

THE VARIATION IN MINERAL COMPOSITION OF
ALFALFA GROWN ON GLENELG SOIL

By

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INTRODUCTION

The composition of the plant is generally accepted as indicative of the kind and amount of nutrients needed for its growth. For many years soil and plant scientists thought that the only chemical elements essential to life processes were: carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, sulfur, magnesium, and iron. Accumulation of information has shown that additional elements are essential to the development of certain if not to all plants. Boron was one of the first of the minor elements to gain a place in the essential list. Conventional nutrient solutions now contain boron, copper, zinc, manganese, and sometimes other elements, in addition to those previously used. Plant and soil investigations have shown that many factors influence the manner and the degree to which elements of the soil are transferred to the tissues of plants.

Certain crops are more drastically changed by variations in mineral environment than others. In general, however, a good nutrient status in the soil tends to produce plant species of good quality and of good nutritive value. The fertilization of an area may change the plant population in the direction of more profitable crops. Blue grass may

be made to crowd out broomsedge. Legumes may take a more prominent place in the flora of an area thus giving a profitable response to the changed mineral level in the soil. Every farmer knows that additions of lime, phosphate, and potash make an environment favorable to clover and alfalfa. Boron is also frequently necessary to produce healthy alfalfa plants and prolong the life of the stand.

Alfalfa is known to be better adapted to certain soils and climates than to others. Soils in the limestone valleys of Maryland will frequently support a profitable growth of alfalfa for eight to ten years. Alfalfa stands on the Piedmont, however, are seldom as permanent. In this Piedmont area the profitable life of a stand is frequently less than five years. All the reasons for this difference are not known. There are many varied factors to be considered in the problem including the nutrient requirements of the plant, resistance to root penetration, moisture supply, and chemical composition of the soils. Alfalfa roots penetrate to greater depths in the soils of limestone valleys than in those of the Piedmont areas. This may be a response to the difference in the chemical composition of the soils. In the limestone valleys there is a gradual approach to the free lime carbonates while the soils of the Piedmont have an acid reaction to a considerable depth.

Alfalfa production in the Piedmont calls for a careful consideration of the whole mineral nutrition system. This subject presents many unsolved problems, one of which is

undertaken in the present investigation. The principal features of this study involve the correlation of the yield of alfalfa with the major and minor element composition of the plant, and the variations of the interrelation of these elements resulting from changes in the mineral nutrient supply of the plant.

REVIEW OF LITERATURE

For more than a decade alfalfa investigations have been directed primarily toward learning the calcium, magnesium, phosphorus, potassium, and boron requirements for best yields. Hunter, Toth, and Bear (13) used Hardistan alfalfa in pot studies with prepared soils having Ca:K ratios in the exchange complex varying between 1:1 and 32:1. Other major and minor nutrients were held constant. They report an abrupt drop in yield (grams of hay per pot) when the calcium content of the plant tissue became greater than 2 per cent, when potassium became less than 1 per cent, or when the Ca:K ratio in the plant exceeded 4:1. It is concluded that alfalfa can adjust itself to wide variations of Ca:K ratios in the soil making normal growth at ratios between 1:1 and 100:1. The highest total yield and the best root development were produced in soil having a Ca:K ratio of 1:1 at the start of the test. The authors state: "Of great practical interest is the fact that as long as the soil contained supplies of both Ca and K, satisfactory yields were produced at wide ratios of these elements in the soil.

... there would be an economic advantage in maintaining the Ca:K ratio in the soil at 32:1 rather than at some lower level."

Haddock and Vandecaveye (12) working with pot cultures used two western Washington soils and found that the best yields were obtained when lime, phosphorus, potassium, boron,

and manganese were included in the treatments. Wide differences in Ca:K, Ca:B, and K:B ratios within the plant were obtained.

Brown, Munsell, and King (6) have studied rate and frequency of field applications of potassium and boron on some Connecticut soils. They found that the Ca:K ratios fluctuated widely among the different cuttings of the same treatment and also between the different treatments of the same cutting. The authors state: "In a comparison of five methods of adding potash, it was found that a single large treatment before seeding produced alfalfa very high in potassium and low in calcium the first year, but the reverse in the third season. This treatment also resulted in poorer stands than where the same total amounts of potash were divided into annual or more frequent applications. ... Although the different potash treatments resulted in wide fluctuations in calcium, magnesium, and potassium contents of alfalfa, the milliequivalents of those cations totalled approximately the same. Borax at 20 pounds per acre in 1938 and none since has almost entirely prevented the appearance of boron deficiency symptoms and increased the boron content of alfalfa 60 per cent through 1944. ... Adding borax has not prolonged the stands or increased the yields of alfalfa, excepting on heavily limed soils or on sandy soils during very dry periods".

Munsell and Brown (16) report that an application of

20 pounds of borax per acre increased the boron in alfalfa an average of 73 per cent.

Recent work reported by Bear and Prince (2) and by Wallace, et al (24) gives evidence supporting the idea of cation-equivalent constancy in alfalfa. These workers analyzed the leaves, the whole plant, stems, roots, and the expressed sap for their potassium, calcium, and magnesium contents. They found that the total content of cations expressed as milliequivalents, tended to have a constant value for the different parts of the plant as well as for the plant as a whole. Bear and Prince (2) report that the sodium content of the alfalfa was too small to be of any significance in connection with their conclusions.

The most comprehensive compilation of the chemical composition of alfalfa found in the literature is that by Beeson (4). Other composition studies are reported by Weathers (27), Snider (23), and Walrath (26).

These and other reports in the literature show that alfalfa, although sensitive to changes in its mineral element environment, permits rather wide fluctuations in its chemical composition. Yields are variable with different levels of the nutrient elements and an ideal cultural situation producing the greatest yield of the highest quality has not been defined. Little work has been directed toward determining the interrelation of the trace constituents among themselves and with the

major elements in alfalfa. The seeming lack of uniformity in the element ratios suggests that the fundamental interrelationship has not yet been discovered.

PLOT AREA, HISTORY, AND TREATMENTS.

The alfalfa samples used for the chemical composition studies were selected from a plot area established in 1942 for the study of the controlling effect of various fertilizers on alfalfa yellows and on the yield of hay. The experiment is on well drained Glenelg silt loam. It has been generally considered a good area for this kind of study in respect to soil type and topography. The field in which the plots are located is part of a farm that had been, for more than a decade, subjected to tenant farming. The soil of this field had a pH of 5.2 when the farm was purchased by the present owner in 1939.

Table I gives the soil management history of the field since 1939. Chart I shows the size and arrangement of the plots. The treatments of the plots used in this study are given in Table II.

TABLE I

Crop and soil management history of field.

Year	Farm practice
1939	Harvested $\frac{1}{2}$ T./A. poor quality mixed hay.
1940	Land plowed in April for corn. 2000 lb. ground limestone / A. applied and worked into surface. Corn, unfertilized, yielded 25 bu. / A. Seeded to wheat in October with an application of 400 lb. 0-14-7 / A.
1941	Wheat yielded approximately 12 bu. / A. Wheat stubble plowed in August for alfalfa. 1000 lb. hydrated lime (45% CaO and 8% MgO) / A. plowed under. 1000 lb. / A. of same kind of lime and 500 lb. of 0-14-7 / A. worked into surface. 20 lb. / A. of Kansas common alfalfa seeded and normal stand obtained.
1942	Early in June the 1st cutting of alfalfa yielded approximately 1 T. / A. About June 20 the 2d cutting growth showed severe yellowing. Plots established for studying the effect of various fertilizers on alfalfa yellows and yield.
1945	In December 1500 lb. / A. of hydrated lime (carrying 8% MgO) applied to alfalfa sod.

CHART I.

Arrangement of variously fertilized experimental plots
within an alfalfa field on Glenelg silt loam.

																	lrd.
40		39		38		37		36		35		34		33		32	31 lrd.
																	5ft.
10		9		8		7		6		5		4		3		2	1
	49		48		47		46		45		44		43		42		41
20		19		18		17		16		15		14		13		12	11
	58		57		56		55		54		53		52		51		50
30		29		28		27		26		25		24		23		22	21

TABLE II.

Plots chosen from the experimental area for consideration of crop yields
in relation to chemical composition of alfalfa.

Plot Nos.:	Date of application and rate of materials added as pounds per acre.		
	June 1942	April 1945	Oct. 1945-500 lb./A. June 1946 " " "
1, 16	:2000 (0-20-0)	:	:5-10-20
2, 17	:2000 (0-20-0); 160 KCl	:	:0-12-12
3, 18	:2000 (0-20-0); 1600 KCl	:	:0-10-20
4	:160 KCl	:	:2-12-12
8, 23	:2000 (0-20-0); 160 KCl; 160 Borax	:	:0-12-12; 160 Borax
9, 24	:2000 (0-20-0); 1600 KCl; 160 Borax	:	:0-10-20; 160 Borax
14	:2000 (0-20-0); 160 KCl; 160 mixt.*	:	:0-12-12; 160 mixt.*
30	:2000 (0-20-0); 1600 KCl; 160 mixt.*	:	:0-10-20; 160 mixt.*
31, 49, 54 :		:500(0-10-20)	:0-10-20
32, 48, 53 :		:500(0-10-20); 25 Borax	:0-10-20
33, 47, 52 :		:500(0-10-20); 100 Borax	:0-10-20
34, 46, 58 :		:500(0-10-20); 25 Borax	:0-10-20
		:100 mixt.*	:
35, 45, 55 :		:500(0-10-20); 100	:0-10-20
		:mixt.*	:
38 :		:500(5-10-20)	:5-10-20
40 :		:500(5-10-20); 100	:5-10-20
		:mixt.*	:

*This material is a privately compounded mixture containing minor elements;
composition unpublished.

ANALYTICAL TECHNIQUES

The samples of alfalfa were collected at the middle bloom stage from a 40-inch strip mown across the center of the plots. The green material was collected, weighed, and chopped into half inch lengths. After thorough mixing a sample was taken for yield data. Another sample (1 kilogram green weight) was air dried for the spectrochemical analysis. After drying, these samples were ground through a Wiley mill with 20-mesh screen and mixed. Approximately 5 grams of this mixture were ground through a 30-mesh screen, dried in an oven at 100° C for 24 hours, and stored in a desiccator. In 1946 composite samples were made of the chopped green material from plots receiving the same treatments and analyses made of the composited material. In 1947 the material from each plot was dried and analyzed separately.

