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Growth Responses of Selected Plant Species on Serpentine Soil of The Western Sierra Nevada Foothills

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by
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INTRODUCTION

The apparent infertility of serpentine soils and the narrowly restricted endemic species occurring upon them have aroused interest wherever serpentine floras are encountered. Several chemically distinctive serpentine soils occur along the west base of the Sierra Nevada Mts. in California. Three such soils, along with two non-serpentine soils, were selected to compare the growth responses of several native plant species on serpentine and non-serpentine soils. These species, planted in the five different soils, provided an opportunity to study the soil-plant relationships.

In the Jurassic period, the sedimentary strata making up the Franciscan, Knoxville, and the Cretaceous formations were deposited over the foothills of the Sierra Nevada (Leet & Judson, 1971). Later, intrusions of magnesium rich rocks became serpentinized. These ultra-basic rocks are exposed today and have, through weathering, given rise to many types of soil. One of these is the soil derived from serpentine rock (Taliaferro, 1943). The essential mineral from which serpentine soil is derived is olivine, $(Mg\ Fe)_3\ Si\ O_4$, or its hydrated form, serpentinite, $H_4\ (Mg\ Fe)_3\ Si\ O_9$. Although serpentine soil is considered infertile for agricultural purposes, it supports a rich flora including many narrow endemics wherever it occurs. Plant life on serpentinite and other rocks of high magnesium and iron composition shows striking discontinuities. There is stark constrast between the barrenness of ultramafic and the luxuriance of contiguous non-ultramafic sites (Kruckeberg, 1951). Ultramafic rocks, including serpentinite, are rich in ferromagnesian minerals. The discontinuity in habitat of flora features a pronounced difference in species composition.

There are two major types of endemic species on serpentine soils. The first consists of depleted species, those which were more widespread and variable in the past but have lost most of their biotypes. These species are rare and, therefore, may be conceived of in genetic terms as being poor in biotypes and are so specialized that they can grow and compete with other species in only a limited area. This group of plants, having the same genetic constitution,is rare due to the depletion of its store of genetic variability. Thus, the geographic distribution is reduced and the number of ecotypes and biotypes is decreased. The species continued existence as a series of small, completely isolated populations will eventually lead to the further depletion of each population (Stebbins, 1942).

The second endemic type consists of insular species, isolated species that have developed on an actual island or on restricted habitats within continental floras. Since insular and depleted species closely resemble each other and may occur together on insular areas, the differentiation between the two types is a difficult problem. A general rule for recognition is that if the endemic is closely related to no other living form and is less specialized morphologically than other species, it is more likely a depleted species or a derivative of one (Stebbins, 1942). Both of these types of endemic species are represented on serpentine outcrops in California.

Any plant that has an affinity for serpentine soil and grows more abundantly on it than any other soil is referred to as serpentinicolous (Pichi-Sermolli, 1948). A more specific term is serpentinophyte which refers to plants that have arisen within serpentine areas and seldom occur outside them. Many serpentine plants must be regarded as relics, now growing on serpentine soils only because of the specific edaphic conditions created by the serpentine rocks. Thus, serpentinicolous relics have occurred outside serpentine during earlier epochs. While these relics may still occur in other kinds of soil within other parts of their distribution areas, they tend to remain only in serpentine areas where they have been conserved owing to specific edaphic conditions (Rune, 1953).

The unsuitability of serpentine soil for agricultural purposes is due to their excessive magnesium content and generally low calcium content. Reduced vitality plus general discoloration and chlorosis is the ultimate result of this chemical combination. Furthermore, the extractable potassium is normally insufficient for normal growth and this deficiency is manifested by stunted growth and early chlorosis (Donahue, Schickluna, and Robertson, 1971). There is also a deficiency of certain micronutrients but they have a lesser impact on the soil productivity (Greulach, 1973). The principal symptoms of micronutrient deficiency are intervenial chlorosis and general necrosis. Molybdenum is required in smaller quantities than any other definitely established trace element, 1 part per 100 million of culture solution being enough to prevent molybdenum-deficiency symptons (Greulach, 1973). Even with this meager requirement, serpentine soils are usually molybdenum deficient. A chemical comparison of serpentine and non-serpentine soils reveals that the major causes of soil infertility in serpentine soils are deficiencies of macronutrients such as calcium and potassium and the micronutrient, molybdenum (Donahue, Shickluna, and Robertson, 1971).

Another reason for infertility in serpentine soil is poor drainage and the slow infiltration rate caused by the platy soil structure. The structure of serpentine soil exhibits a matted, flattened, or compressed appearance which results in a lack of consistence, causing the water to infiltrate slowly around the numerous plates forming the soil structure. The overall result is a generally dry soil with a consistence characterized by rigidity, brittleness, and resistance to rupture or deformation. Because of the platy structure, serpentine soil is not sufficiently open to permit free circulation of water and air causing a lower penetrance and retention than will support normal plant growth (Donahue, Shickluna, and Robertson, 1971).

The xeric, transient spring flora of the dry serpentine hills of California is comparatively independent of climatic conditions. Its presence is due to the serpentine rock and soil which creates a dry and relatively warm microclimate. The dry conditions of the microclimate are caused by the poor drainage of serpentine soil while the warm conditions are caused by the high heat capacity of the serpentine rock (Rune, 1953).

The list of herbaceous rarities endemic to serpentine has grown and continues to grow. It is the pressure of competition that reduces biotype diversity and forces ultimate confinement to serpentine. Some of these narrow endemics appear to be depleted species; however, biotype depletion need not be the prelude to extinction (Gankin & Major, 1964). Having found refuge as edaphic specialists on serpentine, diversification within the serpentine environment may ensue.

This study was undertaken to examine the growth responses of various annual plant species on serpentine and non-serpentine soils from the Sierra Nevada foothills and the adjacent area. Various measurements were taken at intervals during the life cycle to determine the comparative growth patterns on different types of soil. These measurements indicate the degree of serpentine tolerance and intolerance.

LITERATURE REVIEW

Plant life on ultramafic soil has a particular fascination because of the discontinuity of pattern and form compared to that of non-ultramafic soil. Geological and vegetational diversity go hand in hand throughout the world. Biotic and environmental conditions interact on the living ecosystem to produce a soil that gives unique vegetational responses. Serpentine is one of the unique soils demonstrating this principle. It produces a vegetation composed of a large percentage of narrow endemics with individual species sparsely scattered over serpentine outcrops and separated by extensive, completely barren areas (Kruckeberg, 1969).

In the western United States, Kruckeberg has done extensive research on coastal serpentine habitats. The most comprehensive of these (Kruckeberg, 1951) examines the intraspecific variability in the response of selected native plants to serpentine soil in the central Coast Ranges. These coastal serpentine soils have the same general chemical composition as the Sierrian foothill serpentines and they cover a much greater area.

Ultramafic rocks (e.g., serpentinite, periodotite, dunite, etc.) occur in local or extensive outcroppings in the Sierra Nevada foothills. Only serpentinite will be discussed here. The unique chemical qualities of serpentinite rocks contribute to the distinct and often spectacular discontinuities in regional plant distributions. There are two petrological classes of serpentines - igneous and metamorphic.

Weathered from predominantly ferromagnesian minerals, the serpentine soil is dominated by high amounts of exchangeable magnesium and conversely abnormally low amounts of calcium. Other nutrient elements (nitrogen, phosphorus, potassium, and molybdenum) are believed to derive their deficient status primarily from the interaction of the adverse calcium:magnesium ratios with biological nutrient-fixing processes (Kruckeberg, 1969).

