1973

Distillation-Condensation of Water and Nutrient Movement in a Desert Ecosystem

N. Stark

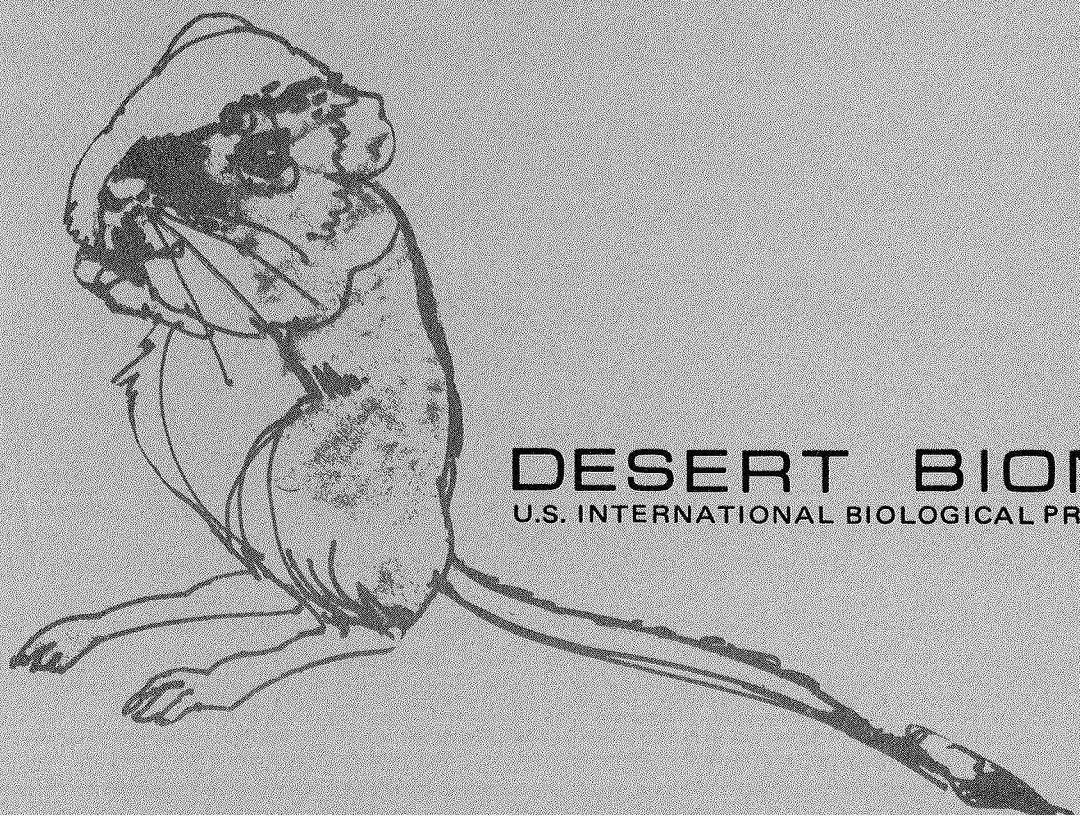
IBP

RESEARCH MEMORANDUM

RM 73-44

DISTILLATION-CONDENSATION OF WATER AND NUTRIENT MOVEMENT IN A DESERT ECOSYSTEM

N. Stark, Project Leader



DESERT BIOME

U.S. INTERNATIONAL BIOLOGICAL PROGRAM

1972 PROGRESS REPORT

DISTILLATION-CONDENSATION OF WATER AND NUTRIENT MOVEMENT IN A DESERT ECOSYSTEM

*N. Stark, Project Leader
Desert Research Institute
University of Nevada System

Research Memorandum, RM 73-44

MAY 1973

Report Volume 3

Page 2.3.5.4.

*Now at University of Montana.

ABSTRACT

Shrub vegetation on hill and wash sites in the Mohave Desert is similar in size and density. Soils immediately beneath shrubs on the hill slopes displayed a higher permeability (5 to 10 x faster infiltration) than soils of shrub interspaces, even though a raised mound of soil is formed at the base of each shrub. It is hypothesized that in addition to throughfall and stemflow, water supply to shrubs is enhanced by the micro-watershed attributes of the surrounding soil surface.

Seedling counts following a November rain (38 mm) showed that seedling density under shrubs was 10 times that in open spaces, with a higher mean weight per seedling in canopy habitats.

Evidence of variation in soil chemistry beneath shrub canopies is derived from pH values (open area 8.7, under *Larrea* 6.9, under *Franseria* 8.1, under *Atriplex* 10.2), water-holding capacity, cation exchange capacity and elemental content. The pH of the immediate environment of the plant roots proved to be acidic (5.5), and extractant solution modified to pH 5.5 released higher levels of some soil elements than NH_4OAc extraction, particularly with regard to phosphorus, although Ca was extracted at about one tenth the concentration by the acid solution. Mg and Na were also less available under acid extracting conditions. The data suggest that roots modify their immediate chemical environment to accentuate major nutrient concentrations and mollify potential toxicities. Soils beneath shrubs varied in chemical content from soils sampled in interspace areas.

Cultures of seedlings of *Larrea divaricata, Atriplex canescens* and *Hymenoclea salsola* exhibited best growth on water which was chemically equivalent (inorganically) to leachate from soil occurring in shrub interspaces. Good growth occurred on nutrient solution equal to the pH 5.5 extract, but all seedlings died when watered with a solution chemically equivalent to leachate from soil taken beneath *Larrea* plants.

Little difference was found in chemical content of *Larrea* leaves between the Rock Valley site (A.E.C. Nevada Test Site) and Dump Canyon (Death Valley). *Atriplex* leaves were high in Na, Ca, K and Mg. Dead wood tended to concentrate Ca, and other cations, while P is removed from dead wood.

Methodology was inadequate to measure the quantity or quality of condensation water.

INTRODUCTION

Nutrient cycling in deserts is little understood, and is complicated by low soil water content for much of the year, and persistently high salt content. Studies of the distillation and condensation of water in desert soils (Evenari, 1962; Stark and Love, 1969) have raised questions concerning the importance of water distributed in this manner to plants, and particularly to nutrient cycling. Soil water which goes into the vapor phase during daytime under the influence of the strong heating of the soil surface should be chemically pure and essentially "distilled water". When the soil cools at night, this water condenses on soil particles and is particularly noticeable on the undersides of larger rocks. Since the distillation-condensation process has been going on for centuries on these same rock surfaces, it is hard to believe that there could be significant amounts of soluble salts left on these rock surfaces. Also, the periods during which free or mobile soil water exist in gravelly and sandy soils such as are found on the bajadas in Death Valley, are very short, usually only a few days after storms, and since most desert plants do take up water during the 3- or 4-month growth period, water concentrated by distillation-condensation should be important to the plants. The undersides of rocks which have mats of roots during the growth phase are observed to be dry in the evening, and moist the next morning from condensation. It has been suggested that plants on gravelly or sandy soils depend heavily on distillation-condensation water during the growing season.

This pattern of water uptake leaves some unanswered questions concerning nutrient uptake. The desert soils of Death Valley have a pH of about 7.6 to 10.2 and very high salt concentrations (Ca 2900 µg/g; Mg 3,680 µg/g; Na, 1400 µg/g). Some plants, such as *Allenrolfea occidentalis* (Wats) Kuntze. and *Atriplex confertifolia* (Torr. & Frem.) Wats. are well adapted to salty soils, and actually store large amounts of some of the abundant cations. Some of the plants which grow on the gravelly and sandy soils in Death Valley, however, are adapted to concentrate only moderate amounts of salts and are found mainly on the drier soils. *Larrea divaricata* Cav. and some annuals are much lower in salt content than is *A. confertifolia* which grows in the same soils. If the ephemeral soil solution, which is quite alkaline (pH 8.8-10.0) and high in salts is the main nutrient supplier, then the low-salt-tolerant plants must be highly selective in elemental uptake.

