)	30,713
3	C. m.	6,435	------	Cot.	1,035	1,770	Cot.	1,763	2,627	18,686	4,863 (3)	22,150
4	C. m.	6,673	------	Cot.	716	1,818	Cot.	1,531	2,395	18,697	4,584 (3)	22,250
5	C. m.	5,870	------	Cot.	1,274	1,736	Cot.	1,580	2,901	18,115	4,982 (3)	18,115
6	C. m.	7,878	------	Cot.	1,433	2,640	Cot.	3,042	3,463	23,789	7,129 (3)	38,321
7	C. m.	6,017	------	Cot.	1,353	2,244	Cot.	1,786	2,850	18,887	5,522 (3)	22,622
8	C. m.	6,615	------	Cot.	1,194	2,214	Cot.	2,780	2,760	20,902	5,691 (3)	33,166
9	C. m.	7,255	------	Cot.	1,990	2,483	Cot.	3,217	3,240	24,415	6,949 (3)	39,535
10	C. m.	7,820	------	Cot.	1,632	2,772	Cot.	2,760	3,786	24,407	7,734 (3)	40,794
11	Soy.	5,528	------	Cot.	1,592	2,472	Cot.	2,319	3,183	18,140	6,852 (3)	33,227
12	V. b.	6,226	------	Cot.	1,353	2,552	Cot.	2,211	3,282	22,191	7,158 (3)	38,060
13	C. s.	5,050	------	Cot.	1,672	2,583	Cot.	2,800	4,057	19,396	7,855 (3)	34,195
14	C. i.	5,031	------	Cot.	1,592	2,650	Cot.	2,591	3,976	19,909	8,101 (3)	36,092
15	Mil.	7,244	------	Cot.	1,592	2,554	Cot.	2,415	3,765	22,112	7,751 (3)	33,030
16	Mil.	7,674	------	Cot.	1,672	2,119	Cot.	3,058	3,652	22,712	6,956 (3)	32,543
17	C. m.	7,106	------	Soy.	1,638	------	Cot.	3,488	3,527	25,784	4,938 (2)	43,588
18	C. m.	7,060	------	Soy.	1,638	------	Cot.	2,371	3,655	23,144	4,995 (2)	36,137
19	C. m.	7,260	------	C. m.	4,897	------	Cot.	3,682	3,442	39,077	3,442 (1)	50,007
20	C. s.	4,605	------	C. s.	2,212	------	Cot.	2,509	3,956	26,450	3,956 (1)	43,230
21	Soy.	7,205	------	C. m.	4,990	------	Cot.	3,328	3,431	35,990	3,431 (1)	51,884
22	Soy.	6,048	------	Mil.	7,330	------	Cot.	4,199	3,990	36,311	3,990 (1)	48,130
23	Cot.	1,425	2,023	Cot.	1,433	2,438	Cot.	2,668	2,736	13,656	8,597 (4)	26,737
24	0	------	------	0	------	------	Cot.	1,898	2,164	3,359	2,164 (1)	3,359

[1] Abbreviations used:
- Cot. = cotton
- C. m. = *Crotalaria mucronata*
- C. s. = *Crotalaria spectabilis*
- C. i. = *Crotalaria intermedia*
- Soy. = soybeans
- V. b. = velvetbeans
- Mil. = Millet

[2] The term residue, as used here, refers to the whole crop or any portion of it that was returned to the soil, except that in the last year of the experiment the cotton residues were not returned.

[3] The values given include the 1945 residues that were not returned to the soil.

[4] Numbers in parentheses refer to the number of cotton crops harvested.

[5] The weights of the winter crops, which are included, are given in table 27.

[6] Not determined.

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FIGURE 16.—Cotton on lysimeter 2. Photographed August 8, 1945.

TABLE 29.—*Yields of seed cotton in the various cropping systems, Sandhill Experiment Station, 1939–45*

Lysimeter No.	Crops grown [1]		Seed cotton (pounds per acre)		
	Summer rotation	Winter	1945	1944 and 1945	1942, 1944, and 1945
1	C. m.-Cot.-Cot.-C. m.-Cot.-Cot	Rye	3,878	6,249	7,506
2	C. m.-Cot.-Cot.-C. m.-Cot.-Cot	Oats	3,648	6,099	6,831
3	C. m.-Cot.-Cot.-C. m.-Cot.-Cot	Vetch	2,627	4,397	4,893
4	C. m.-Cot.-Cot.-C. m.-Cot.-Cot	Peas	2,395	4,213	4,581
5	C. m.-Cot.-Cot.-C. m.-Cot.-Cot	Fallow	2,991	4,637	4,982
6	C. m.-Cot.-Cot.-C. m.-Cot.-Cot	Rye and vetch	3,463	6,103	7,129
7	C. m.-Cot.-Cot.-C. m.-Cot.-Cot	Peas and vetch [2]	2,850	5,091	5,522
8	C. m.-Cot.-Cot.-C. m.-Cot.-Cot	Rye and vetch [2]	2,760	4,974	5,691
9	C. m.-Cot.-Cot.-C. m.-Cot.-Cot	Rye with nitrogen	3,240	5,723	6,910
10	C. m.-Cot.-Cot.-C. m.-Cot.-Cot	Rye	3,786	6,558	7,734
11	Soy.-Cot.-Cot.-Soy.-Cot.-Cot	Rye	3,483	5,655	6,852
12	V. b.-Cot.-Cot.-V. b.-Cot.-Cot	Rye	3,282	5,834	7,158
13	C. s.-Cot.-Cot.-C. s.-Cot.-Cot	Rye	4,057	6,640	7,855
14	C. i.-Cot.-Cot.-C. i.-Cot.-Cot	Rye	3,976	6,626	8,101
15	Mil.-Cot.-Cot.-Mil.-Cot.-Cot	Rye	3,765	6,319	7,751
16	Mil.-Cot.-Cot.-Mil.-Cot.-Cot	Rye	3,682	5,801	6,986
17	C. m.-Soy.-Cot.-C. m.-Soy.-Cot	Rye	3,527		
18	C. m.-Soy.-Cot.-C. m.-Soy.-Cot	Rye and vetch [3]	3,655		
19	C. m.-C. m.-C. m.-C. m.-C. m.-Cot	Rye	3,142		
20	C. s.-C. s.-C. s.-C. s.-C. s.-Cot	Rye	4,456		
21	C. m.-Soy.-C. m.-Soy.-C. m.-Cot	Rye	4,131		
22	Mil.-Soy.-Mil.-Soy.-Mil.-Cot	Rye	3,901		
23	Cot.-Cot.-Cot.-Cot.-Cot.-Cot	Rye	2,736	5,174	6,571
24	0-0-0-0-0-Cot	0	2,164		

[1] Abbreviations used:
Cot. = cotton
C. m. = *Crotalaria mucronata*
C. s. = *Crotalaria spectabilis*
C. i. = *Crotalaria intermedia*
Soy. = soybeans
V. b. = velvetbeans
Mil. = millet

[2] These crops were grown in alternate years in the order given.

[3] Crotalaria was allowed to volunteer in the cotton.

In the comparison of the cotton yields from lysimeters 1 to 10, where the summer rotation was the same but the winter cover crops varied, the lysimeters that gave the lowest yields were the ones that either had no winter cover crop or one that made a very poor growth. Rye alone, or in mixture, was an excellent cover, oats was mediocre, and peas and vetch were very unsatisfactory. Meadow nematodes were found in considerable numbers by G. Steiner, U. S. Department of Agriculture, at Beltsville, on cotton plant samples taken from field plots at the experiment station where peas and vetch had been grown. These organisms may have been responsible in part for the low yields of these two legume cover crops. They are known to be susceptible to this pest.

Reference to table 26 will show that during the last 2 years of this experiment a total of 332 pounds per acre of commercial nitrogen was applied to each of the lysimeters, and 42 percent of this was supplied to the winter cover crop. This explains why the cotton yields during these 2 years were so dependent upon good growths of the winter cover crops. Losses of nitrogen through leaching are inversely correlated with the amount of winter cover, as will be brought out in a later table. Cotton yields in this experiment were apparently determined primarily by nitrogen supply at the time the cotton plants needed it, as was found to be true in the earlier experiment on this soil.