Serpentine soils support a unique vegetation adapted to survive under conditions that would be wholly unsuitable for most species. The endemic plants have a physiological tolerance to the exceptional chemical conditions and the means to accommodate the adverse physical environment. Vegetation of the serpentine soil is always sparse and, compared with that of adjacent non-serpentine areas, the number of species as well as of individuals is smaller (Rune, 1953). Although slope, exposure, soil texture, climate and other factors greatly influence soil productivity and have caused the development of a xeric-adapted flora, these effects are not unique to serpentine. All of the intrinsic mineral peculiarities of the parent material accentuate the character of ultramafic habitats; however, physical properties alone do not account for the floristic uniqueness of ultramafic rocks (Krause, 1958). Soil chemistry provides the most discriminating character.

There are many types of serpentine and non-serpentine soil but what separates them into two distinct groups is their chemical composition. The calcium:magnesium ratio dictates whether a soil should be classified as ultramafic (including serpentine) or non-ultramafic. If the calcium: magnesium ratio is less than one, the soil is ultramafic and invariably infertile. Other chemical properties vary somewhat but this is the critical factor (Walker, 1954). Other toxic effects in the plants are believed to be induced by high chromium and nickel concentrations. The indigenous flora has responded to these rigorous and demanding chemical imbalances (Kruckeberg, 1969).

The global distribution of serpentines indicates that many factors influence the rate of weathering of the mineral constituents (Buol, McCracken and Hole, 1973). Of the various chemical changes due to weathering, oxidation is usually one of the first to be noticed. It is particularly manifest in rocks carrying iron such as the serpentine soil-forming rock, olivine. In olivine, the iron is present in the ferrous (Fe^{++}) form. The ferrous iron is released from its crystal formation and almost simultaneously oxidized to the ferric form (Fe^{+++}). The hydration of olivine and the release of ferrous oxide which is oxidized to ferric oxide (Hematite) is shown below:

$$3\,MgFeSiO_4 + 2H_2O \longrightarrow H_4Mg_3Si_2O_9 + SiO_2 + 3FeO$$

Olivine Serpentine Ferrous Oxide

$$4\,FeO + O_2 \longrightarrow 2\,Fe_2O_3$$

Ferrous Oxide Hematite

Hydrous silicates of magnesia are extensive rock forming materials in some regions, and as such, require mention as serpentine soil formers also. Serpentine rocks are weathered until all essential elements become available to support lichens and other lower forms of plant life. As continuing generations of lichens grow, die, and decay, they leave increasing amounts of organic matter. Organic acids further hasten decay of the serpentinite. Serpentine usually forms blackish-green rock-masses with little definite structure. Although soft, they disintegrate very slowly and are vigorously decomposed only when charged with ferrous oxide which is frequently the case. The conversion of this into ferric hydrate, common in nature, also serves as the point of attack on otherwise stable rock; causing it to crumble slowly. The solvent action of water and the ions it carries as it moves through and around rock and mineral particles furthers the weathering process (Buckman and Brady, 1969).

All minerals, including iron, are subject to solution, specific climatic conditions determine the extent to which it occurs. The chemical composition of soils derived from serpentine rocks may differ considerably, depending on the climatic conditions under which the weathering has taken place. In a humid and rather cold climate, only small changes occur in the composition of the soil, as compared with the parent rock. On the other hand, in a warm and humid climate (Cuba and Puerto Rico), serpentine weathers to a laterite soil from which nearly all magnesium of the parent rock has been leached away (Robinson, Edgington, and Byers, 1935). Sierra Nevada serpentine soils fall somewhere between the two examples but still contain a high percentage of exchangeable magnesium.

One of the primary reasons for the infertility of serpentine soils is the relatively low base exchange capacities, indicating an insubstantial conversion of parent material to an active clay fraction (Kruckeberg, 1969).

There are many variations of serpentine soil throughout the world and, while the chemical content differs in nearly every one, the common characteristic is their infertility. The composition of the serpentine flora may also differ from one place to another; however, the general aspect of serpentine floras are about the same in different parts of the world (Rune, 1953). Prevailing characteristics of serpentine floras are: 1. Reduced species number. 2. Alpine quality to the vegetation (Arboreal species become sparse and often stunted).

3. Species composition changes as opposed to adjacent non-serpentine areas. 4. Endemics few in number but comprising a high percentage of the total species. 5. Flora has a relatively xerophytic character. 6. Flora is dominated by certain genera (i.e., _Streptanthus_, _Quercus_, _Ceanothus_, _Cupressus_, _Achillea_, and _Arenaria_). 7. Plant species appear very disjunctively in serpentine localities. These characteristics are no doubt common to all serpentine floras even though changes in climate and species may occur in various parts of the world.

Prevous experiments on growth response were performed by several scientists (Walker, 1948; Kruckeberg, 1951). Walker found that tomato and lettuce plants attained normal growth on serpentine soil only when the exchangeable calcium level of the soil was raised to values of approximately twice that of exchangeable magnesium. Increases of other nutrient chemicals were ineffective in decreasing the marked deficiency symptoms of plants grown on serpentine unless the exchangeable calcium was also raised. Serpentine soils have been reconstituted with varying amounts of calcium, a nitrate-phosphate-potassium mixture and molybdenum and of these (added singly), only calcium was able to bring about normal growth of a non-serpentine strain on serpentine soil. Nitrate, phosphate, and potassium amendments alone at the lower calcium level were ineffective in decreasing the marked deficiency symptoms of plants grown on serpentine - the single most important limiting factor was the calcium:magnesium ratio. A greater proportion of calcium was needed for normal growth (Kruckeberg, 1951).

In another serpentine experiment, conclusions were drawn that the infertile nature of serpentine soils must be due to the toxic effect of the elements from serpentine rock (Rune, 1953). Also, Robinson et al (1935) determined that the only general and dominant cause of infertility in soils derived from ferromagnesium rocks is the comparatively high percentages of chromium and nickel. Another author (Novak, 1928) has shown that the high calcium:magnesium ratio is probably not the main cause of the infertility of serpentine soils. It is agreed that the occurrence of unbalanced magnesium may be conducive to infertility but other factors may be more responsible. When serpentine rock is calcareous, the serpentine character of the rock decreases. Calcium occurring as carbonate has a much greater positive effect on fertility than silicates of calcium. In addition, iron content possibly contributes to the strange character of serpentine soils. However, this iron theory along with the toxic effect theory has been opposed by numerous investigators (Gohler, 1928; Kruckeberg, 1951, 1967, 1969; Vlamis and Jenny, 1948; Whitaker, 1954; and Willey, 1967). The iron theory is opposed on the basis of anatomical and histochemical studies carried out on plants grown in iron quarries in Austria (Gohler, 1928). These studies demonstrated that a high iron content in the soil does not influence plant growth. However, since iron occurs there as a carbonate together with lime and the vegetation consists mainly of calcicolous plants, Gohler's conclusions are probably based on conditions inapplicable to serpentine (Rune, 1950). Other experiments (Kruckeberg, 1951, 1969; Walker, 1948; Wherry, 1944) conclude that the most important chemical aspect is the high magnesium and low calcium ratio, not the high content of chromium and nickel. The toxic effect of chromium and nickel is brought about by the interplay of the adverse calcium:magnesium ratio.

Serpentine is a residual or barren soil developing from special kinds of rocks that often supports a thin or discontinuous plant cover composed of relatively few taxa, many of which are peculiar to this soil. Certain physiologically essential elements are present in critically low concentrations and certain other elements are unusually abundant and so soluble as to be toxic. Both conditions cooperate to restrict the normal development of vegetation in comparison with contiguous soils with better nutritional balance.

