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Drainage Water Losses From a Sandy Soil as Affected by Cropping and Cover Crops

Windsor Lysimeter Series C

M. F. Morgan, H. G. M. Jacobson and S. B. LeCompte, Jr.

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New Haven

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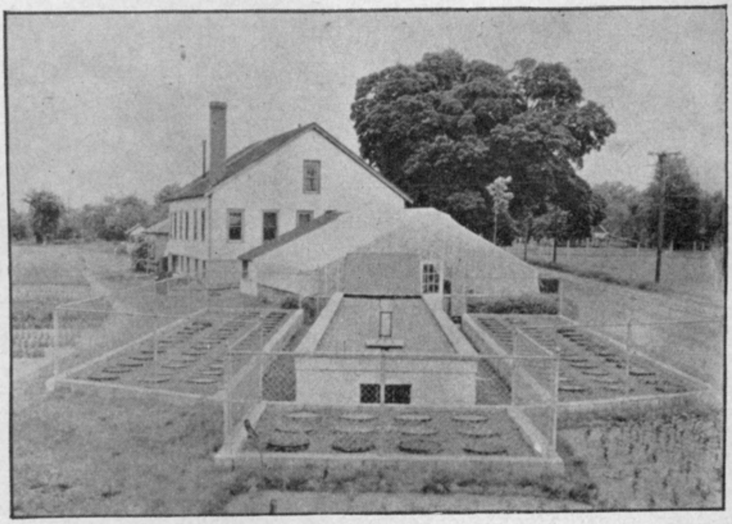

Figure 1. Windsor lysimeters, end view of exterior before planting, June 1936.

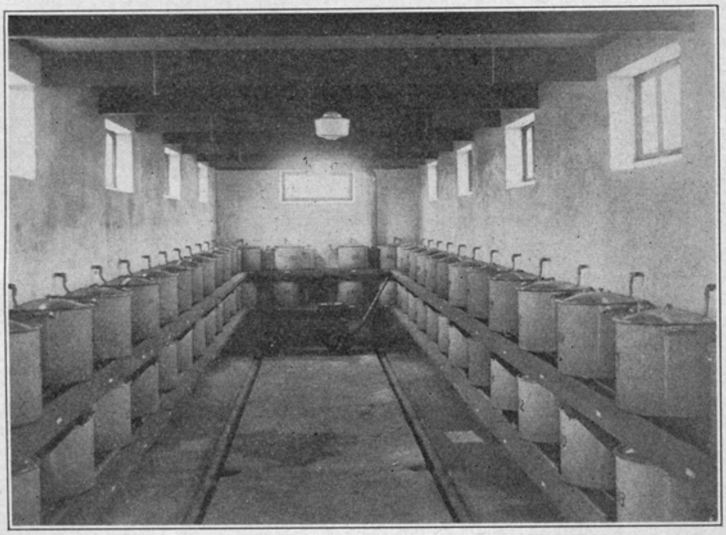

Figure 2. Windsor lysimeters, interior view of collecting chamber.

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Lysimeter experiments conducted at Windsor since the year 1929 have chiefly involved comparisons between various sources of fertilizer nitrogen, under both uncropped and cropped conditions. Under uncropped conditions, drainage water was collected from the surface soil layer, as in Series A (1) and D (6); under cropped conditions, from a shallow subsoil provided by utilizing tanks of the 20-inch depth, as in Series B (2). The present experiment, Series C, involved comparisons under both cropped and uncropped conditions, with and without nitrogen treatment and cover cropping effects. A study of fractional, or divided, nitrogen treatment as applied to the tobacco crop was also made. The tanks were of sufficient depth (30 inches) to include the complete soil profile to fully pervious coarse sand and fine gravel, as in the normal field condition of the soil under investigation.

The experiment was conducted in a series of 24 tanks, 20 inches in diameter and 30 inches deep, installed in April, 1931, as an addition to the facilities of the Windsor lysimeter equipment. The results presented herein cover the 10-year period ending in the spring of 1941.[1]

The main objective has been to measure chemical constituents applied to or liberated from the soil. Crop withdrawals and leaching as affected by nitrogen fertilization and cover cropping were studied with special reference to the Connecticut Valley tobacco crop. The maintenance of organic matter and nitrogen in the soil also was evaluated under controlled conditions, approximating those existing in the field.

PLAN OF INVESTIGATION

The physical equipment and experimental techniques for the conduct of lysimeter studies have been described in previous publications. The installation is shown in Figures 1 and 2. The tanks of Series C occupied the outer row on the courts, on either side and at one end of the collecting chamber. Soil used in the experiment was from Field VII just south of the lysimeter plant. This field had been devoted to tobacco culture for many years, and for the preceding five

[1]Before 1940, the conduct of the work at Windsor was delegated to O. E. Street, former assistant plant physiologist on the staff of the Tobacco Substation. After that time, the junior author was in local charge.

years had been planted to an oats cover crop in connection with an organic matter-maintenance experiment of the Tobacco Substation. Successive fillings of mixed, carefully packed field soil represented: the substratum (C) at from 20½ to 28-inch depths, the subsoil (B) at from 9 to 20-inch depths and the surface soil (A) to the depth of 8 inches. After settling, the soil surface in the tanks was approximately 2 inches below the rims.

The soil is Merrimac sandy loam (deep phase), the type most extensively used for tobacco in the Connecticut Valley. It is practically identical to that used in Tanks 25-34 of Series A and in all tanks of Series B, being taken from within a few feet of the site used for filling those tanks in 1929.

The amounts of soil used in the tanks, on the dry weight basis, were approximately as follows for the various depths:

		Thickness inches	Pounds per acre Total soil	2 mm. soil
Surface Soil	(A)	8	2,543,000	2,500,000
Subsoil	(B)	12	4,475,000	4,400,000
Substratum	(C)	8	3,285,000	3,200,000

Pertinent physical and chemical measurements of the original soil, based on material passing a 2 mm. screen, are given in Table 1.

TABLE 1. PHYSICAL AND CHEMICAL CHARACTERISTICS OF SOIL HORIZONS USED IN LYSIMETER SERIES C, 1931-41

	Surface Soil A	Subsoil B	Substratum C
Mechanical analysis		(In percentages)	
Sand	76.0	76.2	91.4
Silt	18.2	19.4	8.2
Clay (.002 mm.)	5.8	4.4	0.4
Moisture equivalent	8.8	6.9	2.7
Organic matter	1.81	.60	.46
Nitrogen total	.068	.019	.009
Phosphorus total	.124	.049	.042
Potassium total	1.335	1.300	1.300
Calcium total	2.44	.212	.178
Magnesium total	.219	.216	.177
Exchangeable bases		(In mg. equivalents per 100 gms.)	
Calcium	1.41	.65	.28
Magnesium	.57	.52	.37
Potassium	.35	.31	.10
Sodium	.07	.08	.07
Total	2.40	1.56	.82
Exchangeable hydrogen	2.68	.49	.30
Base exchange capacity	5.08	2.05	1.12
Relative base saturation %	47.2	76.1	73.2
Soil reaction—pH	5.47	5.98	5.93

The following combinations of cropping and treatment were compared in duplicate in the various lysimeter tanks:

Tank Nos.	Crop and Treatment
211-212:	*Bare soil,* without crop; *no nitrogen;* fertilizers supplying other constituents applied annually on May 26 (100 pounds P_2O_5, 200 pounds K_2O and 50 pounds MgO per acre, as precipitated bone, carbonate of potash, sulfate of potash and magnesium carbonate).
213-214:	*Tobacco, without cover crop; no nitrogen;* treatment same as above.
215-216:	*Bare soil,* without crop *200 pounds of nitrogen per acre as calurea* (4/5 nitrogen as urea, 1/5 as nitrate of lime) and other fertilizers, as above, applied annually on May 26.
217-218:	*Tobacco, without cover crop; 200 pounds of nitrogen per acre as calurea,* and other treatments applied as above.
219-220:	*Tobacco,* followed by *oats cover crop,* turned under in the spring; *200 pounds of nitrogen per acre as calurea,* and other treatments applied as above.
221-222:	*Tobacco, without cover crop; 200 pounds of nitrogen per acre in the N-1 formula* (generally used for a number of years for field-grown tobacco at the Windsor Substation) applied on May 26 each year. This formula supplies 120 pounds of nitrogen as cottonseed meal, 40 pounds as castor pomace and 40 pounds as nitrate of soda, including sufficient amounts of carbonate of potash, sulfate of potash and magnesium carbonate to provide a total of 200 pounds of potash and 50 pounds of magnesia. The formula contains no special carrier of phosphoric acid. The organic materials supply approximately 71 pounds of P_2O_5 per acre.
223-224:	*Tobacco,* followed by *oats cover crop; 200 pounds of nitrogen in the N-1 formula,* as above.
225-226:	*Tobacco,* followed by *rye cover crop,* turned under about May 1; *200 pounds of nitrogen in the N-1 formula,* as above.
227-228:	*Tobacco,* followed by *timothy cover crop,* turned under about May 1; *200 pounds of nitrogen in the N-1 formula,* as above.
229-230:	*Tobacco, without cover crop; 167 pounds of nitrogen,* and other constituents applied in *successive applications* as follows: May 26, before setting: calurea, supplying 50 pounds of nitrogen; ammophos, supplying 23 pounds of nitrogen and 100 pounds of phosphoric acid; carbonate of potash and "double manure salts," supplying 110 pounds of potash and 20 pounds of magnesia, per acre. 3 weeks after setting: calnitro (commercial ammonium nitrate), supplying 25 pounds of nitrogen. 5 weeks after setting: nitrate of lime, supplying 20 pounds of nitrogen; nitrate of potash, supplying 27 pounds of nitrogen and 90 pounds of potash; magnesium nitrate, supplying 22 pounds of nitrogen and 24 pounds of magnesia, per acre. This scheme of fertilizer application was designed to supply the crop more nearly in accord with the time when the various nutrients are utilized than when a single application is made before setting tobacco.
231-232:	*Permanent grass sod, no nitrogen,* other constituents applied annually on April 16, as used for tobacco, without nitrogen.
233-234:	*Permanent grass sod, 200 pounds of nitrogen per acre as calurea,* applied in *successive applications* as follows: April 15: 100 pounds of nitrogen and other constituents. May 26: 50 pounds of nitrogen. September 1: 50 pounds of nitrogen. In the first year of the experiment, the initial treatment was applied on September 2, 1931, before seeding.

