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Factors Affecting the Movement and Distribution of Anions in Desert Soils

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RESEARCH MEMORANDUM

RM 72-38

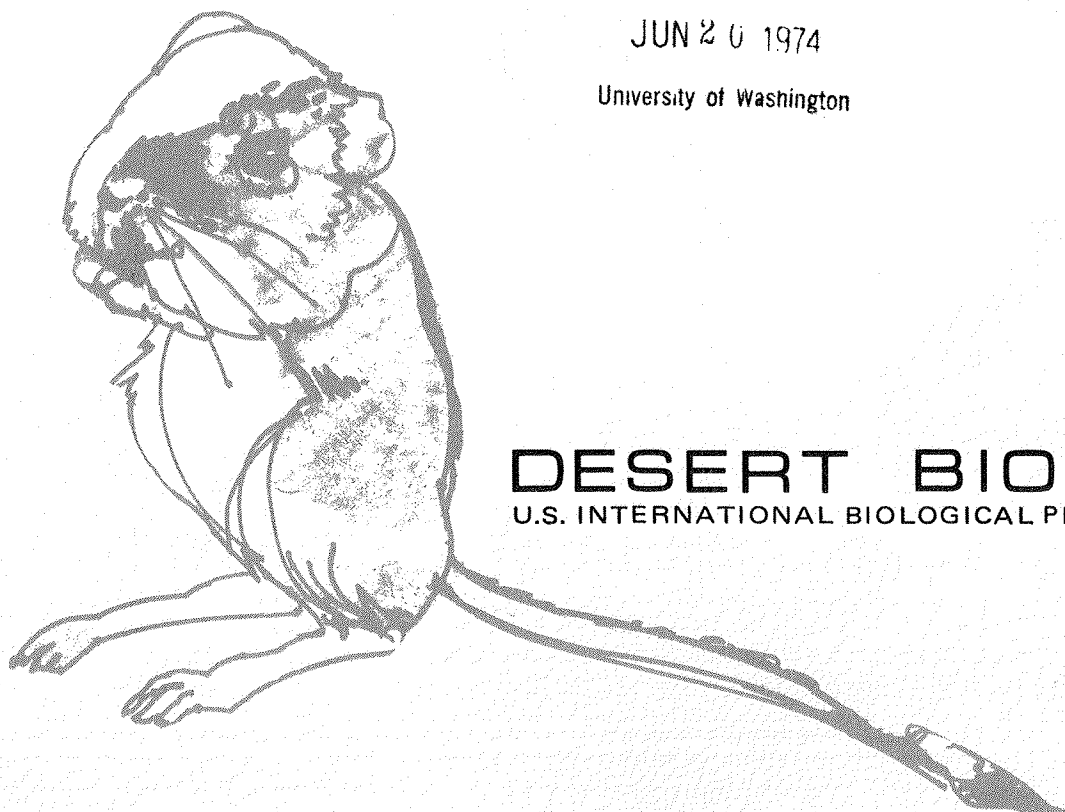
FACTORS AFFECTING THE MOVEMENT
AND DISTRIBUTION OF ANIONS IN DESERT SOILS

J.J. Jurinak & R.A. Griffin

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DESERT BIOME
U.S. INTERNATIONAL BIOLOGICAL PROGRAM

1971 PROGRESS REPORT

FACTORS AFFECTING THE MOVEMENT AND
DISTRIBUTION OF ANIONS IN DESERT SOILS

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R.A. Griffin - Other Author

Utah State University
Logan, Utah

APRIL 1972

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ABSTRACT

Research conducted in 1971 emphasized the chemical characterization of the phosphorus in the soil from the Curlew Valley site. Soil sampling was initiated in April 1971 and continued on a monthly basis in both the crested wheatgrass and sagebrush communities. Soil sampling was to a depth of 160 cm. The pattern of soil phosphorus distribution in the soil with depth was identical in both plant communities. No seasonal variation in plant-available phosphorus or in phosphorus distribution in the soil could be detected.

A limited study was completed concerning the fractionation of inorganic soil phosphorus (P). The results show that 75-90% of the total soil P was in the inorganic form. The calcium phosphate form was predominate (80%) whereas aluminum phosphates accounted for 8-10% and iron phosphates 1-2% of the amount in the calcium form. The calcium phosphate system regulates the concentration of P in the soil solution.

All profiles analyzed from the Curlew Valley site are classified agronomically as phosphorus deficient below the 15 cm depth, i.e., available P < 10 ppm. Available P was highest (25-30 ppm) in the surface (0-3 cm) crust. These data suggest that adequate levels of phosphorus are being supplied to vegetation from only a relatively shallow layer of surface soil.

Organic P distribution in the profile was found to be the inverse of the inorganic fraction. Maximum organic P was found at depths corresponding to regions of maximum root density. About 20-25% of the total P in this region was analyzed as organic P. The percentage of organic P decreased with increasing depth to about 3% of the total P.

The highest concentration of total P was found at the 0-3 cm depth, where the concentration varied between 900-1100 ppm. The total P concentration decreased rapidly with depth and reached a minimum concentration (500-550 ppm) in the depth interval of 28-40 cm. Below a depth of 70 cm, the total concentration of P was constant at 600-700 ppm. These data suggest no cycling of P occurred below a depth of 70 cm.

Moisture and total salt data collected monthly indicate a marked salt accumulation at the lower boundary of moisture penetration. The moisture content did not change significantly below the 70 cm depth. These data, coupled with the phytotoxic levels of salt below this depth, have led to the conclusion that only the upper 70 cm of soil is active in nutrient cycling. The soil P distribution also supports this contention.

The values of soil boron concentration were from 0.2 to 3.3 ppm in the rooting zone of the soil and were not considered as limiting to desert plant growth.

The thermodynamic solubility model for the calcium-phosphate mineral system in Curlew Valley was constructed. Tentative results showed that the mineral form of phosphorus in the surface crust would be estimated by the solubility expression for octo-calcium phosphate $[\text{Ca}_4\text{H}(\text{PO}_4)_3 \cdot 3\text{H}_2\text{O}]$. In the 3-160 cm depth, the soil solution was supersaturated with respect to hydroxyapatite $[\text{Ca}_{10}(\text{OH})_2(\text{PO}_4)_6]$ but undersaturated with respect to octo-calcium phosphate. Although no definitive mineral form could as yet be determined, the soil P concentration boundary conditions were established.

For ease in thermodynamic modeling, a study was conducted that showed the relationship between ionic strength, which is used in the calculation of activity coefficients of ionic species, and the electrical conductivities of soil extracts and natural waters. This was:

$$I \approx .015 \text{ EC}$$

where I = the ionic strength, and EC = millimhos/cm at 25°C . This relationship was found to hold to an EC value of 27 millimhos/cm. The values of the activity coefficients calculated by this equation were verified by various methods. This relationship allows the ionic strength of a solution to be determined without the necessity of chemically analyzing the system.

INTRODUCTION

To achieve the stated goals of the Desert Biome, it is pertinent and necessary to have knowledge of the factors affecting the movement and distribution of plant nutrient elements in desert soils. Chemical characterization of the soil provides a basis for defining the ionic species involved which in turn is used in the development of predictive relationships.

Soil phosphorus is important because of its relationship to the nutrition of native vegetation. Plant nutrient availability is a major ecological factor in determining plant biomass production and distribution. To provide the information needed to evaluate the cycling of phosphorus in the ecosystem, the intensity, capacity and kinetic factors which regulate the movement and distribution of soil phosphorus in the profile are being studied. The data produced will be vital in the ultimate modelling of biomass distribution and production among the biota as well as the flow of energy and matter within the ecosystem.

OBJECTIVES

Research conducted in 1971 was primarily directed toward the chemical characterization of soil phosphorus in the soils of the Curlew Valley site of the Desert Biome. The distribution, form and movement of this nutrient in the soil received particular attention.

To gain insight into the capacity and intensity factors operating during the cycling of phosphorus in both the crested wheatgrass (*Agropyrum desertorum*) and sagebrush (*Artemisia tridentata*) communities, the soil phosphorus was fractionated into its organic and various inorganic components. Soils were sampled and the data obtained throughout the year. In this way, information was also gained about the seasonal variation of phosphorus in the soil profile as a function of plant community.

Initially, a short study was conducted to determine if the boron concentration in the Curlew Valley soils was of a magnitude to limit plant growth.

The objectives of the initial year's research differ from those of the original proposal in that emphasis was placed on phosphorus whereas other anions in the soil system were monitored only by means of specific conductance. Nitrate nitrogen was not studied to avoid duplication of effort with other Biome investigators. In addition, soil column studies in the laboratory were deleted.

METHODS

Soil sampling was initiated on April 10, 1971, at the Curlew Valley site. The sampling was carried out at monthly intervals in both the crested wheatgrass and sagebrush communities. Samples were taken with a 3-inch barrel auger at designated depths up to 160 cm.

