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Spray-Irrigation of Treated Municipal Sewage Effluent and its Effect on Chemical Properties of Forest Soils

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Abstract

The Waste Water Renovation and Conservation Project at The Pennsylvania State University was begun to determine the feasibility and effectiveness of land irrigation as a method of municipal sewage effluent disposal.

Irrigation was begun in 1963 on an old-field area, a hardwood stand, and a red pine plantation on Hublersburg silt loam soil. In 1965, irrigation was begun in a hardwood stand located on Morrison sandy loam soil on State Game Lands. The old-field area and gameland hardwood area received application at a rate of 2 inches per week, and the hardwood stand and red pine plantation 1 inch per week. The irrigation period for the old-field area, hardwood stand and red pine plantation was April through November, while the game-land hardwood area was irrigated year-round.

Soil samples were collected in the fall of 1963, 1967, and 1971. The samples were taken with a Veihmeyer tube by 1-foot depth increments to 5 feet. The soil samples were analyzed for potassium, calcium, magnesium, sodium, exchangeable hydrogen, manganese, boron, phosphorus, pH, total nitrogen, and organic matter. The differences in the amounts of the various elements were tested for significance, using a factorial analysis of variance.

Of the 11 constituents analyzed, only potassium, sodium, manganese, exchangeable hydrogen, boron, and phosphorus had significant changes in concentration over time. Potassium, manganese, exchangeable hydrogen, and boron decreased significantly over time while sodium and phosphorus increased significantly over time.

After 9 years of spray irrigation with treated municipal wastewater, there were no indications that the treatment had any detrimental effects on the soil.

Spray-Irrigation of Treated Municipal Sewage Effluent and its Effect on Chemical Properties of Forest Soils

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INTRODUCTION

As MAN'S population increases, more communities, towns, and cities are formed, creating a greater demand on the nation's water resources. Along with this increasing water demand comes a problem of increasing volumes of wastes. In the past, the nation's streams, rivers, and lakes have been used to dilute these wastes; but now the steadily increasing volume of wastes is exceeding the dilution ability of these waterways. When the waterways can no longer dilute the wastes satisfactorily, the increased concentration of wastes causes an increase in nutrient levels, which may result in excessive growth of algae and aquatic weeds. This excessive growth can upset the ecology of the ecosystem and reduce the aesthetic and recreational value of the body of water.

An alternative to disposing of wastes directly into waterways was investigated at The Pennsylvania State University. This method involved the use of an irrigation system to spray wastewater over croplands and in forested areas. It was hoped that by spraying the wastewater over the land areas, the soil would renovate and return most of the water to the underground reservoir, thus producing three important benefits: (1) the concentration of nutrients in the wastewater would be reduced by the biological, chemical, and physical processes in the soil; (2) the nutrients removed by the soil could be available to the vegetation growing on the irrigated areas; and (3) the renovated water could percolate down through the soil profile and could be used to recharge the groundwater.

The Waste Water Renovation and Conservation Project at The Pennsylvaia State University was begun in 1962. It was designed to determine whether land irrigation with wastewater is an effective and feasible method of wastewater disposal and if potential benefits such as wastewater renovation, vegetation fertilization, and groundwater recharge could be realized.

The study reported here is a part of the Waste Water Renovation and Conservation Project. It deals with the investigation of changes in the chemical properties of the soils in the forested areas as a result of irrigation with wastewater over a 9-year period.

A preliminary study of the changes in the chemical properties of soils in the forested irrigation areas was conducted on soils collected in 1963, 1964, and 1965. This was reported by Kline *(1967)*.

Since the wastewater, or sewage effluent, contains appreciable concentrations of nutrients, this study was designed to determine whether any significant buildup of nutrients at various depths in the treated forested areas has occurred as compared to the control areas, and to measure the change in element concentrations over time.

The study reported here is based on chemical analysis of the soils collected from the forested wastewater irrigation areas in 1963, 1967, and 1971 for 11 constituents—potassium, calcium, magnesium, sodium, exchangeable hydrogen, manganese, boron, organic matter, pH, total nitrogen, and phosphorus.

DESCRIPTION OF STUDY AREA

Location and Design

The sewage effluent irrigation study areas are located in compartment 19 of the University Farm Woodlands in Patton Township, Centre County, Pennsylvania, and in State Gamelands No. 176 (fig. 1).

The study areas on the University Farms consist of an old field, a natural hardwood stand, and a red pine plantation on a Hublersburg silt loam soil. The fourth area, in State Gamelands, was a natural hardwood stand on a Morrison sandy loam soil. Each cover type and soil site was delineated in treatment and control areas.

Vegetative Cover Types

Old-field area.—The old field was once agricultural land, but was subsequently planted with white spruce. The spruce have since dwindled in numbers as a result of deer damage and theft of Christmas trees, and the area has been invaded by herbaceous vegetation and grasses. In 1963 the white spruce saplings ranged from 3 to 5 feet in height.

Hardwood stand.—The hardwood stand in the Hublersburg soil consists mainly of mixed oak species with dominant and co-dominant trees about 70 years old, 14 inches in diameter (dbh), and 75 feet in height.

Red pine plantation.—The red pine plantation was established in 1939 at a spacing of 8 x 8 feet on abandoned agricultural land. In 1963 the average tree height was 40 feet, and average diameter was 8 inches. The forest floor is completely covered with a 2-inch layer of pine needles, which is part of a mor humus. There is no ground vegetation except in a few isolated openings in the plantation.

New Gameland Hardwood Area. — This

Figure 1.—Map of study area.

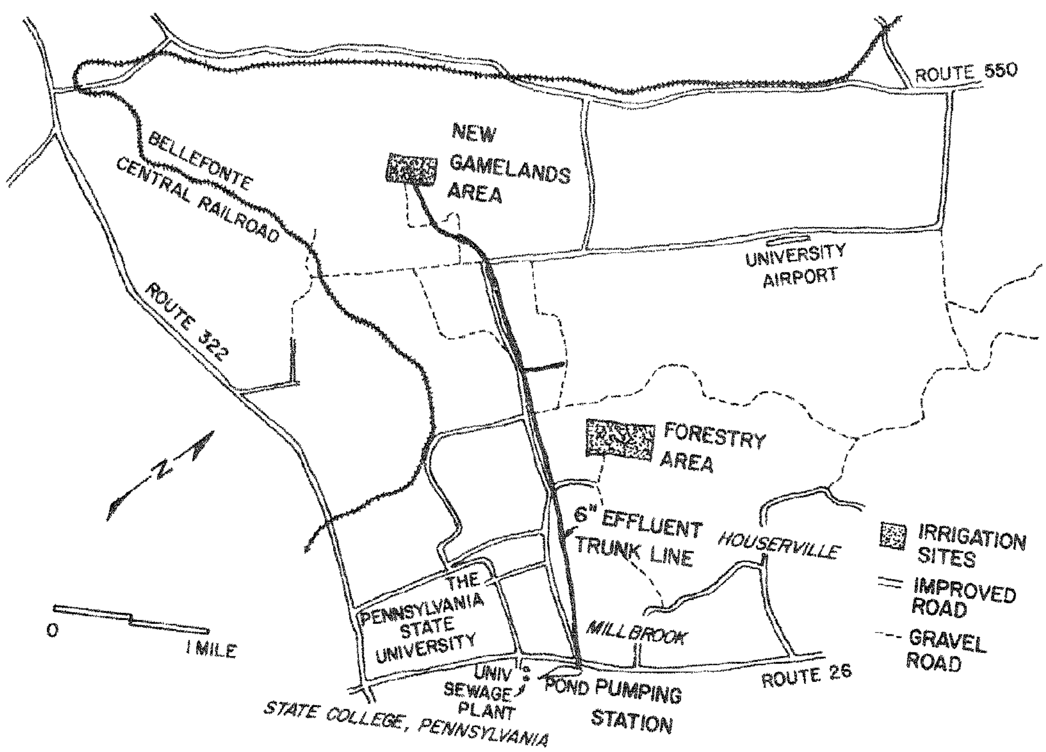


Table 1.—Major vegetation on study plots

Common name	Scientific name
OLD FIELD — HUBLERSBURG SOIL	
Poverty grass	*Danthonia spicata* Beauv.
Goldenrod	*Solidago* spp. Ait.
Dewberry	*Rubus flagellaris* Willd.
White spruce	*Picea glauca* Moench. Voss.
HARDWOOD STAND — HUBLERSBURG SOIL	
Overstory:	
White oak	*Quercus alba* L.
Black oak	*Quercus velutina* L.
Red oak	*Quercus ruba* L.
Scarlet oak	*Quercus ruba* L.
Red maple	*Quercus coccinea* Muench.
Mockernut hickory	*Acer rubrum* L.
Black cherry	*Carya tomentosa* Nutt.
Flowering dogwood	*Cornus florida* L.
Understory:	
Black raspberry	*Rubus occidentalis* L.
Blueberry	*Vaccinium* supp. L.
Poison ivy	*Toxicodendron radicans* L.
Teaberry	*Gaultheria procumbens* L.
Violet	*Viola* spp. L.
Wild sarsaparilla	*Aralia nudicaulis* L.
RED PINE PLANTATION — HUBLERSBURG SOIL	
Red pine	*Pinus resinosa* Ait
NEW GAMELANDS HARDWOOD AREA — MORRISON SOIL	
Overstory:	
White oak	*Quercus alba* L.
Black oak	*Quercus velutina* L.
Red oak	*Quercus ruba* L.
Red maple	*Acer rubrum* L.
Black cherry	*Prunus serotina* Ehrh.
Flowering dogwood	*Cornus florida* L.
Understory:	
Black raspberry	*Rubus occidentalis* L.
Blueberry	*Vaccinium* spp. L.
Teaberry	*Gaultheria procumbens* L.
Violet	*Viola* spp. L.
Wild sarsaparilla	*Aralia nudicaulis* L.

hardwood stand on the Morrison soil consists mainly of mixed oaks and red maple. The stand was about 50 years old in 1963. The height of the dominant and codominant trees averaged about 40 feet, and the diameter averaged about 8 inches.

Table 1 contains a list of all the major species found on the areas.

Soils

The weathered mantle at the University Farm Woodlot is composed of beds of mixed clay, silt, and sand, which have accumulated as relatively insoluble residue from carbonate bedrock. The soil mantle ranges in depth from 17 to 48 feet. The unconfined water table is about 300 feet below the surface.

The soils at the old-field, hardwood, and red pine plots at the University Farm Woodlot are Hublersburg silt loam and silty clay loam derived from the Mines and Ore Hill members of the Gatesburg formation. The soil at the new gameland hardwood plot is Morrison sandy loam derived from the Upper and Lower Sandy members of the Gatesburg formation. The Morrison soil contains smaller amounts of clay, and the cation and anion exchange capacity are less than that of the Hublersburg soil.

A detailed description of the two soil series is included in the appendix.

Climate

The study area is located at the western edge of the Ridge and Valley section of the Folded Appalachian Province. Elevation is approximately 1,100 feet.