The tobacco crops were harvested each year in early August, stalks being cut at ground level. Cover crops were seeded within 10 days after the tobacco was harvested. The tobacco plants were dried, weighed and pulverized for subsequent chemical analysis.[1] Grass clippings from the permanent grass sod were made twice each season. These were also analyzed.

The drainage water was measured and sampled after each period of leaching. Nitrate nitrogen was determined in the current samples. Composite samples were accumulated over six-months periods ending on May 25 and November 25 of each year. Analyses of these leachings were conducted as in the lysimeter studies previously reported.

The tobacco plants set in the tanks in 1940 grew poorly and developed abnormal symptoms characteristic of zinc toxicity. This was ascribed to the weathering of the asphalt coating on the inside walls of the tanks above the ground level and to subsequent corrosion of the galvanized metal surface. Since the results from such a crop were certain to be erratic, the plants were destroyed and turned under when three weeks old. The experimental data for the year was affected by this disturbing factor.

Tanks 209 and 210 were installed at the same time as the others. These were also 20 inches in diameter, but were only 4 inches deep and contained no soil. They were utilized to collect rain and melting snow for the analysis of constituents added by atmospheric precipitation. The total quantities of the various elements added to the tanks during the 10-year period by fertilizer treatments, rain and snowfall are shown in Table 2.

The materials used in these trials were from lots purchased for use on the fertilizer plots conducted by the Tobacco Substation at Windsor. Details of the chemical composition of the various lots of each ingredient are omitted. They are essentially as given in Bulletin **444**, page 286, of this Station. The data of Table 2, however, are based on exact analysis conducted at this Station chiefly by the Department of Analytical Chemistry.

Samples of soil from each of the three horizons have been subjected to laboratory study. These comprised the original soil, collected at the time of filling the tanks, and the soils in the various tanks when removed at the conclusion of the 10-year period. Analysis included: total nitrogen, organic carbon, base exchange capacity, exchangeable bases, exchangeable hydrogen, moisture equivalent and mechanical analysis. Methods for analyses of leachates were essentially as indicated in Bulletin **384** (1).

[1]The cooperation of Dr. E. M. Bailey, Station Chemist, in analyzing the crops and fertilizer materials, has been of great assistance to the conduct of this experiment.

TABLE 2. QUANTITIES OF VARIOUS ELEMENTS ADDED BY TREATMENTS AND RAINFALL, LYSIMETER SERIES C, 10-YEAR PERIOD, 1931-41
(Pounds per acre)

Tank Nos.	Treatment	Nitrogen N	Phosphorus P	Potassium K	Magnesium Mg	Calcium Ca	Sodium Na	Sulfur S	Chlorine Cl
211-212	No nitrogen—fallow	40	437	1,762	362	834	107	584	246
213-214	No nitrogen—tobacco; no cover crop	40	437	1,762	362	834	107	584	246
215-216	Calurea—fallow	2,040	437	1,762	362	1,405	128	584	278
217-218	Calurea—tobacco; no cover crop	2,040	437	1,762	362	1,405	128	584	278
219-220	Calurea—tobacco; oats cover crop	2,040	437	1,762	362	1,405	128	584	278
221-222	N-1[1]—tobacco; no cover crop	2,040	311	1,762	362	281	763	615	284
223-224	N-1—tobacco; oats cover crop	2,040	311	1,762	362	281	763	615	284
225-226	N-1—tobacco; rye cover crop	2,040	311	1,762	362	281	763	615	284
227-228	N-1—tobacco; timothy cover crop	2,040	311	1,762	362	281	763	615	284
229-230	Spl. fract. N[2] tobacco; no cover crop	1,711	437	1,762	332	708	123	654	280
231-232	No nitrogen—grass sod	40	437	1,762	362	834	107	584	246
233-234	Calurea—grass sod	1,940	437	1,762	362	1,348	125	584	275
	Rainfall contributions (included in above)	40	——	92	62	193	103	225	241

[1]N-1: 60 percent of nitrogen from cottonseed meal, 20 percent of nitrogen from castor pomace, 20 percent of nitrogen from nitrate of soda.
[2]Special fractional nitrogen: 167 pounds nitrogen per year—73 pounds before setting; 25 pounds in three weeks; 69 pounds in five weeks.

PRECIPITATION AND OTHER WEATHER CONDITIONS DURING THE EXPERIMENT

There have been wide differences in both amounts and distribution of precipitation in the various years of the experiment, as is evident from Table 3. Generally speaking, the averages by months were

TABLE 3. ATMOSPHERIC PRECIPITATION BY MONTHS, DURING THE PERIOD COVERED BY LYSIMETER SERIES C, 1931-41
(In Inches)

Month	1931-32	1932-33	1933-34	1934-35	1935-36	1936-37	1937-38	1938-39	1939-40	1940-41	Ave. 10 yrs.	Hartford Average 78 yrs.
June	4.74[1]	2.86	1.96	3.47	5.53	2.75	5.63	7.00	4.37	5.88	4.42	3.08
July	2.90[2]	3.99	2.43	3.20	4.30	2.45	4.40	8.54	2.56	3.72	3.85	4.37
Aug.	3.87	5.72	3.42	3.45	2.05[3]	4.35	6.81	2.11	5.62	1.56	3.90	4.92
Sept.	0.98	3.53	4.85	8.63	4.78	3.86	4.33	12.63	2.22	2.57	4.84	3.49
Oct.	1.70	4.18	1.70	2.11	0.43	3.92	4.62	1.83	2.20	2.63	2.53	3.50
Nov.	0.78	5.54	0.58	2.17	4.13	1.14	6.02	3.95	2.81	5.82	3.29	3.55
Dec.	3.00	1.88	3.44	2.75	0.82	5.65	1.67	3.65	3.02	2.49	2.84	3.97
Jan.	4.59	1.73	4.11	4.02	5.80	5.58	4.39	2.79	0.17	2.02	3.52	3.94
Feb.	2.17	3.89	3.98	2.74	2.21	1.69	1.85	2.17	1.91	1.98	2.46	3.83
Mar.	4.89	5.56	3.84	1.49	5.98	3.06	1.49	4.59	4.97	1.40	3.73	3.90
Apr.	1.53	4.13	5.35	1.28	3.38	3.82	4.44	4.39	5.62	1.13	3.51	3.36
May	1.65	1.58	3.85	1.40	2.38	4.09	4.21	0.95	4.08	3.45	2.76	3.60
Lysimeter year	**32.80**	**44.59**	**39.51**	**36.71**	**41.79**	**42.36**	**49.86**	**54.60**	**39.55**	**34.65**	**41.65**	**45.51**

[1]Rainfall during May 1931—6.52 inches.
[2]Includes irrigation water of 1.06 inches.
[3]Includes irrigation water of 0.25 inches.

reasonably comparable to mean conditions over a much longer period, as shown by records taken in Hartford, 7 miles distant. However, the monthly precipitation has varied from 0.17 inches, in January 1940, to 12.63 inches, in September 1938. The yearly range has been from 32.80 inches in 1931-32 to 54.60 inches in 1938-39.

Weather conditions that have had special effects upon the amounts of leaching are briefly reviewed in the following paragraphs.

1931-32: After a wet May, two periods of rainfall produced leaching in June from all tanks. In August, 2.73 inches of rainfall in two days caused leaching from uncropped tanks. With a dry fall, no leaching took place until a period of rains and thaws during the mild weather of December and January. Further passage of drainage water resulted from the March thaw and from a heavy shower early in April.