Chemical characterization of soil phosphorus (DSCODE A3UJD01) and total chemical analysis of soil extracts (DSCODE A3UJD02) were carried out by standard methods (Black, 1965). Electrical conductivity (EC) of the soil extract was measured with a Beckman model RC-19 conductivity bridge using a 2-ml pipette cell with a cell constant of 1.00. Percent soil water was determined gravimetrically. Calcium ion activity was measured with an Orion calcium specific ion electrode. Carbonate and bicarbonate concentrations were

determined by titration with H₂SO₄. Sulfate was measured turbidimetrically. Chloride was determined by electrometric titration with AgNO₃. Boron was measured using the carmine dye method. Available phosphorus is considered to be the sodium bicarbonate soluble fraction. Organic, inorganic and total phosphorus were analyzed by the standard ignition method.

Phosphorus in solution was measured by the ascorbic acid method (Watanabe and Olsen, 1965). The inorganic soil phosphorus was fractionated (DSCODE A3UJD04) by the procedure of Chang and Jackson (1957).

Solubility criteria for the existence of calcium phosphate minerals were determined by the method of Clark and Peech (1955) which was modified to include the octo-calcium phosphate solubility expression reported by Lindsay and Moreno (1960).

FINDINGS & DISCUSSION

The data showing the boron distribution with depth in the soils of the Curlew Valley site are presented in Table 1. These values for boron are low in the rooting zone and are not considered to be at a concentration that is detrimental for growth of desert plant species. It was concluded that boron toxicity was not a factor limiting plant growth at the Curlew Valley site. It was therefore eliminated from consideration as a possible constraint in modelling of the soil system.

In desert regions, the limited rainfall precludes the possibility of drainage. Such situations usually lead to a distinct accumulation of salts at the lower boundary of moisture penetration. This point is well demonstrated by the data collected during 1971. Figures 1 and 2 illustrate the moisture distribution in the soil profile for the months of May and September, respectively. The data show that the depth of maximum moisture penetration was 70-90 cm in May, which was the wettest month during the 1971 growing season. The month of driest soil was September. The data illustrate that practically no change occurred in the soil moisture content below the 70-90 cm depth. The upper profile, however, had lost a considerable amount of moisture. The moisture content below the 70-90 cm depth remained at approximately 14-15% for the entire year. These data also suggest that there was no significant difference in the moisture distribution between site 1 (sagebrush) and site 2 (crested wheatgrass).

Table 1. Boron distribution with depth at Curlew Valley during January and April.

Depth cm	Crested Wheatgrass April	Sagebrush April	Sagebrush January
0-3	1.6	0.8	0.2
3-15	1.1	0.7	0.3
15-28	1.0	-	0.2
28-40	0.9	3.3	0.4
40-70	1.3	2.6	0.2
70-90	1.6	2.4	0.9
90-108	-	2.4	1.4
108-135	1.7	5.3	1.9
135-160	3.3	4.6	2.6

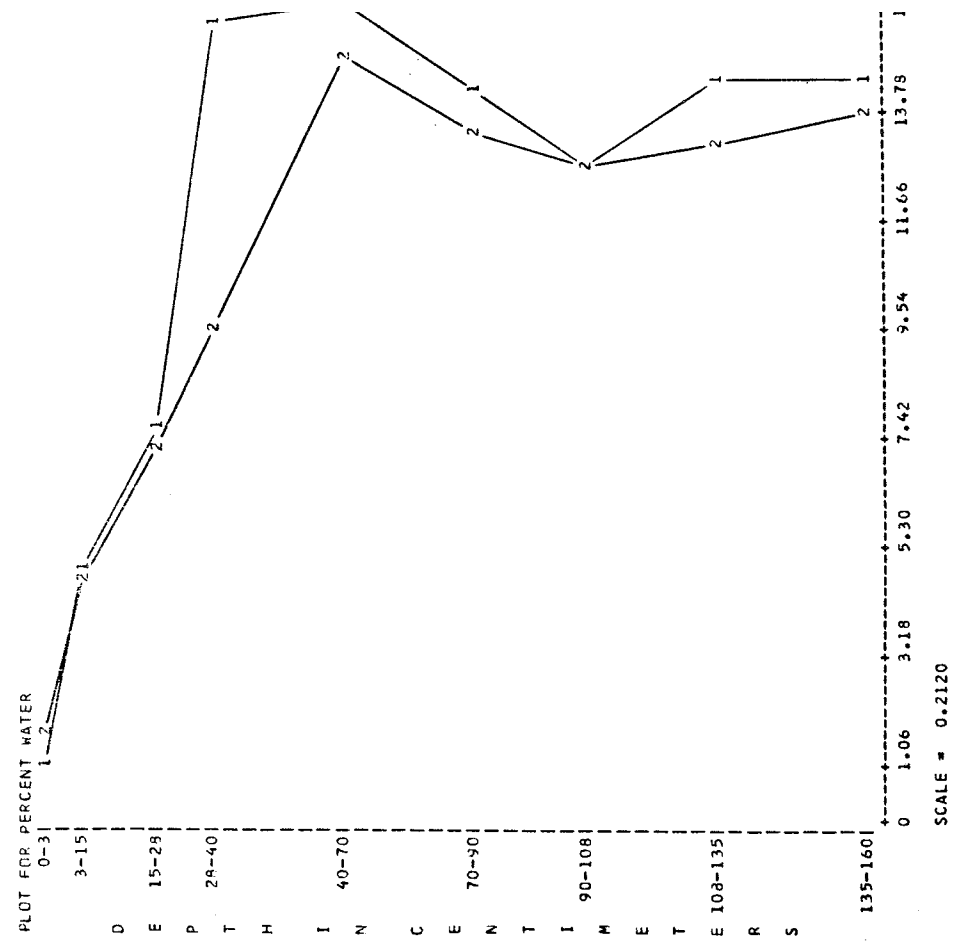


Figure 1. Moisture distribution in the profile sampled May 12, 1971, for sagebrush (1) and crested wheatgrass (2).

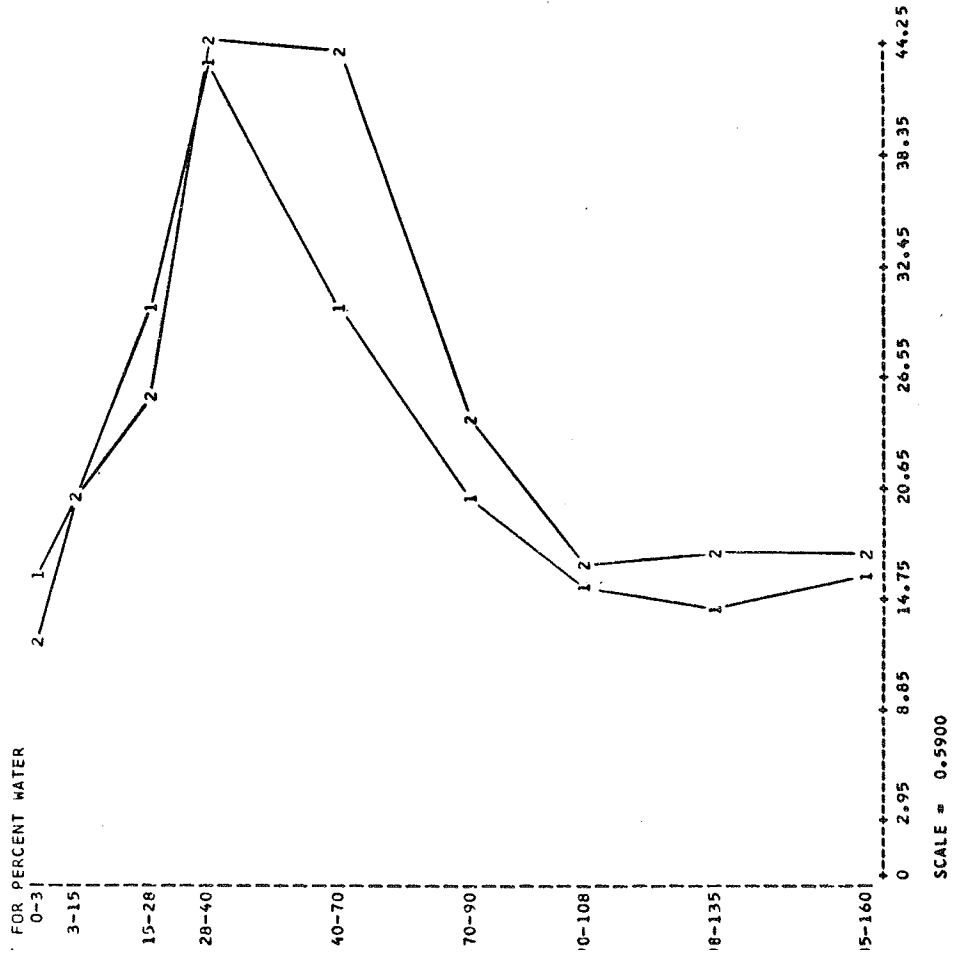


Figure 2. Moisture distribution in the profile sampled September 10, 1971, for sagebrush (1) and crested wheatgrass (2).

