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A STUDY OF THE RELATION BETWEEN THE SUPPLY OF POTASSIUM AND OTHER NUTRIENT ELEMENTS IN SEVERAL MICHIGAN SOIL TYPES AND THE GROWTH OF ALFALFA AND FIELD BEANS

by

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INTRODUCTION

The fact that some Michigan soils are deficient in soil potassium for good legume growth has been partially demonstrated in previous years by fertilizer field trials, greenhouse pot experiments, plant tissue tests, and soil analyses. A more complete investigation was needed, however, to test the validity of the hypothesis that the cause of many low yields and crop failures of alfalfa and other legumes is due to a lack of available potassium.

The importance of potassium in the nutrition of alfalfa and clovers has been indicated by the work of many investigators, including Ames and Boltz (2), Blair and Prince (5), Cook and Millar (10), Donaldson (11), Gustafson (13), Hunter, Toth, and Bear (15), Prince (27), and Weathers (34). Experimental work in Michigan by Cook (8) and Millar (21) has shown that for good legume growth, sandy soils need fertilizers having P:K ratios of 1:1, 1:2, or 1:3, while phosphate alone or fertilizers containing phosphorus and potash in the ratio of 2 to 1 on the heavier loams and silt loams has proved most beneficial. The present fertilizer recommendation (10) for the better sandy loams where seedings may be made with or without a nurse crop is the use of 300 to 400 pounds per acre of 0-12-12. Fertilizer having the ratio 0-9-27 is advised for lighter soils where seedings should be made without a nurse crop. Top dressing of alfalfa stands on sandy soils with 0-12-12 or 0-9-27 has been found to be profitable after the first cutting of the second harvest year, provided fertilizer was applied at seeding time. Subsequent applications may be made every two years for the duration of the stand.

Since the use of field plat trials in experimental work covering a large number of soil areas is both slow and expensive, correlation is needed between soil properties and crop growth. Once information has been established concerning the growth of legumes and such factors as the supply of available soil potassium and calcium, better interpretation can be made of farmers' problems of legume failures, and sounder recommendations can be given in part on a soil type basis for possible correction and solution. Such relationships can be obtained in one way by sampling many problem areas and making intensive greenhouse and laboratory tests on both soils and plants.

The object of this investigation was to determine the supply of available potassium and the soil factors influencing the supply in some Michigan soil types, and to compare the legume growth with the soil properties of samples taken from those soils. The study has been divided into four sections.

1. The collection and analysis of soil and plant samples from good and poor alfalfa fields in western Michigan.
2. Greenhouse pot tests on the growth of alfalfa under controlled nutrient and moisture supply, using soils from known field locations.
3. Investigation of the relation between available soil potassium and the chemical composition of field beans grown in eastern Michigan.
4. The influence of cropping and fertilization on the potassium equilibrium in some major Michigan soil types.

SECTION I. SOIL AND PLANT ANALYSIS

In previous years, many reports have come from farmers in western Michigan to county agricultural agents and soils extension specialists indicating difficulty in growing and maintaining alfalfa and clovers. This area includes the sandy soils extending from the Straits of Mackinac to the southern boundary of the state. In some cases no benefits were reported from the use of lime and fertilizer. The fact that the content of minor elements as well as available potassium tends to be rather low in sandy soil and the degree of leaching high, might be a partial cause for the unsatisfactory growth of legumes. An adequate supply of calcium is of course a prerequisite for a legume program, but it is also possible that overliming of such soils would make boron, manganese, zinc, copper, and cobalt unavailable to plants.

Since legumes are extremely important in the crop rotation on the lighter soils as soil building crops in supplying organic matter and nitrogen, and in the production of hay and pasture, the problem of the establishment and maintenance of alfalfa and clover stands is an important one.

Methods of Sampling

In the summer of 1940 and 1942 soils were collected from farms in St. Joseph, Cass, Kalamazoo, Van Buren, Manistee, Benzie, Antrim, Kalkaska, and Grand Traverse counties for chemical analysis and greenhouse investigation. The fields selected for study were located in general through the cooperation of the county agents. Samples of soil were taken from fields having high yielding alfalfa stands and from fields where the stand was poor or had failed to catch or to produce good crops of alfalfa. An attempt was made to obtain these soils from good and poor fields on the same soil type and from the same farm. In most cases it was necessary to obtain samples of a soil type from several different farms. Criteria for evaluating good and poor alfalfa growth were visual appearance and farmers' reports on the yield. A record of the past history of the field selected was obtained from the farmer. This report included the number of times alfalfa had been grown previously on the area, the duration of each stand, and the condition of each seeding and stand. The time, rate, and kind of fertilizing, manuring, and liming were also considered in the general crop rotation.