During the past two decades much progress has been made in adapting the spectrochemical technique to analytical problems. A comprehensive review of this development and the applications of the method are found in the bibliography compiled by Scribner and Meggers (15), (21), and published by the American Society for Testing Materials. Brunstetter and Myers (7), (8), (17), formerly of the Bureau of Plant Industry, have had a leading part in adapting the technique to the analysis of plant materials. Other workers (1), (14) have also used spectrochemical techniques for plant composition studies.

The Spectrochemical Laboratory of the National Bureau of Standards was available after regular working hours for the qualitative work and that of the Bureau of Plant Industry for the quantitative portion of this study.

Exploratory qualitative spectrochemical analyses of the alfalfa samples were made to determine the number of elements detectable and to learn the best procedures for the quantitative measurements. It was found that pellets of the ground material could be made by simply applying pressure. The best results were obtained with 20 milligrams of ground material making a pellet approximately $2\frac{1}{2}$ millimeters long and $3\frac{1}{2}$ millimeters in diameter. The spectrum of a sample was made by using two such pellets and superimposing the exposure of the second pellet on the first. The pellets were suitable for qualitative work but proved unsatisfactory for quantitative analysis.

The spectrochemical technique involves the application of physical phenomena to the solution of chemical problems (10). Very small amounts of material are required and usually several elements can be determined simultaneously with one exposure. The advantage of using the method lies in its sensitivity and time-saving features when compared to regular chemical procedures. It is especially useful in plant nutrition work when it can be adapted to the determination of both major and minor constituents in plant materials.

The method is subject, however, to many of the vicissitudes of regular chemical analysis plus those of spectrum photography, diffraction of light waves, measurement of light intensity with photoelectric cells and atomic excitation (20), (25). The generally accepted overall analytical error is +10 per cent of the quantity of the element present in the material.

Sample preparation, conditions of exposure, and instrumentation must be adapted to meet the requirements of the specific problem. Each kind of plant material and the combination of elements to be measured offers its own peculiarities. For the quantitative analysis of the alfalfa in this study a stepped sector was adapted to the general procedure developed by Brunstetter and Myers. By this means it was possible to determine eight elements - calcium, phosphorus, magnesium, aluminum, iron, manganese, boron, and copper - with one exposure. Duplicate or more exposures were made of each sample.

Sodium and potassium were determined with a flame photometer. The method outlined by Myers, Dyal, and Borland (18) was altered by not filtering the HCl extract of the plant ash. It was found that a variable quantity of sodium was present in the filter paper. This alteration avoids possible contamination with sodium and materially shortens the procedure. No clogging of the atomizing jet with plant ash particles was experienced.

THE COMPOSITION OF ALFALFA

The qualitative spectrochemical examination of alfalfa collected from various plots indicated more than twenty elements to be detectable. Table III lists the composition of a typical sample.

TABLE III.

Composition of alfalfa determined by
qualitative spectrochemical analysis

Element	Estimated percentage range	Element	Estimated percentage range
Ca	10+	Mo	.001 - .01
K	10+	B	.0001 - .001
P	1 - 10	Cr	.0001 - .001
Si	1 - 10	Cu	.0001 - .001
Al	.1 - 1	Ni	.0001 - .001
Ba	.1 - 1	Pb	.0001 - .001
Fe	.1 - 1	Sn	.0001 - .001
Mg	.1 - 1	Ti	.0001 - .001
Na	.1 - 1	Y	.0001 - .001
Sr	.1 - 1	Zn	.0001 - .001 (?)
Mn	.01- .1	Ag	?

In qualitative work, the order of concentration of an element is estimated by visual comparison of spectral line densities, and the results are recorded in estimated percentage ranges of 1 to 10. Before beginning the spectrochemical quantitative measurement of elements in a material of unknown composition, it is necessary to determine its general composition by exploratory qualitative analysis. Information so acquired is recorded in the manner illustrated in Table III. This system provides suitable margin for obtaining repeatable

results under comparatively uncontrolled analytical conditions as well as furnishing necessary information for establishing the routine procedure for conducting quantitative analysis.

Tables IV - IX present the results of the quantitative determinations with the data listed in order of increasing yield vertically and in general order of increasing abundance of elements horizontally. In this manner any obvious trends of composition in respect to yield should be discernible.

The difference in yield between 1946 and 1947 is outstanding. Since the weather was comparable for the two years, the explanation of the variation must be in the effect of the treatments (Tables I and II). The 1946 yields were extremely low; the highest was lower than the lowest of 1947. It is evident that the greatest response to the fertilizer and lime was given the second crop year after application. This delay in response indicates that a year or more is necessary for plant nutrients to influence the growth of alfalfa when applied to a five-year-old sod.

The second outstanding feature of the data (Tables IV and V) is the difference in total micrograms of elements per gram of alfalfa, comparing the samples of 1946 with those of 1947. Translating into per cent and averaging the four highest yields of each year, the 1946 samples have 3.7 per cent total minerals, while those of 1947 have 5.4, a difference of 1.7 per cent. Goodall and Gregory (11a)

point out that such variations in chemical composition occur when plants grow under deficient nutrient conditions. Considering the history of field and plot treatments and crop removal previous to 1946 it is reasonable to conclude that the low yields of 1946 were due to a deficiency of plant nutrients (Charts II and III). The concentration of each of the elements, except sodium, is greater in 1947 than in 1946. This indicates a tendency for sodium to substitute for the other bases under conditions of low base level in the nutrient supply. The increase of 1.7 per cent in total minerals for 1947 must be attributed to the lime and fertilizer applications. By far the greater proportion of this mineral content is calcium and potassium. The data in this investigation show that the better yielding hay contains more minerals.

The relationship of mineral composition to practical soil management for the production of alfalfa is significant. In producing a good yield of hay as compared to a poor yield, not only must sufficient plant nutrients be available to provide for the increase in production at the same rate of absorption per unit of yield, but an additional quantity must be supplied to provide for the increase in percentage composition. A comparison of the pounds of elements removed per acre (Tables VI and VII) emphasizes this fact. Using the average of the four highest yields of each year as a basis, an increase of 283 per cent in yield for 1947, as

compared to that of 1946, is accompanied by a 400 per cent increase in pounds of minerals removed. Tripling the yield of alfalfa quadruples the demand on the nutrient supply.

Examination of Tables VIII and IX shows a relation that may be significant in regard to variation of total milliequivalent composition of all the samples analyzed for both years. Considering yields .48 (Table VIII) and 1.58 (Table IX), it is observed that the range in composition extends from 144 milliequivalents in the first instance to 284 in the second. The average for these extreme values is 214, while the average of all samples for 1946 and 1947 is 212. In the consideration of extreme individual samples or of the range of concentration of all samples, approximately ± 33 per cent milliequivalent composition is the limit of deviation from the average in this work.

The variation in the mineral composition of alfalfa is evident from the tables. The effect of this variability is quite marked in Tables VI and VII. Consider, for example, samples 2 and 33 in Table VII. No. 2 with a yield of 1.62 tons per acre removes 68.04 pounds of potassium, while No. 33 with a yield of 1.03 tons per acre, removes 73.44 pounds of potassium. In this instance a smaller yield removes more of a nutrient element than a larger yield. This type of relation in the data is the rule and not the exception and results from variations in percentage composition of

TABLE IV.

Yields and micrograms of elements obtained per gram of alfalfa, 1946, composite samples.

Plots in composite samples	Yield as tons/A. (Av. of plots in composite samples)	Quantity of elements expressed in micrograms per gram and arranged in general order of increasing abundance.	Cu	B	Mn	Fe	Al	Na	Mg	P	K	Ca	Total
		ugm./gm.	ugm./gm.	ugm./gm.	ugm./gm.	ugm./gm.	ugm./gm.	ugm./gm.	ugm./gm.	ugm./gm.	ugm./gm.	ugm./gm.	ugm./gm.
1, 16	.32	11.2:	16.4:	40.0:	70.0:	68.0:	950:	2000:	2200:	19500:	19200:	44056	
4, 19	.34	11.2:	14.0:	34.0:	72.0:	62.0:	700:	1800:	1720:	15000:	10600:	30213	
40	.35	9.4:	17.2:	40.0:	90.0:	48.0:	600:	1600:	2200:	22500:	15200:	42305	
33, 47, 52:	.36	10.0:	20.0:	38.0:	62.0:	42.0:	1750:	1680:	2300:	20500:	14000:	40392	
31, 49, 54:	.38	10.4:	10.0:	58.0:	94.0:	80.0:	1400:	1760:	2100:	18500:	12000:	36012	
32, 48, 53:	.38	10.4:	14.0:	64.0:	100.0:	70.0:	900:	1760:	2400:	19500:	14000:	38818	
34, 46, 58:	.41	8.8:	22.0:	32.0:	80.0:	54.0:	650:	1600:	2500:	19500:	12400:	36847	
38, 42, 57:	.42	10.4:	16.0:	40.0:	96.0:	58.0:	650:	2000:	2500:	19000:	15200:	39570	
35, 45, 55:	.43	12.0:	18.0:	40.0:	82.0:	48.0:	950:	1800:	2500:	19500:	14000:	38950	
2, 17	.46	9.2:	17.6:	32.0:	76.0:	46.0:	850:	1520:	2000:	17000:	12000:	33551	
3, 18	.48	21.0:	14.0:	23.0:	58.0:	48.0:	650:	920:	1680:	26000:	8000:	37414	
14, 29	.52	10.8:	25.0:	30.0:	78.0:	64.0:	1300:	2100:	2700:	14500:	14900:	35608	
8, 23	.53	8.0:	40.0:	36.0:	76.0:	64.0:	1950:	1520:	1800:	18500:	10400:	34394	
9, 24	.60	9.0:	25.0:	31.0:	66.0:	50.0:	1000:	1200:	1560:	23500:	8800:	36241	
15, 30	.74	10.8:	21.0:	40.0:	120.0:	92.0:	1150:	1800:	2500:	20500:	16000:	42234	

TABLE V.