A series of comparisons of the effects of various summer cropping systems, where rye was always used as a cover, is given by the 1945 cotton yields from lysimeters 1, 9–17, and 19–23, inclusive (table 29). The yields of cotton from all these lysimeters, except where cotton was grown continuously, ranged from 3,183 to 4,057 pounds of seed cotton per acre. This represents approximately 2 to slightly less than 3 bales of lint cotton. Even the soil that grew cotton annually produced 2,736 pounds of seed cotton the last year of the experiment. Again, this shows that cotton yields were controlled primarily by nitrogen supply, which the rye cover helped to retain during the time when cotton was not growing on the soils. The surprisingly good yields of cotton from lysimeters 15 and 16, which grew millet and no legumes, shows that the fertilizer nitrogen added was adequate for excellent cotton production where precautions were taken to keep the leaching losses as small as possible. Under these conditions of high application of nitrogen and apparently adequate amounts of the other essential elements, it seems that the previous cropping system exerts a comparatively minor effect upon cotton production on this sandy soil.

A comparison of the cotton yield on lysimeter 17 with that on No. 18 shows that a cover crop of rye and vetch in alternate years gave a slightly higher yield of cotton in 1945 than did rye cover. The difference is doubtless within experimental error. The higher yield of cotton on lysimeter 18 than on 8 is probably caused largely by the crop of soybeans grown on No. 18 and turned under the preceding year.

Where a fallow system was maintained both winter and summer for 5 years and then a crop of cotton grown, the yield was 2,164 pounds of seed cotton per acre. Although this yield of nearly 1½ bales of lint cotton was the lowest obtained on any of the lysimeters, it is not low when compared with yields commonly obtained in the area in common farm practice. This again emphasizes the role that commercial fertilizers play. Apparently, the addition of adequate plant nutrients, especially nitrogen, directly to the cotton crop at the time needed can largely substitute for the residual effects of excellent green manuring and crop residue management practices during several preceding years.

Nitrogen Removed in Crops

The approximate amount of nitrogen removed in the crops from each of the lysimeters during the experimental period is given in table 30. As stated above, all summer and winter green crops, after being oven-dried, were returned immediately to the respective lysimeters and spaded into the upper 4.5-inch layer of soil. For the final year of the experiment the cotton residues were not returned but were weighed and analyzed for total nitrogen (table 30). The numbers of crops of seed cotton that were harvested ranged from 1 to 4 for the various cropping systems. The cottonseed and lint were removed but were not analyzed. It is believed, however, that cottonseed produced by plants growing at similar levels of soil nitrogen should be fairly uniform in composition. In obtaining the data in table 30 it was assumed that cottonseed contains 4.47 percent nitrogen, or 2.98 percent for the seed plus lint. The information in table 30 is of value chiefly in drawing up a soil nitrogen balance sheet, as is done in a subsequent table.

TABLE 30.—*Nitrogen removed in cotton crops expressed as pounds per acre, Sandhill Experiment Station, 1938–45*

Lysimeter No.	Number of crops	Seed cotton		Stalks (1945 only)[2]		Total nitrogen in crops
		Dry weight	Nitrogen[1]	Dry weight	Nitrogen	
		Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1	3	7,566	225.5	2,634	45.6	271.1
2	3	6,831	203.6	2,112	36.5	240.1
3	3	4,863	144.9	1,763	26.1	171.0
4	3	4,584	136.6	1,534	24.9	161.5
5	3	4,982	148.5	1,580	23.5	172.0
6	3	7,129	212.4	3,042	50.2	262.6
7	3	5,522	164.6	1,786	27.7	192.3
8	3	5,601	160.6	2,789	47.0	216.6
9	3	6,949	207.1	3,217	43.8	250.9
10	3	7,734	230.5	2,760	43.1	273.6
11	3	6,852	204.2	2,319	36.6	240.8
12	3	7,158	213.3	2,211	34.9	248.2
13	3	7,855	234.1	2,800	40.3	274.4
14	3	8,101	241.4	2,591	37.3	278.7
15	3	7,751	231.0	2,415	37.7	268.7
16	3	6,986	208.2	3,058	45.9	254.1
17	2	4,938	147.2	3,488	56.9	201.1
18	2	4,995	148.9	2,371	40.1	189.0
19	1	3,442	102.6	3,682	58.9	161.5
20	1	3,956	117.0	2,509	40.1	158.0
21	1	3,431	102.2	3,328	53.2	155.4
22	1	3,900	116.2	4,160	65.1	181.3
23	4	8,597	256.2	2,566	41.3	297.5
24	1	2,164	64.5	1,898	25.1	89.6

[1] The seed cotton was not analyzed for nitrogen. The quantities of nitrogen given are based on the assumption that seed cotton (seed and lint) contains 2.98 percent N.

[2] The cotton stalks and leaves for the last season were harvested, dried, weighed, and analyzed but not returned to the soil.

Effect of Crop on Quantity of Leachate

The monthly and yearly rainfall values, as measured on a rain gage located near the lysimeters, are given in table 31. The annual precipitation during the experimental period ranged from 35.1 to 56.8 inches, with an average value of 43.7 inches.

TABLE 31.—*Rainfall during the experimental period (1938–45), Sandhill Experiment Station*

Month	Annual rainfall [1] in inches								Average
	1938	1939	1940	1941	1942	1943	1944	1945	
January	-------	2.54	2.92	1.18	2.23	3.49	3.10	2.17	2.52
February	-------	9.54	3.64	1.82	3.30	1.19	5.00	4.10	4.08
March	-------	3.05	3.46	2.87	6.71	5.88	7.88	1.63	4.51
April	-------	3.12	2.34	2.48	2.76	3.64	5.16	2.10	3.09
May	-------	1.71	2.50	.29	7.11	3.67	4.11	1.76	3.02
June	-------	3.00	3.54	9.76	6.62	2.72	2.42	3.69	4.54
July	-------	7.78	1.71	6.86	7.67	10.10	4.83	8.80	6.82
August	-------	4.65	6.49	2.22	7.07	2.66	4.01	4.70	4.54
September	-------	2.45	.98	.97	5.41	3.73	2.26	12.32	4.02
October	1.97	.15	.58	.93	1.03	.01	4.28	-------	1.29
November	3.17	1.03	5.51	.46	2.57	1.11	1.73	-------	2.23
December	2.79	2.28	1.82	5.26	4.31	3.88	1.17	-------	3.07
Total	7.93	41.30	35.49	35.10	56.79	42.17	45.95	41.33	-------

[1] Average annual rainfall=43.72 inches.

TABLE 32.—*Quantities of water that percolated through the lysimeters during the 7-year experimental period (1938–45), Sandhill Experiment Station*