1932-33: Following dry weather through May and June, considerable rain in July caused no significant leaching. August rainfall, chiefly in two storm periods near the middle of the month, caused slight leaching from uncropped tanks. Frequent, heavy rains through late summer and fall caused considerable leaching from uncropped tanks. However, cropped tanks did not produce drainage water until

November, a wet month, resulting in much leaching. After dry, cold weather in December, the winter was mild, permitting leaching during thaws in January and February. Unusually heavy, early spring rains caused much water to pass through the soil. Dry weather prevailed after mid-April.

1933-34: Generally dry weather with well distributed showers persisted until September, when heavy rains caused leaching from uncropped tanks. Thereafter, the fall was very dry, leaving a moisture deficit in the ground at the time of freezing in late November. Unusually cold weather prevented leaching until the March thaw. A wet April caused drainage water to pass further through the soil.

1934-35: With much moisture already in the soil, one heavy rain in June caused leaching. A hot summer with well distributed rainfall prevented further soil drainage, but heavy September precipitation brought an unusual amount of water through the soils in all tanks. During a cool fall, light rainfall on damp soil was sufficient to cause further leaching. Except during a heavy rainfall and thawing conditions early in January, no further drainage occurred until March thaws. The spring was very dry, with no further leaching.

1935-36: After scattered showers during most of June, a heavy rain of 2.3 inches toward the end of the month caused some leaching in all cases. A rainfall of 3.15 inches in six days toward the end of July failed to leach the soil under tobacco or grass crops, although drainage of more than half an inch occurred in fallow soils. Rains in September caused considerable leaching from uncropped tanks. After a very dry October, slightly above normal precipitation in November was insufficient to saturate the soils of the cropped tanks under cover crops. A dry December and frozen ground during the rest of the winter prevented leaching until March downpours thawed the ground. April showers caused further soil drainage.

1936-37: June and July brought occasional light rains and warm weather. In August, abundant rains failed to leach the soil. Normal rainfall in September and October caused considerable leaching from uncropped tanks, but not from cropped soils. After a dry November, the early winter was generally wet and mild, with much leaching from all tanks. Following a cold, dry February, March rains thawed the ground to produce much drainage water. April showers and heavy rains in May caused further leaching.

1937-38: Abundant June rains, falling on soil already well moistened during the previous month, caused considerable leaching from all tanks. Further soil drainage occurred in July. Heavy rains in August failed to saturate the cropped soils. Wet weather during the fall months caused much leaching. A generally dry, cold winter and an unusually light March rainfall yielded a minimum of soil drainage during the spring-thaw period. Abundant rainfall in April caused considerable leaching. However, by May the soil had attained a sufficient moisture deficit to absorb a normal rainfall, well distributed.

1938-39: Very heavy June rains caused leaching from all tanks. A week of almost continuous rain, from July 19 to 24, produced exceptionally severe summer leaching, even under cropped conditions. Following dry weather in August and early September, a spell of rain from September 17 to 21 culminated in the great hurricane. An estimated four inches of water that should normally have leached through the soil overflowed the rims of the tanks, while the outlet tubes were closed to prevent overflow from the collecting vessels. After several weeks of dry weather, rains in late November produced no leaching. However, the soil was sufficiently moistened to produce drainage water during early December storms. No further leaching occurred during the winter period. The spring thaws and heavy March and April rainfall caused much water to pass through the soil. An unusually dry May ensued.

1939-40: Frequent light rains during June were insufficient to leach the soil, even under fallow conditions. One heavy September storm caused slight leaching from uncropped tanks only. The fall months had insufficient moisture to saturate the cropped soils. The winter was unusually dry. March thaws and April rains leached the soils in all tanks. Rainfall in May was insufficient to cause leaching until after treatments were applied.

1940-41: Heavy rains during the last three days of May and showers in June caused considerable leaching. One heavy rain in July, after frequent showers, produced some drainage water. Late summer and early fall were dry. A heavy rainfall in November produced much leaching from uncropped tanks, but barely more than saturated the soils under grass or cover crops. Rains in January and March thawed the fallow soils, permitting leaching except under the unusually heavy growth of cover crop. April showers caused some leaching from all tanks. In late April, the soils were removed. However, subsequent rainfall would not have produced drainage water, according to observations in previous years.

Comparisons between the leachings from fallow soils and from those cropped to tobacco, fertilized and subsequently cover-cropped to oats are shown in detail in Table 4.

It was noticed that from April to July bare soils leached less readily. The mulching effect of the winter-killed cover crop during the spring months and of the young tobacco plants are believed to keep the soil at a lower moisture deficit. After July, the drying effect of transpiration from the cropped soil became apparent.

TABLE 4. COLLECTIONS OF DRAINAGE WATER FROM FALLOW SOILS AND FROM SOILS CROPPED TO TOBACCO FOLLOWED BY OATS AS A COVER CROP
(In inches, by months)

Month	Soil	1931-32	1932-33	1933-34	1934-35	1935-36	1936-37	1937-38	1938-39	1939-40	1940-41	10-year Average
June	fallow	3.9	—	—	0.8	0.2	—	1.7	2.4	—	2.8	1.18
	cropped	3.9	—	—	1.6	1.4	—	2.1	3.8	0.7	3.5	1.70
July	fallow	—	—	—	—	0.6	—	0.9	5.1	—	0.5	0.71
	cropped	—	0.6	—	—	—	—	0.2	5.1	0.2	1.3	0.74
Aug.	fallow	2.0	0.7	0.1	—	—	—	1.8	0.2	—	—	0.48
	cropped	—	—	0.1	—	—	0.8	—	—	—	—	0.09
Sept.	fallow	—	2.3	2.2	6.0	—	2.1	3.7	9.5	0.2	—	2.60
	cropped	—	—	—	2.8	—	—	0.8	8.0	—	—	1.16
Oct.	fallow	—	2.6	—	—	1.1	2.5	2.2	—	—	—	0.84
	cropped	—	—	—	—	—	—	0.9	—	—	—	0.09
Nov.	fallow	—	5.2	—	1.3	0.8	0.3	5.2	—	2.9	3.2	1.89
	cropped	—	4.7	—	0.3	—	—	4.5	—	—	—	0.95
Dec.	fallow	1.9	—	0.6	—	—	3.9	—	4.1	—	1.6	1.21
	cropped	0.2	—	—	—	—	4.0	—	1.9	—	0.4	0.65
Jan.	fallow	4.2	1.3	—	1.5	—	5.7	—	0.2	—	1.8	1.47
	cropped	2.3	1.2	—	0.9	—	4.8	—	—	—	—	0.92
Feb.	fallow	—	1.2	—	—	—	—	—	—	—	—	0.12
	cropped	—	1.3	—	—	—	—	—	—	—	—	0.13
Mar.	fallow	4.2	6.6	4.2	3.3	7.2	3.9	3.7	3.1	6.3	1.5	4.40
	cropped	3.5	6.0	3.6	3.2	6.2	3.2	1.7	3.8	3.0	—	3.42
Apr.	fallow	1.4	3.4	5.0	—	2.8	0.8	2.3	2.1	3.6	0.7	2.21
	cropped	1.3	3.6	4.8	—	3.1	1.4	3.3	2.8	2.8	0.7	2.38
May	fallow	—	—	—	—	—	1.3	—	—	—	—	0.13
	cropped	—	—	—	—	—	1.9	—	—	0.3	—	0.22
Totals	**fallow**	**17.6**	**23.3**	**12.1**	**12.9**	**12.7**	**20.5**	**21.5**	**26.7**	**13.0**	**12.1**	**17.24**
	cropped	**11.2**	**17.4**	**8.5**	**8.8**	**10.7**	**16.1**	**13.5**	**25.4**	**7.0**	**5.9**	**12.45**

TABLE 5. AVERAGE YEARLY DRAINAGE WATER COLLECTIONS UNDER VARIOUS TREATMENTS, 1931-1941
(In inches)

Treatment	First period May 26—Nov. 25	Second period Nov. 26—May 25	Total for lysimeter year
Fallow soils			
No nitrogen	7.74	9.75	17.49
Calurea	7.10	9.77	16.87
With tobacco crop, no cover crop			
No nitrogen	6.01	9.33	15.34
Calurea	4.95	8.78	13.73
N-1 formula	5.73	9.57	15.30
Nitrogen in fract. appl.	4.84	9.32	14.16
With tobacco crops, cover crops:			
Calurea, oats cover crop	4.41	8.29	12.70
N-1, oats cover crop	4.61	8.19	12.80
N-1 rye, cover crop	5.16	9.07	14.23
N-1, timothy cover crop	6.09	10.02	16.11
Grass sod			
No nitrogen	6.24	9.96	16.20
Calurea	4.12	9.31	13.43
Total precipitation (rain gauge tanks)	22.83	19.14	41.97

Leaching during late fall and early winter was greater when tobacco was grown without a cover crop. Where rye was grown as a cover crop results were somewhat erratic. During early summer, water removed by spring growth allowed less leaching. On the other hand, in early spring more water usually passed through the soil under this crop. Snowfall at this time of year may have better retention against wind action than rain. Under the timothy cover crop leaching was somewhat greater for the year as a whole. Apparently the mulching effect of this crop more than counterbalanced the transpiration. Dry-matter production from timothy was obviously much less before the crop was turned under in the spring, than for the other two species.