Yields and micrograms of elements obtained per gram of alfalfa, 1947

: quantity of elements expressed in micrograms per gram and arranged in Plot:Yield : general order of increasing abundance.												
No. :	as :	Cu :	B :	Mn :	Fe :	Al :	Na :	Mg :	P :	K :	Ca :	Total
: tons/A :	ugm/gm :	ugm/gm :	ugm/gm :	ugm/gm :	ugm/gm :	ugm/gm :	ugm/gm :	ugm/gm :	ugm/gm :	ugm/gm :	ugm/gm :	ugm/gm :
55 :	.80 :	15.2 :	20.0 :	104.0 :	270 :	390 :	900 :	2800 :	3800 :	25000 :	20000 :	53289
31 :	.83 :	11.2 :	18.4 :	58.0 :	68 :	48 :	600 :	2060 :	2900 :	30000 :	11600 :	47364
54 :	.86 :	34.0 :	16.0 :	88.0 :	400 :	700 :	550 :	2500 :	4400 :	20500 :	17200 :	46398
32 :	.91 :	13.2 :	31.0 :	80.0 :	112 :	108 :	750 :	2600 :	3100 :	29000 :	18400 :	54194
17 :	.93 :	12.0 :	13.2 :	52.0 :	124 :	108 :	1050 :	3000 :	3300 :	22500 :	15600 :	45759
24 :	1.01 :	34.0 :	96.0 :	80.0 :	1000 :	920 :	600 :	1760 :	5000 :	21500 :	10800 :	41790
34 :	1.06 :	11.2 :	30.0 :	80.0 :	70 :	46 :	550 :	2200 :	2900 :	27000 :	14400 :	47287
33 :	1.08 :	13.2 :	31.0 :	96.0 :	80 :	62 :	750 :	2200 :	3300 :	34000 :	13600 :	54132
1 :	1.10 :	13.2 :	18.8 :	54.0 :	112 :	100 :	800 :	2800 :	3300 :	29000 :	18000 :	54097
23 :	1.10 :	10.8 :	52.0 :	56.0 :	128 :	200 :	1300 :	2500 :	3300 :	22500 :	17200 :	47247
58 :	1.13 :	12.8 :	36.0 :	96.0 :	76 :	72 :	1000 :	3000 :	3500 :	20500 :	20000 :	48293
35 :	1.16 :	12.8 :	34.0 :	80.0 :	128 :	132 :	850 :	2500 :	3800 :	31000 :	18400 :	56937
47 :	1.16 :	10.0 :	21.0 :	62.0 :	86 :	62 :	756 :	1840 :	2800 :	29000 :	14400 :	49031
4 :	1.18 :	11.2 :	11.0 :	62.0 :	132 :	120 :	700 :	3000 :	2700 :	19000 :	18000 :	43736
8 :	1.19 :	10.0 :	58.0 :	44.0 :	160 :	180 :	1350 :	2600 :	3200 :	21000 :	18000 :	46602
16 :	1.21 :	12.4 :	23.0 :	60.0 :	140 :	100 :	1100 :	2800 :	3400 :	23500 :	16400 :	46536
40 :	1.25 :	13.2 :	28.0 :	80.0 :	112 :	120 :	700 :	2200 :	3300 :	32000 :	16000 :	54553
9 :	1.27 :	10.8 :	46.0 :	54.0 :	92 :	56 :	600 :	1960 :	3100 :	33000 :	11200 :	50119
30 :	1.27 :	11.2 :	28.0 :	70.0 :	102 :	120 :	750 :	1680 :	3100 :	33000 :	11600 :	50461
52 :	1.32 :	31.0 :	28.0 :	96.0 :	620 :	940 :	950 :	2500 :	5000 :	19000 :	16400 :	45565
3 :	1.40 :	9.2 :	17.2 :	42.0 :	84 :	54 :	550 :	1680 :	2500 :	31000 :	12000 :	47936
18 :	1.43 :	11.6 :	22.0 :	54.0 :	214 :	210 :	700 :	2600 :	3800 :	38000 :	19200 :	64812
45 :	1.44 :	13.2 :	22.0 :	70.0 :	128 :	160 :	800 :	2500 :	3400 :	29000 :	24000 :	60093
53 :	1.47 :	14.0 :	27.0 :	62.0 :	116 :	180 :	1000 :	2700 :	3600 :	28000 :	18800 :	54499
14 :	1.48 :	11.6 :	35.0 :	48.0 :	112 :	86 :	1000 :	2800 :	3200 :	20000 :	14000 :	41293
58 :	1.48 :	34.0 :	19.6 :	104.0 :	700 :	940 :	950 :	2500 :	5700 :	20000 :	14800 :	45748
49 :	1.58 :	14.0 :	14.4 :	96.0 :	270 :	320 :	800 :	2800 :	3800 :	32000 :	22000 :	62114
2 :	1.62 :	11.6 :	20.0 :	54.0 :	120 :	100 :	1000 :	3300 :	3400 :	21000 :	19200 :	48208
46 :	1.71 :	13.2 :	33.0 :	112.0 :	184 :	180 :	600 :	2700 :	3600 :	27000 :	22000 :	56422
48 :	1.79 :	12.8 :	18.0 :	78.0 :	104 :	100 :	1000 :	2800 :	3000 :	23000 :	18800 :	48913

TABLE VI.
Yield and pounds of elements removed per acre by alfalfa, 1946
composite samples.

Plot No.	Yield as : : tons/A. : (av. of : plots in : composite : samples)	Cu : : lb/A.	B : : lb/A.	Mn : : lb/A.	Fe : : lb/A.	Al : : lb/A.	Na : : lb/A.	Mg : : lb/A.	P : : lb/A.	K : : lb/A.	Ca : : lb/A.	Total : lb/A.
1, 16	.32	.0072	.0105	.0256	.0448	.0435	.608	1.28	1.41	12.5	12.29	28.2
4, 19	.34	.0076	.0095	.0251	.0490	.0422	.476	1.22	1.17	10.2	7.34	20.54
40	.35	.0066	.0120	.0280	.0630	.0336	.42	1.12	1.54	15.75	10.64	29.61
32, 47, 52:	.36	.0072	.0144	.0202	.0446	.0302	1.26	1.21	1.66	14.76	10.08	29.08
31, 49, 54:	.38	.0079	.0076	.0441	.0714	.0608	1.06	1.34	1.60	14.06	9.12	27.37
32, 48, 53:	.38	.0079	.0106	.0486	.0760	.0532	.68	1.34	1.82	14.82	10.64	29.50
34, 46, 58:	.41	.0072	.0180	.0262	.0656	.0443	.53	1.31	2.05	15.99	10.17	30.21
38, 42, 57:	.42	.0087	.0134	.0336	.0806	.0487	.55	1.68	2.10	15.96	12.77	33.24
35, 45, 55:	.43	.0103	.0155	.0344	.0705	.0413	.82	1.55	2.15	16.77	12.04	33.50
2, 17	.46	.0085	.0162	.0294	.0700	.0423	.78	1.40	1.84	15.64	11.04	30.87
3, 16	.48	.0202	.0134	.0221	.0557	.0461	.62	.88	1.61	24.96	7.68	35.92
14, 29	.52	.0112	.0260	.0312	.0811	.0666	1.35	2.18	2.81	15.08	15.39	37.03
8, 23	.53	.0085	.0424	.0382	.0806	.0678	2.07	1.61	1.91	19.61	11.02	36.46
9, 24	.60	.0108	.0300	.0372	.0792	.0600	1.20	1.44	1.87	28.2	10.56	43.49
15, 30	.74	.0160	.0323	.0592	.1776	.1362	1.70	2.66	3.70	30.34	23.68	62.51

TABLE VII.

Yield and pounds of elements removed per acre by alfalfa, 1947.

Plot: No.:	Yield as	Cu :lb/A.	B :lb/A.	Mn :lb/A.	Fe :lb/A.	Al :lb/A.	Na :lb/A.	Mg :lb/A.	P :lb/A.	K :lb/A.	Ca :lb/A.	Total :lb/A.
tons/A.												
55	.80	.0243	.0320	.1664	.4320	.6080	1.440	4.48	6.08	40.00	32.00	85.26
31	.83	.0186	.0305	.0963	.1129	.0797	.996	3.42	4.81	49.80	19.26	78.62
54	.86	.0585	.0275	.1514	.6880	1.2000	.946	4.30	7.57	35.26	29.58	79.79
52	.91	.0240	.0564	.1456	.2036	.1966	1.370	4.73	5.64	52.78	35.49	98.63
17	.93	.0223	.0246	.0967	.2310	.2010	1.950	5.58	6.14	41.85	29.02	85.11
24	1.01	.0687	.1939	.1616	2.0200	1.8600	1.210	3.56	10.10	43.43	21.82	84.42
34	1.06	.0237	.0636	.1696	.1484	.0975	1.170	4.66	6.15	57.24	30.53	100.25
53	1.08	.0285	.0670	.2074	.1728	.1340	1.620	4.75	7.13	73.44	29.38	116.90
1	1.10	.0290	.0414	.1188	.2464	.2200	1.760	6.16	7.26	63.80	39.60	119.00
23	1.10	.0238	.1144	.1232	.2616	.4400	2.860	5.50	7.26	49.50	37.84	103.94
38	1.13	.0289	.0814	.2170	.1718	.1627	2.260	6.78	7.91	46.33	45.29	109.14
35	1.16	.0297	.0789	.1856	.2970	.3062	1.970	5.80	8.82	71.92	42.69	132.09
47	1.16	.0232	.0487	.1438	.1995	.1438	1.740	4.27	6.50	67.28	33.41	113.75
4	1.18	.0264	.0260	.1463	.3115	.2832	1.650	7.08	6.37	44.84	42.48	103.22
8	1.19	.0238	.1380	.1047	.3808	.4284	3.210	6.19	7.62	49.98	42.84	110.91
16	1.21	.0300	.0557	.1452	.3388	.2420	2.660	6.78	8.23	54.45	39.69	112.61
40	1.25	.0330	.0700	.2000	.2800	.3000	1.750	5.50	8.25	80.00	40.00	136.38
9	1.27	.0274	.1168	.1372	.2337	.1422	1.524	4.98	7.87	83.80	28.45	127.30
30	1.27	.0284	.0711	.1778	.2591	.3048	1.910	4.27	7.87	83.82	29.46	128.17
52	1.32	.0818	.0739	.2534	1.6368	2.4800	2.508	6.60	13.20	50.16	43.30	120.29
3	1.40	.0258	.0482	.1176	.2352	.1512	1.540	4.70	7.00	86.80	33.60	134.22
18	1.43	.0332	.0629	.1544	.6120	.6006	2.002	7.44	10.87	108.68	54.91	185.36
45	1.44	.0380	.0634	.2016	.3686	.4608	2.304	7.20	9.79	83.52	69.12	173.07
53	1.47	.0412	.0794	.1823	.3410	.5292	2.940	7.94	10.58	82.32	55.27	160.23
14	1.48	.0343	.1036	.1421	.3315	.2546	2.960	8.29	9.47	59.20	41.44	122.23
58	1.48	.1006	.0580	.3078	2.0720	2.7820	2.812	7.40	16.87	59.20	43.81	135.41
49	1.58	.0442	.0455	.3034	.8532	1.0112	2.528	8.85	12.01	101.12	69.52	196.28
2	1.62	.0376	.0648	.1750	.3888	.3240	3.240	10.69	11.02	68.04	62.21	156.19
46	1.71	.0451	.1129	.3830	.6293	.6156	2.050	9.23	12.31	92.34	75.24	192.96
48	1.79	.0458	.0644	.2792	.5723	.3560	3.580	10.02	10.74	82.34	67.30	175.11

TABLE VIII.