The climate is characteristic of central Pennsylvania. It is a composite of the relatively dry midwestern continental climate and the more humid conditions found near the eastern seaboard. Minimum temperatures generally remain below freezing from mid-November through March, but only occasionally do temperatures drop below zero. The average date of the last 32° temperature in spring is 29 April and first in the fall is 12 October. Growing season is 166 days. Mean monthly temperatures range from 28.7°F in January to 72.1°F in July. Precipitation is well distributed throughout the year; average is close to 40 inches (U. S. Weather Bureau).

DESCRIPTION OF SEWAGE EFFLUENT AND IRRIGATION SYSTEM

Sewage Effluent

The sewage effluent used at the study area comes from The Pennsylvania State University sewage-treatment plant. This facility services both the University and the Borough of State College; it is made up of two parallel. two-stage treatment plants, each having a design capacity of 2 million gallons per day. The plant employs both primary and secondary treatments. Secondary treatment consists of standard and high-rate trickling filters and a modified activated sludge process, followed by final settling and chlorination to a residual of 0.5 mg chlorine per liter. The chemical composition of the effluent varies from day to day. The typical chemical composition of the effluent is given in table 2.

The fertilizer value of the effluent is readily evident. The amount of N-P-K applied through spray irrigation of effluent at the rate of 2 inches per week during 1963-71 is given in table 3. The effluent applications annually provided commercial fertilizer constituents equivalent, on the average, to approximately 208 pounds of nitrogen, 200 pounds of phosphorus (P_2O_5), and 227 pounds of potash (K_2O). This would be equal to applying about 2,000 pounds of a 10-10-11 fertilizer annually.

Irrigation System and Effluent Application

The pumping station that supplies effluent to the study area is located on a 24-inch bypass line. The station has two pumps, which are alternated manually, one acting as a standby. Each plant includes a vertical centrifugal pump, designed for an output of 350 gallons per minute at 520 feet total head, and a 60-horsepower three-phase electric motor. An in-line meter that measures the amount of effluent pumped is also located at the pumping station.

A 6-inch supply line carries the effluent a distance of 2 miles, where it divides. One 6-inch line carries effluent to the old field, hardwood, and red pine areas; the other 6-inch line carries effluent to the gamelands hardwod area.

The irrigation system is composed of 4- and 5-inch aluminum main lines and 2- and 3-inch aluminum lateral lines, which distribute the effluent to regularly spaced sprinklers on steel risers. With the use of special sprinkler heads, spacing of sprinklers on lateral lines, spacing of the lateral lines, and adjustment of the pressure at each lateral line, an application rate of ¼ inch per hour can be provided to all plots.

Table 2.—Typical chemical composition of municipal sewage effluent

Constituent	Average concentration	Total amount applied[1]
pH	7.9	—
	mg/l	*lbs/a*
MBAS	0.37	5.4
Nitrate-N	13.3	230.75
Organic-N	2.2	37.26
NH_4-N	6.9	110.30
P	4.90	81.68
Ca	31.3	536.41
K	12.3	201.32
Cl	41.3	711.20
Mg	15.1	257.14
Na	20.6	357.01
Fe	.4	8.44
	µg/l	
B	169	2.89
Mn	61	1.04
Cu	109	1.75
Zn	211	3.72
Cr	23	.38
Pb	104	1.89
Cd	9	.17
Co	62	1.13
Ni	93	1.62

[1] Total amount applied during a 24-week irrigation period on areas that received 2 inches of effluent per week.

Table 3.—Amount of N-P-K applied annually in the old-field Hublersburg site through spray irrigation of effluent

Irrigation period	Effluent applied	N	P	K
	Inches	*lbs/a*	*lbs/a*	*lbs/a*
1963	46	119	54	127
1964	66	256	116	234
1965	60	139	122	199
1966	64	170	129	238
1967	56	157	98	176
1968	62	351	119	261
1969	56	275	66	175
1970	50	217	43	120
1971	55	184	40	174
Mean	57	208	87	189

[1] Applied at the rate of 2 inches per week.

A more detailed description of the irrigation system can be found in Parizek et al. *(1967)*, Pennypacker *(1964)*, and Sagmuller *(1965)*.

The treated plots within each vegetative cover type received a fixed amount of sewage effluent each week. The old field and game-

Table 4.—Irrigation programs for treated plots

Location	Vegetative cover	Soil series[1]	Weekly application (inches)	Seasonal irrigation amounts, in inches									
				1963 Jun-Dec	1964 Mar-Nov	1965 Apr-Nov	1966 Apr-Nov	1967 Apr-Nov	1968 Apr-Nov	1969 Apr-Nov	1970 Apr-Nov	1971 Apr-Nov	Total
Forestry area	Old field	H	2	46	66	60	64	56	62	56	50	55	515
Forestry area	Hardwood	H	1	23	33	30	32	28	31	28	25	28	258
Forestry area	Red pine	H	1	23	33	30	32	28	31	28	25	28	258
						Nov 23 -Dec	Jan-Dec	Jan-Dec	Jan-Dec	Jan-Dec	Jan-Dec	Apr-Dec	
Gamelands area	New gameland hardwood	M	2	—	—	12	104	104	102	104	90	79	595

[1] H = Hublersburg silt loam. M = Morrison sandy loam.

lands hardwood treated plots received 2 inches per week, and the hardwood and red pine plantation treated plots received 1 inch per week. The two weekly application rates were chosen because they are approximately and respectively equal to and double the average weekly precipitation in central Pennsylvania. A detailed description of the irrigation program can be found in table 4.

METHODS AND PROCEDURES

Soil-Sampling Technique

Each treatment and control plot within each vegetative type was divided into six subplots. A sampling point was located randomly within each subplot. Care was taken to avoid placing the sampling point in a natural depression, within 2 feet of a tree, or in an area where vegetation might prevent effluent from reaching the ground.

Soil sampling was performed with a Veihmeyer tube by 1-foot increments. Samples were taken to a depth of 5 feet and identified by the greatest depth sampled. For example, the 3-foot sample would consist of soil collected from 2.0 to 3.0 feet below the soil surface.

Twelve soil samples were taken at each depth from each vegetative type, at six positions in the treated plot and at six positions in the control plot. Soil samples were collected from the old-field 2-inch, hardwood 1-inch, and red pine 1-inch plots in 1963, 1967, and 1971. Soil samples were collected from the gameland hardwood 2-inch plot only in 1967 and 1971. All sampling was performed in the fall of the year after irrigation operations had terminated.

Preparation of Soil Samples for Chemical Analysis

The soil samples were air-dried, crushed with a mortar and pestle, and passed through a 2-mm sieve. Large root fragments and pieces of chert and limestone were removed from the soil before crushing. Soil samples from only three randomly selected positions of the six positions sampled within each treatment and control plot were analyzed.

Chemical Analysis

The exchangeable cations (K, Ca, Mg, Na, and Mn) and boron were extracted from the soil with ammonium acetate *(Jackson 1958)* and analyzed with an arc spectrometer *(Baker et al. 1964)*. Exchangeable hydrogen was determined by using a barium chloride buffering technique *(Jackson 1958)*. Organic matter was determined by using a potassium dichromate-sulfuric acid oxidation method *(Peach et al. 1947)*. Soil pH was measured with a glass electrode, using a 1:1 soil-to-water mixture. Total nitrogen was analyzed by using a modified Kjeldahl method to include nitrates *(Jackson 1958)*. The phosphorus concentration was determined by using the Bray extraction procedure *(Jackson 1958)*.

Statistical Analysis

The differences in the concentrations of the various elements in the soil were tested for significance by using a factorial analysis of variance. The results were statistically analyzed to determine differences between treatments at various depths, between years, and between vegetative types.

The samples taken at various depths in the 1963, 1967, and 1971 control areas were compared to their respective treated areas to determine the effects of treatment. The changes at each depth were evaluated for the treated areas and for the control areas. Samples taken from the hardwood 1-inch treatment plot and red pine 1-inch treatment plot in 1963, 1967, and 1971 were compared to determine the difference in element concentration between vegetation cover types.

RESULTS AND DISCUSSION

The mean concentrations of potassium, calcium, magnesium, sodium, exchangeable hydrogen, manganese, boron, organic matter, pH, total nitrogen, and phosphorus for all the soil samples collected in the old-field 2-inch plot, the hardwood 1-inch plot, and the red pine 1-inch plot in 1963, 1967, and 1971; and the gameland hardwood 2-inch plot in 1967 and 1971 are given in tables 5 through 15.

Text continues on page 10.

Table 5.—Mean constituent concentrations for the old-field 2-inch area in 1963

Area	Depth, feet	ME/100gms					PPM			pH	%N	%OM
		K	Ca	Mg	Na	H	Mn	B	P			
Control	1	0.40	1.43	0.27	0.10	11.84	71.60	0.53	8.70	4.79	0.088	2.147
	2	.47	2.00	.83	.17	8.67	20.46	.60	.76	5.23	.016	.370
	3	.47	1.13	1.27	.20	9.33	23.46	.53	.38	4.91	.012	.167
	4	.43	.93	1.57	.20	—	18.60	.53	.38	—	.010	—
	5	.47	.97	1.53	.13	—	18.13	.53	.38	—	.010	—
Treatment	1	.63	1.73	.50	.23	16.06	44.60	1.00	16.05	4.96	.072	2.407
	2	.60	1.87	.90	.20	18.74	20.80	.80	1.48	4.68	.022	.390
	3	.63	1.03	1.00	.10	11.48	26.00	.86	.71	4.45	.019	.183
	4	.53	.77	.97	.10	—	62.00	.80	.00	—	.014	—
	5	.47	.57	.77	.10	—	17.93	.80	.00	—	.016	—

Table 6.—Mean constituent concentrations for the hardwood 1-inch area in 1963

Area	Depth, feet	ME/100gms					PPM			pH	%N	%OM
		K	Ca	Mg	Na	H	Mn	B	P			
Control	1	0.33	1.36	0.26	0.20	19.94	207.13	0.33	19.65	4.73	0.134	4.393
	2	.36	1.73	1.30	.20	14.84	104.80	.26	2.38	4.72	.061	.593
	3	.40	1.60	1.86	.16	15.82	70.66	.33	.20	4.75	.042	.417
Treatment	1	.40	1.03	.30	.30	20.54	150.60	.80	16.05	4.58	.068	4.367
	2	.30	.66	.86	.20	11.05	67.40	.46	2.43	4.68	.035	.643
	3	.40	.86	1.10	.16	11.54	72.93	.53	.83	4.65	.026	.247