PERCOLATE AS INCHES PER UNIT SURFACE

Lysimeter No.	1938–39		1939–40		1940–41		1941–42		1942–43		1943–44		1944–45		1938–45	
	Oct. 25 to Apr. 10	Apr. 11 to Oct. 6	Oct. 7 to Apr. 5	Apr. 6 to Sept. 26	Sept. 27 to Mar. 31	Apr. 1 to Sept. 23	Sept. 24 to Apr. 2	Apr. 3 to Sept. 28	Sept. 29 to Mar. 28	Mar. 29 to Sept. 17	Sept. 18 to Apr. 1	Apr. 2 to Oct. 10	Oct. 11 to Apr. 2	Apr. 3 to Sept. 27	Total percolate	Percentage of water received
1	17.6	8.5	5.7	1.6	2.2	10.7	6.9	20.8	11.1	7.6	9.2	7.0	4.2	11.7	124.8	38.4
2	17.0	8.8	6.7	1.6	3.0	11.0	8.5	22.5	11.6	9.1	11.5	7.0	5.1	13.0	136.4	41.9
3	17.4	8.6	7.4	2.1	4.6	12.3	11.7	23.6	12.7	9.4	14.8	7.8	6.3	15.8	154.5	47.6
4	16.6	8.2	7.8	1.6	4.1	11.9	10.8	23.2	12.4	9.5	13.9	7.9	6.5	15.8	150.2	46.2
5	17.2	8.5	8.5	1.6	5.3	12.1	12.2	23.6	13.2	9.3	15.2	7.9	6.7	15.4	156.7	48.2
6	16.7	8.0	5.8	1.7	2.4	10.7	7.4	21.0	11.0	8.4	10.3	6.8	4.3	11.9	126.4	38.8
7	16.9	8.1	7.9	1.6	4.4	11.6	10.7	23.6	12.7	9.6	14.1	7.0	5.4	14.7	148.3	45.6
8	16.8	8.2	5.6	1.5	4.2	11.8	7.6	21.7	11.7	9.8	9.6	6.8	5.4	13.4	133.9	41.1
9	17.3	8.7	5.8	1.6	2.3	11.2	7.3	22.0	11.4	8.2	9.3	6.9	4.1	11.7	127.8	39.3
10	16.9	8.2	5.6	1.4	2.1	11.0	6.7	16.9	8.7	8.0	9.2	6.7	3.7	10.7	115.8	35.6
11	16.9	8.8	5.5	1.6	3.6	11.6	7.7	20.8	11.3	8.1	9.6	6.8	4.4	13.8	130.5	40.1
12	16.5	8.6	5.7	1.1	2.4	11.0	7.0	20.3	10.7	7.1	9.4	6.3	4.2	12.1	122.4	37.6
13	16.5	8.6	5.6	1.7	2.8	11.0	7.5	20.6	11.1	10.0	9.2	6.2	4.2	11.6	126.6	38.9
14	16.8	8.7	5.8	1.7	3.3	10.0	7.1	20.4	10.8	11.3	9.5	6.8	4.5	12.2	129.8	39.9
15	16.9	8.5	5.6	2.7	6.7	11.0	8.0	20.4	11.2	9.3	12.2	6.8	4.1	11.8	135.2	41.5
16	17.0	8.7	5.8	3.4	5.9	11.4	7.6	21.3	11.0	9.1	12.4	7.0	4.3	11.2	136.1	41.8
17	16.4	8.5	5.7	1.3	2.1	8.1	4.6	20.3	10.8	7.9	9.1	6.1	3.9	10.3	115.1	35.4
18	16.9	8.7	5.7	1.2	4.4	9.4	5.7	21.2	11.9	8.9	9.5	6.2	5.9	13.9	129.5	39.8
19	16.6	8.1	5.7	1.3	2.1	7.6	4.1	10.6	7.7	8.8	9.3	6.4	3.1	10.2	101.6	31.2
20	16.7	8.5	5.7	1.7	2.5	11.5	5.4	13.7	8.1	10.6	9.6	6.5	4.7	12.1	116.9	35.9
21	16.4	8.7	5.7	1.2	2.1	8.1	4.5	11.4	7.2	8.2	9.2	6.4	3.4	10.0	102.5	31.5
22	16.7	8.7	5.8	2.8	6.6	9.3	5.1	18.3	11.9	9.3	12.1	6.4	5.9	11.5	130.1	40.1
23	16.7	8.3	5.6	3.2	4.8	10.8	7.3	20.0	10.7	11.0	9.6	6.5	4.2	11.6	130.3	40.0
24	16.9	8.6	8.5	8.4	7.0	13.6	11.8	24.0	12.8	17.0	16.8	12.8	8.0	16.2	184.2	56.6

RAINFALL AND IRRIGATION WATER [1] RECEIVED AS INCHES PER UNIT SURFACE

Rain	23.9	21.7	13.5	17.4	13.9	21.8	19.7	36.6	18.4	25.2	22.4	22.8	15.2	33.3	------	------
Irrigation	0	1.1	1.2	5.8	.9	1.6	1.3	2.1	.2	2.4	.4	1.0	0	1.6	------	------
Total	23.9	22.8	14.7	23.2	14.8	23.4	21.0	38.7	18.6	27.6	22.8	23.8	15.2	34.9	------	------

[1] Total rainfall (305.8 inches) plus total irrigation water (19.6 inches)=325.4 inches, or an average of 46.5 inches annually. An average of 40.5 percent of this was collected in the percolates.

The quantities of water, expressed as surface inches, that percolated through the soils in the 24 lysimeters are shown in table 32. This table also gives the quantities of irrigation water added during the period. Such additions were made only as necessary, in order to keep the crops alive during very dry periods or to assure quick germination of seeds planted during such periods.

An average of 40.5 percent of the water that reached the soils was collected in the percolates. The extreme ranges were between 31.2 and 56.6 percent. The larger the crop that was produced during the experimental period the smaller was the percentage of water that was lost in the drainage.

Crop Yields and Evapotranspiration

The data showing the relationship between crop yields and water use are given in table 33. Included are the results of calculations of the efficiency of water use in terms of units of dry matter produced. Figure 17 is a plot of dry matter (summer plus winter crops) produced per year vs. inches of water lost through evapotranspiration (evaporation from soil plus transpiration from plants). The data thus plotted fall in a linear pattern ($r=0.963$) with the best straight line intersecting the abcissa at a point corresponding to the water loss from a bare soil. This point of intersection is at 18.7 inches of water per year in contrast to 16 inches observed in the earlier experiment conducted in these lysimeters. The higher value is due chiefly to the 2.8 inches of irri-

TABLE 33.—*The use of water by crops grown in rotation for 7 years, Sandhill Experiment Station, 1938–45*

Lysimeter No.	Average dry matter produced per year (pounds per acre)	Evapotranspiration			
		Average inches of water per year	Pounds of dry matter per inch	Inches of water per 1,000 pounds dry matter	Pounds of water per pound of dry matter
1	6,707	28.7	233.69	4.28	967
2	5,363	27.0	198.63	5.03	1,140
3	3,859	24.4	158.16	6.32	1,432
4	3,835	25.0	153.40	6.52	1,478
5	3,300	24.1	136.93	7.30	1,653
6	6,493	28.4	228.63	4.37	991
7	4,021	25.3	158.93	6.29	1,425
8	5,551	27.4	202.59	4.94	1,116
9	6,683	28.2	236.99	4.22	956
10	6,933	29.9	231.87	4.31	[1] 978
11	5,726	27.8	205.97	4.86	1,101
12	6,460	29.0	222.76	4.49	1,016
13	6,007	28.4	211.51	4.73	1,070
14	6,313	27.9	226.27	4.42	1,002
15	5,912	27.2	217.35	4.60	1,041
16	5,933	27.0	219.74	4.55	1,032
17	6,932	30.0	231.07	4.33	981
18	5,876	28.0	209.86	4.77	1,078
19	8,921	32.0	278.78	3.59	811
20	6,741	29.8	226.21	4.42	1,000
21	8,331	31.8	261.98	3.82	865
22	7,433	27.9	266.42	3.75	849
23	5,048	27.9	180.93	5.53	1,250
24	789	20.2	39.06	25.60	5,791
Weighted average			209.75	4.77	1,079

[1] Crotalaria was allowed to volunteer in the cotton each year, but the yields were not determined; hence, the water utilization values given are high.

gation water added in small amounts during very dry periods. Evidently most of this extra water was lost by evaporation, or evapotranspiration, and little of it was caught in the percolates.

The maximum evapotranspiration was approximately 32 inches of water per year from the lysimeters with the largest crops. In the earlier experiment, where the crop yield was only a little more than half as large, the maximum evapotranspiration was 28 inches, or seven-eighths as large.