Yield and milliequivalents of elements obtained per 100 grams
of alfalfa, 1946 composite samples.

Plot No.	Yield as : tons/A. (Av. of plots in composite samples)	Cu* : m.e./ 100 gm.	B : m.e./ 100 gm.	Mn** : m.e./ 100 gm.	Fe : m.e./ 100 gm.	Al : m.e./ 100 gm.	Na : m.e./ 100 gm.	Mg : m.e./ 100 gm.	P*** : m.e./ 100 gm.	K : m.e./ 100 gm.	Ca : m.e./ 100 gm.	Total m.e./ 100 gm.
1, 16	.32	.0352	.0455	.291	.376	.756	4.13	16.5	35.5	50.0	94.4	202.
4, 19	.34	.0352	.0388	.248	.387	.690	3.04	22.4	27.7	38.4	53.1	146.
40	.35	.0296	.0477	.291	.484	.601	2.61	13.2	35.5	57.6	74.7	185.
33, 47, 52	.36	.0315	.0555	.670	.333	.467	7.61	13.8	37.1	52.4	68.8	181.
31, 49, 54	.38	.0327	.0277	.422	.505	.890	6.09	14.5	33.8	47.3	59.0	163.
32, 48, 53	.38	.0327	.0388	.466	.537	.779	3.91	14.5	38.7	49.9	68.8	178.
54, 46, 58	.41	.0277	.0610	.233	.430	.601	2.83	13.2	40.3	49.9	60.9	168.
38, 42, 57	.42	.0327	.0444	.291	.516	.645	2.83	16.5	40.3	48.6	74.7	184.
35, 45, 55	.43	.0378	.0499	.291	.441	.534	4.13	14.8	40.3	49.9	68.8	179.
2, 17	.46	.0289	.0488	.233	.408	.512	3.70	12.5	32.2	43.5	59.0	152.
3, 18	.48	.0321	.0388	.168	.312	.534	2.83	7.57	27.1	66.5	39.3	144.
14, 29	.52	.0340	.0693	.219	.419	.712	5.65	17.3	43.5	37.1	72.7	178.
8, 23	.53	.0252	.1109	.262	.408	.712	8.48	20.1	29.0	47.3	51.1	158.
9, 24	.60	.0283	.0693	.226	.355	.556	4.35	9.87	25.1	60.1	43.2	144.
15, 30	.74	.0340	.0582	.291	.645	1.023	5.00	14.8	40.3	52.4	78.6	193.

*Valence = 2. **Valence = 4. ***Valence = 5.

TABLE IX.

Yield and milliequivalents of elements obtained per 100 grams of alfalfa, 1947.

Plot:	Yield:	Cu*	B	Mn**	Fe	Al	Na	Mg	P***	K	Ca	Total
No.:	as	m.e./	m.e./	m.e./	m.e./	m.e./	m.e./	m.e./	m.e./	m.e./	m.e./	m.e./
: tons/	: 100	: 100	: 100	: 100	: 100	: 100	: 100	: 100	: 100	: 100	: 100	: 100
: A.	: gm.	: gm.	: gm.	: gm.	: gm.	: gm.	: gm.	: gm.	: gm.	: gm.	: gm.	: gm.
55	: 80	: 0478	: 0555	: 7573	: 1.4510	: 4.2270	: 3.91	: 23.03	: 61.24	: 63.95	: 98.28	: 256.9
31	: 83	: 0352	: 0510	: 4224	: 3654	: 5339	: 2.61	: 16.94	: 46.74	: 76.74	: 57.00	: 201.4
54	: 86	: 1070	: 0444	: 6408	: 2.1490	: 7.7860	: 2.39	: 20.56	: 70.91	: 52.44	: 84.52	: 241.5
32	: 91	: 0415	: 0860	: 5826	: 6018	: 1.2010	: 3.26	: 21.38	: 49.96	: 74.18	: 90.42	: 241.7
17	: 93	: 0378	: 0368	: 3787	: 5663	: 1.2010	: 4.57	: 24.67	: 53.18	: 57.56	: 76.66	: 219.0
24	: 1.01	: 1070	: 2662	: 5826	: 5.3730	: 10.2300	: 2.61	: 14.47	: 80.58	: 55.00	: 53.07	: 222.3
34	: 1.06	: 0352	: 0832	: 5826	: 3761	: 5117	: 2.39	: 18.09	: 46.74	: 69.07	: 70.76	: 162.4
33	: 1.08	: 0415	: 0860	: 6991	: 4298	: 6896	: 3.26	: 18.09	: 53.18	: 86.97	: 66.83	: 230.3
1	: 1.10	: 0415	: 0521	: 3932	: 6018	: 1.1120	: 3.48	: 23.03	: 53.18	: 74.10	: 88.45	: 244.5
23	: 1.10	: 0340	: 1442	: 4078	: 6877	: 2.2250	: 5.65	: 20.56	: 53.18	: 57.56	: 84.52	: 225.0
38	: 1.13	: 0403	: 0998	: 6991	: 4083	: 8009	: 4.35	: 24.67	: 56.41	: 52.41	: 98.28	: 236.2
35	: 1.16	: 0403	: 0943	: 5926	: 6877	: 1.4680	: 3.70	: 20.56	: 61.24	: 79.30	: 90.42	: 258.1
47	: 1.16	: 0315	: 0582	: 4515	: 4621	: 6896	: 3.26	: 15.13	: 45.12	: 74.18	: 70.76	: 210.1
4	: 1.18	: 0352	: 0305	: 4515	: 7092	: 1.3350	: 3.04	: 24.67	: 43.51	: 48.60	: 88.45	: 210.9
8	: 1.19	: 0315	: 1608	: 3204	: 8597	: 2.0020	: 5.87	: 21.38	: 51.57	: 53.72	: 88.45	: 224.4
16	: 1.21	: 0390	: 0638	: 4569	: 7522	: 1.1120	: 4.78	: 23.03	: 54.79	: 57.56	: 80.59	: 223.2
40	: 1.25	: 0415	: 0776	: 5826	: 6018	: 1.3350	: 3.04	: 18.09	: 53.18	: 81.86	: 78.62	: 237.4
9	: 1.27	: 0340	: 1276	: 3932	: 4943	: 6229	: 2.61	: 16.12	: 49.96	: 84.41	: 55.04	: 209.8
30	: 1.27	: 0352	: 0776	: 5097	: 5480	: 1.3350	: 3.26	: 13.82	: 49.96	: 84.41	: 57.00	: 211.0
52	: 1.32	: 0975	: 0776	: 6991	: 3.3310	: 10.4600	: 4.13	: 20.56	: 80.58	: 48.60	: 80.59	: 249.1
3	: 1.40	: 0289	: 0477	: 3058	: 4513	: 6006	: 2.39	: 13.82	: 40.29	: 79.30	: 56.97	: 196.2
18	: 1.43	: 0365	: 0610	: 3932	: 1.1500	: 2.3360	: 3.04	: 21.38	: 61.24	: 97.20	: 94.35	: 281.2
45	: 1.44	: 0415	: 0610	: 5097	: 6877	: 1.7800	: 3.48	: 20.56	: 54.79	: 74.18	: 117.94	: 274.0
53	: 1.47	: 0440	: 0749	: 4515	: 6233	: 2.0020	: 4.35	: 22.20	: 58.02	: 71.62	: 92.38	: 251.8
14	: 1.48	: 0365	: 0971	: 3495	: 6018	: 9566	: 4.35	: 23.03	: 51.57	: 51.16	: 68.80	: 201.0
58	: 1.48	: 1070	: 0544	: 7573	: 3.7610	: 10.4600	: 4.13	: 20.56	: 91.86	: 51.16	: 72.73	: 255.6
49	: 1.58	: 0440	: 0399	: 6991	: 1.4510	: 3.5590	: 3.48	: 23.03	: 61.24	: 81.86	: 108.11	: 283.5
2	: 1.62	: 0365	: 0555	: 3932	: 6448	: 1.1120	: 4.35	: 27.14	: 54.79	: 53.72	: 94.35	: 236.6
46	: 1.71	: 0415	: 0915	: 8156	: 9886	: 2.0020	: 2.61	: 22.20	: 58.02	: 69.07	: 108.11	: 263.9
48	: 1.79	: 0403	: 0499	: 5680	: 5588	: 1.1120	: 4.35	: 23.03	: 48.35	: 58.83	: 92.38	: 229.3

* Valence = 2 ** Valence = 4 *** Valence = 5

alfalfa. This characteristic of plant composition data is mentioned by Goodall and Gregory (11b) as a serious handicap in using results of plant analysis as a basis of diagnosis in nutrition studies. There is no doubt that this condition poses a problem in evaluating data for determining the relation of composition to yield. Under the system of tabulation used in these tables, however, definite trends can be observed. Tables VI and VII show that as yield increases the quantity of elements removed per acre also increases. This trend, although negated by many individual samples in respect to different elements, is nevertheless definitely established by the volume of data. This feature demonstrates the need for analyzing a large number of plant samples for several elements when trends in mineral content are to be related to yield. The spectrochemical technique is at present the most practical method of obtaining plant composition data in such a study.

