The effect of controlled water level and nitrogen fertilization on some physical and chemical characteristics of mountain meadow soils
by Harold A R Houlton

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of Master of Science in Soils
Montana State University

Abstract:
Mountain meadow soil from the Big Hole Valley of Montana was put into 55-gallon oil drums in a manner so as not to disturb the natural sequence of horizons. The soil was transported to the Experiment Station at Bozeman, Montana, where controlled water level and nitrogen fertilizer studies were conducted for a period of three years. At the end of this time, physical and chemical determinations were made in an effort to ascertain what changes, if any, in the physical and chemical characteristics of the 0- to 3-inch and 3- to 6-inch depths had occurred.

The experimental data shows that water treatment was the most important in influencing characteristics of this soil. High water levels increased capillary pore space and maintained a high organic matter content.

Nitrogen fertilization was found to be effective in increasing nitrifiable nitrogen, helping to maintain organic matter content, and also increasing capillary pore space.

THE EFFECT OF CONTROLLED WATER LEVEL AND NITROGEN FERTILIZATION ON SOME PHYSICAL AND CHEMICAL CHARACTERISTICS OF MOUNTAIN MEADOW SOILS

30

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ABSTRACT

Mountain meadow soil from the Big Hole Valley of Montana was put into 55-gallon oil drums in a manner so as not to disturb the natural sequence of horizons. The soil was transported to the Experiment Station at Bozeman, Montana, where controlled water level and nitrogen fertilizer studies were conducted for a period of three years. At the end of this time, physical and chemical determinations were made in an effort to ascertain what changes, if any, in the physical and chemical characteristics of the 0- to 3-inch and 3- to 6-inch depths had occurred.

The experimental data shows that water treatment was the most important in influencing characteristics of this soil. High water levels increased capillary pore space and maintained a high organic matter content.

Nitrogen fertilization was found to be effective in increasing nitrifiable nitrogen, helping to maintain organic matter content, and also increasing capillary pore space.

INTRODUCTION

The soil used for this study was taken from the Big Hole River Valley of southwestern Montana. The valley is located in mountain terrain at altitudes in excess of 5,000 feet. The average temperature for the months from May to August, inclusive, is 55° F. The growing season is 100 days or less. Ranching and hay raising constitute the major portion of the agriculture in the valley.

The mountain meadow soils of the valley are characterized by a heavy mat of undecomposed organic material. This mat presents a cultivation problem. No ordinary plow or cultivator is effective in breaking up this mat; therefore, a seedbed is difficult to establish.

These soils are subjected to extreme fluctuations of water table level. The water conditions range from flood conditions in the spring and early summer to dry conditions in late summer. The irrigation method now in use is of the "wild flood type". Water is turned onto the land and is pretty much allowed to find its own way. Very little attempt is made to control it. This situation accentuates the high water table condition. The resulting vegetation has a high proportion of sedges and other water-loving species.

In 1954, plans were initiated to conduct studies on these soils. The objectives of these studies were to determine the

1. Influence of different water table levels on soil properties and the release of plant nutrients.
2. Influence and relative effectiveness of fertilizers and soil amendments.

3. Influence and effectiveness of certain tillage practices.

This phase of the study is concerned with the effects of water levels and nitrogen fertilization on the physical and chemical properties of these soils.

REVIEW OF LITERATURE

There is evidence, as indicated by Bertrand and Kohnke (4), that bulk density, pore size distribution, and moisture content effect plant root growth through their influence on oxygen diffusion.

Epstein and Kohnke (8) found that high moisture content and compaction of the soil decreased the oxygen at the 8-inch depth. They also determined that, when organic matter was added to the soil, a lowering of the oxygen content resulted.

With high water conditions which prevent adequate supplies of oxygen, anaerobic conditions predominate, with the formation of large amounts of reduced soil constituents. Some of the changes in state of oxidation of certain soil constituents are given by Bradford (5) as follows:

Element	Normal form in well-oxidized soils	Reduced form in water-logged soils
Carbon	CO_2	CH_4
Carbon	---	Complex aldehydes, etc.
Nitrogen	NO_3^-	N_2 and NH_3
Sulfur	SO_4^{--}	H_2S
Iron	Fe^{+++} (ferric)	Fe^{++} (ferrous)
Manganese	Mn^{+++} (manganic)	Mn^{++} (manganous)

Lawton (10) reported an increase in the extractable ferrous iron content with an associated decrease in extractable ferric iron when soils were maintained at high moisture content.

Anaerobic conditions resulting from waterlogging of soil may cause an increase (very large in some soils) in exchangeable divalent manganese, as reported by Leeper (12).

Benidict (3) reported that anaerobic decomposition of organic matter in waterlogged soils produces substances which are toxic to plants.

Wet, poorly drained soils are favorable to the development of anaerobes and inhibitive to aerobes. Since anaerobes are capable of using oxygen that is in chemical combination with soil components to meet the needs of their life processes, their activities effect reduction of nitrates.

Willis and Sturgis (23) observed that large quantities of nitrogen as ammonia are lost from waterlogged soils.

De and Sarker (6) found that much of the difference in nitrogen between the amount of nitrate applied to a waterlogged soil and that recoverable as ammonia was due to nitrogen assimilated by the increased population of micro-organisms.

Wallihan (22) found that there was a relatively rapid rate of nitrate production following the drainage of waterlogged soils.

Stephens (18) found that on Florida peat and muck soils as the water table was lowered the organic matter decomposition increased.

Baver (1) states that wet soils are cold soils and thus microbial activity is depressed. Nutrient availability dependent on this activity will be correspondingly depressed.

The consideration of varying water levels with nitrogen fertilization would seem to be involved directly with several soil-water-soil atmosphere relationships. High water levels exclude the normal soil atmosphere required for micro-organisms to function aerobically. The anaerobic conditions directly affect the amount of organic matter being activated. Organic matter in its different forms and degrees of oxidation would influence the non-capillary pore space through its granulating action. Capillary pore space would also be conditioned by the colloids produced from organic matter.

The release of important plant nutrients such as nitrogen and phosphorus from organic matter decomposition would be influenced by the organic matter decomposition.

Again, with reference to organic matter colloids, the total exchange capacity would be conditioned according to the amount and kind of colloid produced under different water conditions.

The above statements are accepted and professed in soils texts (1), (13), (15), (16), (19) but with little or no supporting quantitative data.

MATERIALS AND METHODS

Description and Method of Filling Soil Tanks

As this project was initiated before the author's time at Montana State College, the collection of the drums of mountain meadow soil and the resulting experimental setup were under the supervision of Dr. J. A. Asleson. The method of filling the soil tanks, as they were popularly called, shall be directly quoted from Dr. Asleson's first report[1].

> "Twenty-four 55-gallon drums were filled with undisturbed sod and soil from a meadow in the Big Hole River Valley of southwestern Montana. The soil was placed in the barrels in such a way that the sequence of horizons approximated the profile in the field. The surface 10 inches of the profile, including the sod, were cut out as to size and shape so as to be placed in the barrels as nearly undisturbed as possible. An attempt was made to keep the composition and density of the forage in all barrels as uniform as possible. The barrels, previously fitted with outlets, were transported to Bozeman. Each barrel was fitted with a 3/4-inch pipe drain and stand pipe. They were then placed in a deep pit and soil filled in around the barrels. The water level within the barrels will be controlled by means of stand pipes." (See figure 1).