MATERIALS AND METHODS

Soil Samples

Soil samples were collected from three serpentine and two non-serpentine sites. The three serpentine soils vary considerably in chemical make-up as indicated in Table I. The two non-serpentine soils were chosen because of their distinct differences as well. One, West Lane, is an extremely fertile agricultural soil while the second, Don-Pedro Reservoir, is a relatively infertile, roadside soil in an area contiguous to one of the serpentine soils. The five soils were selected to give a cross section of serpentine and non-serpentine soils. Location of these soil collection sites are shown in Figure I.

Seeds

Seeds from twenty plant species were used, including domesticated tomato, Lycopersicon esculentum and buckwheat, Fagopyrum esculentum. The seeds of eighteen native plant species were collected at the five soil sampling sites plus various other localities throughout the Sierra Nevada foothills. Table II lists plant species and collection stations.

Laboratory Procedures

All soil samples were sterilized by heating at 100°C for four hours. Seeds from the twenty plant species were planted in 2½" plastic pots containing the sterile soil

TABLE I

Chemical Analysis of Soil Samples *

Soil Sample	Cation Exchange Capacity 1.0 Normal NH_4 Acetate Procedure	1.0 Normal Ammonium Acetate Extractable (meq/100 gm)				pH Value
		Potassium	Sodium	Calcium	Magnesium	
(Serpentine)						
Chinese Camp	12.8 meq/100 gms	0.22	< 0.1	3.6	10.2	6.0
Rawhide Hill	14.6 "	0.36	< 0.1	4.2	8.9	6.6
Tuolumne-Mariposa	40.2 "	0.14	< 0.1	5.5	28.7	5.6
(Non-Serpentine)						
Don Pedro Reservoir	9.3 "	0.36	< 0.1	4.3	1.2	5.6
West Lane	8.3 "	1.30	< 0.1	7.2	2.0	6.8

* Chemical analysis performed by Nelson Laboratories, Stockton, Ca.

Figure 1

Map of the Soil Sample Area

A MAP OF THE SOIL SAMPLE AREA

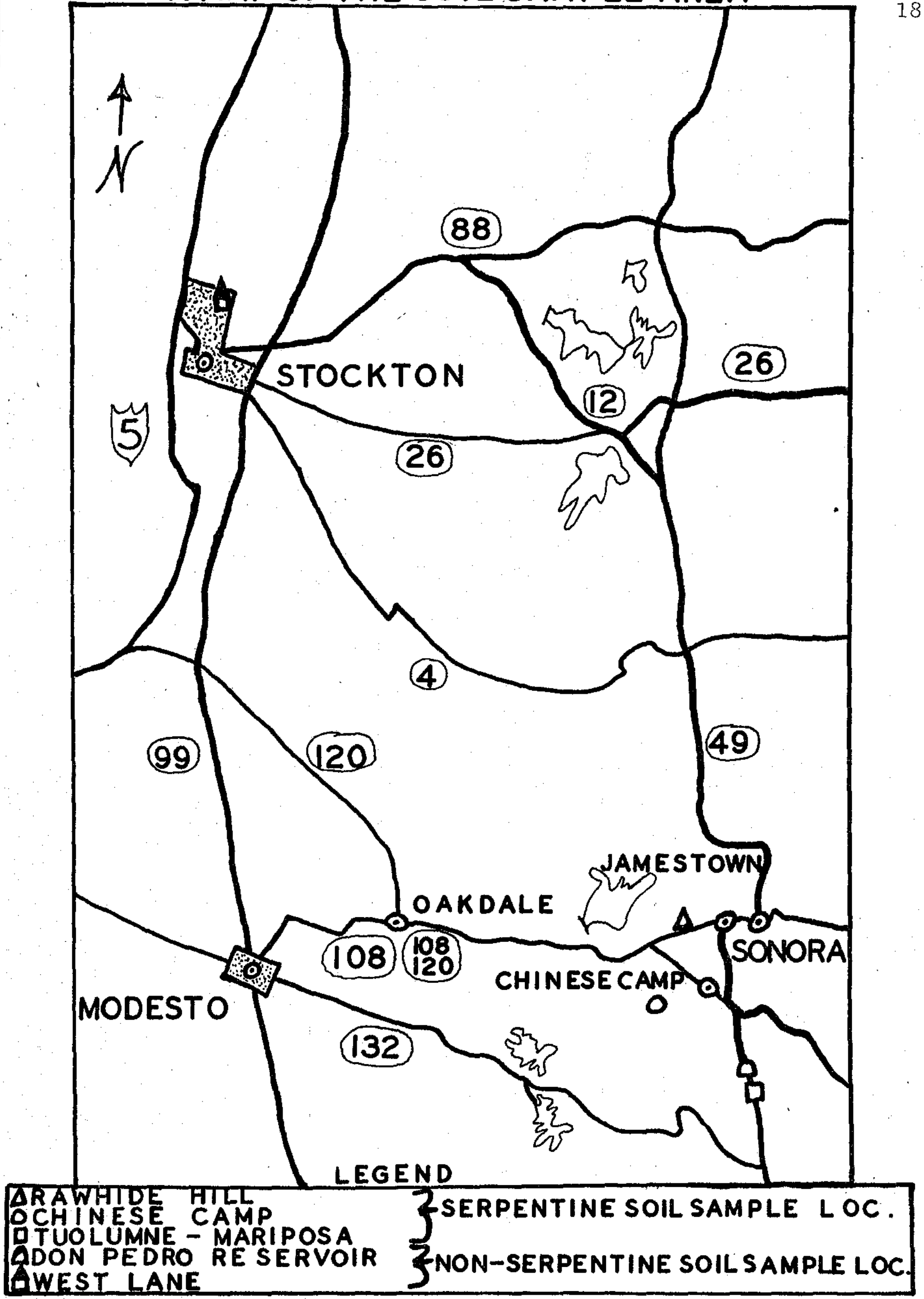

TABLE II

Plant Species

Number		Species	Soil Type	Location Collected	No. of Seeds Per Pot
1.	Mimulus	guttatus	Serpentine	Rawhide Hill	5
2.	Plantago*	hookeriana	Serpentine	Rawhide Hill	3
3.	Orthocarpus*	lacerus	Serpentine	Rawhide Hill	5
4.	Velezia	rigida	Serpentine	Rawhide Hill	3
5.	Githopsis	pulchella	Serpentine	Tuolumne-Mariposa	4
6.	Madia*	exigua	Serpentine	Tuolumne-Mariposa	4
7.	Clarkia*	biloba	Serpentine	Chinese Camp	4
8.	Festuca*	eastwoodiae	Serpentine	Chinese Camp	4
9.	Velezia	rigida	Non-serpentine	Jct. Hwys. 49 & 120	3
10.	Arenaria*	douglasii	Serpentine	Tuolumne-Mariposa	3
11.	Mentzelia	dispersa	Serpentine	Tuolumne-Mariposa	4
12.	Streptanthus*	polygaloides	Serpentine	Chinese Camp	4

* Denotes plants with positive growth response in at least one soil.

TABLE II (cont.)