Figures 3 and 4 illustrate the total salt distribution in the profile, as measured by electrical conductivity, for the months of May and September, respectively. These data show the marked accumulation of salts at approximately the lower boundary of moisture penetration as shown in Figure 1. The zone of high salt accumulation was essentially static in the profile during the entire growing season.

These results are significant in that they suggest that only the upper 70 cm of soil is suitable for active root growth. Below a depth of 70 cm, both the low moisture and the high salt concentrations would be expected to drastically limit root activity. The evidence leads to the conclusion that only the total amount of nutrients in the upper 70 cm of soil need be considered when modelling the nutrient cycle at the Curlew Valley site of the Desert Biome.

This conclusion is further substantiated by the data for both total and inorganic phosphorus (Figures 5, 6, 7, and 8). The data show an accumulation of phosphorus on the surface with decreasing concentrations with depth down to a minimum at the 28-40 cm depth. The phosphorus concentration then increased to approximately the 70 cm depth where it remained constant with depth for the remainder of the profile. This pattern is constant for both inorganic and total phosphorus throughout the year and in both plant communities.

These data are interpreted to indicate a transfer of phosphorus by the plant from the rooting zone to the surface via leaf fall and plant tissue decay. The fact that the phosphorus concentration remains constant below 70 cm corroborates the conclusion that only the upper 70 cm of soil is active in nutrient cycling. The data for the lower depths further suggest that the total indigenous phosphorus content of the original soil material was between 600-700 ppm.

The data also indicate that between approximately 70-95% of the total phosphorus in the profile is in the inorganic fraction.

The data for the distribution of organic phosphorus in the profile during the months of May and September are shown in Figures 9 and 10, respectively. The distribution of the organic phosphorus fraction in the profile is approximately the inverse of the inorganic phosphorus. Organic phosphorus has its maximum accumulation at the depths of minimum inorganic phosphorus. Maximum concentrations were found to correspond to those soil depths where maximum root activity would be expected. These data suggest that the organic phosphorus in these soils is associated with plant root activity.

The plant-available phosphorus fraction data are presented in Figures 11 and 12. Tables 2 and 3 present the data of Figures 1-12 in summary form. In all profiles analyzed from the Curlew Valley site, the soils would be classified as phosphorus deficient below the 15 cm depth (i.e., available P < 10 ppm). The plant available phosphorus was found to be highest (25-30 ppm) in the surface crust (0-3 cm).

These results, based on agronomic criteria, suggest that phosphorus is being supplied to plants from a relatively thin layer of surface soil and that phosphorus deficiency may occur under certain conditions.

In terms of a nutrient cycle model, if a vector for phosphorus removal, such as grazing cattle, is introduced into the cycle, depletion of the plant-available phosphorus may occur rapidly. The result could be phosphorus deficient soils and reduced biomass production. Therefore the rate of phosphorus removal from the cycle and the rate of replenishment of plant-available phosphorus by the soil are important parameters which need to be determined in order to model the phosphorus cycle in the desert ecosystem.

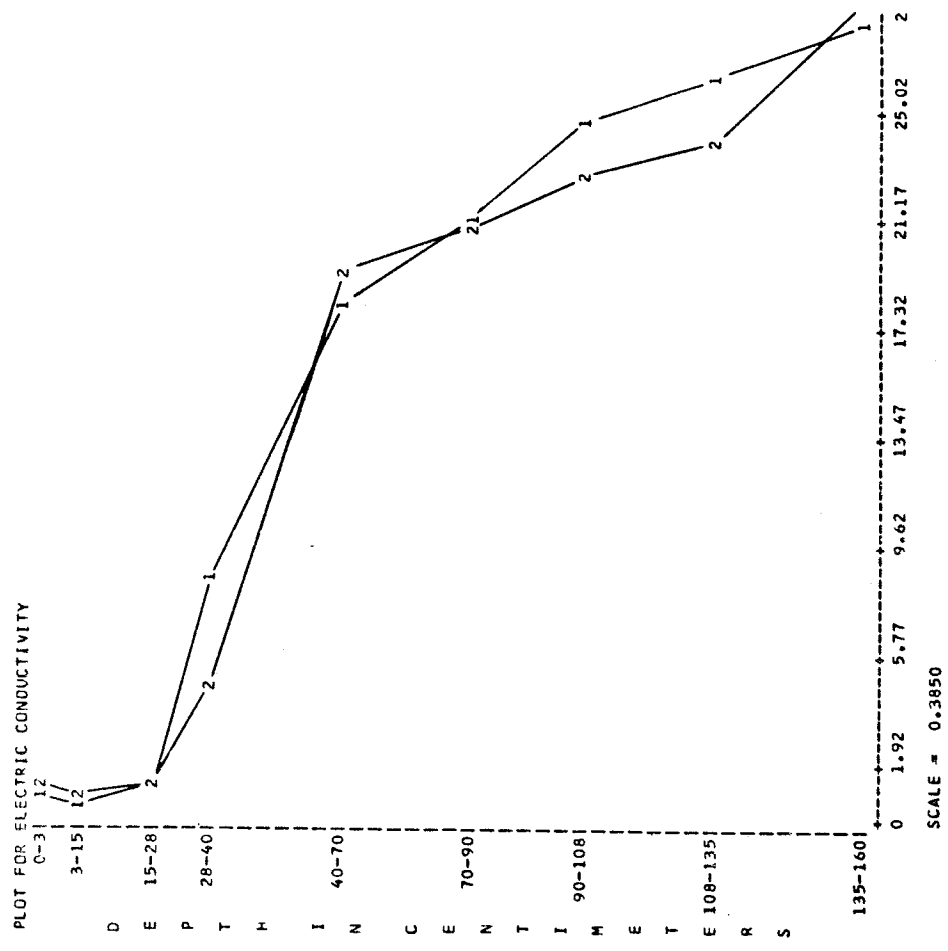


Figure 4. Total Salt (E.C.) distribution in the profile sampled September 10, 1971, for sagebrush (1) and crested wheatgrass (2).

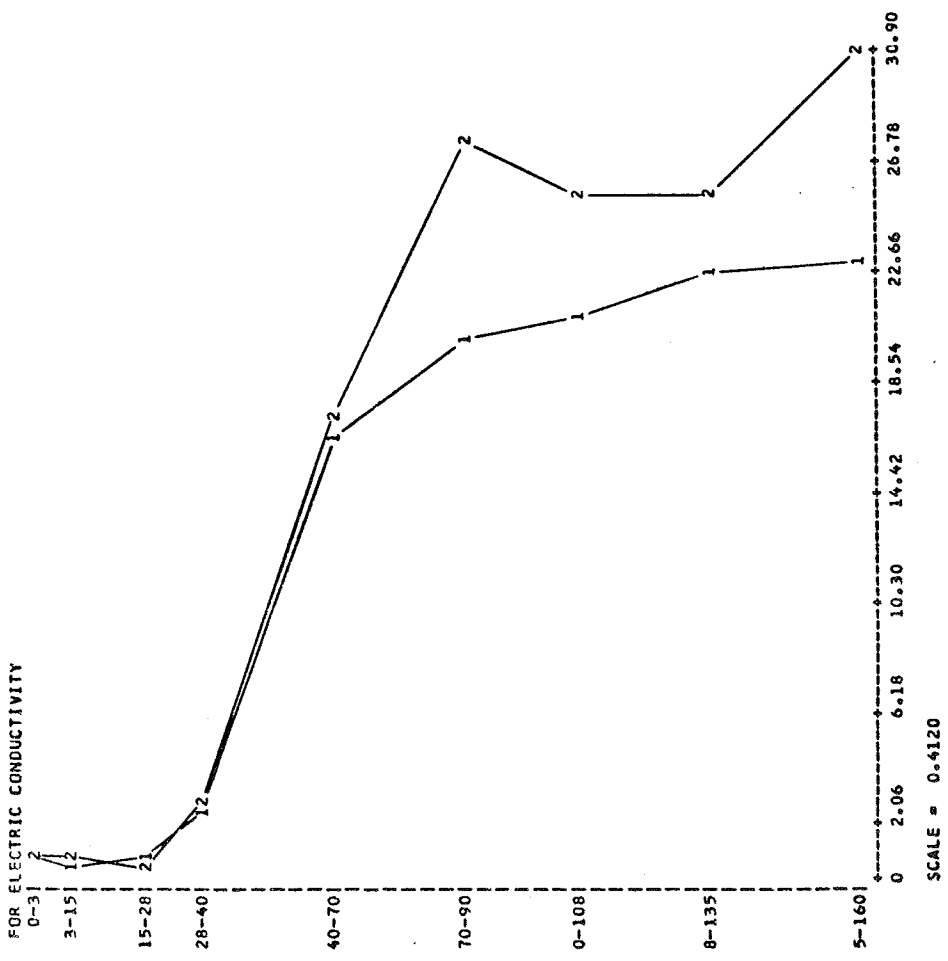


Figure 3. Total salt (E.C.) distribution in the profile sampled May 12, 1971, for sagebrush (1) and crested wheatgrass(2).

