PRELIMINARY NUTRIENT UPTAKE STUDIES OF EXPERIMENTAL VEGETATIVE COVERS AT THE MAXEY FLATS LOW-LEVEL NUCLEAR WASTE DISPOSAL SITE

A Thesis
Presented to
the Faculty of the School of Sciences and Mathematics
Morehead State University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Biology

by
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July 1981

Accepted by the faculty of the School of Sciences and Mathematics, Morehead State University, in partial fulfillment of the requirements for the Master of Science degree.

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7-27-81
(date)

ABSTRACT OF THESIS

PRELIMINARY NUTRIENT UPTAKE STUDIES OF EXPERIMENTAL VEGETATIVE COVERS AT THE MAXEY FLATS LOW-LEVEL NUCLEAR WASTE DISPOSAL SITE

Leaf and stem tissues of alfalfa (*Medicago sativa* L.), lespedeza (*Lespedeza striata* (Thunb.) H. & A.), red clover (*Trifolium pratense* L.), fescue (*Festuca arundinacea* Schreb.), and crown vetch (*Coronilla varia* L.) were sampled every two weeks over a three month sample period, and analyzed by emission spectrometry to determine interspecific differences in phosphorus, potassium, calcium, strontium, and zinc content. The plants were grown under field conditions on disturbed Tilsit silt loam at the Maxey Flats Low-level Nuclear Waste Disposal Site such that the interspecific differences in uptake of the elements studied could reflect expected uptake of the corresponding radionuclides on the same soil type.

Alfalfa, red clover, and crown vetch showed the highest overall levels of the elements studied, and fescue and lespedeza the lowest. Similarities in calcium and strontium uptake were evident. The legumes showed at least 2x as much calcium, and 1.3x as much strontium as did fescue.

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ACKNOWLEDGEMENTS

The writer wishes to thank Dr. David M. Brumagen for his advice in the preparation of the manuscript, and encouragement and supervision throughout this study.

Special thanks to Dr. Margaret B. Heaslip and Dr. Howard L. Setser for serving on my graduate committee.

Appreciation is extended to Donald J. Herman of the Laboratory of Nuclear Medicine and Radiation Biology, Los Angeles, California for his assistance in plant analysis, and advice during the study.

The advice and class instruction of Dr. Frank Osborne made possible the use of the Statistical Analysis System computer package. The staff of the Educational and Research Computing Center are commended for their patience in handling the extensive number of computer cards involved in this study.

Appreciation is also extended to Morehead State University for the assistantship which made this study possible.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES
(Continued)

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The Maxey Flats Low-level Nuclear Waste Disposal Site

The Maxey Flats Disposal Site (MFDS), located in northeastern Kentucky, consists of two-hundred and fifty-two acres, forty-five of which constitute the restricted area where the waste burial trenches are located (Figure 1). The site location was chosen following the enactment of legislation by the Kentucky General Assembly in 1962 allowing the establishment of a nuclear waste disposal site in the state of Kentucky. The MFDS was licensed in 1962 as well, and, in 1963, was opened for the disposal of low-level nuclear wastes.

By definition, low-level refers not to the degree of radioactivity, but rather to the source of the radioactive material. The Nuclear Regulatory Commission defines non-high-level radioactive wastes as those resulting from sources other than extraction processes for the production of reactor fuels (Gilmore 1977). It is not unusual, therefore, that Maxey Flats received highly-radioactive materials such as cobalt 60, cesium 137, strontium 90, and plutonium along with less-radioactive materials (Cleveland and Rees 1981; Legislative Research Commission 1980).

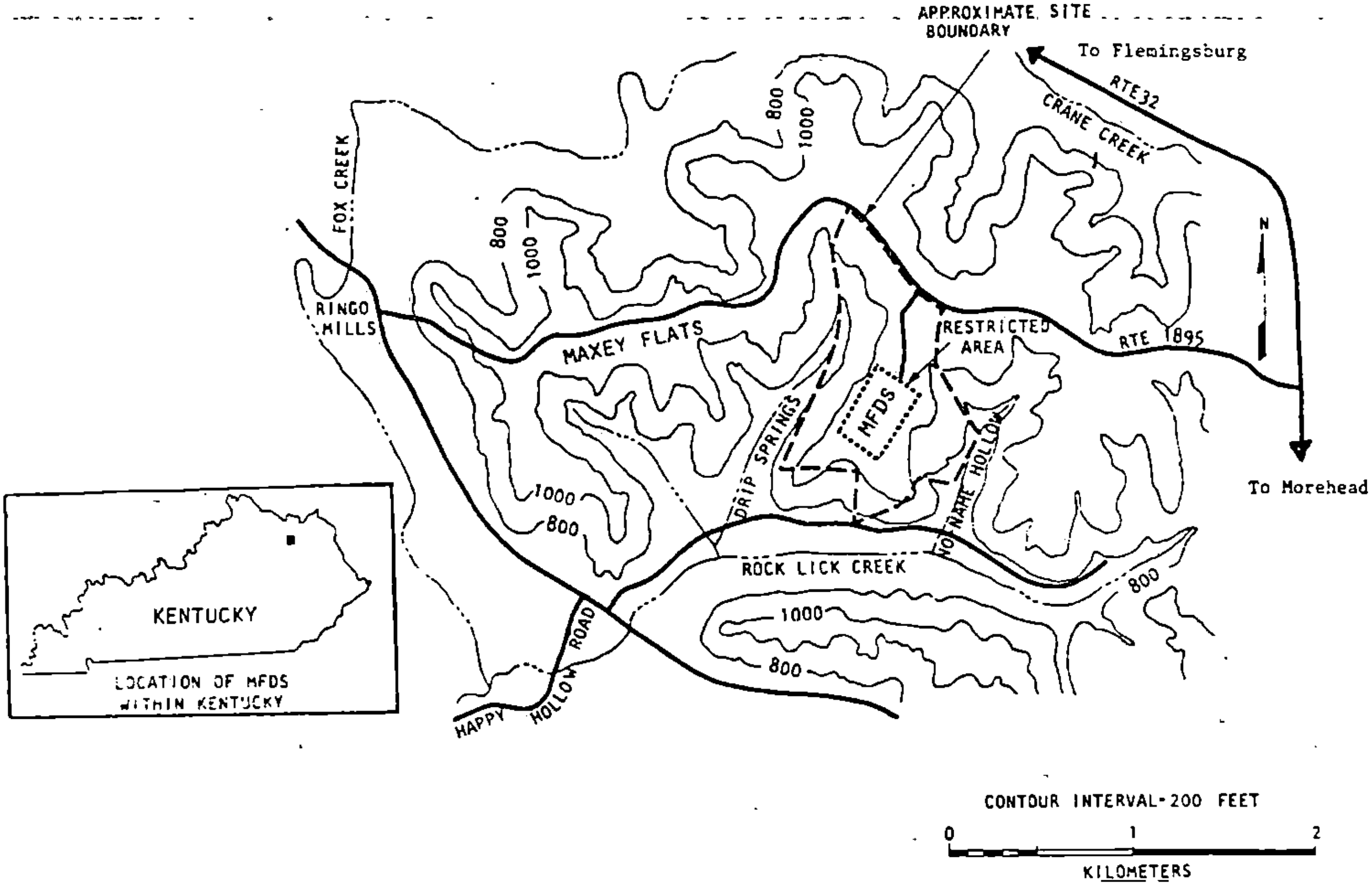

Figure 1. Location of the Maxey Flats Low-level Nuclear Waste Disposal Site. From the 1978-79 Interim Report of the Special Advisory Committee on Nuclear Waste Disposal, with modifications (Legislative Research Commission 1980).

In 1972, increased amounts of off-site radioactivity were detected by the Radiation Control Branch of the Department of Health. Subsequent studies indicated the source as surface runoff water, and changes were made in certain unsatisfactory management procedures at the MFDS.

In August 1977, the Nuclear Engineering Company, which had operated the site since 1963, informed the Kentucky Department for Human Resources of the detection of radioactivity in a new unused trench. The detected seepage was determined to be small, and to present no public health hazard. This event, however, demonstrated the possibility of subsurface migration of radioactive materials.

The geology of the Maxey Flats area is such that the burial trenches lie on, above, or extend into a sandstone layer (Figure 2). The seepage detected in 1977 was believed to have occurred as a result of the buildup of rainwater in a deeper burial trench, and consequent movement of the water along the sandstone layer.