Observations show that existing individuals of the three dominant plants mentioned above nearly always have some dead organic matter associated with the root system. Often this is a dead root system from a plant which inhabited the spot much earlier, or it may be parts of the existing plant which have died. The roots of most of the

living plants have been observed to be mycorrhizal during some parts of the year, particularly during the growth period. It has been postulated that dead, buried organic matter would have an ideal balance of micronutrients which could be available to mycorrhizal fungi for possible transport directly into the living roots. The dead organic matter is another potential direct source of nutrients for plant roots.

Rain water or bulk precipitation is a potential source of elemental input, but rain in the desert is infrequent and the annual input from rain is expected to be low. The amount of elements returned to the soil annually by throughfall (rain washing over the leaves) and stemflow (water washing down the stems) is not known, but is likely to be small because of the infrequency of the rains.

Lateral transport of elements in dust is an important factor near unpaved roads or eroded areas, but desert pavement tends to keep lateral movement to a very low level where there has been no disturbance of the pavement.

These observations raise some questions about the mode of nutrient cycling in deserts, and particularly about the requirements of desert plants for nutrients.

OBJECTIVES

The objectives of this work were to explore the various potential sources of nutrients for desert plants, and to study the importance of distillation-condensation in the soil as a water and nutrient source. The study concentrated on rocky and gravelly soils in Death Valley in *Larrea divaricata*, *Franseria dumosa* and *Atriplex confertifolia* vegetation. The goal was to determine what sources of nutrients and water are most important to these plants.

METHODS

Dump Canyon in Death Valley, one mile east of the Grapevine Ranger Station, was selected as the main study site because of the abundance of large rocks and the wide distribution of soils of gravel/sand type. The Nevada Test Site was selected as a secondary study site.

The area is hilly with *Larrea divaricata*, *Franseria dumosa* Gray. and *Atriplex confertifolia* as dominants. The plants are spaced naturally at 1-3 m, with seasonal annuals growing abundantly at the base of the shrubs, and sometimes in the open.

The area receives about 50-60 mm of precipitation annually, although the actual rainfall is quite variable. Annual air temperatures range from about -1 to +46 C. Wind is a persistant and strong environmental factor which helps to keep the relative humidity below 5-10% during the day and 30-40% at night throughout much of the year.

Four soil pits were dug (two on hills and two in small washes), to 1 m depth and the soil profiles described. The four sites represent two examples each of the local variability between hill and wash locations. Soil samples were taken at 5 cm intervals to 35 cm depth and also from 60-65 cm depth for analysis. Zero tension lysimeters with plastic reservoirs were installed at 0.9 to 1.0 m in all four pits.

Four rain collectors made of 20 cm (i.d.) plastic funnels and attached to plastic reservoirs by Tygon tubing were set in holders in the field to catch water for water quality studies. The funnels were covered with cheesecloth to keep out insects.

The soil samples were analyzed for soil separates using nested sieves and the American Classification. Bulk density was determined for 0-10 cm and 20-25 cm from 8 locations (Buckman and Brady, 1969). Soil pH was determined for all depths collected. Samples which had passed a 1 mm sieve were extracted with 1N NH_4OAc for determination of the extractable cations, and the cation exchange capacity was determined on these same samples according to the procedures described by Jackson (1958). Since 1N NH_4OAc is used mainly for extracting cations from agricultural soils, it was felt that this extractant would have little relationship to the extractant in the immediate vicinity of the roots of desert plants. Tests of the pH of crushed and intact moist roots using pH papers showed that the roots produced a pH of about 5.5 in their immediate environment. For this reason, a second set of extractions was run on a series of soil samples from 5 cm intervals beneath the three different living shrub species, beneath dead shrubs and in the open. All extractions were run on an atomic absorption spectrophotometer (Techtron AA-120) for Ca, Cu, Fe, K, Mg, Mn, Na, and Zn. Total organic nitrogen plus soluble nitrates was determined on all samples using the modified micro-Kjeldahl procedure (Jackson, 1958) and phosphates were determined colorimetrically using the molybdenum blue procedure (Black et al., 1965).

Since it did not rain until the end of the study, no natural soil leachate could be collected. To find out approximately how much of each of the biologically important elements are available in the soil solution, funnels were set up in the field, and soil samples from various depths and from the open and under shrubs of the three species were leached with 500 ml of deionized water (pH 6.8). The water-holding capacity of the soil samples was determined by subtracting the ml of leachate from the original ml added to the soil after 1 hr drainage. The elemental content and pH were determined by the same procedures used for soils.

The numbers of seedlings germinating after 38 mm of rain was determined by counts/ m^2 under the three shrub species and of m^2 plots in the uphill adjacent watershed on 100 sites in the wash and on clay soils.

The undersides of rocks are potential sites for the condensation of water and for the solution of salts by condensed water. Some surface rocks had white mineral crusts while others did not. The dominant rock types present were determined, and 100 rocks were turned over and the nature and type of crust was recorded for each, along with rock type. To determine if there are soluble materials which are biologically important on the undersides of rocks, 12 rocks were washed with 100 ml of deionized water, and another 16 rocks were washed with 100 ml of deionized water adjusted to pH 5.5 using HCl. The water was applied to an area of 10 x 10 cm on the undersides of rocks of various compositions, and the pH and elemental content of the water after washing were determined as with soils.

Another method of studying the elements available to roots growing in mats under rocks which received daily natural condensation water, was to place ashless filter paper under marked rocks for periods of 1 hr, 24 hr, and 30 days. Ten of the rocks used for this study had root mats, and ten did not. Another ten rocks were in a wash, while those mentioned previously were on the slopes. Some filter papers were supported by rings so that they did not touch the soil or rocks. pH papers were placed under the rock not touching the filter papers, but rarely was there enough moisture moving to produce a reaction in the pH papers. The 260 filter papers from field tests were treated in two ways. One group was placed one at a time in a funnel and rinsed with 10 ml of deionized water so that a group of 10 papers from a single run was leached to make 100 ml which was analyzed for elemental content and pH as with the soils. The second group of 10 papers was put into an Erlenmeyer flask, predigested with concentrated nitric acid and the digestion completed with tri-acid (HNO_3 - H_2SO_4 - $HClO_4$). Controls of 10 unexposed papers were run in the same manner to determine if there were any interfering elements in the filter paper. The digestate was run for elemental content (Ca, Cu, Fe, K, Mg, Mn, Na, and Zn) on the atomic absorption spectrophotometer. Total nitrogen was determined by the modified microKjeldal procedure, and phosphates were determined colorimetrically by the molybdenum blue method (Black et al., 1965).

The permeability of the soil in the open and under the shrubs was determined by seating a 20 cm diameter cylinder in the soil to a depth of 4-5 cm and timing the infiltration of 1 liter of deionized water into the soil.

Three times during the year, before growth began (February) during growth (May) and after growth was completed (July), leaves and small branches of *Atriplex confertifolia*, *Larrea divaricata*, and *Franseria dumosa* were collected, cleaned, dried at 70 C, ground to pass a 1 mm sieve, and 0.5 g subsamples digested as described for filter paper

(with uptake in 5 ml 6N HCl). The digestate was analyzed in the same manner as was the filter paper except that the molybdophosphoric acid yellow reaction was used for phosphorus. Samples of old wood above and below ground, live wood with bark, roots, and litter were analyzed in the same manner as the leaves.

