Effect of Rainfall on N and P Changes in Fallow Loam

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The work reported here forms part of an extensive program of research at Swift Current on the complex interactions between weather variables and soil processes causing fluctuations in the level of plant available nutrients.

The objectives of this particular field study were to determine (a) the short-term effects of rainfall and subsequent drying on changes in plant available N and P and (b) to relate these changes to microbially mediated and physical processes in soil.

The first two experiments were concerned with the movement of soluble anions in fallow soil. ^{36} Chloride was placed at 15- or 30-cm depth in 15 cm wide and 53 cm long aluminum cylinders containing Wood Mountain loam. (Table 1)

During the growing season the ^{36}Cl was leached to at least 50 cm depth during and immediately following rains of $>$ 1.75 cm. As the soil dried after rains and throughout the summer, ^{36}Cl moved upwards. By September 5 it was found in the 0- to 2.5-cm and in the 10- to 12.5-cm segments of the 15- and 30-bm placements, respectively. It was concluded that nitrate, a highly soluble anion, could also have moved up and down the profile in a similar manner.

In a second experiment six relatively undisturbed soil cores in aluminum lysimeters, 30 cm wide and 30 cm long, were placed snugly into holes in a fallow plot. After each rainfall, the leachate was siphoned off from the bottom of the lysimeters and its volume and NO_3-N concentration were measured. (Table 2)

The results from this experiment corroborated the leaching evidence from the tracer experiment. During the three occasions on which more than 1.75 cm rain fall, nitrate was leached to a depth of more than 30 cm.

The effect of rainfall and subsequent soil drying on changes in the bacterial population and plant-available N and P were measured in

Table 1

Movement of ^{36}Cl in loam soil (cylinders buried in field)

Depth sampled (cm)	15-cm placement								30-cm placement							
	June 5	June 12	July 4	July 13	July 31	Aug 8	Aug 14	Aug 29	June 5	June 12	July 4	July 13	July 31	Aug 8	Aug 14	Aug 29
0- 7.5				Cl	Cl	Cl	Cl	Cl								
7.5-15	Cl*	Cl	Cl	Cl	Cl	Cl	Cl	Cl								Cl
15 -22.5	Cl	Cl	Cl	Cl	Cl	Cl	Cl	Cl				Cl	Cl	Cl	Cl	Cl
22.5-30		Cl	Cl	Cl	Cl	Cl	Cl	Cl	Cl	Cl	Cl	Cl	Cl	Cl	Cl	Cl
30 -37.5				Cl	Cl	Cl	Cl	Cl	Cl	Cl	Cl	Cl	Cl	Cl	Cl	Cl
37.5-45										Cl	Cl	Cl	Cl	Cl	Cl	Cl
45 -52.5											Cl	Cl	Cl	Cl	Cl	Cl

* Cl denotes presence of ^{36}Cl.

Table 2

NO_3-N leached to 30-cm depth as measured in lysimeters placed *in situ*

Cylinder No.*	Sampled May 29/72 Rain[†]: 4.32 cm		Sampled June 12/72 Rain[‡]: 2.25 cm		Sampled June 26/72 Rain[§]: 2.30 cm	
	Leachate (cc)	NO_3 (ppm)	Leachate (cc)	NO_3 (ppm)	Leachate (cc)	NO_3 (ppm)
1	630	128	26	90	700	22
2	645	162	64	103	2093	34
3	260	374	85	200	1340	154
4	990	157	30	103	21	78
5	680	124	10	65	1555	47
6	460	154	19	92	405	62
Mean	611	188	39	109	1019	66
NO_3 leached/cyl.	115 mg		4 mg		67 mg	

* Cylinders 1, 2, and 6 were cropped; 3, 4, and 5 were fallow.

[†] Total rain on May 25, and 26, 1972; fell over 27.5 hr; peak rate for 1 continuous hr: 0.75 cm.

[‡] Total rain on June 8 and 9, 1972; fell over 27.5 hr; peak rate for 1 continuous hr: 0.70 cm.

[§] Total rain on June 23, 1972; fell over 3.5 hr; peak rate for 1 continuous hr: 1.32 cm.

first- and second-year fallow plots. Measurements were taken in the 0- to 2.5- and in the 2.5- to 15-cm segments.

The installation of an automatic rain shelter permitted the simultaneous determination of similar changes under gradual drying conditions in second-year fallow. However, this latter aspect will not be reported on at this time.