In response to this development, the state of Kentucky placed a two-year moratorium on the MFDS. In 1979, the Department for Natural Resources and Environmental Protection was given the responsibility for developing short-term and long-term plans for the site. A new contract was sought that included corrective

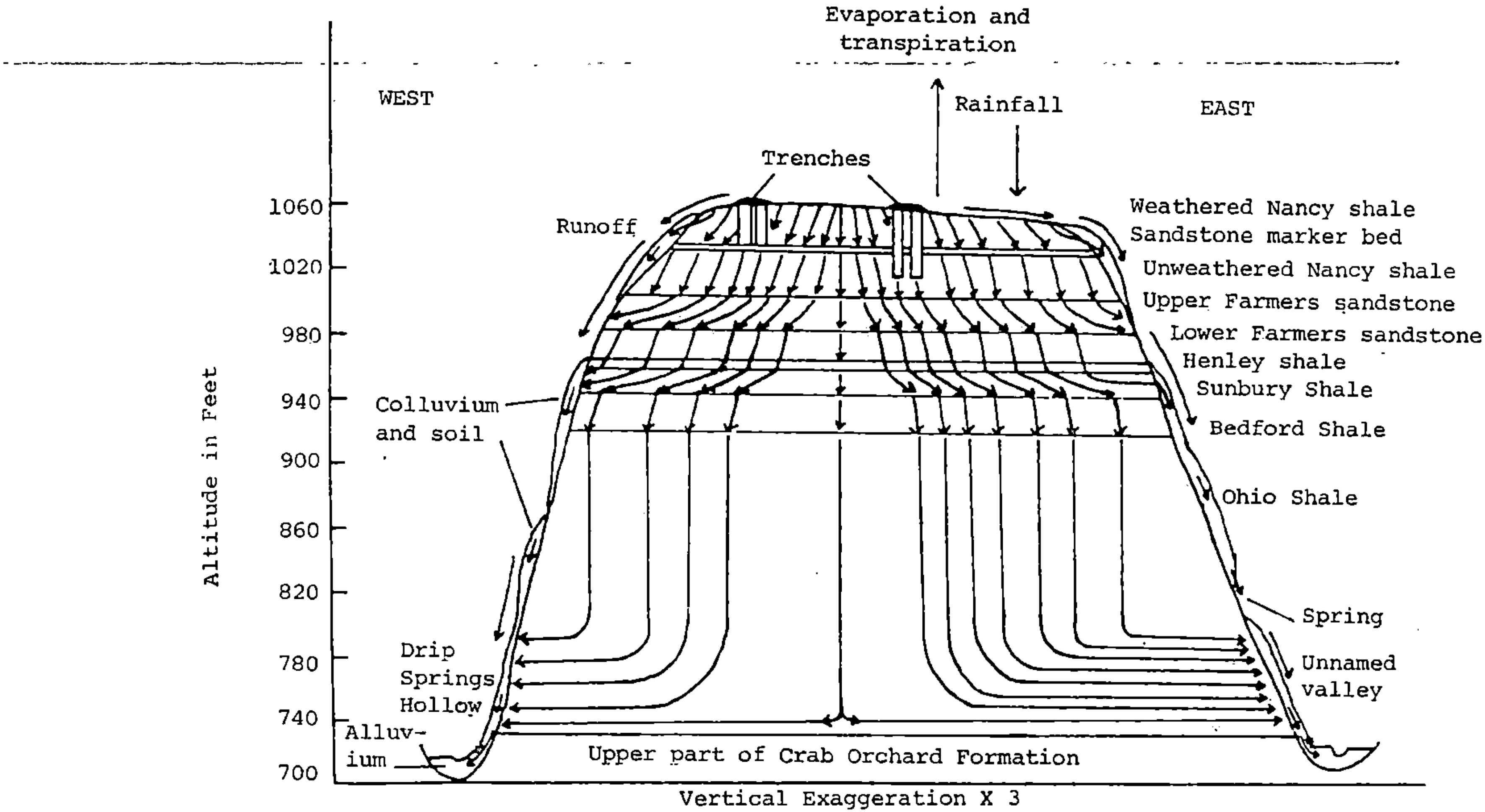

Figure 2. Geological position of the Maxey Flats Disposal Site waste burial trenches. From the U.S. Geological Survey as taken from the 1978-79 Interim Report of the Special Advisory Committee on Nuclear Waste Disposal, with modifications (Legislative Research Commission 1980).

activities, with proposals from six contractors, including the Nuclear Engineering Company being considered. In 1979, Dames and Moore was selected as the new contractor, the main goal being that of water management. Since then, measures have been taken to improve site drainage. Significant amounts of water have been removed from burial trenches and evaporated, with several surface and subsurface synthetic layers being considered as possible barriers to further water entry into the trenches. No radioactive waste has been received at the MFDS since its closing in 1977.

Objectives of this Study

The main problem at the MFDS, and the concern at other sites is that of water percolation into burial trenches. In lieu of some type of synthetic surface, or in conjunction with a subsurface synthetic layer, a vegetative cover is necessary to prevent the problems of surface runoff and erosion. A vegetative cover, via evapotranspiration, also removes water from the soil of the trench caps that would otherwise enter the trenches. Consequently, it would be of importance to choose a vegetative cover having a high transpiration rate while presenting little possibility of root penetration into the trenches.

In considering different plant species for nuclear waste disposal sites, nutrient uptake is important in determining nutrient requirements of the plant on the particular soil type. Nutrient uptake may also be correlated with the uptake of radionuclides, so a plant species could be chosen that would take up radionuclides in smaller quantities, a concept discussed by Myers (1960). This is important in that radionuclides taken up by plants may then be introduced into the food chain of the area. By studying the nutrient uptake of vegetative covers grown on disturbed soil characteristic of burial trench caps, knowledge may be gained concerning the relative rates of uptake between species that could be expected in the presence of radioactive elements. Thus, the corresponding food chain effects could be better understood.

The objective of this study is to determine the interspecific uptake of selected elements by six vegetative covers grown on disturbed soil of the MFDS, with observations being made of possible interspecific differences in the uptake of radionuclides.

CHAPTER II

LITERATURE REVIEW

As observed by Ulrich (1952), and Munson and Nelson (1973), deSaussure's work in 1804 is considered the earliest research in plant analysis. His studies showed the ash content of plants varying with plant age, plant part, and soil types. Later attempts were made to relate the nutrient compositions of plant tissues to optimum plant growth. Macy (1936) developed the concept of critical nutrient levels, one of the most important and most widely researched areas of plant analysis to date. Critical nutrient levels have since been determined for most plants of agricultural importance. The critical concentration of a nutrient is defined as the range of nutrient composition of the plant tissue above which no further plant growth occurs, and below which the plant is deficient. Critical nutrient levels for several agricultural crops have been compiled by Melsted et al. (1969), and Martin and Matocha (1973). The methods of handling, preparation, and analysis of plant tissue were reviewed by Jones and Steyn (1973).

The nutrient composition of a plant is a result of a multiplicity of factors that interact to influence it. Munson and Nelson (1973) reviewed some of the major factors that result in differences in plant nutrient levels.

The determination of interspecific and intraspecific differences in nutrient composition of plant tissues was inevitable as plant analysis research continued. Myers (1960) reviewed many findings of interspecific differences. Munson (1970) has reviewed varietal differences in the analysis of several crops.

While little work has been done concerning the genetics of interspecific and intraspecific differences in plant uptake, the implications in plant breeding have been utilized in producing plants with desired nutrient compositions. Rasmusson et al. (1964) provided a review of literature citing specific genes that account for differences in mineral uptake and utilization in certain species.

The basis for radiotracer methods in biological research is the fact that stable elements and their radioactive counterparts possess similar physical and chemical behaviors. The similarity in plant uptake of radioactive elements and their stable counterparts forms the basis for mineral uptake studies involving the use of radioisotopes. The International Atomic Energy Agency (1962) provided an extensive survey of soil-plant nutrient studies employing radioisotopes.

The interspecific differences in uptake of stable elements are applicable as well to the uptake of radionuclides. The implications of this in the avoidance of plants that accumulate harmful radionuclides, or the use of such plants in soil decontamination have been discussed by Romney (1957) and Myers (1960).

Not only do similarities occur in uptake of stable elements and their corresponding radionuclides, but between different elements as well. Due to its similarity to calcium, strontium, if ingested by mammals, results in its retention in bones and transmission to milk (Comar 1957). This calcium-strontium similarity also applies to plant uptake of these elements. Myers (1960) reviewed the literature on this relationship, the implication being that interspecific differences in radiostrontium uptake may be predicted by calcium uptake as well as by the uptake of stable strontium. Russell and Newbould (1966) cited findings of Vose and Koontz in which abosrption of stable strontium and calcium were studied on different soils. Results showed nearly the same ratio of strontium to calcium for each species on each soil type. A study by Andersen (1963) showed the same relationships.