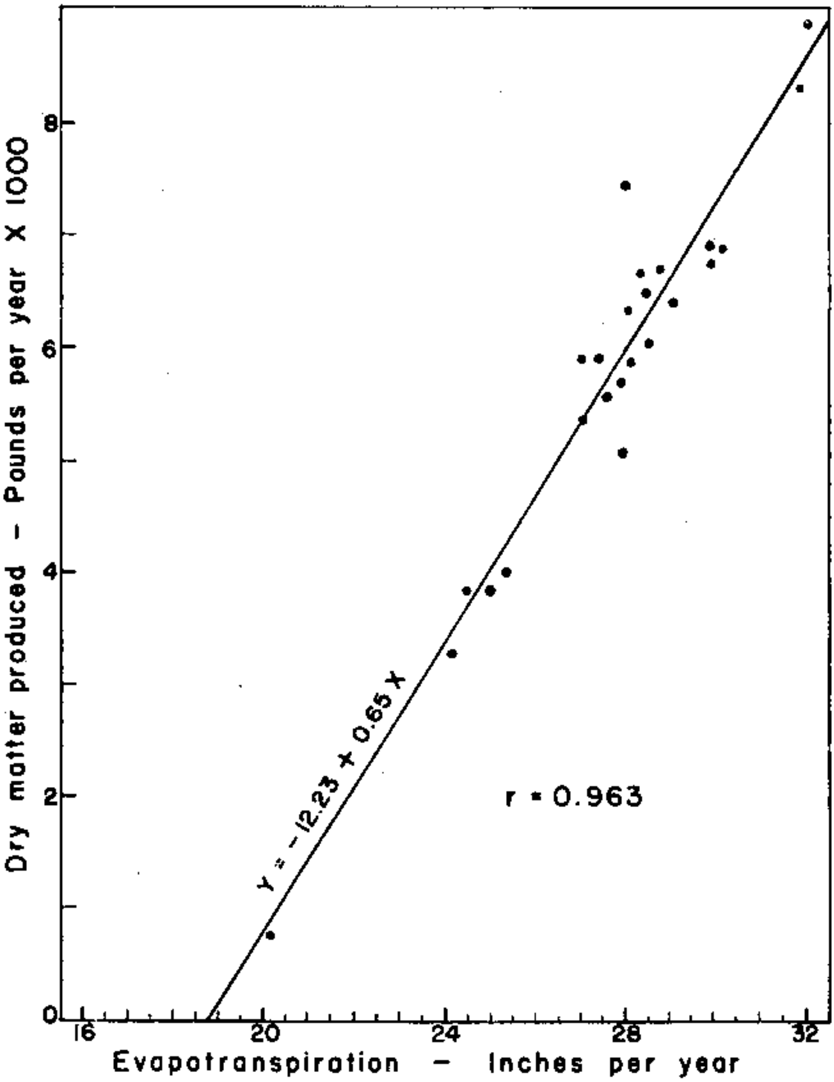

FIGURE 17.—The relationship between crop yields and evapotranspiration.

Evapotranspiration (table 33, col. 6) ranged from 311 to 5,791 pounds of water per pound of dry matter produced, with an average weighted value of 1,079 pounds. Cropping systems that left the soil bare for a minimum time and produced the largest yields required the least water per unit of crop produced. This agrees with the results of the earlier lysimeter experiment. The facts are more easily seen when crop yields are plotted against the efficiency of water use (fig. 18). The best straight line drawn through the various points

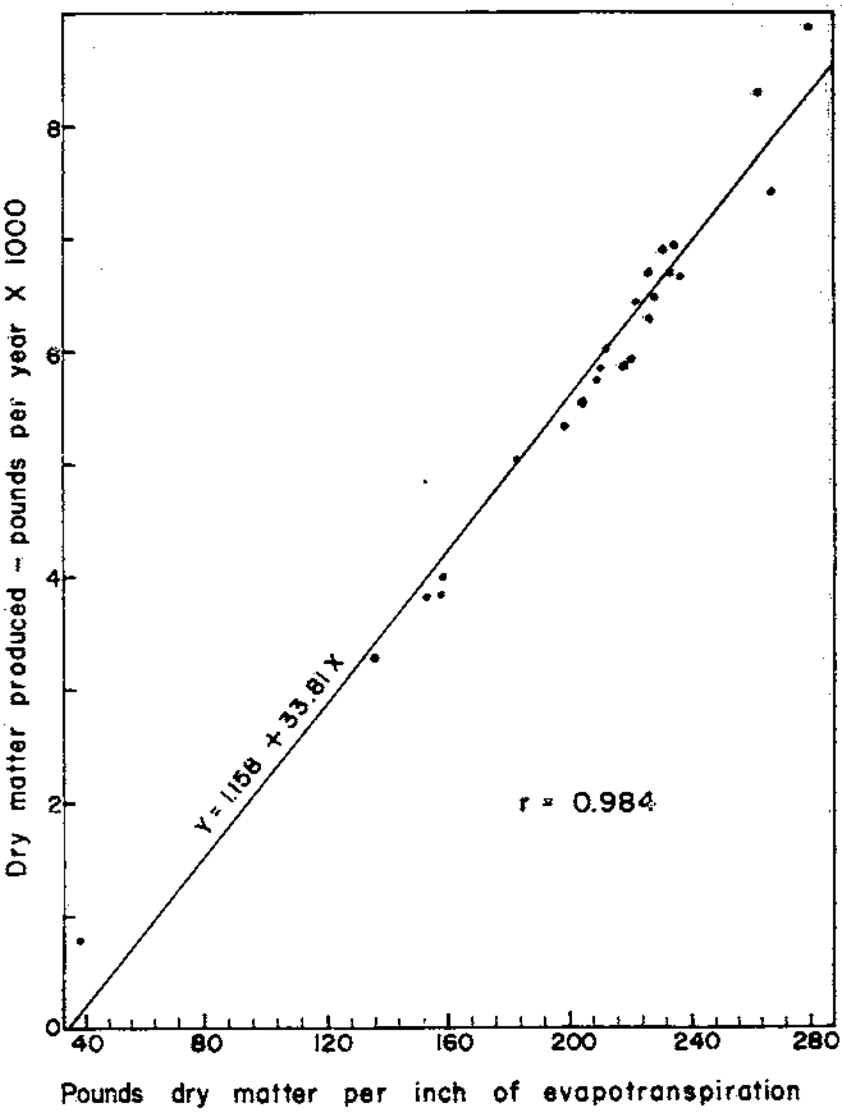

FIGURE 18.—The relationship between crop yields and efficiency of water use.

shows a correlation coefficient of 0.984. Kind of crop or rotation used was of minor importance, except as this affected total dry matter production.

The evapotranspiration data reported here, obtained in lysimeter experiments, should not be interpreted as strictly identical with data that might be obtained in the field. Water losses from lysimeters are likely to be somewhat higher than from field soils for reasons discussed in another report [12] and in the preceding section. The conclusions to be drawn from such lysimeter data are, however, believed to be applicable to field conditions. The conclusions given for the earlier experiment also apply to the present experiment and need not be repeated. Any factor that increases the amount of dry matter produced per unit area, regardless of kind of crop or rotation, will increase the efficiency with which water is used.

Nitrogen in Leachates

The total nitrogen that was leached from each of the 24 lysimeters during the time of the experiment for the winter and summer periods is given in table 34. Each lysimeter received a total of 748 pounds of fertilizer nitrogen during the 7-year period. In addition, all but four of the lysimeters grew legumes for 2 to 5 years out of the 7 years and fixed considerable, but unknown, amounts of nitrogen.

TABLE 34.—*Total nitrogen in percolates, expressed as pounds per acre, Sandhill Experiment Station, 1938–45*