Table 7.—Mean constituent concentrations for the red pine 1-inch area in 1963

Area	Depth, feet	ME/100gms					PPM			pH	%N	%OM
		K	Ca	Mg	Na	H	Mn	B	P			
Control	1	0.26	1.30	0.23	0.16	12.71	125.80	0.20	12.50	4.95	0.070	2.497
	2	.40	2.00	.73	.13	12.93	36.46	.46	1.18	4.76	.017	.377
	3	.36	.96	1.16	.10	14.07	49.20	.33	.58	4.57	.014	.177
	4	.36	.90	1.36	.16	—	36.13	.46	—	—	.014	—
	5	.50	.80	1.36	.13	—	41.60	.33	—	—	.008	—
Treatment	1	.46	1.26	.50	.30	17.32	121.60	.46	17.80	5.04	.088	3.123
	2	.30	1.90	.63	1.10	16.54	47.73	.26	1.15	4.70	.021	.280
	3	.36	1.36	.76	.13	15.09	48.13	.53	.90	4.79	.014	.170
	4	.50	1.06	.90	.13	—	55.53	.40	—	—	.014	—
	5	.56	.73	.76	.16	—	45.50	.60	—	—	.010	—

Table 8.—Mean constituent concentrations for the old-field 2-inch area in 1967

Area	Depth, feet	ME/100gms					PPM			pH	%N	%OM
		K	Ca	Mg	Na	H	Mn	B	P			
Control	1	0.03	1.20	0.20	0.20	16.37	53.60	0.13	13.55	4.81	—	1.793
	2	.30	1.53	1.00	.20	17.10	37.86	.33	1.25	4.64	—	.663
	3	.03	.96	1.66	.20	14.86	53.26	.00	.90	4.62	—	.467
	4	.13	.93	2.16	.20	—	78.00	.20	1.36	—	—	—
	5	.06	.83	1.76	.20	—	39.06	.13	1.25	—	—	—
Treatment	1	.26	3.36	1.36	.33	19.61	61.40	.20	42.05	5.20	—	2.783
	2	.13	2.23	1.10	.33	19.75	55.40	.13	2.11	4.79	—	.973
	3	.10	1.76	1.23	.33	18.77	55.53	.13	1.58	4.68	—	.420
	4	.00	.96	1.00	.26	—	35.33	.06	2.15	—	—	—
	5	.03	.83	1.03	.26	—	48.80	.06	1.70	—	—	—

Table 9.—Mean constituent concentrations for the hardwood 1-inch area in 1967

Area	Depth, feet	ME/100gms					PPM			pH	%N	%OM
		K	Ca	Mg	Na	H	Mn	B	P			
Control	1	0.33	1.76	0.43	0.20	24.71	138.40	0.53	28.30	4.70	—	4.330
	2	.40	1.30	1.26	.20	18.63	79.46	.40	2.30	4.61	—	.903
	3	.40	1.60	1.83	.23	21.89	94.46	.33	2.70	4.59	—	.713
	4	.43	1.26	1.70	.16	—	65.40	.40	2.60	—	—	—
	5	.13	1.30	1.63	.16	—	87.73	.13	2.88	—	—	—
Treatment	1	.16	1.80	.66	.23	15.22	117.73	.33	25.15	4.83	—	3.650
	2	.20	1.13	.96	.30	15.79	77.26	.13	2.60	4.76	—	.623
	3	.30	.70	1.30	.33	12.96	86.20	.33	2.16	4.82	—	.570
	4	.33	.63	1.90	.33	—	89.66	.33	2.36	—	—	—
	5	.33	.60	1.76	.33	—	72.46	.40	3.20	—	—	—

Table 10.—Mean constituent concentrations for the red pine 1-inch area in 1967

Area	Depth, feet	ME/100gms					PPM			pH	% N	% OM
		K	Ca	Mg	Na	H	Mn	B	P			
Control	1	0.26	1.46	0.26	0.20	14.90	97.06	0.40	15.65	4.60	—	2.133
	2	.13	1.43	.53	.16	14.37	50.26	.20	1.36	4.64	—	.497
	3	.36	.53	1.03	.16	17.48	63.93	.40	1.00	4.62	—	.250
	4	.26	.40	.70	.20	—	62.60	.26	1.90	—	—	—
	5	.16	.33	.56	.13	—	73.66	.13	2.68	—	—	—
Treatment	1	.36	1.96	.66	.30	17.83	102.33	.66	35.60	5.06	—	3.178
	2	.33	1.30	.70	.43	12.83	68.26	.33	1.42	4.92	—	.340
	3	.26	1.03	1.10	.30	15.73	89.86	.40	1.05	4.77	—	.320
	4	.66	1.03	1.50	.30	—	107.20	.66	1.50	—	—	—
	5	.50	1.80	2.20	.23	—	59.40	.26	2.30	—	—	—

Table 11.—Mean constituent concentrations for the new gamelands hardwood 2-inch area in 1967

Area	Depth, feet	ME/100gms					PPM			pH	%N	%OM
		K	Ca	Mg	Na	H	Mn	B	P			
Control	1	0.16	0.90	0.10	0.16	13.43	55.93	0.26	16.50	4.55	—	2.210
	2	.16	.70	.33	.16	12.07	16.46	.13	2.13	4.67	—	.547
	3	.16	.46	.33	.20	10.38	10.46	.13	1.23	4.76	—	.223
	4	.26	.43	.53	.20	—	4.80	.33	.83	—	—	—
	5	.06	.36	.56	.20	—	10.13	.06	.88	—	—	—
Treatment	1	.13	1.36	.40	.23	12.94	19.93	.26	75.55	5.50	—	1.240
	2	.06	.50	.30	.23	10.76	11.86	.00	4.90	4.99	—	.560
	3	.13	.46	.36	.23	13.37	19.20	.13	2.18	4.94	—	.350
	4	.16	.60	.36	.20	—	16.26	.13	1.92	—	—	—
	5	.26	1.46	1.10	.26	—	15.33	.20	1.50	—	—	—

Table 12.—Mean constituent concentrations for the old-field 2-inch area in 1971

Area	Depth, feet	ME/100gms					PPM			pH	%N	%OM
		K	Ca	Mg	Na	H	Mn	B	P			
Control	1	0.10	2.00	0.23	0.23	14.91	15.86	0.06	10.95	5.06	0.082	2.683
	2	.03	2.16	.80	.23	11.56	12.13	.06	.91	4.89	.016	.313
	3	.00	1.80	1.43	.23	12.05	10.60	.00	1.00	4.84	.009	.167
	4	.03	1.53	1.63	.20	—	9.46	.06	.90	—	.005	—
	5	.00	1.16	1.50	.20	—	8.66	.00	1.78	—	.005	—
Treatment	1	.43	3.33	1.73	.33	15.52	14.53	.60	50.80	5.42	.095	2.300
	2	.20	2.00	1.33	.30	16.36	17.20	.20	3.48	4.99	.026	.343
	3	.06	1.40	1.23	.33	16.68	15.80	.06	1.90	4.82	.017	.190
	4	.16	1.00	1.36	.30	—	15.66	.06	1.66	—	.020	—
	5	.13	1.00	1.43	.33	—	16.06	.13	1.76	—	.028	—

Table 13.—Mean constituent concentrations for the hardwood 1-inch area in 1971

Area	Depth, feet	ME/100gms					PPM			pH	%N	%OM
		K	Ca	Mg	Na	H	Mn	B	P			
Control	1	0.13	0.96	0.23	0.16	25.29	52.93	0.13	15.25	4.60	0.116	3.643
	2	.26	1.23	1.23	.20	18.13	32.73	.26	.98	4.83	.040	.877
	3	.23	1.10	1.73	.20	12.59	23.53	.13	.45	4.88	.015	.267
	4	.16	1.00	2.06	.20	—	14.86	.06	.76	—	.013	—
	5	.33	.80	1.70	.20	—	13.13	.33	.70	—	.005	—
Treatment	1	.23	1.86	1.06	.30	16.17	26.93	.26	31.60	5.01	.089	3.140
	2	.30	1.13	1.46	.33	14.69	18.86	.26	.50	4.85	.034	.483
	3	.33	1.00	1.36	.36	12.85	17.40	.33	.20	4.88	.016	.230
	4	.36	1.40	1.20	.36	—	16.33	.26	.60	—	.020	—
	5	.36	1.10	1.26	.36	—	21.40	.26	1.56	—	.018	—

Table 14.—Mean constituent concentrations for the red pine 1-inch area in 1971

Area	Depth, feet	ME/100gms					PPM			pH	%N	%OM
		K	Ca	Mg	Na	H	Mn	B	P			
Control	1	0.06	1.76	0.40	0.20	15.90	34.40	0.06	7.00	4.96	0.101	2.077
	2	.30	1.93	1.20	.20	11.10	12.86	.26	.66	5.04	.029	.263
	3	.13	1.33	1.46	.30	11.82	12.00	.06	.61	4.90	.021	.137
	4	.46	1.56	1.50	.23	—	10.53	.26	.66	—	.018	—
	5	.43	1.43	1.53	.33	—	9.60	.06	1.05	—	.017	—
Treatment	1	.33	3.10	1.26	.30	16.79	22.93	.60	36.20	5.42	.104	2.653
	2	.13	1.66	.70	.33	10.32	18.40	.20	1.05	4.93	.020	.437
	3	.30	.66	.73	.50	13.03	19.86	.20	.50	4.85	.010	.160
	4	.36	.46	.63	.43	—	16.33	.26	.65	—	.013	—
	5	.40	.40	.53	.36	—	17.40	.33	.93	—	.010	—

Table 15.—Mean constituent concentrations for the new gameland hardwood 2-inch area in 1971

Area	Depth, feet	ME/100gms					PPM			pH	%N	%OM
		K	Ca	Mg	Na	H	Mn	B	P			
Control	1	0.00	0.53	0.10	0.20	13.72	32.73	0.06	6.25	4.96	0.109	2.867
	2	.16	1.13	.80	.20	13.36	11.00	.20	3.16	4.97	.036	.300
	3	.26	.76	1.03	.20	11.54	10.86	.26	.66	4.99	.028	.230
	4	.20	.53	.83	.20	—	9.86	.20	1.06	—	.023	—
	5	.00	.50	.96	.16	—	7.26	.00	.68	—	.016	—
Treatment	1	.06	1.86	.53	.23	7.35	4.13	.13	143.75	6.15	.084	1.483
	2	.03	.96	.36	.20	5.20	4.93	.20	31.60	5.51	.052	.413
	3	.10	1.30	.73	.20	9.34	5.73	.13	9.95	5.06	.037	.243
	4	.03	1.10	.83	.23	—	6.40	.06	1.98	—	.032	—
	5	.13	.73	.80	.23	—	4.20	.20	.98	—	.032	—

The effects of effluent irrigation on exchangeable potassium, boron, organic matter, pH, and total nitrogen were small and inconsistent. Exchangeable hydrogen concentrations were inconsistently affected by wastewater treatment except in the upper foot of the sandy Morrison soil on the gameland hardwood 2-inch plot. At this location and depth the exchangeable hydrogen in 1971 was 13.7 m.e./100g in the control area and only 7.3 m.e./100g in the treatment area.