Studies of radionuclide uptake show soil factors being prominent in determining rates of plant uptake.

Romney (1957) found the highest Sr^{90} uptake in plants grown on acidic soils low in calcium, and the lowest levels in plants grown on alkaline-calcareous soils. Hoyt and Adriano (1979) found higher uptake of Americium 241 on 24% clay soil than on 10% clay soil, and found that lime reduced the uptake on both soils. The findings of Adriano et al. (1977) and Wallace (1972) showed the same effects of soil pH. Adriano et al. (1977) found that soil amendments influenced the uptake of Co^{60} similarly in both Zea mays and Phaseolus vulgaris. With all other factors constant, interspecific differences in nutrient uptake would determine the uptake of radionuclides (Routson and Cataldo 1978).

CHAPTER III

MATERIALS AND METHODS

Establishment of Experimental Plots

The following plant species commonly grown in the Maxey Flats area were selected as being possible vegetative covers for sites such as the MFDS, and were the plant species considered in this study: alfalfa (*Medicago sativa L.*), lespedeza (*Lespedeza striata* (Thunb.) H & A.), fescue (*Festuca arundinacea* Schreb.), red clover (*Trifolium pratense* L.), orchard grass (*Dactylis glomerata* L.), and crown vetch (*Coronilla varia* L.). In order to assure a good start of these plants, alfalfa, lespedeza, and red clover were started in greenhouse flats three months prior to transplanting to field plots. Crown vetch was transplanted as two-year crowns, and fescue and orchard grass were seeded four weeks prior to transplanting of the other species on May 28, 1980.

The plants were established on 6' x 6' plots on two of five experimental trenches within the restricted area of the MFDS (Figure 3). The random order of alfalfa, lespedeza, fescue, red clover, orchard grass, and crown vetch was selected, with the same order duplicated on

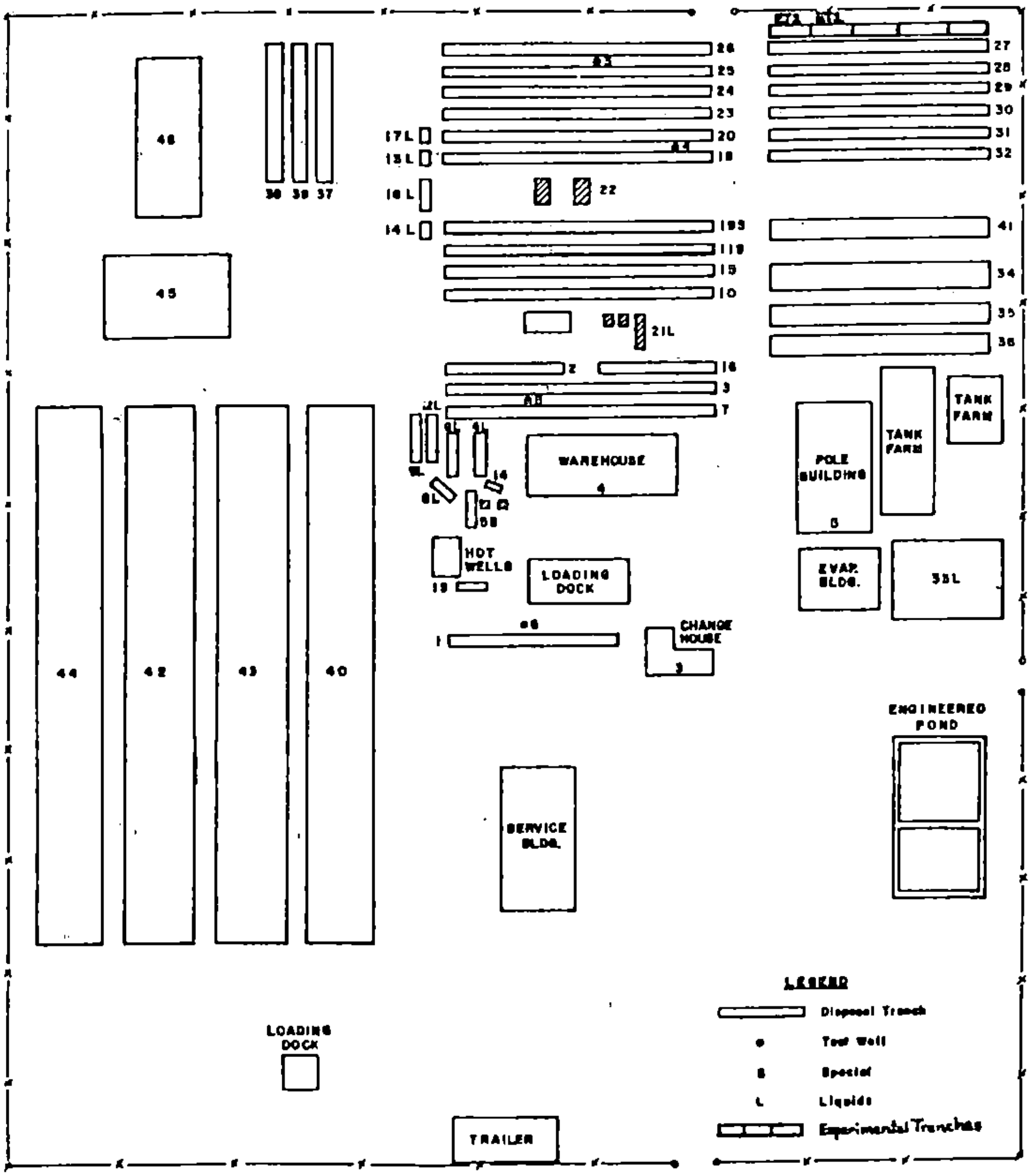

Figure 3. Approximate location of experimental trenches within the restricted area of the Maxey Flats Disposal Site. From the 1978-79 Interim Report of the Special Advisory Committee on Nuclear Waste Disposal, with modifications (Legislative Research Commission 1980).

each of Experimental Trenches 1 and 2. The soil of the plots may be described as disturbed Tilsit silt loam, disturbance of the soil occurring as a result of excavation and capping of the experimental trenches.

Maintenance of Experimental Plots

The experimental plots had received one application of 10-10-10 fertilizer prior to establishment. A second application of fertilizer was made on July 15 at the rate of two-hundred pounds of nitrogen per acre. The fertilizer analysis is shown (Table 1). All plots were kept as weed-free as possible throughout the sample period. The plants were treated with wettable Sevin insecticide every two weeks just after sampling.

Plant Tissue Sampling

In order to obtain random samples, each plot was subdivided into three subplots from which samples for plant tissue analysis were taken. Sampling of the tips of new stem growth was begun four weeks following transplanting, and repeated every two weeks thereafter through October 3, making a total of nine sample dates. Approximately twenty milligrams of sample were taken from each subplot on each sample date. Samples were immediately placed in 4" x 3" manila envelopes, and oven-dried at 70°C for 48

TABLE I

ANALYSIS OF FERTILIZER APPLIED TO EXPERIMENTAL PLOTS

Nutrient	Percentage
Nitrogen	5.30 Ammoniacal N 2.70 Urea N
Phosphoric Acid	12.00
Soluble Potash	4.00
Calcium	1.50
Magnesium	1.00
Sulfur	2.50
Iron	0.20
Manganese	0.08
Zinc	0.09

hours, each envelope being numbered according to trench, plot, subplot, and date.

Sample Analysis

Plant tissue samples were sent to the Laboratory of Nuclear Medicine and Radiation Biology at the University of California at Los Angeles for analysis by emission spectrometry. While spectrometry long required both grinding and ashing of the sample prior to analysis, neither was required in this case due to a special design of the electrodes (Alexander and McAnulty 1981). The samples, however, were ground to assure homogeneity. In all cases, the sample of approximately twenty milligrams was divided into subsamples of six to seven milligrams following grinding. The spectrometer employed allowed analysis for twenty-six elements, the end result of analysis being computer printouts, one for each sample date, with concentrations of the elements in parts per million or percent for each subsample analyzed. Readings were restricted to upper and lower limits as shown (Table 2).

Data Analysis

The data for all elements were transferred to computer cards according to the format shown (Table 3). "Offsite" data were not considered in this study.

