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Investigation of lower Colorado River Valley desert soil mineral and nutrient content in relation to plant proximity and identity

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INVESTIGATION OF LOWER COLORADO RIVER VALLEY DESERT SOIL MINERAL AND NUTRIENT CONTENT IN RELATION TO PLANT PROXIMITY AND IDENTITY

A Thesis

Presented to the

Faculty of

California State

University, San Bernardino

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

in

Biology

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ABSTRACT

Desert plant distribution and success are determined by many factors including climatic patterns and soil chemistry, texture, and particle size. Soil nutrient concentrations have been cited as the most frequently limiting factor in semiarid climates. Not only does soil affect the plants growing in it, but plants can modify the soil as well. This study was performed to determine whether or not there is a significant difference between the mineral composition of plant-inhabited soil and the bare soil adjacent to growing plants. Soil samples from under Encelia farinosa, Ambrosia dumosa, and adjacent barren areas in the Colorado portion of the Sonoran Desert in Southern California, east of Joshua Tree National Monument were examined. Essential plant nutrient concentrations were similar in soils under the two plant species, while there was a significant difference between plant-associated soils and soils that do not support plant growth. Although differences were not so apparent among the nutrients not considered essential for plant growth,

discriminent analysis revealed a significant separation between Encelia-, Ambrosia-, and bare soil nutrient concentrations at 1 and 25 cm depths when all nutrients were considered simultaneously. An individual soil sample at any one depth could be correctly classified as its species- or bare-soil-related group with almost 100 percent accuracy. The chemical composition of the plant tissue extracts was highly similar to the chemical composition of the species associated soils, suggesting that the plants themselves may provide a mechanism for accumulation of these nutrients in the soil surrounding them.

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2M	2 Moles solute per liter solution
ANOVA	Analysis of Variance
CEC	Cation Exchange Capacity
cm	centimeters
F	Measure of significance for an ANOVA Statistical Test
ft	feet
g	gram
ICP	Inductively Coupled Plasma
ml	milliliter
NS	Not statistically significant
p	The probability of a Type I error
pH	Measure of soil acidity
ppm	parts per million
rpm	revolutions per minute
S	Significant at the 0.05 level
SE	Standard Error
TSC	Total Structure Coefficient
UCR	University of California, Riverside

Chemical Elements:

Al	Aluminum
B	Boron
Ba	Barium
Be	Beryllium
Ca	Calcium
Cd	Cadmium
Co	Cobalt
Cr	Chromium
Cu	Copper
Fe	Iron
K	Potassium
Li	Lithium
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
N	Nitrogen
Na	Sodium
Ni	Nickel
P	Phosphorus
Pb	Lead
Si	Silicon
Sr	Strontium
Ti	Titanium
V	Vanadium
Z	Zinc

CHAPTER I

INTRODUCTION

For many years it was thought low precipitation in the desert was the most limiting factor of plant growth. However, it is becoming clear that numerous soil factors, including the chemical makeup, texture, and particle size, are as important in determining plant distributions as are climatic factors (Crosswhite, 1983). Of the 16 known essential nutrients for plant growth, the soil must supply all the plant needs for 10 of these nutrients (see Table 1). Further, except for plants associated with N-fixing bacteria, all plants obtain nitrogen from the soil as well. The other five essential nutrients are derived from the atmosphere (Fried and Broeshart, 1967). The soil nutrients can become unavailable to plants because of leaching, gaseous losses, incorporation into the inorganic matrix, or utilization by the biosphere (Fried and Broeshart, 1967). Recently, nutrient concentrations, especially of nitrogen, have been reported to be the most frequently limiting factors of growth in semiarid climates (van Keulen, 1981; West, 1981; Cline and Richard, 1973; Floret et al., 1982). However, a thorough

analysis of the limiting effects of other essential nutrients is lacking.

The soil supporting plant growth is neither static nor homogeneous; the mineral and organic composition is subject to both spatial and temporal variation (Ag. Research Inst., 1959). The availability of N and other nutrients in desert ecosystems is affected by many factors, including litter inputs, root intake and output (Tinker and Lauchlin, 1986), rates of translocation and burial of litter, organic matter accumulation from faunal activity, and decay rates (Whitford, 1986). Desert soils are typically low in organic matter and need constant replenishment to support plant growth. If the process of nutrient turnover is disturbed, the soil nutrient levels may decrease below the levels necessary to support plant growth. Unless the replenishing process, hence nutrient availability, is reestablished, there may be no success in the revegetative process of disturbed areas. (Fuller, 1975; Whitford, 1986).

The goal of this study was to determine whether there is a difference between the actual nutrient compositon of the plant-inhabited soil and the bare soil adjacent to growing plants. In the desert, increased nutrient concentration and increased infiltration rates

are associated with soils directly under shrub canopies (Ludwig et al., 1988; Whitford, 1986; Parker and Jones, 1951). Therefore, shrub influences may make their locations, rather than adjacent bare areas, more suceptible to invasion by other plants by providing nutrients and a suitable substrate for plant growth (Whitford, 1986). Most of these nutrients tend to be concentrated in the upper five cm of the soil, with deeper soils being nutrient poor (Skujins, 1981). The deeper soils could be depleted of nutrients as plants draw upon them for their needs. Annual plants, which are more sensitive to water availability and nutrient levels due to their short life span, are concentrated under shrub canopies (Parker et al., 1982). Low nutrient levels in the inter-shrub spaces, lower infiltration rates, and a harsher thermal environment combine to produce sparse annual plants in the inter-shrub areas (Whitford, 1986).

Although litter inputs are a major factor influencing the chemical makeup of the soil, plants can modify their chemical surroundings by secreting compounds into the soil through the roots, and different species will secrete different compounds. Keever (1950) showed that the output of the roots can influence the succession

of plants in a specific spot, depending upon the particular tolerances or requirements of the successor species. Indeed, the chemical secretions of one species may stimulate the growth of another (Keever, 1950). Although it has not been measured, root intake and output may vary as soil moisture changes, hence influencing the soil nutrient content around roots (Ag. Research. Inst., 1959). Plants may affect both their own tissue mineral content and the soil mineral content by the distribution of roots. The fibrous-root plants explore and extract from the soil intensively, and species with taproots explore and utilize the soil nutrients less completely (Ag. Research Inst., 1959). The root membranes act as barriers to the loss or uptake of nutrients between plants and the soil; work must be performed in order to transport nutrients across the barrier (Ag. Research Inst., 1959).

Decomposition of plant litter and animal wastes is the critical part of the nutrient cycling process, rendering the nutrients within organic matter available for plant use. The apparently simple process like litter decomposition actually involves many complex interactions such as growth of bacteria, yeast, and fungi; protozoan and nematode feeding habits; predation; translocation of

litter into the soil by organisms; etc. (Whitford, 1986). Indeed, subterranean termites are responsible for most of the mass loss and mineralization of carbon and nitrogen in dead grass and herbaceous roots in the Sonoran and Chihuahuan deserts (Whitford et al., 1988; Nutting et al., 1987). Schiemer (1983) has speculated that although desert rainfall pulses are not as important in triggering decomposition as previously thought, the nutrient availability may be important for determining nematode population sizes, hence rates of decomposition. Nematode density and oribatid mite activity are not affected by soil moisture because the organisms can be dormant during unfavorable conditions and become active in the cooler parts of the day (Freckman et al., 1987; Santos and Whitford, 1981; Whitford et al., 1981). Vertebrates can also act to enhance the decomposition process as they transform and transport materials, either for storage or as waste products (Brown, 1986). They modify soil by burrowing and mixing organic matter underground; their activities are mostly restricted to areas beneath shrubs and cacti (Thames and Evans, 1981), and can be shrub-species selective in their foraging and burrowing.

Because evidence supports both the importance of the nutrient content of desert soils and the extensive biotic

interactions that must take place to provide essential nutrients for plant growth, the patterns of nutrient availability of desert soils should be better understood. Quantifying the type of soil nutrients affected by these processes will provide the first step toward identifying the nutrient distribution patterns. Determining whether the effect is significant between shrub locations and adjacent areas not supporting plant growth will add to the knowledge concerning the delicate interaction that desert plants have with their environment.

CHAPTER II

MATERIALS AND METHODS

Location of the Study Site:

A study site was chosen in the Colorado Desert portion of the Sonoran Desert, east of Joshua Tree National Monument near Coxcomb Mountains (Figure 1). The study site is on a very broad, flat bajada covered by a creosote bush-ragweed community. There is no evidence of a well-defined runoff channel from the Coxcomb Mountains in the distance, indicating a sheet erosion predominance. Quaternary-age aluminum (Jennings, 1967) of sand and gravel, with rocks (2-10 cm) scattered throughout, underlie the study site. This material is classified as a fluvent entisol soil related to water transport although wind transported soils are in the area as well. Entisols exhibit no natural distinctive horizons or layers which may be used for identification purposes (Fuller, 1975).

The study site is in an area characterized as having the greatest water deficit in the state (Ruffner, 1985), an area ranging from Death Valley to the Mexican border and covering the eastern third of California. There is

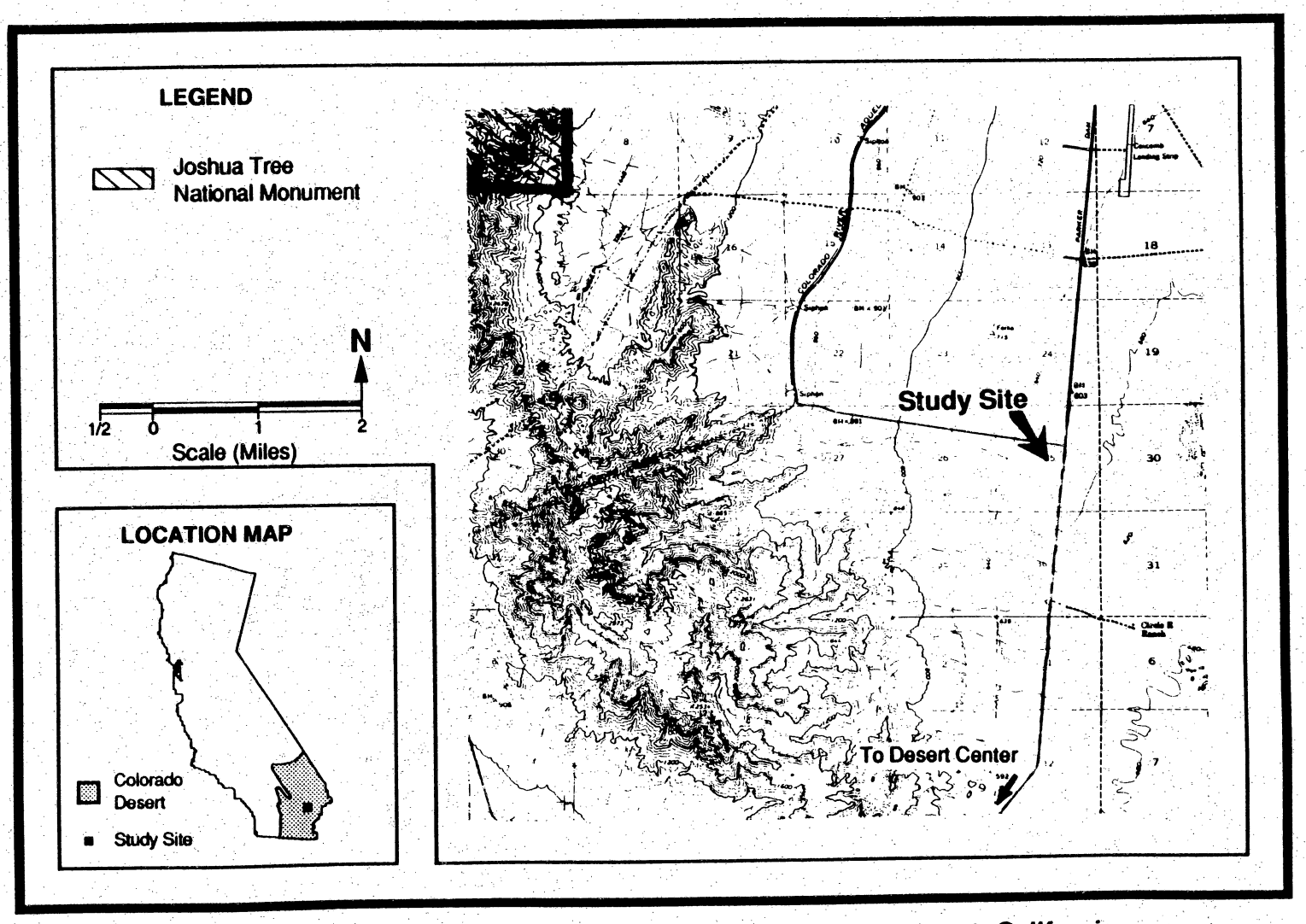

FIGURE 1: Desert Soil Study Site, East of Joshua Tree National Monument, California
(Ref: USGS 15 min. quads., Coxcomb Mtns. (1963) and Palen Mtns. (1952), California)

an average of 350 frost-free days per year with monthly temperature means ranging from 5.5 to 42 degrees Celsius (Ruffner, 1985). The highest temperatures occur in June, July, and August, and the lowest occur in December, January, and February. There is an average annual precipitation of 100mm which falls in a bimodal fashion typical of the Sonoran Desert (Crosswhite, 1982).

Species studied:

Colorado Desert plants tend to have reduced leaf size, are adapted to water loss, and the plant community is dominated by Larrea and Ambrosia on the valley floors (MacMahen, 1985). Ambrosia dumosa and Encelia farinosa (another common shrub), as described by Munz (1974), were selected as the study species.