The soil profile for the soil tanks is described briefly as follows:

0 to 3	inches	- undecomposed organic matter
3 to 10	inches	- black silt loam
10 to 17	inches	- black coarse sandy loam
17 to 36	inches	- light-brown coarse sand
36	inches +	- gravel

To prevent corrosive action on the walls of the barrels, a coat of water-resistant asphalt paint was applied to the inside walls before soil

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[1]Asleson, J. A. Annual report, Dept. of Agronomy and Soils, Montana State College, 1954.

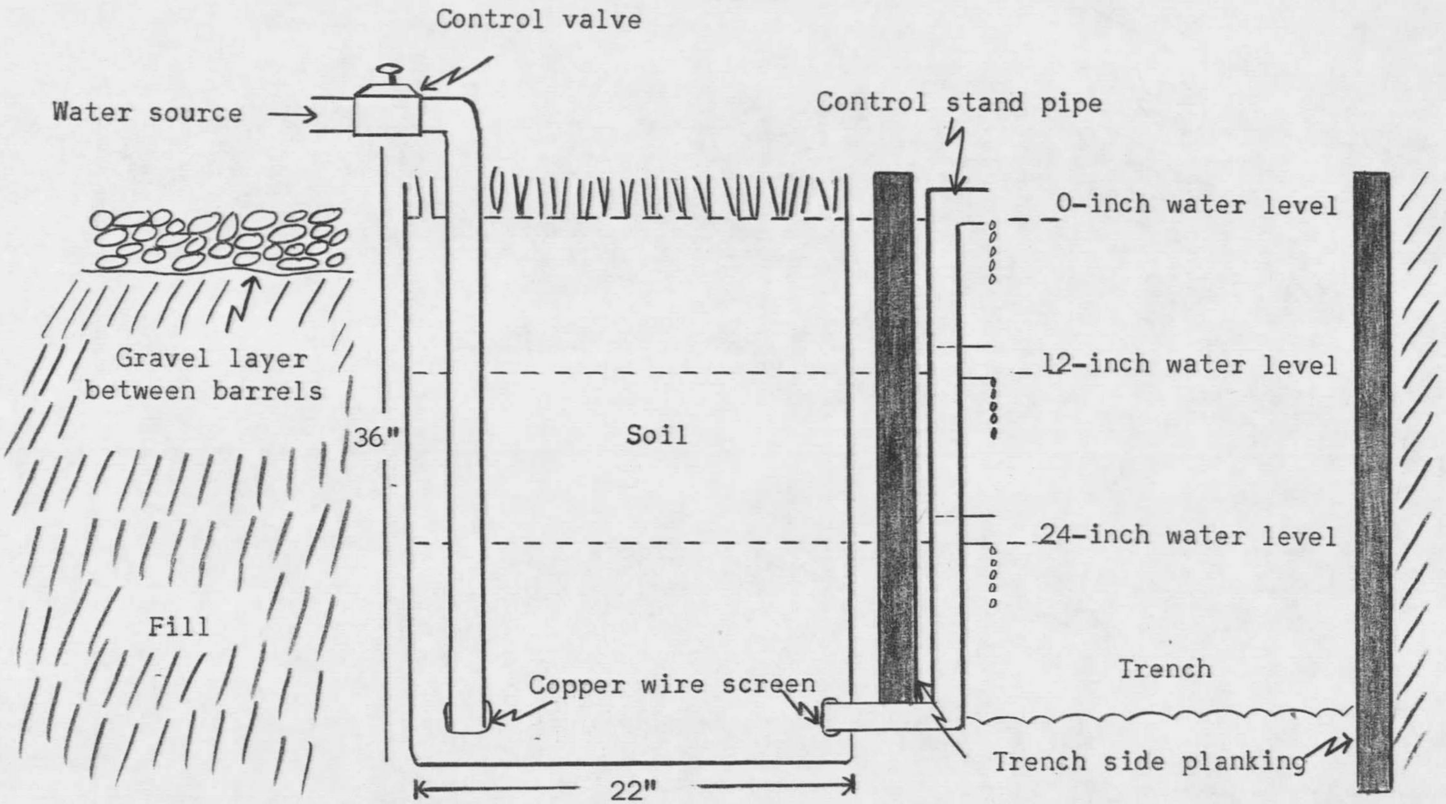

Figure 1. Cut-away view of soil tank with control stand pipe showing for the three water levels.

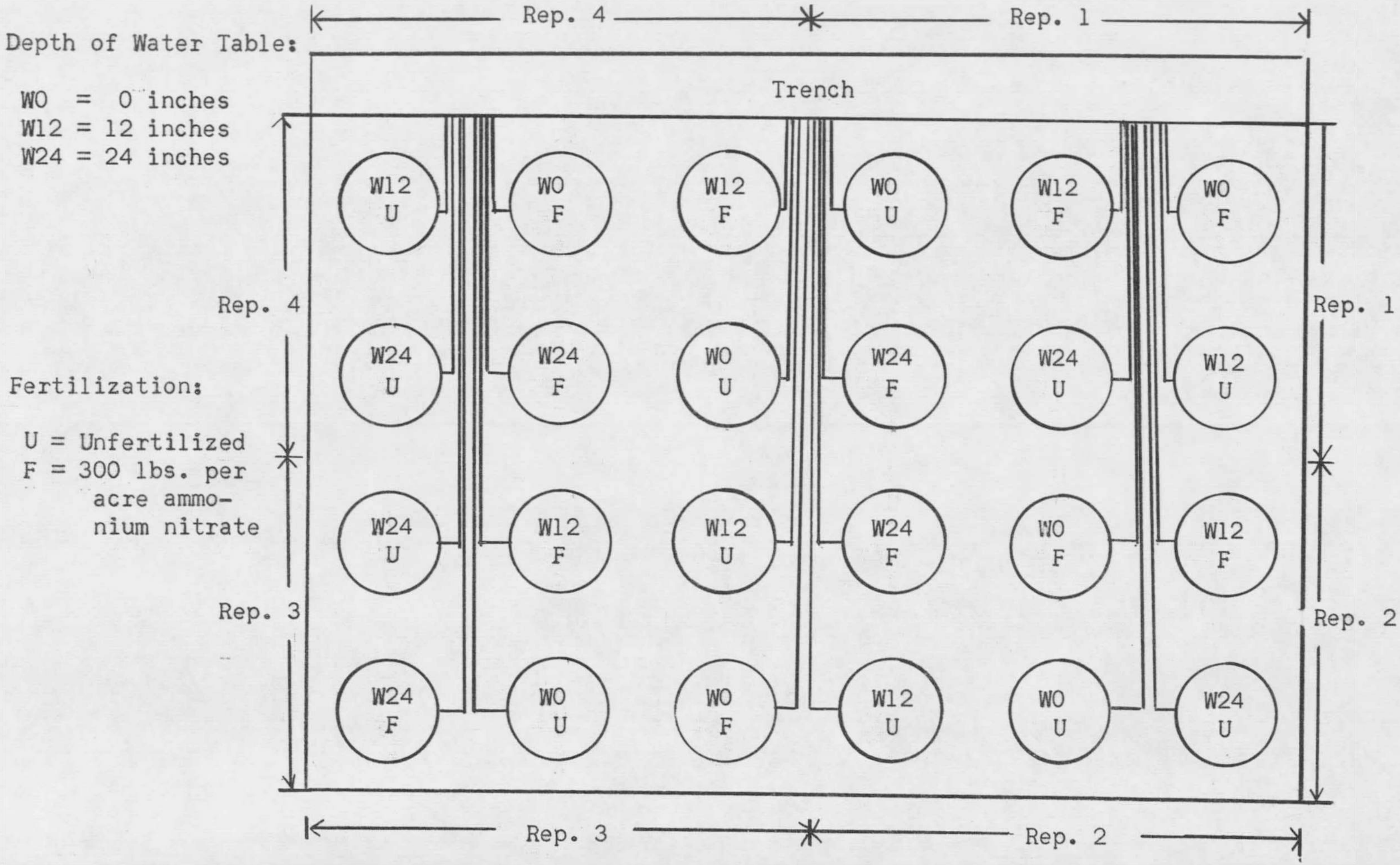

Figure 2. Controlled water level and fertilizer experiment design.

was put into them. Also the openings from the barrels to the water level control stand pipes were covered with wire screening to prevent clogging. This was also done for the water entrance pipe.