TABLE II

SPECTROMETER UPPER AND LOWER LIMITS (ppm or %)

Element	Upper Limit	Lower Limit
P	10.00%	50.0 ppm
NA	20.00%	1.0 ppm
K	20.00%	150.0 ppm
CA	20.00%	1.0 ppm
MG	5.00%	50.0 ppm
ZN	10.00%	5.0 ppm
CU	1000 ppm	0.2 ppm
FE	5000 ppm	0.6 ppm
MN	5.00%	0.1 ppm
B	3000 ppm	1.0 ppm
AL	5000 ppm	1.0 ppm
SI	10.00%	1.0 ppm
TI	1000 ppm	0.5 ppm
V	500 ppm	1.0 ppm
CO	200 ppm	1.5 ppm
NI	400 ppm	0.5 ppm
MO	200 ppm	0.2 ppm
CR	300 ppm	0.2 ppm
SR	1000 ppm	0.2 ppm
BA	2000 ppm	0.2 ppm
LI	2000 ppm	0.3 ppm
AG	100 ppm	0.1 ppm
SN	100 ppm	0.3 ppm
PB	3000 ppm	1.0 ppm
BE	1.00%	0.2 ppm
CD	1.10%	3.0 ppm

TABLE III

DATA FORMAT ON COMPUTER CARDS

Note: There are three cards per subsample. Columns 1-13 have the same format for all three cards. The ppm numbers are six digits with one digit to the right of the decimal.

Card(s)	Column(s)	Description
1-3	1-12	PID (Subsample identification number)
1-3	1-6	Sample Date
1-3	7-8	Site - (01 = Onsite, 02 = Offsite)
1-3	9	Area - (1 = Trench 1, 2 = Trench 2, 3 = Offsite 1, 4 = Offsite 2)
1-3	10	Plot - (1 = Alfalfa, 2 = Lespedeza, 3 = Fescue, 4 = Red Clover, 5 = Orchard Grass, 6 = Crown Vetch)
1-3	11	Subplot (1, 2, 3)
1-3	12	Subsample
1-3	13	Card Number (1, 2, 3)
1	14-19	Phosphorus
1	20-25	Sodium
1	26-31	Potassium
1	32-37	Calcium
1	38-40	Magnesium
1	44-49	Zinc
1	50-55	Copper
1	56-61	Iron
1	62-67	Manganese
2	14-19	Boron

TABLE III (Continued)

Card(s)	Column(s)	Description
2	20-25	Aluminum
2	26-31	Silicon
2	32-37	Titanium
2	38-43	Vanadium
2	44-49	Cobalt
2	50-55	Nickel
2	56-61	Molybdenum
2	62-67	Chromium
3	14-19	Strontium
3	20-25	Barium
3	26-31	Lithium
3	32-37	Silver
3	38-43	Tin
3	44-49	Lead
3	50-55	Beryllium
3	56-61	Cadmium

Trenches will hereafter be referred to as "area(s)". Five of the twenty-six elements were selected for detailed statistical analysis, with elements of concentrations less than or equal to ten ppm not being considered due to the lower accuracy involved.

In order to determine the significance of the ppm and percent values, a four-way analysis of variance was performed using the SAS (Statistical Analysis System) computer package (Helwig and Council 1979). The ANOVA was run using "area", "plot", "subplot", and "date" as the four independent variables. Phosphorus, potassium, calcium, strontium, and zinc concentrations were the dependent variables considered.

Tests of hypotheses were performed for the independent variables and their interactions. Because of the difficulty, however, in drawing conclusions concerning differences between dates, trenches, and subplots, further analysis was limited to the independent variable "plot". The "plot" values analyzed were mean values for the entire sample period.

To determine the exact differences between "plots", Duncan's multiple range tests were performed ($\alpha = .05$ and $\alpha = .01$). Kramer's adjustment was automatically applied in instances of unequal sample sizes.

Due to the small amount of red clover available by the time of the last samplings, the final three sample dates were omitted from the analysis. Orchard grass was also omitted due to the lack of vegetation to sample throughout the study.

CHAPTER IV

RESULTS AND DISCUSSION

The objective of this study was to determine the interspecific differences in plant uptake of phosphorus, potassium, calcium, strontium, and zinc as they occur on disturbed Tilsit loam soil at the Maxey Flats Low-level Nuclear Waste Disposal Site. The plant species studied were alfalfa (*Medicago sativa* L.), lespedeza (*Lespedeza striata* (Thunb.) H. & A.), fescue (*Festuca arundinacea* Schreb.), red clover (*Trifolium pratense* L.), and crown vetch (*Coronilla varia* L.). Such interspecific differences may be correlated to the uptake of radionuclides by these plants on the same soil type. In consideration of the variability of nutrient uptake in successive seasons, whether due to climatic or plant age factors, it is noted that the data herein are considered preliminary.

Phosphorus

The ANOVA tests of hypotheses for phosphorus content of the plant tissues showed significant differences between all independent variables and their interactions ($F = 3.85$ to 187.41, $p = 0.0196$ to 0.0001) (Table 4). The Duncan's multiple range test ($\alpha = .05$) showed significant differences between all species studied (Table 5). Red

TABLE IV

DEPENDENT VARIABLE P

TESTS OF HYPOTHESES USING THE ANOVA MS FOR PID (PLOT*DATE*SUBPLOT*AREA) AS AN ERROR TERM

Source	DF	ANOVA SS	F Value	PR > F
Plot	4	251479607.43458461	187.41	0.0001
Date	5	214149405.13423728	127.67	0.0001
Subplot	2	10138022.41379261	15.11	0.0001
Area	1	1843719.54247570	5.50	0.0196
Plot*Date	20	301104435.98494529	44.88	0.0001
Plot*Subplot	8	36169441.33235741	13.48	0.0001
Date*Subplot	10	54289105.71893692	16.18	0.0001
Plot*Area	4	15314884.33000851	11.41	0.0001
Subplot*Area	2	4713391.44696522	7.03	0.0010
Date*Area	5	29219751.80662823	17.42	0.0001
Plot*Date*Subplot	40	138075916.33948802	10.29	0.0001
Plot*Date*Area	20	136068347.16525363	20.28	0.0001
Plot*Subplot*Area	8	42944822.82282448	16.00	0.0001
Date*Subplot*Area	10	12917580.43375111	3.85	0.0001
Plot*Date*Subplot*Area	40	100153755.98907947	7.46	0.0001

clover, lespedeza, and fescue were significantly different in phosphorus content ($\alpha = .01$). Crown vetch and alfalfa differed significantly from the other species, but not from each other (Table 6).

The species, arranged in order from highest to lowest phosphorus content, were red clover, crown vetch, alfalfa, lespedeza, and fescue (4944.98, 4090.12, 3902.72, 3492.47, and 2840.43 ppm, respectively). The differences are presented graphically (Figure 4).

Interspecific and intraspecific variations in phosphorus uptake have been the basis for selection and breeding of forage plants with desirable phosphorus levels for livestock nutrition (Duel and Trout 1972; Sleper et al. 1977). Legumes such as alfalfa, red clover, and common vetch are utilized for their relatively high phosphorus contents as compared to fescue and lespedeza, lespedeza generally having a higher phosphorus content than fescue (Morrison 1961). The results of this study demonstrated these differences with fescue showing the lowest phosphorus content and red clover the highest.

Based on the results of this study, the five species studied could, on the same soil type, be expected to display similar differences in the uptake of radioactive phosphorus.