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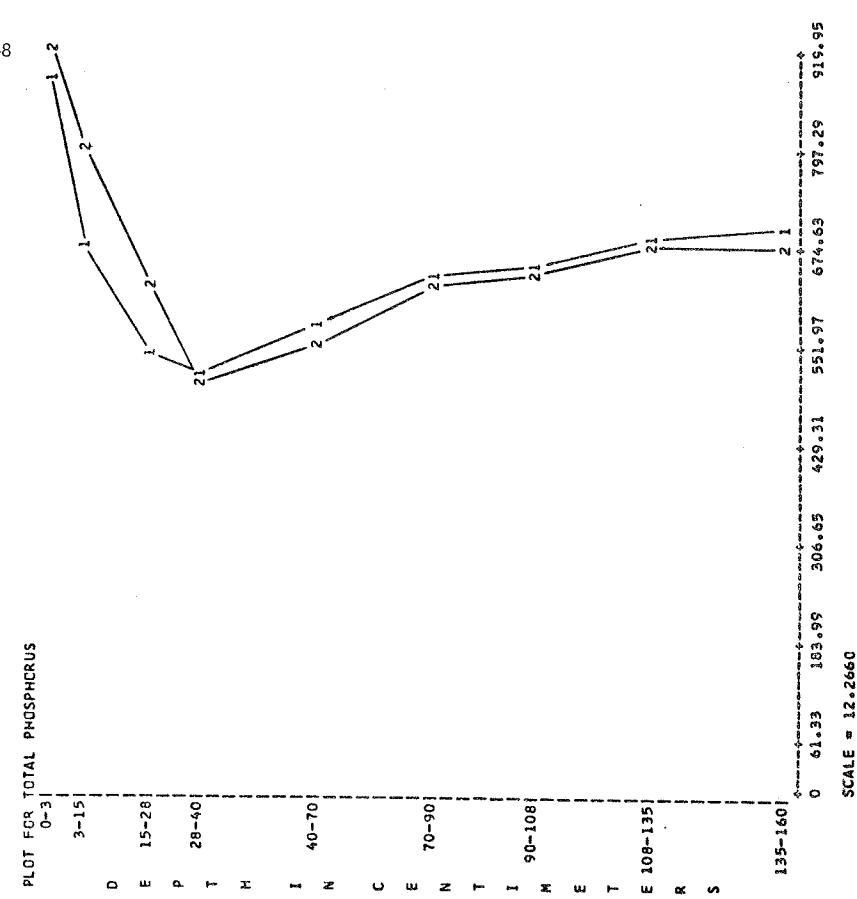


Figure 5. Total phosphorus distribution in the profile sampled May 12, 1971, for sagebrush (1) and crested wheatgrass (2).

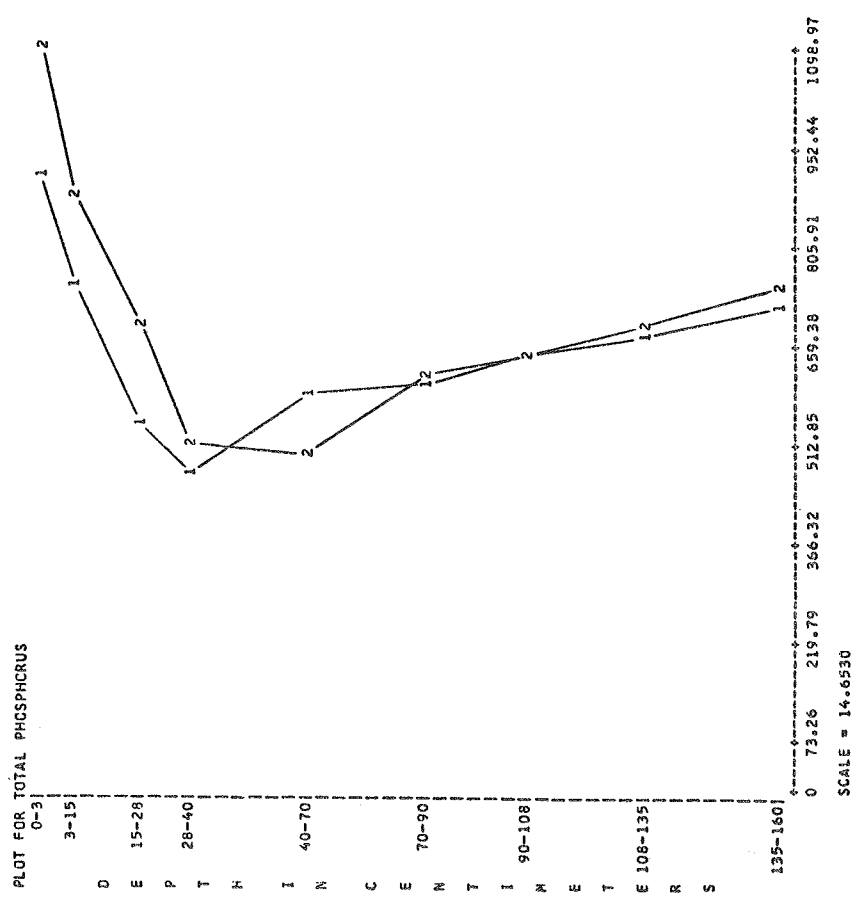


Figure 6. Total phosphorus distribution in the profile sampled September 10, 1971, for sagebrush (1) and crested wheatgrass (2).

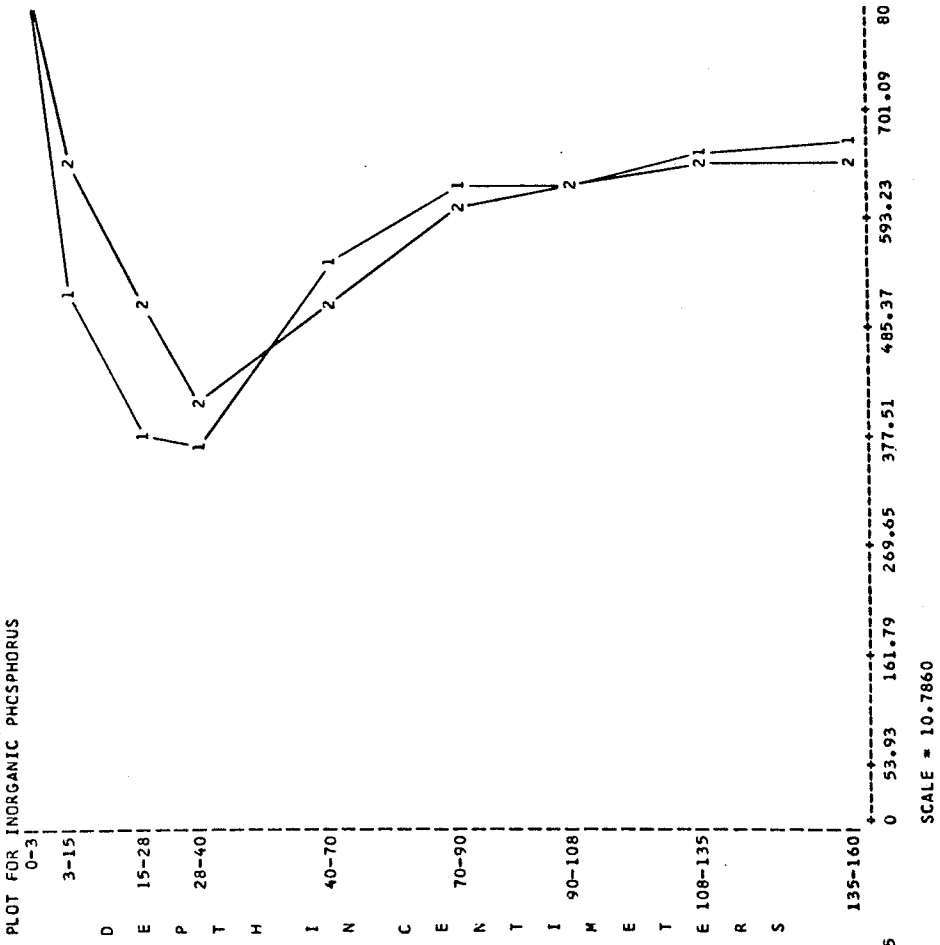


Figure 7. Inorganic phosphorus distribution in the profile sampled May 12, 1971, for sagebrush (1) and crested wheatgrass (2).