Plant Species

Number		Species	Soil Type	Location Collected	No. of Seeds Per Pot
13.	Centaurium	floribundum	Serpentine	Ione (Hwys 24 & Tonzi Rd.)	5
14.	Calycadenia*	multiglandulosa	Serpentine	Ione (Hwys 24 & Tonzi Rd.)	4
15.	Clarkia*	arcuata	Serpentine	Hwy. 49 (½ mi. S. of Calveras Riv.)	4
16.	Castilleja	stenantha	Serpentine	Chinese Camp	4
17.	Nevarritia	filicaus	Serpentine	Tuolumne-Mariposa	4
18.	Panicum	hillmanii	Non-serpentine	Hwys. 108 & 120 (5 mis. E. of Oakdale)	4
19.	Fagopyrum*	esculentum	Non-serpentine	Domestic seeds	4
20.	Lycopersicon*	esculentum	Non-serpentine	Domestic seeds	4

* Denotes plants with positive growth response in at least one soil.

samples. A total of twelve pots per species were planted for each soil type. The number of seeds per pot varied according to the estimated growth potential of each species; the number of seeds per pot is shown in Table II.

All 1200 pots were positioned by species in a greenhouse, then each of the sixty pots per species was randomly placed. During the study, all plants were watered to their field capacity with distilled water. Each soil type of each species was monitored and the emergence date of the first seedling was recorded for each pot. A modal emergence date was used as the starting time of the three week examining period of all pots for each soil of each species. The same date was used for the six and nine week periods as well. Three weeks after emergence, four randomly selected pots for each soil and species were selected and the dry weight of the above ground parts and internode distance between the first and second nodes were measured and recorded. The same measurements were performed six and nine weeks after emergence and averages were ascertained for each of these periods.

Methods of Data Analysis

A computor analysis was performed to compare the growth responses between the species and soils. All comparisons with significance levels of $\alpha = 0.05$ were significant and considered too great to be attributed to chance alone. The chi square and ANOVA analyses were performed at the University of the Pacific Computor Center using a Burroughs ASSIST package with a Burroughs B-3500 Computor.

RESULTS

The growth responses for the eleven germinating species are shown in Tables III - VI. These measurements are portrayed for both serpentine and non-serpentine soils and are for all three examining periods plus a cumulative total in Table VI. The chi square analyses in Table VII are for treatment (species and soil) / growth, soil / growth and species / growth.

The next six Tables; VIII - XIII; reflect the plant growth by internode distance and dry weight. There is a "F" test analysis, degree of freedom, and significance factor for both distance and weight shown in Table XIV. All significance factors on Tables VII and XIV are less than 1% and are therefore highly significant.

Tables XV - XVII depict growth response comparison by soils for the three, six, and nine week periods. The cumulative growth response comparisons by soils is shown in Table XVIII. All three significance levels in this table are greater than 5% and are not significant.

TABLE III

Growth Response 3 Weeks After Emergence

	Number of Pots - No Growth/Growth					
Species Soil	Plantago hookeriana	Orthocarpus lacerus	Madia exigua	Clarkia biloba	Festuca eastwoodiae	Arenaria douglasii
Serpentine						
Chinese Camp	1/3	2/2	4/0	4/0	0/4	4/0
Rawhide Hill	2/2	2/2	0/4	4/0	0/4	1/3
Tuolumne-Mariposa	2/2	3/1	1/3	4/0	0/4	4/0
Non-Serpentine						
Don Pedro Reservoir	0/4	4/0	4/0	4/0	0/4	4/0
West Lane	1/3	2/2	0/4	3/1	0/4	4/0
Species Totals	6/14	13/7	9/11	19/1	0/20	17/3

TABLE III (cont.)

Growth Response 3 Weeks After Emergence

	Number of Pots - No Growth/Growth					Soil Totals
Species Soil	Streptanthus polygaloides	Calycadenia multiglandulosa	Clarkia arcuata	Fagopyrum esculentum	Lycopersicon esculentum	
Serpentine						
Chinese Camp	4/0	4/0	4/0	1/3	4/0	32/12
Rawhide Hill	0/4	3/1	2/2	0/4	1/3	15/29
Tuolumne-Mariposa	0/4	1/3	0/4	0/4	2/2	17/27
Non-Serpentine						
Don Pedro Reservoir	2/2	4/0	2/2	0/4	0/4	24/20
West Lane	4/0	2/2	1/3	0/4	2/2	19/25
Species Totals	10/10	14/6	9/11	1/19	9/11	107/113

TABLE IV

Growth Response 6 Weeks After Emergence

	Number of Pots - No Growth/Growth					
Species / Soil	*Plantago hookeriana*	*Othocarpus lacerus*	*Madia exigua*	*Clarkia biloba*	*Festuca eastwoodiae*	*Arenaria douglasii*
Serpentine						
Chinese Camp	2/2	2/2	4/0	4/0	0/4	4/0
Rawhide Hill	1/3	1/3	2/2	4/0	0/4	4/0
Tuolumne-Mariposa	2/2	0/4	1/3	4/0	0/4	4/0
Non-Serpentine						
Don Pedro Reservoir	1/3	4/0	4/0	4/0	0/4	4/0
West Lane	1/3	1/3	2/2	2/2	0/4	4/0
Species Totals	7/13	8/12	13/7	18/2	0/20	20/0

TABLE IV (cont.)

Growth Response 6 Weeks After Emergence

	Number of Pots - No Growth/Growth					Soil Totals
Species / Soil	*Streptanthus polygaloides*	*Calycadenia multiglandulosa*	*Clarkia arcuata*	*Fagopyrum esculentum*	*Lycopersicon esculentum*	
Serpentine						
Chinese Camp	4/0	4/0	4/0	0/4	4/0	32/12
Rawhide Hill	1/3	1/3	1/3	0/4	0/4	15/29
Tuolumne-Mariposa	0/4	2/2	2/2	1/3	1/3	17/27
Non-Serpentine						
Don Pedro Reservoir	1/3	4/0	3/1	0/4	0/4	25/19
West Lane	4/0	1/3	1/3	0/4	1/3	17/27
Species Totals	10/10	12/8	11/9	1/19	6/14	106/114

TABLE V

Growth Response 9 Weeks After Emergence

Soil \ Species	Number of Pots - No Growth/Growth					
	Plantago hookeriana	Othocarpus lacerus	Madia exigua	Clarkia biloba	Festuca eastwoodiae	Arenaria douglasii
Serpentine						
Chinese Camp	2/2	4/0	4/0	4/0	0/4	4/0
Rawhide Hill	1/3	2/2	2/2	4/0	0/4	2/2
Tuolumne-Mariposa	0/4	0/4	3/1	4/0	0/4	4/0
Non-Serpentine						
Don Pedro Reservoir	3/1	4/0	4/0	4/0	0/4	4/0
West Lane	1/3	1/3	2/2	1/3	0/4	4/0
Species Totals	7/13	11/9	15/5	17/3	0/20	18/2

TABLE V (cont.)

Growth Response 9 Weeks After Emergence

Soil \ Species	Number of Pots - No Growth/Growth					Soil Totals
	Streptanthus polygaloides	Calycadenia multiglandulosa	Clarkia arcuata	Fagopyrum esculentum	Lycopersicon esculentum	
Serpentine						
Chinese Camp	4/0	4/0	4/0	0/4	4/0	34/10
Rawhide Hill	0/4	1/3	2/2	0/4	0/4	14/30
Tuolumne-Mariposa	0/4	1/3	0/4	0/4	1/3	13/31
Non-Serpentine						
Don Pedro Reservoir	1/3	4/0	1/3	0/4	0/4	25/19
West Lane	4/0	0/4	0/4	1/3	1/3	15/29
Species Totals	9/11	10/10	7/13	1/19	6/14	101/119

TABLE VI

Cumulative Growth Response 3,6,9 Weeks After Emergence

	Number of Pots - No Growth/Growth					
Soil \ Species	Plantago hookeriana	Orthocarpus lacerus	Madia exigua	Clarkia biloba	Festuca eastwoodiae	Arenaria douglasii
Serpentine						
Chinese Camp	5/7	8/4	12/0	12/0	0/12	12/0
Rawhide Hill	4/8	5/7	4/8	12/0	0/12	7/5
Tuolumne-Mariposa	4/8	3/9	5/7	12/0	0/12	12/0
Non-Serpentine						
Don pedro Reservoir	4/8	12/0	12/0	12/0	0/12	12/0
West Lane	3/9	4/8	4/8	6/6	0/12	12/0
Species Totals	20/40	32/28	37/23	54/6	0/60	55/5

TABLE VI (cont.)