TABLE V

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE P

Means with the same letter are not significantly different.
Alpha Level = .05 DF = 344 MS = 335463

Grouping	Mean	N	Plot
A	4944.981731	104	Red Clover
B	4090.124762	105	Crown Vetch
C	3902.717143	105	Alfalfa
D	3492.467619	105	Lespedeza
E	2840.430476	105	Fescue

TABLE VI

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE P

Means with the same letter are not significantlv different.
Alpha Level = .01 DF = 344 MS = 335463

Grouping	Mean	N	Plot
A	4944.981731	104	Red Clover
B	4090.124762	105	Crown Vetch
B	3902.717143	105	Alfalfa
C	3492.467619	105	Lespedeza
D	2840.430476	105	Fescue

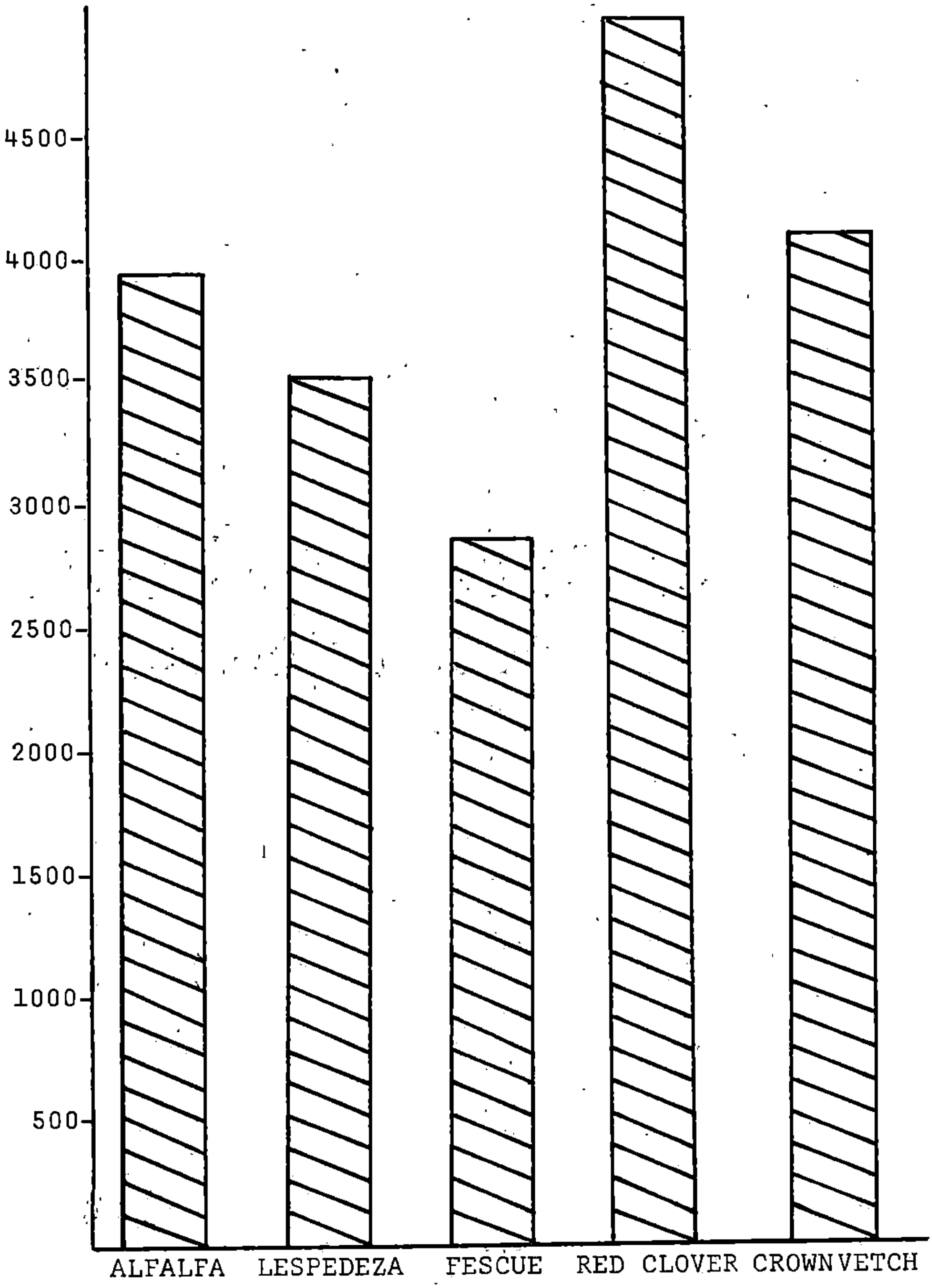

Figure 4. Bar chart of means for phosphorus (ppm).

Potassium

The ANOVA tests of hypotheses for potassium content of the plant tissues showed significant differences between all independent variables and their interactions with the exception of the interaction of "subplot*area" ($F = 1.08$ to 206.97, $p = 0.3391$ to 0.0001) (Table 7). The Duncan's multiple range tests ($\alpha = .05$ and $\alpha = .01$) showed significant differences between the potassium content of red clover, fescue, alfalfa, and lespedeza. Crown vetch differed signficantly from alfalfa and lespedeza, but not from red clover or fescue (Tables 8 and 9).

The species, arranged in order from highest to lowest potassium content, were red clover, crown vetch, fescue, alfalfa, and lespedeza (20937.50, 20644.76, 20340.00, 18481.90, and 16352.38 ppm, respectively). The differences are presented graphically (Figure 5).

As with phosphorus, potassium uptake is generally higher in legumes such as red clover, alfalfa, and common vetch. Lespedeza and fescue show lower potassium uptake, with that of lespedeza slightly higher than that of fescue (Morrison 1961). The higher than expected ranking of fescue in this study could be a result of the stage of growth of the fescue sampled, most values of mineral content being given for tall hay stage fescue. The difference could also reflect different interspecific

TABLE VII

DEPENDENT VARIABLE K

TESTS OF HYPOTHESES USING THE ANOVA MS FOR PID (PLOT*DATE*SUBPLOT*AREA) AS AN ERROR TERM

Source	DF	ANOVA SS	F Value	PR > F
Plot	4	1563655561.34132380	206.97	0.0001
Date	5	1214598789.77896110	128.62	0.0001
Subplot	2	121777156.00471496	32.24	0.0001
Area	1	139946533.23025512	74.10	0.0001
Plot*Date	20	569437135.75776670	15.07	0.0001
Plot*Subplot	8	95042165.42378234	6.29	0.0001
Date*Suplot	10	140556317.61015319	7.44	0.0001
Plot*Area	4	46493337.40463256	6.15	0.0001
Subplot*Area	2	4097774.30053711	1.08	0.3391
Date*Area	5	240792898.86599731	25.50	0.0001
Plot*Date*Subplot	40	322870994.94808959	4.27	0.0001
Plot*Date*Area	20	346638086.70812988	9.18	0.0001
Plot*Subplot*Area	8	97598937.11401367	6.46	0.0001
Date*Subplot*Area	10	57744032.02676391	3.06	0.0010
Plot*Date*Subplot*Area	40	155357067.01635742	2.06	0.0003

TABLE VIII

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE K

Means with the same letter are not significantly different.

Alpha Level = .05 DF = 344 MS = 1888726

Grouping		Mean	N	Plot
	A	20937.500000	104	Red Clover
B	A	20644.761905	105	Crown Vetch
B		20340.000000	105	Fescue
	C	18481.904762	105	Alfalfa
	D	16352.380952	105	Lespedeza

TABLE IX

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE K

Means with the same letter are not significantly different.

Alpha Level = .01 DF = 344 MS = 1888726

Grouping		Mean	N	Plot
	A	20937.500000	104	Red Clover
B	A	20644.761905	105	Crown Vetch
B		20340.000000	105	Fescue
	C	18481.904762	105	Alfalfa
	D	16352.380952	105	Lespedeza