In order to determine the depth and growth pattern of the main root mass, two individuals of Ambrosia dumosa were excavated. Both plants had one main descending root which reached down 40 cm (Figure 2). Other roots emerged in a horizontal direction then tapered downward at an angle, penetrating deeper than the main vertical root. An Encelia farinosa was also excavated and found to have a stout tap root which descended about 40 cm before turning 90 degrees to spread out in a horizontal fashion;

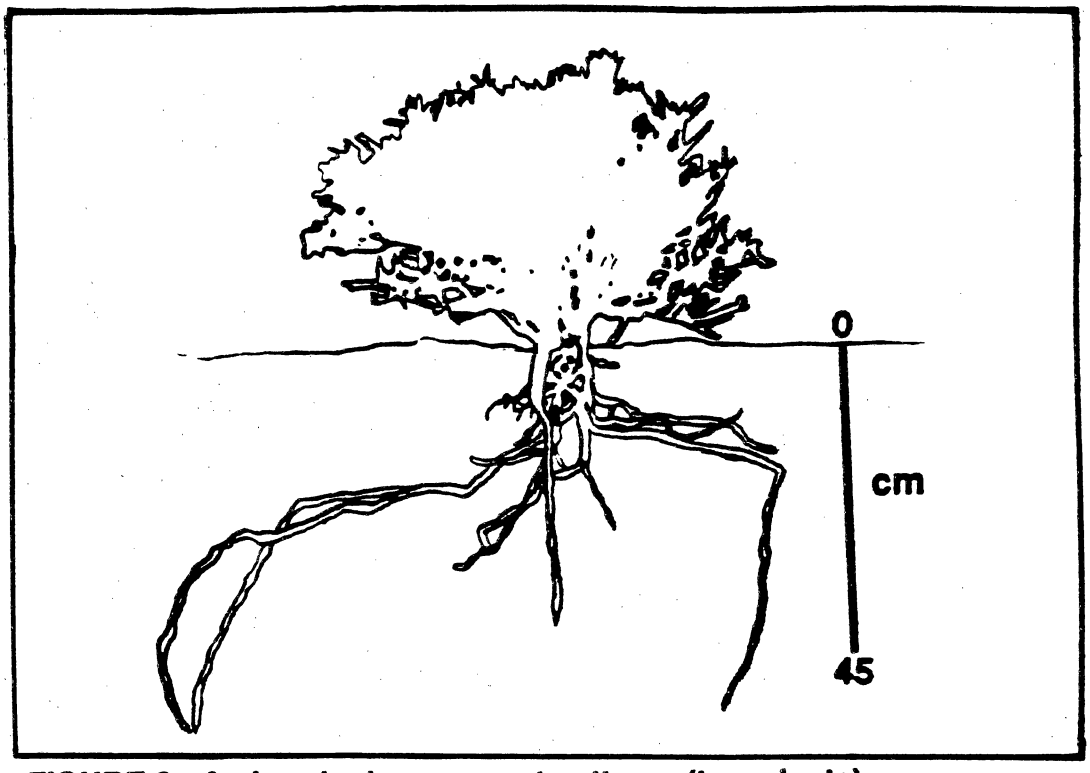

FIGURE 2: Ambrosia dumosa root patterns (two plants).

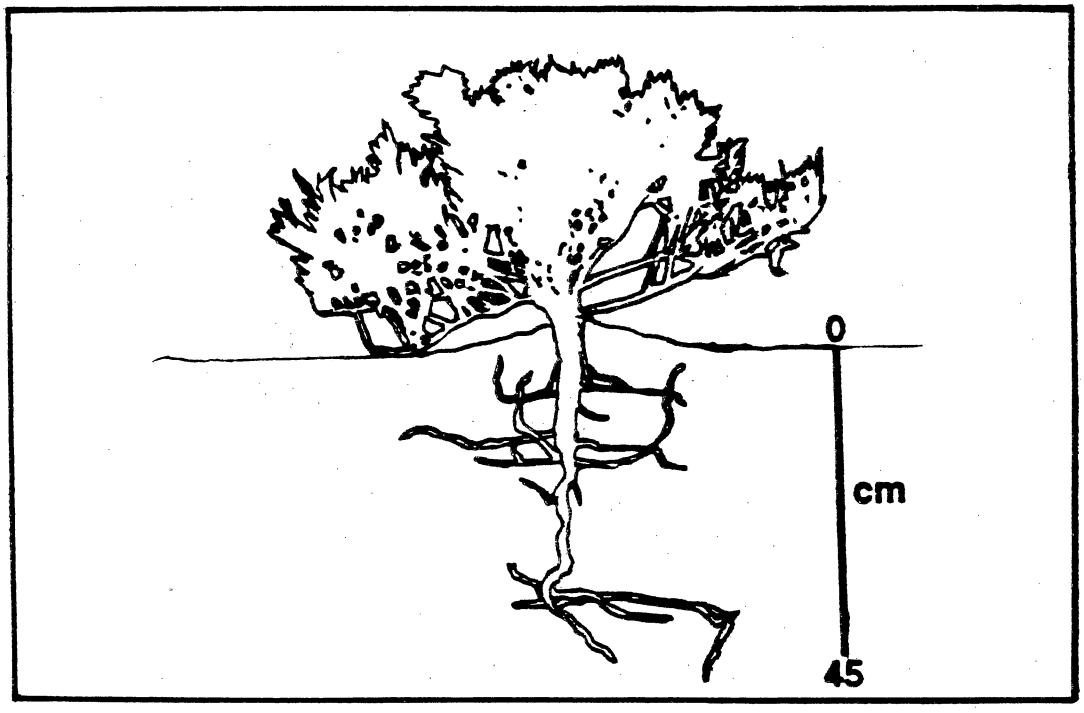

FIGURE 3: Encelia farinosa root patterns.

numerous horizontal roots grew off the main root but did not extend out as far as seen in Ambrosia (Figure 3).

Study Design and Sample Collection:

Soil samples were collected during two consecutive days in October 1988. Soils just beneath the humus layer, at 1 cm below the surface, and those soils in contact with the main root mass at 25 cm below the surface were studied. A previously-conducted pilot study determined that the soil chemical composition at any depth under a given plant may be variable. The variability could be a result of plant litter redistribution by the wind; because shrub clumps cause eddy currents that allow transported fragments to settle out, there is an accumulation of plant material on the lee side of plants (Whitford, 1986). In order to minimize variability, 60 cubic cm of soil was gathered within 5 cm of the central axis or trunk of each plant at each of the 4 main compass headings at each depth. This yielded a total of 240 cubic cm of soil at each of 2 depths underneath any one plant canopy. The samples from one cm in depth were collected after the top cm of leaf litter was carefully removed. The samples from 25 cm were collected directly below the 1 cm samples. In order

to prevent iron contamination of the samples, a clean, rust-free metal shovel was used to dig to a depth of 24 cm, where a plastic trowel was used to excavate the last cm to the depth for sampling. A plastic measuring container was used to collect the 60 cm sample, which was placed in a plastic zip-lock bag. No rocks larger than two cm in diameter were collected in the samples, although rocks this size were common and found in every sample.

Soil samples and plant voucher specimens were collected for 20 individuals of each species, and from 20 bare soil areas. An individual of the rarer species, Encelia, was first chosen, then a bare spot was selected within three meters of it. In an attempt to standardize site variations experienced by individuals of each soil-type group, an Ambrosia was then selected the same distance from the bare spot as the Encelia (Figure 20 in Appendix 2).

Lab techniques:

After thoroughly mixing the soil samples from each depth, 50.0 g were removed and mixed with 15 ml of distilled water. A water-extract method was recommended by the Inductively Coupled Plasma (ICP) spectrometer operator (Bradford, UCR, personal communication) as the

best single method for getting "plant-available" readings. In addition, samples of 3.0 g of each species' roots and 2.0 g of each species' leaves were crushed and soaked in 15 ml of distilled water. After 24 hours, the plant and soil suspensions were aspirated into a 50 ml flask through filter paper and transferred to an 8 ml vial. The total amount of aspirated water was noted. Water-holding capacity of the soil was calculated as the percent of water volume retained by the soil after being aspirated. The extracts, along with appropriate water blanks, were analyzed on an ICP spectrometer, which quantified water soluble elements (listed in Table 1) from the soil and tissue extracts.

Since nitrogen content cannot be analyzed on the ICP spectrometer, the procedure outlined by Keeney and Nelson (1972) was used for inorganic nitrogen analysis. A 50-ml vial containing 2.5 g of soil and 25 ml of 2M KCl was shaken mechanically for one hour. The soil-KCl suspension was then centrifuged for 8 minutes at 15000 rpm, until the liquid was clear. The supernatant was then injected into a Technicon autoanalyzer, run by the Alpkem computer system, to quantify the nitrogen available in the form of nitrate and ammonium.

The pH of the soils was determined as described by Palmer and Troeh (1977). Several samples of soil from each of the soil groups and depths were passed through a 2 mm sieve; 10 g of soil were added to 20 ml of distilled water and mixed well. The mixture was stirred several times over a 15 minute period, then a Chemcadet pH meter was used to determine pH.

Two-way-(depth x species) Analysis of Variance (ANOVA) and Scheffe's Tests were calculated for the data (Howell, 1987). The ANOVA was conducted on the three sample groups at both depths to determine whether there was a significant difference within that data. Of particular concern was the variability caused by the difference in element concentrations existing between the species or bare soil locations. When ANOVAs significant for the species-source variability were found, Scheffe's Tests were run to determine which pairs of conditions (i.e., Ambrosia vs. Encelia, Ambrosia vs. bare soil, Encelia vs. bare soil) contained the significant difference in element concentration.

Discriminant analysis was then used to further refine patterns and identify trends that may be hidden (Klecka, 1980). Two standardized canonical coefficients were developed for each element and used to derive the

total structure coefficients. Total structure coefficients were used because they are simple, bivariate correlations not affected by relationships with other variables and are useful to graphically observe the differences between group centroids. Both types of coefficients give a measure of the importance of each variable in distinguishing among depths and among species-or bare-associated soils.

CHAPTER III

RESULTS

Desert plants interact with two broad categories of nutrients: those which are essential to plant growth and those which are not essential. As a group, essential plant nutrient concentrations are highly similar in Encelia farinosa and Ambrosia dumosa, with a significant difference between plant-associated soils and soils that are not associated with plants. The differences, although significant, are more apparent among the nutrients considered essential for plant growth than for the nutrients not considered essential. Discriminant analysis identified a significant separation between each plant species and the bare soil when all nutrients were considered simultaneously. The soil nutrient concentration characteristics for the species and the bare soil allow individual soil samples at any one depth to be correctly classified into their species- or bare-soil-related group with almost 100 percent accuracy.

Table 1 shows the nutrient levels for each sample group taken. Note that in many of the 28 parameters, "Bare Soil" has lower nutrient concentrations than soils

TABLE 1

GROUP MEANS AND STANDARD ERRORS OF SOIL CHEMICAL CONCENTRATIONS (ppm)

Mean ppm / SE ppm	Ca*	Mg*	Na	K*	P*	S I	B*
Encelia 1 cm	158 ±33.549	14.096 ±2.026	27.255 ±3.739	152.09 ±11.675	0.373 ±0.061	7.444 ±0.316	0.255 ±0.031
Ambrosia 1 cm	144.395 ±32.892	20.093 ±2.818	24.104 ±2.798	146.229 ±12.649	0.6 ±0.062	8.545 ±0.366	0.571 ±0.05
Bare Soil 1 cm	33.155 ±1.759	2.332 ±0.109	11.47 ±0.719	0.807 ±0.397	0.114 ±0.015	12.291 ±0.935	0.08 ±0.008
Encelia 25 cm	44.667 ±6.056	4.689 ±0.618	23.718 ±1.941	22.036 ±4.167	0.107 ±0.011	9.191 ±0.595	0.295 ±0.031
Ambrosia 25 cm	51.502 ±6.31	7.775 ±1.181	21.948 ±1.718	53.686 ±8.086	0.227 ±0.037	16.551 ±6.474	0.443 ±0.041
Bare Soil 25 cm	21.693 ±1.067	2.362 ±0.109	11.588 ±0.719	0.835 ±0.403	0.123 ±0.009	12.012 ±0.68	0.082 ±0.009

Mean ppm / SE ppm	Ba	Sr	Li	Ti	Al	Fe *	Mn*
Encelia 1 cm	0.372 ±0.03	1.792 ±0.321	0.042 ±0.006	0.022 ±0.004	0.28 ±0.078	0.22 ±0.042	0.009 ±0.002
Ambrosia 1 cm	0.376 ±0.029	2.096 ±0.309	0.034 ±0.004	0.027 ±0.005	0.344 ±0.081	0.269 ±0.046	0.11 ±0.026
Bare Soil 1 cm	0.105 ±0.011	0.295 ±0.018	0.004 ±0.001	0.122 ±0.02	2.116 ±0.379	1.125 ±0.192	0.034 ±0.005
Encelia 25 cm	0.086 ±0.005	0.521 ±0.067	0.032 ±0.003	0.084 ±0.019	0.861 ±0.189	0.429 ±0.102	0.009 ±0.002
Ambrosia 25 cm	0.109 ±0.017	0.621 ±0.083	0.04 ±0.003	0.346 ±0.196	4.014 ±2.418	1.985 ±1.192	0.044 ±0.023
Bare Soil 25 cm	0.057 ±0.003	0.216 ±0.012	0.015 ±0.001	0.195 ±0.02	2.188 ±0.233	1.065 ±0.115	0.019 ±0.002

*Essential Plant Nutrient

TABLE 1 - Continued

Mean ppm / SE ppm	Cu *	Zn *	Cd	Pb	V	Mo*	Ni
Encelia 1 cm	0.028 ±0.004	0.011 ±0.003	0.001 ±4Ex-4	0.152 ±0.025	0.001 ±0.0004	0.008 ±0.002	0.013 ±0.003
Ambrosia 1 cm	0.031 ±0.005	0.007 ±0.001	0.001 ±2Ex-4	0.28 ±0.033	0.001 ±4Ex-4	0.012 ±0.002	0.014 ±0.004
Bare Soil 1 cm	0.002 ±0.001	0.001 ±0.001	5Ex-6 ±5Ex-6	0.05 ±0.011	0.002 ±0.001	0.001 ±4Ex-4	0.001 ±0.001
Encelia 25 cm	0.038 ±0.006	0.001 ±3Ex-4	2Ex-4 ±7Ex-5	0.091 ±0.008	0.005 ±0.001	0.01 ±0.001	0.004 ±0.001
Ambrosia 25 cm	0.037 ±0.005	0.006 ±0.004	4Ex-4 ±1Ex-4	0.103 ±0.014	0.009 ±0.003	0.012 ±0.001	0.006 ±0.001
Bare Soil 25 cm	0.02 ±0.002	0.002 ±4Ex-4	3Ex-4 ±1Ex-4	0.05 ±0.005	0.006 ±0.001	0.004 ±0.001	0.003 ±5Ex-4

Mean ppm / SE ppm	Co	Cr	Be	NH 4	Nitrates *	H2 O (%) *	pH
Encelia 1 cm	0.014 ±0.006	1Ex-4 ±1Ex-4	1Ex-5 ±1Ex-5	1.139 ± 0.171	0.201 ±0.014	30.699 ±0.565	8.065 ±0.075
Ambrosia 1 cm	0.006 ±0.001	3Ex-4 ±3Ex-4	3Ex-4 ± 2Ex-4	1.85 ± 0.293	0.221 ±0.028	30.333 ±0.77	8.26 ± 0.14
Bare Soil 1 cm	6Ex-5 ±5Ex-5	4Ex-4 ±3Ex-4	1Ex-4 ±3Ex-5	0.142 ± 0.024	0.158 ±0.042	26.366 ±0.406	8.72 ± 0.3
Encelia 25 cm	0.003 ±4Ex-4	0.002 ±4Ex-4	2Ex-4 ±3Ex-5	0.179 ±0.062	0.026 ± 0.001	23.2 ±0.575	8.2 ± 0.15
Ambrosia 25 cm	0.004 ±0.001	0.004 ±0.001	4Ex-4 ±1Ex-4	0.286 ±0.061	0.033 ± 0.006	27.234 ±0.842	8.725 ± 0.155
Bare Soil 25 cm	0.003 ±0.001	0.004 ±0.001	3Ex-4 ±3Ex-5	0.042 ±0.015	0.015 ± 0.002	24.601 ±0.66	8.21 ± 0.03

*Essential Plant Nutrient

under either plant species. Also note that when concentrations of nutrients in "Bare Soil" are higher than those of only one plant species, the plant species is Encelia farinosa. Ambrosia dumosa has significantly higher concentrations of more nutrients than Encelia, especially at 25 cm in depth.