Although total nitrogen had no significant change in concentration as a result of treatment, it is an important constituent associated with wastewater disposal. For this reason, the average concentrations of total nitrogen at various depths in the treated and control old-field 2-inch plot for 1963, 1967, and 1971 and gameland hardwood 2-inch plot for 1967 and 1971 are indicated in figures 2 and 3.

Figure 2.—Average concentration of percent total nitrogen at various depths in the treated and control old-field 2-inch plots (Hublersburg silt loam).

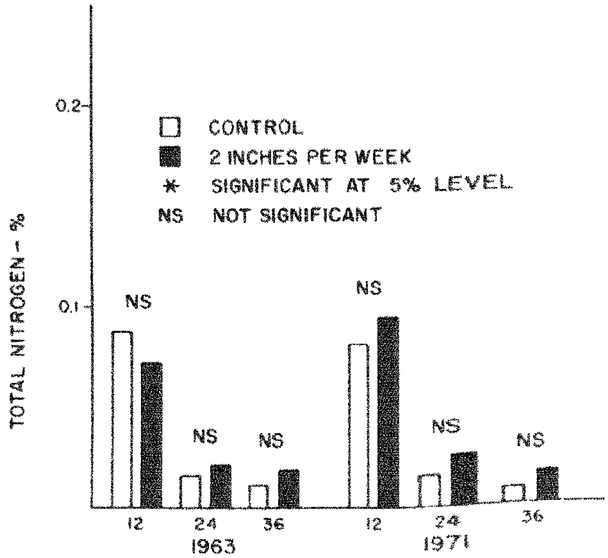
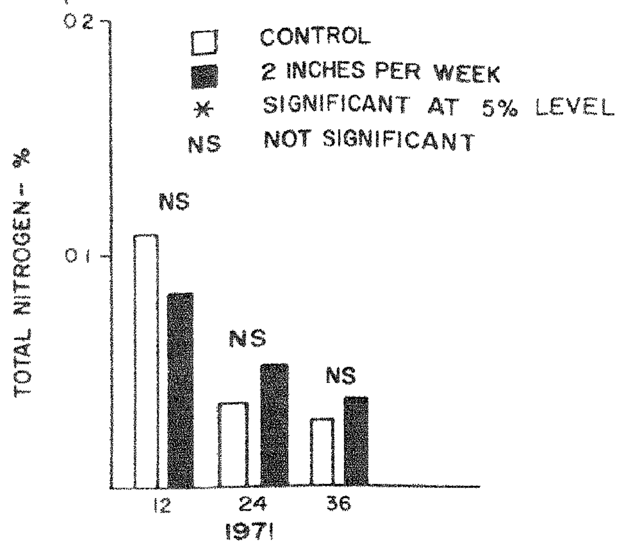


Figure 3.—Average concentration of percent total nitrogen at various depths in the treated and control gameland hardwood 2-inch plots (Morrison sandy loam).



Element Concentrations Affected by Effluent Irrigation

The element concentrations that were more frequently affected significantly by effluent irrigation were calcium, magnesium, sodium, manganese, and phosphorus.

Calcium and magnesium concentrations increased significantly at the 1-foot depth. For example, the concentrations of calcium and magnesium in the Hublersburg silt loam on the old-field 2-inch plot in 1971 were 2.0 and 3.3 m.e./100g for the calcium control and treatment, respectively, and 0.2 and 1.7 m.e./100g for the magnesium control and treatment, respectively.

These increases may be due to the strong adsorptive power that soil colloids have for calcium and magnesium. Calcium and hydrogen have approximately the same bonding strength with respect to soil colloids. If calcium is applied to the soil, the cation-exchange reaction is reversed, and hydrogen and weaker bonded cations are replaced by a mass action of active calcium ions. As a result, the soil becomes higher in exchangeable calcium and lower in hydrogen. As the soil adjusts to this altered proportion of bases and hydrogen, the soil pH is raised and the chemical makeup is modified.

The average concentrations of calcium and magnesium at various depths in the treated and control old-field 2-inch plot for 1963, 1967, and 1971 and the new gameland hardwood 2-inch plot for 1967 and 1971 are indicated in figures 4 through 7.

The concentration of exchangeable sodium increased in all the depths as a result of treatment. The increase in concentration was experienced in all the vegetative types, and an increase was seen throughout the 9 years of treatment. The samples taken in 1971 from the treated plots showed a range in maximum exchangeable sodium from 0.5 m.e./100g in the red pine 1-inch area on the fine-textured *Hublersburg* soil to 0.2 m.e. /100g in the new gameland hardwood 2-inch area on the sandy Morrison soil. These values are equivalent, respectively, to exchangeable sodium percentage values of 2.9 and 3.2.

In a review of the literature by Edwards *(1968)* it was indicated that much of the concern about soil chemical changes focused on changes in sodium concentrations relative to the other exchangeable cations in the soil. This concern with exchangeable sodium stems from the well-documented research in irrigation agriculture, which has shown that, when the exchangeable sodium percentage reaches a value of about 15, a deterioration of soil structure and adverse effects on infiltration can be expected in medium- and fine-textured soils. Thus it appears highly probable that, with the present effluent quality and applicatoion rates, sodium will not present a hazard to soil structure and permeability.

The average concentrations of sodium at various depths resulting from applications of 1 and 2 inches of effluent per week in the hardwood 1-inch and old-field 2-inch plots, respectively, are indicated in figure 8.

The average concentrations of sodium at various depths in the treated and control old-field 2-inch plot for 1963, 1967, and 1971 and the gameland hardwood 2-inch plot for 1967 and 1971 are indicated in figures 9 and 10.

Manganese, although not commonly measured among exchangeable cations, was included because of the possible effect of the increased wetness on the solubilization of manganese by oxidation-reduction reactions.

The average concentration of manganese decreased significantly in the upper 3 feet of the hardwood 1-inch plot on the fine-textured Hublersburg soil and the upper 3 feet of the gameland hardwood 2-inch plot on the sandy Morrison soil. The other areas and depths had small and inconsistent changes. This reduction in the manganese concentration could be due to the slightly more acidic conditions in the hardwood 1-inch treated plot and the extra effluent added year round in the gameland hardwood 2-inch treated plot. Manganese tends to dissolve and wash out in soils with conditions such as low pH and increased wetness.

The average concentrations of manganese at various depths in the treated and control old-field 2-inch plot for 1963, 1967, and 1971 and the gameland hardwood 2-inch plot for 1967 and 1971 are indicated in figures 11 and 12.

Boron concentrations increased significantly at the 1-foot depth in the Hublersburg soil on the old-field 2-inch, hardwood 1-inch, and red pine 1-inch plots and in the 1-foot depth of the Morrison soil on the gameland hardwood 2-inch plot. Boron concentrations should not be expected to change much as a result of irrigation. Soil has a poor ability to build up boron due partly to the relatively weak bonding between boron ions and soil colloids. Also, boron concentrations in the effluent were relatively low compared to cation concentrations present.

The average concentrations of boron at various depths in the treated and control old-field 2-inch plot for 1963, 1967, and 1971 and the gameland hardwood 2-inch plot for 1967 and 1971 are indicated in figures 13 and 14.

When phosphorus is added to soils it usually is in the soluble orthophosphate form. The orthophosphate anions bond chemically with surfaces of iron and aluminum oxyhydroxides and will form precipitates with iron and aluminum when these are in solution. The strength of the bonds formed from surface and precipitation reactions varies. The weakest bonded are the most soluble phosphates which readily equilibrate with the soil solution and become available to plants. A good measure of the amount of available phosphorus is the Bray dilute-acid/ dilute-fluoride extraction.

There was a significant increase in the concentration of Bray-tested phosphorus at the 1-foot depth in the Hublersburg silt loam soil on the old-field 2-inch plot, the hardwood 1-inch plot, and the red pine 1-inch plot. There was no significant change in the concentration of Bray phosphorus below the 1-foot depth. Since the vegetation was not removed from the plots, the phosphorus contained in the vegetation was recycled through and built up in the soil.

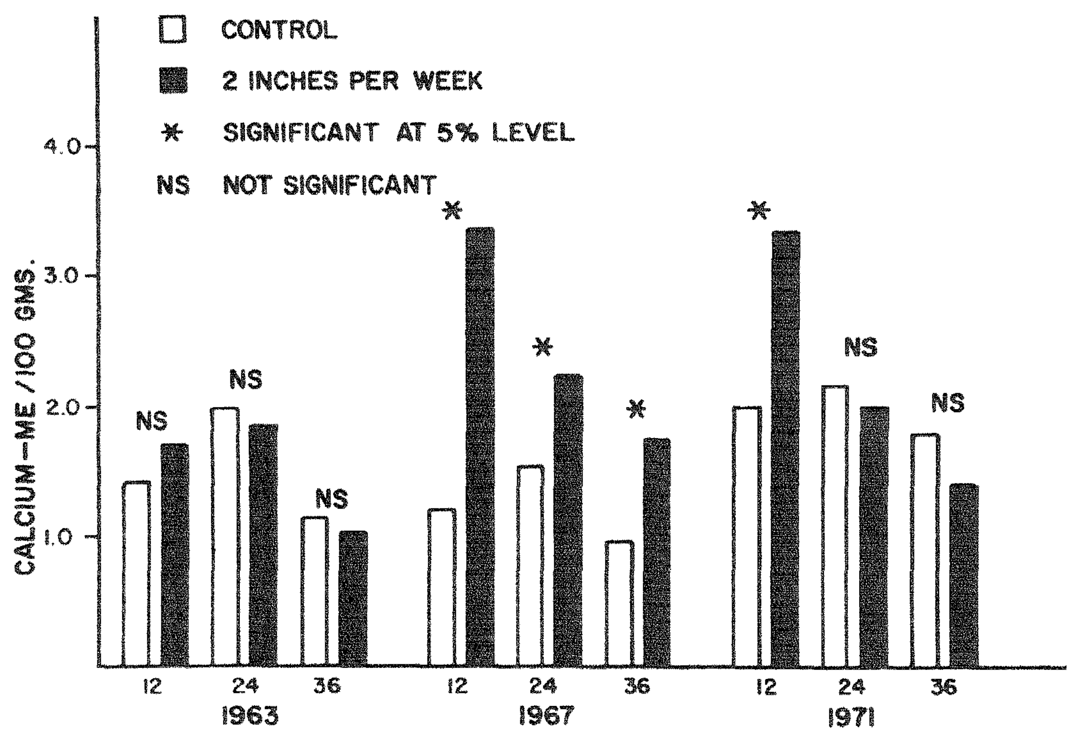
Bray phosphorus concentrations increased significantly to a depth of 5 feet in the Morrison sandy loam soil on the gameland hardwood 2-inch plot. The Morrison sandy loam soil had a very large increase in Bray phosphorus in response to the year-round effluent irrigation. In 1971, after 7 years of treatment, the irrigated plots had 143.8, 31.6, and 9.9 μg P/gram of soil while the control had 6.3, 3.2, and 0.7 μg P/gram of soil in the respective depths.