A summary of leaching from the various treatments during the 10-year period is shown in Table 5. Other features of the effects of cropping and cover crops on distribution and amounts of leaching, based on data from 1931 to 1937, were discussed in a previous publication (3). Data for the subsequent years show the same general trends.

NITROGEN LEACHINGS AT VARIOUS SEASONS

The soil columns in this series of tanks were of practically normal depth. Nitrates, either from nitrate of soda in the treatment or from the nitrification of fertilizer materials and the soil itself, must be washed from the surface soil through 20 inches of subsoil before appearing in the drainage water. It required the cumulative effect of several rainfalls to leach any considerable amount of nitrates.

Some years showed insignificant leachings of nitrates for several months after fertilizer application. On the average, nitrate concentration in leachings from uncropped soils receiving nitrogen treatment did not increase significantly until at least 3 inches of water had passed through the soil. The peak concentrations usually occurred in the leachings representing from 5 to 7 inches of drainage water. Since these leachings were attained at different seasons of the year, depending upon conditions pointed out in the preceding section, there was a marked variation in the seasonal distribution of leaching.

Nineteen thirty-eight was the only year when large amounts of nitrates were washed from both soil and subsoil during the summer, under any treatment. The unusual results during this very wet season were presented in detail in a previous publication (4). Since leachings during June and July of that year represented from 7.5 to 9 inches of water, it is obvious that nitrates and other soluble material would be almost entirely removed from the entire soil column.

When the soils were cropped to tobacco, nitrate nitrogen in excess of crop intake was not leached for some time after harvest. In several years of the experimentation much of this residue did not appear in the drainage water before the March thaws. However, after this month nitrate leachings were insignificant.

NITROGEN UTILIZATION BY CROPS IN RELATION TO LEACHING LOSSES UNDER VARIOUS TREATMENTS

Nitrogen as it was leached and removed by crops during the nine years that tobacco crops were harvested is shown in Table 6.

TABLE 6. AVERAGE YEARLY NITROGEN LEACHINGS AND CROP REMOVALS, WINDSOR LYSIMETER SERIES C, NINE-YEAR PERIOD
(In pounds per acre)

Treatments	Leachings		Crop removals	Total nitrogen recovery in crop and leaching	Percentage of total in the crop
	Nitrate N	Ammonia N			
No nitrogen—fallow	53.0	0.4	——	53.4	——
No nitrogen—tobacco, no cv.cp.[1]	26.7	0.4	20.7	47.8	43.3
Calurea—fallow	226.2	0.4	——	226.6	——
Calurea—tobacco, no cv. cp.	80.2	0.7	99.4	180.3	55.2
Calurea—tobacco, oats cv. cp.	48.2	0.3	104.9	153.4	68.4
N-1—tobacco, no cover crop	74.0	0.2	80.8	155.0	52.1
N-1—tobacco, oats cover crop	31.9	0.2	85.8	117.9	72.8
N-1—tobacco, rye cover crop	25.1	0.3	86.9	112.3	77.4
N-1—tobacco, timothy cv. cp.	50.6	0.4	79.3	130.3	60.9
Spl. fract. N—tobacco, no cv.cp.	67.9	0.3	94.1	162.3	58.0
No nitrogen—grass sod	2.6	0.4	18.1	21.1	85.8
Calurea—grass sod	17.0	0.6	85.1	102.7	82.9

[1]Cover crop.

Fallow soil, without nitrogen, showed an excellent capacity for nitrogen liberation during the earlier years of the experiment. Two hundred forty-eight pounds of nitrate nitrogen per acre were leached from this soil during the first two years. However, after 1932 the yearly recoveries ranged from 52 to 16 pounds per acre.

The tobacco crop was able to utilize only 43.3 percent of the nitrogen liberated during the year that no nitrogen was applied. This was insufficient for normal growth. When ample nitrogen was provided, relative crop recovery was greater, particularly when the leaching of nitrogen was checked by the growth of cover crops. However, the greatest efficiency of nitrogen from the standpoint of relative utilization by cropping was under a continuous grass sod.

SOIL CHANGES WITH RESPECT TO NITROGEN AND ORGANIC MATTER

Samples of each of the three soil layers or horizons, taken at the time of tank filling in 1931 and at the end of the 10-year period in 1941, were analyzed for total nitrogen and organic matter. Data shown in Table 7 represent averages of repeated determinations for each of the replicate tanks. Data on the organic matter of the surface soils (A) were obtained by both the Schollenberger method and the Parr combustion bomb procedure.

The nitrogen content of the soils should be in harmony with the net gains or losses of nitrogen computed from the lysimeter data, assuming no material nitrogen fixation by non-symbiotic organisms

Table 7. Nitrogen and Organic Matter Content of Soils in Windsor Lysimeter Series C After 10 Years of Treatment
(In percentages)

Treatment	Nitrogen			Organic matter[1]		
	Surface soil A	Subsoil B	Substratum C	Surface soil A	Subsoil B	Substratum C
No nitrogen—fallow	.0500	.0175	.0072	1.465	.517	.434
No nitrogen—tobacco, no cover crop	.0520	.0175	.0070	1.500	.535	.483
Calurea—fallow	.0495	.0160	.0060	1.448	.535	.347
Calurea—tobacco, no cover crop	.0605	.0185	.0060	1.741	.638	.390
Calurea—tobacco, oats cover crop	.0730	.0160	.0080	2.001	.586	.453
N-1—tobacco, no cover crop	.0675	.0155	.0070	1.914	.535	.399
N-1—tobacco, oats cover crop	.0866	.0180	.0045	2.201	.569	.420
N-1—tobacco, rye cover crop	.0898	.0185	.0075	2.334	.621	.237
N-1—tobacco, timothy cover crop	.0830	.0150	.0055	2.172	.569	.438
Spl. fract. N—no cover crop	.0560	.0130	.0050	1.758	.569	.243
No nitrogen—grass sod	.0560	.0185	.0060	1.827	.586	.419
Calurea—grass sod	.0761	.0175	.0065	2.052	.535	.446
Original soil, 1931	.0681	.0188	.0085	1.810	.596	.455

[1]Organic matter computed from organic carbon—factor 1.724.

or nitrogen losses to the atmosphere. The amounts entering the soil in the treatments and as atmospheric precipitation are indicated in Table 2. The total amounts in the crops, harvested for nine years of the experiment and leached during the 10 years, are summarized in the first column of Table 8.

Table 8. Nitrogen Changes in Soils Under Various Treatments, Windsor Lysimeter Series C
(In pounds per acre)

Treatment	Sum of leaching[1] and crop removal in 10 years	Computed net gain (G) or loss (L)	Total nitrogen content of three horizons	Net gain or loss based on soil analysis
No nitrogen—fallow	516	476 L	2,250	552 L
No nitrogen—tobacco, no cv. cp.	472	432 L	2,294	508 L
Calurea—fallow	2,246	204 L	2,134	668 L
Calurea—tobacco, no cover crop	1,870	170 G	2,519	283 L
Calurea—tobacco, oats cover crop	1,420	620 G	2,721	81 L
N-1—tobacco, no cover crop	1,606	434 G	2,594	208 L
N-1—tobacco, oats cover crop	1,112	908 G	3,101	299 G
N-1—tobacco, rye cover crop	1,075	965 G	3,299	497 G
N-1—tobacco, timothy cover crop	1,353	687 G	2,911	109 G
Spl. fract. nitrogen, no cover crop	1,652	59 G	2,132	670 L
No nitrogen—grass sod	218	178 L	2,406	396 L
Calurea—grass sod	1,044	796 G	2,881	79 G
Original soil, 1931	——	——	2,802	——

[1]Including NO_3, NO_2 and NH_3 nitrogen.

Computed net gains or losses are compared in Table 8 with the results of the soil measurements. The latter represent the total nitrogen found in the soil in the entire profile. Figures were calculated from the data in Table 7 and from the acre-equivalent weight of "2 mm." soil, for each layer.

The soils receiving no nitrogen treatments showed losses corresponding to the net losses from the lysimeter data. On the other hand, under nitrogen treatment, gains were of less magnitude, losses being considerably in excess of those computed from the lysimeter and crop data.

Without crop, the nitrogen treatment as urea showed a net loss from both standpoints. Applied to tobacco without cover crop, the nitrogen was not fully accounted for, but failed to produce a net gain, even with the N-1 formula, supplying 80 percent of its nitrogen in organic materials. With cover crops, nitrogen gains in the soil of significant magnitude were obtained under this treatment. As would be expected, rye was the most effective of the three materials. The soil under grass sod, top-dressed with nitrogen, failed to gain as much nitrogen as would be expected from the lysimeter "balance sheet."