The trends noted in Table 1 are summarized in Tables 2 and 3. Table 2 shows that significant differences exist for most of the nutrient concentrations, whether the source of variability is from the depth-related differences in nutrient concentration, (18 are significant), species (including bare soil) differences in nutrient concentration (18 are significant), or concentration differences caused by depth and species interactions (16 are significant). Of the three sources of variability, the interaction source had the least significant nutrient concentrations. Depth and species sources had the same number of significantly different nutrients. Further, when a difference was not significant at the species-source of variability, it was usually also insignificant at the interaction-source of variability.

TABLE 2

2-WAY-BETWEEN ANOVA RESULTS COMPARING THE SOILS UNDER ENCELIA AND AMBROSIA AND AT BARE SOIL LOCATIONS AT 1 AND 25 CM

SOIL PARAMETERS	SOURCE OF VARIABILITY ($p \leq x$)		
	DEPTH (D)	SPECIES (S)	Dx'S INTERACTION
Ca*	0.0001	0.0001	0.01
Mg*	0.0001	0.0001	0.0005
Na	0.5	0.0001	0.75
K*	0.0001	0.0001	0.0001
P*	0.0001	0.0001	0.0001
Si	0.2	0.25	0.5
B*	0.001	0.0001	0.05
Ba	0.0001	0.0001	0.0001
Sr	0.0001	0.0001	0.0005
Li	0.5	0.0001	0.02
Tl	0.025	0.25	0.25
Al	0.1	0.2	0.2
Fe*	0.2	0.2	0.2
Mn*	0.0001	0.02	0.05
Cu*	0.0025	0.0001	0.5
Zn*	0.02	0.02	0.01
Cd	0.2	0.1	0.05
Pd	0.0001	0.0001	0.0001
V	0.0001	0.5	0.5
Mo*	0.1	0.0001	0.75
Ni	0.005	0.002	0.05
Co	0.1	0.02	0.02
Cr	0.0001	0.25	0.5
Be	0.5	0.5	0.5
NH4*	0.0001	0.2	0.75
NO3*	0.0001	0.0001	0.0001
H2O*	0.0001	0.0005	0.0001

*Plant essential nutrients

The species-source of variability is mainly significant between the plant-inhabited soils and the bare soil (Table 3). Even though some significant differences were found among the concentration of nutrients between the two plant species (e.g., $p \leq .05$ for P and B), there was always a significant difference between one or both of the plant-associated soils and the bare soil.

Figures 4 through 10 show comparisons of the quantities of essential plant nutrients under plants and in bare areas. Note how similar the nutrient concentrations are for the two plant species at either depth (Figures 4 and 5). There are significant differences between the plant-associated soil and the bare soil nutrient concentrations in 8 of the 12 nutrients at one cm, and in 9 of the 12 nutrients at 25 cm.

Another noteworthy difference occurs between the 1 cm and the 25 cm depths (Figures 4 and 5). At 25 cm, the essential plant nutrient concentrations are not as high as they are at the 1 cm depth. There still are significant differences between plant-associated soil nutrient concentrations and bare soil concentrations at 25 cm; however, fewer of the nutrient contentrations are

TABLE 3

SCHEFFE'S TEST SIGNIFICANCE FOR THE PARAMETERS WITH A SIGNIFICANT ANOVA RESULT AT THE SPECIES-SOURCE OF VARIABILITY

SOIL PARAMETERS	1cm			25 cm		
	Encelia vs Ambrosia	Encelia vs Bare Soil	Ambrosia vs Bare Soil	Encelia vs Ambrosia	Encelia vs Bare Soil	Ambrosia vs Bare Soil
Ca* [1]	NS [2]	S [3]	S	NS	S	S
Mg*	NS	S	S	S	NS	S
Na	NS	S	S	NS	S	S
K*	NS	S	S	S	S	S
P*	S	S	S	S	NS	S
B*	S	S	S	S	S	S
Ba	NS	S	S	NS	NS	S
Sr	NS	S	S	NS	S	S
Li	NS	S	S	NS	S	S
Cu*	NS	S	S	NS	S	NS
Pb	S	S	S	NS	S	S
Mo*	NS	S	S	NS	S	S
Ni	NS	S	S	NS	NS	NS
Co	NS	S	NS	NS	NS	NS
NO3*	S	S	S	NS	NS	S
H2O*	NS	S	S	S	NS	S

1 * Essential Plant Nutrient
2 NS Not Significant
3 S Significant at p 0.05

NOTE: Si, Ti, Al, Fe, Mn,Zn,Cd, V, Cr, Be, NH4 not included because they were not significant at the species-source of variability (Table 2).

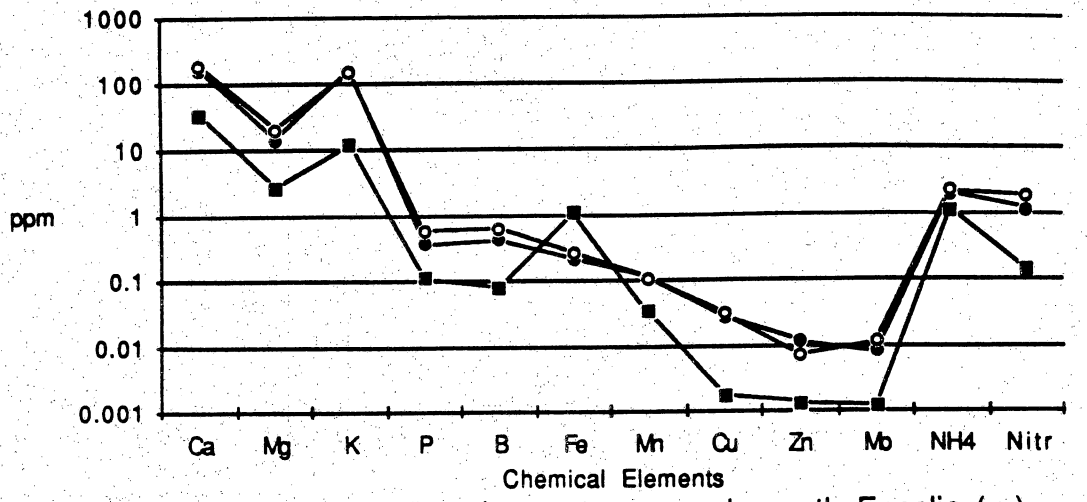

FIGURE 4: Essential plant nutrients at one cm beneath Encelia (●), Ambrosia (o), and bare soil (■).

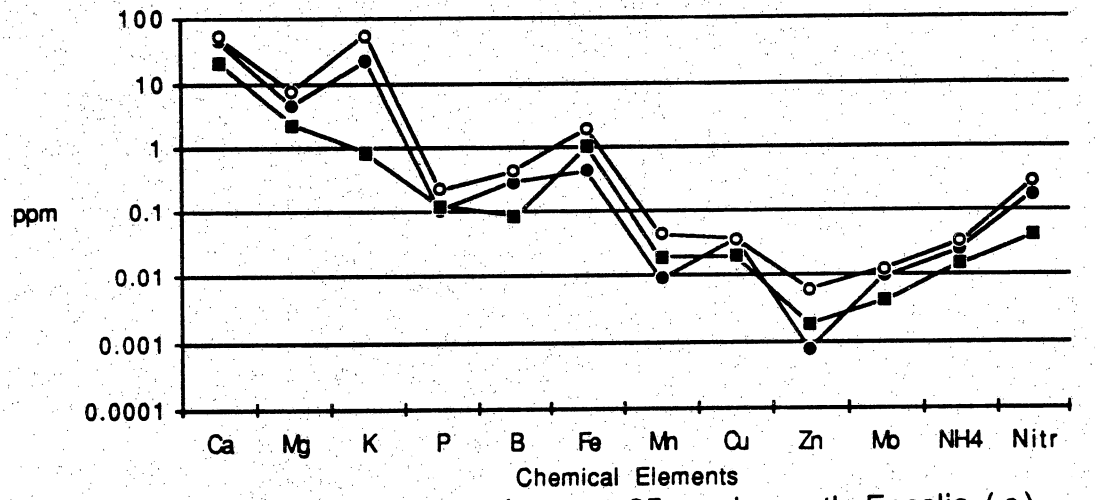

FIGURE 5: Essential plant nutrients at 25 cm beneath Encelia (●), Ambrosia (o), and bare soil (■).

significantly different between both plant species and the bare soil (e.g., P, NO3, and Ni).

Some of the specific nutrient concentrations at one cm in depth are interesting for varying reasons. Figure 4 and Tables 2 and 3 show no significant difference between the groups (Encelia-, Ambrosia-, or bare soil-related soils) for ammonium concentrations at 1 and 25 cm. However, nitrate concentrations are significantly different at 1 cm, but at 25 cm, differences in nitrate concentration were significant only between Ambrosia soils and bare soils (Figure 5). There is a significant difference ($p \leq .001$) for ammonium and nitrate concentrations found between the depths. One other element to note is P; its concentrations are significantly different between species and depths. All essential plant nutrients are required for plant growth so all of these nutrients can bear significance to a system.

At 25 cm quantities of many of the nutrients become more similar in soils; a reduction in plant-associated soil concentration of nutrients occurs as the depth increases, with the concentrations associated with bare soil remaining relatively stable as the depth increases

(Figure 5). The difference in nitrate at 25 cm becomes significant, with the plant associated soils containing greater concentrations of nitrate than the bare soil. However, the other limiting nutrient in the desert, P, loses one of the three significant interactions (Encelia vs bare soil) at 25 cm. The bare soil P-concentration remained constant from 1 to 25 cm; it was the plant-associated soil concentrations that became more similar to the bare soil concentrations when P was measured at the greater depth of 25 cm.

The essential-nutrient concentrations were also quantified for plant-tissue extracts. Figure 6 shows the relative concentrations of tissue extracts taken from Ambrosia and Encelia leaves and roots. Differences between leaf and root extracts appear more distinctive than species-specific tissue differences; Ca, Mg, and P display the greater differences in concentrations in the root- and leaf-associated samples.

In order to see essential plant nutrient concentration trends that may be associated with cause and effect, the leaf extracts and the soil most likely to be affected by leaf litter (1 cm) were compared with the bare soil at the same depth (Figures 7 and 8). The similarity is evident between the tissue extracts and the

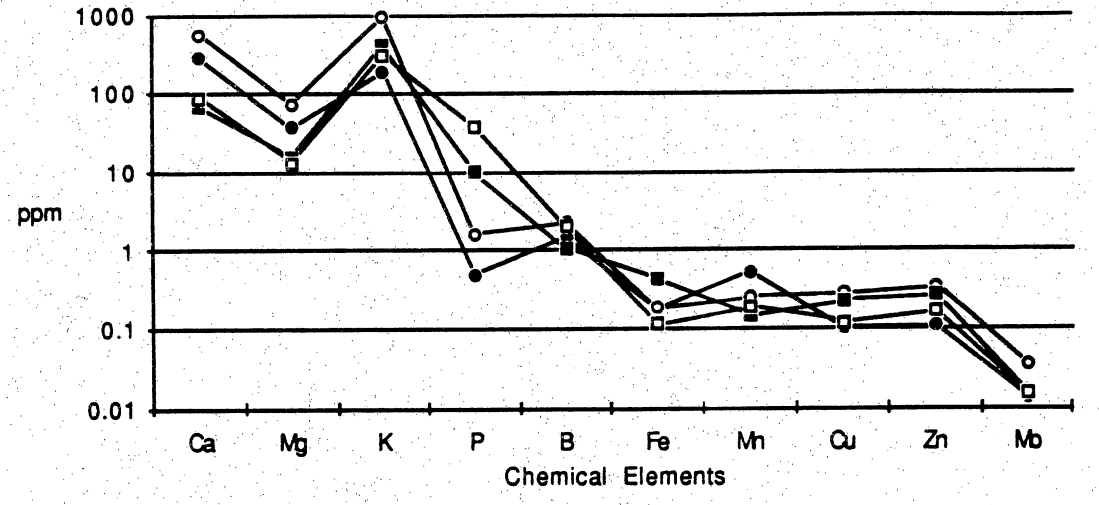

FIGURE 6: Essential plant nutrients from Ambrosia and Encelia tissue extracts: Ambrosia leaves (●) and roots (■), and Encelia leaves (○) and roots (□).