The average concentrations of phosphorus at various depths in the treated old-field 2-inch and hardwood 1-inch plots on Hublersburg silt loam for 1963, 1967, and 1971 are indicated in figure 15.

The average concentrations of phosphorus at various depths in the treated and control old-field 2-inch plot for 1963, 1967, and 1971 and the gameland hardwood 2-inch plot for 1967 and 1971 are indicated in figures 16 and 17.

Text continues on page 19.

Figure 4.—Average concentration of calcium at various depths in the treated and control old-field 2-inch plots (Hublersburg silt loam).



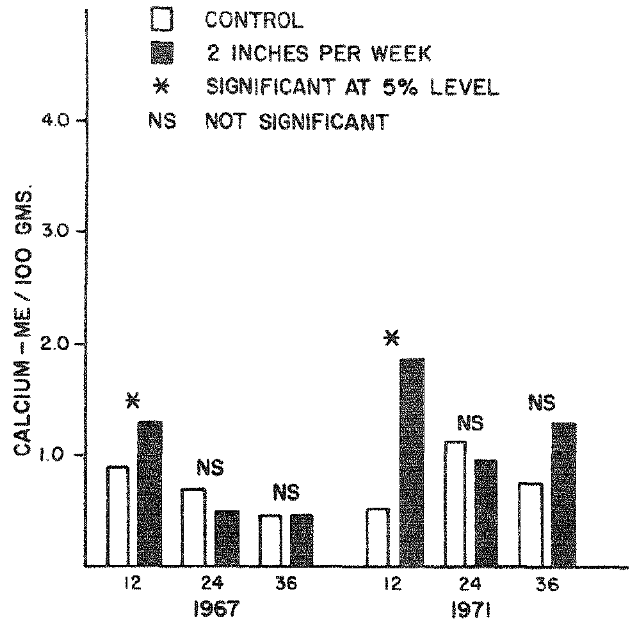


Figure 5.—Average concentration of calcium at various depths in the treated and control gameland hardwood 2-inch plots (Morrison sandy loam).

Figure 6.—Average concentration of magnesium at various depths in the treated and control old-field 2-inch plots (Hublersburg silt loam).

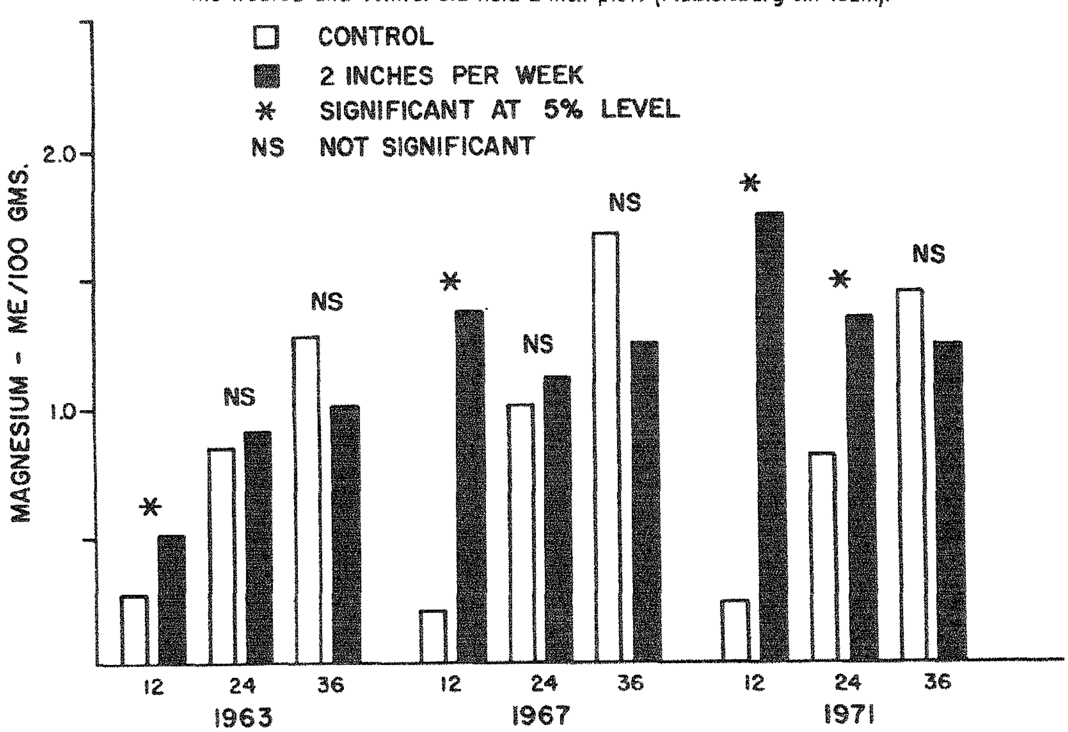


Figure 7.—Average concentration of magnesium at various depths in the treated and control gameland hardwood 2-inch plots (Morrison sandy loam).

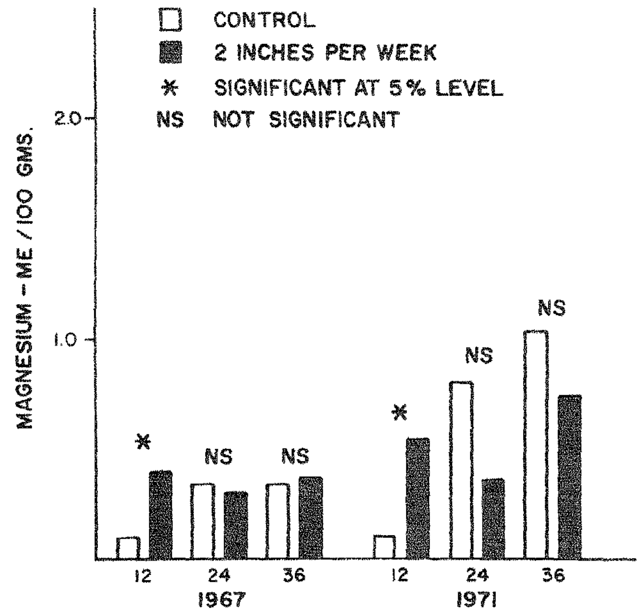


Figure 8.—Average concentration of sodium at various depths in the treated old-field 2-inch and hardwood 1-inch plots (Hublersburg silt loam).

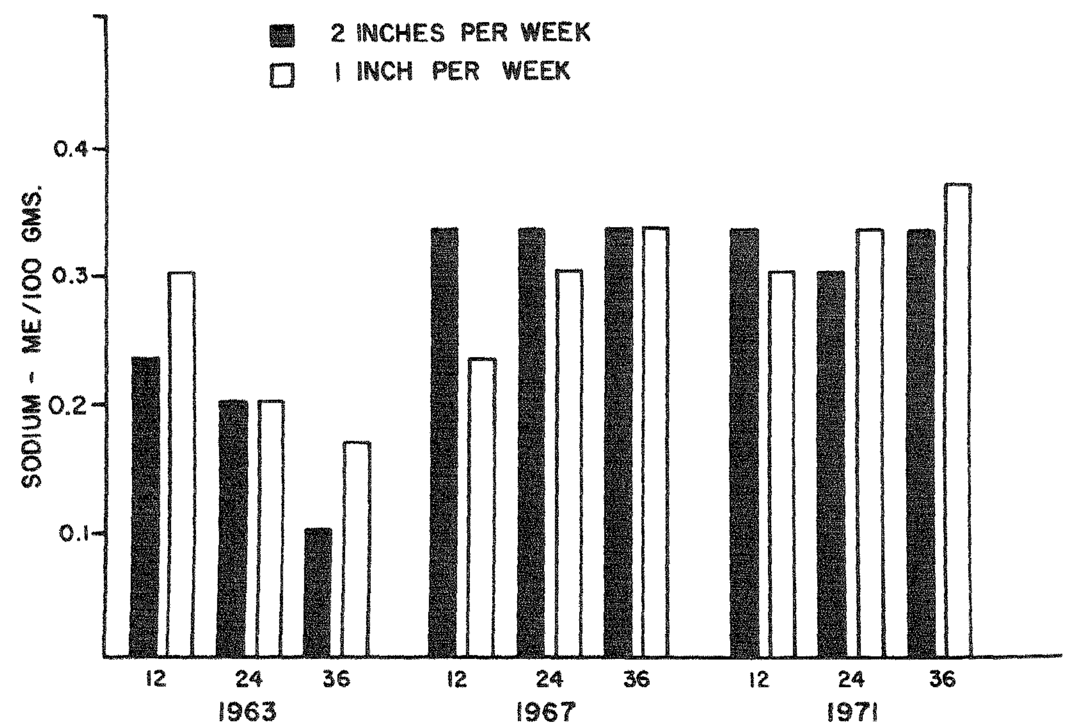
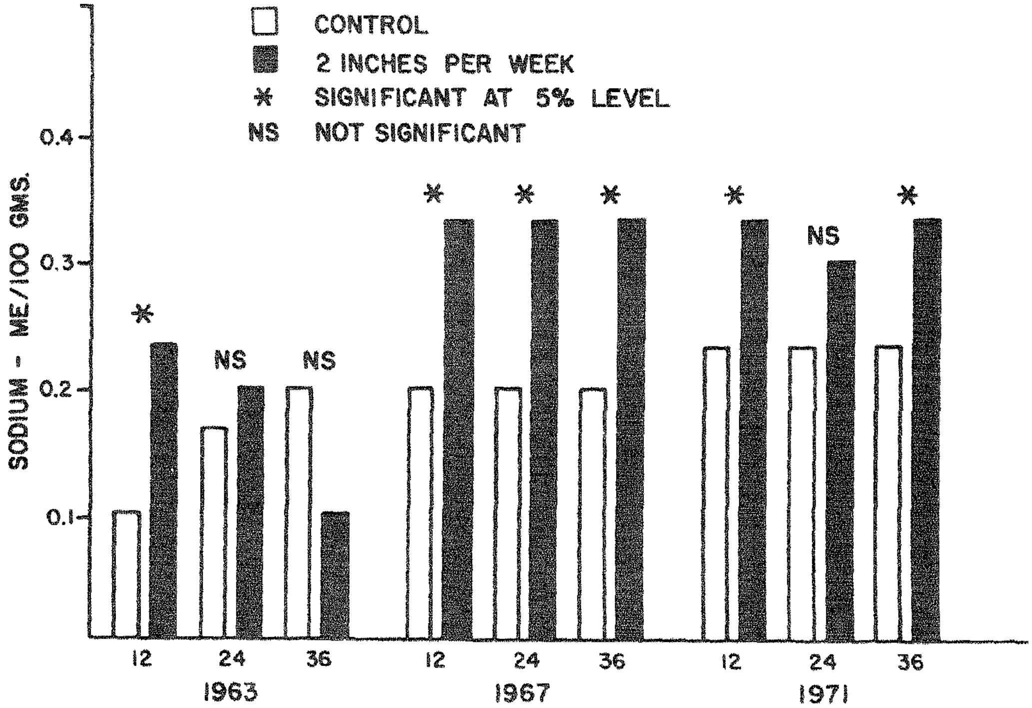


Figure 9.—Average concentration of sodium at various depths in the treated and control old-field 2-inch plots (Hublersburg silt loam).