Although data show plant composition to be variable, there is, however, a certain order of concentration for each element. When the quantity of an element exceeds the maximum or minimum requirement of the plant for that element, certain physiological disorders result. Plants manifest persistent nutrient unbalance by exhibiting characteristics of growth, color, or tissue malformation peculiar to the physiological function of the element (25). It has been the ambition of plant physiologists to be able to recognize

and interpret element deficiency and excess symptoms so that future practices of fertilization and management of crops and soils could be indicated by past performance of plants grown under known nutrient conditions. Accumulation of information from such investigations has been helpful to practical agriculture and has served to prove the complexity of the problem of plant nutrition. It has been established that a so-called "deficiency" of one element may be due to an excess of another. A "deficiency" symptom of magnesium appearance in the leaf, for example, may be caused by an excess accumulation of potassium (5). Shear, Crane and Myers (22a) have found that the same effect may result from the accumulation of calcium. Magnesium or calcium accumulation, or a combination of both, may also produce potassium "deficiency". The first and sometimes only symptom of a deficiency is a reduced rate of growth. The appearance of visual symptoms means that a radically unbalanced nutrition has existed for some time. These authors also state: "All other factors being constant, plant growth is a function of the two variables of nutrition, intensity and balance, as they are reflected in the composition of leaves when the plants are in the same stages of growth or development. At any given level of nutritional intensity (total equivalent concentration of all functional nutrient elements in the leaf) a mul-

tiplicity of ratios may exist between these elements.

Many investigators use various ratios of the concentrations and combinations of concentrations of elements in expressing nutrient interrelations. The objective of such evaluations is to correlate mineral composition with the yield and the nutrient supply of the plant. Due to the extent of variation of plant composition, within the limitations of maximum and minimum requirements, which result from the innumerable factors involved in plant growth and relative nutrient absorption and accumulation, such correlations become almost meaningless (11c). It is generally recognized, however, that there must be some relation between the proportion of the elements present in the plant and the proportion supplied to the plant. The knowledge of methods establishing this relation is meager. Goodall and Gregory (11d) state: "To base the conclusions from diagnostic analyses on the data for a single element will in general be unsatisfactory. ... the increase in yield to be expected from an increase in the supply of a nutrient is related not only to the internal concentration of that nutrient, but also to that of other nutrients. Consequently a method of interpretation of the results of diagnostic analyses must not only take account of the value for the nutrient primarily considered, but must also allow for variations in the internal concentration of the other nutrients." It is further pointed out that such an "exhaustive treatment"

of data has never been attempted. The method of data analysis later described in this investigation is a step toward the formulation of such a treatment.

The data collected in this study show variations in plant composition similar to those reported by other workers (6), (12), (13). The extensive chemical composition determinations and the wide variation in yield, however, offer certain advantages for interpretation not provided by most investigations. The tabular arrangement used with the volume of data show definite trends that would not be discernible from individual samples and fewer element determinations. This indicates that a statistical method of data analysis would be valuable in the study of element interrelations in plants and in correlating these interrelations with yield and treatment.

Milliequivalent values are sometimes used in ratio studies for expressing elements in terms of their chemical significance. In calculating and tabulating the milliequivalent values (Tables VIII and IX) it was noticed that the elements could be grouped, in general, according to a logarithmic relation of their concentrations. This is considered the key to the formulation of the method of data evaluation proposed in this thesis. Plotting log milliequivalent concentration of elements against log milliequivalent per cent composition (a linear function with slope of one), revealed a puzzling variation of the

elements with respect to yield. Thought was directed toward establishing a method for measuring this linear movement. The logical procedure would have been to formulate a method for comparing the composition of different samples with suitable standards. Since standards of alfalfa composition do not exist, the composition of the samples from the four highest yielding plots were used. Goodall and Gregory (11e) cite the often used practice of choosing the best sample as a standard, but consider a "normal range based on good plants from a considerable number of diverse sites" a better basis of comparison. After several trials for determining the best method of comparing samples the present formulation was established.

THE BASIC RATIO METHOD OF PLANT COMPOSITION DATA

EVALUATION.

(Brief outline of the method)

- I. Establishment of the relative proportion of elements and the construction of nutrient element interrelation curves
 - A. Arrangement of data
 - B. Calculation of the basic ratios of elements weighted progressively toward the values of the best yields
 - C. Calculation of the relative proportion of elements
 - D. Computation of the composition of a theoretical sample
 - E. Construction of nutrient element interrelation curves
- II. Comparison of samples
 - A. Calculation of the per cent deviation of elements from the theoretical values
 - B. Computation of nutrient element index numbers
 - C. Tabulation of element index numbers according to nutrient element groups.

(Detailed description of method)

- I. Establishment of the relative proportion of elements and the construction of nutrient element interrelation curves
 - A. Arrange the data as illustrated in Tables VIII and IX
 - B. Select the highest yields and calculate the basic ratios of the elements weighted progressively toward the highest yields.
 1. The basic ratios are derived by calculating the ratio of each element to the preceding element in the general order of next lower milliequivalent value as listed in Table IX. (Table X illustrates the entire procedure.)

Table X

Calculation of element basic ratios, relative milliequivalent proportion of elements, and the composition of a theoretical sample.

Yield as tons/A.	Computation label	Element in least m.e. quantity	Ratios of elements from their milliequivalent values									
			Cu	B/Cu	Mn/B	Fe/Mn	Al/Fe	Na/Al	Mg/Na	P/Mg	K/P	Ca/K
1.58	D	.0440		.91	17.50	2.08	2.45	.98	6.62	2.66	1.34	1.32
1.62	C	.0365		1.52	7.08	1.64	1.72	3.91	6.23	2.02	.98	1.76
1.71	B	.0415		2.21	8.91	1.21	2.03	1.30	8.51	2.61	1.19	1.57
1.79	A	.0403		1.24	11.38	.98	1.99	3.91	5.29	2.10	1.22	1.57
A+B+C+D			.1623	5.88	44.87	5.91	8.19	10.10	26.65	9.39	4.73	6.22
A+B+C			.1183	4.97	27.37	3.83	5.74	9.12	20.03	6.73	3.39	4.90
A+B			.0818	3.45	20.29	2.19	4.02	5.21	13.80	4.71	2.41	3.14
w=av. of A+B+C+D			.0406	1.47	11.22	1.48	2.05	2.52	6.66	2.35	1.18	1.55
x=" " A+B+C			.0394	1.66	9.12	1.28	1.91	3.04	6.68	2.24	1.13	1.63
y=" " A+B			.0409	1.72	10.14	1.09	2.01	2.60	6.90	2.35	1.21	1.57
z=" " A			.0403	1.24	11.38	.98	1.99	3.91	5.29	2.10	1.22	1.57
w+x+y+z			.1612	6.09	41.86	4.83	7.96	12.07	25.53	9.04	4.74	6.32
av.= $\frac{w+x+y+z}{4}$.0403	1.52	10.46	1.21	1.99	3.02	6.38	2.26	1.19	1.58
Element basic ratios			Unity	1.5	10.	1.2	2.0	3.0	6.4	2.3	1.2	1.6
Element			Cu	B	Mn	Fe	Al	Na	Mg	P	K	Ca
Relative milli-equivalent proportion of elements			1	1.5	15	18	36	108	691	1589	1907	3051
Theoretical sample *			.0403	.0605	.6050	.7254	1.451	4.35	27.85	64.04	76.85	123.

*Milliequivalents of copper x relative proportion of element

This is done for the four highest yields.

To aid in clarifying the process, the samples are labeled A, B, C, D, beginning with the best yield.

2. The ratios of the four samples are weighted progressively toward the values of the highest yield. This is accomplished by taking the total of the ratios of the elements in samples A, B, C, D, of A, B, C, and of A, B. The average of each ratio of each of these groups is computed and all are combined with the corresponding ratio of sample A. The values of the highest yield then appear in the total four times, those of the next highest three times, and so forth.
3. The averages of the weighted total give weighted average ratio values which are rounded to the nearest number containing two digits. These values are the basic ratios of the elements in alfalfa occurring in the highest yields of this investigation. Considered singly, each ratio represents the relation of the two elements (I-B-1 above). The ratio value depends only upon the milliequivalent quantity of the two elements used in its calculation. These ratios taken together and listed in the order of the

increasing milliequivalent quantity of elements, as illustrated in Table X, give a coordinated pattern of plant composition as that pattern exists in the yields used in the derivation of the ratio values.

- C. Consider the ratio value of the element present in least milliequivalent quantity (copper in this data) as unity, and multiply by the basic ratio of the next element to copper (B/Cu in this instance). Multiply this product by the ratio of the next element to boron (Mn/B in this instance) and continue consecutively, multiplying the previous product by the next ratio. This procedure is continued for all ratio values and establishes the relative proportion of each element in respect to the quantity of the element present in least value (Table X, lower section).
- D. Use the weighted value of the element present in least milliequivalent quantity (copper in this data) obtained in I-B-3 above for calculating the composition of a theoretical sample. This is done by multiplying the weighted average value of copper by the relative proportion of each element in respect to copper as obtained in I-C above. This gives a "theoretical sample"

with its "composition" derived from the element interrelations existing in the plant material produced on the highest yielding plots. The nutrient equilibrium of this theoretical sample reflects the influence of the nutrient balance of each of the four highest yields.

- E. Plot on log-log paper, one sample per section, the milliequivalent values of the elements in each sample against the relative proportion of elements obtained in I-C. On the same section with each sample, plot the computed milliequivalent values of the elements in the theoretical sample. This gives a graphic presentation of the interrelation and balance of the elements in each sample with respect to the theoretical linear interrelation established from the best yields (Charts II and III).

II. Comparison of samples and calculation of element interrelations. (The use of algebraic signs is necessary in all computations described in this division.)

- A. Subtract algebraically the theoretical milliequivalent value of each element from the actual value of that element in each sample. This difference is the deviation from the theoretical. (The algebraic sign is important at this point.) A plus sign indicates that the actual value is

the sample is larger, and a minus sign, that it is smaller than the theoretical value (Table XI-A). Using these values calculate the per cent deviation from the theoretical and give to the result the same sign as the deviation (Table XI-A). This computation applies to each element a value commensurate to all elements. It indicates the degree and the direction of the change in concentration of each element in respect to the position of that element in the nutrient equilibrium of the theoretical sample.