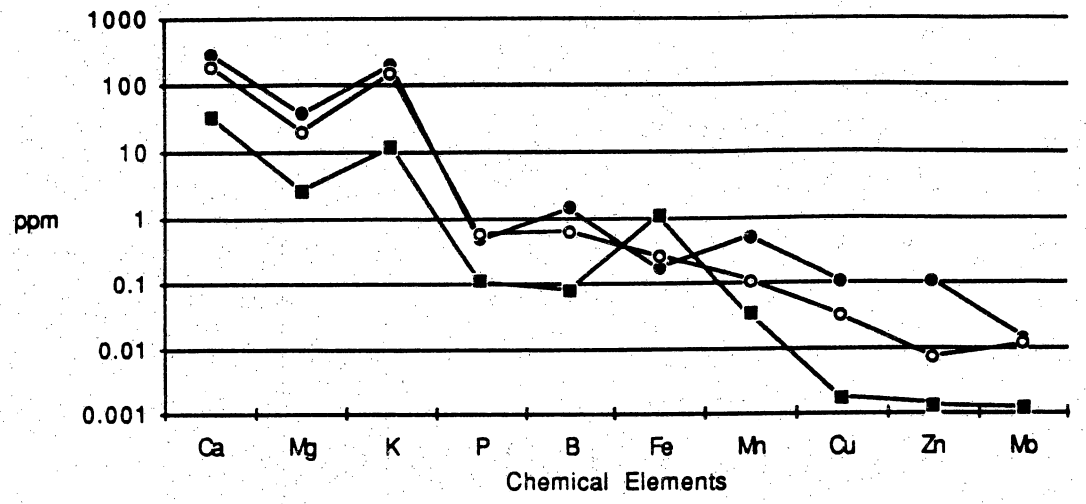

FIGURE 7: Comparison of essential plant nutrients from Ambrosia leaves (●), its soil at one cm (o), and the bare soil at one cm (■).

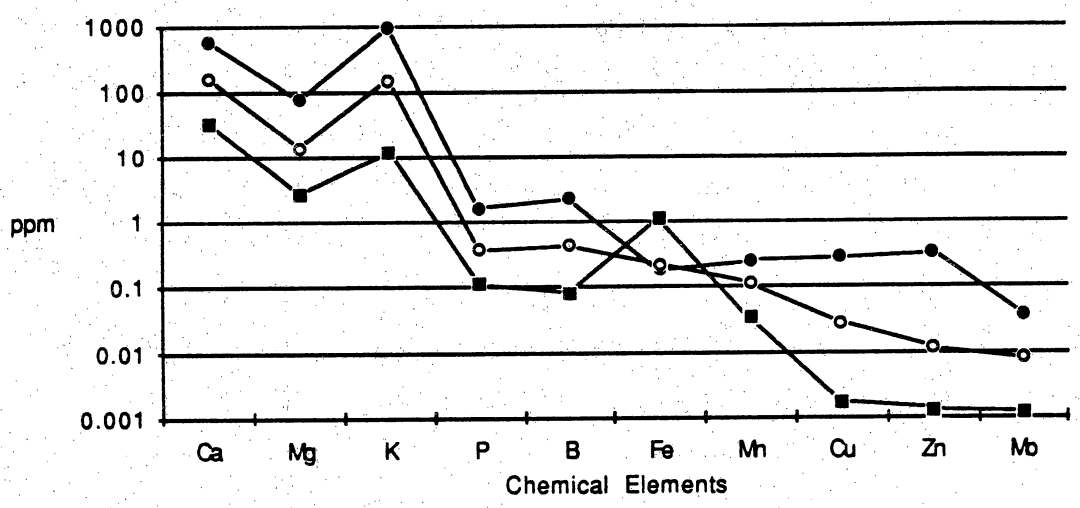

FIGURE 8: Comparison of essential plant nutrients from Encelia leaves (●), its soil at one cm (o), and the bare soil at one cm (■).

shallow soil underneath the plant species canopy (only 4 of the 10 nutrients are significantly different). The most significant differences occurred between the bare soil nutrient concentrations and plant-soil or plant-tissue concentrations (9 or 10 of 10 nutrients are significantly different for each interaction). Note also the variability between species is mainly in the leaf extract concentrations, whereas the soil concentrations are similar underneath the two shrub types (Figures 4 and 5).

Root inputs may also affect soil nutrient concentrations. Figures 9 and 10 show root extracts of plant-essential nutrient concentrations compared to plant-root-associated soil and bare soil concentrations at the same depth where the root sample was collected (25 cm). The significant differences of root extract concentrations showed similar trends to those of leaf extracts: Ambrosia soils at 25 cm and the root extract nutrient concentrations were more similar (5 nutrients are significant) than the Encelia root and soil extracts (8 nutrients are significant). The most significant differences in nutrient concentration also occurred between the bare soil and the plant-soil or plant-tissue nutrient concentrations.

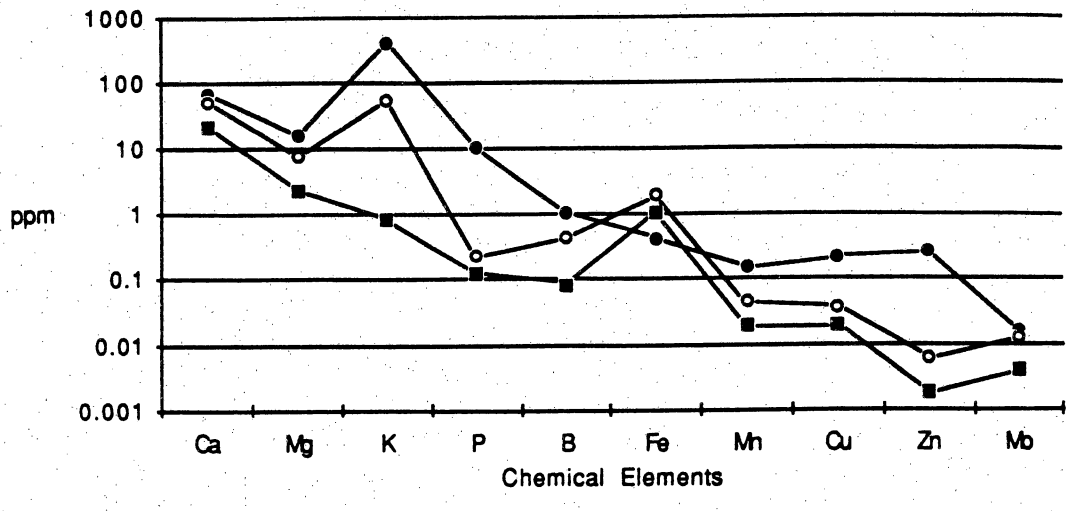

FIGURE 9: Comparison of essential plant nutrients from Ambrosia roots (●), its soil at 25 cm (o), and the bare soil at 25 cm (■).

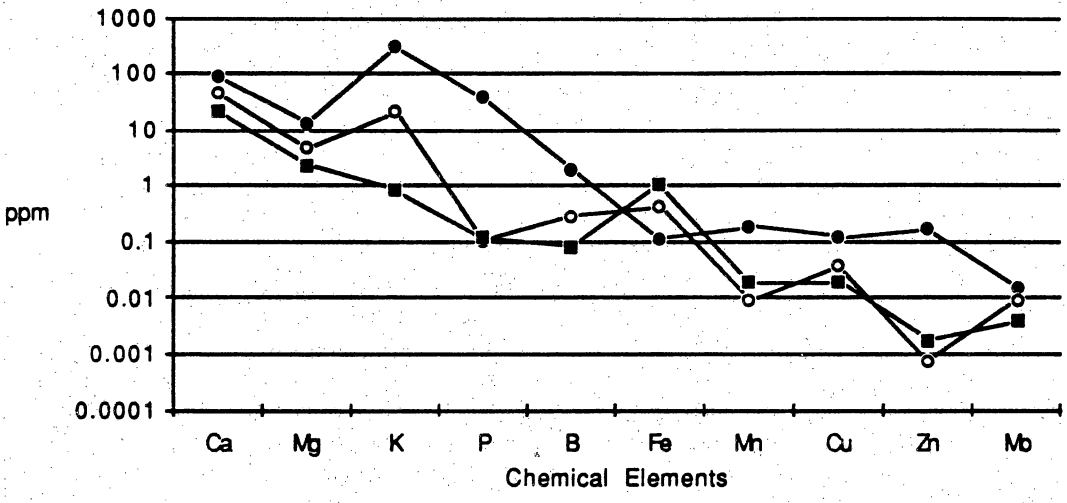

FIGURE 10: Comparison of essential plant nutrients from Encelia roots (●), its soil at 25 cm (o), and the bare soil at 25 cm (■).

Figures 11-17 show comparisons of the nutrients not essential for plant growth. The differences are significant ($p<.05$) between the plant-associated soil and bare soil nutrient concentrations at one cm in 7 of the 14 nutrients (Figure 11). The plant species' nutrient concentrations are not statistically significant between each other. Although the relative concentrations found in the bare soil are statistically significant from the plant-associated soil concentrations, they also show a similarity in concentration proportions. At the depth of 25 cm, the nonessential nutrients beneath plants become more similar between plant-associated soils and bare soils, with only 5 out of the 14 nutrients showing a significant concentration difference (Figure 12). All three groups, thus, appear similar, much more so than the concentrations that found for the essential nutrients for plant growth.

Nonessential nutrients in Ambrosia and Encelia leaf and root tissue extracts were compared (Figure 13). The nutrient concentration of the extracts was positively correlated except for 3 of the 14 nutrients; one of the deviations was root/leaf related, and one was species related. The leaf extracts were compared with the plant-associated soils and the bare soil at one cm for the

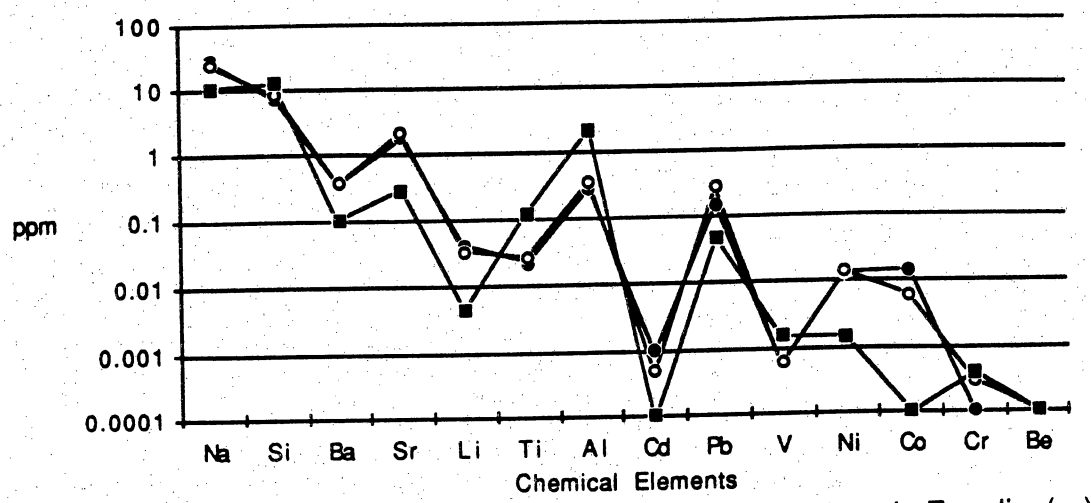

FIGURE 11: Nonessential plant nutrients at one cm beneath Encelia (●), Ambrosia (o), and bare soil (■).

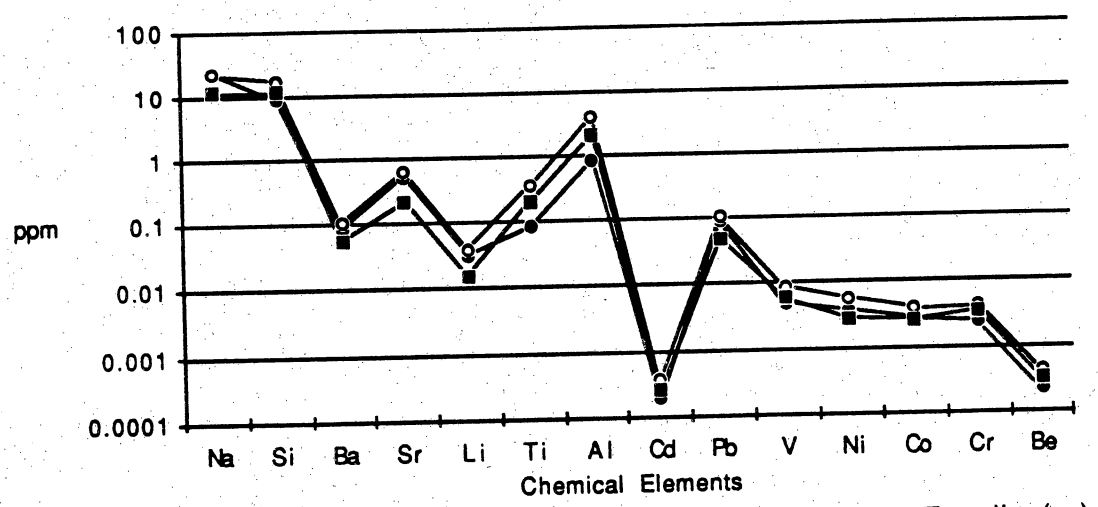

FIGURE 12: Nonessential plant nutrients at 25 cm beneath Encelia (●), Ambrosia (o), and bare soil (■).