The organic matter data, computed on the basis of pounds per acre, are shown in Table 9. The results are compared both with respect to the surface soil 8 inches deep and to the entire soil profile.

TABLE 9. EFFECTS OF VARIOUS TREATMENTS ON SOIL ORGANIC MATTER, AFTER 10 YEARS IN LYSIMETERS
(In pounds per acre)

Treatment	Total organic matter		Net gain (G) or loss (L)	
	Surface soil to 8-inch depth	All three horizons	Surface soil to 8-inch depth	All three horizons
No nitrogen—fallow	36,625	73,261	8,625 L	12,773 L
No nitrogen—tobacco, no cv. cp.	37,500	76,496	7,750 L	9,538 L
Calurea—fallow	36,200	70,844	9,050 L	15,190 L
Calurea—tobacco, no cover crop	43,525	84,077	1,725 L	1,957 L
Calurea—tobacco, oats cover crop	50,025	89,729	4,775 G	3,695 G
N-1—tobacco, no cover crop	47,850	84,158	2,600 G	1,876 L
N-1—tobacco, oats cover crop	55,025	93,501	9,775 G	7,467 G
N-1—tobacco, rye cover crop	58,350	93,258	13,100 G	7,224 G
N-1—tobacco, timothy cover crop	54,300	93,442	9,050 G	7,408 G
Spl. fract. N—tobacco, no cv. cp.	43,950	76,762	1,300 L	9,272 L
No nitrogen—grass sod	45,676	84,867	426 G	1,167 L
Calurea—grass sod	51,300	89,112	6,050 G	3,078 G
Original soil, 1931	45,250	86,034	——	——

Data for the surface soils are considered more reliable and more fully representative of the practical values of the treatments. The subsoil and subsurface samples contained a much lower percentage of organic matter (Table 7). However, since these layers represented large acre-weights of soil, small errors in measurement are greatly expanded when calculated on this basis. The data for the surface soils were confirmed by two different analytical methods.

In general, nitrogen and organic matter changes followed the same trends. It is apparent that a soil of this type receiving complete fertilization for the tobacco crop, suffers little change over a 10-year period, in contrast to a fallow soil or one in which the crop is starved for nitrogen. The organic nitrogen in the N-1 formula produced a gain in organic matter in the surface soil, even without cover crop. Under cover cropping, organic matter was definitely on the increase. Rye produced a relatively greater organic matter residue in the surface soil in relation to the effected gain in nitrogen. Although oats winter-kills in the Connecticut Valley climate, it proved an effective cover crop from the standpoint of organic matter maintenance. Timothy produced a greater effect than would be anticipated from the amount of top growth produced. Some effect of the deep root system of this species may explain this.

The permanent grass sod produced on this sandy soil was not as dense or vigorous as might be obtained on a more favorable soil type. However, even when starved for nitrogen, it maintained soil organic matter. When fully fertilized there was a gain of considerable magnitude.

CROP PRODUCTION AND CHEMICAL COMPOSITION

The crops harvested from tanks under various treatments during nine seasons of the experiment were separately measured and analyzed each year. The yearly results were generally similar, except for the 1938 season. In that instance, all tobacco crops gave poor yields of exceptionally low nitrogen content, even when fertilized with the N-1 formula, as discussed in a previous publication (4). This was associated with the extreme soil leaching during the growing period.

Average yields and chemical composition data for the nine harvested crops are shown in Table 10. The leaves and stalks were

TABLE 10. CROP PRODUCTION AND CHEMICAL COMPOSITION, WINDSOR LYSIMETER SERIES C, AVERAGE DATA NINE SEASONS

Crop	Treatment	Dry weight pounds per acre	Percentage of dry weight								
			N	P	K	Mg	Ca	Na	S	Mn	Cl
Tobacco	No nitrogen, no cover crop	16,100	1.16	.24	2.11	.33	.86	.06	.27	.005	.28
	Calurea										
Tobacco	No cover crop	40,909	2.19	.18	2.29	.39	1.43	.05	.17	.022	.16
Tobacco	Oats cover crop	42,390	2.23	.20	2.23	.42	1.54	.05	.18	.022	.14
	N-1 formula										
Tobacco	No cover crop	37,607	1.93	.17	2.23	.43	.99	.12	.20	.011	.19
Tobacco	Oats cover crop	37,775	2.04	.17	2.42	.47	1.04	.12	.20	.010	.18
Tobacco	Rye cover crop	39,172	2.00	.18	2.34	.46	1.05	.12	.20	.010	.18
Tobacco	Timothy cover crop	38,566	1.85	.16	2.19	.43	1.01	.12	.19	.010	.19
	Special fractional nitrogen										
Tobacco	No cover crop	37,656	2.25	.18	2.32	.44	1.30	.06	.20	.018	.18
Grass[1]	No nitrogen	10,014	1.63	.39	1.69	.30	.49	.10	.19	.010	.28
Grass[1]	Calurea	35,417	2.16	.34	2.61	.27	.45	.08	.18	.010	.13

[1]Timothy, fescue, bluegrass, etc.

not separately analyzed, since in this experiment the chief concern is one of total crop intake.

The "no nitrogen" treatments gave very low production as compared with those including adequate nitrogen. The crops were also much lower in nitrogen content. The tobacco yields from the calurea (4/5 urea, 1/5 nitrate of lime) were definitely greater and contained higher percentages of nitrogen, as compared with the results from the N-1 formula. A greater availability of nitrogen from this treatment is indicated. Successive applications (special fractional nitrogen) of 167 pounds of nitrogen from inorganic materials gave as large yields as with the N-1 formula which has higher nitrogen content. The cover crops slightly increased both yields and nitrogen contents.

The chemical composition from the standpoint of other elements reflected certain differences in the treatments. The N-1 formula contained some nitrate of soda, giving a slight increase in the crop. The calurea treatment furnished more calcium. The net soil effect of the calurea was slightly more acid, producing more manganese in the crop.

Differences in composition of mixed grasses and tobacco were apparent under corresponding treatments. With total yields of similar magnitude, the grasses were much richer in phosphorus and poorer in calcium. Nitrogen effected a marked increase in the potassium content of the grasses, at the expense of other bases. This reciprocal relationship was less apparent in the tobacco crop.

DRAINAGE WATER LOSSES AND CROP REMOVALS OF SEVERAL CONSTITUENTS UNDER VARIOUS TREATMENTS

The nine years in which crops were harvested afforded a comparison of various basic constituents liberated by the crop, with the total amounts liberated by both crop removal and leaching. These data are shown in Table 11.

Without fertilizer nitrogen to produce a considerable concentration of nitrates, leaching, or combined crop removal and leaching, of potassium was considerably less than the amounts added to the soil. Under the complete fertilizer treatments, however, most of this element was accounted for. Cover crops or grass sod tended to conserve potash. The oats cover crop was particularly effective in this respect. When the crop production was normal, leaching was much less of a factor in potassium losses than was crop intake.

The additional sodium in the N-1 formula was chiefly reflected in the leaching. The amounts added were almost completely lost from the soil.

The removal of calcium from the soil was generally greater than amounts added to the soil. Leaching accounted for the greater proportion of this loss, even when cover crops were grown.

Magnesium was taken up by the crop to a greater relative degree. Leaching and crop removal were of similar magnitude, except when crop production was depressed by the omission of nitrogen from the treatment.

TABLE 11. AVERAGE YEARLY DRAINAGE WATER LOSSES (L) AND CROP REMOVALS (C) of VARIOUS CONSTITUENTS FOR NINE YEARS, WINDSOR LYSIMETER SERIES C (In pounds per acre)