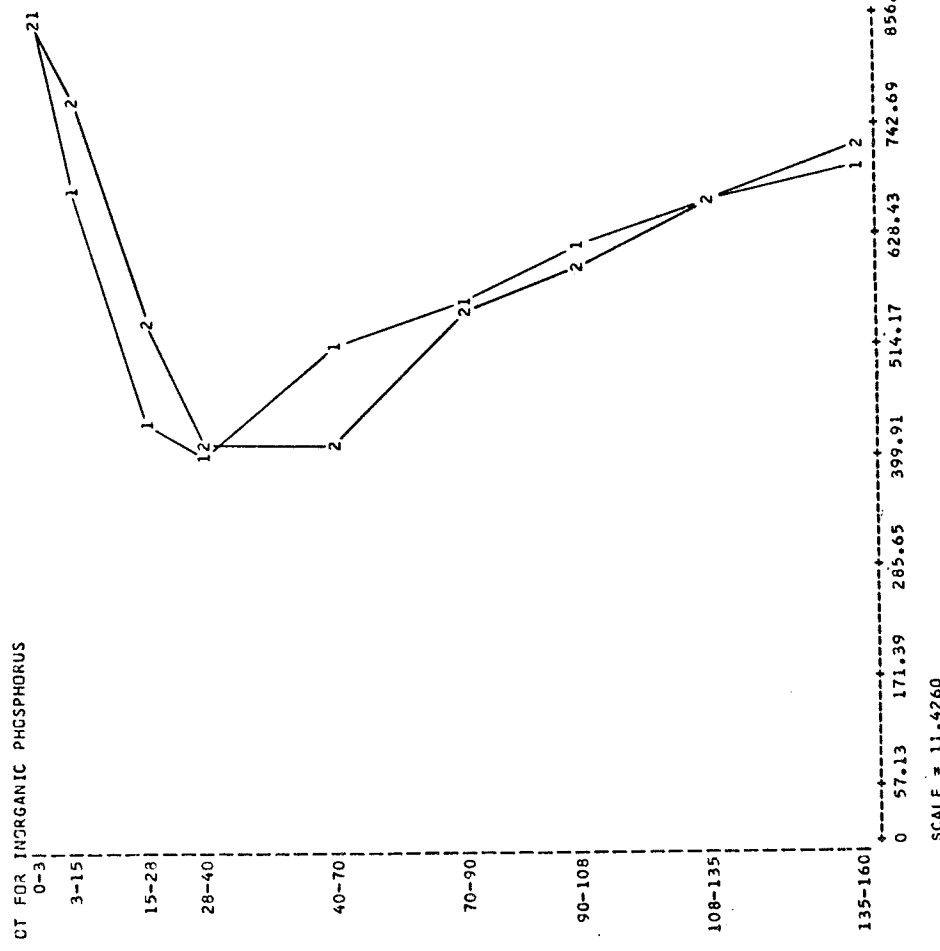


Figure 8. Inorganic phosphorus distribution in the profile sampled Sept. 10, 1971, for sagebrush (1) and crested wheatgrass (2).

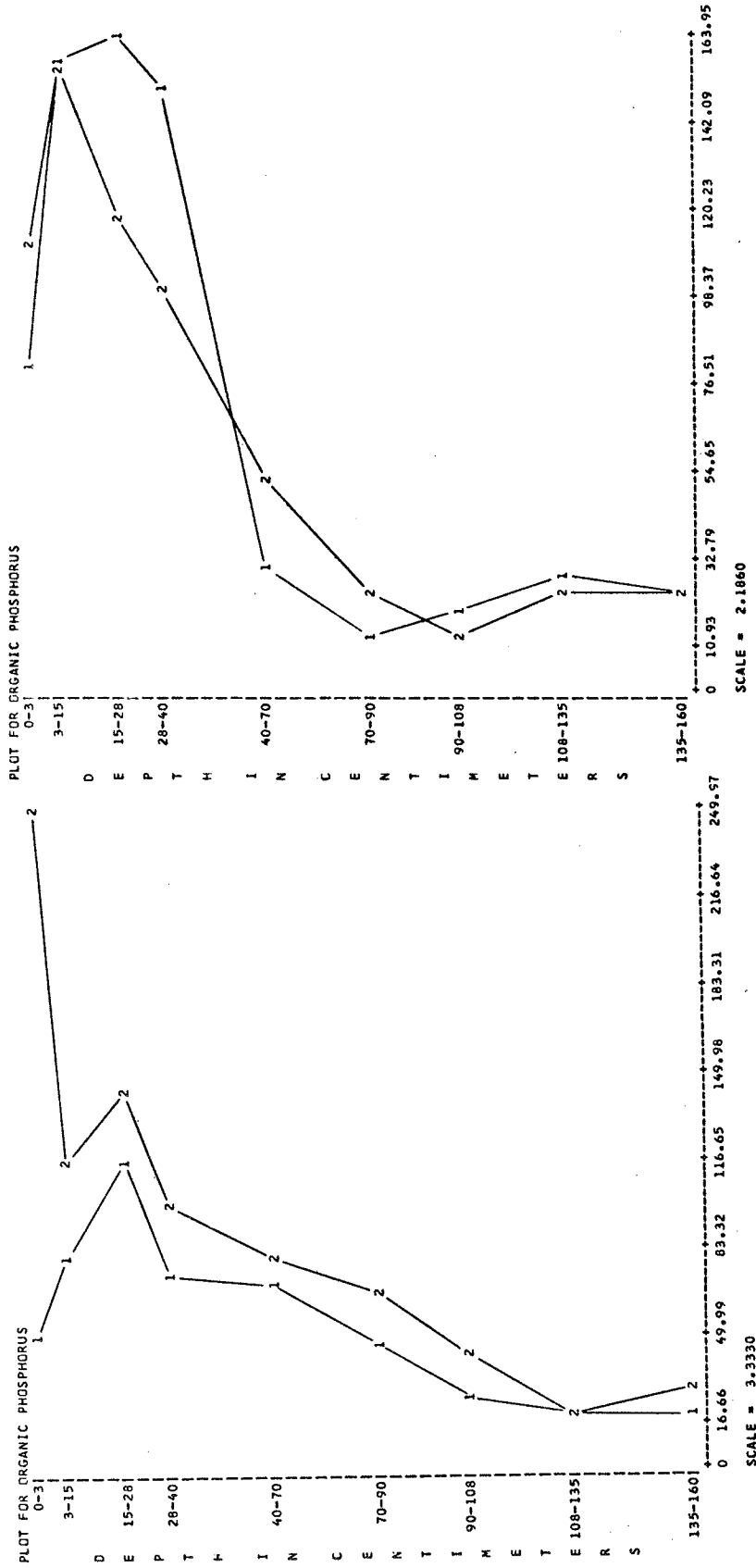


Figure 9. Organic phosphorus distribution in the profile sampled May 12, 1971, for sagebrush (1) and crested wheatgrass (2).

Figure 10. Organic phosphorus distribution in the profile sampled Sept. 10, 1971, for sagebrush (1) and crested wheatgrass (2).

Table 2. Summary of data presented in Figures 1-12 for profiles sampled May 12, 1971, for sagebrush (top) and crested wheatgrass (bottom).

Depth Centimeters	Percent Water	Electric Conductivity	Inorganic Phosphorus	Total Phosphorus	Plant Available Phosphorus	Organic Phosphorus
0-3	15.90	0.92	857.00	907.00	25.50	50.00
3-15	19.80	0.47	672.00	753.00	14.20	81.00
15-28	30.20	0.78	430.00	546.00	2.60	116.00
28-40	43.30	2.37	403.00	476.00	1.70	73.00
40-70	30.20	16.34	511.00	580.00	3.00	69.00
70-90	19.90	20.03	561.00	607.00	2.60	46.00
90-108	15.40	20.96	622.00	649.00	2.20	27.00
108-135	13.90	22.53	661.00	680.00	2.50	19.00
135-160	15.70	22.87	695.00	715.00	4.70	20.00
0-3	12.50	0.87	849.00	1099.00	30.50	250.00
3-15	19.90	0.72	761.00	876.00	12.60	115.00
15-28	25.10	0.57	542.00	684.00	6.60	142.00
28-40	44.30	3.08	415.00	515.00	2.60	100.00
40-70	43.80	17.25	411.00	492.00	3.00	81.00
70-90	24.40	27.73	553.00	619.00	2.60	66.00
90-108	16.80	25.40	596.00	638.00	2.00	42.00
108-135	16.90	25.70	664.00	684.00	2.50	20.00
135-160	17.00	30.90	715.00	745.00	3.60	30.00

Table 3. Summary of data presented in Figures 1-12 for profiles sampled September 12, 1971, for sagebrush (top) and crested wheatgrass (bottom).