For chemical analysis, two or three sets of profile soil samples were taken at random in each field. Samples were generally obtained to a depth of about three feet. Care was taken to avoid low wet areas and high droughty knolls where conditions for alfalfa growth were not consistent with those of the general section of the field. The samples were air dried and sieved through a two millimeter screen. The percentage of soil in the sample passing the screen was calculated and the soil then stored in glass containers.

The soil types collected, their series number and location, the condition of the alfalfa stand, and the study or studies for which the soils were used are given in Table 1.

Table 1. The soil types, their series number, the location of sampling, the condition of the stand or field, and the study or studies for which these soils were used

Series number	Soil type	Location	Condition of stand or field	Study
1	Plainfield sandy loam	C. Holtom St. Joseph Co. NE¼, Sec. 22 T6S R11W	Good alfalfa	Laboratory
2	Plainfield sandy loam	H.O. Berkhold St. Joseph Co. NE¼ Sec. 28 T6S R11W	Poor alfalfa	Laboratory
3	Plainfield loamy sand	R. Samson Van Buren Co. NW¼ Sec. 13 T3S R13W	Poor alfalfa	Laboratory and greenhouse
4	Fox sandy loam	D. Dermott St. Joseph Co. SW¼ Sec. 12 T7S R12W	Good alfalfa	Laboratory
5	Fox sandy loam	E.P. Wolf St. Joseph Co. NE¼ Sec. 13 T8S R11W	Fair to good alfalfa	Laboratory and greenhouse
6	Fox sandy loam	E.P. Wolf St. Joseph Co. NE¼ Sec. 13 T8S R11W	Poor alfalfa	Laboratory and greenhouse
7	Fox sandy loam	E.P. Wolf St. Joseph Co. SE¼ Sec. 12 T8S R11W	Poor alfalfa	Laboratory and greenhouse
8	Fox sandy loam	A. Huff St. Joseph Co. SW¼ Sec. 12 T8S R11W	Good alfalfa	Laboratory
9	Fox sandy loam	G. Swift Cass Co. SE¼ Sec. 30 T6S R16W	Poor alfalfa	Laboratory

Table 1. (continued)

Series number	Soil type	Location	Condition of stand or field	Study
10	Fox fine sandy loam	A. Nower Van Buren Co. NW¼ Sec. 25 T3S R15W	Good alfalfa	Laboratory and greenhouse
11	Fox sandy loam	A. Nower Van Buren Co. SW¼ Sec. 25 T3S R15W	Poor alfalfa	Laboratory and greenhouse
12	Fox loam	J. Woodman Van Buren Co. SW¼ Sec. 20 T3S R14W	Good alfalfa	Laboratory and greenhouse
13	Fox loam	C. Billsborrow Van Buren Co. NW¼ Sec. 5 T3S R13W	Fair alfalfa	Laboratory
14	Fox silt loam	H. Lurkins Van Buren Co. SW¼ Sec. 29 T3S R14W	Good alfalfa	Laboratory
15	Coloma sandy loam	W.A. Cook St. Joseph Co. NE¼ Sec. 36 T7S R11W	Good alfalfa	Laboratory
16	Coloma sandy loam	W.A. Cook St. Joseph Co. NE¼ Sec. 36 T7S R11W	Poor alfalfa	Laboratory
17	Coloma sandy loam	B. Fee Kalamazoo Co. SE¼ Sec. 6 T3S R12W	Fair alfalfa	Laboratory
18	Bellefontaine sandy loam	L. Huff Cass Co. SE¼ Sec. 27 T6S R15W	Good alfalfa	Laboratory
19	Bellefontaine sandy loam	M. Whipple Kalamazoo Co. NE¼ Sec. 27 T1S R9W	Poor alfalfa	Laboratory

Table 1. (continued)