Treatment		Basic constituents					Acidic constituents			
		Potassium	Sodium	Calcium	Magnesium	Manganese	Phosphorus	Sulfur	Chlorine	Bicarbonate
No nitrogen—fallow	L	95.4	7.7	83.3	18.3	....	....	65.0	20.5	95.3
No nitrogen—tobacco	L	75.0	7.5	57.6	15.1	....	....	57.8	15.3	96.6
no cover crop	C	37.8	1.0	15.3	5.9	.09	4.3	4.8	5.0	....
	T	112.8	8.5	72.9	21.0	.09	4.3	62.6	20.3	96.6
Calurea—fallow	L	164.9	9.4	216.9	39.9	....	....	53.8	21.7	73.3
Calurea—tobacco, no cover crop	L	70.0	7.0	111.3	24.1	....	....	54.1	14.6	90.9
	C	104.0	2.4	65.2	17.7	1.01	8.3	7.7	7.1	....
	T	174.0	9.4	176.5	41.8	1.01	8.3	61.8	21.7	90.9
oats cover crop	L	59.2	8.1	94.3	21.5	....	....	52.9	14.2	132.5
	C	105.2	2.6	72.6	19.8	1.03	9.2	8.6	6.4	....
	T	164.4	10.7	166.9	41.3	1.03	9.2	61.5	20.6	132.5
N-1—tobacco no cover crop	L	70.0	62.5	55.4	17.7	....	....	53.0	17.3	114.3
	C	93.0	4.9	41.3	17.9	.47	7.2	8.2	7.8	....
	T	163.0	67.4	96.7	35.6	.47	7.2	61.2	25.1	114.3
oats cover crop	L	47.3	53.7	51.6	11.7	....	....	52.4	13.4	142.3
	C	101.6	5.2	43.8	19.6	.46	7.2	8.3	7.7	....
	T	148.9	58.9	95.4	31.3	.46	7.2	60.7	21.1	142.3
rye cover crop	L	51.3	59.3	48.3	13.0	....	....	52.4	12.8	202.1
	C	101.8	5.1	45.9	20.0	.46	7.7	8.9	7.8	....
	T	153.1	64.4	94.2	33.0	.46	7.7	61.3	20.6	202.1
timothy cover crop	L	62.7	63.4	60.2	17.3	....	....	52.2	15.1	178.9
	C	93.8	5.0	43.3	18.6	.44	7.0	8.1	8.0	....
	T	156.5	68.4	103.5	35.9	.44	7.0	60.3	23.1	178.9
Spl. fract. nitrogen no cover crop	L	67.3	10.1	98.6	25.9	....	....	55.4	15.6	94.9
	C	97.1	2.7	54.4	18.3	.73	7.7	8.2	7.6	....
	T	164.4	12.8	153.0	44.2	.73	7.7	63.6	23.2	94.9
Grass sod no nitrogen	L	63.5	7.9	47.7	12.8	....	....	57.4	15.8	158.4
	C	18.8	1.1	5.4	3.3	.11	4.3	2.1	3.1	....
	T	82.3	9.0	53.1	16.1	.11	4.3	59.5	18.9	158.4
Calurea	L	39.3	7.0	59.9	14.2	....	....	50.1	10.6	124.2
	C	102.6	3.2	17.8	10.4	.40	13.3	7.2	5.1	....
	T	141.9	10.2	77.7	24.6	.40	13.3	57.3	15.7	124.2

The calurea treatment, in comparison with the N-1 formula, caused increased manganese intake by the crop. However, the liberation of manganese was not sufficient to cause measurable leaching in any case.

As in previous lysimeter results, phosphorus did not leach. The crop utilization of this element was generally in proportion to the yield, except for the greater use of phosphorus by the grass sod.

Sulfur and chlorine were removed from the soil approximately as supplied. The crop used very small proportions of the total sulfur supply. Chlorine was more readily absorbed by the crop.

The bicarbonate data showed much higher leachings when the soil was supplied with decomposing organic matter contributed by residues, organic nitrogenous fertilizer and cover crops. The increased soil acidity from the calurea treatment caused lower bicarbonate concentrations in the drainage water. When green cover crops (rye and timothy) were turned under, the bicarbonate leachings were particularly high.

NET SOIL GAINS OR LOSSES OF VARIOUS CONSTITUENTS

The elements added to the soil by treatments and by atmospheric precipitation (see Table 2) were compared with the total quantities removed by crop and drainage water during the 10 years of the experiment. The latter are summarized in Table 12. The computed net gains or losses, obtained by comparing the data in Table 12 with that of Table 2, are shown in Table 13.

The general trends for the 10-year period were similar to those for the nine years during which crops were harvested. They will be considered further in connection with the data obtained in soil studies.

CHANGES IN EXCHANGEABLE SOIL BASES

The most active portion of a soil's supply of the various bases (potassium, calcium, magnesium, sodium, etc.) is measurable by extraction with ammonium acetate. Quantities of bases thus determined are considered as "exchangeable". The amounts of exchangeable bases are conventionally expressed in terms of milligram equivalents per 100 grams of soil.

Data for the separate horizons of the soil removed from the various tanks are shown in later tables (see 16, 17, 18), in connection with discussions of soil changes from the standpoint of soil acidity. However, in order to make direct comparisons with the net changes shown in Table 13, it was necessary to compute the base exchange data to pounds per acre, considering the totals for the three horizons. This was the basis upon which Table 14 was prepared. Net changes, in comparison with the original soils, and the combined net changes in the four bases, in terms of calcium carbonate equivalent, are also included. The latter indicates the amount of limestone that would be

TABLE 12. TOTAL REMOVALS OF VARIOUS CONSTITUENTS BY BOTH LEACHING AND CROP DURING THE 10-YEAR PERIOD, 1931-41, WINDSOR LYSIMETER SERIES C
(In pounds per acre)

Treatment	Potassium	Sodium	Calcium	Magnesium	Manganese	Phosphorus	Sulfur	Chlorine
No nitrogen—fallow	939	76	795	177	—	—	618	205
No nitrogen—tobacco, no cover crop	1,090	81	704	199	0.8	37	593	204
Calurea—fallow	1,601	92	2,107	387	3.3	—	500	217
Calurea—tobacco, no cover crop	1,630	93	1,831	407	8.9	75	556	217
Calurea—tobacco, oats cover crop	1,499	98	1,545	376	8.3	83	563	194
N-1—tobacco, no cover crop	1,553	696	1,083	356	4.2	65	584	238
N-1—tobacco, oats cover crop	1,370	565	834	287	4.1	65	547	202
N-1—tobacco, rye cover crop	1,408	572	897	320	4.1	69	567	203
N-1—tobacco, timothy cover crop	1,440	633	1,041	350	4.0	63	577	232
Spl. fract. N—tobacco, no cover crop	1,543	112	1,548	443	6.6	69	595	229
No nitrogen—grass sod	858	95	553	165	1.0	40	610	180
Calurea—grass sod	1,375	101	820	242	3.6	50	585	152

TABLE 13. NET GAINS (G) OR LOSSES (L) OF VARIOUS CONSTITUENTS THROUGH CROP REMOVAL AND LEACHING, WINDSOR LYSIMETER SERIES C, 1931-41
(In pounds per acre)

Treatment	Potassium	Sodium	Calcium	Magnesium	Phosphorus	Sulfur	Chlorine
No nitrogen—fallow	823 G	31 G	39 G	185 G	437 G	34 L	41 G
No nitrogen—tobacco, no cover crop	672 G	26 G	130 G	163 G	400 G	9 L	42 G
Calurea—fallow	161 G	36 G	702 L	25 L	437 G	84 G	61 G
Calurea—tobacco, no cover crop	132 G	35 G	426 L	45 L	362 G	28 G	61 G
Calurea—tobacco, oats cover crop	263 G	30 G	140 L	14 L	354 G	21 G	84 G
N-1—tobacco, no cover crop	209 G	67 G	802 L	6 G	246 G	31 G	46 G
N-1—tobacco, oats cover crop	392 G	198 G	553 L	75 G	246 G	68 G	82 G
N-1—tobacco, rye cover crop	354 G	191 G	616 L	42 G	242 G	48 G	81 G
N-1—tobacco, timothy cover crop	322 G	130 G	760 L	12 G	248 G	38 G	52 G
Spl. fract. N—tobacco, no cover crop	219 G	11 G	840 L	111 L	368 G	59 G	51 G
No nitrogen—grass sod	904 G	12 G	281 G	197 G	397 G	26 L	66 G
Calurea—grass sod	387 G	24 G	528 G	120 G	387 G	1 L	123 G

Table 14. Basic Soil Constituents Extracted With Ammonium Acetate, Windsor Lysimeter Series C, After 10 Years of Treatment in Comparison With the Original Soil
(In pounds per acre for the entire soil profiles)

Treatments	Calcium		Magnesium		Potassium		Sodium		Calcium Carbonate Equivalent of Total Changes
	Final	Change	Final	Change	Final	Change	Final	Change	
No nitrogen—fallow	1142	325—	652	58+	1502	500+	122	49—	39—
No nitrogen—tobacco, no cover crop	1282	185—	666	72+	1227	225+	104	67—	24—
Calurea—fallow	545	922—	259	335—	876	126—	119	52—	3952—
Calurea—tobacco, no cover crop	765	702—	328	266—	988	14—	129	42—	2955—
Calurea—tobacco, oats cover crop	967	500—	308	286—	1005	3+	115	56—	2542—
N-1—tobacco, no cover crop	522	945—	250	344—	951	51—	122	49—	3944—
N-1—tobacco, oats cover crop	740	727—	393	201—	1009	7+	226	55+	2516—
N-1—tobacco, rye cover crop	743	724—	360	234—	1061	59+	173	2+	2689—
N-1—tobacco, timothy cover crop	616	851—	330	264—	931	71—	201	30+	3244—
Spl. fract. N—tobacco, no cover crop	515	952—	178	416—	801	201—	124	47—	4445—
No nitrogen—grass sod	1351	116—	495	99—	1350	348+	136	35—	328—
Calurea—grass sod	1620	153+	339	255—	854	148—	141	30—	921—
Original soil, 1931	1467	——	594	——	1002	——	171	——	——

required to compensate with the net loss, or that is replaced in overcoming soil acidity by the net gain, from a base equivalent standpoint.