The movement of water in the soil by distillation-condensation was measured gravimetrically using a field balance. The percent moisture present under large rocks was determined after 6 p.m. and again at 6 a.m. each day in the field to determine if distillation-condensation was occurring. Gravimetric moisture determinations of soils and leaves were made periodically.

The radionuclide studies originally projected as a part of this work could not be carried out in the field because of unforeseen licensing problems.

FINDINGS AND DISCUSSION

The results presented below are for the specific study sites in Death Valley and Rock Valley. The extent to which these data may safely be extrapolated is not known at this time, but comparisons with data collected and analyzed in a similar manner suggest that these results may have generally broad applicability.

Soils

The permeability of the soil proved to be low, 3.5 cm/hr for deionized water standing over 314 cm^2 of soil in the open (Table 1). The actual infiltration rate was probably much lower since no guard ring was used, which allowed horizontal flow. Also, the influence of raindrop impact is not included in this study. As water strikes the surface of the soil, very fine clay particles float to the surface and seal it so that air cannot move out freely, and water cannot move in readily. Therefore, only the slowest rains of long duration would penetrate the soil in the open to a depth where the moisture would be beneficial to the roots. A defloculating substance (Pentrex) was applied which improved the permeability slightly (32 min). The properties of impermeable desert soils are known and this knowledge was used in "runoff" farming in early times in Israel (Tadmore et al., 1971). The soils on the slopes have 14.0% silt and clay at 5 cm, 40% fine sand and 46% coarse sand and gravel.

The penetration of water in the wash areas was much faster than in the open (18.3 - 42.8 cm/hr, theoretical, Table 1). With this information and a knowledge of the topography, one would expect that the impermeable hills would shed great quantities of water into the washes and that plants in the wash would be much taller and more vigorous than those on the slopes because of the extra water. Subjective observation

of the vegetational distribution pattern shows that this is not the case. The shrubs on the slopes are about the same in height and vigor as those in the wash. In dry years, the shrubs in the wash may be "greener", but where the same species are involved, they are usually about the same size as the plants on the slope. This prompted an investigation of the permeability of the soil under shrubs. Water must enter at some point on the slopes or the vegetation would not be so uniformly distributed or so uniform in size. The base of each shrub has a mound of lighter soil combined with much organic matter. At first glance, these mounds would appear to be poor places for water entry because of their elevation, but repeated tests (Table 1) showed that these areas directly under shrubs are much more permeable (infiltration rate of 41.5 - 125 cm/hr) than are the open soils (5 to 10 x faster infiltration under shrubs than in the open). The presence of partly decomposed organic matter under the shrubs appears to prevent the formation, upon wetting, of solid clay skins and hence maintains a freer flow of air and water at the air-soil interface.

Table 1. Infiltration rate on Death Valley soils (avg cm/hr)

Site	Location	cm/hr
1	open hill	3.5
2	open wash	18.3
3	open hill	7.8
4	open wash	42.8
1	under *Larrea*	83.3
1	under *Franseria*	41.5
1	under *Atriplex*	125.0

Thus, in theory, in a rain of average intensity, the water penetrates slightly in the open but is quickly sealed off by clay and begins to run over the surface until it reaches a shrub base where it quickly moves into the soil. Where desert pavement and the natural vegetation have been undisturbed there is little erosion, but gully erosion on a small scale is common where bulldozers have cleared the surface of the clay soils, or along car tracks. Because of the low soil permeability in the open, each shrub has its own microwatershed which supplies it with water. Unfortunately, this was not observed during an actual storm, but the theory held up under simulated storm conditions. Adams et al. (1970) found that soil which had been subjected to fire was very water repellent in *Larrea* deserts. Lyford and Qashu (1969) found 2 to 3 times greater infiltration under shrubs in Texas deserts. Sammis et al. (1972) described the theory of infiltration in some detail.

This pattern of water movement might have considerable significance to nutrient cycling, seed germination and plant growth. The growth form of many desert shrubs conforms to Y or V patterns which would funnel water to the base of the plant through stem flow. Also, most of the leaves which fall from the shrub land at its base. Later, sand partly covers these and decay begins. The runoff and funneling patterns would supply more water beneath a shrub than elsewhere, making more water available for leaf decay and hence a recycling of elements in the leaves back into the soil.

The zone directly under a shrub is also a main point for the germination of annual seeds, especially in a dry year. In a wet year with over 40 mm of rain at a time, seeds germinate in a variety of microhabitats. In a dry year, such as 1972, very few seeds germinate in the open, ($0.01/m^2$) but many germinate under shrubs ($10\text{-}250/m^2$). This difference in germination is probably partly due to insufficient leaching of inhibitors in seeds in the open in a dry year, but greater leaching under the shrub which receives more water. Counts of the numbers of seedlings present in November 1972, two weeks after 38 mm of rain, showed that 10 times as many seedlings per meter square (av 4.0) were found under shrubs as in the open (av. 0.4).

Atriplex had the largest numbers of seedlings (55% of the count) with a concentration of seedlings at the margin of the shrub canopy and in the shallowest litter. *Atriplex* tends to form deeper litter (to 2 cm) than do the other species and the soil mounds have rapid infiltration which could influence leaching and germination. *Larrea* had 15% of the total seedlings counted with weak mound formation, except in very old specimens. *Franseria*, with the lowest infiltration rates and good mound formation, had 30% of the seedlings counted on clay soils and provided a good germination site. These data represent only one sampling during the cool, moist period of the year (November), and mainly fall or low-temperature germinators were found.

Larrea has been found to have large numbers of young seedlings in the spring. Invariably, the seedlings under shrubs were larger than those in the open. The average dry weights of groups of ten seedlings under the shrubs were 0.089 g compared to 0.0536 g for groups of ten seedlings in the open. Where small rocks impede water movement in a low spot, or where a rock has been moved, germination may be slightly better than on flat or convex desert pavement surfaces. Soil moisture to 5 cm under the shrubs, three weeks after the rain, was 2.36% compared to 1.73% in the open (November, 1972). Whether growth differences are the result of moisture differences or N and P differences is not known.

Shrubs can alter soil pH as seen in the soil immediately under *Larrea divaricata* which has a pH of about 6.9 - 8.2, while that under *Franseria dumosa* has a pH of 7.7 - 8.3, and that under *Atriplex confertifolia* has a pH of 8.8 - 10.2 (Table 2). This alteration of soil pH, with the addition of acids, cations and anions, as well as the alteration of infiltration rate, createsa soil chemistry very different from that in the open.

Table 2. pH of Death Valley Soils

Site	Depth(cm)		pH
1 (open)	0-5		8.3
	5-10		8.7
	10-15		8.7
	15-20		8.9
	20-25		8.6
	25-30		8.8
2	0-5		8.4
	5-10		8.5
	10-15		9.0
	15-20		9.0
	20-25		8.9
	25-30		8.0
3	0-5		8.6
	5-10		8.6
	10-15		8.6
	15-20		8.7
	20-25		8.8
	25-30		8.8
4	0-5		8.6
	5-10		9.0
	10-15		8.5
	15-20		8.7
	20-25		8.7
	25-30		8.7
Soil			
Under *Larrea*	0-5	Range	6.9 - 8.2
Under *Franseria*	0-5	Range	7.7 - 8.3
Under *Atriplex*	0-5	Range	8.8 - 10.2
Under rocks with roots	0-5	Range	7.3 - 9.0
Under rocks no roots	0-5	Range	8.6 - 8.7
Soil leachate (D.W.)			
Under *Larrea*		Range	6.9 - 6.9
Under *Franseria*		Range	8.0 - 8.2
Under *Atriplex*		Range	10.1 - 10.2
In open		Range	8.6 - 8.8

When soil was collected from the open and beneath the three shrub species in 20 cm depth increments, the pH of distilled water leachate of soil in the open ranged from 8.6 - 8.8 while that under *Larrea* was 6.9, under *Franseria* 8.0 - 8.2, and under *Atriplex* 10.1 - 10.2 (Table 5). Again, the shrubs appear to have modified the chemistry of their immediate environment so that *Larrea* soils are less alkaline, and *Atriplex* soils are considerably more alkaline than soil of the same depths without shrubs.