There were three relatively large rainfalls occurring between May 25 and June 29. These rainfalls caused marked increases in soil moisture in the top inch, while the increases in the 1- to 6-inch depth were apparent but less pronounced. (Fig. 1)

After each rain, moisture in the top inch decreased rapidly in the first week and more slowly in the second week. The third rainfall occurred on a Friday night and no measurements were taken until the following Tuesday when the soil had already dried out to some extent. Estimates of moisture and nitrate-N were made for the 0- to 1-inch depth for Day 1 after the third large rain.

During each large rainfall most of the nitrate-N in the top inch was immediately lost. The evidence suggests that leaching was partly responsible for this loss. Denitrification may also have contributed to the loss, especially during the first rain where the top inch was saturated. The lysimeter results definitely showed that leaching was involved in the losses. The pronounced decrease in bacteria during the first rain might be the result of temporary anaerobiosis or of plasmolysis since the soils were saturated; if it were due to anaerobiosis, this would make the denitrification theory quite plausible.

During the drying-out phases following rainfalls there was a consistent and recurring pattern of increase in nitrate-N as moisture decreased in the top inch of second-year fallow. The pattern was similar but the increases in nitrate-N were not as pronounced in the first-year fallow. (Fig. 2)

The relationship between daily change in nitrate-N and daily change in soil moisture for the 0- to 1-inch depth over the duration of the experiment was determined by stepwise multiple regression analysis.

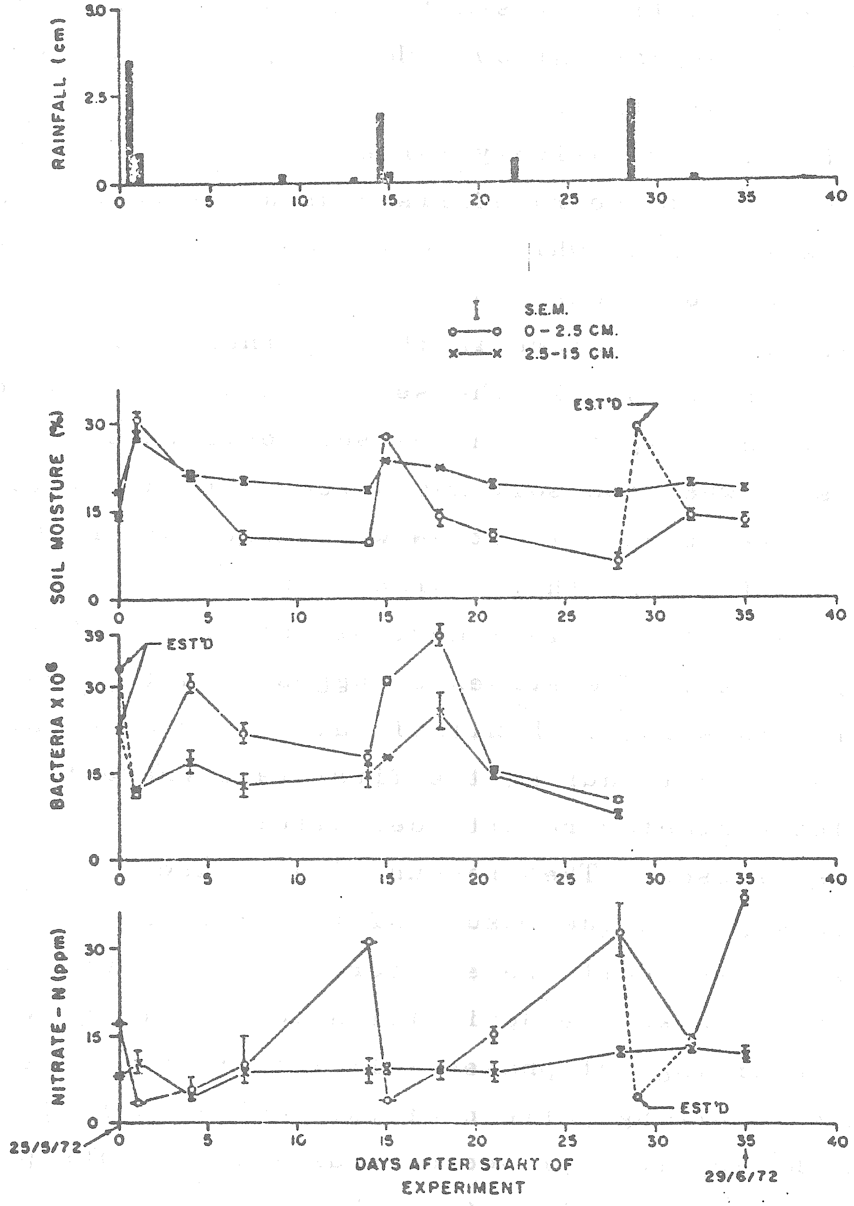

Fig. 1 Effect of rainfall on soil moisture, bacteria and NO_3-N in loam surface soil - unsheltered second-year fallow. (Bacteria are expressed as per gram O.D. soil.)