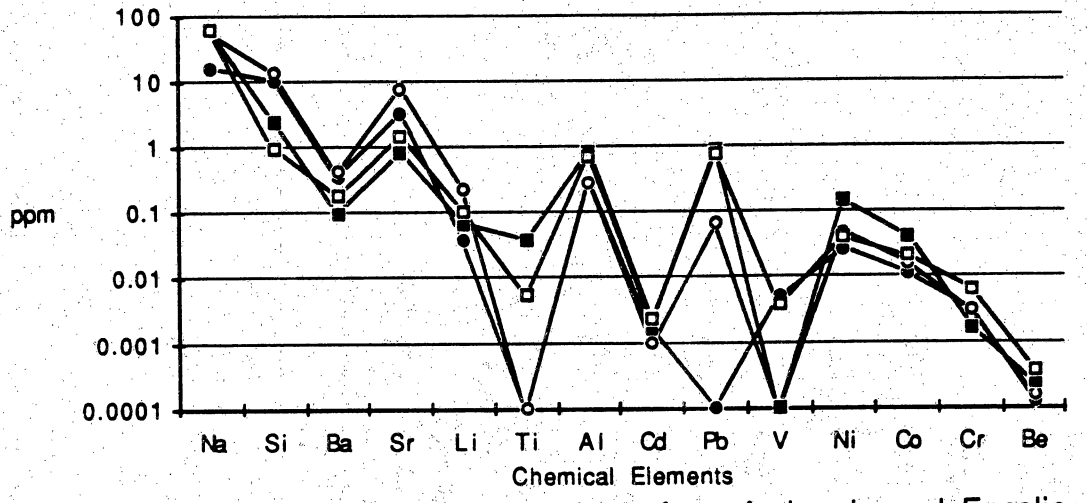

FIGURE 13: Nonessential plant nutrients from Ambrosia and Encelia tissue extracts: Ambrosia leaves (●) and roots (■), and Encelia leaves (o) and roots (□).

nonessential nutrients (Figures 14 and 15). Ambrosia leaf nutrient concentrations were extremely similar to the soil concentrations associated with the species (3 nutrients out of 14 are significantly different). Encelia showed some similarity as well (6 of the 14 are significant). However, leaf-extract concentrations were often found to be lower than either of the soil concentrations, so the leaves alone cannot be the main source of those nutrients. Although there was a general nutrient-concentration difference between the leaf extracts and the bare plant-associated soil, the difference is not nearly as significant as it was for the essential nutrient group (Figures 7 and 8).

The root-extract concentrations for nonessential plant nutrients (Figures 16 and 17) are more similar between plant tissue and soil for nonessential nutrients than for essential nutrients at 25 cm (Figures 9 and 10). More of the root extract nutrient concentrations were significantly different from concentrations in the soil than the leaf extract concentrations.

Figures 18 and 19 show how well the chemical variables classify the sample groups for the three conditions at two different depths. The horizontal and vertical axes are the total structure coefficients for

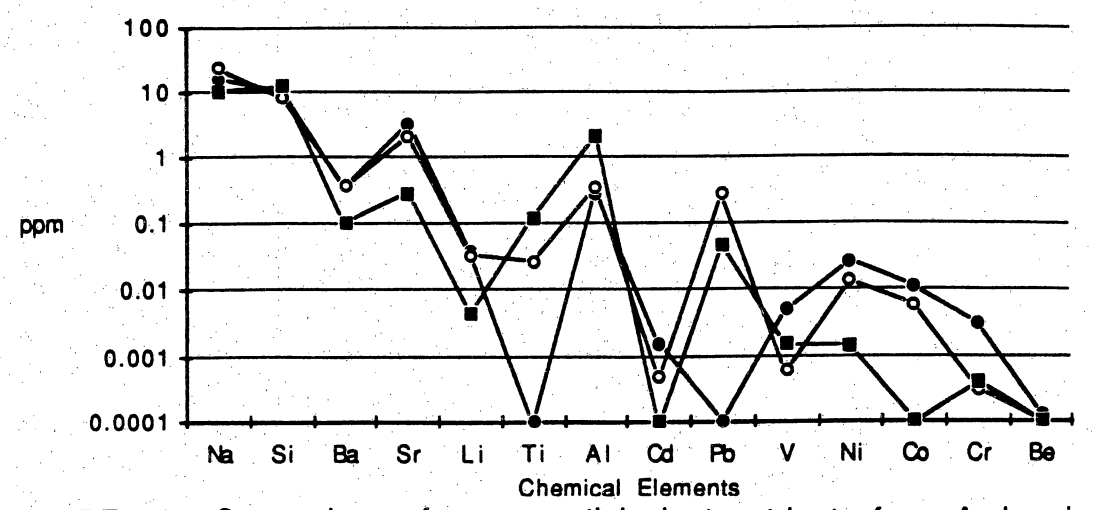

FIGURE 14: Comparison of nonessential plant nutrients from Ambrosia leaves (●), its soil at one cm (o), and the bare soil at one cm (■).

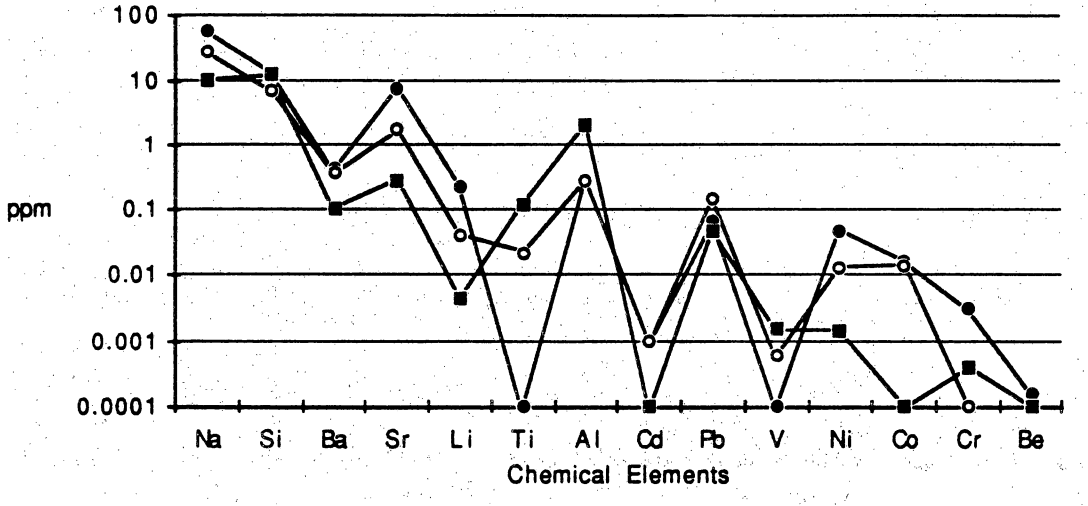

FIGURE 15: Comparison of nonessential plant nutrients from Encelia leaves (●), its soil at one cm (o), and the bare soil at one cm (■).

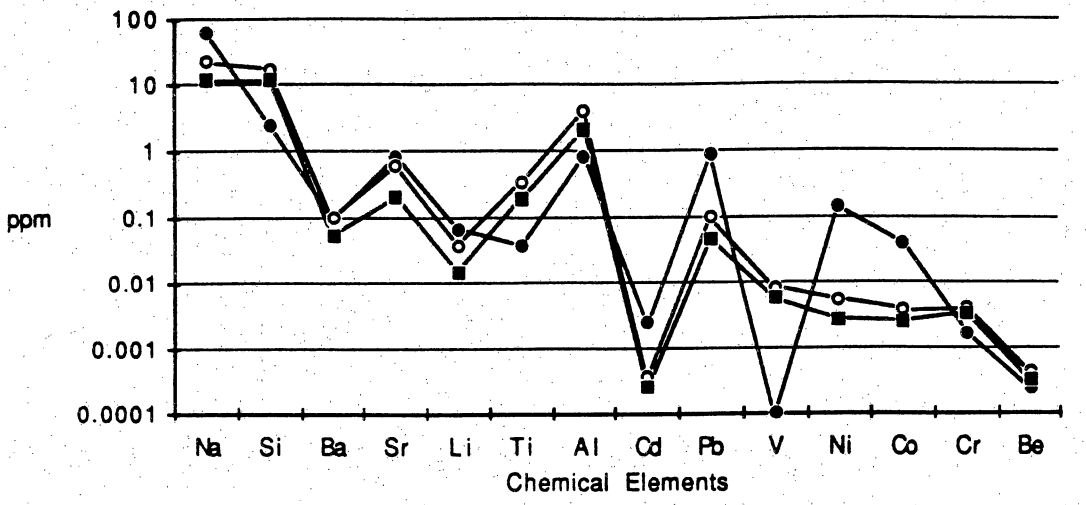

FIGURE 16: Comparison of nonessential plant nutrients from Ambrosia roots (●), its soil at 25 cm (o), and the bare soil at 25 cm (■).

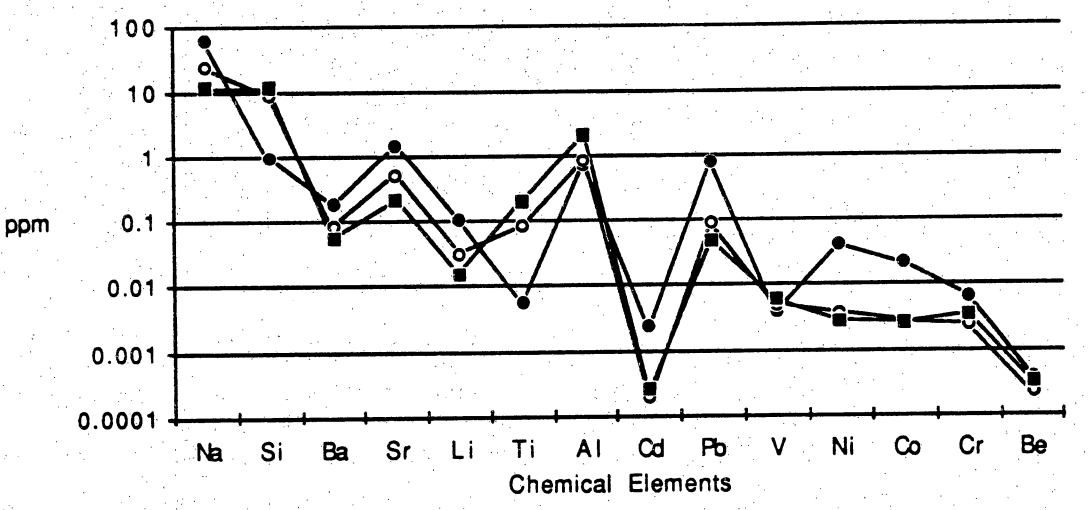

FIGURE 17: Comparison of nonessential plant nutrients from Encelia roots (●), its soil at 25 cm (o), and the bare soil at 25 cm (■).

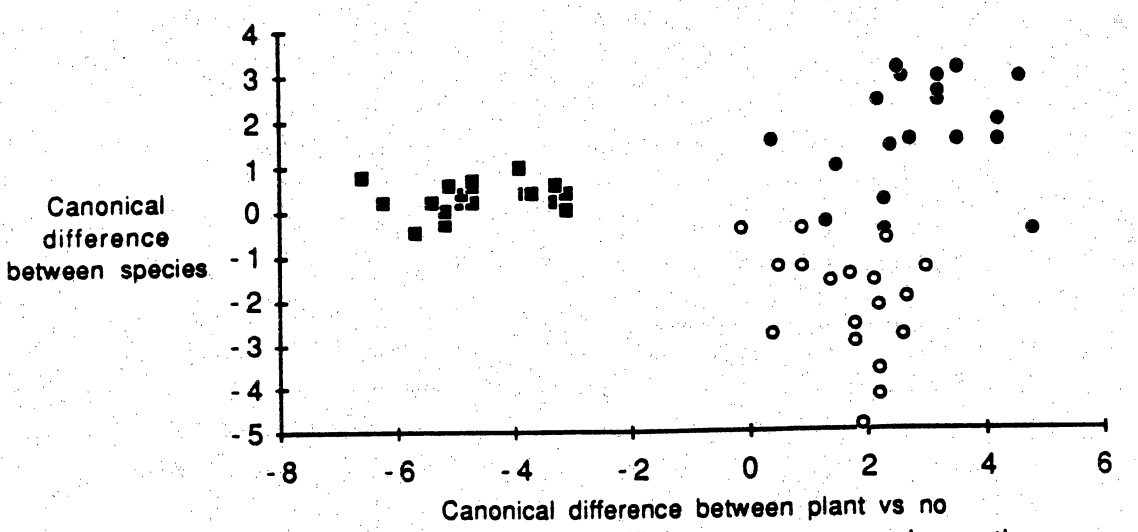

FIGURE 18: Plot of total structure coefficients at one cm beneath Encelia (●), Ambrosia (o), and bare soil (■).

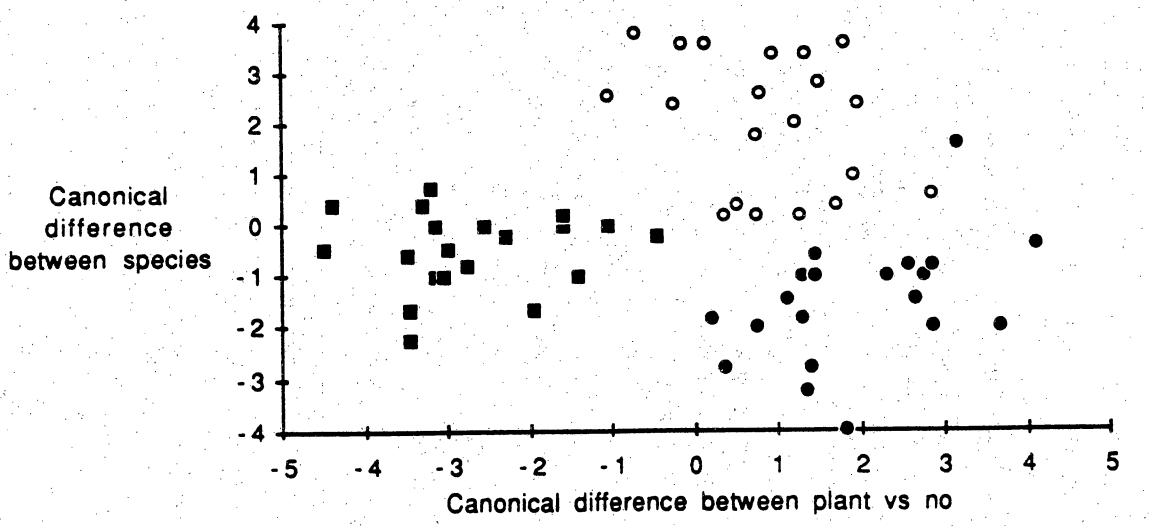

FIGURE 19: Plot of total structure coefficients at 25 cm beneath Encelia (●), Ambrosia (o), and bare soil (■).

plant versus no-plant differences, and the Encelia versus Ambrosia differences, respectively. The figures show the groups clearly distinguished from each other, indicating a significant difference in group characteristics. If all 60 individuals at each depth were placed together, the probability of correctly classifying all of the members into three conditions, i.e., Encelia-, Ambrosia-, or no-plant-associated soils, would be almost, if not exactly, 100 percent at either depth. The clearly-defined classification is surprising, especially at 25 cm in depth, because of the lack of distinction noted in Figures 5 and 17 between the three conditions. The nutrients responsible for most of the distinguishing parameters in species and bare soil are about equally comprised by the essential nutrients for plant growth and those not essential for plant growth (Table 4). However, plant essential nutrients did contribute significantly to creating the differences found between Encelia and Ambrosia at 25 cm.