The water levels in the soil tanks were controlled at 0, 12, and 24 inches from the soil surface. The water supply was taken from a natural spring which provided water free of chlorides and fluorides. There was no pressure as the water flow from the spring was by gravity, thus the water was not forced into the soil tanks.

Nitrogen fertilizer was applied to the tanks at two rates--0 and 300 pounds per acre of ammonium nitrate annually.

There was a total of six different combinations of treatments replicated four times, and treatments were randomly applied within each replication. (See figure 2).

The combination of water levels and fertilizer treatments was applied for three years before soil testing began.

Sampling of Soil from the Tanks

Samplings of soil from the soil tanks were taken at two depths--the 0- to 3-inch depth and the 3- to 6-inch depth. Undisturbed 3-inch soil core samples and loose samples were taken from each depth. The soil core samples were taken with the Uhland soil core sampler (20).

Soil Testing

pH.--pH measurements were made with a Beckman Model H-2 pH meter on 1:2 soil dilution for the 0- to 3-inch depth and 1:1 dilution for the 3- to 6-inch depth.

Soluble salts.--Soluble salts were determined by conductivity measurements on soil extracts from the suspensions used for pH measurements. The apparatus used was a direct-indicating Wheatstone bridge. Conductivity readings were converted to parts per million figures by using the plot of conductivity against salt concentration in parts per million presented in figure 21 of Agricultural Handbook No. 60. The procedure used was that outlined by the Handbook (21).

CO_2-soluble phosphorus.--The procedure described by Ensminger and Larson (7) was used.

Percent organic matter.--The percent organic matter was determined by the Walkley-Black method adapted from Jackson[2].

Cellulose decomposing activity as indicated by the breaking strength of thread.--As an estimate of cellulose decomposing activity, cotton thread was buried in the soil. After two weeks, the thread was taken up and the breaking strength measured by adding successive 10-gram weights until the thread broke. After three weeks, another set of threads was taken up and the breaking strength measured.

Percent total nitrogen.--Total nitrogen measurements were made using the Kjeldahl method prescribed by Jackson[2].

Carbon:nitrogen ratio.--For the carbon data, the organic matter determinations were multiplied by the coefficient .58, since soil organic matter averages 58% carbon. The calculated carbon values and the total

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[2]Jackson, M. L. Soil analysis--chemical and physicochemical methods. Mimeographed. University of Wisconsin, Madison.

nitrogen values, as determined by the Kjeldahl method, were then used to calculate the carbon:nitrogen ratios[3].

Total cation exchange capacity.--Total cation exchange capacity measurements were made using the ammonium acetate method taken from Agricultural Handbook No. 60 (21).

Nitrifiable nitrogen.--A combination of two procedures was used for this determination. The procedure for production of nitrates in these soils was the one developed by Stanford and Hanway (17) in Iowa. The measurements were made by the method used in Jackson's manual[3].

Bulk density.--Bulk densities were determined by weighing the soil cores obtained from sampling and then determining the amount of water that they contained. From the core weights and water contents, weight of the dry soil was ascertained. Dividing this by the volume of the cylinder in which the core sample was taken gave the figure for bulk densities.

Percent total, capillary, and non-capillary pore space.--Total pore space, capillary pore space, and non-capillary pore space measurements were made on the 3-inch soil cores by means of the tension table apparatus. The procedure followed was that of Leamer and Shaw (11).

Moisture percentages.--Electrical resistance measurements were made daily for a week with Fiberglas soil moisture units placed in the surface $1\frac{1}{2}$ inches of soil. Readings were taken with a soil moisture ohm meter. Calibration of the electrical resistance units was done in the laboratory.

[3]Ibid.

A weighed amount of soil, representative of the surface soil in the soil tanks, had increasing amounts of moisture added. The soil was allowed to reach equilibrium, and resistance readings were taken[4].

[4]Beckman Instruments Inc., Berkeley Division, 2200 Wright Ave., Richmond, California, Instruction manual, Fiberglas soil moisture unit and soil moisture ohm meter, Model 300.

EXPERIMENTAL RESULTS

The data obtained is presented in tables I to XIII. Statistical evaluation of the data is presented in the Appendix, tables XIV to XXVI.

Table I. Effect of water and nitrogen levels on pH.

Treatment	R1[5]	R2	R3	R4	Average
		0- to 3-inch depth			
W OU[5]	6.7	6.2	6.2	6.6	6.4
W12U	6.1	6.7	6.3	6.4	6.4
W24U	6.5	6.3	5.6	6.2	6.1
W OF	5.7	6.0	6.7	5.4	5.9
W12F	6.7	6.0	6.4	6.2	6.3
W24F	6.6	6.2	6.1	6.0	6.2
		3- to 6-inch depth			
W OU	6.7	6.0	6.2	6.2	6.3
W12U	6.0	6.5	6.4	5.9	6.2
W24U	5.9	6.5	5.8	6.3	6.1
W OF	6.5	6.1	6.0	5.7	6.1
W12F	6.8	5.9	6.0	6.7	6.3
W24F	6.8	6.0	6.5	6.2	6.3

No differences were indicated in the pH data for either depth. All readings fell within one pH unit and averaged between 5.9 and 6.4 for the 0- to 3-inch depth and between 6.1 and 6.3 for the 3- to 6-inch depth.

[5] R_1, R_2, R_3, R_4 refer to replication numbers.
WO, W12, W24 refer to water table levels.
U and F refer to unfertilized and fertilized plots, respectively.

Table II. Effect of water and nitrogen levels on soluble salts (in parts per million).

Treatment	R_1	R_2	R_3	R_4	Average
			<u>0- to 3-inch depth</u>		
W 0U	1,660	1,220	700	1,160	1,185
W12U	660	830	770	900	790
W24U	530	800	1,040	860	807
W 0F	1,020	960	1,400	1,140	1,130
W12F	1,800	900	460	1,260	1,105
W24F	1,800	800	470	680	937
			<u>3- to 6-inch depth</u>		
W 0U	480	320	249	365	353
W12U	900	265	280	475	480
W24U	450	240	385	249	331
W 0F	415	265	370	340	347
W12F	280	249	540	285	338
W24F	230	520	215	280	311

Salts were found to be present. The concentrations were considerably higher for some plots in the surface depth than for those of the lower depth. Higher concentration occurred in more of the fertilized plots of the surface depth than occurred in the unfertilized plots. In no instance were the concentrations high enough to be serious.

Table III. Effect of water and nitrogen levels on CO_2-soluble phosphorus (in percent).