Cumulative Growth Response 3,6,9 Weeks After Emergence

	Number of Pots - No Growth/Growth					Soil Totals
Soil \ Species	Streptanthus polygaloides	Calycadenia multiglandulosa	Clarkia arcuata	Fagopyrum esculentum	Lycopersicon esculentum	
Serpentine						
Chinese Camp	12/0	12/0	12/0	1/11	12/0	98/34
Rawhide Hill	1/11	5/7	5/7	0/12	1/11	44/88
Tuolumne-Mariposa	0/12	4/8	2/10	1/11	4/8	47/85
Non-Serpentine						
Don Pedro Reservoir	4/8	12/0	6/6	0/12	0/12	74/58
West Lane	12/0	3/9	2/10	1/11	4/8	51/81
Species Totals	29/31	36/24	27/33	3/57	21/39	314/346

TABLE VII

Chi Square Analysis

Correlated Pairs	Chi Square	Degrees of Freedom	Significance
3 Weeks			
Treatment x Growth	142.943	54	0.000
Soil x Growth	16.849	4	0.002
Species x Growth	70.900	10	0.000
6 Weeks			
Treatment x Growth	139.894	54	0.000
Soil x Growth	18.643	4	0.001
Species x Growth	77.411	10	0.000
9 Weeks			
Treatment x Growth	156.575	54	0.000
Soil x Growth	30.275	4	0.000
Species x Growth	69.996	10	0.000

TABLE VIII

Internode Distance Growth 3 Weeks After Emergence

Mean and Standard Deviation - Internode Distance Per Treatment (mm)

Species Soil	*Plantago hookeriana*	*Orthocarpus lacerus*	*Madia exigua*	*Clarkia biloba*	*Festuca eastwoodiae*	*Arenaria douglasii*
Serpentine						
Chinese Camp	1.0 ±0.0	0.0 ±0.0	0.0 ±0.0	0.0 ±0.0	3.8 ±3.8	0.0 ±0.0
Rawhide Hill	2.0 ±0.0	0.0 ±0.0	2.0 ±0.0	0.0 ±0.0	6.3 ±0.5	3.0 ±1.0
Tuolumne-Mariposa	1.5 ±0.7	2.0 ±0.0	0.7 ±0.6	0.0 ±0.0	3.8 ±3.8	0.0 ±0.0
Non-Serpentine						
Don Pedro Reservoir	2.0 ±0.8	0.0 ±0.0	0.0 ±0.0	0.0 ±0.0	3.3 ±0.5	0.0 ±0.0
West Lane	1.3 ±1.5	0.0 ±0.0	2.0 ±0.0	2.0 ±0.0	7.5 ±1.9	0.0 ±0.0

TABLE VIII (cont.)

Internode Distance Growth 3 Weeks After Emergence

Mean and Standard Deviation - Internode Distance Per Treatment (mm)

Species Soil	*Streptanthus polygaloides*	*Calycadenia multiglandulosa*	*Clarkia arcuata*	*Fagopyrum esculentum*	*Lycopersicon esculentum*
Serpentine					
Chinese Camp	0.0 ±0.0	0.0 ±0.0	0.0 ±0.0	0.0 ±0.0	0.0 ±0.0
Rawhide Hill	0.5 ±1.0	1.0 ±0.0	0.0 ±0.0	0.0 ±0.0	4.0 ±2.0
Tuolumne-Mariposa	0.0 ±0.0	1.0 ±0.0	0.0 ±0.0	0.0 ±0.0	2.0 ±2.8
Non-Serpentine					
Don Pedro Reservoir	0.0 ±0.0	0.0 ±0.0	13.0 ±4.2	0.0 ±0.0	1.5 ±1.3
West Lane	0.0 ±0.0	1.0 ±0.0	0.0 ±0.0	0.0 ±0.0	18.0 ±2.8

TABLE IX

Internode Distance Growth 6 Weeks After Emergence

Mean and Standard Deviation - Internode Distance Per Treatment (mm)

Species Soil	*Plantago hookeriana*	*Orthocarpus lacerus*	*Madia exigua*	*Clarkia biloba*	*Festuca eastwoodiae*	*Arenaria douglasii*
Serpentine						
Chinese Camp	2.0 ±1.4	1.0 ±0.0	0.0 ±0.0	0.0 ±0.0	8.3 ±2.2	0.0 ±0.0
Rawhide Hill	3.7 ±0.6	0.0 ±0.0	0.5 ±0.7	0.0 ±0.0	11.5 ±1.7	0.0 ±0.0
Tuolumne-Mariposa	3.0 ±0.0	1.3 ±0.5	1.0 ±0.0	0.0 ±0.0	16.8 ±6.7	0.0 ±0.0
Non-Serpentine						
Don Pedro Reservoir	3.3 ±0.6	0.0 ±0.0	0.0 ±0.0	0.0 ±0.0	12.3 ±7.5	0.0 ±0.0
West Lane	4.0 ±0.0	0.0 ±0.0	1.5 ±0.7	32.5 ±3.5	28.8 ±6.3	0.0 ±0.0

TABLE IX (cont.)

Internode Distance Growth 6 Weeks After Emergence

Mean and Standard Deviation - Internode Distance Per Treatment (mm)

Species Soil	*Streptanthus polygaloides*	*Calycadenia multiglandulosa*	*Clarkia arcuata*	*Fagopyrum esculentum*	*Lycopersicon esculentum*
Serpentine					
Chinese Camp	0.0 ±0.0	0.0 ±0.0	0.0 ±0.0	2.3 ±3.2	0.0 ±0.0
Rawhide Hill	1.0 ±0.0	4.3 ±1.2	5.7 ±5.1	2.5 ±0.6	7.0 ±5.0
Tuolumne-Mariposa	0.0 ±0.0	1.5 ±0.7	5.5 ±2.1	2.7 ±0.6	7.3 ±0.6
Non-Serpentine					
Don Pedro Reservoir	0.7 ±0.6	0.0 ±0.0	20.0 ±0.0	0.5 ±0.6	5.5 ±3.1
West Lane	0.0 ±0.0	4.3 ±1.2	9.0 ±1.0	3.8 ±4.2	16.0 ±7.6

TABLE X

Internode Distance Growth 9 Weeks After Emergence

	Mean and Standard Deviation - Internode Distance Per Treatment (mm)					
Species Soil	Plantago hookeriana	Orthocarpus lacerus	Madia exigua	Clarkia biloba	Festuca eastwoodiae	Arenaria douglasii
Serpentine						
Chinese Camp	4.0 ±1.4	0.0 ±0.0	0.0 ±0.0	0.0 ±0.0	10.5 ±1.3	0.0 ±0.0
Rawhide Hill	6.7 ±0.6	2.0 ±0.0	5.5 ±2.1	0.0 ±0.0	18.3 ±2.6	6.5 ±3.5
Tuolumne-Mariposa	5.0 ±1.6	2.3 ±0.5	5.0 ±0.0	0.0 ±0.0	9.5 ±2.5	0.0 ±0.0
Non-Serpentine						
Don Pedro Reservoir	5.0 ±0.0	0.0 ±0.0	0.0 ±0.0	0.0 ±0.0	9.3 ±3.9	0.0 ±0.0
West Lane	4.0 ±2.0	1.3 ±0.6	5.0 ±0.0	23.0 ±3.6	12.8 ±6.1	0.0 ±0.0

TABLE X (cont.)