Series number	Soil type	Location	Condition of stand or field	Study
20	Bellefontaine sandy loam	L. Cronkite Kalamazoo Co. SE¼ Sec. 20 T1S R11W	Poor alfalfa	Laboratory
21	Warsaw loam	H. Stears St. Joseph Co. SW¼ Sec. 29 T7S R11W	Poor alfalfa	Laboratory and greenhouse
22	Warsaw loam	H. Stears St. Joseph Co. SW¼ Sec. 32 T7S R11W	Good alfalfa	Laboratory and greenhouse
23	Warsaw sandy loam	W. Bingham Kalamazoo Co. SW¼ Sec. 25 T3S R12W	Poor alfalfa	Laboratory
24	Emmet loamy sand	L. Lutz Manistee Co. SW¼ Sec. 26 T23N R15W	Poor alfalfa	Greenhouse
25	Emmet sandy loam	W. Lindeman Manistee Co. NW¼ Sec. 17 T23N R15W	Fair alfalfa	Laboratory and greenhouse
26	Emmet sandy loam	A.J. White Benzie Co. NW¼ Sec. 15 T27N R13W	Good alfalfa	Laboratory and greenhouse
27	Emmet sandy loam	F. Armstrong Kalkaska Co. SW¼ Sec. 8 T27N R6W	Fair alfalfa	Laboratory and greenhouse
28	Emmet sandy loam	R. Brown Kalkaska Co. SW¼ Sec. 18	Fair alfalfa	Greenhouse
29	Kalkaska loamy sand	F. Wakley Benzie Co. SW¼ Sec. 27 T27N R6W	Poor alfalfa	Laboratory and greenhouse

Table 1. (continued)

Series number	Soil type	Location	Condition of stand or field	Study
30	Kalkaska sandy loam	C. Brown Kalkaska Co. NW$\frac{1}{4}$ Sec. 4 T27N R6W	Poor alfalfa	Laboratory and greenhouse
31	Mancelona sandy gravelly loam	K. Derror Antrim Co. NE$\frac{1}{4}$ Sec. 9 T29N R6W	Poor alfalfa	Laboratory and greenhouse
32	Onaway sandy loam	G. Steiner Antrim Co. NE$\frac{1}{4}$ Sec. 4 T29N R8W	Good alfalfa	Laboratory and greenhouse
33	Onaway sandy loam	J. Kratchovil Grand Traverse Co. NE$\frac{1}{4}$ Sec. 24	Good alfalfa	Greenhouse
34	Miami loam	M. Pasco Shiawassee Co. M-47 2 mi. N. Owosso	Poor beans	Laboratory
35	Conover loam	M. Petell Shiawassee Co. M-47 4 mi. N. Owosso	Good beans	Laboratory
36	Oshtemo loamy sand	C. Rouake Saginaw Co. 2 mi. E. of Oakley	Poor beans	Laboratory
37	Kawkawlin sandy loam	F. Sabo Saginaw Co. M-13 10 mi. S. Saginaw	Poor beans	Laboratory
38	Brookston silt loam	Sugar Company Saginaw Co. 4 mi. E. of Saginaw	Good beans	Laboratory
39	Gilford sandy loam	D. Mitchell Tuscola Co. 2 mi. N. of Fairgrove	Poor beans	Laboratory

Table 1. (concluded)

Series number	Soil type	Location	Condition of stand or field	Study
40	Miami loam	F. Kennedy Sanilac Co. M-53 E. and S. Cass City	Poor beans	Laboratory
41	Brookston silt loam	N. Gilmore Tuscola Co.	Good beans	Laboratory
42	Gilford sandy loam	P. Kruse Tuscola Co. 4 mi. W. of Unionville	Fair beans	Laboratory
43	Miami loam	J. Dillman Tuscola Co. 2 mi. W. of Cass City	Good beans	Laboratory
44	Brookston loam	H. Armbruster Huron Co. 4 mi. N. of Unionville	Poor beans	Laboratory
45	Conover loam	L. Austin Clinton Co. M-21 12 mi. W. St. Johns	Poor beans	Laboratory

Alfalfa plant samples were collected in the spring of 1941 from the above locations where it was possible to do so. The plants were selected at random over the field. No attempt was made to obtain the roots. After drying the plant material in an oven at 65° C., it was ground for chemical analysis.