Treatment	R_1	R_2	R_3	R_4	Average
		0- to 3-inch depth			
W OU	10.88	8.28	5.75	7.00	7.98
W12U	5.75	9.40	9.50	5.43	7.52
W24U	12.24	12.20	6.80	11.50	10.68
W OF	4.49	8.98	4.87	1.43	4.94
W12F	17.54	10.30	5.59	0.55	8.49
W24F	13.80	8.10	3.23	4.61	7.43
		3- to 6-inch depth			
W OU	0.65	1.50	0.70	2.30	1.29
W12U	1.10	0.65	0.98	0.60	0.83
W24U	0.45	3.92	2.30	0.92	1.90
W OF	1.97	0.65	1.02	7.00	2.66
W12F	0.65	0.65	3.60	0.70	1.40
W24F	1.30	0.50	0.98	2.10	1.22

Carbon-dioxide-soluble phosphorus for the 0- to 3-inch depth was considerably higher than that of the 3- to 6-inch depth. No general trend was observed for either depth.

Table IV. Effect of water and nitrogen levels on organic matter (in percent).

Treatment	R_1	R_2	R_3	R_4	Average
			0- to 3-inch depth		
W OU	25.56	26.28	17.04	12.24	20.28
W12U	16.44	23.88	15.72	12.48	17.31
W24U	13.56	17.64	16.80	15.96	15.99
W OF	21.72	26.52	16.92	15.96	20.28
W12F	18.24	20.40	10.32	21.56	17.63
W24F	19.32	19.31	15.84	12.84	16.83
			3- to 6-inch depth		
W OU	4.35	8.56	5.73	8.57	6.80
W12U	5.20	2.59	6.49	7.31	5.39
W24U	4.03	3.78	5.17	5.86	4.71
W OF	8.88	3.84	10.21	5.46	7.10
W12F	2.59	4.72	13.16	3.84	6.08
W24F	3.97	3.72	3.72	6.99	4.60

For both depths, the percent organic matter decreased with decreasing water level. Fertilized plots in both depths showed decreases in organic matter.

The values in the 0- to 3-inch depth were higher than those in the 3- to 6-inch depth.

Table V. Effect of water and nitrogen levels on breaking strength of thread (in grams).

Treatment	R_1	R_2	R_3	R_4	Average
			Buried two weeks		
W 0U	670	760	710	340	620
W12U	770	600	570	610	638
W24U	410	570	720	630	582
W 0F	660	590	810	610	672
W12F	290	500	560	290	410
W24F	780	430	570	570	588
			Buried three weeks		
W 0U	510	580	670	710	618
W12U	410	610	680	400	572
W24U	340	350	300	460	362
W 0F	660	770	590	360	595
W12F	100	680	470	550	450
W24F	610	10	540	220	345

There was significant effect due to the water levels on the breaking strength of thread at the 10% level for the three-week period. The low water level decreased the breaking strength of the thread. There was a tendency, as indicated by the averages, for the breaking strength of the thread buried for three weeks to be less than that of the thread buried for two weeks.

Table VI. Effect of water and nitrogen levels on total nitrogen (in percent).

Treatment	R_1	R_2	R_3	R_4	Average
			0- to 3-inch depth		
W OU	1.39	1.13	1.17	1.15	1.21
W12U	1.43	1.37	1.17	1.13	1.27
W24U	1.12	1.13	1.14	1.23	1.15
W OF	1.11	1.96	1.01	0.98	1.26
W12F	1.37	1.35	0.62	1.53	1.17
W24F	1.48	0.97	1.00	1.17	1.15
			3- to 6-inch depth		
W OU	.44	.50	.49	.79	.55
W12U	.54	.23	.60	.68	.51
W24U	.48	.20	.51	.54	.43
W OF	.61	.34	.80	.78	.63
W12F	.24	.39	.87	.38	.47
W24F	.34	.51	.33	.60	.44

Total nitrogen data for the surface depth was two to three times greater than that for the lower depth. No consistent pattern was observable for any of the treatments at either depth.

Table VII. Effect of water and nitrogen levels on C:N ratio.

Treatment	R_1	R_2	R_3	R_4	Average
			0- to 3-inch depth		
W OU	10.66	13.48	8.44	6.17	9.68
W12U	6.66	10.01	7.79	6.41	7.72
W24U	7.02	9.05	8.54	7.50	8.03
W OF	11.34	7.85	9.71	9.44	9.58
W12F	7.71	8.76	9.64	8.17	8.57
W24F	7.57	11.53	9.18	6.37	8.66
			3- to 6-inch depth		
W OU	5.72	9.92	6.77	6.29	7.17
W12U	5.57	6.52	6.26	6.23	6.14
W24U	3.64	10.95	5.88	6.29	6.69
W OF	8.44	6.56	7.40	4.06	6.61
W12F	6.25	6.08	8.77	5.87	6.74
W24F	6.76	3.70	6.54	6.75	5.93

Carbon:nitrogen ratios widened as the water level increased for both depths. Values on fertilized and unfertilized plots did not show any consistent trend for either depth. Average values for the surface depth were higher than those of the lower depth.

Table VIII. Effect of water and nitrogen levels on total cation exchange capacity (in m.e. per 100 grs.)

Treatment	R_1	R_2	R_3	R_4	Average
			0- to 3-inch depth		
W OU	46.32	47.81	30.62	35.32	40.02
W12U	45.75	67.69	38.81	48.91	50.29
W24U	41.17	40.49	40.18	51.94	43.44
W OF	46.28	51.85	33.21	33.79	41.28
W12F	45.30	39.68	25.27	50.67	40.23
W24F	49.42	38.77	40.39	35.88	41.11
			3- to 6-inch depth		
W OU	24.69	30.66	30.41	32.66	29.60
W12U	26.77	20.15	33.33	29.08	27.33
W24U	28.16	20.27	27.19	22.85	24.62
W OF	35.71	23.13	35.34	38.82	33.25
W12F	24.72	27.05	37.79	22.75	28.08
W24F	30.29	25.11	27.94	27.40	27.68

The highest total exchange values in the 0- to 3-inch depth occurred with the 12-inch water level. No pattern was established with the fertilized and unfertilized plots for the 0- to 3-inch depth.

For the 3- to 6-inch depth, exchange values were higher for higher water levels. The difference was significant at the 10% level.

In general, high exchange values were obtained for the surface depth.

Table IX. Effect of water and nitrogen levels on nitrifiable nitrogen per two-week period (in parts per million).

Treatment	R_1	R_2	R_3	R_4	Average
			0- to 3-inch depth		
W OU	95.96	209.97	13.80	50.10	92.45
W12U	179.97	31.70	13.50	32.40	64.39
W24U	21.42	37.69	29.40	14.40	25.72
W OF	169.98	255.97	132.80	26.56	121.32
W12F	223.97	223.97	82.25	94.24	156.10
W24F	219.97	107.95	68.54	38.55	108.75
			3- to 6-inch depth		
W OU	21.60	67.20	13.80	14.40	29.25
W12U	18.60	3.39	4.20	10.50	9.17
W24U	10.50	14.10	6.30	6.60	9.37
W OF	10.50	10.50	23.40	19.80	16.05
W12F	25.50	4.99	21.00	3.00	13.62
W24F	13.50	9.00	1.20	6.00	7.42

For the 0- to 3-inch depth, fertilized plots increased significantly over the unfertilized plots. Water differences in the 3- to 6-inch depth were significant, with the surface water level being the highest. Higher nitrification rates were obtained for the 0- to 3-inch depth than for the 3- to 6-inch depth.

Table X. Effect of water and nitrogen levels on bulk density measurements (in grs. per c.c.).