Internode Distance Growth 9 Weeks After Emergence

	Mean and Standard Deviation - Internode Distance Per Treatment (mm)				
Species Soil	Streptanthus polygaloides	Calycadenia multiglandulosa	Clarkia arcuata	Fagopyrum esculentum	Lycopersicon esculentum
Serpentine					
Chinese Camp	0.0 ±0.0	0.0 ±0.0	0.0 ±0.0	13.0 ±6.5	0.0 ±0.0
Rawhide Hill	3.3 ±1.0	8.7 ±2.9	21.0 ±5.7	4.8 ±3.5	12.0 ±2.7
Tuolumne-Mariposa	3.5 ±1.7	5.7 ±0.6	16.0 ±11.6	4.5 ±4.5	7.3 ±4.5
Non-Serpentine					
Don Pedro Reservoir	3.0 ±1.0	0.0 ±0.0	20.3 ±8.8	4.5 ±4.7	5.8 ±4.3
West Lane	0.0 ±0.0	5.3 ±0.5	22.0 ±6.8	9.7 ±5.7	18.3 ±7.2

TABLE XI

Dry Weight Growth 3 Weeks After Emergence

	Mean and Standard Deviation - Dry Weight Per Treatment (g)					
Species Soil	Plantago hookeriana	Orthocarpus lacerus	Madia exigua	Clarkia biloba	Festuca eastwoodiae	Arenaria douglasii
Serpentine						
Chinese Camp	0.004 ±0.00	0.005 ±0.00	0.000 ±0.00	0.000 ±0.00	0.004 ±0.00	0.000 ±0.00
Rawhide Hill	0.006 ±0.00	0.000 ±0.00	0.031 ±0.03	0.000 ±0.00	0.008 ±0.00	0.001 ±0.00
Tuolumne-Mariposa	0.005 ±0.01	0.003 ±0.00	0.012 ±0.01	0.000 ±0.00	0.006 ±0.00	0.000 ±0.00
Non-Serpentine						
Don Pedro Reservoir	0.010 ±0.01	0.000 ±0.00	0.000 ±0.00	0.000 ±0.00	0.005 ±0.00	0.000 ±0.00
West Lane	0.004 ±0.00	0.000 ±0.00	0.027 ±0.02	0.002 ±0.00	0.009 ±0.00	0.000 ±0.00

TABLE XI (cont.)

Dry Weight Growth 3 Weeks After Emergence

	Mean and Standard Deviation - Dry Weight Per Treatment (g)				
Species Soil	Streptanthus polygaloides	Calycadenia multiglandulosa	Clarkia arcuata	Fagopyrum esculentum	Lycopersicon esculentum
Serpentine					
Chinese Camp	0.000 ±0.00	0.000 ±0.00	0.000 ±0.00	0.045 ±0.01	0.000 ±0.00
Rawhide Hill	0.001 ±0.00	0.002 ±0.00	0.001 ±0.00	0.039 ±0.01	0.021 ±0.02
Tuolumne-Mariposa	0.000 ±0.00	0.002 ±0.00	0.001 ±0.00	0.040 ±0.02	0.008 ±0.01
Non-Serpentine					
Don Pedro Reservoir	0.000 ±0.00	0.000 ±0.00	0.005 ±0.00	0.044 ±0.02	0.014 ±0.01
West Lane	0.000 ±0.00	0.001 ±0.00	0.000 ±0.00	0.048 ±0.03	0.151 ±0.01

TABLE XII

Dry Weight Growth 6 Weeks After Emergence

Soil \ Species	Mean and Standard Deviation - Dry Weight Per Treatment (g)					
	Plantago hookeriana	Orthocarpus lacerus	Madia exigua	Clarkia biloba	Festuca eastwoodiae	Arenaria douglasii
Serpentine						
Chinese Camp	0.009 ±0.01	0.003 ±0.00	0.000 ±0.00	0.000 ±0.00	0.047 ±0.01	0.000 ±0.00
Rawhide Hill	0.017 ±0.01	0.000 ±0.00	0.106 ±0.03	0.000 ±0.00	0.041 ±0.02	0.000 ±0.00
Tuolumne-Mariposa	0.014 ±0.00	0.005 ±0.00	0.018 ±0.00	0.000 ±0.00	0.023 ±0.01	0.000 ±0.00
Non-Serpentine						
Don Pedro Reservoir	0.040 ±0.02	0.000 ±0.00	0.000 ±0.00	0.000 ±0.00	0.013 ±0.01	0.000 ±0.00
West Lane	0.020 ±0.01	0.001 ±0.00	0.082 ±0.02	0.301 ±0.16	0.045 ±0.01	0.000 ±0.00

TABLE XII (cont.)

Dry Weight Growth 6 Weeks After Emergence

Soil \ Species	Mean and Standard Deviation - Dry Weight Per Treatment (g)				
	Streptanthus polygaloides	Calycadenia multiglandulosa	Clarkia arcuata	Fagopyrum esculentum	Lycopersicon esculentum
Serpentine					
Chinese Camp	0.000 ±0.00	0.000 ±0.00	0.000 ±0.00	0.042 ±0.04	0.000 ±0.00
Rawhide Hill	0.002 ±0.00	0.006 ±0.00	0.005 ±0.01	0.068 ±0.04	0.048 ±0.04
Tuolumne-Mariposa	0.001 ±0.00	0.002 ±0.00	0.003 ±0.00	0.080 ±0.01	0.048 ±0.02
Non-Serpentine					
Don Pedro Reservoir	0.001 ±0.00	0.000 ±0.00	0.031 ±0.00	0.066 ±0.03	0.020 ±0.01
West Lane	0.000 ±0.00	0.003 ±0.00	0.009 ±0.00	0.104 ±0.05	0.233 ±0.16

TABLE XIII

Dry Weight Growth 9 Weeks After Emergence

Species / Soil	Mean and Standard Deviation - Dry Weight Per Treatment (g)					
	Plantago hookeriana	*Orthocarpus lacerus*	*Madia exigua*	*Clarkia biloba*	*Festuca eastwoodiae*	*Arenaria douglasii*
Serpentine						
Chinese Camp	0.028 ±0.02	0.000 ±0.00	0.000 ±0.00	0.000 ±0.00	0.176 ±0.05	0.000 ±0.00
Rawhide Hill	0.091 ±0.04	0.001 ±0.00	0.174 ±0.04	0.000 ±0.00	0.163 ±0.03	0.016 ±0.00
Tuolumne-Mariposa	0.039 ±0.03	0.016 ±0.01	0.095 ±0.00	0.000 ±0.00	0.099 ±0.05	0.000 ±0.00
Non-Serpentine						
Don Pedro Reservoir	0.043 ±0.00	0.000 ±0.00	0.000 ±0.00	0.000 ±0.00	0.055 ±0.01	0.000 ±0.00
West Lane	0.085 ±0.07	0.005 ±0.00	0.170 ±0.02	0.643 ±0.24	0.116 ±0.08	0.000 ±0.00

TABLE XIII (cont.)