Lysimeter No.	1938–39		1939–40		1940–41		1941–42		1942–43		1943–44		1944–45		Total for 7 years
	Oct. 25 to Apr. 10	Apr. 11 to Oct. 6	Oct. 7 to Apr. 5	Apr. 6 to Sept. 26	Sept. 27 to Mar. 31	Apr. 1 to Sept. 23	Sept. 24 to Apr. 2	Apr. 3 to Sept. 28	Sept. 29 to Mar. 25	Mar. 26 to Sept. 17	Sept. 18 to Apr. 1	Apr. 2 to Oct. 10	Oct. 11 to Apr. 2	Apr. 3 to Sept. 27	
1	38.5	28.0	13.9	0.2	16.5	82.8	8.1	118.5	4.6	12.9	60.1	42.5	7.5	30.7	464.8
2	40.4	29.7	18.2	.4	22.9	88.1	13.1	125.7	7.3	25.5	91.6	33.6	16.3	43.9	556.7
3	43.1	31.7	25.1	3.5	45.7	131.6	51.3	144.8	18.9	48.7	140.4	49.0	20.1	98.6	852.5
4	43.4	23.8	34.1	3.1	38.0	142.0	43.3	131.9	18.9	52.9	135.1	61.2	30.0	115.0	872.7
5	42.3	32.1	35.5	3.1	44.2	111.6	52.6	113.6	20.6	39.1	144.3	47.8	13.3	77.2	777.3
6	43.8	26.3	12.2	.1	23.8	93.6	9.5	122.1	5.2	25.3	90.1	39.1	18.9	36.6	580.6
7	44.1	27.2	31.5	3.1	42.2	130.0	42.9	171.9	24.8	50.1	133.7	61.2	17.1	81.2	861.0
8	44.2	27.1	12.7	.2	44.6	162.4	10.6	115.2	22.6	79.3	71.2	32.9	23.3	91.4	737.9
9	44.0	32.0	12.0	.1	17.4	90.2	5.9	126.7	5.5	23.0	58.9	49.4	7.3	15.5	488.8
10	43.3	30.5	10.9	.1	15.3	97.6	7.2	99.6	13.5	21.7	65.5	37.5	9.7	10.5	402.9
11	42.8	32.3	9.4	.4	16.9	89.1	8.8	108.5	5.0	11.8	66.4	40.4	11.6	38.4	483.6
12	41.8	33.2	10.6	.1	18.3	88.2	14.5	109.8	4.5	7.8	77.3	32.5	14.0	21.8	474.4
13	43.2	33.1	12.9	.2	15.1	80.0	15.9	107.4	5.6	44.4	49.2	28.4	10.7	13.3	459.4
14	41.6	33.0	11.6	.1	32.6	98.7	13.7	102.7	5.6	80.9	66.8	33.4	10.2	34.0	565.5
15	39.8	34.3	10.6	.2	2.3	49.3	15.4	99.9	4.7	1.2	10.9	26.1	8.2	17.9	320.8
16	43.5	31.9	10.7	3.3	3.2	62.2	13.6	90.8	4.9	.5	10.0	35.5	6.6	4.5	322.1
17	42.2	35.2	10.5	.1	12.1	66.0	13.6	124.1	6.0	18.9	50.7	33.0	41.0	14.6	466.0
18	41.4	36.5	16.3	.1	33.1	123.3	14.5	117.0	29.4	65.1	63.5	31.0	57.1	107.7	738.0
19	43.0	30.6	13.9	.1	11.9	78.9	26.7	88.0	42.4	49.6	67.0	38.3	13.0	27.3	530.7
20	43.0	31.8	10.2	.1	13.2	102.9	17.4	104.0	33.4	76.7	62.6	40.9	42.2	34.3	612.7
21	42.3	32.3	12.7	.1	14.5	66.6	13.3	83.2	28.4	36.3	73.2	41.0	13.7	14.8	472.4
22	41.1	32.6	13.8	.2	1.9	46.2	14.1	23.3	5.0	.9	10.4	29.2	6.0	10.2	234.9
23	43.0	32.2	13.0	1.0	8.1	58.1	12.2	74.2	4.8	48.5	8.1	18.8	6.8	15.3	344.7
24	45.1	37.4	41.8	84.0	50.3	86.3	45.2	105.6	19.4	78.7	91.7	74.4	52.8	77.1	889.8

[12] See footnote 8, p. 16.

The average loss of nitrogen in the percolates for the period was 566 pounds. The largest loss (890 pounds) was from lysimeter 24, which was in fallow most of the time. The smallest loss (235 pounds) was from lysimeter 22 that grew soybeans, millet, cotton, and rye. Although these losses are unusually large, it should be remembered that usually only three, and in some lysimeters only one or two, crops were harvested during the 7-year period. All other crops, and also the cotton residues, were returned to the soil. In this sort of a cropping system it is not surprising that so much of the nitrogen was collected in the leachate. It could not be expected to accumulate in large quantities as soil organic matter, especially in this very sandy soil. The only other possibility would be for it to be lost in gaseous forms. Certainly under more normal farming conditions much more of the nitrogen would have been recovered in the crops.

The leaching data show in general that soluble forms of nitrogen do not long remain in a soil, such as this Lakeland sand, following rains sufficient to produce much leaching. The best way to prevent this is to have a crop growing on the soil as much of the time as possible and to add soluble nitrogen only at times when the crop can use it quickly. Nitrogen added as plant materials (see table 34) is also rapidly converted into soluble forms if soil moisture and temperature are such as to favor decomposition.

Changes in Soil Nitrogen and Carbon

The nitrogen and carbon analyses of the soils in each of the lysimeters, made at the beginning and end of the experiment, are given in table 35. The initial nitrogen contents of the soils in the various lysimeters show good agreement, which indicates that the soils were well mixed. Unfortunately, however, the carbon analyses are not entirely satisfactory, as shown by the ranges in the carbon values for the various lysimeters at the beginning of the experiment. These values should have been nearly identical. Later work showed that these variations were the result chiefly of the use for analysis of a small (1 gram) sample of soil that had not been ground to a sufficient degree of fineness. Such fine grinding of at least a 100-gram sample of the soil to be analyzed is essential, especially for a coarse-textured soil of low carbon content. In addition, some variation in the final carbon analyses may be attributed to sampling procedures. During the 7 years of the experiment the plant materials that were added to the soils were merely spaded into the upper 4-inch layer. At the end of the experiment cores were taken to a depth of 10 inches for analysis. The poor correlation between gains in soil carbon (table 35, col. 5) and crop yields (table 33, col. 2) is probably owing in considerable part to the above factors that affected the analyses.

TABLE 35.—*The total carbon and nitrogen contents of the upper 10-inch layer of soil in lysimeters, Sandhill Experiment Station, May 27, 1938, and September 27, 1945*

Lysimeter No.	Total carbon				Total nitrogen			
	May 27, 1938	September 27, 1945	Gain or loss		May 27, 1938	September 27, 1945	Gain or loss	
			Percent	Pounds per acre [1]			Percent	Pounds per acre [1]
	Percent	*Percent*			*Percent*	*Percent*		
1	0.575	0.602	0.027	918	0.0212	0.0257	0.0045	153
2	.570	.638	.068	2,312	.0217	.0267	.0050	170
3	.618	.587	−.031	−1,054	.0222	.0213	−.0009	−31
4	.611	.632	.021	714	.0218	.0237	.0019	65
5	.566	.616	.050	1,700	.0220	.0220	0	0
6	.635	.694	.059	2,006	.0215	.0285	.0070	238
7	.614	.624	.010	340	.0230	.0254	.0024	82
8	.640	.687	.047	1,598	.0223	.0290	.0067	226
9	.630	.609	−.021	−714	.0211	.0256	.0045	153
10	.602	.735	.133	4,522	.0221	.0299	.0078	265
11	.599	.645	.046	1,564	.0216	.0263	.0047	160
12	.610	.721	.111	3,774	.0227	.0303	.0076	258
13	.600	.606	.006	204	.0221	.0251	.0030	102
14	.595	.629	.034	1,156	.0224	.0265	.0041	139
15	.628	.618	−.010	−340	.0217	.0250	.0033	112
16	.623	.605	−.018	−612	.0219	.0245	.0026	88
17	.608	.630	.022	748	.0208	.0282	.0074	252
18	.575	.635	.060	2,040	.0209	.0260	.0051	173
19	.633	.627	−.006	−204	.0213	.0269	.0056	190
20	.645	.695	.050	1,700	.0223	.0290	.0067	228
21	.593	.649	.056	1,904	.0216	.0302	.0086	292
22	.583	.675	.092	3,128	.0215	.0284	.0069	235
23	.625	.600	−.025	−850	.0218	.0225	.0007	24
24	.610	.540	−.070	−2,380	.0213	.0164	−.0049	−167

[1] Calculations are based on 3,400,000 pounds per acre 10-inch layer of soil.

The average of all analyses shows a gain of 1,007 pounds of carbon and 142 pounds of nitrogen per acre. If all negative values were disregarded, which is not justified, the corresponding gains are 1,784 and 172 pounds, respectively. The carbon-nitrogen ratio of the new organic matter is, therefore, between 7 and 10. This is a slightly narrower ratio than obtained in the earlier experiment on these lysimeters. The quantity of carbon added as plant material during the experiment was not determined, but from the crop yields a fair estimate can be made. The average addition to the 24 lysimeters was probably about 15,000 to 16,000 pounds during the entire experiment. This means that only 6 to 10 percent of the added plant carbon remained in the soil as soil organic matter at the end of the experiment, and some of this carbon had been added so recently that it may not have been thoroughly decomposed. These results emphasize the futility of trying to build up soil organic matter in a sandy soil under warm climatic conditions.