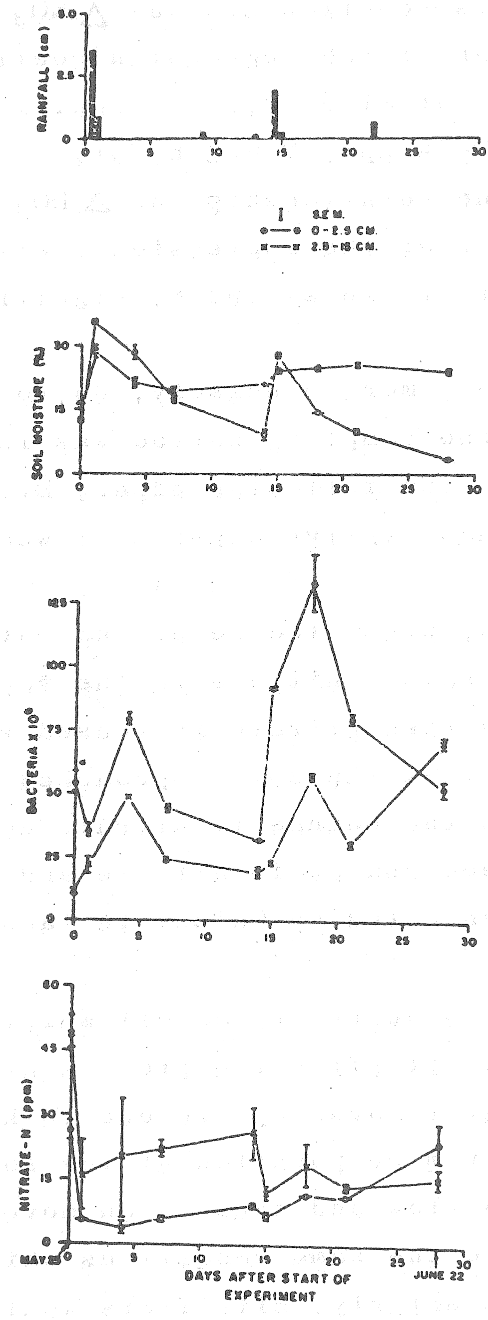

Fig. 2 Effect of rainfall on soil moisture, bacteria and NO_3-N in loam surface soil - unsheltered first year fallow. (Bacteria expressed as per gram O.D. soil.)

In first-year fallow this relationship was $\Delta NO_3\text{-}N = -0.45 - 0.56 \Delta M$ with a standard error of the regression coefficient of 0.16 and a correlation coefficient of minus 0.81*, significant at the 5% level; (Δ = daily change; NO_3 = ppm; M = % by wt).

In second-year fallow the relationship was $\Delta NO_3\text{-}N = -0.55 - 1.11 \Delta M$ with a standard error of the regression coefficient of 0.16 and a correlation coefficient of minus 0.94**, significant at the 1% level.

Thus the major portion or, more precisely, 65 to 90% of the nitrate-N vaiability during the sampling period was in response to changes in soil moisture. In the following paper, Dr. Campbell will delve more deeply into the quantitative aspects of weather-nutrient interactions.

The regression equations, presented here, indicate that when soil moisture increased - as in a rain - nitrate in the top inch decreased. If moisture decreased rapidly then nitrate increased rapidly. However, if moisture decreased slowly - as the soil approached and dried below the wilting percentage - then the change in nitrate approached zero. An inverse relationship between change in nitrate and change in soil moisture content has also been noted by Calder in laboratory experiments with Ugandan soils (1).

The response of nitrate to decreases in soil moisture can be explained equally well by the nitrification process as by a process where nitrate dissolved in water moves upward due to high suction gradients in soil resulting from evaporation at the soil surface. The conditions which favor liquid flow and thus anion movement to the soil surface due to evaporation are the same conditions which are considered optimal for nitrification. Similarly, nitrifiers would be less active at or below the wilting percentage, but evaporative losses of moisture at these low contents would be predominantly in the vapor phase thus nitrate movement would be small here too.