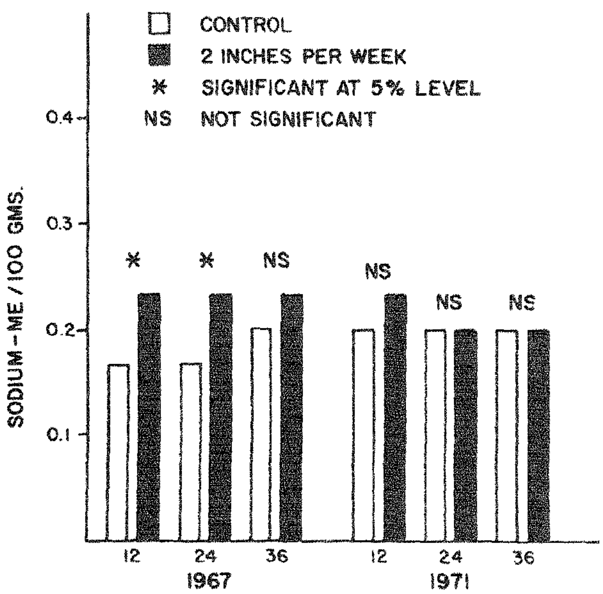
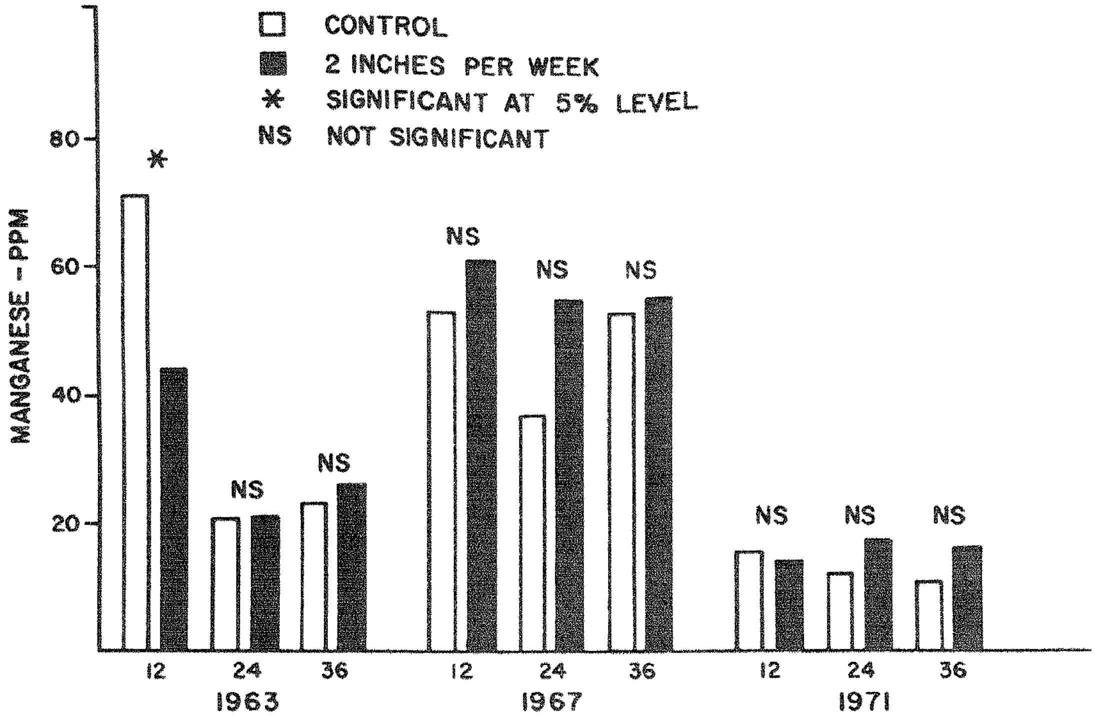


Figure 10.—Average concentration of sodium at various depths in the treated and control gameland hardwood 2-inch plots (Morrison sandy loam).

Figure 11.—Average concentration of manganese at various depths in the treated and control old-field 2-inch plots (Hublersburg silt loam).



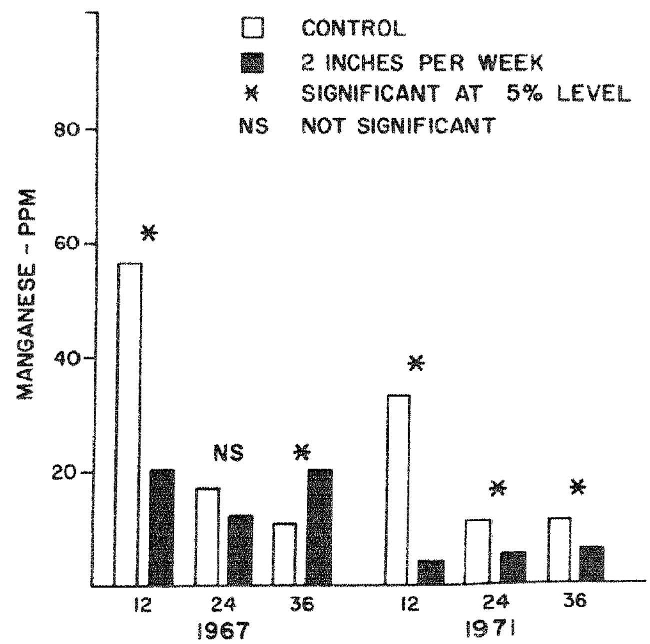


Figure 12.—Average concentration of manganese at various depths in the treated and control gameland hardwood 2-inch plots (Morrison sandy loam).

Figure 13.—Average concentration of boron at various depths in the treated and control old-field 2-inch plots (Hublersburg silt loam).

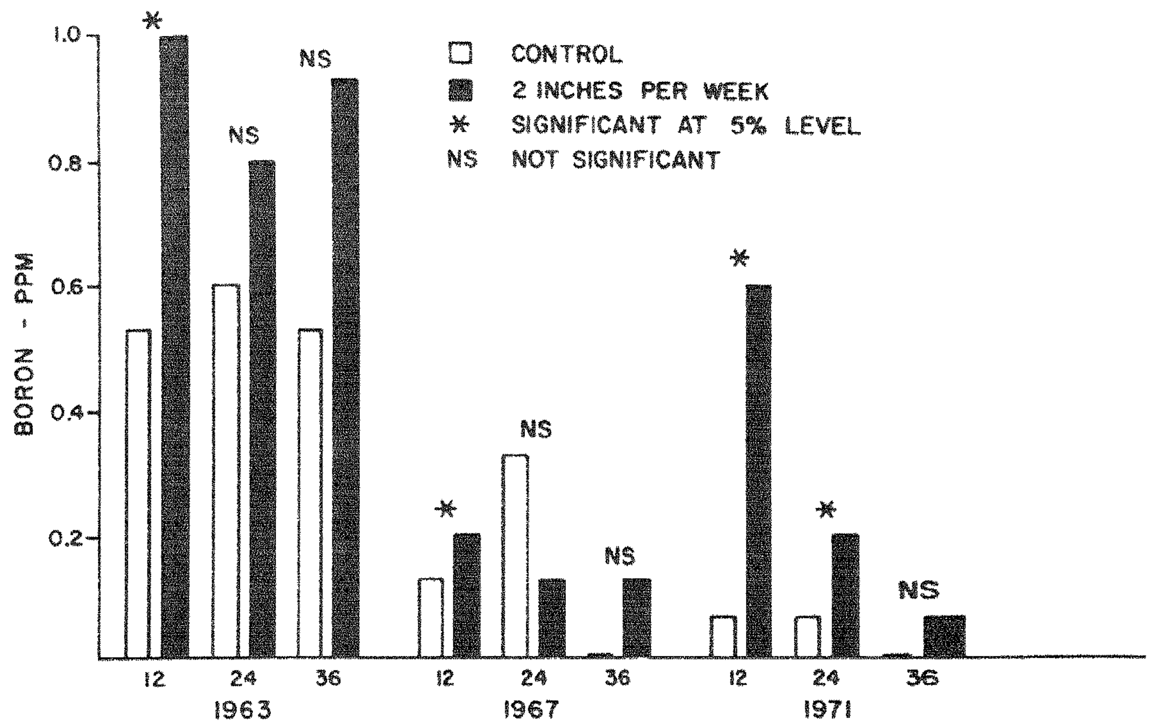


Figure 14.—Average concentration of boron at various depths in the treated and control gameland hardwood 2-inch plots (Morrison sandy loam).

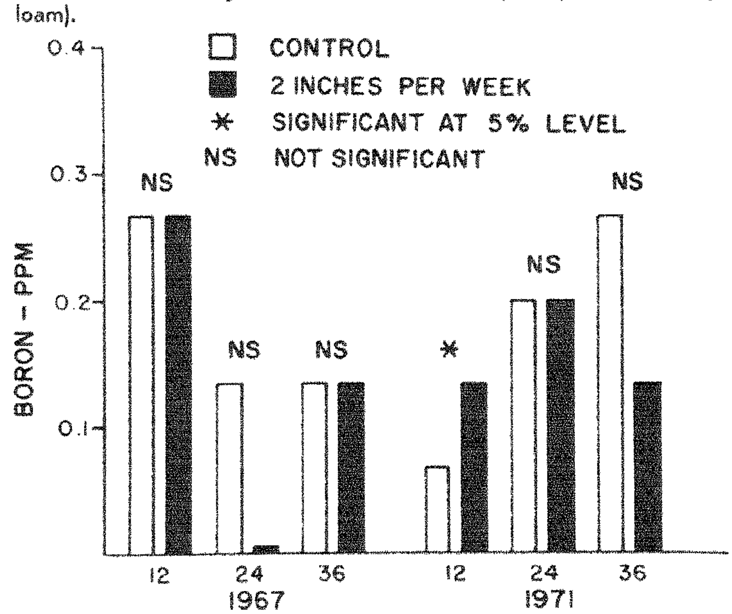


Figure 15.—Average concentration of phosphorus at various depths in the treated old-field 2-inch and hardwood 1-inch plots (Hublersburg silt loam).