Depth Centimeters	Percent Water	Electric Conductivity	Inorganic Phosphorus	Total Phosphorus	Plant Available Phosphorus	Organic Phosphorus
0-3	1.10	0.69	808.00	888.00	26.60	80.00
3-15	4.80	0.44	516.00	673.00	5.90	157.00
15-28	7.60	0.97	377.00	541.00	2.20	164.00
28-40	15.40	8.48	370.00	520.00	2.50	150.00
40-70	15.90	17.92	551.00	582.00	2.00	31.00
70-90	14.30	21.05	621.00	634.00	2.20	13.00
90-108	12.70	24.81	628.00	648.00	2.70	20.00
108-135	14.40	26.27	655.00	683.00	4.60	28.00
135-160	14.50	27.99	673.00	697.00	6.60	24.00
0-3	1.80	1.00	809.00	920.00	28.70	111.00
3-15	4.70	0.66	643.00	799.00	10.20	156.00
15-28	7.20	1.04	509.00	626.00	4.80	117.00
28-40	9.60	4.62	405.00	505.00	4.50	100.00
40-70	14.90	19.27	502.00	554.00	2.20	52.00
70-90	13.40	20.91	602.00	626.00	2.00	24.00
90-108	12.80	22.78	626.00	640.00	2.80	14.00
108-135	13.10	23.94	650.00	675.00	3.40	25.00
135-160	13.70	28.90	650.00	675.00	4.80	25.00

Further chemical characterization of the inorganic portion of the soil phosphorus yielded the data shown in Figure 13. The results indicate that calcium phosphates were the predominate solid phase of phosphorus with aluminum-phosphates constituting only 8-10% and iron-phosphates 1-2% as much as the calcium forms. These data are significant in terms of a nutrient cycling model because the solubility of calcium phosphate minerals will largely determine soil solution phosphorus concentrations. As a first approximation, the iron and aluminum phosphates may be ignored with little resultant loss of predictive power.

To determine one of the constraints involved in modelling the phosphorus cycle, an attempt was made to identify the predominate mineral form of phosphorus in the profile and at the same time develop an expression of its solubility. Previous data have suggested that calcium-phosphates constitute the major reservoir of inorganic phosphorus in the soil. To identify the solid phase, a thermodynamic model of the calcium phosphate mineral system in Curlew Valley soil was constructed. A necessary requirement for the thermodynamic model is that a knowledge be gained of the ionic strength of the soil solution from which the activity coefficients of the ionic species in the soil solution can be calculated.

For ease of modelling, a study was conducted which showed the relationship between the ionic strength and the electrical conductivities of the soil solution extracts. The relationship between ionic strength (I) and electrical conductivity (EC) of 27 soil extracts from Curlew Valley soil and 85 irrigation waters were found to be highly correlated. The analyses of the soil extracts used in this study are shown in Table 4. Figure 14 shows the observed relationship between the calculated ionic strength and the EC of soil extracts, irrigation water and pure electrolyte solutions. The ionic strength was calculated from the expression, $I = 1/2 \sum z_i^2 m_i$, where m_i is the molar concentration of each ionic specie in solution and z_i is the valence of each specie. The linear regression for all solutions whose EC was less than 27 millimhos/cm was

$$Y = .015X + .001$$

or

$$I \approx .015 \text{ EC} \quad (1)$$

where EC is in millimhos/cm at 25°C. The relationship shown in equation (1) corroborates the findings of Ponnampetuma et al. (1966) who investigated solutions which were considerably less saline. It was noted that EC measurements greater than 27 mmhos/cm deviated from equation (1). This result is ascribed to the high concentration of Mg^{++} , Ca^{++} and $SO_4^{=}$ in the soil extracts (see Table 4). These ions are active in forming ion pairs. The presence of ion pairs would be expected to reduce the EC of a solution at any given ionic strength. Ion pair formation is considered the basic property of solutions which determines the positive or negative deviation from equation (1).

The regression lines for pure $MgSO_4$ and $NaCl$ solutions (Ponnampetuma et al., 1966) are considered as the limit of error possible when using equation (1). The intermediate position of natural water and soil extracts exemplified the mixed ion nature of the solutions. The effect of ion pair formation on equation (1) is currently under study. It is expected that ion pair formation will be important at higher salt concentrations.

The ionic strength is used to calculate the activity coefficient, γ , which is used to convert ionic concentration, m , to ionic activities, a . The relation used is $a = \gamma m$. The activity coefficient is calculated by use of the familiar Debye-Hückel equation (Garrels and Christ, 1965).

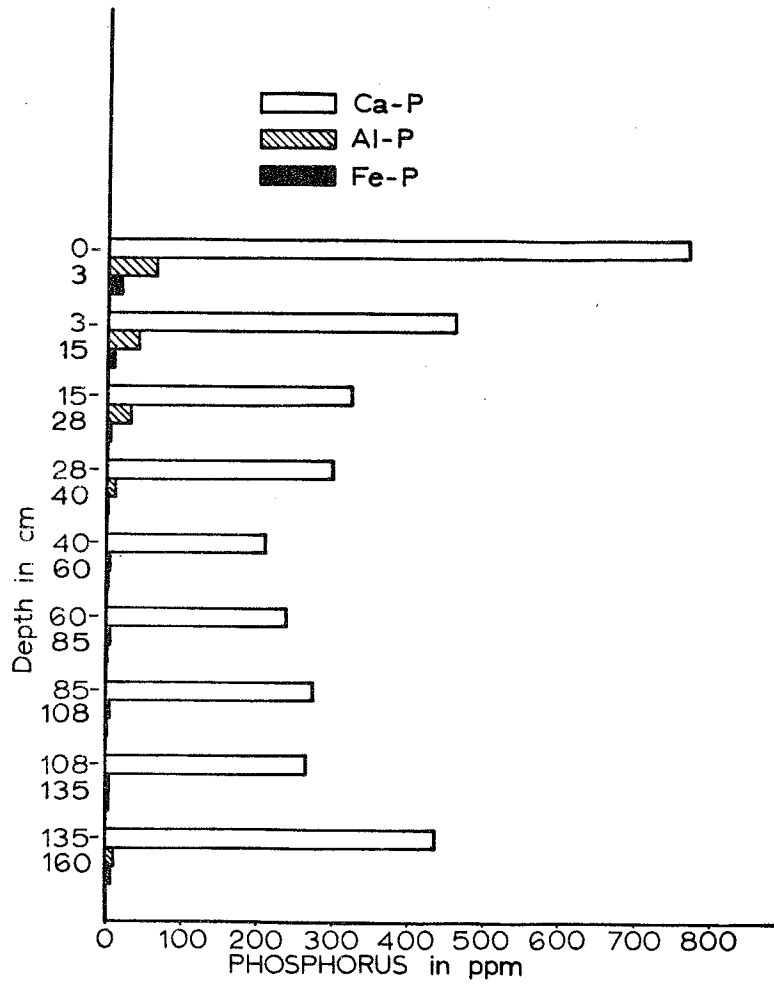


Figure 13. Fractionation of inorganic phosphorus with depth in Curlew Valley soil.

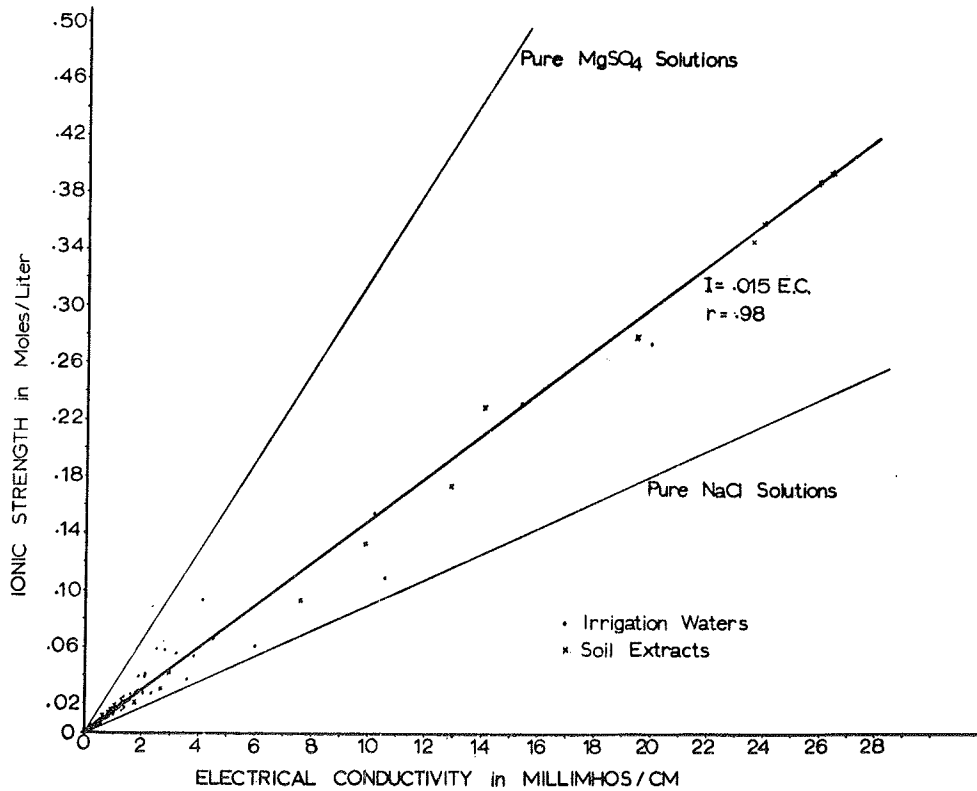


Figure 14. Relationship between ionic strength and electrical conductance of natural aqueous solutions.