The net changes indicated in Table 14 show that the exchangeable bases were more depleted or less increased than would be expected on the basis of measurements from the drainage losses and crop removals (see Table 13). This trend was consistent in all cases. The average discrepancies, in terms of pounds per acre, for the four bases under consideration were as follows: calcium — 245, magnesium — 265, potassium — 359 and sodium — 103.

These results might be considered as due to errors in the chemical analyses of the drainage water or the crop, or in the base exchange measurements of the soils. In the former case, however, it appears unlikely that all errors would be cumulative in the same direction. From the latter standpoint, since all base exchange data are referred to those for the original soil, it might be assumed that this was in error. If the original soil contained less of each of the bases than were thus measured, then the soil changes would be in closer agreement with the lysimeter balance sheet.

In previous studies, bases applied in the treatments and not leached or removed by the crop, have been similarly unaccounted for in base exchange measurements. This has been most consistently true with respect to potassium. Potash fixation in the soil in non-exchangeable forms is considered the chief explanation. Calcium residues in the soil have also failed to contribute their full effects on exchangeable calcium. Previous data with respect to the other bases have been less consistent in one direction than in the present experiment.

When the mean differences cited are taken into consideration, the changes under the various treatments are in agreement. They indicate clearly that the amounts of exchangeable bases in the soil

Table 15. Average Net Changes in the Base Status of Soils From Both Lysimeter and Soil Measurements
(In pounds per acre)

Treatment	Calcium	Magnesium	Potassium	Sodium	Calcium Carbonate Equivalent of Total Changes
No nitrogen—fallow	143—	122+	662+	9—	971+
No nitrogen—tobacco, no cover crop	23—	118+	448+	21—	955+
Calurea—fallow	812—	180—	18+	8+	2,726—
Calurea—tobacco, no cover crop	564—	156—	59+	4—	1,982—
Calurea—tobacco, oats cover crop	320—	150—	133+	13—	1,274—
N-1—tobacco, no cover crop	874—	169—	79+	9+	2,755—
N-1—tobacco, oats cover crop	640—	63—	200+	126+	1,327—
N-1—tobacco, rye cover crop	670—	96—	207+	97+	1,591—
N-1—tobacco, timothy cover crop	806—	126—	126+	80+	2,194—
Spl. fract. N—tobacco, no cover crop	896—	264—	9+	18—	3,271—
No nitrogen—grass sod	83+	49+	626+	12—	1,183+
Calurea—grass sod	341+	68—	120+	3—	718+

are directly influenced by the relationships between leaching and crop removal losses and the quantities added to the soil. It seems reasonable that a closer approach to the true picture of the effects of the various treatments upon the soil bases can be obtained from the average net changes from both the lysimeter and the soil data, as shown in Table 15.

The base status of the soil under tobacco cropping was best maintained when cover crops were grown. Oats appeared to be most effective. Both calurea and the N-1 formula were base-depleting. Under grass sod conditions the treatment including calurea was basic, but to a less degree than when no nitrogen was used.

EFFECTS OF VARIOUS TREATMENTS IN RELATION TO SOIL ACIDITY

Various soil measurements in relation to soil acidity are presented in Tables 16, 17 and 18. These are given for the three horizons of the soil profiles under the various treatments.

As would be expected, the effects of treatment were most fully expressed in the surface soils. Calurea was most acid under fallow conditions, depleting to a marked degree all exchangeable bases except sodium. Compared with the "no nitrogen" treatment, cropped to tobacco, calurea gave a less acid effect especially when the cover crop was grown. Applied to grass sod, calurea caused the least effect. However, the residual exchangeable calcium was more than counterbalanced by the depletion of exchangeable magnesium.

The N-1 formula, supplying little calcium, was quite depleting of this element, especially when no cover crop was grown. Exchangeable potassium was less maintained than under the calurea treatment. The reverse was indicated for magnesium. Oats was somewhat more effective than rye or timothy in repressing the acid effect of the treatment.

The special fractional nitrogen treatment, supplying only 167 pounds of nitrogen per year in successive applications, was more acid in its effect than any other. This was more pronounced than would be expected from the materials applied. They furnished 91.7 pounds of nitrogen as nitrates, 40 pounds as urea and 35.3 pounds as ammophos. It was apparent that under these conditions the nitrate materials had exerted no significant basic effects to counteract the strongly acid ammophos and moderately acid urea materials.

The differences in base exchange capacity are small and of no apparent significance, in relation to treatment. It is to be noted that the base exchange capacity values given in Tables 16, 17 and 18 represent the means of summation and separately determined measurements, and that exchangeable hydrogen data represent differences between the base exchange capacities thus determined, and the totals of the exchangeable bases.

TABLE 16. BASE EXCHANGE DATA, SURFACE SOILS (A) FROM LYSIMETER SERIES C, AFTER 10 YEARS IN THE TANKS

(In milligram equivalents per 100 grams of soil, except as indicated)

Treatment	Exchangeable bases					Exchange H	Base exchange capacity	Relative base saturation	Final pH
	Ca	Mg	K	Na	Total				
No nitrogen—fallow	1.53	.66	.66	.07	2.92	2.71	5.63	51.9	6.31
No nitrogen—tobacco, no cover crop	1.60	.75	.64	.06	3.05	2.68	5.73	53.2	6.22
Calurea—fallow	.54	.12	.29	.07	1.02	4.53	5.55	18.4	5.00
Calurea—tobacco, no cover crop	.81	.14	.40	.08	1.43	4.30	5.73	25.0	5.03
Calurea—tobacco, oats cover crop	.81	.25	.46	.07	1.59	3.95	5.54	28.7	5.37
N-1—tobacco, no cover crop	.35	.18	.25	.06	0.84	4.38	5.22	16.1	4.76
N-1—tobacco, oats cover crop	.49	.35	.47	.07	1.38	4.02	5.40	25.6	5.23
N-1—tobacco, rye cover crop	.46	.31	.53	.08	1.38	3.91	5.29	26.1	5.15
Spl. fract. N—tobacco, no cover crop	.45	.32	.26	.07	1.10	4.18	5.28	20.8	5.06
N-1—tobacco, timothy cover crop	.33	.09	.26	.03	0.71	4.36	5.07	14.0	4.83
No nitrogen—grass sod	1.78	.71	.62	.03	3.14	2.32	5.46	57.5	6.05
Calurea—grass sod	1.81	.39	.46	.04	2.70	2.95	5.65	47.8	5.32
Original soil	1.41	.57	.35	.07	2.40	2.68	5.08	47.2	5.87

TABLE 17. BASE EXCHANGE DATA, SUBSOILS (B) FROM LYSIMETER SERIES C, AFTER 10 YEARS IN THE TANKS
(In milligram equivalents per 100 grams of soil, except as indicated)

Treatment	Exchangeable bases					Exchange H	Base exchange capactiy	Relative base saturation	Final pH
	Ca	Mg	K	Na	Total				
No nitrogen—fallow	.32	.66	.41	.03	1.42	.75	2.17	65.4	5.80
No nitrogen—tobacco, no cover crop	.35	.67	.29	.02	1.33	.88	2.21	60.2	5.80
Calurea—fallow	.21	.29	.29	.02	0.81	1.15	1.96	41.3	4.91
Calurea—tobacco, no cover crop	.31	.33	.29	.02	0.95	1.13	2.08	45.7	5.38
Calurea—tobacco, oats cover crop	.51	.32	.27	.02	1.12	.92	2.04	54.9	5.76
N-1—tobacco, no cover crop	.30	.21	.34	.04	0.89	1.03	1.92	46.4	5.82
N-1—tobacco, oats cover crop	.48	.32	.25	.12	1.17	.72	1.89	61.9	6.34
N-1—tobacco, rye cover crop	.46	.33	.26	.07	1.12	.77	1.89	59.3	6.07
N-1—tobacco, timothy cover crop	.35	.35	.33	.11	1.14	.91	2.05	55.6	6.09
Spl. fract. N—tobacco, no cover crop	.32	.18	.25	.06	0.81	1.02	1.83	44.3	5.79
No nitrogen—grass sod	.44	.33	.34	.07	1.18	.73	1.91	61.8	6.15
Calurea—grass sod	.70	.25	.18	.07	1.20	.61	1.81	66.3	6.15
Original soil	.65	.52	.31	.08	1.56	.49	2.05	76.1	5.98

Table 18. Base Exchange Data, Substrata (C) From Lysimeter Series C. After 10 Years in the Tanks
(In milligram equivalents per 100 grams of soil, except as indicated)