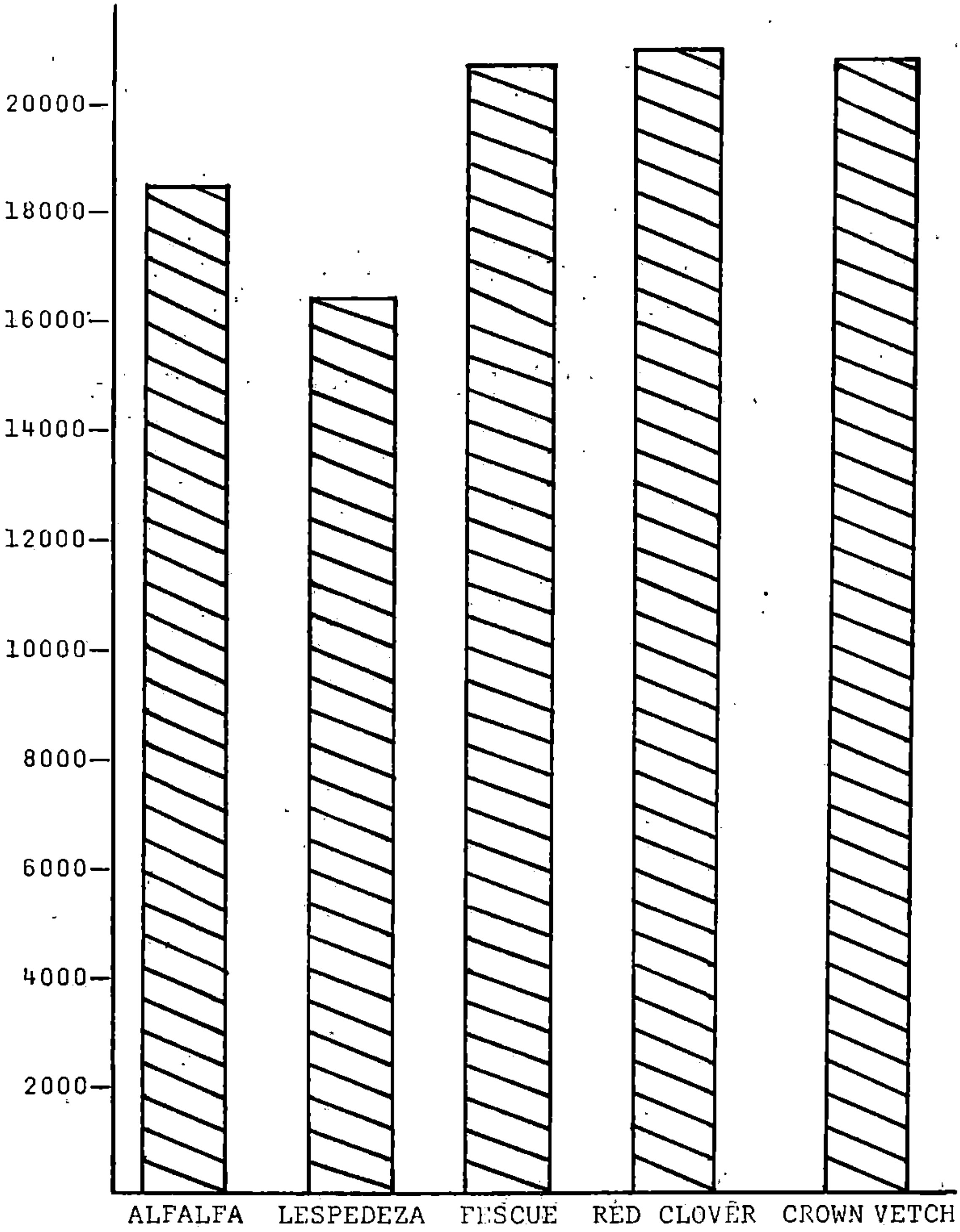

Figure 5. Bar chart of means for potassium (ppm).

responses to the unique soil type.

Based on the results of this study, similar interspecific differences in radioactive potassium uptake could be expected on the same soil type.

Despite the chemical similarities of potassium and cesium as mentioned by Myers (1960), the behavior of the two elements in food chains does not seem to be such that they would be similar in plant uptake (Fredriksson et al. 1966). Thus, potassium uptake cannot be reliably correlated to the uptake of cesium.

Calcium and Strontium

Because of its well-documented similarity to strontium in plant uptake (Myers 1960; Russell and Newbould 1966; Garner 1972), the ranking of plants according to calcium uptake should correspond to that of strontium. The results of this study were nearly perfect in this relationship. The ratios of calcium absorbed to strontium absorbed were, in this study, 655.74, 525.84, 275.22, 544.47 and 536.80 for alfalfa, lespedeza, fescue, red clover, and crown vetch, respectively.

It is well documented that legumes take up more calcium and strontium than grasses, a difference also notable in this study. Drake (1951) cited the high cation exchange capacity of dicotyledons as the reason for higher strontium and calcium uptake by legumes. Differences as well occur among legumes and among grasses though not to as great an extent (Thomas 1952).

Based on the established similarities, interspecific calcium uptake may be used to predict interspecific radioactive calcium uptake, and stable or radioactive strontium uptake or vise versa. Thus, radioactive calcium and strontium could be expected to display interspecific differences in uptake similar to those determined in this study for calcium and strontium, again on the soil type of the study area.

The ANOVA tests of hypotheses for calcium content of the plant tissues showed significant differences between all independent variables and their interactions with the exception of the interaction of "subplot*area" ($F = 0.00$ to 1485.01, $p = 1.0000$ to 0.0001) (Table 10). The Duncan's multiple range tests ($\alpha = .05$ and $\alpha = .01$) showed significant differences in the calcium content of red clover, alfalfa, and fescue. Lespedeza and crown vetch, while differing significantly from the other species, did not differ significantly from each other (Tables 11 and 12).

The species, arranged in order from highest to lowest calcium content were red clover, alfalfa, lespedeza, crown vetch, and fescue (14412.15, 13573.84, 11258.31, 10993.57, and 4430.97 ppm, respectively). The differences

TABLE X

DEPENDENT VARIABLE CA

TESTS OF HYPOTHESES USING THE ANOVA MS FOR PID (PLOT*DATE*SUBPLOT*AREA) AS AN ERROR TERM

Source	DF	ANOVA SS	F Value	PR > F
Plot	4	6441638741.7143130	1485.01	0.0001
Date	5	2906375953.4113245	536.01	0.0001
Subplot	2	118386076.2785091	54.58	0.0001
Area	1	214809393.1823750	198.08	0.0001
Plot*Date	20	1891523907.5605535	87.21	0.0001
Plot*Subplot	8	154575561.3087559	17.82	0.0001
Date*Subplot	10	109374482.5337868	10.09	0.0001
Plot*Area	4	123689062.1008892	28.51	0.0001
Subplot*Area	2	7432351.4094477	3.43	0.0336
Date*Area	5	0.0000000	0.00	1.0000
Plot*Date*Subplot	40	617426989.1716728	14.23	0.0001
Plot*Date*Area	20	285024732.9105024	13.14	0.0001
Plot*Subplot*Area	8	193275978.3290472	22.28	0.0001
Date*Subplot*Area	10	66456248.0507097	6.13	0.0001
Plot*Date*Subplot*Area	40	369797912.2096357	8.53	0.0001

TABLE XI

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE CA

Means with the same letter are not significantly different.

Alpha Level = .05 DF = 344 MS = 1084447

Grouping	Mean	N	Plot
A	14412.150962	104	Red Clover
B	13573.845714	105	Alfalfa
C	11258.312381	105	Lespedeza
C	10993.572381	105	Crown Vetch
D	4430.974286	105	Fescue

TABLE XII

DUNCAN'S MULTIPLE TANGE TEST FOR VARIABLE CA

Means with the same letter are not significantly different.

Alpha Level = .01 DF =344 MS = 1084447

Grouping	Mean	N	Plot
A	14412.150962	104	Red Clover
B	13573.845714	105	Alfalfa
C	11258.312381	105	Lespedeza
C	10993.572381	105	Crown Vetch
D	4430.974286	105	Fescue

are presented graphically (Figure 6).

For strontium, the ANOVA tests of hypotheses showed significant differences between all independent variables and their interactions ($F = 6.63$ to 359.09, $p = 0.0014$ to 0.0001) (Table 13). The Duncan's multiple range test ($\alpha = .05$) showed significant differences in strontium content between red clover, lespedeza, and fescue. While crown vetch and alfalfa differed significantly from the other species, they did not differ significantly from each other (Table 14). The Duncan's multiple range test for strontium ($\alpha = .01$) showed significant differences between red clover, lespedeza, crown vetch, and fescue. Alfalfa differed significantly from all species with the exceptions of lespedeza and crown vetch (Table 15).

The species, arranged in order from highest to lowest strontium content, were red clover, lespedeza, alfalfa, crown vetch, and fescue (26.47, 21.41, 20.70, 20.48, and 16.10 ppm, respectively). The differences are presented graphically (Figure 7).

Zinc

The ANOVA tests of hypotheses for zinc content of the plant tissue showed significant differences between the independent variables "plot", "date", and the interactions "plot*date", "plot*area", and "date*area"