Treatment	R_1	R_2	R_3	R_4	Average
			0- to 3-inch depth		
W OU	.50	.50	.55	.66	.55
W12U	.61	.58	.66	.64	.62
W24U	.59	.47	.64	.62	.58
W OF	.56	.45	.65	.57	.56
W12F	.57	.65	.79	.54	.64
W24F	.50	.61	.75	.59	.61
			3- to 6-inch depth		
W OU	1.30	0.83	1.02	1.14	1.07
W12U	1.31	1.48	1.16	0.95	1.22
W24U	1.34	1.35	1.12	1.08	1.22
W OF	1.20	1.25	1.06	1.09	1.15
W12F	1.29	1.28	0.99	1.20	1.19
W24F	1.17	1.32	1.30	1.00	1.20

Bulk density results in the 0- to 3-inch depth were highest where the water level was kept at 12 inches below the surface. The lowest values for this depth were obtained with the surface water level.

General bulk density measurements for the upper depth were all lower than those for the lower depth.

Table XI. Effect of water and nitrogen levels on total pore space (in percent).

Treatment	R_1	R_2	R_3	R_4	Average
			0- to 3-inch depth		
W OU	76.6	80.5	73.7	67.3	74.5
W12U	74.2	75.2	70.7	62.6	70.7
W24U	75.4	81.8	64.5	73.4	73.8
W OF	74.6	84.3	70.8	70.0	75.0
W12F	77.0	73.6	67.5	67.0	71.3
W24F	78.8	70.0	67.3	72.7	72.2
			3- to 6-inch depth		
W OU	52.9	68.0	60.5	60.0	60.3
W12U	56.1	49.7	57.8	64.3	57.0
W24U	55.7	49.5	55.0	60.9	55.2
W OF	61.0	58.0	58.4	66.1	60.9
W12F	59.0	55.5	61.4	54.9	57.7
W24F	60.3	52.7	52.4	60.6	56.5

The percent total pore space values in both depths were greatest for the surface water level. The lowest values in the 0- to 3-inch depth occurred at the 12-inch water level, while the lowest values in the 3- to 6-inch depth were at the 24-inch water level.

Over-all values in the surface depth were all higher than those in the lower depth.

Table XII. Effect of water and nitrogen levels on capillary pore space (in percent).

Treatment	R_1	R_2	R_3	R_4	Average
			0- to 3-inch depth		
W OU	46.7	46.7	41.6	44.6	44.9
W12U	50.1	45.0	45.3	35.0	43.8
W24U	47.8	52.1	40.1	44.8	46.2
W OF	40.4	45.0	45.8	42.2	43.3
W12F	48.4	47.9	39.6	37.5	43.3
W24F	51.5	44.4	43.1	43.3	45.6
			3- to 6-inch depth		
W OU	43.0	45.5	43.7	43.5	43.9
W12U	35.4	36.2	43.4	43.9	39.7
W24U	43.4	32.1	41.7	47.8	41.2
W OF	55.4	47.9	47.0	48.4	49.7
W12F	38.2	43.0	42.6	42.8	41.6
W24F	57.1	38.5	41.4	44.7	45.4

Water and nitrogen treatments had real effects on capillary pore space values. Both values were significant at the 10% level in the 3- to 6-inch depth. The capillary pore space was greatest with the higher water level. Fertilization increased capillary pore space. Somewhat higher values were obtained for the surface depth than the lower depth.

Table XIII. Effect of water and nitrogen levels on non-capillary pore space (in percent).

Treatment	R_1	R_2	R_3	R_4	Average
			0- to 3-inch depth		
W OU	29.9	33.8	32.1	22.7	29.6
W12U	24.1	30.2	25.4	27.6	26.8
W24U	27.6	29.7	24.4	28.6	27.6
W OF	34.2	39.3	25.0	27.8	31.6
W12F	28.6	25.7	27.9	29.5	27.9
W24F	27.3	25.6	24.2	29.4	26.6
			3- to 6-inch depth		
W OU	9.9	22.5	16.8	16.5	16.4
W12U	20.7	13.5	14.4	20.4	17.2
W24U	12.3	17.4	13.3	13.1	14.0
W OF	5.6	10.1	11.4	17.7	11.2
W12F	20.8	12.5	18.8	12.1	16.0
W24F	3.2	14.2	11.0	15.9	11.1

Percent non-capillary pore space values increased in the 0- to 3-inch depth with higher water tables. Water and nitrogen treatments both produced significant changes at the 5% level for the lower depth. Nitrogen decreased the percent non-capillary pore space, and lower water levels decreased it also. Higher values were obtained for the surface depth than for the lower depth.

Moisture Percentages

The fertilized and unfertilized plots for each water level followed fairly similar moisture patterns. (See figure 3). Greater differences occurred between fertilized and unfertilized plots for the surface water level than for the lower water levels. The fertilized surface water plots were lower than the unfertilized plots. At the 12-inch water level, fertilized plots gave an indication toward being lower in moisture. The fertilized 24-inch water level plots were somewhat higher than the unfertilized plots.