- B. The per cent deviation (obtained in Section II-A and Table XI-A) of the elements in each alfalfa sample are compared with the per cent deviations of the elements of the best yield. This is done by algebraic subtraction of the latter values from the former, and gives values that will be referred to as nutrient element index numbers (Table XI-B). This comparison shows the order of change of the concentration of elements in lower yielding material in respect to the change in concentration of elements in higher yielding material. The departure of the elements in the best

yielding material from the theoretical value indicates the direction and degree an element could change and still produce a good yield. It follows, then, if an element in another sample has a greater digression in a given direction, it has varied too much and is deficient or excess with respect to a desirable equilibrium; if its divergence is not so great, the deficiency or excess of the element is correspondingly less. This comparison provides a basis for measuring the degree of deviation of the concentration of each element in all samples from a desirable equilibrium as expressed by the composition of the best yielding material.

- C. The algebraic differences computed in II-B, i.e., the nutrient element index numbers, indicate the interrelation of element concentrations within a given alfalfa sample. To aid in comprehending the significance of their interplay, the elements under consideration are divided into three groups and the index numbers are tabulated accordingly.

TABLE XI - C

Index numbers and element groups

Plot:Yield :		Element groups												
No.	:as tons:	Metal group Y					:Non-metal group:			Metal group Z				
		:/A.	:Cu:Mn	:Fe:Al	:Total:	:P :B :Total	:Na	:Mg:	K	:Ca:	Total			
1	: 1.10	:+5:-27	:+7:-3	: -18	:+8:+2:+10	: -20:0	:+27:-3	:+4						
		:	:	:	:	:	:	:	:	:	:	:	:	:

The non-metals, boron and phosphorus, are referred to by Beckenbach (3) as buffer constituents. Observation of their behavior in this data indicates that their absorption may be related to the absorption of various metal elements. Because of this seeming "pivotal" position in respect to the metals, boron and phosphorus as a non-metal group are placed between two metal groups. Copper, manganese, iron, and aluminum are grouped together, while sodium, magnesium, potassium, and calcium form another metal group. The metals seem to fall naturally in this order with respect to relative concentration and plant absorption variations. Charts II and III indicate that a rather definite "break" or dividing point exists in the portion of the element interrelation curves joining aluminum with sodium. Certain chemical properties such as ionic strength may also be considered in establishing the metal groupings. Cooper (9) places magnesium with the weaker elements. In this alfalfa investigation, however, because of the similar absorption

pattern of magnesium and calcium, it seems logical for purposes of using the index numbers to place these two elements in the same group.

THE USE OF THE NUTRIENT ELEMENT INDEX NUMBERS FOR THE
INTERPRETATION OF ELEMENT INTERRELATIONS.

The nutrient element index numbers of the 1947 alfalfa samples, calculated as described above, are tabulated in Table XII. This tabulation provides a tool for observing many relations existing within the nutrition equilibrium system of the plant as revealed by the element composition of the different samples. The relative quantity of each element in respect to the composition of the best yield is indicated by the index number. Consequently the interrelation of changes in the concentration of elements from sample to sample is automatically indicated. This tabulation provides a definite and concise means of comparing the nutrient level of one sample with another. In conjunction with this table, nutrient element interrelations may also be studied in Charts II and III.

Observation of the data shows that in many samples concomitant and substitution tendencies of internal nutrient concentrations occur. This is especially noticeable when the behavior of element group Y is compared with that of Z. In many instances the non-metal group increases simultaneously with group Y. This is in agreement with Beckenbach (3) working with tomatoes: "...the phosphate and borate ions may function interchangeably as essential

TABLE XII

Distinctive features of treatments, yield and nutrient element interrelations of the 1947 alfalfa samples.

Distinctive features of treatment	Plot No.	Yield as tons /A.	Nutrient element groups and index numbers												
			Metal Group Y					Non-metal Group			Metal Group Z				
			Cu	Mn	Fe	Al	Total	P	B	Total	Na	Mg	K	Ca	Total
High K Mixture	55	.80	+19	+32	+123	+223	+397	+21	+9	+30	-10	+1	+6	+5	+2
High K	31	.83	-13	-23	-27	-38	-101	-2	+1	-1	-39	-21	+23	-29	-66
High K	54	.86	+166	+14	+215	+443	+838	+36	-9	+25	-45	-8	-8	-6	-67
High K	32	.91	+3	+4	+6	+6	+19	+3	+59	+62	-25	-5	+19	-2	-13
Low B															
Low K	17	.92	-6	-24	+15	+6	-9	+8	-23	-15	+5	+6	-2	-12	-3
Extra High K	24	1.01	+167	+3	+660	+603	+1433	+51	+359	+410	-41	-30	-6	-32	-109
Extra High B															
High K	34	1.06	-13	+3	-25	-43	-78	-3	+53	+50	-45	-17	+33	-17	-46
Low B Mixture															
High K	33	1.08	+5	+22	-18	-30	-21	+8	+59	+67	-25	-17	+36	-21	-27
High B															
High K	1	1.10	+5	-27	+7	-3	-18	+8	+2	+10	-20	0	+27	-3	+4
High N															
Low K	23	1.10	-15	-26	+18	+72	+49	+8	+150	+158	+30	-8	-2	-6	+14
Extra High B															
High K	38	1.13	0	+23	-21	-24	-22	+13	+83	+96	0	+7	-9	+5	+3
High N															
High K	35	1.16	0	+3	+17	+21	+41	+21	+71	+92	+2	-8	+26	-2	+18
Mixture															
High K	47	1.16	-20	-18	-13	-30	-81	-5	+7	+2	-25	-28	+19	-17	-51
High B															
Low K	4	1.18	-13	-19	+21	+12	+1	-7	-32	-39	-32	+7	-14	-3	-42
Low N															
Low K	8	1.19	-20	-40	+41	+56	+37	+45	+181	+226	+34	-5	+53	-3	+79
Extra High B															
High K	16	1.21	-25	-21	+27	-4	-23	+11	+22	+33	+9	0	-2	-9	-2
High N															
High K	40	1.25	+5	+2	+5	+15	+27	+8	+50	+58	-32	-17	+29	-11	-31
High N															
Mixture															
Extra High K	9	1.27	-15	-29	-10	-34	-88	+3	+127	+130	-41	-25	+33	-30	-63
Extra High B															

Continued on next page

TABLE XII (Continued)

Distinctive features of treatment	Plot No.	Yield as tons /A.	Nutrient element groups and index numbers												
			Metal Group Y					Non-metal				Metal Group Z			
			Cu	Mn	Fe	Al	Total	P	B	Total Na	Mg	K	Ca	Total	
Extra High K	50	1.27	-12	-9	-2	+15	-8	+3	+45	+48	-3	-33	+33	-29	-32
Extra High Mix.															
High K	52	1.32	+145	+22	+379	+623	+1169	+51	+45	+96	-7	-8	-14	-9	-38
High B															
Extra High K	3	1.40	-27	-43	-15	-36	-121	-12	-3	-15	-45	-33	+25	-27	-80
Extra High K	18	1.43	-8	-29	+81	+84	+128	+20	+19	+39	-32	-5	+49	+1	+13
High K	45	1.44	+5	-9	+18	+46	+60	+11	+17	+28	-20	-8	+19	+21	+12
Mixture															
High K	53	1.47	+10	-19	+8	+61	+60	+16	+40	+56	0	-3	+17	0	+14
Low B															
Low K	14	1.48	-8	-36	+5	-11	-50	-6	+76	+70	0	0	-11	-19	-30
Extra High Mix.															
High K	58	1.48	+167	+32	+438	+644	+1281	+69	+6	+75	-7	-8	-11	-16	-42
Low B															
Mixture															
High K	49	1.58	+10	+23	+123	+164	+320	+20	-17	+3	-20	0	+30	+13	+23
Low K	2	1.62	-8	-27	+12	0	-23	+11	+9	+20	0	+14	-7	+1	+8
High K	46	1.71	+5	+41	+59	+60	+165	+16	+67	+83	-41	-3	+13	+13	-18
Low B															
Mixture															
High K	48	1.79													
Low B															

(Highest Yield)

juice buffers, or in precipitating out excess cations which form relatively insoluble salts with these ions, or in both of these functions." Attention should be directed particularly to the action of phosphorus, iron, and aluminum in this respect. (See Table XII for yields: .80, .86, 1.01, 1.32, and 1.48 - plot 58). (Yield values are used to denote samples since the data are tabulated according to increasing yield for evaluation purposes. When reference is made to two samples having the same yield, the plot number is given also). The samples from the plots receiving the extra high boron applications are interesting because of the interplay of elements in establishing different nutrient equilibrium systems under the stress of the same dominant treatment. (See Table XII for yields: 1.01, 1.10 - plot 23, 1.19, and 1.27.) A comparison of the total of the index numbers of the respective element groups reveals in yield 1.01 a tendency to balance high boron uptake with high copper, iron, and aluminum, while group Z elements are all relatively low. Yields 1.10 (plot 23) and 1.19 show the opposite tendency, i. e., high boron is balanced by an increase of the group Z elements, particularly sodium in the first instance and sodium and potassium in the second. Yield 1.27 is unique in that it is the highest yield of the four under consideration, and yet the metals (groups Y and Z) are low. In contrast to the other samples, however, potassium is much higher in relation to the other group

Z metals. The yield response, then, must be due to this relative increase in the potassium level and the reduced boron as shown by an index number of +127, the lowest of the four samples receiving the extra high boron application. This discussion serves to illustrate the effectiveness of the index numbers in revealing element interrelations and differences in internal nutrient equilibrium systems. All the samples, either as individual instances or as groups, offer potential studies relating various trends of element concentrations to yield and treatment. In general the variability of the data of Table XII in respect to yield demonstrates the significance of the statement of Shear, Crane, and Myers (22b): "Maximum growth and yield occur only upon the coincidence of optimum intensity and balance."