The acidity and water-holding-capacity of the soils play important parts in nutrient characteristics and interactions with each other and with a plant. All soil samples showed a basic soil measurement, mainly between pH 8 and 8.5. The water-holding capacity of the soils

TABLE 4

DISCRIMINANT ANALYSIS COEFFICIENTS

SOIL PARAMETERS	1 CM				25 CM			
	STANDARDIZED CANONICAL COEFFICIENT		TOTAL STRUCTURE COEFFICIENT		STANDARDIZED CANONICAL COEFFICIENT		TOTAL STRUCTURE COEFFICIENT	
	1	2	1	2	1	2	1	2
Ca	1.16	-0.58	0.48	-0.17	0.26	-1.93	0.50	0.25
Mg	-1.91	-3.13	0.58	-0.35	-5.00	0.86	0.41	0.48
Na	0.90	1.86	0.55	0.02	1.06	-1.07	0.68	0.06
K	2.24	-0.41	0.86	-0.10	0.09	-0.66	0.50	0.62
P	1.98	-0.08	0.56	-0.46	-0.32	2.24	0.10	0.55
Si	-3.47	-0.83	-0.64	-0.05	-0.71	-9.78	-0.02	0.21
B	1.05	-0.50	0.67	-0.45	0.37	2.50	0.66	0.53
Ba	2.56	0.82	0.78	-0.14	1.99	-0.78	0.37	0.32
Sr	-2.45	1.05	0.57	-0.20	3.53	1.99	0.53	0.28
Li	-0.62	1.15	0.67	0.05	-1.76	-0.34	0.62	0.38
Tl	-0.64	0.05	-0.68	0.08	-20.45	9.43	-0.03	0.25
Al	0.92	0.53	-0.67	0.09	-4.72	-29.86	-0.03	0.24
Fe	2.61	0.24	-0.66	0.07	28.17	31.10	-0.03	0.24
Mn	-0.64	0.48	0.40	-0.06	-1.74	-2.85	0.01	0.29
Cu	0.01	0.04	0.61	-0.16	-0.21	0.47	0.39	0.07
Zn	-0.31	0.84	0.48	0.16	-0.03	1.74	0.03	0.29
Cd	0.50	0.49	0.32	0.13	0.41	0.22	-0.01	0.19
Pb	-0.70	-0.67	0.51	-0.52	0.99	-1.56	0.47	0.24
V	0.21	0.06	-0.19	0.04	0.53	0.07	0.02	0.22
Mo	-0.58	-0.45	0.54	-0.34	2.11	-0.12	0.62	0.42
Ni	0.24	0.20	0.42	-0.09	0.43	-0.41	0.20	0.28
Co	0.66	-1.76	0.34	0.20	-1.23	-0.22	0.08	0.24
Cr	-0.17	0.14	-0.11	-0.05	-0.77	0.68	-0.08	0.25
Be	-0.75	1.18	0.12	0.17	1.22	-1.13	-0.04	0.24

1. Coefficients best chosen to separate plant-associated soils from bare soils.

2. Coefficients best chosen to separate Encelia-associated soils from Ambrosia-associated soils.

NOTE: Coefficients represent relative importance of the element in identifying the separation of groups and accounts for most of the variation between the groups.

is significantly different ($p \leq .05$) between the plant-associated soils and the bare soils at one cm (Table 2). At 25 cm, there is a significant difference ($p \leq .05$) between Ambrosia and Encelia soils and between Ambrosia and bare soils.

Thus, the concentration of elements is greater for soils associated with plants compared to those not covered by plants. Most of these nutrients are found in the surface layer of soil and are similar to the nutrient concentrations in the leaves. This is particularly true for the nutrients essential for plant growth. Some element concentrations were found to be greater in the soil underneath the plants than could be accounted for using nutrient concentrations in the leaves.
These plant-associated soil concentrations near the surface were also much more similar in the two species than were the same-species leaf extract concentrations. The roots concentrate these essential nutrients from the soil, but elements not considered essential for growth were found to be in very similar concentrations in the root extract as they were in the soil at 25 cm, no matter where the sample was collected. Even though this difference between conditions is small, the specific nutrient concentrations for each of the 20 individuals in

each group have collectively defined the soils in those conditions (depth or species cover) at the location of the study site.

CHAPTER IV

DISCUSSION

Soil nutrients are the most frequently limiting factor in semiarid environments, yet plant-soil relationships in the desert are not widely described and are rarely studied (Crosswhite, 1983). The availability of the nutrients essential for plant growth must be the most crucial factor in determining plant success. Many factors influence nutrient availability: the decomposition process, soil salinity, shrub location as deposition sites for wind and water-transported debris, and faunal-floral-substrate interactions. Up to 1989, micro-habitat differences influenced by shrubs were only generally addressed (e.g., more annuals were observed growing under shrubs than in the open) or were limited to description of one nutrient, nitrogen. Much speculation has addressed the determinants of shrub distribution in the desert (Whitford, 1986; Attenborough, 1984; Phillips and MacMahon, 1981; Grime, 1979; Yeaton and Cody, 1976; Woodell et al., 1969); however, little or no chemical analysis has been conducted to address the nutrient-limiting factors for these desert species.

Significant differences in nutrient concentration were found between Encelia farinosa soils, Ambrosia dumosa soils, and adjacent soils without plant cover, both immediately below the surface of the soil (1 cm) and in the root zone (25 cm). The variation between these groups was attributed to three possible sources: species and bare soil associated differences, depth differences, and the differences caused by the interaction of species (or bare soil) and depth. Although all three sources of variation contained nutrients that were significantly different, species-attributed differences seemed most important. When there was not a significant difference between species, there was also not a significant difference attributed to the species and depth interaction. The concentrations were generally greater in the areas containing plants compared with those areas not containing plants. The soils of the different shrub species soils also had significant differences in nutrient concentrations, but the magnitude of those differences was not as great as for the plant versus no-plant differences.

Plant essential nutrients were studied because of their importance to desert plant establishment and success. Significant differences in nutrient

concentrations were found between the higher concentrations at shrub locations and the lower concentrations at the adjacent barren areas, not only for the surface layer of soil directly in contact with plant debris, but for the soils 25 cm below the surface. Root and leaf interactions with the soil involve nutrient exchange from decaying material or active roots, textural modification, and downward leaching of surface litter decay products. Because the leaf-tissue extract nutrient concentrations are similar to the soil nutrient concentrations, especially at one cm, the source of these nutrients in the soil may come largely from the leaf litter of the plant. Indeed, the leaves tend to concentrate particular nutrients, such as Ca and Mg, that are also found in higher concentrations in the surface soils having the most contact with the leaf litter.

There is a species-specific variation in tissue-extract concentrations of nutrients that would be expected to influence the soils directly under those species. Despite the differences in leaf-extract nutrient concentrations between the two shrub species, the soil nutrient concentration differences between the plant species were often insignificant. In fact, the

leaf-extract nutrient concentrations were often lower than the soils at one cm, indicating a concentration of available nutrients.

A redistribution of nutrients and their concentrations occur via wind and water transport, and by other living organisms (Whitford, 1986). Shrubs become deposition sites for nutrients because of their ability to trap the transported debris and because burrowing animals and other vertebrates concentrate activities under plant canopies rather than on exposed soils (Brown, 1986).

Despite the importance of N availability in desert plant systems (Whitford, 1986), there was no significant difference found between soil groups for ammonium concentrations. Nitrate concentrations were significantly different between the soil groups at 1 cm but not so different at 25 cm. P concentration was significantly different between all groups and depths. It is hypothesized that P may also be a limiting nutrient in desert environments because of its important role in all living organisms (West, 1981). The significant difference of P concentration in the different soil settings gives reason to believe that P may be limiting to plant establishment. Indeed, P was found in higher

concentrations in the root extracts than in leaf extracts of the soils contacting the roots, indicating a preferential transport of this element into the roots. Further study will be necessary to determine the sensitivity desert plants have to the presence of P in the soil and the plants' effect on P concentrations in immediate soil vicinities.

As the depth increases from 1 to 25 cm, a general decline in existing nutrient concentrations occurs. However, the essential plant nutrients are more concentrated in the root extracts than in either plant-associated or bare soil at 25 cm. The roots, most likely, preferentially acquire these nutrients through active transport. The higher concentrations of these nutrients in the plant-associated soils compared with the bare soils may be from the upper horizon nutrients filtering down through the soil.

The essential nutrient/root effect contrasts the nonessential nutrients for plant growth. Root content concentrations of nonessential elements are more similar in proportion to concentrations found in the soil at 25 cm than to the essential element concentrations even from the samples collected in areas without plant growth. The roots may not be as selective for nonessential elements

and may be regulated by diffusion alone. The effect is the soil influence on the root, not the root changing the soil as leaf debris is expected to do. Although nonessential nutrients are not required for plant growth, many enhance growth in small concentrations (Chapman, 1966). In larger concentrations, many of these nonessential nutrients can become toxic to plants, so that certain plant "strategies" can be developed to affect the mineral concentrations in the soil surrounding the roots. A desert plant can exclude an element from uptake through selective active transport or, if it is a root toxin such an Al, transport it out of the root area and up into the leaves where the damage will not be so great (Pratt, 1966a). Thus, a plant can modify the soil within its immediate contact.

The significant differences of all nutrients combined are described through discriminent analysis. The nutrient concentrations within each soil group (species-, bare soils-, or depth-related) are compared with those of other groups. The difference between this analysis and regular pair-wise tests is in the simultaneous comparison of all nutrients in a group to all nutrients in another group, at the same time taking into account the interaction of each nutrient with all

other nutrients within each group. Thus a complex series of interactions can be measured to develop a better description of a group in relationship to other groups.

Because nitrogen concentrations have already been demonstrated to be greater under plant canopies than in open areas (Whitford, 1986), this factor was excluded from this analysis in order to determine other factors which affect nutrient levels. All three groups of soils analyzed at each depth were found to be significantly different. They were so different by group that only 2 individuals out of 120 could not be classified into their group characterized by a particular combination of nutrient concentrations. In fact, the soils not supporting plant growth had very little variation between individual sites at one cm. Thus, the same influences that affect the soil chemistry may be affecting all areas equally. The plant-associated soils were more similar to each other than they were to the bare soils, but Encelia- and Ambrosia-associated soils also contained their own distinct characteristics. Because the two species are significantly different, one can speculate that chemical differences are occurring on a species-specific basis.

Leaf and root extracts contained different

concentrations of the essential and nonessential chemical nutrients; plant tissue input is one source of soil content variation as the litter leachates percolate through the soil. The shape of the shrub may also cause a difference in capturing ability of wind and water-transported debris. The branching pattern of Encelia farinosa was found to prevent a nutrient-filled mound from accumulating underneath the canopy, in contrast to two other common desert shrubs, Franseria dumosa and Thamnosma montana (Muller and Muller, 1956). Indeed, the nutrient concentration of Encelia was found to be lower than Ambrosia in almost all nutrients measured. The bare soil concentrations were always the same or significantly lower than the plant inhabited soils, probably due to lack of attractiveness to animal activities (hence, no litter turnover and decomposition) usually provided by desert shrub cover (Whitford, 1986; Brown, 1986). It is anticipated that further collection of samples at the site would support the specific differences described by the data in this study. The cause of the differences between groups can only be hypothesized without additional work. However, it seems reasonable to assume these conditions were caused by the existence of the plant and not the plant "selecting" (through differential

germination) a place with these conditions. Perhaps if these conditions did previously exist because of the presence of another plant, the succeeding plant had a better chance at establishment than plants attempting to colonize previously bare soil.

In hypothesizing a cause for the differences discovered between the three soil groups, the nutrients contributing the most to the differences should be considered. Plant essential nutrients contributed proportions similar to those of nonessential nutrients in creating most of these differences, except at 25 cm where plant essential nutrients were the major contributing factor to distinguishing between Encelia- and Ambrosia-associated soils. Of the many contributing elements, Na, Sr, Li, and Mo helped to distinguish plant-associated soils from those in adjacent, open areas. In addition, K, P, B, and Pb also contributed to the plant/no plant difference distinction, but also contributed to the distinction between Encelia- and Ambrosia-associated soils. It is interesting to note that the element contributing the most to those differences, overall, is K. Perhaps the limiting effects of this element also need further study.

Soil water-holding capacity was an additional discriminating parameter between the three groups. The water-holding capacity of the soils turned out to be significantly higher in the plant-inhabited soils than in the bare soil at one cm. The added humus in the soil at the surface under plant canopies may have increased the soil's potential to retain water. At 25 cm, only the Ambrosia-related soil was significantly higher than the bare soil. The ability of Ambrosia to trap more debris under its canopy may be the factor causing this difference.

Even though it was not a discrimination factor, soil acidity is still an important parameter affecting nutrient interactions with each other and with the plant. Acidity also affects the cation exchange capacity (CEC) of the soil; CEC is a measure of the soil's ability to retain nutrients, functioning best at a basic pH. The soil pH in the study site ranged from 8 to 8.5. Soils dominated by ions such as Ca++ and Mg++ will have a maximum pH of about 8.4, whereas if Na+ dominates, the pH may exceed 10 (Palmer and Troeh, 1977). Ca was found in greater concentrations than Na, supporting the lower soil pH prediction. The Ca dominance increases the CEC and thus a soil's capacity to retain plant nutrients

otherwise subject to leaching. The CEC of these soils do not seem to be affected by the existence of plants.