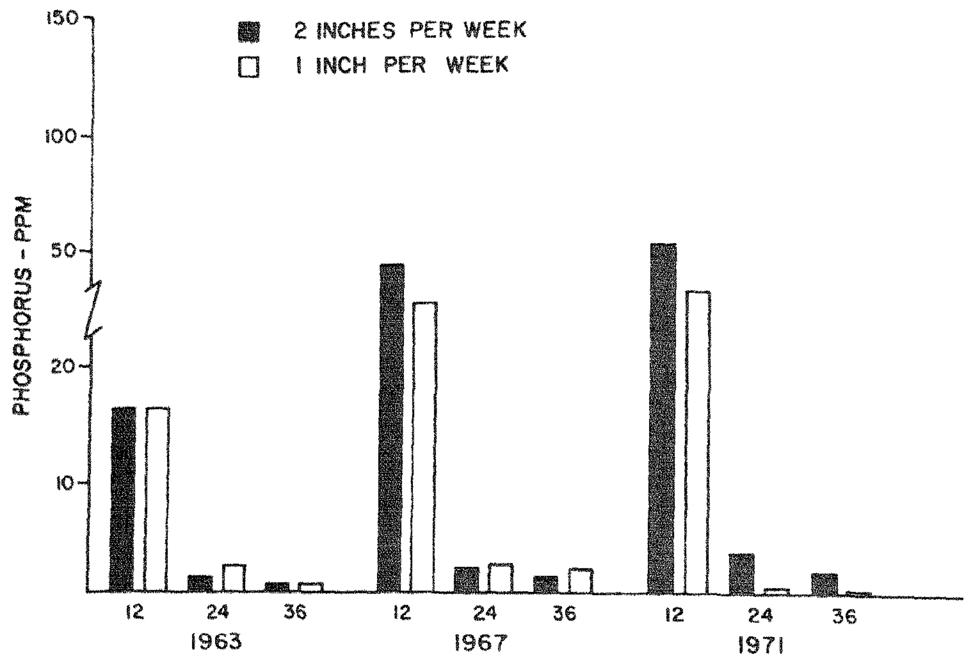


Figure 16.—Average concentration of phosphorus at various depths in the treated and control old-field 2-inch plots (Hublersburg silt loam).

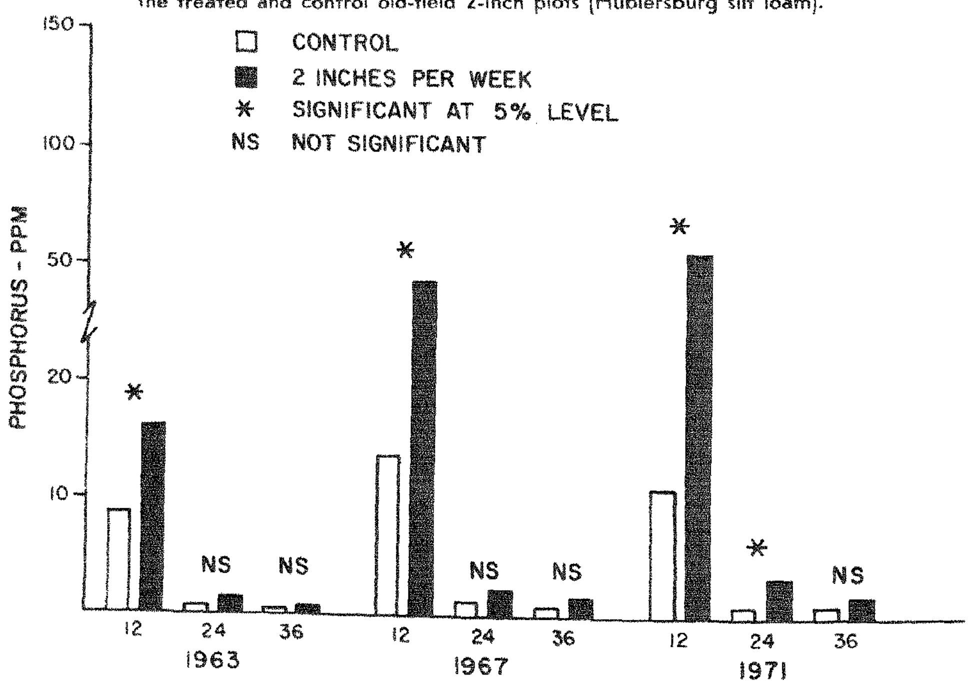
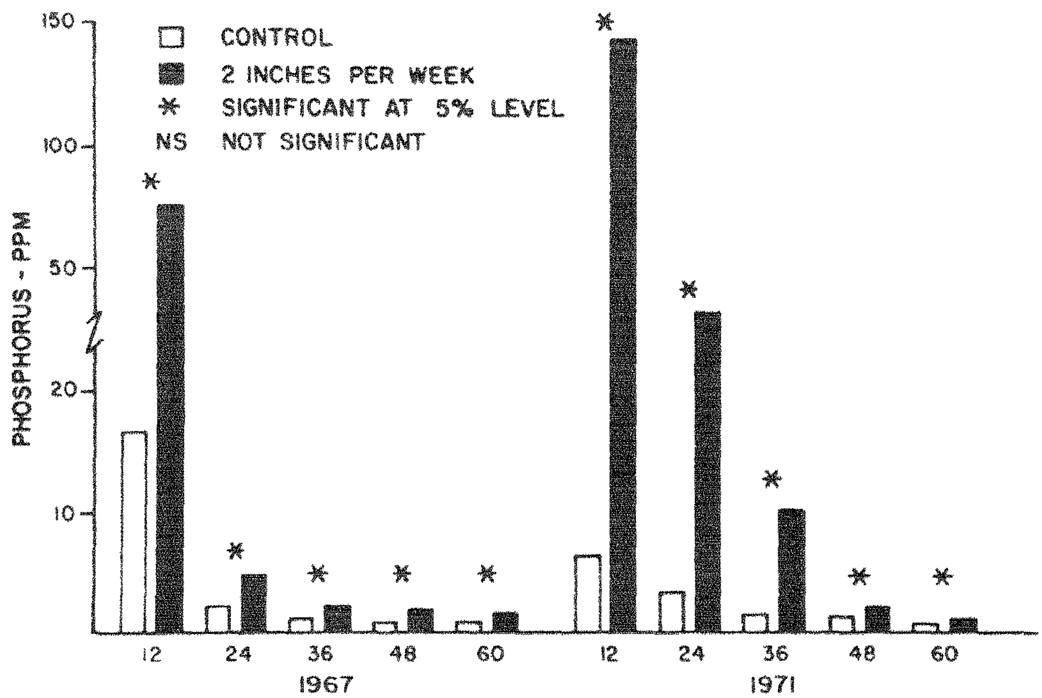


Figure 17.—Average concentration of phosphorus at various depths in the treated and control gameland hardwood 2-inch plots (Morrison sandy loam).



Effect of Vegetative Cover Type on Element Concentrations

The effect of vegetative cover tpye on the concentrations of the various elements was determined by comparing the mean constituent concentrations in the hardwood 1-inch treatment plot and the red pine 1-inch treatment plot. Both plots were located on Hublersburg silt loam, and both received applications of effluent at the rate of 1 inch per week. Both received the same seasonal and total amounts of effluent applied over the 9-year study period. The two areas had similar slopes and aspects and were located adjacent to each other.

Of the 11 constituents analyzed, potassium, calcium, magnesium, boron, and organic matter showed significant differences between areas.

Potassium was significantly higher throughout all five depths of the red pine 1-inch treatment plot in 1967. There were no significant differences for the 1963 and 1971 samples.

Calcium concentrations were significantly higher in the second and third foot of the red pine 1-inch treatment plot in 1963. In 1967 the differences were inconsistent. In 1971 the calcium concentrations were significantly higher in the lower 3 feet of the hardwood 1-inch treatment plot.

Magnesium concentrations were not significantly different in 1963 and 1967, but were significantly higher in the lower 4 feet of the hardwood 1-inch treatment plot in 1971.

Boron concentrations were significantly higher in the upper 2 feet of the hardwood 1-inch treatment plots in 1963. In 1967 boron differences were inconsistent except in the upper 2 feet, where the red pine 1-inch treatment plot had significantly higher concentrations. In 1971, the red pine 1-inch treat-

Table 16.—Average chemical content of the tree foliage in the hardwood 1-inch and red pine 1-inch plots at the end of the 1971 irrigation season

Plot	N	P	K	Ca	Mg	Mn	Fe	Cu	B	Al	Zn	Na
	Percent of dry weight					*µg/g*						
Hardwood 1-inch:												
Irrigated	2.64	0.19	1.17	1.12	0.12	1,191	132	11	57	79	38	18
Control	2.99	.20	.90	.98	.19	1,623	133	10	86	61	38	17
Red pine 1-inch:												
Irrigated	1.40	.14	.40	.23	.06	1,273	55	4	15	206	37	3
Control	2.11	.13	.51	.23	.08	790	52	4	22	92	24	2

ment plot had a significantly higher boron concentration in the first foot.

Organic matter was significantly higher in the second- and third-foot depths of the hardwood 1-inch treatment plot in 1963 and 1967, but was not significant in 1971.

The differences between the concentrations of calcium, magnesium, and boron in the Hublersburg soil on the hardwood 1-inch and red pine 1-inch treated plots are possibly due to the effects of the foliage. Foliage in hardwood stands contains higher concentrations of calcium, magnesium, and boron than the foliage in red pine stands (table 16). When this foliage drops to the ground and decomposes, the nutrient concentrations are recycled in the soil, causing an increase in the soil's nutrient concentrations.

The decrease in the potassium concentrations could be caused by the replacement of the weaker bonded potassium ions by the stronger bonded calcium and magnesium ions supplied by the decomposing litter.

The difference in the percentage of organic matter between the two vegetative types was present at the beginning of the study and therefore could be due to the characteristics of the study site rather than differences due to different vegetative cover effects.

Change in Element Concentrations

Of the 11 constituents analyzed, only exchangeable potassium, sodium, manganese, and hydrogen and extractable boron and phosphorus had significant changes in time.

The potassium concentrations decreased significantly from 1963 to 1967 in all five depths of the Hublersburg soil in the old-field 2-inch treated plots. This change was accompanied by a significant decrease in the potassium concentrations in all five depths in the control plots of the old-field 2-inch area. Since the change occurred in both the treated and control areas, unknown factors other than effluent treatment must have been responsible.

Sodium concentrations increased significantly from 1963 to 1967 in the five depths of the Hublersburg soil on the old-field 2-inch treated plot, the second- and third-foot depths of the hardwood 1-inch treated plot, and the lower 3 feet of the red pine 1-inch treated plot. As the sodium was applied to the soil by the effluent irrigation, the concentrations increased until an equilibrium exchangeable sodium level was reached. This point was reached by the time the 1967 samples were taken, since there was no change in exchangeable sodium levels from 1967 to 1971.

Manganese concentrations decreased significantly from 1967 to 1971 in all five depths of the Hublersburg soil on the old-field 2-inch, hardwood 1-inch, and red pine 1-inch treated plots, and in all five depths of the Morrison soil on the gameland hardwood 2-inch treated plots. These changes in concentrations in the treated plots were accompanied by significant decreases in manganese from 1967 to 1971 in all five depths of the control plots. Since there was a high concentration of manganese present in the soil before treatment began, it is possible that the changes in the control and treated areas were caused by differences in sampling positions and the greater leaching that occurred in the wetter meterological years from 1967 to 1971.