The data of this investigation further indicate, because of the complexity in respect to both yield and treatment, that a factor in addition to internal nutrient concentration is involved. Goodall and Gregory (11f) emphasize that there are at least two major relations in correlating yield with treatment: (1) nutrient supply and uptake, and (2) nutrient concentration within the plant. This study deals primarily with the latter relation as it is affected by variations in the former. It is generally recognized that the results of field plot experiments are subject to certain variations that are not encountered

in rigidly controlled studies. There may be soil differences affecting availability of nutrients applied in fertilizers; soils may sometimes supply additional quantities of the same nutrients as the fertilizers as well as other nutrients not contained in the fertilizers. These and other causes of variation not considered in this work may account for the seeming lack of correlation of yield with treatment noted in Table XII, and also to some extent for the complex relations of nutrient element balance. Under these conditions a general summary of the data of Table XII proves more helpful than sample-to-sample evaluation in getting a complete picture of the nutrient element requirements of alfalfa and the possible correlation of different nutrient equilibrium systems with yield and treatment.

For summarizing purposes, the samples listed in Table XII are divided into five groups on the basis of yield. A range of .20 tons per acre in yield is permitted in choosing the samples included in each group. The averages of the data of Table XII, compiled in Table XIII, show trends which become more significant when considered against the background of the relative quantity of elements added to the soil. Table XIV illustrates the method of translating the pounds of fertilizers into the relative quantity of nutrient elements in respect to yield groups. Correlating the data of Tables XIII and XIV discloses these tendencies: (1) phosphorus absorption remains relatively constant; (2) the increase of boron and potassium absorption is in general

TABLE XIII.

Summary of Nutrient Element Index Numbers, 1947 Samples.

Yield group*	Plot Nos.	Av. yield	Nutrient element groups and index number averages													
			Metal Group Y					Non-metal Group			Metal Group Z					
		tons	Cu	Mn	Fe	Al	Total	P	B	Total	Na	Mg	K	Ca	Total	
		/A.														
E	:55,31,54 :32,17	:.87	:+34.	:+.6	:+66.	:+128.	:+229.	:+13.	:+7.4	:+20.	:-23.	:-5.4	:+8.	:-9.	:-29.	
D	:24,34,33 :1,23,38 :35,47,4, :8,16	:1.13	:+6.5	:-9.	:+65.	:+57.	:+120.	:+14.	:+87.	:+101.	:-10.	:-9.	:+15.	:-10.	:-14.	
C	:40,9,30 :52	:1.28	:+31.	:-3.5	:+95.	:+155.	:+275.	:+16.	:+67.	:+83.	:-20.	:-20.	:+20.	:-20.	:-40.	
B	:3,18,45 :53,14,58	:1.45	:+23.	:-17.	:+89.	:+131.	:+226.	:+16.	:+26.	:+42.	:-17.	:-10.	:+15.	:-7.	:-19.	
A	:49,2, :46**	:1.64	:+2.	:+12.	:+65.	:+41.	:+120.	:+15.	:+20.	:+35.	:-20.	:+4.	:+12.	:+9.	:+4.	

*Each yield includes a range of .20 tons per acre.

**Sample, 48, the highest yield, is not included since it was used as the basis of comparison in computing the index numbers.

TABLE XIV

Relative quantities of elements * added to plots
in respect to yield groups.

Yield group and total no. of plots in group (From Table XIII)	Elements applied in variable quantities in fertilizers														
	B			K			P			Mixture			N		
	No. of plots in group receiv- ing the level of ferti- lizer indicated by symbol	% of plots in group receiv- ing the level indi- cated	Rela- tive quan- tity of nutri- ent	No. of plots in group receiv- ing the level of ferti- lizer indicated by symbol	% of plots in group receiv- ing the level indi- cated	Rela- tive quan- tity of nutri- ent	No. of plots in group receiv- ing the level of ferti- lizer indicated by symbol	% of plots in group receiv- ing the level indi- cated	Rela- tive quan- tity of nutri- ent	No. of plots in group receiv- ing the level of ferti- lizer indicated by symbol	% of plots in group receiv- ing the level indi- cated	Rela- tive quan- tity of nutri- ent	No. of plots in group receiv- ing the level of ferti- lizer indicated by symbol	% of plots in group receiv- ing the level indi- cated	Rela- tive quan- tity of nutri- ent
E, 5	1, L	20	low	4, H 1, L	80 20	low medium	1, H 4, L	20 80	low	1, L	20	low	-	-	-
D, 11	3, EH 2, H 1, L	27 18 9	extra high	1, EH 5, H 5, L	9 64 27	high medium	4, H 2, M 5, L	36 18 46	high medium	2, L	18	extra low	3, H 1, L	27 9	High
C, 4	1, EH 1, H	25 25	high	2, EH 2, H	50 50	extra high	2, H 2, L	50 50	high	1, EH 1, L	25 25	extra high	1, H	25	me- dium
B, 6	2, L	33	me- dium	2, EH 3, H 1, L	33 50 17	high	3, H 3, L	50 50	high	1, EH 2, L	17 33	high	-	-	-
A, 3	1, L	33	me- dium	2, H 1, L	67 33	low	1, H 2, L	33 67	low medium	1, L	33	me- dium	1, L	33	low

* Refer to Table II for treatments

** Symbols represent total pounds fertilizer applied per acre during the period, 1942-1946.

Potassium

EH = 1000 lbs. 0-10-20 + 1600 lb. KCl/A.
H = 1500 " 0-10-20, or
1500 " 5-10-20, /A.
L = 1000 " 5-10-20, or
1000 " 0-12-12+160 lb. KCl/A., or
1000 " 2-12-12+160 " " "

Phosphorus

H = 1000 lbs. 0-10-20 + 2000 lb. superphosphate/A., or
1000 " 0-12-12-2000 " " "
1000 " 5-10-20 + 2000 " " "
M = 1000 " 0-12-12, or
1000 " 2-12-12/A.
L = 1500 " 0-10-20, or
1500 " 5-10-20/A.

Boron

EH = 320 lbs. borax/A.
H = 100 " " "
L = 25 " " "

Mixture

EH = 320 lbs. minor element mixture/A.
L = 100 " " " " "

Nitrogen

H = 1000 lbs. 5-10-20, or
1500 " 5-10-20/A.
L = 1000 " 2-12-12/A.

in proportion to the additions of these elements to the soil; (3) fluctuations of sodium absorption are small, the greatest increase in sodium content occurring with the extra high boron application; (4) manganese variations show no apparent relation to yield, to application of minor elements, or to the degree of absorption of other elements under study, with the possible exception of sodium. Although manganese fluctuations are in general more marked, they are in opposition to sodium.

If yield response to boron absorption and application is thought of as a main premise in evaluating the data of Tables XIII and XIV, a number of interesting trends in respect to element interrelations and yield are noted. Consider first the relation of potassium absorption to the relative quantities of potassium additions and boron absorption. Potassium uptake follows the same order as potassium additions with the exception of yield groups A and E. (Yield groups in Tables XIII and XIV are designated by letters.) Group E absorbs less potassium than group A, yet a higher quantity was applied to E. Comparing this with the boron relations, it is observed that boron absorption is lower in group E than in A. The higher absorption of boron in group A must have enabled the plant to obtain a greater quantity of potassium from a smaller supply (19). Calcium and magnesium uptake bear the same relation to each other in all yields.

Considering these elements in relation to boron absorption, it is seen that a somewhat increased calcium and magnesium uptake occurs at the low boron level. This tendency is most pronounced in groups E and A. In A, B, and C, where boron is gradually increasing, while yields are gradually decreasing, calcium and magnesium show a constant decrease (19). Copper, iron, and aluminum show gradual increases in absorption with decrease in yield in groups A, B, C; that is, they increase with boron increase. The behavior of these elements is unique when yields D and E are observed in regard to boron absorption. The high boron content of yield D apparently unbalanced the nutrient equilibrium resulting in a lower uptake of copper, iron, and aluminum and a slight increase in calcium and magnesium. In yield E, representing the opposite extreme of boron absorption (i. e., a low absorption) copper, iron, and aluminum are again high (19). The uptake of these elements is apparently more closely related to boron absorption than to the applications of the minor element mixture.

The overall picture of Table XIII indicates that yields A, B, C are fairly well balanced in respect to the variations of copper, iron, aluminum, and boron and that yield decrease is uniform with calcium and magnesium decrease. It must be noted here, however, that potassium uptake shows a gradual increase in these samples. In this instance, then, it is probable that the calcium and magnesium decrease is due to

increased boron and potassium (19), (2) and that the lower yields are symptoms of boron and potassium excess absorption in relation to the deficient absorption of calcium and magnesium (23). It would be interesting to learn whether under the nutrient equilibrium represented by these samples, if increasing the supply of calcium and magnesium would overcome the deficiency of these elements (in groups B and C as compared to A) apparently caused by the high boron and potassium uptake.

Doubtless yield D is low because of the unbalanced nutrient equilibrium resulting from high boron and lower potassium applications. Evidently the boron absorption is too large for the quantities of copper, iron, and aluminum. It must be noted in this connection that the application of minor elements is low. At the same time that boron uptake has increased, potassium has slightly decreased from its value in yield C due to a lower application to the soil as well as to increased boron absorption (19). This reduced absorption of potassium apparently results in increased uptake of calcium, magnesium (2), and sodium. Parks (19) working with tomatoes, found that increasing the absorption of boron decreased the absorption of calcium and magnesium. Under the conditions of this alfalfa study where in this instance, two variable nutrients, boron and potassium, are exerting influence upon the equilibrium system, that of potassium is apparently dominant over boron in respect to calcium and

magnesium uptake. This behavior of calcium and magnesium is opposite to that sometimes encountered when boron is the only variant in the equilibrium system. Comparing yield groups B and D, where the metal group Z elements are at approximately the same level (i. e., -19 and -14, respectively) the chief difference in the two nutrient equilibrium systems is the unbalance of boron with the metal group Y elements. This situation results in a yield decrease of one-third ton per acre. Yield group E represents the reverse situation in comparison with D; boron absorption is low while that of metal group Y elements is high. Simultaneously with this relation the elements of metal group Z decrease as a group, although calcium and magnesium increase slightly because of the decrease of sodium and potassium (2). The result of this equilibrium is the lowest yield of the five groups and occurs with a low boron and a low medium potassium application. The decrease in boron, sodium, and potassium uptake most certainly reflects the smaller quantity of borax- and potassium-carrying fertilizers supplied to the soil.

Further comment should be made on the implications of the behavior of phosphorus. While phosphorus absorption remains comparatively constant, the slight variations are all the more significant since they agree almost perfectly with the variations in the supply. This indicates that under the conditions of this experiment the effect of other elements on phosphorus uptake in general is not dominant

over its supply. It also verifies the precision of the spectrochemical technique and the accuracy of the method of evaluating data.