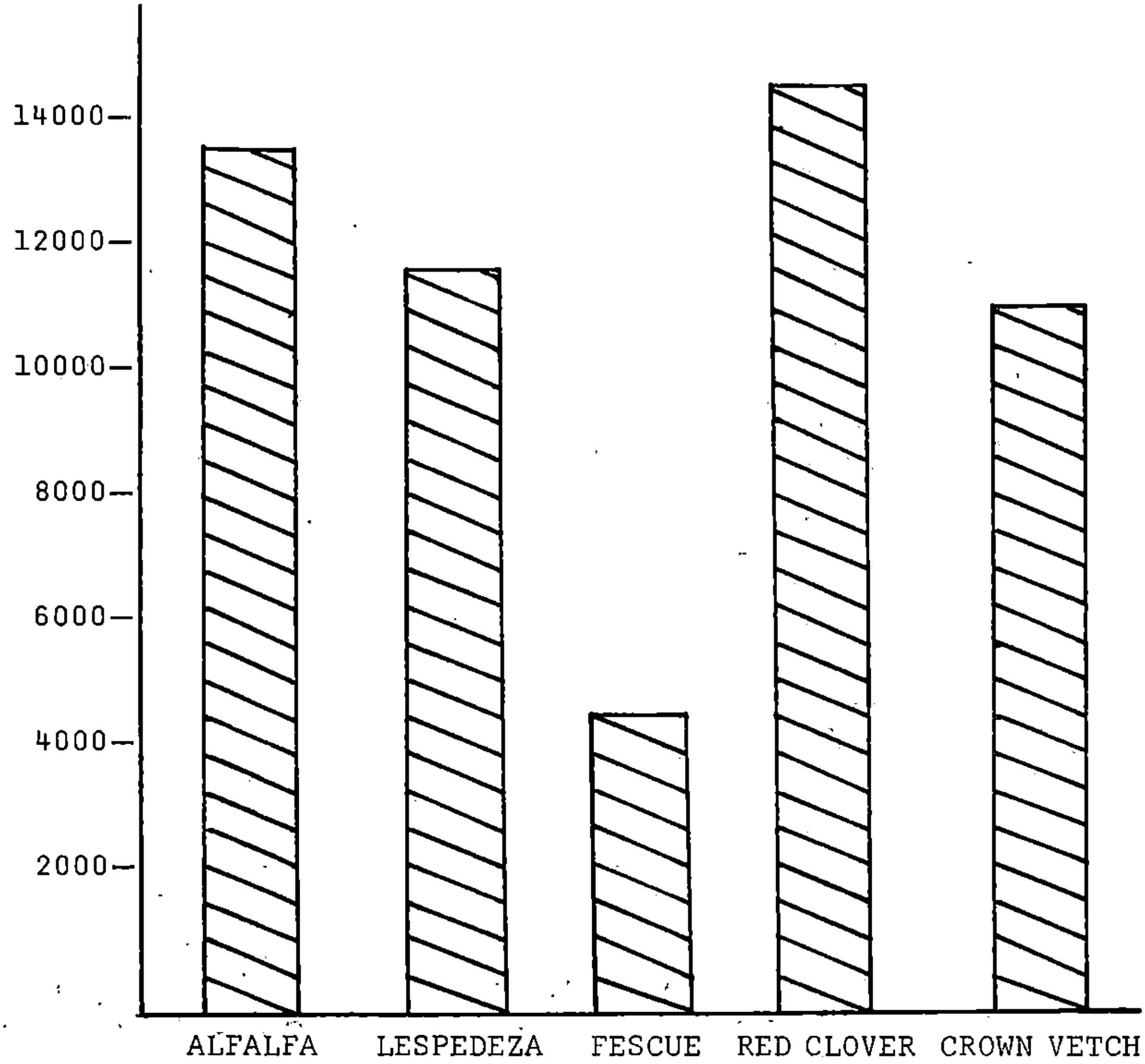

Figure 6. Bar chart of means for calcium (ppm).

TABLE XIII

DEPENDENT VARIABLE SR

TESTS OF HYPOTHESES USING THE ANOVA MS FOR PID (PLOT*DATE*SUBPLOT*AREA) AS AN ERROR TERM

Source	DF	ANOVA SS	F VALUE	PR > F
Plot	4	5678.52073848	359.09	0.0001
Date	5	3992.27969338	201.96	0.0001
Subplot	2	1602.88579731	202.72	0.0001
Area	1	1098.26453586	277.80	0.0001
Plot*Date	20	3299.16086363	41.73	0.0001
Plot*Subplot	8	1192.32111450	37.70	0.0001
Date*Subplot	10	293.52273322	7.42	0.0001
Plot*Area	4	368.58892354	23.31	0.0001
Subplot*Area	2	52.72804402	6.67	0.0014
Date*Area	5	486.61322222	24.62	0.0001
Plot*Date*Subplot	40	1191.25881901	7.53	0.0001
Plot*Date*Area	20	1466.71203242	18.55	0.0001
Plot*Subplot*Area	8	1408.28311889	44.53	0.0001
Date*Subplot*Area	10	414.98916210	10.50	0.0001
Plot*Date*Subplot*Area	40	1048.07329427	6.63	0.0001

TABLE XIV

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE SR

Means with the same letter are not significantly different.
Alpha Level = .05 DF = 344 MS = 3.95345

Grouping	Mean	N	Plot
A	26.466346	104	Red Clover
B	21.409524	105	Lespedeza
C	20.697143	105	Alfalfa
C	20.485714	105	Crown Vetch
D	16.104762	105	Fescue

TABLE XV

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE SR

Means with the same letter are not significantly different.
Alpha Level = .01 DF = 344 MS = 3.95345

Grouping		Mean	N	Plot
	A	26.466346	104	Red Clover
	B	21.409524	105	Lespedeza
C	B	20.697143	105	Alfalfa
C		20.485714	105	Crown Vetch
	D	16.104762	105	Fescue

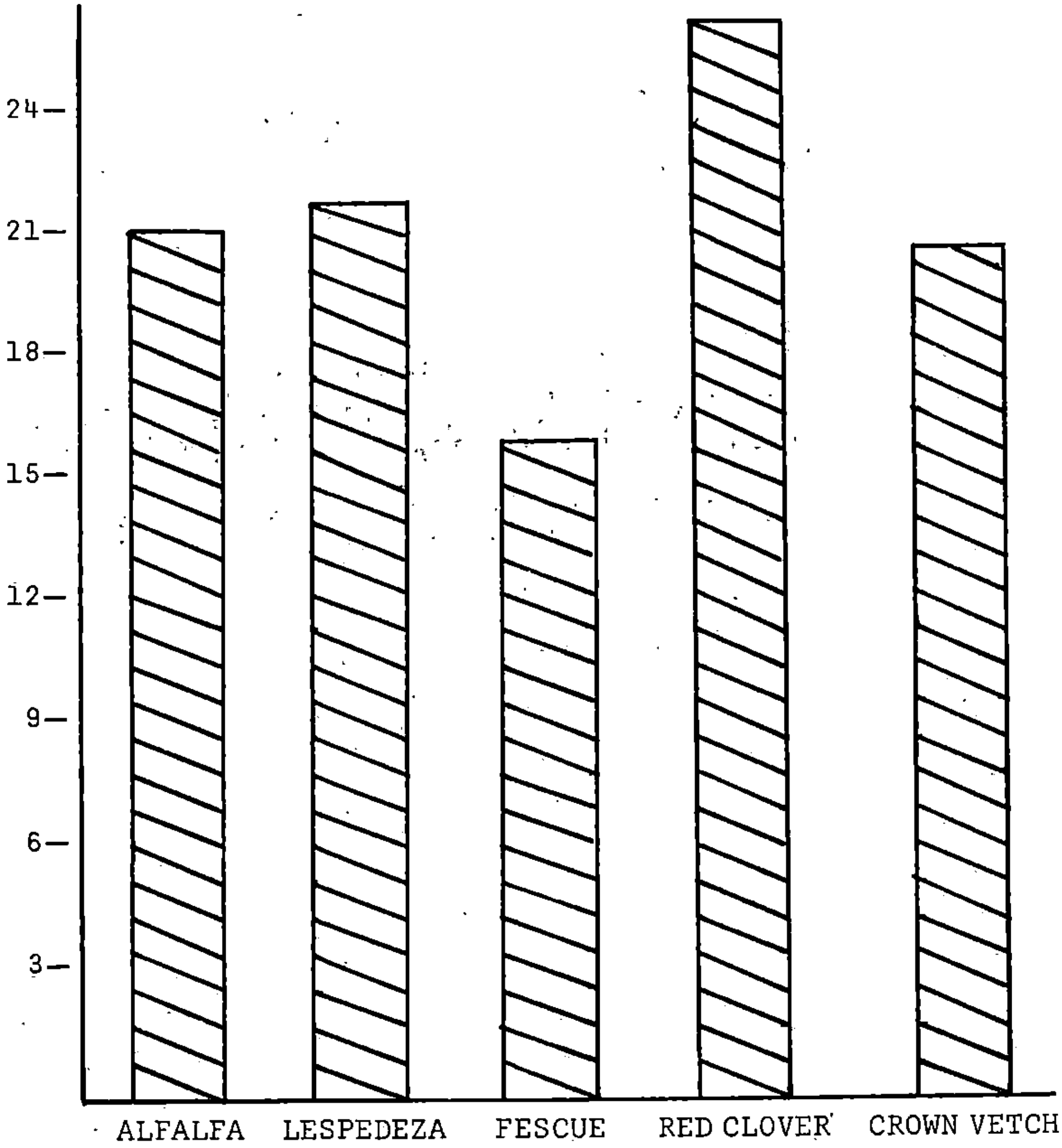

Figure 7. Bar chart of means for strontium (ppm).