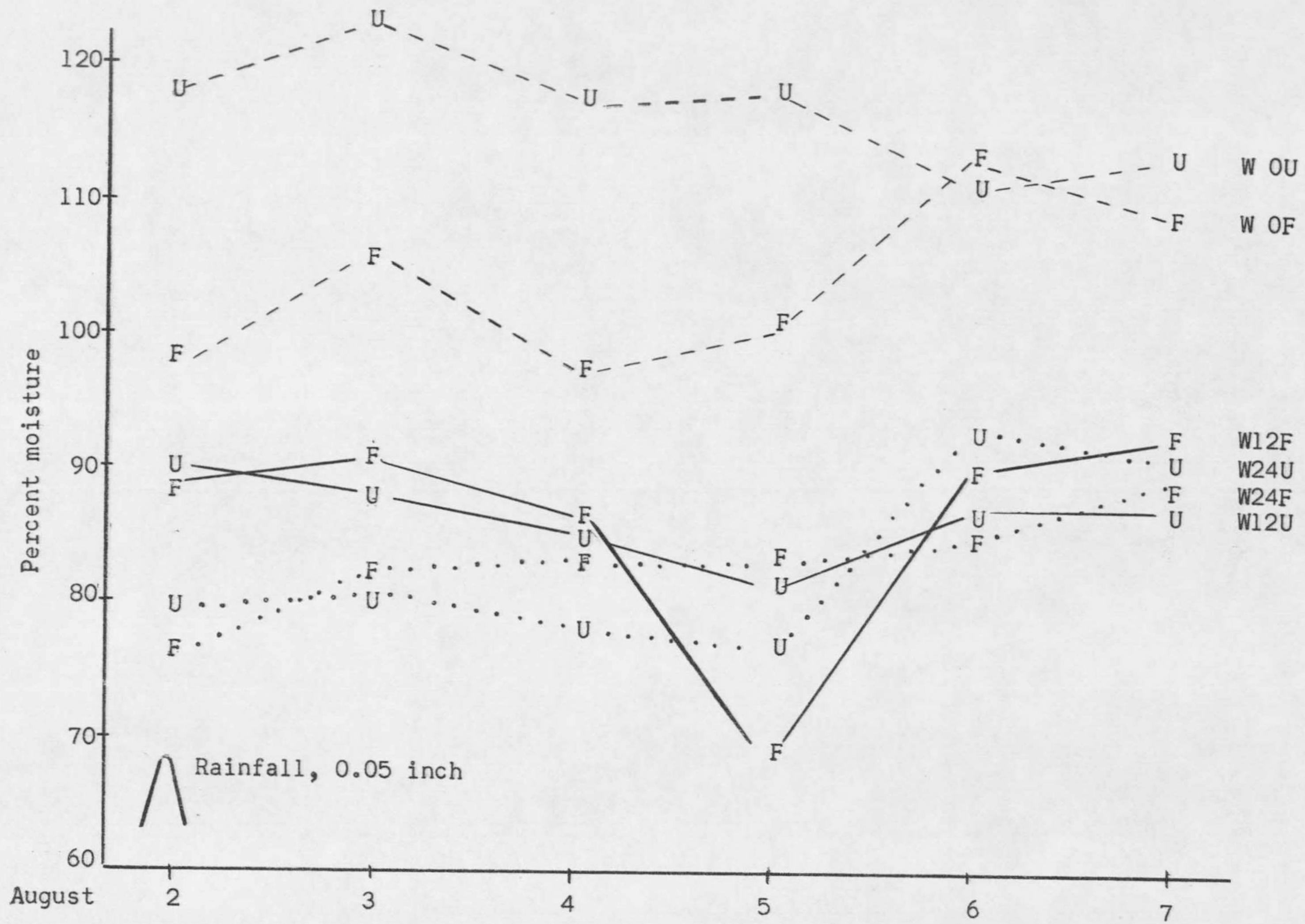

Figure 3. Moisture percentages for fertilized and unfertilized plots with 0-, 12-, and 24-inch water tables over a six-day period.

DISCUSSION OF RESULTS

pH

The pH determinations indicate that these soils are slightly acid. The average pH was 6.2. If any influence was exerted by treatment, it was not great enough to reach significance.

Soluble Salts

The salt data, as determined by conductivity measurements, indicate that this soil can be classified as non-saline. There were no significant effects on salt content due to treatment. The average salt contents for the 0- to 3-inch and 3- to 6-inch depths were 992.5 and 360.3 parts per million, respectively.

The only information provided is that salts do exist but not in harmful amounts.

CO_2-Soluble Phosphorus

No effects on phosphorus content were noted to treatment. The data for phosphorus indicate that some of these soils are deficient in phosphorus for the 0- to 3-inch depth and in every case are deficient in the 3- to 6-inch depth. The averages for the 0- to 3-inch and 3- to 6-inch depths were 7.84 and 1.54, respectively. The standards now in use at the Montana Experiment Station state that 3.3 to 6.5 parts per million of P is usually deficient. This is considered the borderline range. When soils test low in available phosphorus, an increase is usually brought about by use of phosphate fertilizer. Since the pH of these soils falls in the range of greatest phosphorus availability, it is natural to assume that any phosphorus made available was quickly utilized by plants and micro-organisms.

Percent Organic Matter

Although no significant changes due to treatment were obtained for percent organic matter, there was a trend for organic matter to decrease with decreasing water level, indicating increased biological activity with improved drainage. The trend indicated an organic matter decrease of 0.78%.

Cellulose Decomposing Activity as Indicated by the Breaking Strength of Thread

The lowest water table produced the lowest breaking strength in the 3- to 6-inch depth. It reduced the breaking strength by 41.7%. This is supporting evidence for the increased biological activity with lower water levels. In all cases, the breaking strength of the cotton thread was less for the 24-inch water level than for the 12- and 0-inch water levels. In all but one case, the breaking strength of the cotton thread for the 12-inch level was less than the 0-inch water level.

Percent Total Nitrogen

As indicated in the results, no real effects were exerted upon the total nitrogen by treatment. After applications of 100 pounds of nitrogen per year for three years, it was felt that some changes would occur. Pratt, Goulben, and Harding (14) found that, after adding nitrogen at the rate of 130 pounds of nitrogen per acre for 12 years and 390 pounds of nitrogen per acre for 16 years, the total nitrogen was not increased.

Carbon:Nitrogen Ratio

No significant changes were effected upon the carbon:nitrogen ratio by treatments. This is understandable when the total nitrogen data is considered. A change in the total nitrogen content would have materially affected the carbon:nitrogen ratio.

As compared to the general average of carbon:nitrogen ratios for soils which ranges from 8 to 15, the ratios for these soils are somewhat low. However, as the carbon was calculated on the basis of oxidizable organic matter, assuming 74% oxidation, this may have given the lower ratios. The decrease in organic matter suggests increased bacterial activity which, due to a high demand for nitrogen, should have narrowed the ratios. However, this was not the case.

Total Cation Exchange Capacity

The total cation exchange capacity was significantly increased in the 3- to 6-inch depth by the surface water level treatment. This relationship was confusing when first encountered, but there may be a logical explanation as indicated in the literature (9). At the present time, it is thought that the substance "lignin", when set free from plant residues, forms the major constituent of humus. Lignin is thought to be a polymer formed mainly of units of substituted derivatives of phenyl propane. When organic accumulation occurs under excessive water conditions, it is made up mainly of slightly humified but anaerobically decomposed plant remains. The humified remains, e.g., lignin, have structures with potentially active groups attached. While under anaerobic conditions, the exchange activity of the active groups are "chemically protected" from rapid oxidation which would oxidize and inactivate the active groupings. Mainly, it is OH groups that would be deactivated. These are phenol OH groups situated in the para position to the propene group. The anaerobic conditions then, by suppressing oxidation, keep the exchange capacity up.

It will be noted that there is a relationship indicated between organic matter and cation exchange capacity. They both increase with the high water table. This relationship may have a direct bearing on the validity of the above discussion.

Nitrifiable Nitrogen

These soils exhibited a strong potential for nitrifiable nitrogen production. This characteristic was exhibited very notably in the high organic surface layer, where nitrogen fertilization increased the nitrifying rate. The residual effect of the nitrogen applications is indicated here whereas it was not picked up by the total nitrogen test.

The high nitrifying activity due to nitrogen fertilization indicates that nitrogen is a definite limiting factor in these soils.

Bulk Density

The low bulk density measurements obtained on the 0- to 3-inch depth are in keeping with its higher organic matter percentages. Also, as would be expected, the lower depth with less organic matter gave correspondingly higher values. The 12-inch water treatment tended to increase the bulk density. This would appear to be further evidence in support of the hypothesis for increased bacterial activity with a resulting decrease in organic matter as the water level is decreased.

Percent Total Pore Space

The total pore space was not significantly affected by any treatment.

The values are somewhat greater in the surface depth, which is due in part to the higher organic matter values. The average value for the surface depth was 72.89% and 57.94% for the lower depth.

Organic matter should have a direct and indirect influence on the pore space. The direct influence is due to the bulky and porous nature of organic matter which would increase total pore space. The indirect effects of organic matter are to reduce compaction and increase aggregation.

Percent Capillary Pore Space

Capillary pore space data increased with decreasing water level in the 0- to 3-inch depth. This, however, was not significant and cannot be considered as a real effect. On the other hand, significant effects due to water and nitrogen at the 10% level occurred in the 3- to 6-inch depth. Both nitrogen and high water level increased capillary pore space.

Since the high water table held the organic matter content high, the effect of increased capillary pore space is due directly to high organic matter content. Poor aeration with excess water conditions, resulting in slow oxidation, and increased plant growth through fertilization contributed substantially to the organic matter increase.

Percent Non-Capillary Pore Space

Since no change occurred in the total pore space, the increase in capillary pore space in the 3- to 6-inch depth was at the expense of the non-capillary pore space. Water at the 12-inch level gave the highest non-capillary pore space. The values at the surface water level were significantly lower than the 12-inch level, which may account for the decrease in non-capillary values and the increase in capillary values.