Tables XIII and XIV further emphasize the effectiveness of the index numbers in studying nutrient element interrelations. Originating as per cent values (Sections II-A and II-B above) these numbers show the relative magnitude of changes of the elements occurring from one equilibrium system to another. (An instance is the behavior of manganese and sodium.) Consequently the influence the degree of absorption of one element may have upon the uptake of another is indicated by comparing the difference in the changes of the two elements. To illustrate: yield groups A and E show that potassium is four units higher in A than in E, even though the potassium supplied to the soil is smaller. This behavior (noted above as the same as that observed by Parks (19) is accredited to the influence of increased boron uptake due to a greater supply of boron in the soil. The index numbers show, however, that to cause an increase of four units in potassium uptake the boron absorption increased thirteen units. Likewise, comparing yield C with D, it is observed that a decrease of five units of potassium results (according to the hypothesis of Bear, et al (2)) in an increase of ten and eleven units of calcium and magnesium, respectively. These examples seem to indicate that using the system of index numbers for determining element interrelations

affords a method of observing the efficiency of different elements in influencing the absorption of other elements and in controlling the growth of plants. Further information of this nature when obtained will doubtless permit more efficient use of commercial fertilizers and lime than is now possible.

Considering the fertilizer applications outlined in Tables XIII and XIV, it is significant that the yield response is generally - with the exception of the lowest supply - in reverse order to the increase of the mineral element supply and in agreement with the degree of unbalance of the equilibrium systems. This is also true of nitrogen applications. The data demonstrate that the most desirable supply is in the medium range used in this experiment. It is of no little consequence that the best yields of the experiment were produced by samples showing the least overall element deviation from the theoretical milliequivalent values of the elements as established by the basic ratios, that the method of data evaluation is capable of measuring the relative magnitude of element absorption, and that the efficiency of elements in controlling the absorption of other elements and affecting yield is indicated. This demonstrates that the application of the element basic ratio principle to plant composition studies should indicate the need of the crop for various nutrients and could possibly be used as a guide for more efficient use of fertilizers and lime when correlated with soil composition and element availability.

SUMMARY

Alfalfa samples from differently fertilized field plots on Glenelg soil were analyzed spectrochemically to determine the detectable elements and to measure the quantity of the major and of some minor elements. Variations in yield, resulting from different nutrient levels in the soil, were correlated with fertilizer treatments, mineral element composition, pounds of nutrients removed per acre, and element interrelations within the plant. A detailed description of the formulation of an element basic ratio method and its application in evaluating plant composition data for the determination and interpretation of element interrelations is given.

The data indicate several significant features:

- (1) when lime and fertilizers are applied to alfalfa sod, at least a year is required for nutrients to influence the growth of five-year-old plants;
- (2) hay produced at a higher level of nutrient supply contains more minerals per ton than hay produced at a lower level of nutrient supply;
- (3) tripling the yield of alfalfa quadruples the removal of plant nutrients from the soil;
- (4) comparison of individual alfalfa samples shows a wide variation in composition;
- (5) the average of all samples collected in two different years and analyzed for the

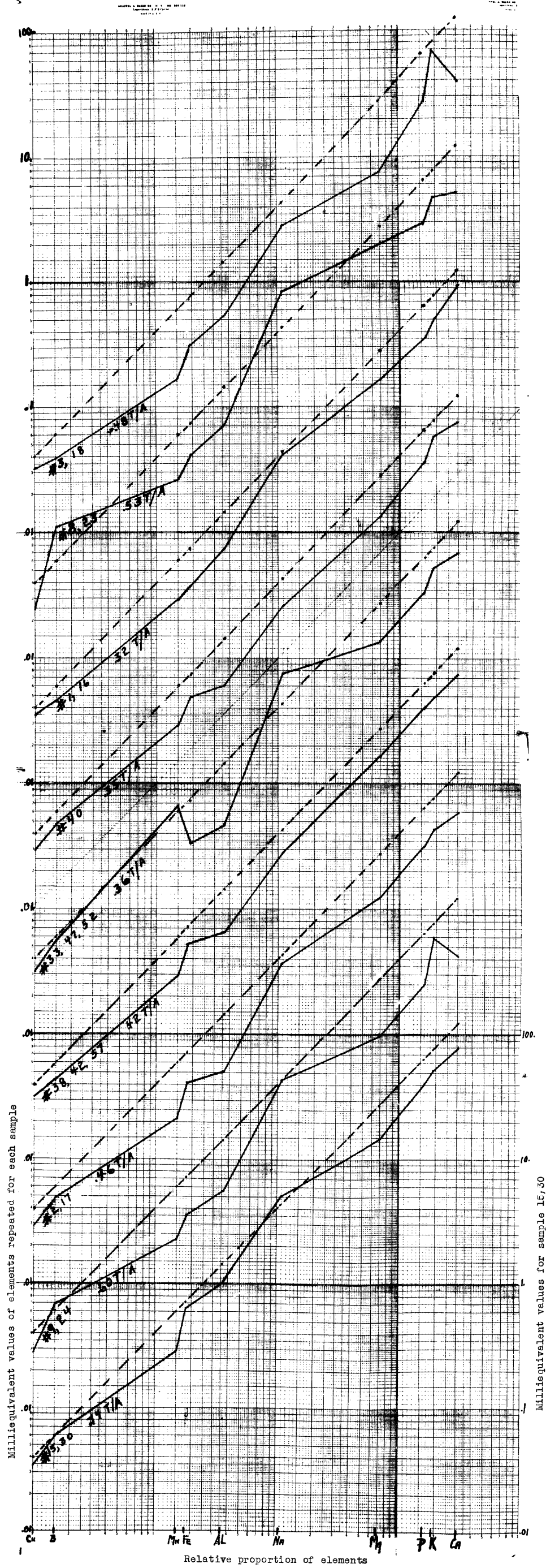
content of ten elements indicates that the variation in total milliequivalent composition is no greater than ± 33 per cent.

An arrangement of the ten elements studied in this investigation revealed a general pattern of element composition. The disclosure of a logarithmic relation resulted in the expression of alfalfa composition by element basic ratios. Using these ratios, curves were constructed and element index numbers were derived that show nutrient element interrelations. Elements were grouped as metals and non-metals according to their plant absorption characteristics and different plant nutrient element equilibrium systems were compared. Correlations with yield and fertilizer treatments showed that an increasing degree of unbalance in the equilibrium system resulted in decreased yield and that the influence on plant growth of increasing applications of fertilizers was subordinate to the influence of the equilibrium system.

A summary of element interrelations indicated that under the conditions of this experiment, phosphorus remained relatively constant; manganese uptake was in general in opposition to that of sodium; boron and potassium absorption was in proportion to the additions of these elements to the soil, or in relation to their interaction within the nutrient equilibrium system of the plant, and that the interaction of these two principal variants with other elements resulted in the differential absorption of calcium, magnesium, sodium,

aluminum, iron, and copper.

This investigation demonstrates: (1) that the spectrochemical technique can be used as an analytical tool in plant nutrition studies; (2) that the best yields of alfalfa are produced when the nutrient equilibrium system of the plant approaches that expressed by the basic ratios of the elements; (3) that the use of element index numbers for evaluating the magnitude of the effect of one element on the absorption of another promises to indicate the correct nutrient balance necessary for efficient and economical use of fertilizers and lime; (4) that notwithstanding wide variations in nutrient element absorption, there is a general pattern of nutrient requirement for the best growth of alfalfa.



Logarithmic plotting of milliequivalent values against the relative proportion of elements, 1946 composite samples.

(Broken line represents the weighted average of the four highest 1947 yields. Solid line represents individual samples).

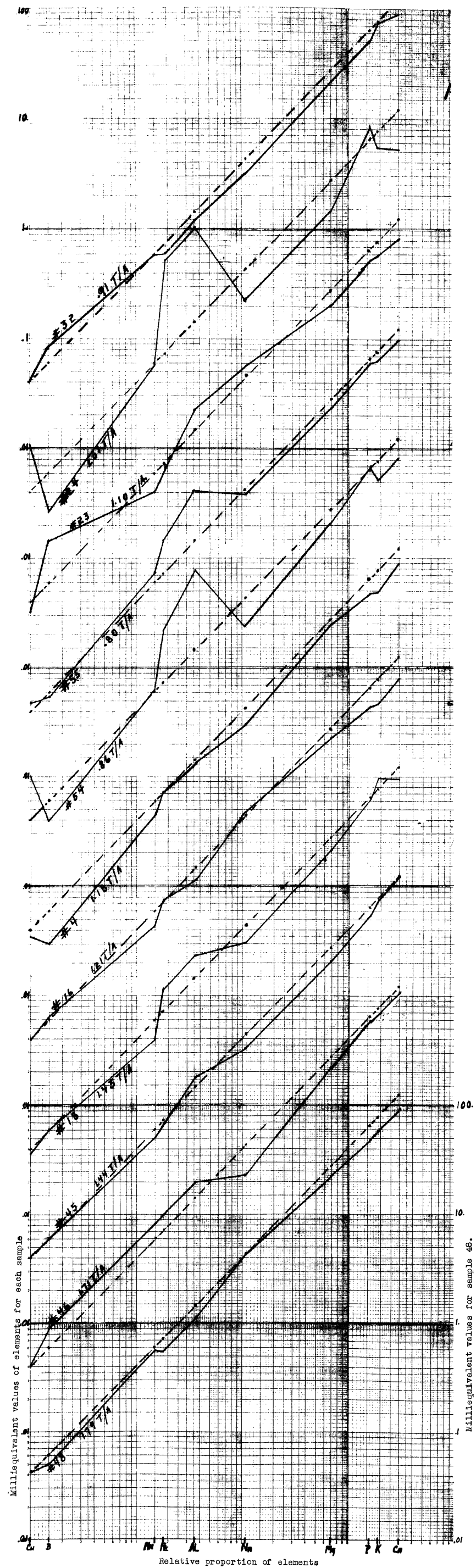


CHART III

Logarithmic plotting of milliequivalent values against the relative proportion of elements, 1947 samples.

(Broken line represents the weighted average of the four highest yields. Solid line represents individual samples).

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