Dry Weight Growth 9 Weeks After Emergence

Species / Soil	Mean and Standard Deviation - Dry Weight Per Treatment (g)				
	Streptanthus polygaloides	*Calycadenia multiglandulosa*	*Clarkia arcuata*	*Fagopyrum esculentum*	*Lycopersicon esculentum*
Serpentine					
Chinese Camp	0.000 ±0.00	0.000 ±0.00	0.000 ±0.00	0.124 ±0.06	0.000 ±0.00
Rawhide Hill	0.008 ±0.00	0.009 ±0.00	0.009 ±0.01	0.094 ±0.06	0.210 ±0.07
Tuolumne-Mariposa	0.008 ±0.00	0.008 ±0.00	0.018 ±0.02	0.094 ±0.04	0.068 ±0.03
Non-Serpentine					
Don Pedro Reservoir	0.005 ±0.00	0.000 ±0.00	0.049 ±0.05	0.162 ±0.09	0.032 ±0.02
West Lane	0.000 ±0.00	0.009 ±0.01	0.025 ±0.01	0.104 ±0.09	0.342 ±0.18

TABLE XIV

F Test Analysis

Correlated Pairs	F Value	Degrees of Freedom	Significance
3 Weeks			
Internode Distance x Treatment	15.111	112	0.002
Dry Weight x Treatment	13.735	112	0.002
6 Weeks			
Internode Distance x Treatment	15.465	113	0.002
Dry Weight x Treatment	7.138	113	0.003
9 Weeks			
Internode Distance x Treatment	6.2796	118	0.003
Dry Weight x Treatment	11.118	118	0.002

TABLE XV

Growth Response Comparison By Soils 3 Weeks After Emergence

Response / Soil	Number of Pots No Growth	Growth	Significance
Chinese Camp/Rawhide Hill	32/15	12/29	0.0006
Chinese Camp/Tuolumne-Mariposa	32/17	12/27	0.0027
Chinese Camp/West Lane	32/19	12/25	0.0096
Chinese Camp/Don Pedro Reservoir	32/24	12/20	0.1209
Rawhide Hill/Tuolumne-Mariposa	15/17	29/27	0.8246
Rawhide Hill/West Lane	15/19	29/25	0.5113
Rawhide Hill/Don Pedro Reservoir	15/24	29/20	0.0860
Tuolumne-Mariposa/West Lane	17/19	27/25	0.8284
Tuolumne-Mariposa/Don Pedro Reservoir	17/24	27/20	0.1998
West Lane/Don Pedro Reservoir	19/24	25/20	0.3936

TABLE XVI

Growth Response Comparison by Soils 6 Weeks After Emergence

Soil \ Response	Number of Pots No Growth	 Growth	Significance
Chinese Camp/Rawhide Hill	32/15	12/29	0.0006
Chinese Camp/Tuolumne-Mariposa	32/17	12/27	0.0027
Chinese Camp/West Lane	32/17	12/27	0.0027
Chinese Camp/Don Pedro Reservoir	32/25	12/19	0.1806
Rawhide Hill/Tuolumne-Mariposa	15/17	29/27	0.8246
Rawhide Hill/West Lane	15/17	29/27	0.8246
Rawhide Hill/Don Pedro Reservoir	15/25	29/19	0.0540
Tuolumne-Mariposa/West Lane	17/17	27/27	0.8267
Tuolumne-Mariposa/Don Pedro Reservoir	17/25	27/19	0.1352
West Lane/Don Pedro Reservoir	17/25	27/19	0.1352

TABLE XVII

Growth Response Comparison By Soils 9 Weeks After Emergence

Soil \ Response	Number of Pots No Growth	 Growth	Significance
Chinese Camp/Rawhide Hill	34/14	10/30	0.0001
Chinese Camp/Tuolumne-Mariposa	34/13	10/31	0.0000
Chinese Camp/West Lane	34/15	10/29	0.0001
Chinese Camp/Don Pedro Reservoir	34/25	10/19	0.0696
Rawhide Hill/Tuolumne-Mariposa	14/13	30/31	1.0000
Rawhide Hill/West Lane	14/15	30/29	1.0000
Rawhide Hill/Don Pedro Reservoir	14/25	30/19	0.0319
Tuolumne-Mariposa/West Lane	13/15	31/29	0.8190
Tuolumne-Mariposa/Don Pedro Reservoir	13/25	31/19	0.0179
West Lane/Don Pedro Reservoir	15/25	29/19	0.0540

TABLE XVIII

Number of Pots - Cumulative Growth Response Comparisons By Soils

Soil / Response	Serpentine Group	Non-Serpentine Group	Totals
3 Weeks			
No Growth	64	43	107
Growth	68	45	113
Significance = 0.4788			
6 Weeks			
No Growth	64	42	106
Growth	68	46	114
Significance = 0.2656			
9 Weeks			
No Growth	61	40	101
Growth	71	48	119
Significance = 0.1458			

DISCUSSION

Chi square analyses (Table I, XV, XVI, XVII, and XVIII) indicate that a direct relationship may exist in this study between the different chemical constituents of the soil and the various species growing on it. This discussion will center mainly upon the soils, their physical structure and chemical content.

Eleven species germinated successfully; however, meaningful discussion can not be made on two of these, *Arenaria douglasii* and *Clarkia biloba*, because of the very limited positive results in growth responses. The non-serpentine soils served as controls by which comparisons in relative growth on serpentine soil could be made.

The three serpentine soils used in this experiment were collected within a twenty mile radius of Chinese Camp. These three primary soils were formed under different weathering conditions and differ markedly in their physical make-up. Two of these serpentines, Chinese Camp and Tuolumne-Mariposa, are very similar in chemical composition but vary greatly in structure. Chinese Camp serpentine is a finely textured, powdery soil that is red in color and becomes extremely compacted when wet. This compaction decreases the water and air absorption and retention capabilities thereby reducing plant growth. Conversely, Tuolumne-Mariposa is a smoother textured soil, brown in color, that has a much higher water-holding-capacity and is more productive as evidenced by the comparative growth response soil totals in Tables XV - XVII. The dark serpentine soil of Rawhide Hill is somewhat different in physical structure than either of the other two serpentines; however, it is closest to Tuolumne-Mariposa since it also has a high water-holding-capacity. Rawhide Hill growth response also closely parallels that of Tuolumne-Mariposa as portrayed in Tables XV - XVII. Although all three serpentine soils have lower calcium levels and marked deficiency symptoms, the poorest overall growth response was found in Chinese Camp soil because of the very poor soil structure, low water-holding-capacity, and high wilting percentage.

Several species had limited growth response in all measurement categories on Chinese Camp serpentine as indicated in Tables VI, IX, X, XI, XII, and XIII. Comparing Chinese Camp and Tuolumne-Mariposa soils, the best contrasting results are between _Streptanthus_ _polygaloides_ and _Clarkia arcuata_ as depicted in Table VI. Chinese Camp has almost negative results while Tuolumne-Mariposa is highly productive.

The two non-serpentine soils, Don Pedro Reservoir and West Lane, are very similar in chemical make-up but differ somewhat in soil structure. Because of these chemical similarities, the growth responses on these two non-serpentines are comparatively close as revealed in Table VI. West Lane is a very fertile, agricultural soil that has a very high proportion of exchangeable calcium (72%) as against 20% magnesium. This calcium:magnesium ratio as pointed out earlier seems to be the most critical factor for good plant growth. Although Don Pedro Reservoir non-serpentine has a favorable calcium:magnesium ratio (43%:12%) also, the water-holding-capacity is less which contributes to a slightly reduced overall growth response. Even though the macronutrient, potassium,and the micronutrient, molybdenum, are vital to soil fertility, the interaction of a favorable calcium:magnesium ratio is essential to obtain this fertility.