Thus, more questions have been raised by this study than have been answered. The cause/effect relationship of plant growth and establishment and the desert environment where plants have to live is a complex system and should not be oversimplified by claiming water or nitrogen is the limiting factor for a plant's success. More studies will need to be conducted on the nutrient effects on particular species and species effects on nutrient availability. More research on nutrient distribution in the desert soils could add dimensions to the knowledge of desert ecosystems. Other studies, such as research on existing organic material in the soil, seed germination, seedling establishment, and adult plant survival, which would take many years to conduct, are necessary to determine whether the soil differences found in this study actually do have an effect on the success of these species. Studies on the distribution of microorganisms in the soil on a microhabitat level may also provide some insight. Caution should be used, however, when conducting greenhouse experiments on desert plants because the effect caused by the soil differences may be seen only when the soil-moisture is limited. Of

course, greenhouse experiments cannot truly reflect all factors in the desert because the soil compacts when it is removed from the desert and put into pots; additives are needed to reduce this compaction (Augustine et al., 1979) and may influence the outcome when the factors involved are so small in concentration.

Whatever the additional study may be, the topic is still plant/soil relationships. Plants can modify their surroundings in four ways. They can chemically alter the soil through species-specific leaf litter leachates and through root uptake activities. They can trap wind or water-transported nutrients with their canopies. Their very existence attracts deposition of nutrients through animal activities and their waste products. And the soil structure and water-holding capacities can be modified under a plant through the addition of humus, the attraction of burrowing animals, and the physical influences of the roots.

In a habitat as sensitive as the desert, one must consider the delicate balance of many parameters that influence the success of a species. Soil on a micro-habitat level is not well studied, and especially not in the desert. Differences in desert soils only two meters apart, or 25 cm difference in depth, do exist. The

significance of the nutrient differences and the effects of these variations are not yet known.

APPENDIX 1

SOIL/PLANT CHEMICAL PROPERTIES

TABLE 5

ELEMENT PHYSICAL CHARACTERISTICS

SYMBOL	NAME	ESSENTIAL FOR PLANTS	ION	NATURAL SOURCE OF ELEMENTS	H2O SOLUBILITY	CHARACTERISTICS WITH PLANTS
Ca	Calcium	Yes	Ca^{2+}	Carbonates (CO_3^{2-})	Yes - as a Salt	Has a vital role in soil-structure maintenance and affects the availability and absorbability of other nutrients.
Mg	Magnesium	Yes	Mg^{2+}	Carbonates	Yes	Deficiency reduces growth and causes necrosis and yellowing and can be prompted by Ca, K. N can minimize any deficiency.
Na	Sodium	Some Plants	Na^{+}	Halide Salts	Yes - as a Salt	Can sometimes substitute for part of the K requirements. Can also cause moisture stress in and environment by decreasing moisture suction and osmotic pressure.
K	Potassium	Yes	K+	Halide Salts	Yes	Related to almost every physiological function, travels straight to growing parts and can cause Mg deficiency.
P	Phosphorus	Yes	5+/3+/3-P	Phosphates (PO_4^{3-})	Yes	Deficient in many soils, plays a role in growth and development, can lower Cu, Zn, and Fe uptake.
Si	Silicon	No	$Si^{4+/4-}$	Silicates (SiO_4^{4-})	No	Not an essential plant nutrient but some plants can accumulate this element.
B	Boron	Yes	B^{3+}	Borax (Borate=BO_3^{3-})	Yes	Performs a protective function at the sites of sugar synthesis, has positive and negative associations with Ca, N, and P
Ba	Barium	No	Ba^{2+}	Carbonates	Yes - as a Salt	Although toxic effects can occur when the amount of Ba exceeds that of sulfate, the total Ba content of the soil is of little significance.
Sr	Strontium	No	Sr^{2+}	Carbonates	Yes - as a Salt	Can replace Ca to some extent, toxic amounts not observed in nature.
Li	Lithium	No	Li^{+}	Sulfides (S^{2-})	Yes - as a Salt	Can cause stimulating and toxic effects to plants by affecting germination and vegetation. Toxicity not observed in nature.
Ti	Titanium	No	4+/3+/2+ Ti	Oxides (O^{2-})	Yes-at High Temps	May act as a photocatalyst changing nitrite to nitrate; enhances root growth; may reduce toxicity of some other elements.

TABLE 5 - continued

SYMBOL	NAME	ESSENTIAL FOR PLANTS	ION	NATURAL SOURCE OF ELEMENTS	H2O SOLUBILITY	CHARACTERISTICS WITH PLANTS
Al	Aluminum	No	Al^{3+}	Oxides	Yes	Can eliminate toxic Cu effects and reduce disease organisms in soil; is a specific root poison; solublizes in soils of pH5 or less; P causes Al to be insoluble
Fe	Iron	Yes	$Fe^{3+/2+}$	Oxides	Yes-as a Salt	Deficiency causes "leaf chlorosis." Toxicity in nature not a problem. Deficiency associated with many things: K def., bicarb ions, high pH high Cu or P, etc.
Mn	Manganese	Yes	$Mn^{7+/6+/4+}$ $Mn^{3+/2+}$	Oxides	?	Involved in N assimulation & functions with iron in the synethsis of chlorophyll. Becomes insoluble at higher pH.
Cu	Copper	Yes	$Cu^{2+/+}$	Sulfides	No	Deficiency causes a lack of growth, & subsequently fungal attack; excess causes stunting & an iron deficiency. Cu held in soil like Ca and Mg; organic matter lowers available Cu
Zn	Zinc	Yes	Zn^{2+}	Sulfides	Yes-at HighTemps	Total Zn low in acid, leached soils; unavailable in alkaline soils, organic soils, with addition of P or N. Ca increase Zn uptake by adding NH4, grows alfalfa, sterilize soil. Organic matter adds it.
Cd	Cadmium	No	Cd^{2+}	Sulfides	?	N/A
Pb	Lead	No	$Pb^{2+/4+}$	Sulfides	Sparingly	Small amts can stimulate growth as a side effect of increased nitrification rates in the soil. Concentrates in the roots.
V	Vanadium	No	$V^{5+/4+}$ $V^{3+/2+}$	Oxides	?	Essential for growth of certain beneficial algae and bacteria. Toxic or deficient conditions are not observed in nature.
Mo	Molybdenum	Yes	$Mo^{6+/4+}$ $Mo^{3+/2+}$	Sulfides	Yes	Imp. in N fixation and N utilization; no toxic effects in nature; sulfate is an competitor for adsorption sites on roots & lowers pH.
Ni	Nickel	No	Ni^{2+}	Sulfides	Yes-at high temps	Some beneficial effects, many toxic effects. Toxic amts. aggravated by Ca, Mg, N, K, def. and P excess; Fe or Mo can decrease toxicity.
Co	Cobalt	No	$Co^{3+/2+}$	Sulfides	Yes-at high temps	Required by N-fixing bacteria but not for plants. Excess not likely to occur in nature. Parent rock content related to Mg content.
Cr	Chromium	No	$Cr^{6+/3+/2+}$	Oxides	?	May have an indirect effect on pathogen control. Toxic effects displayed in roots.
Be	Beryllium	No	Be^{2+}	Oxides	?	N/A
N	Nitrogen	Yes	N^{3-}	Uncombined	Yes	Controls growth & fruiting. Forms NO3, NH4, organic nitrogenous compounds. Mo required for N breakdown, Mg absorption affected can affect soil structure.

ALUMINUM (Pratt, 1966)

There is no proof that aluminum is essential to plant growth. Aluminum can have some stimulating effects on plant growth indirectly. Small amounts of aluminum can eliminate toxic effects of copper, reduce pH, and its salt can reduce disease organisms in the soil. Aluminum toxicity, which occurs in soils of pH 5 or less, is not visual in plant tops although it depresses growth. Aluminum is a specific root poison (Trenel and Alten, 1934). Acidity is the most important parameter in making aluminum soluble, although salts such as gypsum, potassium chloride, and calcium choride can increase soluble aluminum. Phosphate can lower the toxic effect of aluminum by precipitating it as aluminum-phosphate. Phosphate also increases a plant's tolerance to aluminum. Surface soils have less aluminum contents, generally, than subsurface soils.

BARIUM (Vanselow, 1966)

Barium is not essential nor beneficial to plant growth. There is an adverse effect on plants only when the exchangeable barium exceeds the exchangeable calcium and magnesium: a situation possible only when the amount of barium exceeds that of sulfate (Robinson et al., 1950). Barium is very similar to calcium in its chemical

properties and is always associated with calcium where calcium is found. Since barium is not essential for plant growth and is not toxic, the total barium content of a soil is of little significance; some of the soils highest in barium are among the most productive (Vanselow, 1966).

BORON (Bradford, 1966)

Boron is an essential plant nutrient that appears to perform a protective function in plants by preventing the excessive polymerization of sugars at sites of sugar synthesis (Scott, 1960). At low concentrations, this function manifests itself as growth-promoting; at high concentrations, boron uptake is related to other nutrients in the substrate. Calcium in high amounts leads to high boron requirements; yet when calcium is in low supply, the tolerance for boron will be low as well. Nitrogen and phosphate have opposite boron effects: low nitrogen requires less boron, whereas low phosphate requires more boron. Boron-deficient areas in the United States tend to be in the Pacific coastal area among other places.

CALCIUM (Chapman, 1966)

Calcium has a vital role in soil-structure maintenance and is an essential plant nutrient. It is essential for root development (Lundegardh, 1953). However, excess calcium effects result from the anion with which the element is associated (e.g., soluble salts such

as calcium chloride or calcium sulfate). Calcium carbonate affects the alkalinity of the soil thus decreasing the availability of other nutrients, such as Mg, Fe, Zn, Cu, B and P. High amounts of calcium may cause potassium and boron to fix into less soluble forms unless pH is high. Calcium also increases the absorption of sodium, potassium, rubidium, and cesium at low pH because of the blocking effect of the calcium ion on the hydrogen ion at the cell surface. At high pH, calcium may decrease manganese and phosphorus concentrations from the soil and may decrease the absorption of lithium. High pH also increases sodium concentration and decreases that of calcium as well as affecting the absorbability or availability of the remaining exchangeable calcium in the soil, causing structural deterioration of the soil because of the "dispersing effect" of sodium. Phosphorus, manganese, zinc, boron and iron solubility and absorbability can also be affected under these conditions.

CHROMIUM (Pratt, 1966)

Chromium is considered not an essential nutrient for plants. Although there is no conclusive evidence that chromium is essential for the growth of plants, some investigators have reported growth stimulation from the application of small amounts of chromium salts. Chromium may have an indirect effect of pathogen control.

Chromium salts can cause toxic effects, and that main effect is exerted in the roots where it may accumulate. Chromium is found in higher amounts in serpentine soils than in other types.

COBALT (Vanselow, 1966)

Cobalt is an element essential to animals and is a component part of vitamin B_{12}, but it is not an element essential to plant growth. Most plants do not accumulate cobalt to any great extent. Cobalt is required for the symbiotic fixation of nitrogen by soybeans and alfalfa. Although an excess of cobalt is not likely to occur in nature, toxic effects are noted in conditions as low as 0.1 ppm. These effects are displayed as reduced growth, chlorosis, necrosis and death. Molybdenum and iron salts can lessen the effect of excess cobalt. Cobalt is prone to leaching, so natural concentrations usually are not too high. Acidic soils and the addition of gypsum can increase the availability of cobalt uptake in some plants. Cobalt content in parent rocks is related to the magnesium content.

COPPER (Reuther and Labanauskas, 1966)

Copper is an essential nutrient of plants, but only in the correct amounts. A deficiency in copper creates a lack of growth which is complicated by fungal attack and other related deficiencies. An excess in copper can also

reduce growth, causing stunting, etc., and bring about an iron deficiency in the leaves. Copper is tightly held by the colloidal fraction of the soil, much in the same manner as base elements such as calcium or magnesium. Very little of this copper is removed by the plants, but it remains near the plant because it is not subject to leaching out of the root zone. Organic matter in the soil lowers the available copper in the soil. The kind and amount of clay minerals and the acidity of the soil are also factors affecting copper availability. HCl extracts have been used to determine copper available to plants, and a correlation has been found between soil copper amounts and the copper content of plants. Some plants are indicators of high concentrations of copper: Caryophyllaceae, Fabaceae, and mosses.

IRON (Wallihan, 1966)

Iron is an essential micronutrient for plant life. Plants lacking iron will display "leaf chlorosis" or leaf yellowing. Iron deficiency is more of a problem than iron toxicity because there is not much evidence in nature that toxic levels of iron occur. Many factors influence iron uptake of plants so that the condition of the plants bears no general relation to total iron content of the soil. Therefore, knowing the total content of iron in the soil will not measure plant response, yet it may provide useful

information along with plant observations in an area. Unlike other plant essential elements whose concentrations in plant tissues are about the same or greater than that existing in the soil, iron concentration in the leaves is usually one-tenth to one-one-thousandth times that found in the associated soil. Iron deficiency is associated with higher pH, excessively wet soils, low pH because of copper toxicity, high or low soil temperatures, the presence of certain microorganisms in the soil, potassium deficiency, bicarbonate ions, and application of phosphate fertilizer.

LEAD (Brewer, 1966)

Lead is only a minor part of plants and soils and is not shown to be an essential nutrient to plants. Most lead in soils is sparingly soluble and largely unavailable to plants. In California, the quantities of lead in soils are from 0.5 ppm to 46 ppm, with 5 ppm being the average amount. Lead seems to be held more in soils with a high humus content. Small amounts of lead have stimulated growth of some plants, probably as a side effect of the increased nitrification rates in soils where lead salts have been added. Lead seems to concentrate in the roots of many plants that uptake it, except for eggplant which concentrates lead in the edible fruit. In procedures extracting lead from the soils, water was found

to extract about the same amount of lead as 0.5N acetic acid or neutral ammonium acetate washes.