The water-holding capacities of these soils, when saturated, also differ. Soil under *Atriplex* holds less water (52.1%) than soil under *Larrea* (59.8%) or under *Franseria* (66.9%). Schumm and Lusby (1963) described seasonal variations in infiltration capacity of northern desert hillslopes indicating a difference in water-holding capacity of the soil.

The elemental content of soil indicates quite different levels of extractable elements when 1N NH_4OAc was used and when pH 5.5 *HCl* (to approximate the conditions adjacent to roots) was used (Tables 3 and 4). The NH_4OAc extraction which is typically used for agricultural soils shows 2350 µg/g for Ca, while the pH 5.5 HCl extraction shows about one-tenth as much, or 240 µg/g at 0-5 cm depth for the open site 3. Copper is slightly lower (0.23 µg/g) in the pH 5.5 extraction than in the NH_4OAc extraction (0.40 µg/g). Iron, on the other hand, is higher in the pH 5.5 extraction, 35 µ g/g, compared to 0.5 µg/g in the NH_4AOc extraction (0-5 cm, site 3). Potassium is only slightly lower in the pH 5.5 extraction (81 µg/g) than in the NH_4OAc extraction (95 µg/g). Magnesium, an element needed in relatively small amounts, is moderately high (1950 µg/g) in the NH_4OAc extraction compared to 11 µ g/g in the pH 5.5 extraction. Manganese, a trace element, was slightly higher in the pH 5.5 extraction (0.55 µg/g) than in the NH_4OAc extraction (0.1 µg/g).

Total nitrogen was determined by the modified microKjeldahl method, and was about the same in February as in June. Sodium, which can be toxic to some plants, was highest in the NH_4OAc extraction, but not more than 1.5 x higher than in the pH 5.5 extraction (59 µg/g , Tables 3 and 4). Phosphorus was about 10 x higher (10.3 µg/g) in the pH 5.5 extraction than in the NH_4OAc extraction (1.1 µg/g). Since phosphorus is extremely important to plant growth and is generally high in desert plant leaves, it would appear that the pH 5.5 HCl extraction would more nearly provide levels of P needed by the plants than did the other extraction. Zinc availability was slightly different between the two extractions (0.40 µ g/g and 0.55 µg/g at 0-5 cm, site 3). These differences in extractable elements appear to be related to the pH of the extracting solution. The solution most like the pH of the root microenvironment should be best.

Although only one level (0-5 cm) and one site (3) were compared, the same general relationships hold for soils lacking shrubs for most depths and sites. The pH 5.5 HCl extraction does not show high levels of elements which might be toxic at any levels to 35 cm, while the 1N NH_4OAc extraction has high levels of Ca at all levels, high levels of Mg at all levels, and high Na at 25-30, and 30-35 cm and at 55-60 cm (595-1300 µg/g), which could be toxic or cause nutrient imbalances or microorganism deficiencies which would be detrimental to roots. Judging by nutrient levels needed in liquid culture of plants (Hewitt, 1966), the levels of elements in the pH 5.5 extraction should support plant growth.

Table 3. Content of ammonium acetate extractable elements in Death Valley and Rock Valley soils sampled at interspaces (avg µg/g soil)

Site	Depth(cm)	Ca	CU	Fe	K	Mg	Mn	N	Na	P	Zn
Death Valley											
1	0-5	2800	0.35	1.0	92	2400	0.20	282	65	1.1	0.35
	5-10	2825	0.33	1.1	93	2360	0.20	259	81	1.0	0.35
	10-15	2925	0.45	1.2	93	2510	0.18	238	74	1.0	0.45
	15-20	2725	0.40	1.4	92	2600	0.08	476	71	1.0	0.35
	20-25	2725	0.33	1.2	93	2580	0.15	322	71	1.0	0.38
	25-30	3450	0.48	1.1	93	2960	0.14	280	595	1.0	0.35
	55-60	2375	0.45	1.0	93	1290	0.11	266	875	3.0	0.30
2	0-5	2075	0.39	1.4	90	1120	0.30	182	22	1.4	0.20
	5-10	1900	0.35	1.7	90	1115	0.20	182	22	0.6	0.38
	10-15	1900	0.35	1.4	93	1260	0.20	182	28	1.1	0.32
	15-20	1900	0.30	1.3	94	1480	0.20	196	38	1.0	0.30
	20-25	1090	0.45	1.0	95	1017	0.20	210	59	1.0	0.45
	25-30	2000	0.40	0.8	95	1555	0.17	367	66	1.5	0.40
	55-60	1875	0.35	0.7	96	1360	0.13	189	860	0.9	0.38
3	0-5	2350	0.40	0.5	95	1950	0.10	329	71	1.1	0.40
	5-10	2600	0.37	0.7	94	2800	0.30	336	94	1.5	0.39
	10-15	2675	0.35	1.0	94	2800	0.05	280	94	1.6	0.43
	15-20	2625	0.45	1.0	94	2720	0.10	-	99	1.6	0.40
	20-25	2650	0.44	0.5	95	2360	0.15	-	595	1.6	0.55
	25-30	2600	0.48	0.5	95	3680	0.12	210	98	1.3	1.00
	55-60	2250	0.40	0.5	93	790	0.13	238	1400	1.4	0.40
4	0-5	2175	0.33	1.0	89	1050	0.15	-	18	1.5	0.48
	5-10	2225	0.33	1.0	89	1190	0.23	210	22	1.8	0.43
	10-15	2425	0.40	1.0	90	1570	0.27	252	27	1.0	0.43
	15-20	2450	0.40	1.0	92	1660	0.20	266	30	1.4	0.38
	20-25	2650	0.39	1.0	92	1760	0.20	224	40	1.2	0.35
	25-30	2250	0.35	1.0	92	1960	0.15	231	65	3.0	1.00
	55-60	2150	0.40	1.0	89	3375	0.12	224	1200	1.6	0.55
Rock Valley											
Wash	0-5	2050	0.30	0.7	94	80	0.45	168	47	1.7	0.50
	5-10	2100	0.45	0.5	96	81	0.35	504	565	1.2	0.75
	10-15	2025	0.38	0.7	92	77	0.33	413	77	1.6	0.53
	15-20	2125	0.35	0.7	94	80	0.30	119	89	1.7	0.53
Hill	0-5	2825	0.40	0.9	95	3520	0.20	136	59	2.7	0.24
	5-10	2700	0.45	1.0	92	2720	0.18	420	80	3.0	0.35
	10-15	2500	0.45	1.0	92	3420	0.40	259	60	4.1	0.20
	15-20	2950	0.38	1.0	93	1340	0.20	182	62	1.8	0.30

Table 4. Content of pH 5.5 extractable elements in Death Valley soils (avg µg/g soil) from interspaces and under shrubs