Nitrogen Balance Sheet

Since legumes were grown in all but four of the lysimeters for two or more years during the experiment and the amount of nitrogen fixed by them is not known, it is impossible to draw up a complete nitrogen balance sheet for any lysimeter except the four lysimeters that grew only nonlegumes. A partial balance sheet is, however, shown in table 36. The four lysimeters (Nos. 15, 16, 23, and 24) that were cropped to nonlegumes only show an average of 82 pounds per acre of nitrogen unaccounted for during the 7 years, or approximately 10 percent of that added. Considering the errors in soil sampling, discussed above, this value may be within experimental error. The other lysimeters that grew legumes showed nitrogen balances, disregarding legume fixation, ranging from −143 to +387 pounds of nitrogen per acre; the average value was +172 pounds for the experimental period. This corresponds to an average fixation of 65 pounds of nitrogen per year by every summer legume crop, if it be assumed that no gaseous losses of nitrogen occurred. Five of the lysimeter soils grew legume cover crops or legume-nonlegume cover crop mixtures. If these are included, then the average annual fixation per legume crop was approximately 50 pounds.

TABLE 36.—*Nitrogen balance sheet for the experimental period (1938–45), expressed as pounds of nitrogen per acre, Sandhill Experiment Station*

Lysimeter No.	Nitrogen additions			Nitrogen recovery				Net gain or loss [1]
	Fertilizer	Rain and seed	Total, except legumes	Crop	Percolate	Soil	Total	
1	748	48	796	271	465	153	889	+93
2	748	48	796	240	557	170	967	+171
3	748	48	796	171	853	−31	993	+197
4	748	48	796	162	873	65	1,099	+303
5	748	44	792	172	777	0	949	+157
6	748	48	796	263	587	238	1,087	+291
7	748	48	796	192	861	82	1,135	+339
8	748	48	796	217	738	228	1,183	+387
9	748	48	796	251	489	153	893	+97
10	748	48	796	274	463	265	1,002	+206
11	748	48	796	241	484	160	885	+89
12	748	48	796	248	474	258	981	+185
13	748	48	796	274	459	102	836	+40
14	748	48	798	279	566	139	983	+185
15	748	46	794	269	321	112	702	−92
16	748	46	794	254	322	88	664	−130
17	748	48	796	204	468	252	924	+128
18	748	48	796	180	738	173	1,100	+304
19	748	48	796	162	531	189	882	+86
20	748	48	796	158	613	228	999	+203
21	748	48	796	155	472	292	920	+124
22	748	46	794	181	235	235	651	−143
23	748	48	796	298	345	24	666	−130
24	748	40	788	90	890	−167	812	+24

[1] The gains shown are chiefly owing to fixation of nitrogen by the legumes.

Inasmuch as nitrogen fixation was depressed each year by an average addition of 107 pounds of fertilizer nitrogen, it seems likely that the quantities of nitrogen fixed by the legumes were not very much greater than these values would indicate. If this is true, the experiment shows that, on the average, gaseous losses of nitrogen were negligible or at least small. This finding, so far as the results are comparable, agrees with that reported for the earlier experiment conducted on this soil, even though the quantities of fertilizer nitrogen added were much larger in the second experiment.

Potassium in Leachates

The potassium contents of the percolates from the 24 lysimeters are given in table 37 by winter and summer periods, and summarized in the last column. During the experimental period each lysimeter received 444 pounds of K_2O as commercial fertilizer. Approximately one-fourth of this was applied during October and the rest in April, May, or June.

The greatest loss of potash (368 pounds per acre) in the percolates was from lysimeter 24, which was uncropped for most of the experimental period. The average loss from all the lysimeters was 192 pounds, with the ranges covering 110 to 368 pounds. All crops were effective in reducing the leaching losses, even though most of the plant material was returned to the soil. The combination of a large summer crop and a good winter cover, especially rye, was most effective in reducing leaching losses.

TABLE 37.—*Potassium* [1] *contents of percolates, expressed as pounds of K_2O per acre in lysimeters, Sandhill Experiment Station, 1938–45*

Lysimeter No.	1938–39		1939–40		1940–41		1941–42		1942–43		1943–44		1944–45		Total for 7 years
	Oct. 25 to Apr. 10	Apr. 11 to Oct. 6	Oct. 7 to Apr. 5	Apr. 6 to Sept. 26	Sept. 27 to Mar. 31	Apr. 1 to Sept. 23	Sept. 24 to Apr. 2	Apr. 3 to Sept. 28	Sept. 29 to Mar. 25	Mar. 26 to Sept. 17	Sept. 18 to Apr. 1	Apr. 2 to Oct. 10	Oct. 11 to Apr. 2	Apr. 3 to Sept. 27	
1	9.8	8.6	3.3	0.9	2.5	10.7	6.7	37.4	13.4	13.5	11.6	10.9	6.6	16.7	152.6
2	10.0	5.1	3.2	.5	4.2	12.2	9.9	48.8	15.4	17.5	20.4	9.2	8.2	24.3	191.9
3	10.2	8.3	3.9	1.5	2.0	17.8	28.3	70.4	26.2	22.1	22.5	13.5	15.4	55.7	307.7
4	8.9	7.7	3.0	.8	5.4	18.6	23.3	76.3	18.5	23.7	24.5	12.0	22.3	51.7	297.6
5	9.1	10.0	3.7	1.0	8.0	12.9	22.9	77.3	18.7	21.8	24.1	12.5	12.0	42.3	276.3
6	9.2	7.3	3.0	.7	2.0	11.5	8.6	31.8	13.0	15.8	15.0	7.9	5.6	14.9	146.3
7	9.7	8.2	4.1	.8	3.7	16.6	21.5	75.9	19.7	23.1	23.3	13.1	18.3	47.9	285.9
8	9.0	8.3	3.2	.8	4.2	15.8	11.6	58.3	19.0	27.2	16.0	9.4	12.7	31.5	227.8
9	9.2	8.1	2.4	.9	2.8	25.5	7.2	46.7	13.3	15.5	11.3	8.9	9.7	13.8	175.3
10	9.7	9.0	3.0	.7	2.8	25.7	6.5	34.2	11.1	10.9	9.4	7.9	8.3	14.4	153.6
11	9.2	7.9	2.8	.7	3.0	22.7	14.7	41.4	12.7	13.9	15.8	10.2	7.9	10.9	185.8
12	9.0	6.7	2.7	.5	2.8	20.2	8.6	41.2	11.9	12.1	13.7	10.7	7.8	16.8	164.7
13	9.4	9.0	2.5	.7	2.4	23.5	9.4	43.2	12.5	18.5	16.0	6.8	6.4	16.6	176.9
14	9.4	8.6	2.9	1.1	3.3	17.4	6.7	33.6	12.2	20.8	19.8	8.6	7.8	16.5	177.7
15	10.1	8.2	2.7	1.8	5.9	12.1	6.1	29.1	13.0	11.6	19.8	6.6	8.2	10.8	146.0
16	10.3	8.0	2.7	2.4	7.0	16.0	5.9	42.2	10.3	10.4	15.8	5.7	8.4	9.2	157.3
17	8.8	7.9	2.5	.5	3.5	11.6	5.2	34.0	12.3	15.6	14.5	6.6	5.1	13.9	142.9
18	10.2	7.6	2.8	.5	5.1	17.6	8.0	53.6	16.4	21.5	16.2	6.9	8.7	31.4	206.5
19	10.0	8.2	3.2	.6	2.7	13.4	4.7	11.9	5.5	30.4	13.3	8.1	6.0	13.7	111.7
20	10.9	7.5	3.2	.8	2.5	23.0	7.8	31.5	10.0	20.0	14.7	9.6	10.1	31.1	182.7
21	9.9	7.6	3.2	.5	2.6	13.0	5.0	20.3	5.0	8.1	12.6	7.3	6.1	12.6	114.1
22	9.3	7.5	3.5	1.3	4.6	12.2	4.5	16.1	9.9	4.0	10.8	5.3	11.9	9.5	110.4
23	9.4	7.2	3.4	2.2	3.2	20.1	8.5	31.3	3.9	21.4	12.5	9.2	7.3	10.1	152.7
24	9.3	6.7	5.3	12.4	11.1	30.4	22.9	63.6	17.0	35.5	27.8	26.5	26.0	72.5	367.9

[1] The total quantity of potassium added to all lysimeters in the form of muriate of potash during the 7-year experimental period was 444 pounds K_2O.