The exchangeable hydrogen concentrations decreased significantly from 1967 to 1971 in the upper 3 feet of the Morrison soil on the gameland hardwood 2-inch treated plot. This change could be due to the increased adsorption of calcium and magnesium from the effluent applied throughout the year at a level of 2 inches per week.

The changes in boron concentrations were small and inconsistent in the treated areas. In the control areas, however, the boron concentrations decreased significantly in all five depths of the Hublersburg soil on the old-field 2-inch and red pine 1-inch plots from 1963 to 1971. These changes in the boron concentrations could be reflections of the higher annual precipitation and leaching in the study area since 1967.

Phosphorus concentrations increased significantly from 1963 to 1971 in the upper foot of the Hublersburg soil on the hardwood 1-inch and red pine 1-inch treated areas, and in the upper 3 feet of the Hublersburg and Morrison soils on the old-field 2-inch and gameland hardwood 2-inch plots respectively. These buildups in the phosphorus concentrations over time reflect the soil's ability to fix and hold phosphorus in an unavailable form. Changes in phosphorus concentrations were small and inconsistent in the control areas.

SUMMARY AND CONCLUSIONS

From the results reported here, we made the following conclusions about what effects sewage effluent irrigation had on the chemical properties of Hublersburg silt loam and Morrison sandy loam:

1. The plots irrigated with sewage effluent had significant increases in the concentrations of calcium, magnesium, sodium, boron, and phosphorus, and significant decreases in manganese concentrations.

   Calcium and magnesium concentrations increased significantly at the 1-foot depth in all plots. Changes below the 1-foot depth were small and inconsistent.

   Sodium concentrations increased significantly at all depths in all plots.

   Boron concentrations increased significantly in the upper foot of all plots.

   Phosphorus concentrations increased significantly in the Hublersburg soil in the 1-foot depth of the hardwood 1-inch plot, the upper 2 feet of the old-field 2-inch and red pine 1-inch plots; and at all depths of the Morrison soil on the gameland hardwood 2-inch plot.

   Manganese concentrations decreased significantly in the upper 3 feet of the Hublersburg soil on the hardwood 1-inch treated plot and the upper 3 feet of the Morrison soil on the gameland hardwood 2-inch treated plot.

2. A comparison of the 11 constituent concentrations in the hardwood 1-inch and red pine 1-inch plots indicated that potassium, calcium, magnesium, boron, and organic matter had significant differences. Of these five, only calcium and magnesium had significant differences after the ninth year of treatment. Both calcium and magnesium concentrations were significantly higher in the lower 3 feet of the soil in the hardwood 1-inch plot.

3. Of the 11 constituents analyzed, only potassium, sodium, manganese, exchangeable hydrogen, boron, and phosphorus had significant changes over time.

   Potassium concentrations decreased from 1963 to 1967 in all five depths of the treated and control plots in the Hublersburg soil on the old-field 2-inch plots.

   Sodium concentrations increased significantly from 1963 to 1967 in all five depths of the Hublersburg soil in the old-field 2-inch treated plot, the second- and third-foot depths of the hardwood 1-inch treated plot, and the lower 3 feet of the red pine 1-inch treated plots.

   Manganese concentrations decreased significantly from 1967 to 1971 in all five depths of the Hublersburg soil on the old-field 2-inch, hardwod 1-inch, and red pine 1-inch treated plots, and in all five depths of the Morrison soil on the gameland hardwood 2-inch treated plot.

   Exchangeable hydrogen concentrations decreased significantly from 1967 to 1971 in the upper 3 feet of the Morrison soil on the gameland hardwood 2-inch treated plot.

Boron decreased significantly in all five depths of the Hublersburg soil on the old-field 2-inch and red pine 1-inch treated plots from 1963 to 1971.

Phosphorus increased significantly from 1963 to 1971 in the upper foot of the Hublersburg soil on the hardwood 1-inch and red pine 1-inch treated plots, and in the upper 3 feet of the Hublersburg soil on the old-field 2-inch and the Morrison soil on the gameland hardwood 2-inch treated plots.

4. It can be concluded that, after 9 years of spray irrigation with treated municipal waste water, there were no indications that the treatment had any detrimental effects on the soil.

LITERATURE CITED

Baker, D. E., G. W. Gorsline, C. B. Smith, W. I. Thomas, W. E. Grube, and J. L. Ragland. 1964. TECHNIQUE FOR RAPID ANALYSIS OF CORN LEAVES FOR 11 ELEMENTS. Agron. J. 56: 133-136.

Edwards, Ivor K. THE RENOVATION OF SEWAGE PLANT EFFLUENT BY THE SOIL AND BY AGRONOMIC CROPS. Ph.D. thesis. The Pennsylvania State University, University Park.

Jackson, M. L. 1958. SOIL CHEMICAL ANALYSIS. 498 p. Prentice-Hall, Englewood Cliffs, N.J.

Kline, G. W. 1967. EFFECT OF SEWAGE EFFLUENT IRRIGATION ON THE CHEMICAL PROPERTIES OF THE SOIL IN A HARDWOOD STAND, RED PINE PLANTATION AND OPEN OLD FIELD. M.S. thesis, The Pennsylvania State University, University Park.

Parizek, R. R., L. T. Kardos, W. E. Sopper, E. A. Myers, D. E. Davis, M. A. Farrell, and J. B. Nesbitt. 1967. WASTE WATER RENOVATION AND CONSERVATION. Pa. State Stud. Monogr. 23. 71 p.

Peech, M., L. T. Alexander, L. A. Dean, and J. F. Reed. 1947. METHOD OF SOIL ANALYSIS FOR SOIL FERTILITY INVESTIGATIONS. U.S. Rep. Agric. Circ. 757. 89 p.

Pennypacker, S. P. 1964. RENOVATION OF SEWAGE EFFLUENT THROUGH IRRIGATION OF FOREST LAND. M.S. thesis, The Pennsylvania State University, University Park.

Sagmuller, C. J. 1965. MIXED OAK, RED PINE, AND OLD FIELD PLANT RESPONSES TO IRRIGATION WITH MUNICIPAL SEWAGE EFFLUENT. M.S. thesis, The Pennsylvania State University, University Park.

U.S. Soil Conservation Service. 1965. CENTRE COUNTY, PENNSYLVANIA, SOIL SURVEY LEGEND, FIRST REVIEW, AUGUST 12, 1955. USDA Soil Conserv. Serv. 67 p.

U.S. Weather Bureau. CLIMATIC SUMMARY OF THE UNITED STATES — PENNSYLVANIA. Climatography of U.S. No. 86-32. 95 p. Washington.

Table 17.—Description of Hublersburg soil series

[Hublersburg silt-loam, cultivated (B-1, 3-8% slope)]

GENERAL

Hublersburg is a deep, well-drained intergrade of red and yellow and gray-brown podzolic soils developed from limestone and dolomite. It differs from the Hagerstown by being yellower in the B horizon (7.5 yr hue and yellower) and generally having more chert in all the horizons; and it differs from the Morrison by having finer textured B horizons. Hublersburg stands alone in the catena in Centre County except for a shallow phase. The moderately-well to somewhat poorly-drained Lawrence poorly-drained Guthrie and the very-poorly-drained Burgin — the usual associates of Hagerstown and Hublersburg in the drainage catena—are, in Centre County, associated with Araby and Wiltshire as local alluvium soils.

Profile		Description
Horizon	Depth	
	Inches	
Ap	0-8	Silt loam; moderate, very fine crumb or granular structure; brown to yellowish brown (10 yr 4/3-5/4 moist); friable when moist, slightly sticky when wet. pH 5.8. Chert fragments numerous.
B_{21}	8-24	Silty clay or clay loam; moderately durable, fine to medium subangular blocky structure; brownish yellow or yellowish brown (10 yr 6/6-5/6 moist); very firm when moist, plastic when wet. pH 5.8.
B_{22}	24-48	Heavy silty clay or clay; tough, moderately durable, coarse blocky structure; yellowish brown to brownish yellow (10 yr 5/4-6/6 moist) with some dark brown (7.5 yr 4/2-4/4 moist) very firm when moist; plastic when wet. pH 5.6.
C	48+	Limestone

Range in Characteristics
Small areas of brown and reddish-brown soils occur. Fragments of chert and limestone are scattered locally over the surface and in profile. Outcroppings of limestone are common.

Physiography and Relief
Slightly to steeply rolling upland. Some karst topography.

Drainage
Well-drained. Permeability is moderate to moderately rapid.

Vegetation
A high percentage is under cultivation. Forested areas contain mixed hardwoods.

Table 18.—Description of Morrison soil series

[Morrison sandy loam; woods site near cropland (B-1, 3-8% slope)]

GENERAL

Morrison is a deep, well-drained intergrade of the red and yellow and gray-brown podzolic soils developed from sandstone and low-grade limestone and dolomite. It develops from the Gatesburg formation. It is redder and finer textured than the Gatesburg series. It differs from the Hagerstown and Hublersburg by being sandy throughout the profile. Normally it is deeper to bedrock. It is redder throughout the profile than the Hublersburg. Morrison stands alone in the drainage catena.

Profile		Description
Horizon	Depth	
	Inches	
A_1	0-4	Sandy loam to fine sandy loam; moderate, very fine granular structure when moist; very dark gray-brown (10 yr 3/2 moist); very friable when moist, non-sticky when wet. pH 5.2. Numerous small chert fragments present, with some larger sandstone pieces.
A_2	4-11	Sandy clay loam; moderate, very fine granular structure when moist; yellowish-brown (10 yr 5/6-5/8 moist); slightly sticky when wet. Lower boundary coarse-wavy. pH 5.2. Numerous small chert fragments present.
B_2	11-20	Clay loam; moderate, very fine angular-block; structure when moist; strong brown (7.5 yr 5/6 moist); firm consistency when moist, very sticky when wet. Coarse-wavy lower boundary. pH 5.4.
B_{22}	20-60+	Clay loam; moderate, coarse-angular, blocky structure with some platyness when moist; strong brown (7.5 yr 5/8 moist); firm consistency when moist, very sticky to plastic when wet. pH 5.4. Chert fragments and sandstone channers are present. Very few roots in this zone. Manganese dioxide coatings are very numerous, with small bits of iron ore giving this horizon a blackish look.

Range in Characteristics

On cultivated land the range in color as described may not be present because of disturbance. 7.5 yr 5/8 moist to 5 yr 5/8 moist seems to predominate. The A_2, as a rule, is incorporated in the Ap, and the other horizons will be clay loam. The textures of the surface will range from fine to coarse sandy loam. The chert content will vary considerably from slightly cherty to very cherty. The platy structure is not always found in the B_{22}.

Physiography and Relief

Rolling uplands with some karst topography; slopes 1 to 12%. Occasional sinkholes outside karst topography.

Drainage

Well-drained. Permeability is moderately rapid to rapid.

Vegetation

In wooded areas, the vegetation is mostly white and black oak, ash, maple, white pine, and other species of hardwoods.

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