Treatment	Exchangeable bases					Exchange H	Base exchange capactiy	Relative base saturation	Final pH
	Ca	Mg	K	Na	Total				
No nitrogen—fallow	.14	.24	.12	.06	.56	.67	1.23	45.5	6.10
No nitrogen—tobacco, no cover crop	.27	.21	.08	.06	.62	.69	1.31	47.3	6.32
Calurea—fallow	.14	.18	.07	.09	.48	.76	1.24	38.7	6.05
Calurea—tobacco, no cover crop	.13	.27	.08	.08	.56	.80	1.36	41.2	6.04
Calurea—tobacco, oats cover crop	.17	.16	.08	.08	.49	.88	1.37	35.8	6.38
N-1—tobacco, no cover crop	.13	.21	.10	.07	.51	.87	1.38	37.0	6.32
N-1—tobacco, oats cover crop	.11	.30	.10	.09	.60	.63	1.23	48.7	6.07
N-1—tobacco, rye cover crop	.16	.23	.07	.08	.54	.63	1.17	46.2	6.72
N-1—tobacco, timothy cover crop	.13	.12	.09	.07	.40	.68	1.08	37.0	6.49
Spl. fract. N—tobacco, no cover crop	.10	.13	.09	.06	.38	.67	1.05	36.2	6.23
No nitrogen—grass sod	.12	.26	.12	.06	.56	.43	.99	56.6	6.48
Calurea—grass sod	.15	.23	.07	.07	.52	.42	.94	55.3	6.24
Original soil	.28	.37	.10	.07	.82	.30	1.12	73.2	5.93

The relative base saturation and pH results are in reasonably close relation to the net effects of the treatment from the standpoint of soil bases. The surface soils were considerably affected by the treatments. In general, the subsoil showed similar trends. The cover crops and grass sod were especially effective in maintaining exchangeable calcium. On the other hand, exchangeable potassium was not as well maintained for corresponding treatments.

The substratum soils, of very low base exchange capacity, showed less consistent relationships to treatment. The relative base saturation was lower for corresponding pH values than that of the subsoil or surface soil. Exchangeable bases more definitely reflected the effects of treatment than other standards of measurement.

SUMMARY

Windsor lysimeter series C involved a study of the effects of cropping, cover crops and nitrogenous fertilization with reference to drainage water losses and the removal of various constituents by crops and soil changes. The following comparisons were included:

- Without nitrogen
  - No crop
  - Cropped to tobacco, without cover crop
  - Cropped to tobacco, with oats cover crop
  - Permanent grass sod
- With nitrogen, supplied as calurea (4/5 urea nitrogen, 1/5 nitrate nitrogen)
  - No crop
  - Cropped to tobacco, without cover crop
  - Cropped to tobacco, with oats cover crop
  - Cropped to tobacco, with rye cover crop
  - Cropped to tobacco, with timothy cover crop
  - Permanent grass sod
- With nitrogen, in a special program of successive fertilizer application
  - Cropped to tobacco, without cover crop

The treatments were applied to sandy soil of a type commonly used for tobacco culture in Connecticut. Lysimeter tanks of 30-inch depth were used during a period of 10 years, from 1931 to 1941. Nine crops were harvested and analyzed. Drainage waters were collected and analyzed during the entire period. The soils were sampled at the conclusion of the experiment and compared with samples collected when the tanks were filled.

The greatest quantities of drainage water were collected from the fallow soils. Cropping caused diminished amounts of leaching, especially when nitrogen fertilization supported normal crop growth. The percolation of water through the soil under grass sod was similar to that under tobacco cropping, followed by oats as a cover crop. Oats was somewhat more effective than rye or timothy in reducing the amount of leaching. The effects of cropping were greatest during the late summer and early fall and winter. In late spring and early summer, leaching was somewhat greater from the cover-cropped soils.

Nitrogen leachings at various seasons of the year depended upon the amounts and distribution of precipitation during the first few months after fertilizer treatments. When no crop was grown, most of the nitrogen, applied as calurea, was leached from the soil. The tobacco crop caused smaller drainage-water losses due to the crop intake of nitrogen. Under cover cropping, relatively small losses of nitrogen by leaching occurred. Rye was the cover crop most effective in conserving nitrogen against removal in the drainage water. The following yearly treatments were found to prevent nitrogen leaching: for oats under calurea fertilization — 27 pounds; for oats under mixed nitrogen tobacco fertilizer formula — 37 pounds; for rye — 43 pounds; and for timothy — 25 pounds.

Nitrogen losses from the soil were greatest under uncropped conditions. Cover cropping with nitrogen treatment was especially effective in maintaining soil nitrogen. Rye was the most effective of the three cover crops. Under grass sod, very little nitrogen was carried from the soil by leaching, even when liberally fertilized. Soil under permanent grass without nitrogen became depleted. With calurea treatment, there was a net gain.

Organic matter losses during the 10-year period were considerable from the fallow soils, representing a depletion of from 15 to 18 percent of the initial amount. Cropping retarded organic matter losses, even without organic fertilizer or cover crop. Cover cropping produced net gains in soil organic matter. Under the three cover crops with identical fertilization, there were no significant differences in soil organic matter maintenance for the soil profile as a whole. Rye contributed the greatest gains in organic matter to the surface soil. Grass sod without nitrogen caused soil depletion; when fully fertilized an organic gain was obtained.

Crop yields were materially diminished when nitrogen was omitted from the treatment. Calurea supported somewhat larger crops of greater nitrogen content, than when 80 percent of the nitrogen was supplied as vegetable organics. Cover crops caused insignificant increases in tobacco yields, and slightly favored total nitrogen utilization by the crop. The assimilation by the crops of constituents other than nitrogen was not materially affected by the treatments. However, under the same fertilization, mixed grass hay was much richer in phosphorus and poorer in calcium than was tobacco. Nitrate of soda, included in the N-1 formula, caused but slight increases in the sodium intake of the crop.

A study of drainage water losses in relation to crop removals indicated that the chief effects of cover crops in conserving various chemical soil constituents are associated with decreased leaching of nitrates.

Comparisons of drainage water losses, crop removals and amounts added to the soil during the 10-year period indicated gains of the various constituents with the exception of nitrogen and calcium. Gains in sodium, sulfur, and chlorine were of small magnitude in relation to the amounts applied. Crop removals accounted for the small proportions of phosphorus in the treatments. This element did not leach.

Base exchange studies for the entire soil profile indicated net depletions of exchangeable calcium in all cases, except under grass sod with calurea. Magnesium was depleted in most cases. Except under fallow conditions without crop, potassium was increased under tobacco without cover crop, under the timothy cover crop and grass sod with nitrogen fertilization. Slight and inconsistent gains or losses in exchangeable sodium were obtained.

The total calcium carbonate equivalents of the net changes in the four bases, for the entire soil profile, indicated greatest over-all depletions under the special fractional nitrogen treatment and the N-1 formula without cover crop. Cover cropping tended to stabilize the soil against base depletion. Oats was slightly better than other cover crops in this respect. The calurea treatment was much more base-depleting to the fallow soil than to the soil cropped to tobacco, and caused a minimum of change in this respect when applied to the soil under grass sod. Without nitrogen, the soil bases were practically maintained under tobacco crop or grass sod, and showed a considerable net gain under fallow conditions.

Taking into consideration both changes in exchangeable bases and net gains or losses indicated by the lysimeter and crop removal data, the results show somewhat less base depletion in general and indicate net gains in the base status of the soil under grass sod and without nitrogen fertilization. These data are in close agreement with the final pH of the surface soils, as measured in April 1941.

Details of the base exchange studies by separate soil horizons indicate that the subsoils must be taken into consideration in order to represent the full picture of base depletion or accumulation as a result of treatment. The substrata samples at a greater depth than 20 inches from the soil surface were but slightly changed by the treatments, and the differences were less consistent with the character of the treatments.

Since the general trends of the data obtained in base exchange studies are in close relationship to leaching and crop removal measurements, it is apparent that the amounts of exchangeable bases in the sandy soils of the Connecticut Valley fairly represent the working balance of calcium, magnesium, potassium and sodium as regulated by amounts added to the soil and removed by crops and drainage water. The organic matter and total nitrogen content of the soil are also greatly modified by soil management.

REFERENCES

1. Morgan, M. F. Soil changes resulting from nitrogenous fertilization: a lysimeter study. Conn. Agr. Expt. Sta. Bul. **384**. 1936.
2. ———— and H. G. M. Jacobson. A lysimeter study of soil and crop inter-relations of various nitrogenous fertilizers. Conn. Agr. Expt. Sta. Bul. **458**. 1942.
3. ———— and O. E. Street. The role of cover crops in the maintenance of the fertility of tobacco soils. Conn. Agr. Expt. Sta. Bul. **410**: 382-392. 1938.
4. ———— and ————. Losses of fertilizer constituents during an abnormally wet season. Conn. Agr. Expt. Sta. Bul. **422**: 6-16. 1939.
5. ———— and ————. Seasonal water and nitrate leachings in relation to soil and source of fertilizer nitrogen. Conn. Agr. Expt. Sta. Bul. **429**. 1939.
6. ————, H. G. M. Jacobson and O. E. Street. The neutralization of acid-forming nitrogenous fertilizers in relation to nitrogen availability and soil bases. Soil Sci. **54**:127-148. 1942.