LITHIUM (Bradford, 1966)

Lithium is not known to be an essential plant nutrient, but it does exhibit some stimulating and toxic effects on several plant species. Excess lithium affects germination and the vegetation. However, naturally occurring instances of lithium toxicity to plants is not known except for citrus. In plants, lithium becomes fixed in the old leaves and roots. The concentration can be lessened in the roots by a transfer to the surrounding soil if the lithium gradient favors movement in that direction. Pyroxenes, amphiboles, and micas often have a lithium and magnesium ion association. Bradford (1960) found extractable lithium in California soils to be between 0.1 and 0.9 ppm, with the average being 0.3 ppm. However, there is no evidence available to indicate that total lithium in soils is related to plant availability. Plant availability may rely on other factors, such as increased availability if a soil becomes acidified or decreased absorption of lithium if calcium ions are added to the soil.

MAGNESIUM (Embleton, 1966)

Magnesium is an essential plant nutrient whose deficiency reduces growth and causes necrosis and

yellowing. Magnesium is displaced from the surface to lower depths as calcium salts are increased, but the severity of this may be lessened by an increase in nitrogen in the soil and plant tissues because nitrates improve magnesium utilization. Calcium in the form of calcite also is correlated with lower uptake of magnesium in soybeans, even if magnesium is high in the soil. (Mulder, 1958). Phosphate forms magnesium-phosphate which resists leaching and thus minimizes magnesium deficiency (Cooper, 1932).

MANGANESE (Labanauskas, 1966)

Manganese is an essential micronutrient because it is involved in nitrogen assimilation as a necessary catalyst in plant metabolism and also functions with iron in synthesis of chlorophyll. Therefore, manganese stimulates growth, but high concentrations can be harmful to the plant. Total soil manganese is not a good measure of plant available supply because other factors influence manganese solubility. At pH greater than 6.5, soil organisms convert manganese from the soluble manganous form to the insoluble manganic form.

MOLYBDENUM (Johnson, 1966)

Molybdenum is one of the essential micronutrients whose function is related to other nutrients, and can cause other nutrient disease symptoms. Molybdenum is

important in the nitrogen fixation process, and its deficiency is common and is often viewed as nitrogen deficiency even when plenty of nitrogen is present in the soil. Molybdenum is an anion strongly absorbed by soil minerals and colloids at pH lower than 6.0. Thus total amounts may not indicate adequate plant-available molybdenum if pH of the soil is too low. This is supported by a lack of correlation between available molybdenum in the soil and total molybdenum content of the soil or plant tissues. Molybdenum is preferentially accumulated in the interveinal areas of leaves, and although plants may accumulate large tissue concentrations of it, its excess has not been observed in the field in the recent past, and rarely in years past.

Phosphate can enhance the uptake of molybdenum by plants, and nitrogenous fertilizers can lower the need for molybdenum in the plant. Sulfate has a complex interaction with molybdenum. Not only does sulfate cause a greater growth of plants, causing a greater demand for molybdenum, sulfate also competes with molybdenum for absorption sites on the plant root. Indirectly, sulfate may promote a lower pH and thereby limit molybdenum availability. To complicate matters, magnesium is an "antagonist" of molybdenum, and as pH gets lower, magnesium becomes more soluble.

NICKEL (Vanselow, 1966)

Although nickel is found in most plants, it has not been proven as being essential to plant growth. Some slightly beneficial effects have been reported. However, the toxic effects of nickle have been well documented. Toxic effects include dwarfing, chlorosis or yellowing, and death. In the field, nickel toxicity is difficult to quantify because calcium, magnesium, nitrogen, and potassium deficiencies, as well as phosphate excess, aggravate nickel toxicity. Low pH increases nickel uptake, but usually these amounts are not enough to cause a nickel-toxicity reaction. Low pH may, instead, make other toxic ingredients of the soil, such as boron and lithium, soluble. The addition of iron or molybdenum can decrease toxic effects of nickel. Nickel toxicity is usually associated with serpentine soils. Vanselow (1952) reports southern California soils as having a total nickel content of 8 to 10 ppm with the exchangeable nickel averaging only 1 ppm. Nickel content of the soils is not truly a good measure of nickel availability, whereas the nickel content of plants is a better indicator of exchangeable nickel of the soils.

NITROGEN (Jones, 1966)

Nitrogen is one of the essential nutrients for plants. It is important in controlling growth and

fruiting, but the critical levels are difficult to determine. In plant physiology, nitrogen is very mobile. It enters many compounds, such as amino acids, alkaloids, and chlorophyll, and it is influenced by many internal and external factors. The supply of nitrogen in the soil occurs largely in three forms: nitrate nitrogen, ammonia nitrogen, and organic nitrogenous compounds. Nitrate nitrogen moves with the water in the soil. Ammonia nitrogen is fixed on the clay particles for a short time until it is changed to nitrate; it, too, then moves with the soil water. The nitrogen in organic compounds is slowly released by the activity of soil microorganisms.

There is no long-time fixed supply of nitrogen in the soil. This organic nitrogen is not immediately available to plants. Nitrate nitrogen must be reduced in the plant before it can be utilized. Molybdenum is required for this reduction (Evans, 1956; McElroy and Nason, 1954). Molybdenum deficiency is common and can cause nitrate to elevate to a toxic level. On the other hand, ammonium and nitrate may influence absorption of other elements such as magnesium. There are seasonal requirements for nitrogen; a nitrogen deficiency causes a uniform yellowing of leaves as chlorophyll is reduced. The secondary effects of nitrogen carriers may be important. In areas with high amounts of ammonium and nitrate, associated

ions ($-SO_4$, Na^+, Ca^{++}) may markedly affect soil structure and plant response (Parker and Jones, 1951; Pratt et.al., 1959). Arable soils tend to have a variable nitrate concentration, 2 to 60 ppm, and it varies throughout the season, and throughout the day.

PHOSPHORUS (Bingham, 1966)

Many soils are deficient in phosphorus which is an essential plant nutrient. It plays a role in emergence and growth, color, root development, fruit production, and overall plant structure. Phosphorus impedes the uptake of three nutrients: copper, zinc, and iron. Excess phosphorus can also reduce nodulation on legumes. Environmental conditions can affect phosphorus availability. A decrease in soil moisture can increase soil suction, thus decreasing phosphorus use. Plants also lose the ability to extract soil phosphorus as the soil temperature drops. As soils have lower pH, phosphorus availability to the plant increases except in the case of intense soil weathering where both the phosphorus levels and the pH decrease.

POTASSIUM (Ulrich and Ohki, 1966)

Potassium is an essential element for plant growth; in fact, it is related to almost every physiological function taking place within the plant. Potassium allows the plant to photosynthesize better during cool and cloudy

weather because of the larger leaf area it promotes. It is related to pigment formation, respiration enzyme reactions, formation of peptide bonds in protein synthesis and the associated nitrogen metabolism, and to better carbohydrate translocation. Potassium moves directly from the soil to the growing parts of the plant. Potassium deficiency occurs because it is leachable from the soils. Deficiencies in potassium would be noted in the older leaves first as "leaf scorch", whereas effects of excess potassium occur rarely because it fixes in nonexchangeable forms, so it is not excessively absorbed by the plants.

Potassium may cause a magnesium deficiency; it is thought that potassium may hinder magnesium uptake or simply increase the magnesium demand by increasing the growth requirements. Manganese, zinc, and iron may also be negatively affected by the presence of potassium.

SODIUM (Lunt, 1966)

Sodium plays a major role in soil-plant relationships, especially in arid and semi-arid regions. Sodium is required for certain enzymatic reactions such as photosynthesis in Synechococcus cedrurum (Allen, 1952). Sodium increases carbon dioxide assimilation in spinach and tomatoes, and it may cause a larger transfer of potassium from the roots to the shoots and increase the potassium availability in the soils. In alkaline soils,

sodium can provide 15 percent or more of the exchangeable cations. Sodium is essential for some plants such as those in the Chenopodiaceae, while others almost completely exclude sodium from their shoots and may accumulate in considerable quantities in their roots. Sometimes sodium can substitute for a part of the potassium requirements. Sodium can also cause negative effects when combined with moisture stress experienced in the deserts. It causes growth depression because of the soil moisture suction and osmotic pressure that results from dissolved solids (Hayward, 1955). High amounts of sodium can lower calcium absorption which is required for root development (Chang and Dregne, 1955).

STRONTIUM (Vanselow, 1966)

Strontium is not essential for plant growth but is absorbed into plants because of its similarity to calcium. Plants do not appear to be affected by strontium content and, in fact, strontium may be able to replace calcium to some extent. Strontium excess in toxic amounts has not been reported in nature.

TITANIUM (Pratt, 1966)

While titanium is considered non-essential and non-toxic to plants, it does seem to produce beneficial effects in some cases. Titanium is insoluble at pH 4-8, but titanium-oxide may be more available to plants because

it is associated with these beneficial effects. Titanium-oxide may act as a photocatalyst in the photochemical oxidation of nitrite to nitrate (Dhar and Mukerii, 1941). This may play a part in the fixation of nitrogen in nodules of legumes. Titanium may also enhance root growth and may result in a reduction in toxicity of some other elements.

VANADIUM (Pratt, 1966)

Although nearly all soils and plants contain some vanadium, it is not an essential nutrient for plant growth. Its presence in soils may benefit plants, however, because it is essential for the growth of certain algae and bacteria, including those that fix nitrogen. Vanadium can become toxic to the roots, tops, and germinating seeds, although neither toxicity nor deficiency has been observed under field conditions. Under lab conditions, an increase in iron can decrease vanadium toxicity.

ZINC (Chapman, 1966)

Zinc is an essential nutrient of plants whose deficiency creates a "mottle leaf" effect and whose excess creates iron chlorosis. Zinc deficiency can result from numerous parameters. It occurs in acidic, leached soils where the total zinc is low. It can also be rendered unavailable to plants in alkaline soils, organic soils,

soils with a low silicon/magnesium ratio, or through the addition of phosphorus, nitrates, or through the liming of the soils where zinc's minimum solubility occurs at pH 6 to 8 (Jurinak and Thorne, 1955). Zinc uptake can be increased by the addition of ammonium compounds, the zinc solubilization by alfalfa roots, and the sterilization of soils that results in the increase in root growth. Zinc accumulation in soils can be increased by the accumulation of soil organic matter, and it may be brought up from lower soil horizons, although the mechanics of this were not discussed.

APPENDIX 2

DATA COLLECTION FIELD MAP

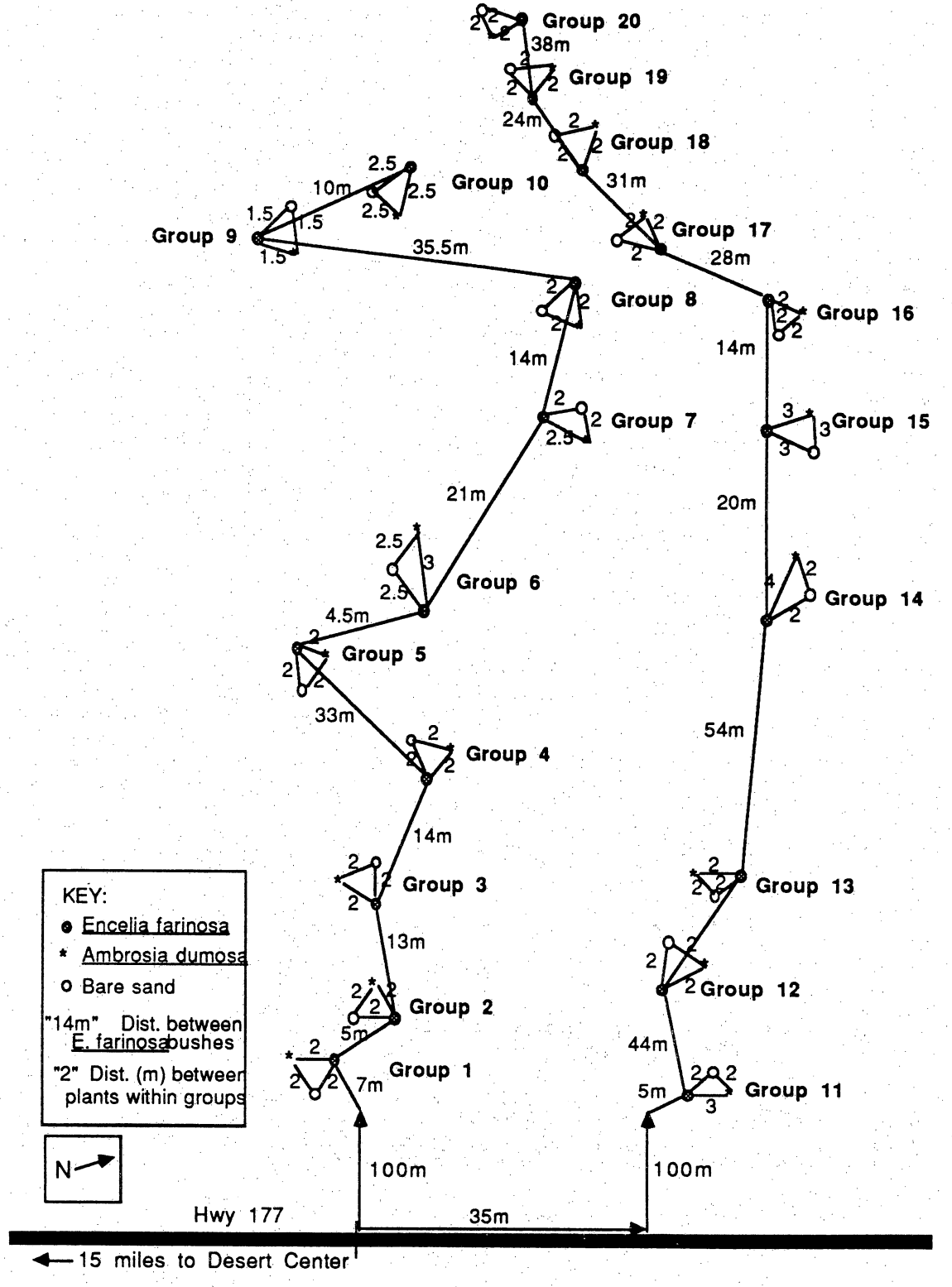

FIGURE 20: Data Collection Field Map (Drawing not to scale).

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