An analysis of the data for the period May 26 to June 22 showed that there was a negative linear relationship between change in nitrate-N and change in bacterial numbers in the top inch of first- and second-year fallow. (Table 3)

Table 3

Correlation (r) between NO_3-N and rainfall, soil moisture and soil bacteria at two depths in first-year and second-year unsheltered fallow loam

Variables$^+$	Rain	Moisture	Bacteria
<u>0 to 2.5 cm</u>			
NO_3-N, first-year fallow	-0.77*	-0.79*	-0.67*
NO_3-N, second-year fallow	-0.99**	-0.96**	-0.77**
<u>2.5 to 15 cm</u>			
NO_3-N, first-year fallow	-0.94**	-0.86**	0.05
NO_3-N, second-year fallow	0.01	0.39	0.40

$^+$ Data for all variables were expressed on a daily change basis before correlations were determined.

*, ** Denotes significance at $P < 0.05$ and $P < 0.01$, respectively.

If the production of nitrate was the result of the mineralization-nitrification process, then there should have been a positive relationship between nitrate and bacterial population levels. This indicates that the increase in nitrate in the top inch as the soil dried after rainfalls was primarily due to upward movement occurring as a result of evaporation.

It should be possible to assess the relative importance of each of the above-mentioned phenomena (responsible for nitrate increases) by looking at the behaviour of available phosphorus. The available P should increase as nitrate increases due to mineralization. However, phosphorus will not move very far in soil, so upward movement of nitrate will not be accompanied by P movement. This facet will be examined later in this paper.

In both fallow plots bicarbonate-soluble inorganic P, henceforth referred to as IP, generally exceeded bicarbonate-soluble organic P or OP. This contrasts with results reported by Halm, Stewart and Halstead for native grassland soils (2). It also lends credence to the use of the bicarbonate-soluble inorganic P fraction for determining plant-available phosphorus in cultivated soil systems.

Table 4

Correlation (r) between $NaHCO_3$ extractable organic- and inorganic-P and some selected soil and environmental factors, based on first-year fallow loam data

Variables+	Rain	Soil Moisture	NO_3-N	Bacteria	Organic-P
0 to 2.5 cm					
Organic-P	0.13	0.16	-0.56	0.00	1.00**
Inorganic-P	0.98**	0.97**	-0.76*	0.88**	0.22
2.5 to 15 cm					
Organic-P	0.72*	0.82*	-0.88**	0.32	1.00**
Inorganic-P	0.72*	0.29	-0.69*	0.21	0.36

+ Data for all variables were expressed on a daily change basis before correlations were determined.

*, ** Denotes significance at $P < 0.05$ and $P < 0.01$, respectively

In the top inch of the first-year fallow, changes in OP were not related to rainfall, moisture or bacterial population changes, but changes in IP were directly related to these three factors.

This suggests that rainfall and thus increases in soil moisture causes increases in bacterial numbers and mineralization of more soil-P to IP in the surface soil.

At the 1- to 6-inch depth, the OP fraction seemed to be more affected by environmental conditions than was the IP.

In neither soil segment was there a relationship between the two forms of bicarbonate-soluble P. This seems to indicate that the OP fraction in fallow soil is not the precursor of the IP fraction.

At both depths there was a negative relationship between in bicarbonate-soluble P and nitrate-N. If both nutrients were being changed by the same process, for example mineralization, then they should be directly related. The only process by which plant-available P could be produced is mineralization since inorganic P moves very little in soil. This then indicates that a large proportion of the nitrate increase observed in the top inch of fallow soil during the drying-out phase was the result of upward movement by physical processes rather than of the biological mineralization-nitrification process. This theory of nitrate movement into, and accumulation in the surface layer of dryland soils is further supported by the results of our earlier mentioned tracer study with chloride-36 which has shown that soluble anions can be transported upwards by evaporation.

References

1. Calder, E. A. 1957. Features of nitrate accumulation in Uganda soil. J. Soil Sci. 8:60-72

2. Halm, _et al_. 1972. The phosphorus cycle in a native grassland ecosystem. In Isotopes and Radiation in Soil - Plant Relationships Including Forestry. (Int. Atomic Energy Agency, Vienna, Austria). pp. 571-586.