($F = 0.51$ to 9.18, $p = 0.5960$ to 0.0001) (Table 16). The Duncan's multiple range test ($\alpha = .05$) showed significant differences in zinc content of crown vetch and lespedeza. Red clover, alfalfa, and fescue differed significantly from crown vetch and lespedeza, but not from each other (Table 17). The Duncan's multiple range test ($\alpha = .01$) showed no significant differences between red clover, alfalfa, fescue, and lespedeza. Crown vetch, however, differed significantly in zinc content from all other species (Table 18).

The species, arranged in order from highest to lowest zinc content were crown vetch, red clover, alfalfa, fescue, and lespedeza (28.53, 22.27, 22.04, 22.00, and 17.49 ppm, respectively). The differences are presented graphically (Figure 8).

An examination of the literature showed no mention of major interspecific trends in zinc uptake. In this study, red clover, alfalfa, and fescue were similar in zinc uptake. The highest zinc content occurred in crown vetch, and the lowest in lespedeza, species for which relatively little nutrient uptake data were found. Radioactive zinc could display the interspecific differences in plant uptake that were determined in this study, again assuming the same soil type.

TABLE XVI

DEPENDENT VARIABLE ZN

TESTS OF HYPOTHESES USING THE ANOVA MS FOR PID (PLOT*DATE*SUBPLOT*AREA) AS AN ERROR TERM

Source	DF	ANOVA SS	F VALUE	PR > F
Plot	4	6509.14769210	9.18	0.0001
Date	5	5208.99575113	5.88	0.0001
Subplot	2	274.52068499	0.77	0.4619
Area	1	89.90470638	0.51	0.4769
Plot*Date	20	10460.91885666	2.95	0.0001
Plot*Subplot	8	1886.26126173	1.33	0.2274
Date*Subplot	10	2262.59056545	1.28	0.2424
Plot*Area	4	2635.05161818	3.72	0.0056
Subplot*Area	2	356.78672457	1.01	0.3667
Date*Area	5	3310.15433257	3.73	0.0028
Plot*Date*Subplot	40	7536.70864468	1.06	0.3740
Plot*Date*Area	20	3167.77905528	0.89	0.5960
Plot*Subplot*Area	8	1876.21311928	1.32	0.2308
Date*Subplot*Area	10	1654.39121546	0.93	0.5027
Plot*Date*Subplot*Area	40	7555.05389494	1.07	0.3700

TABLE XVII

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE ZN

Means with the same letter are not significantly different.
Alpha Level = .05 DF = 344 MS = 117.3

Grouping	Mean	N	Plot
A	28.530476	105	Crown Vetch
B	22.268269	104	Red Clover
B	22.040952	105	Alfalfa
B	21.997143	105	Fescue
C	17.488571	105	Lespedeza

TABLE XVIII

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE ZN

Means with the same letter are not significantly different.
Alpha Level = .01 DF = 344 MS = 117.3

Grouping	Mean	N	Plot
A	28.530476	105	Crown Vetch
B	22.268269	104	Red Clover
B	22.040952	105	Alfalfa
B	21.997143	105	Fescue
B	17.488571	105	Lespedeza

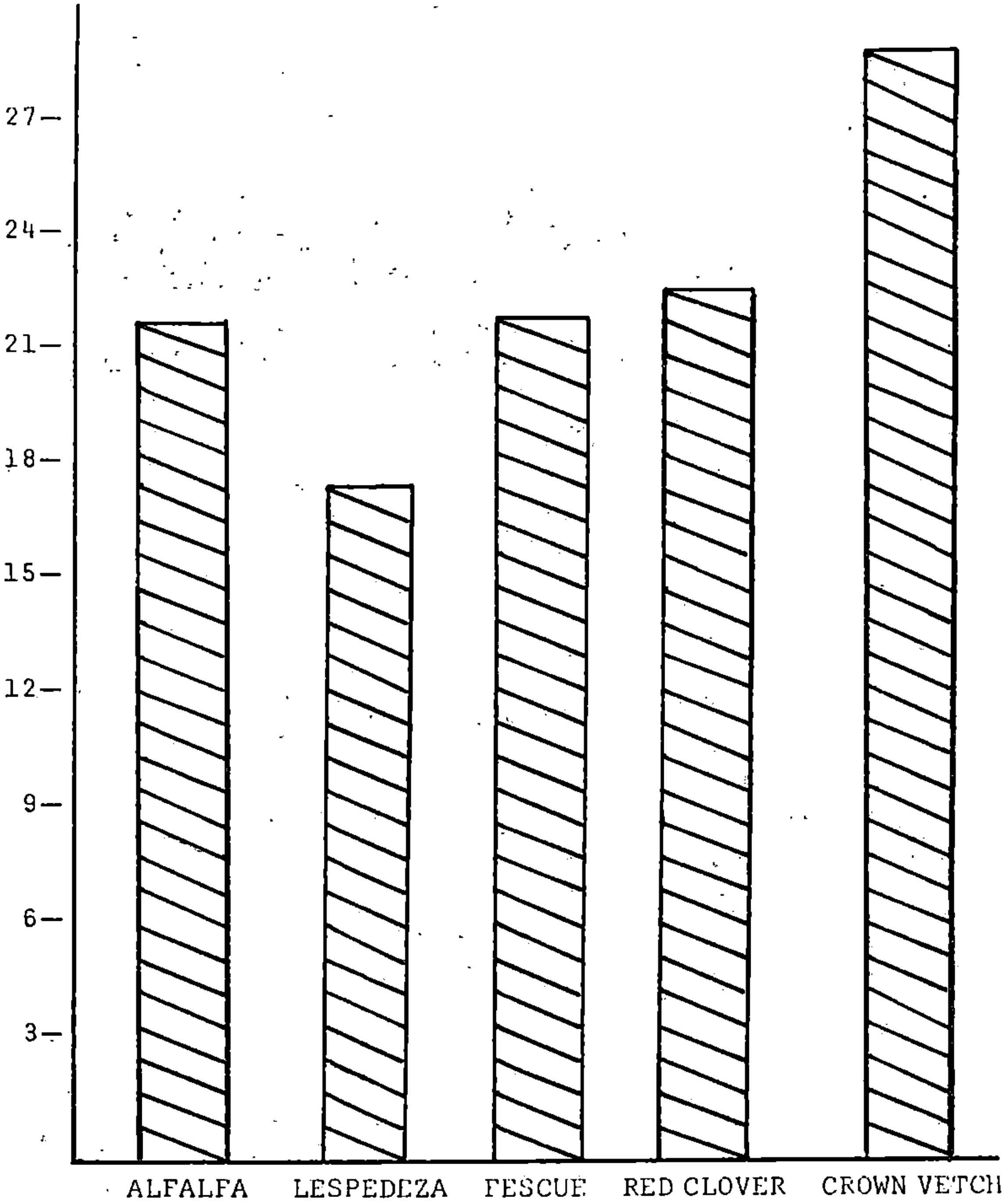

Figure 8. Bar chart of means for zinc (ppm).

CHAPTER V

SUMMARY

Differences in the uptake of selected elements by five possible vegetative covers for nuclear waste disposal sites were studied as possible indicators of interspecific uptake of radionuclides on the same soil type. Alfalfa (_Medicago sativa_ L.), lespedeza (_Lespedeza striata_ (Thunb.) H. & A.), fescue (_Festuca arundinacea_ Schreb.), red clover (_Trifolium pratense_ L.), and crown vetch (_Coronilla varia_ L.) were grown under field conditions on disturbed Tilsit silt loam within the restricted area of the Maxey Flats Low-level Nuclear Waste Disposal Site, soil characteristic of the burial trench caps. Leaf and stem samples collected biweekly over a three-month sample period were analyzed by emission spectrometry, with the concentrations of five elements (phosphorus, potassium, calcium, strontium, and zinc) being considered in this study.

Significant interspecific differences occurred in the uptake of all elements studied. Lespedeza and fescue showed the lowest overall uptake, and red clover and crown vetch the highest. Alfalfa was intermediate in overall uptake. The lower uptake of the elements by fescue and lespedeza suggested that these species would

also be low in radionuclide uptake. As expected, fescue was especially low in strontium and calcium uptake.

In considering vegetative covers for nuclear waste disposal sites, some other factors need to be investigated. Studies of root penetration and evapotranspiration would be important. Due to the seasonal variability of nutrient uptake, it would be important, as well, to conduct studies such as this one over a longer period of time to determine any changes in the interspecific differences in nutrient, and thus radionuclide uptake.

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