Fertilization decreased non-capillary values. This situation is difficult to explain, but it may be related to increased plant growth which is indicated by higher water requirements for the fertilized plots. It may also have some relation to increased organic matter, but this is not indicated in the organic matter data.

Moisture Percentages

Moisture measurements over a six-day period show that the surface water level maintained higher moisture percentages than the 12-inch and 24-inch water levels. However, even though the 12- and 24-inch water levels were lower than the surface water level, their moisture percentages were high, never dropping below 70% moisture.

The fertilized surface water level and 12-inch water level indicate higher moisture demands. This would indicate greater vegetative activity due to fertilization.

CONCLUSIONS

The conclusions as obtained from the data of this study are as follows:

1. Water and nitrogen fertilizer treatments had no effect upon the pH of these soils.
2. The salt level in these soils is above that usually encountered in normal soils, but it is not high enough so that crop injury from salts would be anticipated.
3. Phosphorus content was not influenced by treatment.
4. No significant effects were exerted by water levels and nitrogen upon organic matter content. There was an indication that organic matter decreased with decreasing water levels.
5. The cellulose decomposing activity of these soils is increased with a lowering of the water table.
6. Treatments did not vary the total nitrogen level of these soils.
7. The carbon:nitrogen ratio did not change with treatment. There was some indication that water may have had a slight effect over a three-year period.
8. High water levels maintained a higher cation exchange capacity in the 3- to 6-inch depth than did the lower water levels.
9. Nitrifiable nitrogen was increased by nitrogen fertilization in the 0- to 3-inch depth.

10. Bulk density was not affected by treatment.

11. No changes in total pore space occurred due to treatment.

12. Percent capillary pore space increased in the 3- to 6-inch depth with high water levels. Percent capillary pore space was increased in the 3- to 6-inch level with fertilization.

13. Non-capillary pore space was increased with the 12-inch water level in the 3- to 6-inch depth. Fertilization decreased non-capillary pore space in the 3- to 6-inch depth.

Although few positive changes due to treatment were found in this study, it is felt that certain trends are evident. Water is the more dynamic factor in effecting changes and holding pre-existing conditions constant. High water table conditions on these soils as they exist in their natural location are responsible for maintaining the high degree of organic matter, the high cation exchange capacity, the high capillary pore space, and the low bulk densities.

Decreasing the amount of water applied and controlling the water level would result in better soil aeration and oxidative conditions. This would tend to decrease or break down raw organic matter and facilitate cultivation.

With controlled water table levels, nitrogen will be an important limiting factor. These soils will require the application of commercial nitrogen. It is felt that higher applications of nitrogen than were used in this study may have to be applied, at least in the early stages of soil improvement. The competition for nitrogen would be great in view of the high organic matter content and the prevalence of raw organic matter.

It may be necessary to conduct an experiment of this type over a long period of time in order to determine significant measurable effects from water control and fertilization.

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APPENDIX

Table XIV. Analysis of variance -- pH.

0- to 3-inch depth

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	0.1950	.0650	0.9246	3.29	2.49
Water	2	0.1409	.0704	1.0014	3.68	2.70
Nitrogen	1	0.1350	.1350	1.9203	4.54	3.07
Nitrogen x Water	2	0.3325	.1662	2.3641	3.68	2.70
Error	15	1.0550	.0703			
Total	23	2.8584				

$\bar{x} = 6.24$
C.V. = 4.25%

3- to 6-inch depth

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	0.3767	.1255	.9789	3.29	2.49
Water	2	0.0434	.0217	.1692	3.68	2.70
Nitrogen	1	0.0267	.0267	.2082	4.54	3.07
Nitrogen x Water	2	0.2233	.1116	.8705	3.68	2.70
Error	15	1.9233	.1282			
Total	23	2.5934				

$\bar{x} = 6.23$
C.V. = 5.74%

Table XV. Analysis of variance -- soluble salts.

0- to 3-inch depth

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	623,083.30	207,694.43	1.46	3.29	2.49
Water	2	349,200.00	174,600.00	1.23	3.68	2.70
Nitrogen	1	101,400.00	101,400.00	0.71	4.54	3.07
Nitrogen x Water	2	136,900.00	68,450.00	0.48	3.68	2.70
Error	15	2,131,266.70	142,084.44			
Total	23	3,341,850.00				

$\bar{x}$ = 992.50
C.V. = 3.74%

3- to 6-inch depth

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	81,135.12	27,045.04	1.10	3.29	2.49
Water	2	32,214.58	16,107.29	0.65	3.68	2.70
Nitrogen	1	18,648.38	18,648.38	0.76	4.54	3.07
Nitrogen x Water	2	22,248.25	11,124.12	0.45	3.68	2.70
Error	15	369,014.63	24,600.97			
Total	23	523,260.96				

$\bar{x}$ = 360.29
C.V. = 43.50%

Table XVI. Analysis of variance -- CO_2-soluble phosphorus.

0- to 3-inch depth

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	135.15	45.05	4.05	3.29	2.49
Water	2	27.36	13.68	1.23	3.68	2.70
Nitrogen	1	18.79	18.79	1.69	4.54	3.07
Nitrogen x Water	2	22.63	11.31	1.02	3.68	2.70
Error	15	166.84	11.12			
Total	23	370.77				

$\bar{x}$ = 7.84
C.V. = 42.47%

3- to 6-inch depth

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	5.15	1.71	.67	3.29	2.49
Water	2	2.94	1.47	.58	3.68	2.70
Nitrogen	1	1.06	1.06	.42	4.54	3.07
Nitrogen x Water	2	4.26	2.13	.84	3.68	2.70
Error	15	38.02	2.53			
Total	23	51.43				

$\bar{x}$ = 1.54
C.V. = 103.00%

Table XVII. Analysis of variance -- organic matter.

0- to 3-inch depth

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	207.97	69.32	5.56	3.29	2.49
Water	2	64.91	32.45	2.60	3.68	2.70
Nitrogen	1	1.19	1.19	0.09	4.54	3.07
Nitrogen x Water	2	0.71	0.35	0.01	3.68	2.70
Error	15	187.12	12.47			
Total	23	461.90				

$\bar{x}$ = 18.02
C.V. = 19.59%

3- to 6-inch depth

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	32.52	10.84	1.63	3.29	2.49
Water	2	21.09	10.54	1.59	3.68	2.70
Nitrogen	1	0.50	0.50	0.07	4.54	3.07
Nitrogen x Water	2	0.62	0.31	0.04	3.68	2.70
Error	15	99.48	6.63			
Total	23	154.21				

$\bar{x}$ = 5.78
C.V. = 44.53%

Table XVIII. Analysis of variance -- breaking strength of thread.

Buried Two Weeks

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	67,500	22,500.00	1.26	3.29	2.49
Water	2	57,500	28,750.00	1.61	3.68	2.70
Nitrogen	1	20,400	20,400.00	1.14	4.54	3.07
Nitrogen x Water	2	87,800	43,900.00	2.46	3.68	2.70
Error	15	268,000	17,866.60			
Total	23	501,200				

$\bar{x} = 584.00$
C.V. = 22.88%

Buried Three Weeks

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	67,879	22,626.00	0.54	3.29	2.49
Water	2	260,234	130,117.00	3.11	3.68	2.70
Nitrogen	1	17,604	17,604.00	0.42	4.54	3.07
Nitrogen x Water	2	14,033	7,016.00	0.18	3.68	2.70
Error	15	628,546	41,903.31			
Total	23	988,296				

$\bar{x} = 490.00$
C.V. = 41.77%

Table XIX. Analysis of variance -- total nitrogen.