Site	Depth(cm)	Ca	CU	Fe	K	Mg	Mn	N	Na	P	Z
3 open	0-5	240	0.23	35.0	81	11	0.55	287	59	10.3	0.55
	5-10	220	0.18	21.0	81	13	0.35	231	37	6.7	0.30
	10-15	230	0.15	15.0	84	13	0.20	259	55	5.9	0.30
	15-20	210	0.30	27.0	83	9	0.25	273	54	11.5	0.60
	20-25	209	0.30	26.0	81	9	0.30	245	53	10.3	0.55
4 open	0-5	170	0.20	16.0	74	9	0.35	175	47	3.7	0.20
	5-10	175	0.15	17.0	78	9	0.40	210	32	4.7	0.20
	10-15	165	0.15	9.0	78	9	0.25	248	36	4.0	0.20
	15-20	185	0.20	16.0	76	9	0.25	255	43	4.9	0.10
	20-25	184	0.20	11.0	79	9	0.15	168	51	4.8	0.10
3 under	0-5	280	0.23	13.0	65	17	0.55	903	50	4.0	0.10
dead	5-10	213	0.30	25.0	81	10	0.50	364	48	8.0	0.30
Larrea	10-15	233	0.20	30.0	87	10	0.50	399	43	10.3	0.38
	15-20	203	0.43	27.0	89	6	0.23	308	58	8.3	0.30
	20-25	240	0.28	27.0	90	5	0.20	259	96	8.5	0.28
	25-30	280	0.37	24.0	90	4	0.20	301	177	8.3	0.25
	30-35	303	0.38	23.0	89	4	0.20	746	230	8.8	0.20
3 under	0-5	235	0.30	13.0	87	15	0.45	826	66	0.4	0.38
live	5-10	222	0.33	27.0	85	11	0.27	350	46	0.5	0.50
Larrea	10-15	203	0.33	29.0	86	10	0.25	385	41	0.4	0.45
	15-20	206	0.25	28.0	87	11	0.25	280	47	0.5	0.55
	20-25	206	0.28	22.0	87	13	0.25	287	94	0.6	0.50
1 under	0-5	78	0.28	7.0	80	12	0.30	1904	49	2.2	-
dead	5-10	172	0.15	18.0	89	11	0.28	826	49	20.0	0.50
Franseria	10-15	115	0.23	21.0	88	6	0.25	581	35	17.0	0.10
	15-20	108	0.25	25.0	88	6	0.23	574	40	14.1	0.10
	20-25	140	0.15	31.0	89	6	0.25	420	45	16.5	0.15
	25-30	150	0.20	28.0	88	6	0.25	441	40	14.0	-
	30-35	155	0.15	12.0	88	4	0.23	-	260	7.0	-
1 under	0-5	128	0.45	9.0	89	24	0.45	1386	92	52.0	-
live	5-10	95	0.40	15.0	90	9	0.30	1400	36	16.0	-
Franseria	10-15	75	0.38	15.0	89	7	0.28	553	31	10.0	-
	15-20	73	0.20	17.0	89	6	0.25	532	24	8.0	-
	20-25	90	0.18	14.0	89	5	0.28	350	34	8.0	-
	25-30	107	0.30	14.0	90	5	0.23	364	90	7.0	-
1 under	0-5	198	0.33	12.0	86	17	0.38	644	74	5.3	0.20
dead	5-10	148	0.38	22.0	87	10	0.35	329	59	7.8	0.25
Atriplex	10-15	202	0.50	28.0	90	6	0.30	287	67	11.3	0.40
	15-20	200	0.50	26.0	91	4	0.30	380	178	11.8	0.40
	20-25	90	0.23	12.0	67	70	0.63	252	112	3.3	0.10
	25-30	82	0.20	11.0	62	48	0.63	310	156	5.8	0.10
	30-35	39	0.20	9.0	62	48	0.92	-	378	7.0	0.10
1 under	0-5	105	0.20	20.0	168	28	0.63	756	237	9.5	0.23
live	5-10	106	0.20	18.0	169	25	0.63	322	240	8.0	0.25
Atriplex	10-15	75	0.25	19.0	590	55	1.10	336	600	7.5	0.23
	15-20	94	0.20	19.0	72	33	0.90	350	180	7.3	0.20
	20-25	81	0.33	15.0	70	50	0.78	336	99	6.0	0.10
	25-30	80	0.50	15.0	73	50	0.63	287	92	5.3	0.10
	30-35	90	0.50	15.0	72	50	0.63	252	87	4.5	0.10

Site 3 does not have any *Franseria dumosa*. The texture of the soils, their moisture and the C.E.C. (Table 5) are not vastly different among sites 1, 2 and 3, although site 3 has the highest C.E.C. The lack of *Franseria* on site 3 would not appear to be related to the physical characteristics of the soil, but may be linked to their chemical properties. Site 3 does have less surface moisture than profiles 1 and 2, but the storage at depth is not greatly different (Table 6). The high levels of Mg which are known to be present at 25 cm and below from the NH_4OAc extraction suggest that this element could be limiting to the survival of *Franseria*, which also has low foliar Mg compared to that of *Atriplex* foliage (Table 9). Site 3 also had more water extractable Ca, Fe, K, Mg, Mn, Na, P, and Zn (Table 7) than did the other sites. The absence of *Franseria* on site 3 could be coincidence, or it could be related to the abundance of Na, or Zn or Cu below 25 cm, or to some unmeasured element.

These data suggest that the uptake of element by the roots of desert plants may be governed by the chemistry of the immediate environment of the root rather than the broad soil chemistry. We know from the NH_4OAc extractions that high levels of Ca and Mg occur along with Na in these soils, but it is unlikely that the roots actually live in this type of immediate chemical environment. The fact that the roots of all three shrub species studied appear to maintain a pH of about 5.5 - 6 in soils with an overall pH of 7.8 - 10.2 to 30 cm (Table 2) suggests that the root is able to modify its immediate environment to solubilize and extract levels of biologically important elements needed by the plant, without saturating the soil solution with possibly toxic levels of abundant Ca, Na, and Mg cations. This could be, conceivably, the mechanism which allows the low concentrator plants such as *Larrea* to survive in alkaline soils. Certainly the balance of cations and anions in the pH 5.5 HCl extractions is better for most biological terrestrial uptake than that in the 1N NH_4OAc extraction. The pH 5.5 HCl extractant is probably not the same extractant used in the dynamic environment by the plant, but the pH is correct.

In general, the soil under dead *Larrea* (estimated 5+ years dead) had more P (at 20-25 cm) and less Mg and Zn for the same sites than did the soil under live *Larrea*. The difference in P under the living shrub (0.6 µg/g) and that under the dead shrub (8.5 µg/g) is fourteen-fold at 0-5 cm, indicating that this element is in strong demand by living plants, whereas it tends to build up under dead shrubs lacking annuals or other growth (Table 4), and under low rainfall. The differences in phosphate at all depths vary widely from those under live and dead *Larrea* suggesting some basic differences in use and release between dead and live shrubs.

Soil under dead *Franseria* shrubs had higher levels of Ca, Fe, P at 25-30 cm, and lower Na than did the soil under living shrubs.