Serpentine soils as a group are much less fertile than non-serpentines primarily because of the platy soil structure and the adverse calcium:magnesium ratio. There are differences between the two soil groups in most physical factors and some of the unfavorable characteristics for serpentine are listed here: 1) platy soil consistence, 2) low water-holding-capacity, 3) high wilting percentage, and 4) coarsely textured soil. These undesirable physical factors contribute to an infertile soil by limiting the water and nutrient supply available to the plant which restricts luxuriant growth. The other cause of serpentine infertility is the presence of an abnormally low percentage of exchangeable calcium and a high amount of exchangeable magnesium (Donahue, Shickluna, and Robertson, 1971). This chemical imbalance causes an apparent deficient status of other nutrients such as molybdenum, nitrogen, phosphorus, and potassium. Table I presents some of the chemical differences between the two soil types and they can be readily contrasted in terms of chemical analyses.

Growth response comparisons between serpentine and non-serpentine soils can best be seen by observing the results in Tables XV - XVIII. The most outstanding difference is between Chinese Camp (serpentine) and West Lane (non-serpentine) as evidenced in Tables XV, XVI, and XVII. These figures reveal a greater growth response in non-serpentine which probably can be attributed to the poor soil structure and the adverse calcium:magnesium ratio of serpentines. The combination of these two adversities usually result in serpentine flora that is stunted and with a xerophytic character. While the statistics (Tables VI, VIII, IX, X, XI, XII, and XIII) on growth response of _Madia exigua_ are relatively the same on serpentine and non-serpentine, the specimens which grew were under-developed on serpentine as opposed to the luxuriant growth on the non-serpentine. Other species (_Plantago hookeriana_, _Lycopersicon esculentum_, and _Calycadenia multiglandulosa_) revealed that the same phenomena in growth pattern and disparity was more pronounced upon plant maturity.

Tuolumne-Mariposa (serpentine) has similar growth responses in most species to that of West Lane (non-serpentine) but the chemical content is vastly different. Since all serpentine soils differ in chemical composition from non-serpentines, the apparent reason for the close resemblance in growth response is the similarity in soil structure.

Both soils have a finely textured structure which indicates a high water-holding-capacity. Also, both soils display a large bulk density which expresses adequate natural pore space and aeration. Pore space is one of the most important factors in determining a satisfactory supply of water and air for vigorous plant growth. Most serpentine soils have a platy soil structure which has a slow water infiltration rate and a generally dry type of soil. However, Tuolumne-Mariposa resembles the non-serpentine soil structure type in that it has a single grain soil structure with rapid water infiltration. Because of the similarity of the soil structures, Tuolumne-Mariposa serpentine soil is seemingly able to overcome part of its chemical limitations and attain near growth parity with the non-serpentine soil, West Lane (Tables XV, XVI, and XVII).

This study indicates that most plant species will grow better on non-serpentine soil rather than serpentine as indicated in Tables XV - XVIII. The overlying reasons appear to be the favorable calcium:magnesium ratio and chemical interaction (Table I), the better soil structure, and the combination of the two which produces a luxuriant non-serpentine flora.

SUMMARY AND CONCLUSION

In the Sierra Nevada foothills, soils derived from serpentine rock support a unique flora, many species of which are narrowly endemic on this infertile soil type. Soils weathered from this ultra-basic rock are deficient in calcium, nitrogen, phosphate, and molybdenum but have an unusually high amount of magnesium, chromium, and nickel. Twenty plant species were planted on three of these foothill serpentines and growth response measurements were taken to determine the response of certain native plants to serpentine soil.

Chi square and ANOVA analyses were performed between all species and soils and are displayed in the various tables under results. Individual growth response comparisons by soils (Tables XV, XVI, and XVII) indicate Chinese Camp (serpentine) was the most infertile soil while West Lane (non-serpentine) was the most fertile soil. This variation appears to be attributable to a relationship between the chemical and physical properties of the soil and the plants growing on it.

This study revealed different growth responses on the five experimental soils. These variances can be attributed in part to the different chemical composition and soil structure or a combination of both. Together, these two factors have lessened the water and nutrient supply available on serpentine soils resulting in a xerophytic vegetation and a barren aspect.

LITERATURE CITED

Buckman, H. O. and N. C. Brady. 1969. The Nature and Property of Soils. Macmillan Co. London.

Buol, S. W., D. McCracken, and F. D. Hole. 1973. Soil Genesis and Classification. Iowa State Univ. Press. Ames.

Donahue, R. L., J. C. Schickluna, and L. S. Robertson. 1971. Soils. Prentiss-Hall. Englewood Cliffs, New Jersey.

Gankin, R. and J. Major. 1964. Arctostaphlos myrtifilia, its Biology and relationship to the problem of endemism. Ecology 45:792-808.

Gohler, F. 1928. Die Flora uber Eisenkarbonat. Biol. Gen: 4. Wein-Leipzig.

Greulach, V. A. 1973. Plant Function and Structure. Macmillan Co. New York.

Krause, W. 1958. Andere Bodenspezialisten, pp 755-806. In W. Ruhland: Handbuch der Pflanzenphysiologie. Springer-Verlag, Berlin.

Kruckeberg, A. R. 1951. Intraspecific variability in the response of certain native plant species to serpentine soil. Amer. J. Bot. 33:408-419.

__________. 1967. Ecotypic response to ultramafic soils by some plant species of northwestern United States. Brittonia 19:133-151.

__________. 1969. Soil diversity and the distribution of plants with examples from western North America. Madrono 20:139-154.

__________. 1969. Plant life on serpentinite and other ferromagnesian rocks in northwestern North America. Syesis, Vol. 2:16-114.

Leet, L. D., and S. Judson. 1971. Physical Geology. Prentiss-Hall. Englewood Cliffs, New Jersey.

Novak, F. A. 1928. Quelques remarques rel. au prob. de la veg. sur les terrains serpentiniques. Preslia 6. Praha.

Pichi-Sermolli, R. 1948. Principal observance of serpentine soil. N. Gior. Bot. Ital. 43.

Robinson, W. O., G. Edgington, and H. C. Byers. 1935. Chemical Studies of infertile soils derived from rocks high in magnesium and generally high in chromium and nickel. U. S. Dept. Agr. Techn. Bul. 471.

Rune, O. 1950. Smalands Taberg. Natur. i Smaland, Goteborg.

_______. 1953. Plant life on serpentines and related rocks in the north of Sweden. Acta Phytogeogr. Succ. 31.

Stebbins, G. L., Jr. 1942. The genetic approach to problems of rare and endemic species. Madroño 6:241-272.

Taliaferro, N. K. 1943. The Franciscan-Knoxville problem. Bull. Amer. Assoc. Pet. Geo. 27:109-219.

Vlamis, J. and H. Jenny. 1948. Calcium deficiency in serpentine soils as revealed by absorbent technique. Science, 107:549.

Walker, R. B. 1948. Molybdenum deficiency in serpentine barren soils. Science, 108:473-475.

_____________. 1954. Factors affecting plant growth on serpentine soils, pp 259-266. In the ecology of serpentine soils: A symposium. Ecology, 35.

Wherry, E. T. 1944. A classification of endemic plants. Ecology 25:247-248.

Whitaker, R. H. 1954. The vegetational response to serpentine soils, pp 275-288. In the ecology of serpentine soils: A symposium. Ecology, 35.

Willey, P. J. 1967. Ultramafic and related rocks. John Wiley and Sons, New York.