Table 4. Chemical analysis of saturation extracts from three profiles located at the US/IBP Great Basin Desert Biome site in Curlew Valley, Utah.

Depth in cm	concentration in moles/liter										Activity in moles/liter		Ionic Strength	E.C. mmhos/cm	
	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	HCO ₃ ⁻	CO ₃ ⁻	SO ₄ ⁻	Cl ⁻	aCa ⁺⁺	I					
Site 1															
0-3	.00194	.00042	.00221	.00249	.00612	.00101	.00111	.00220	.00130	.015	0.78				
3-13	.00172	.00042	.00168	.00113	.00448	.00092	.00126	.00170	.00120	.013	0.62				
13-25	.00138	.00048	.00245	.00134	.00397	.00092	.00109	.00250	.00090	.013	0.68				
25-33	.00099	.00038	.00324	.00178	.00410	.00138	.00092	.00320	.00064	.013	0.66				
33-48	.00053	.00020	.00827	.00171	.00509	.00129	.00153	.00830	.00030	.019	0.91				
48-69	.00030	.00008	.01094	.00095	.00701	.00184	.00161	.01090	.00019	.023	1.02				
69-94	.00038	.00026	.03015	.00145	.00443	.00092	.00253	.03020	.00090	.042	3.02				
94-137	.00246	.00030	.11671	.00288	.00196	.00037	.00334	.11700	.00090	.132	10.86				
137-165	.00395	.00049	.15000	.00323	.00186	.00018	.00349	.25000	.00140	.230	14.10				
Site 2															
0-3	.00226	.00061	.00272	.00247	.00335	.00023	.00090	.00061	.00140	.013	0.90				
3-15	.00059	.00019	.00399	.00160	.00217	.00023	.00112	.00120	.00035	.009	0.64				
15-28	.00049	.00022	.01240	.00322	.00217	.00014	.00256	.01084	.00030	.021	1.76				
28-41	.00309	.00273	.11686	.00616	.00180	.00009	.02039	.11650	.00125	.173	12.92				
41-71	.00732	.00880	.26555	.00445	.00203	-----	.04676	.26750	.00250	.396	26.38				
71-91	.00582	.00819	.27580	.00360	.00145	-----	.04436	.26375	.00220	.389	25.96				
91-109	.01832	.01377	.27990	.00445	.00099	-----	.11821	.26875	.00520	.578	28.54				
109-137	.02531	.01874	.33528	.00521	.00067	-----	.13298	.30750	.00690	.678	32.16				
137-157	.02474	.02076	.31989	.00521	.00055	-----	.12873	.31000	.00700	.666	32.40				
Site 3															
0-3	.00284	.00052	.00189	.00104	.00344	.00014	.00160	.001212	.00180	.014	0.80				
3-15	.00113	.00030	.00228	.00111	.00113	.00009	.00149	.00274	.00084	.010	0.65				
15-28	.00152	.00053	.01897	.00264	.00118	.00009	.00278	.02000	.00090	.031	2.72				
28-46	.00156	.00077	.06993	.00379	.00162	.00012	.00874	.06500	.00082	.093	7.58				
46-66	.00582	.00518	.20505	.00485	.00099	.00005	.02775	.19250	.00249	.279	19.47				
66-89	.00704	.00779	.26042	.00451	.00088	.00005	.03643	.24625	.00300	.359	24.02				
89-112	.00668	.00693	.24606	.00415	.00081	.00005	.03698	.24000	.00280	.347	23.57				
112-132	.02222	.01466	.26760	.00532	.00067	-----	.12651	.25375	.00690	.590	27.68				
132-152	.02348	.01678	.26760	.00573	.00067	-----	.12688	.26750	.00700	.605	28.39				

To verify equation (1), the activity coefficients of Ca^{++} were determined for 27 soil extracts using three methods. The data are shown in Table 5. The "experimental" activity coefficients were calculated by the Debye-Hückel equation with the ionic strengths computed by $I = 1/2\sum Z_i^2 m_i$, using the analytical data shown in Table 4. The "computed" activity coefficients were calculated from ionic strength values obtained from equation (1), using the Debye-Hückel equation. The "electrode" activity coefficients were computed from the ratio of the calcium ion activity, as measured by the calcium ion specific electrode, and the analytical calcium concentration. Table 5 shows good agreement between the methods for determining the activity coefficients and supports the relation shown in equation (1).

This study shows that as a first approximation in determining the ionic strength of a natural water or soil extract a measurement of the EC of the solution used in conjunction with equation (1) is sufficient. This method eliminates the necessity of conducting total chemical analyses for estimating ionic strength. It is emphasized that although the method described gives a moderately accurate approximation of ionic strength, it is not intended to replace total analyses when highly accurate thermodynamic relationships are sought.

Table 5. Comparison of calcium ion activity coefficients obtained by three different methods.

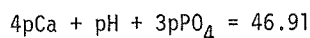
Depth in cm	Experimental	Computed	Electrode
	γCa^{++}	γCa^{++}	γCa^{++}
Site 1			
0-3	.63	.63	.67
3-13	.65	.65	.69
13-25	.65	.65	.65
25-33	.65	.65	.65
33-48	.60	.60	.57
48-69	.58	.58	-
69-94	.51	.50	.50
94-137	.37	.36	.36
137-165	.32	.33	.35
Site 2			
0-3	.65	.64	.62
3-15	.69	.68	.64
15-28	.59	.56	.61
28-41	.34	.33	.36
41-71	.27	.27	.27
71-91	.27	.27	.29
91-109	.24	.26	.23
109-137	.23	.25	.23
137-157	.23	.25	.23
Site			
0-3	.64	.66	.63
3-15	.68	.68	.74
15-28	.54	.51	.58
28-46	.41	.39	.48
46-66	.30	.29	.34
66-89	.28	.28	.33
89-112	.28	.28	.33
112-132	.24	.26	.24
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With the aid of the EC-ionic strength relationship given by equation (1), a thermodynamic model was constructed to describe the calcium phosphate system that exists in Curlew Valley. The data used for the model are shown in Table 6. The soil samples were obtained in the sagebrush community.

Table 6. Experimental data and calculated parameters for a thermodynamic model of the calcium-phosphates.

Sample	Depth (cm)	pH	E.C.	P (ppm)	Ca (ppm)	pH-1/2pCa	$\text{pH}_2\text{PO}_4 + 1/2 \text{ pCa}$
1	0-3	7.87	0.46	1.642	62.9	6.39	6.23
2	3-15	7.65	0.41	.023	38.6	6.07	7.97
3	15-28	8.49	1.17	.066	22.7	6.76	8.50
4	28-40	8.17	4.43	.015	101.5	6.71	8.55
5	40-70	8.38	5.87	.048	60.0	6.78	8.40
6	70-90	8.62	5.54	.117	35.9	6.91	8.36
7	90-108	8.58	6.03	.147	47.7	6.92	8.16
8	108-135	8.15	8.43	.045	365.2	6.92	7.84
9	135-160	8.08	8.73	.059	381.8	6.85	7.64

The thermodynamic equilibrium data used to construct the phosphate model were obtained from Lindsay and Moreno (1960). The method of plotting experimental data follows that of Clark and Peech (1955). The results of this study are shown in Figure 15. The phosphate model shows which solid-phase calcium phosphate compound regulates the phosphate activity in the profile of soil from the Curlew Valley site. All data points, except for the one representing the surface crust, lie between the calcium hydroxyapatite and the octo-calcium phosphate solubility lines. The soil solution thus appears to be supersaturated with respect to hydroxyapatite. The surface crust contains phosphorus in a more soluble chemical form than that found in the lower profile. Its solubility is closely described by the equilibrium solubility of octo-calcium phosphate. This situation is not unexpected since the soil crust is the region where one might expect that the majority of phosphate is being mineralized and hence has not had sufficient time to revert to the lesser soluble form of phosphate. The solubility of phosphorus in the surface crust may be estimated from the solubility expression of octo-calcium phosphate (Lindsay and Moreno, 1960).