The average losses of potash during the winter and summer periods were 36 and 64 percent, respectively. This reflects in part the smaller additions of fertilizer potash during the fall than during the spring season. The most important factor determining losses was, apparently, the amount of soluble potash present at the time that heavy rains occurred. This is well illustrated by the potash contents of the leachates during the summer of 1942 when the rainfall was especially high (table 31). During this 6-month period, 23 percent of the potash removed during the entire 7 years was collected in the leachates. Obviously, potash is not retained to any marked extent by a very sandy soil and, like nitrogen, is removed readily by heavy rains unless the crop present is adequate to assimilate and hold it in an insoluble form.

Calcium and Magnesium in Leachates

The calcium contents of the percolates from the 24 lysimeters are shown in table 38, and the magnesium contents in table 39. During the time of the experiment 1,751 pounds of CaO were added in fertilizer and as dolomitic limestone. During this period calcium was removed in the leachings at the average rate of 55 percent of the amount added. If one excludes the lime added the last season of the experiment, the leachates contained 70 percent of the added calcium.

TABLE 38.—*Calcium [1] contents of percolates, expressed as pounds of CaO per acre, in lysimeters, Sandhill Experiment Station, 1938–45*

Lysimeter No.	1938–39		1939–40		1940–41		1941–42		1942–43		1943–44		1944–45		Total for 7 years
	Oct. 25 to Apr. 10	Apr. 11 to Oct. 6	Oct. 7 to Apr. 5	Apr. 6 to Sept. 26	Sept. 27 to Mar. 31	Apr. 1 to Sept. 23	Sept. 24 to Apr. 2	Apr. 3 to Sept. 28	Sept. 29 to Mar. 25	Mar. 26 to Sept. 17	Sept. 18 to Apr. 1	Apr. 2 to Oct. 10	Oct. 11 to Apr. 2	Apr. 3 to Sept. 27	
1	57.5	39.4	20.0	2.7	17.7	123.1	46.9	177.3	44.7	33.8	107.8	62.8	23.3	55.8	815.8
2	58.7	43.2	24.8	3.7	31.8	134.3	62.7	188.7	45.5	44.3	155.0	62.9	30.6	85.1	971.3
3	65.1	45.2	32.2	6.4	64.3	187.3	117.0	205.3	61.2	70.0	205.7	60.4	43.3	123.6	1,287.0
4	60.8	35.6	41.3	5.3	51.0	208.0	103.2	225.8	64.6	74.1	197.6	70.6	51.7	155.8	1,345.4
5	59.3	44.5	40.7	5.4	69.2	162.3	122.7	201.6	66.5	65.7	218.5	59.1	35.9	105.0	1,256.4
6	60.5	38.9	25.9	2.6	21.8	143.6	52.5	191.4	45.7	38.6	158.1	62.5	29.8	74.7	946.6
7	63.7	38.4	38.4	4.7	43.9	188.1	107.6	237.7	70.3	69.0	216.3	65.3	32.8	111.0	1,290.2
8	63.9	37.6	19.8	2.4	50.2	220.6	56.7	175.1	66.9	103.2	124.9	56.1	36.9	121.6	1,135.9
9	63.5	45.0	19.0	3.0	19.0	135.9	50.5	192.3	42.9	38.8	106.0	67.7	20.7	65.1	870.3
10	61.9	40.9	17.2	2.3	16.4	144.6	51.6	156.7	53.7	46.7	111.7	58.4	22.6	61.9	846.7
11	64.3	43.4	14.3	2.6	21.3	139.8	49.5	164.7	39.6	30.5	116.8	57.9	24.3	87.2	856.2
12	62.6	45.7	15.9	2.0	19.4	137.8	47.5	178.4	39.2	23.7	102.8	53.4	25.0	66.9	820.3
13	62.3	46.5	18.7	2.5	16.5	129.1	50.3	160.8	43.0	67.4	90.5	50.9	22.8	64.3	835.5
14	61.5	46.5	18.1	2.8	38.7	144.2	50.5	177.1	42.1	103.4	120.8	56.8	25.1	67.9	955.5
15	59.4	46.0	16.7	5.2	23.3	88.9	41.7	158.6	35.4	20.2	56.5	41.5	17.3	50.6	660.3
16	61.5	43.0	17.1	9.6	23.6	113.5	39.0	160.5	35.8	18.4	54.8	45.9	18.4	42.3	683.4
17	59.6	48.8	16.7	2.2	14.4	90.4	47.6	198.9	46.9	39.0	98.4	52.3	47.8	70.2	842.2
18	61.3	49.5	18.9	1.8	34.5	162.1	47.6	191.2	65.5	84.7	116.0	53.3	79.1	171.4	1,136.9
19	62.7	43.5	20.0	2.2	13.6	94.9	63.2	137.5	111.7	88.8	122.4	58.4	22.0	71.9	912.8
20	62.0	46.1	16.2	2.6	14.9	144.5	51.5	148.9	80.8	111.5	112.2	57.1	57.2	91.8	997.3
21	59.5	47.4	16.9	2.0	6.8	96.7	44.8	138.8	94.9	76.9	119.4	59.0	23.3	55.2	843.6
22	62.0	44.8	17.9	4.8	19.2	74.3	42.0	113.2	43.6	31.0	57.1	40.1	23.1	46.5	619.6
23	62.7	47.7	18.4	5.7	20.3	95.6	44.3	148.0	35.6	64.9	48.5	37.2	19.3	46.8	695.0
24	62.2	51.1	43.4	93.6	92.0	139.0	84.4	182.4	66.7	112.8	142.0	78.6	79.3	114.3	1,341.8

[1] The total quantity of calcium added to all lysimeters in fertilizers and as dolomite during the 7-year experimental period was 1,751 pounds CaO.

Additions of magnesium during the 7-year period amounted to 814 pounds MgO, and an average of 32 percent of this was removed in the leachates. Exclusive of the magnesium added as dolomite the final year, the removal was 53 percent.

The minimum losses of CaO and MgO from any of the lysimeters through leaching during the 7-year period were 620 pounds CaO and 186 pounds of MgO. The losses were reduced to some extent by a good winter cover crop, but regardless of cropping system large losses of these two nutrients can be expected.

TABLE 39.—*Magnesium*[1] *contents of percolates, expressed as pounds of MgO per acre, in lysimeters, Sandhill Experiment Station, 1938–45*