Table 5. Cation exchange capacity of Death Valley soils (meg/100g)

Site	Depth(cm)	E.C.
1	0-5	8.8
	5-10	10.2
	10-15	9.0
	15-20	8.5
	20-25	8.5
	25-30	3.3
	55-60	7.8
2	0-5	5.4
	5-10	6.8
	10-15	7.0
	15-20	7.5
	20-25	8.7
	25-30	7.9
	55-60	7.1
3	0-5	10.0
	5-10	10.5
	10-15	10.5
	15-20	10.9
	20-25	10.3
	25-30	10.0
	30-35	7.0
	55-60	6.5

Phosphorus was highest under dead *Franseria* at all but the 0-5 cm depth. Differences in extractable P under *Franseria* and *Larrea* suggest basic differences in use or production of phosphurus in the soil. Soil under dead *Atriplex* shrubs had more Ca, different Cu distribution, less K, Mg, Mn, Na (suggesting downward leaching), and variable P than occurred in the same depths of soils under live *Atriplex*. Since the female of this shrub sheds large quantities of fruits and leaves, many of which remain at the base of the shrub, the amount of nutrients available for release annually should be much higher than for *Franseria* which is small and has sparse, small leaves and fruits which are only partly shed, and *Larrea* which sheds only a portion of its small leaves annually and disperses large quantities of wind-blown fruits. The annual organic accumulation under *Atriplex* appears to be much larger than for the other two species so the higher levels of pH 5.5 extractable K, Mg, Mn, and Na probably result from leaf and fruit decay over long periods of time with low leaching levels. The difference between living and dead *Atriplex* soil phosphate is not great in this instance. The soils from the open generally

have more Ca, less N, P, and Na than the soil under shrubs as a result of reduced leaching in the open and increased release of elements from decay under shrubs. These differ by species as well as by site.

Table 6. Percent moisture in Death Valley soils in February, 1972

Site	Depth(cm)	% Moisture
1	0-5	3.06
	5-10	5.22
	10-15	6.72
	15-20	6.69
	20-25	7.44
	25-30	6.66
	55-60	5.64
2	0-5	10.70
	5-10	4.49
	10-15	5.11
	15-20	4.35
	20-25	4.28
	25-30	4.90
	55-60	3.30
3	0-5	2.87
	5-10	7.18
	10-15	8.00
	15-20	8.97
	20-25	7.70
	25-30	6.61
	55-60	4.63
4	0-5	1.67
	5-10	3.12
	10-15	6.02
	15-20	7.20
	20-25	7.17
	25-30	8.04
	55-60	10.56

When the elemental content of distilled water leachate (pH 6.8) of soil in the open and under shrubs was compared, there were considerable differences in the amounts of Ca, K, P, and Zn (Table 7). Site 1 had such a slow infiltration rate with time that it was difficult to leach the soil without extensive evaporation losses. For this reason, most leaching tests were run on soils from sites 2 - 4. The wash sites, 2 and 4, were generally lower in Ca, K, Na, P, and Zn than were the hill sites, except for cemented layers (1 and 3, Table 7). These differences would be expected in light of the greater water movement in the washes, and the solubility of some compounds of these elements. Similar differences occurred with the pH 5.5 extractions (Table 4). Often elemental deposition patterns in the soil are dependent on how intensive and heavy the last rains were.

A study conducted by a student, Ruth Squires, used 1) water equivalent chemically (inorganically) to the leachate from open ground, 2) nutrient solution equivalent (inorganically) to water leachate of soil from under *Larrea*, and 3) nutrient solution equivalent chemically (inorganically) to the pH 5.5 extract of soil under *Larrea*, to water vermiculite cultures of seedlings of *Larrea divaricata*, *Atriplex canescens* and *Hymenoclea salsola*. The results showed that these plants survived and grew best over a seven-week period on water which was chemically equivalent (inorganically) to leachate from open soil. Good growth occurred for most species on nutrient solution equal to the pH 5.5 extract, and all seedlings died when watered with nutrient solution equal inorganically to the water leachate of soil under *Larrea*. However, less *Larrea* seedlings (57%) died when they received water chemically equivalent to that from the open ground than when they received pH 5.5 extractions (80-88% mortality). *Atriplex* grew and survived well on nutrient equal to the water extract of open soil, indicating that this species is better suited to the saline habitat than is *Larrea*. Why all plants died in nutrient solution equivalent to that of water extract under *Larrea* is not known, but this solution contained much more Ca (8 x), less Fe (10 x), more K (2 x), the same Mg, Mn, N, less Na, P (13 x less), and less Zn than did the solution from open soil. Any combination of deficiencies and imbalances could occur in the *Larrea* solutions. The purpose of this study was to determine what general types of soil solutions favored growth and survival. The results indicate that water leachate of open soil, acted on by the roots with their pH adjustment, is the best of the three tested. Apparently a solution equal to the pH 5.5 extract of soil is not well balanced for growth and survival when the pH action of the roots is added, although some plants did survive. These data suggest that uptake is dependent on the action of the roots on the soil solution and not so much on the solution itself.

Table 7. Elemental content of soil leachate from Death Valley soils in the open and under shrubs using distilled water as a leaching agent (mg/l)

Soil in open	Depth(cm)	Ca	Cu	Fe	K	Mg	Mn	Na	P	Zn
1	0-20	0.4	0.01	0.05	2.1	2.8	0.0	16	0.00	0.00
2	0-20	0.3	0.00	0.05	4.6	2.2	0.0	25	0.02	0.00
	20-40	0.3	0.02	0.15	4.1	2.5	0.0	31	0.07	0.00
	40-60	0.3	0.05	0.20	4.6	2.8	0.0	26	0.13	0.00
3	0-20	1.1	0.05	8.80	8.0	8.6	0.8	95	2.86	0.13
	20-40	1.2	0.04	1.70	6.1	5.9	0.2	64	0.61	0.03
	40-60	3.3	0.00	0.40	7.7	8.6	0.6	52	2.10	0.05
4	0-20	0.3	0.05	3.70	4.6	2.1	0.2	22	0.44	0.02
	20-40	2.5	0.03	5.20	6.7	9.6	0.5	19	1.10	0.07
	40-60	0.6	0.04	4.30	4.5	2.7	0.1	22	0.37	0.03
Soil under *Larrea*										
Site 1	0-20	96.0	0.03	0.20	9.1	8.8	0.2	25	0.03	0.01
Site 2	0-20	100.0	0.05	0.30	9.0	10.0	0.2	30	0.09	0.02
Site 3	0-20	100.0	0.04	0.28	9.2	9.6	0.1	30	0.48	0.01
Soil under *Franseria*										
Site 1	0-20	80.0	0.03	0.15	9.3	9.3	0.1	30	0.34	0.01
Site 2	0-20	100.0	0.04	0.25	9.2	10.0	0.1	38	0.20	0.02
Site 3	0-20	67.0	0.03	0.25	9.2	8.9	0.1	40	0.16	0.01
Soil under *Atriplex*										
Site 1(male)	0-20	59.0	0.04	0.50	9.1	3.9	0.1	65	0.10	0.01
Site 2(female)	0-20	61.0	0.03	0.20	9.1	4.3	0.1	65	0.08	0.01
Site 3(female)	0-20	41.0	0.03	0.30	9.2	3.7	0.1	70	0.01	0.01

Soil from under *Larrea*, *Franseria* and *Atriplex* was much higher in water extractable Ca, K and Mg (in some cases) than was soil at the same depths in the open. The difference between water soluble Ca in the open and under shrubs suggests that the Ca in the open is in some form which is not readily water soluble, whereas the Ca under shrubs is in a water soluble form. This could be another modification of the soil by the shrub.

Surprisingly, less water soluble Ca and Mg occurred beneath *Atriplex* than beneath the other two species. This could be related to solubility and pH since both *Larrea* and *Franseria* have lower pH readings in soil immediately beneath them, but this is only speculation. More Na occurred under *Atriplex*,which is reasonable since the foliage of this plant is very high in Na (Table 9).

Distillation-condensation did occur during the study year, but attempts to measure the quality of condensation water showed that it was impossible to collect this water without contacting either the root or soil, or rock. All of these surfaces have soluble

elements on them, so that the true quality of the condensed water was not ascertained. The elemental content of filter papers placed under rocks did not vary greatly with time of exposure, suggesting that what was found on the filter papers was local contamination and not materials transported or dissolved by the water over time.