0- to 3-inch depth

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	0.36	.12	1.71	3.29	2.49
Water	2	0.03	.01	0.14	3.68	2.70
Nitrogen	1	0.00	.00	0.00	4.54	3.07
Nitrogen x Water	2	0.02	.01	0.14	3.68	2.70
Error	15	1.07	.07			
Total	23	1.48				

$\bar{x}$ = 1.21
C.V. = 22.00%

3- to 6-inch depth

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	.29	.96	3.69	3.29	2.49
Water	2	.10	.50	1.92	3.68	2.70
Nitrogen	1	.00	.00	0.00	4.54	3.07
Nitrogen x Water	2	.02	.01	0.04	3.68	2.70
Error	15	.39	.26			
Total	23	.80				

$\bar{x}$ = 0.51
C.V. = 27.00%

Table XX. Analysis of variance -- C:N ratio.

0- to 3-inch depth

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	23.48	7.82	2.96	3.29	2.49
Water	2	10.49	5.24	1.98	3.68	2.70
Nitrogen	1	1.28	1.28	0.48	4.54	3.07
Nitrogen x Water	2	1.01	0.50	0.19	3.68	2.70
Error	15	39.61	2.64			
Total	23	75.87				

$\bar{x}$ = 9.54
C.V. = 16.98%

3- to 6-inch depth

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	8.01	2.67	.74	3.29	2.49
Water	2	1.49	0.74	.20	3.68	2.70
Nitrogen	1	0.34	0.34	.09	4.54	3.07
Nitrogen x Water	2	2.13	1.06	.29	3.68	2.70
Error	15	54.09	3.61			
Total	23	66.06				

$\bar{x}$ = 6.55
C.V. = 29.00%

Table XXI. Analysis of variance -- total cation exchange capacity.

0- to 3-inch depth

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	584.67	19.49	0.32	3.29	2.49
Water	2	87.43	43.71	0.73	3.68	2.70
Nitrogen	1	82.51	82.51	1.37	4.54	3.07
Nitrogen x Water	2	133.96	66.98	1.12	3.68	2.70
Error	15	899.11	59.94			
Total	23	1,787.68				

$\bar{x}$ = 42.73
C.V. = 15.29%

3- to 6-inch depth

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	175.65	58.55	3.09	3.29	2.49
Water	2	117.63	58.81	3.10	3.68	2.70
Nitrogen	1	37.08	37.08	1.96	4.54	3.07
Nitrogen x Water	2	9.42	4.71	0.31	3.68	2.70
Error	15	284.19	18.94			
Total	23	623.97				

$\bar{x}$ = 28.42
C.V. = 18.75%

Table XXII. Analysis of variance -- nitrifiable nitrogen per two-week period.

0- to 3-inch depth

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	58,961.57	19,653.85	6.45	3.29	2.49
Water	2	12,408.87	6,204.43	2.04	3.68	2.70
Nitrogen	1	34,841.69	34,841.69	11.43	4.54	3.07
Nitrogen x Water	2	1,571.85	785.92	0.25	3.68	2.70
Error	15	45,701.76	3,046.78			
Total	23	153,485.74				

$\bar{x}$ = 98.96
C.V. = 55.70%

3- to 6-inch depth

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	275.63	91.87	0.56	3.29	2.49
Water	2	903.11	451.55	2.75	3.68	2.70
Nitrogen	1	75.69	75.69	0.46	4.54	3.07
Nitrogen x Water	2	320.00	160.00	0.97	3.68	2.70
Error	15	2,464.59	164.31			
Total	23	4,039.02				

$\bar{x}$ = 14.15
C.V. = 90.50%

Table XXIII. Analysis of variance -- bulk density.

0- to 3-inch depth

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	.0628	.0209	4.26	3.29	2.49
Water	2	.0226	.0113	2.31	3.68	2.70
Nitrogen	1	.0019	.0019	0.39	4.54	3.07
Nitrogen x Water	2	.0007	.0003	0.06	3.68	2.70
Error	15	.0748	.0049			
Total	23	.1628				

$\bar{x}$ = 0.59
C.V. = 11.80%

3- to 6-inch depth

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	.1722	.0574	2.81	3.29	2.49
Water	2	.0507	.0253	1.24	3.68	2.70
Nitrogen	1	.0002	.0002	0.01	4.54	3.07
Nitrogen x Water	2	.0155	.0077	0.37	3.68	2.70
Error	15	.3064	.0204			
Total	23	.5450				

$\bar{x}$ = 1.17
C.V. = 1.20%

Table XXIV. Analysis of variance -- total pore space.

0- to 3-inch depth

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	378.73	126.26	7.95	3.29	2.49
Water	2	56.33	28.16	1.77	3.68	2.70
Nitrogen	1	0.22	0.22	0.01	4.54	3.07
Nitrogen x Water	2	5.80	2.90	0.18	3.68	2.70
Error	15	238.11	15.87			
Total	23	679.19				

$\bar{x}$ = 72.89
C.V. = 5.21%

3- to 6-inch depth

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	96.84	32.28	1.50	3.29	2.49
Water	2	93.74	46.87	2.18	3.68	2.70
Nitrogen	1	4.08	4.08	0.19	4.54	3.07
Nitrogen x Water	2	0.53	0.26	0.01	3.68	2.70
Error	15	322.87	21.52			
Total	23	518.06				

$\bar{x}$ = 57.94
C.V. = 8.00%

Table XXV. Analysis of variance -- capillary pore space.

0- to 3-inch depth

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	172.57	57.52	4.24	3.29	2.49
Water	2	22.97	11.48	0.85	3.68	2.70
Nitrogen	1	4.77	4.77	0.35	4.54	3.07
Nitrogen x Water	2	1.32	0.66	0.05	3.68	2.70
Error	15	203.27	13.55			
Total	23	404.90				

$\bar{x} = 44.54$
C.V. = 14.98%

3- to 6-inch depth

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	91.81	30.60	1.25	3.29	2.49
Water	2	150.33	75.16	3.07	3.68	2.70
Nitrogen	1	93.61	93.61	3.82	4.54	3.07
Nitrogen x Water	2	14.79	7.39	0.30	3.68	2.70
Error	15	366.92	24.46			
Total	23	717.46				

$\bar{x} = 43.61$
C.V. = 11.33%

Table XXVI. Analysis of variance -- non-capillary pore space.

0- to 3-inch depth

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	57.94	19.31	1.46	3.29	2.49
Water	2	60.60	30.30	2.30	3.68	2.70
Nitrogen	1	2.94	2.94	0.22	4.54	3.07
Nitrogen x Water	2	8.86	4.43	0.34	3.68	2.70
Error	15	197.80	13.18			
Total	23	328.14				

$\bar{x} = 28.36$
C.V. = 12.80%

3- to 6-inch depth

Source	df	SS	MS	F	F 5%	F 10%
Replications	3	49.01	16.33	2.06	3.29	2.49
Water	2	70.44	35.22	4.45	3.68	2.70
Nitrogen	1	58.59	58.59	7.41	4.54	3.07
Nitrogen x Water	2	16.40	8.20	1.03	3.68	2.70
Error	15	118.64	7.90			
Total	23	313.08				

$\bar{x} = 14.33$
C.V. = 19.60%