Lysimeter No.	1938–39		1939–40		1940–41		1941–42		1942–43		1943–44		1944–45		Total for 7 years
	Oct. 25 to Apr. 10	Apr. 11 to Oct. 6	Oct. 7 to Apr. 5	Apr. 6 to Sept. 26	Sept. 27 to Mar. 31	Apr. 1 to Sept. 23	Sept. 24 to Apr. 2	Apr. 3 to Sept. 28	Sept. 29 to Mar. 25	Mar. 26 to Sept. 17	Sept. 18 to Apr. 1	Apr. 2 to Oct. 10	Oct. 11 to Apr. 2	Apr. 3 to Sept. 27	
1	26.0	12.9	6.3	0.9	5.8	37.3	13.0	62.8	10.6	8.8	33.6	25.2	9.5	20.2	275.9
2	27.8	13.3	7.5	1.2	8.9	40.1	19.7	61.1	13.1	12.0	50.6	24.9	11.9	28.8	320.9
3	29.4	14.2	6.6	2.0	15.1	58.7	38.7	61.1	15.0	17.3	76.0	23.8	16.9	39.7	414.5
4	28.5	10.9	10.3	1.7	13.1	65.7	34.6	55.1	14.6	18.0	72.1	27.6	19.0	48.6	419.8
5	27.2	14.4	18.3	1.7	17.6	53.5	40.2	55.2	15.9	17.0	79.2	23.8	13.5	32.7	410.2
6	23.1	12.4	5.6	.8	7.1	43.8	15.8	62.6	13.4	12.7	52.5	25.7	12.2	26.3	319.0
7	28.5	12.7	11.7	1.5	14.1	56.2	36.0	64.7	15.6	17.5	77.6	24.6	12.9	36.4	410.0
8	28.6	12.9	5.9	.8	11.5	70.2	22.3	52.5	16.4	26.8	44.5	19.6	14.0	42.9	369.1
9	29.0	15.0	5.5	.9	6.0	39.0	15.7	59.6	12.6	12.0	34.0	25.3	8.3	22.2	285.1
10	28.4	13.8	5.0	.8	5.5	41.5	16.4	48.7	13.0	13.2	36.8	21.9	9.4	21.6	276.0
11	28.8	14.5	4.1	.8	6.6	38.7	14.4	52.0	11.2	9.5	42.8	22.3	8.8	29.3	284.8
12	28.5	14.6	4.4	.5	5.9	40.6	14.8	63.7	12.9	7.7	34.4	22.5	12.2	29.9	292.6
13	26.9	15.6	6.3	.9	4.9	38.6	14.4	53.4	9.6	19.7	33.8	20.5	10.3	25.0	279.9
14	28.2	16.1	6.0	1.0	8.2	44.7	16.1	54.5	11.1	29.6	43.7	20.0	8.7	20.8	308.7
15	27.6	17.8	5.2	2.0	6.8	26.8	8.9	41.2	11.3	6.9	22.6	15.3	6.4	17.3	216.1
16	27.5	15.7	5.6	3.2	7.0	31.3	10.2	50.5	7.9	6.1	21.1	15.9	6.3	16.4	224.7
17	25.9	15.8	6.2	.7	4.5	28.0	12.4	56.0	11.4	12.1	37.0	21.5	20.0	24.2	275.7
18	27.1	16.5	6.6	1.0	10.4	46.6	14.8	52.2	24.6	26.6	46.9	19.4	28.2	55.7	376.6
19	29.5	13.9	5.8	.7	4.6	27.5	16.3	50.3	27.0	25.7	46.3	23.8	8.8	25.6	305.8
20	28.3	14.4	4.9	.9	5.0	44.4	14.5	49.9	24.9	35.7	36.2	24.3	23.9	28.5	335.8
21	27.0	15.2	5.9	.7	4.9	27.2	10.9	36.9	25.7	22.5	47.3	25.3	10.1	22.1	281.7
22	28.5	14.3	6.0	1.6	7.0	22.8	9.9	20.7	8.6	8.4	19.9	13.9	8.2	16.6	186.4
23	25.8	15.0	5.7	1.9	6.7	28.3	11.0	46.1	17.1	22.3	16.0	14.8	7.4	17.0	235.1
24	28.2	16.1	24.5	23.9	21.9	56.6	26.5	42.6	12.2	30.9	61.0	30.5	31.4	39.6	446.2

[1] The total quantity of magnesium added to all lysimeters as dolomite during the 7-year period was 814 pounds MgO.

SUMMARY

The results of a lysimeter experiment, designed to obtain both practical and fundamental information on the use of green manure crops and fertilizers in cotton production on a Lakeland sand, are reported.

1. Heavy growths of summer legume crops that were incorporated into the soil had a very beneficial effect upon the growth of a cotton crop that followed. This was owing largely to the nitrogen fixed from the air by the legume. No very marked advantage in the use of legumes rather than nonlegumes occurred where abundant commercial fertilizer was supplied under conditions that kept leaching losses to a minimum.

2. A heavy growth of a winter cover crop, such as rye, was very beneficial to the crop that followed, chiefly because it decreased the loss of nutrients by leaching. Less vigorous growing cover crops, such as peas and vetch, were not so satisfactory.

3. Any system of fertilization and cover crops that was effective in providing cotton with an adequate supply of nutrients, especially nitrogen, at the time that cotton needed it, was effective. Past cropping systems, except in some cases for the preceding year, were comparatively unimportant.

4. Under lysimeter conditions, the loss of water from cropped soils by evapotranspiration was always greater than the loss from un-

cropped soils by evaporation. A direct and high degree of correlation occurred between the dry weights of the crops and evapotranspiration, regardless of the kind of crop or rotation used. The efficiency of use of water was also directly correlated with dry matter production. Apparently any factor that favors increased crop yields also results in the more efficient use of water.

5. The quantity of nitrogen in the percolates for the 7-year experimental period ranged from 235 to 890 pounds per acre for the 24 lysimeters. The average loss of nitrogen was 566 pounds, or 75 percent of that added as fertilizer. Some of this nitrogen was nitrogen added by legumes rather than in fertilizer. These extremely high losses are due in large part to the fact that during the 7-year experiment usually only 3, and in some lysimeters only 1 or 2, crops were harvested. Continuous cropping, summer and winter, markedly decreased leaching losses.

6. The gains in soil carbon and nitrogen during the experiment averaged 1,007 and 142 pounds per acre, respectively, with several soils showing losses for one or the other of these elements. It is estimated that, on the average, only 6 to 10 percent of the carbon added during the 7 years remained in the soil at the end of the experiment. These results emphasize the futility of trying to increase markedly the organic matter content of sandy soils in a warm climate

7. Complete nitrogen balance sheets for the various lysimeter soils could not be calculated, because all but four grew legumes. An approximate, but fairly accurate, balance indicates, however, that on the average gaseous losses of nitrogen were negligible. The figures also indicate that under conditions where legumes received approximately 107 pounds of fertilizer nitrogen annually, the fixation per legume crop averaged about 50 to 65 pounds each season. If the fixation was greater than this the additional nitrogen fixed was later lost in gaseous forms.

8. Potassium losses from the various soils ranged from 110 to 368 pounds per acre for the 7-year period; the average loss was 192 pounds, or 43 percent of that added as fertilizer. Potassium, like nitrogen, was readily leached from the soil unless the crop present was adequate to utilize it.

9. About 55 percent or slightly more of the calcium added as fertilizer and dolomite during the experiment was removed by leaching. The loss of magnesium, added as dolomite alone, was 35 percent. These losses were from soils that were approximately neutral at all times.

SOME PRACTICAL CONCLUSIONS

The main practical conclusions from these experiments that are applicable to very sandy soils in warm, humid climates are as follows.

1. Summer legumes, used as green manures, are highly beneficial to crops that follow. This is owing chiefly to the nitrogen fixed from the air by the legumes. Nonleguminous crops that receive abundant fertilizer nitrogen behave similarly to legumes when used as green manures.

2. For maximum utilization of added nutrients, it is essential that the soil be kept in crops as much of the time as possible. Winter-cover crops are very effective in reducing leaching losses.

3. Comparatively heavy fertilization with complete fertilizers is essential on very sandy soils. The nutrients, especially nitrogen and potassium, which are readily removed by leaching, should be supplied at intervals during the growing season and at a time when the crop can utilize them quickly.

4. Green manures and winter cover crops should be grown on very sandy soils primarily for the purpose of fixing or conserving nitrogen for the crop that follows; they will not increase appreciably the level of soil organic matter.

5. The efficient use of the nitrogen in animal manures is favored by prompt incorporation of the manures with the soil and by keeping the soil in crop for a maximum percentage of the time.

6. As moisture deficiency is common in sandy soils, it is advisable to grow drought-resistant, deep-rooted crops unless supplemental irrigation is available. Excellent yields of a crop such as cotton can, however, often be obtained with natural rainfall if adequate attention is given to time and rate of fertilization and the use of cover crops. Inclusion of summer green manure crops in the rotation is not essential if adequate fertilizer nitrogen is supplied.

7. Much more emphasis should be given to the efficiency of use of water in crop production, bearing in mind that any factor, such as fertilizer, that increases crop yields favors efficiency. This applies rather uniformly to all crops.

U. S. GOVERNMENT PRINTING OFFICE 1959

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