In the 3 to 70 cm depth where the maximum root activity and apparent phosphorus cycling is centered, however, the model presents a more complex picture. The solubility does not appear to be regulated by any definite calcium phosphate compound, although hydroxyapatite should be the thermodynamically stable compound in this system. Rootare et al. (1962) and Deitz et al. (1964) have postulated that, in the presence of water, hydroxyapatite undergoes surface hydrolysis and forms a surface complex which regulates the ionic solubility equilibrium. If this is the case, this study suggests that the solubility product of the hypothesized surface complex is $\text{pK} \approx 77$. This is intermediate between octo-calcium phosphate ($\text{pK} = 46.91$) and calcium hydroxyapatite ($\text{pK} = 113.7$).

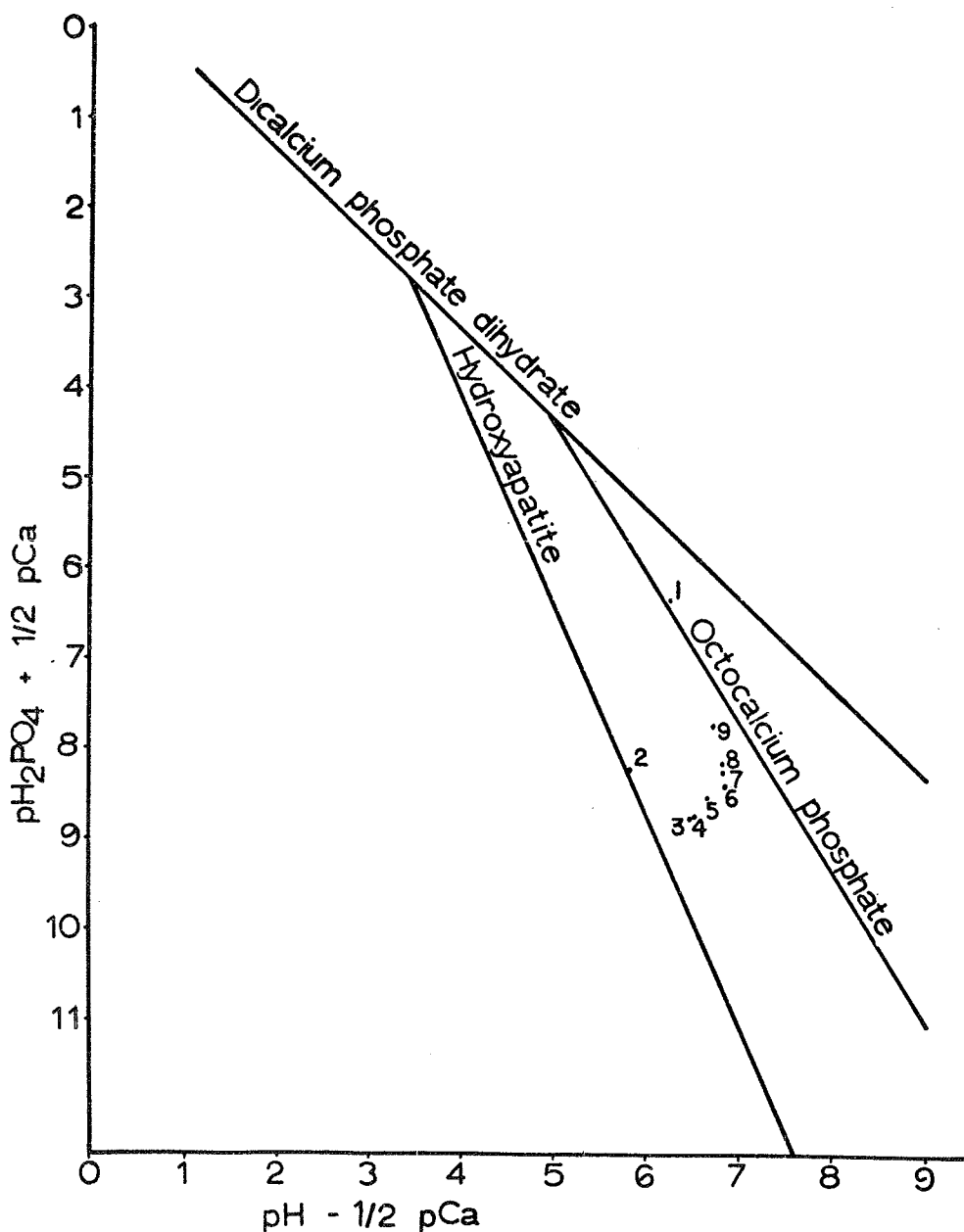


Figure 15. Solubility diagram for the calcium-phosphates with data plotted for Curlew Valley soil. Data points 1-9 correspond to depth increments shown in Figure 13.

Although no definite phosphate solubility expression can be given for the lower profile, the boundary phosphate concentrations are established. The maximum phosphorus concentration in the soil solution can be computed from the solubility expression for octo-calcium phosphate and the minimum phosphate concentration from the hydroxyapatite solubility expression.

Currently, additional phosphorus solubility data are being obtained and ion pair corrections are being applied to the analytical data to observe if data refinement will alter the conclusions obtained from the phosphorus solubility model.

EXPECTATIONS

The research conducted during 1971 yielded data which allow the capacity and intensity factors of soil phosphorus to be evaluated. In order to complete the model for estimating the flow of phosphorus in the ecosystem, kinetic studies, using anion exchange resins as a simulated plant root, will be initiated to arrive at a rate parameter which will estimate the phosphorus flux in the soil system.

To further define the phosphate flux, the phosphorus adsorption maximum will be determined on the soil of Curlew Valley. When these data are coupled with plant-available phosphorus values, the percentage saturation of the soil in phosphorus can be determined. This parameter is related to the intensity/kinetic complex of the soil which is involved in the flux of soil phosphorus to the plant root.

An important parameter in the phosphate scheme is the total amount of phosphorus cycled in the vegetative biomass. An estimate of this amount will be accomplished by an inventory of the phosphorus content of the natural vegetation, litter, and animal residues at the Curlew Valley site. The phosphorus content of the vegetation can then be coupled with the total biomass data, collected by other workers on the biome, to yield the total amount cycled in the various components. These data will be of importance in the ultimate modelling of biomass distribution and the flow of energy and matter within the ecosystem.

Soil Fertility and the Phosphorus Cycle. An important aspect of this project is to study the soil fertility level as an ecological factor in the Curlew Valley ecosystem. Data obtained in a study of this type are critical if predictions concerning human manipulation and its effect on the desert ecosystem are to be made, particularly with regard to possible agricultural use. Water is commonly considered as the major limiting factor in plant biomass production in desert regions; however, the distinct possibility exists that under a given moisture regime, the fertility status of the soil also has an important bearing on the distribution and productivity of vegetative biomass.

To determine how soil fertility affects biomass production, field plot studies at the Curlew site and greenhouse pot experiments at Utah State University will be initiated. The first study will be designed to determine if soil phosphorus or nitrogen or both are limiting factors in productivity. The field trials will be in areas fenced off to exclude grazing rabbits and cattle, the treatment plots will be delineated, and various levels of phosphate and nitrogen fertilizers will be applied alone and in mixtures. The experimental design will be a four-replicated, randomized complete block. The trials will be established in the fall of the year. The following spring and summer, herbage will be sampled for yield and chemical analyses. An attempt will be made to study both the sagebrush and crested wheatgrass communities in the field. Pot experiments, with soil obtained from the Curlew site, will be conducted in a greenhouse using crested wheatgrass or another suitable grass, and applying the same treatments as those used in the field. In this study, water will be applied as needed until harvest. In both studies, the soil will be analyzed for resin-extractable and NaHCO_3 -extractable P, which will be correlated with plant phosphorus and biomass production.

To determine the potential of the soils in Curlew Valley to sustain plant biomass production, a greenhouse pot study will be conducted with crested wheatgrass, to evaluate the phosphorus-supplying power of the soil under a simulated intensive long-term cropping or grazing sequence. Indigenous soil P will be the only source of this element whereas nitrogen will be added as needed. This study will show the ability of the soil to supply phosphorus in the absence of nutrient cycling. Both yield and phosphorus uptake by the plant will be determined after each cutting, and correlated with resin-extractable and NaHCO_3 -extractable phosphorus in the soil. The length of this study is tentatively set at 6 to 10 cuttings. The difference between the two greenhouse experiments lies in the fact that the initial pot experiment is not a long-term capacity study but essentially a study to define the fertility status of the Curlew soil in terms of its response to nitrogen and phosphorus applications on a short-term basis.

This project is primarily designed to investigate the effects of human interference within the Curlew Valley ecosystem. Essentially, the project is directed toward the inherent problems associated with the ability of the soil to supply plant nutrients as plant biomass production is increased.

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