Distillation-condensation performs a vital function daily by bringing water which is presumably relatively pure to the root surfaces. With this water, the roots are able to live and to adjust the pH of their immediate surroundings to levels favorable for nutrient uptake. This study, in a dry year, suggests that most elemental uptake occurs from soil in the immediate vicinity of roots using condensation water, and not the soil solution which lasts for only a few days or weeks after storms.

Perhaps the low permeability also prevents the loss of water from the soil surface. After a rain, the surface 1-2 cm dries, losing water to the atmosphere. Once this surface zone is dry, however, little water is lost from the soil surface. The dry, surface clay has many tiny air spaces which do not connect directly to one another. These probably act to restrict the movement of air in and out of the soil, thus reducing vapor losses as well. After an October rain, the plants took up enough soil moisture to flower or begin growth independent of distillation-condensation.

Another side effect of low permeability is the crusts formed on the undersides of surface rocks. The crusts are high in Ca and K. They appear to form by the crystallization of salts from the small puddles under rocks as they dry after a rainstorm.

The undersides of rocks are sites of root concentration, fungal activity, arthropod activity, nutrient uptake, condensation of water, and sometimes litter accumulation from wind or small animal collections. For this reason, the undersides of rocks are key centers of biological activity and are extremely important in desert soils.

When the undersides of surface rocks were washed with deionized water or acidified deionized water, the elemental content was quite variable (Table 8). Much of the variation may be the result of varying degrees of biological activity under the rocks, and possibly their composition. When deionized-distilled water with a pH of 5.5 (HCl) was used for washing, the amount of most elements readily available was considerably higher than when plain deionized water was used. This tends to confirm the acid action of roots on rocks and soil, and it indicates that readily soluble elements are available on rock surfaces despite centuries of distillation-condensation.

Table 8. Elemental content of water from washing the undersides of rocks, Death Valley

Rock type	Extractant	Ca	Cu	Fe	K	Mg	Mn	Na	P	Zn
Rhyolite	pH 5.5	730	0.4	28	24	25	0.8	10	0.01	0.2
	pH 5.5	285	0.5	90	53	181	4.0	12	0.50	0.9
	D.W.*	220	0.3	5	26	18	0.5	5	1.25	0
	D.W.	90	0.9	5	15	5	0	4	1.40	0
Basalt	pH 5.5	875	1.2	175	77	240	10.0	30	0.03	2.2
	pH 5.5	535	0.8	95	73	240	5.0	48	0.04	0.9
	D.W.	285	0	5	53	23	0	13	0.37	0
	D.W.	140	0	0	57	16	0	51	1.60	0

*D.W. = deionized, distilled water

Plants

A comparison of the elemental content of *Larrea* leaves from Death Valley and Rock Valley show that the latter had the highest content of Cu, Fe, N, Na, and Zn (Table 9). These differences show up in the two soils when hill sites are compared for Mg, Mn, Na, and Zn (Table 4). The slightly high Mn in Rock Valley soils does not appear to be responsible for the high Mn in Rock Valley *Larrea* leaves, and differences in other elements in the two soils are not necessarily reflected in the elemental content of these leaves. Phosphorus was slightly higher in the Rock Valley hill soils than in the Death Valley hill sites, but little difference in leaf phosphorus was found. Soil textural differences could explain some of the differences, particularly if textural variations are such that they influence water movement. The Rock Valley and Death Valley *Larrea* appears to differ in elemental content as much as other vegetation from over a hundred miles away would differ.

No analysis of the differences in elemental content of plants growing on the hills versus those growing in the wash was made. The soils differ between hill and wash locations, probably from differing amounts of leaching (Table 4). For all general comparisons, Rock Valley may be compared to Death Valley in terms of soil and plant chemistry but not species composition. The nutrient cycling phenomena described for Death Valley impermeable soils would probably apply to other desert areas with similar impermeable soils.

Table 9. Range of the elemental content of plants from Death Valley and Rock Valley (µg/g)

Death Valley	Plant Part	Ca	Cu	Fe	K	Mg	Mn	N	Na	P	Zn
Larrea d.	Wd.	325	7.0	68	2500	4000	2	-	300	2900	7.5
		1000	10.5	82	4200	5000	8	-	675	3200	10.5
Atriplex c.	Wd.	7800	7.0	130	4200	2500	12	-	415	4300	8.8
		14000	9.0	3100	8500	3250	42	-	5500	-	10.3
Franseria d.	Wd.	4000	8.0	140	13250	2000	8		800	-	13.2
		4750	12.5	215	18750	3500	15	-	2850	-	13.2
Larrea d.	lvs.	9500	7.0	185	16500	1750	21	17976	130	600	12.0
		16250	9.5	255	19500	2400	40	19096	294	1600	16.0
Atriplex c.	lvs.	16250	8.5	185	34750	9000	40	11060	100000	600	11.0
		31500	9.5	280	39500	11000	63	17584	137500	1900	13.0
Franseria d.	lvs.	12600	8.0	172	5000	1900	22	21112	1375	3200	16.0
		24750	15.0	400	17750	3750	60	31892	4500	-	31.0
Larrea d.	Old Wd	8500	11.0	475	500	4800	15	4480	315	600	19.0
		21250	15.0	6750	9500	19500	65	8092	1900	650	73.5
Atriplex c.	Old	13250	9.5	130	1000	4500	22	5404	950	2900	12.5
	Wd.	28500	13.0	5500	30000	18750	82	3076	47500	-	17.5
*Larrea d.**	Roots	6000	9.5	110	5400	750	5	-	600	5800	8.0
		7500	10.5	475	5500	2250	15	-	800	-	11.0
*Atriplex c.**	Roots	13250	9.5	580	25750	4500	22	-	22250	2900	14.5
		-	11.5	865	30000	7500	22	-	47500	-	16.5
*Larrea d.**	Litter	10500	10.0	3400	2250	2500	40	-	47600	5800	14.5
		12250	12.0	3700	2500	3000	40	-	48000	-	15.0
*Atriplex c.**	Litter	28500	10.5	130	10750	18750	22	5404	950	-	12.5
		28500	10.5	130	10750	18750	22	-	2250	-	13.0
*Franseria d.**	Litter	21500	13.0	7250	3500	6000	88	-	1800	-	19.0
		21500	13.0	7250	3750	6250	89	-	1800	-	22.0
Rock Valley											
*Larrea d.**	lvs.	9750	9.8	220	8250	1550	12	19152	250	750	14.0
		16500	15.5	450	15500	3000	25	21728	1450	1400	18.2

* Limited data (under four measurements)

In terms of elemental content, living wood of *Atriplex* was consistently highest of the three species in Ca, Fe, Mn, and Na. This plant appears to be a true concentrator plant adapted to dry soils high in salts. *Larrea* wood was consistently low in Ca, Fe, K, Mn, and Na. It grows at the other extreme and does not concentrate cations to a high level. It does not appear to build the high moisture tension related to water and salt uptake which *Atriplex* has, but *Larrea* is slightly high in Mg (Table 9). *Franseria* wood tends to fall between *Larrea* and *Atriplex* wood in its elemental content.

The same general relationship holds for the leaves of these three desert species. *Atriplex* has leaves which are high in Ca, K, Mg, Mn, and Na. The sodium levels in *Atriplex* leaves are extremely high, exceeding 100,000 µg/g, compared to 294 µg/g for *Larrea* and 450 µg/g for *Franseria* (Table 9). These data suggested that *Atriplex* is less selective in elemental uptake than are the other two species, and that it has evolved to survive with the salt by selective uptake. However, water leachate of soil from beneath *Atriplex* was quite low in Na (Table 7) as was the pH 5.5 extract (Table 4). Calcium, K, Na, and Mg were high (relative to temperate zone humid forests) in all desert leaves. Pine needles from Jeffrey pine forest show about 1000 µg/g Ca (Stark, 1972) compared to 9500 to 31500 ug/g for desert plants. Copper, Fe, K, Mg, N, P, and Na were generally higher in the desert vegetation than in pine needles. The high levels of nitrogen and phosphorus in the desert vegetation suggest that these plants are prepared chemically for rapid growth once water becomes available.

It was originally hypothesized that old, dead wood could be an excellent source of well-balanced, biologically important elements which could be available to mycorrhizal fungi which are known to associate with the roots of some desert plants and decaying wood. It is now known that some fungi concentrate very high levels of elements, although desert fungi have not been studied (Stark, 1972). If the mycorrhizal fungi concentrate high levels of elements from wood which is already high in elemental content, then the balance and concentration of cations and anions would not necessarily be favorable to the living roots. Also, old, dry dead wood near the surface of the soil acts as a wick when it rains, soaking up salts and water. As the water evaporates, the salts are left behind and become more concentrated. Thus, *Larrea* live wood had 325-100 µg Ca/g, while dead wood of various ages had 8500-21250 µg Ca/g, or over 21 times more Ca.

The copper content of live and dead wood did not increase very much over time (Table 9). Iron was about 82 x more concentrated g/g in dead *Larrea* wood than in live, K was about 2 x more concentrated, Mg was about 4 x more concentrated, Mn was 7 to 8 x greater, Na was the same to 3 x greater, P was about 1/5 of the level found in living wood, and Zn was about 7 x greater (Table 9), indicating that as dead wood ages in the soil it increases in cations to levels which would appear to be poorly balanced for the living plant. Phosphorus, on the other hand, is withdrawn from the wood, possibly by fungi, and may be moved to points in the ecosystem where growth is occurring.

Atriplex dead wood varied in elemental content, but concentrated most elements in the same manner as did *Larrea* wood, but to a lesser degree. Old *Atriplex* wood had from 2 x to 10 x more of each element except P (Table 9). The old wood of *Franseria* was not studied.

Although radionuclides were not available to determine if P and other elements are moving from dead wood into living roots via mycorrhizal fungi, this source of elements for desert plants would seem to be much less important than originally hypothesized. Wood which is deeper in the soil and is not so strongly subjected to the "wick" phenomenon might still be useful to mycorrhizal fungi. Centainly fungi and roots associate readily with subterranean dead wood, but the reason for this relationship is not clear.

The roots of *Larrea* and *Atriplex* are quite high in Ca, Cu, Fe, K, Mg, Na, and Zn (Table 9), relative to roots of forest vegetation. *Atriplex* has roots which are extremely high in K and Na compared to roots from non-desert areas.

The litter of the three species tends to be high in those elements which are abundant in the living leaves (Table 9).

The moisture content of the leaves of these three desert species increases during the growth period (late March-May) and decreases to low levels during the cold and drier season. Moisture uptake and growth coincide closely with the periods of strong distillation-condensation (Stark and Love, 1969). *Larrea* tends to have under 100% moisture on a dry weight basis (71.7 - 91.3), while *Atriplex* usually remains over 200% (220.8 - 419.5%), and *Franseria* has a bit over 100% (108.6 - 133.4%). It is reasonable to assume that *Atriplex* maintains high levels of internal moisture by virtue of its high salt concentration.

Skujins (1972) found low nitrogen levels in soils from Curlew Valley, northern Utah. The sampling procedure suggests that samples were taken from areas between shrubs and where dead organic matter is scarce. These results agree with those from similar sites in Death Valley, but the situation under shrubs where there is more organic matter would appear to be very different. This may be particularly true since cryptogamic crusts are less abundant in the warm desert than in the cold desert. The higher nitrogen levels in the surface soil of Curlew Valley agree with the conditions in Death Valley under shrubs. Dutt and Hanks (1972) discuss the dynamics of nitrogen transformations on warm desert soils. McKell and Kline (1972) also found more nitrogen under the shrubs than in the open in northern desert soils. The levels of nitrogen in the cold desert soils were generally higher than those from the warm desert.

Studies of the total P content of desert soils by Jurinak and Griffin (1972) showed the most inorganic P at the surface with higher organic P at depths to 70 cm in Curlew Valley soils. These results agree generally with studies of extractable P in Death Valley soils.

Studies of the elemental distribution in cold desert plants (West, 1972) show generally lower levels of K, Na, P, and Mg, and higher Cu and Mn than was found in warm desert plants.

EXPECTATIONS

This work will not be continued because the author has moved to an area which is remote from the desert. If work is to be continued on this general topic, the role of dead wood and fungi in supplying phosphorus and water should be studied. More work should be done on the uptake of elements, and on the nutritional requirements of desert plants. All aspects of this study should be continued to obtain valid, long-term data which reflect climatic variation.

LITERATURE CITED

Adams, Susan, B.R. Strain, and M.S. Adams. 1970. Water-repellent soils. Fire and annual plant cover in a desert scrub community of southeastern California. Ecology 51 (4):696-700.

Black, C.A. et al., eds. 1965. Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. Am. Soc. of Agronomy.

Buckman, H.O., and N.C. Brady. 1969. The Nature and Properties of Soils. The Macmillan Co., 653 p.

Dutt, G.R. and J. Hanks. 1972. Predicting nitrogen transformations and osmotic potentials in warm desert soils. IBP Desert Biome Research Memorandum RM 72-39.

Evenari, M. 1962. Plant physiology and arid zone research. Arid Zone Research V, Proc. Paris Symposium 28.

Hewitt, E.J. 1966. Sand and Water Culture Methods Used in the Study of Plant Nutrition. Commonwealth Agricultural Bureau.

Jackson, M.L. 1958. Soil Chemical Analysis. Prentice-Hall, Inc. N.J. 498 p.

Jurinak, J.J., and R.A. Griffin. 1972. Factors affecting the movement and distribution of anions in desert soils. IBP Desert Biome Research Memorandum 72-38.

Lyford, F.P., and Hasan K. Qashu. 1969. Infiltration rates as affected by desert vegetation. Water Resources Research 5(6):1373-1376.

McKell, C.M., and L.G. Kline. 1972. Role of annual grasses and shrubs in nutrient cycling of Great Basin plant communities. IBP Desert Biome Research Memorandum RM 72-25.

Sammis, T., H. Qashu, J. Ryan, and J. Thames. 1972. Water balance techniques. I. Sampling soil moisture changes. II Channel transmission losses. IBP Desert Biome Research Memorandum RM 72-13.

Schumm, S.A., and G.C. Lusby. 1963. Seasonal variation of infiltration capacity and runoff on hill slopes in western Colorado. Jour. Geophys. Res. 68(12): 3655-3666.

Skunins, J. 1972. Nitrogen dynamics in desert soils. IBP Desert Biome Research Memorandum RM 72-40.

Stark, N., and L.D. Love. 1969. Water relations of three warm desert species. Israel Jour. of Botany 18:175-190.

Stark, N. 1972. Nutrient cycling pathways and litter fungi. BioScience. 22(6): 355-360.

Tadmore, N.H., L. Shanan and M. Evenari. 1971. "Run-off farming" in the desert Persistence and yields of annual range species. Agron. Jour. 63:93-95.

West, N 1972.Biomass and nutrient dynamics of some major cold desert shrubs. IBP Desert Biome Research Memorandum RM 72-15.