Methods of Chemical Analysis

Partial chemical analysis of the soils included base exchange capacity, reaction, exchangeable calcium, magnesium, and potassium, and available phosphorus. The base exchange capacity was determined according to the method of Chapman and Kelly (7). Agitating the soil suspensions in flasks in a shaking machine was substituted for the 15 hour digestion period. Exchangeable calcium, magnesium, and potassium analyses were made on ammonium acetate leachates of soil samples. The leaching solution was made up as described by Schollenberger and Dreibelbis (29) and a ratio of 10 to 1 of solution to soil was used. The soil suspension was shaken 30 minutes, filtered under suction, and the soil washed on the filter with four 50 cc. portions of leaching solution. Tests showed that 15 to 30 minutes of agitation of the sandy soil suspensions would remove amounts of bases comparable to digestion or percolation procedure lasting 12 to 24 hours. The filtrate was evaporated to dryness and the organic matter destroyed. Gentle ignition was used to decompose the acetates, and the resulting residue was taken up with dilute HCl and the solution filtered.

This solution was analyzed for calcium by precipitating the oxalate, dissolving it in dilute sulfuric acid, and titrating with standard potassium permanganate. Magnesium was determined gravimetrically on the filtrate and washings of the calcium determination using the organic precipitant, 8-hydroxyquinoline, as outlined by Kolthoff and Sandell (18). Before precipitation, the oxalate ion was destroyed as suggested by Alexander and Harper (1). After destroying the excess hydroxyquinoline by ignition, potassium was determined gravimetrically as the chloroplatinate on the filtrate and washings from the magnesium analysis. Available phosphorus was determined by Truog's (30) method using a Duboscq colorimeter for color comparison. Measurements of pH were made using Spurway's "Soiltex" indicator and the glass electrode.

The analysis of plant materials was carried out by ashing from 2 to 5 grams of finely ground tissue, moistened with 1 to 10 sulfuric acid, in a muffle furnace at 350° C. for 12 hours. The ash was taken up with 1 to 5 hydrochloric acid and the silica dehydrated by evaporating the residue to dryness on the steam bath. The residue was then redissolved in dilute HCl and NH_4OH added dropwise until a precipitate formed which could be dissolved on stirring. The solution was heated nearly to boiling and NH_4OH added to precipitate the iron, aluminum, and phosphorus in the sample. The precipitate was filtered off at once and washed with hot water until free of ammonium ions. From an aliquot of this filtrate, calcium was determined as the oxalate. Magnesium in the filtrate and washings of the calcium analysis was determined gravimetrically as magnesium quinolate after the oxalate ion had been removed. The potassium present in the filtrate and washings of the magnesium analysis was precipitated as potassium chloroplatinate and washed with 80 per cent ethanol according to standard procedure.

Nitrogen analyses on the plant material were run using the Gunning-Arnold modification of the Kjeldahl method.

Condition of Legume Stands as Related to Exchangeable Potassium and Other Chemical Characteristics of Some Sandy Soils

On the supposition that there would be a difference in the chemical characteristics of soils that supported good and poor legume growth, soil samples from 26 good and poor alfalfa fields were analyzed for exchangeable calcium, magnesium, potassium, available phosphorus, base exchange capacity and reaction. The results of these tests are listed in Table 2. From the data available, the per cent base saturation and the Ca+Mg/K ratio were calculated. Since no total base determinations were made, only Ca, Mg, and K are considered in the per cent saturation. There appears to be quite a large variation in the content of elements present between profile samples at certain locations. In some cases the differences between samples in the same field were greater than between samples from different fields on the same soil type.

In order to present a more comprehensive and condensed picture of the supply of plant nutrients, the mean of the analyses for all the soils grouped as having good or poor legume stands for each chemical characteristic is given in Table 3. The mean deviation and standard deviation are presented to indicate the amount of dispersion of the analyses from the mean.

Table 2. Partial chemical analyses of profile soil samples from good and poor alfalfa stands in western Michigan

Soil type and condition and location of stand	Depth of sample	pH	Exchange capacity per 100 grams	Base sat.	$\frac{Ca+Mg}{K}$	Ca per 100 grams	Mg per 100 grams	K per 100 grams	Available P
	inches		m.e.	%		m.e.	m.e.	m.e.	p.p.m.
Plainfield	0-11	6.2	4.65	89.5	23.5	3.59	0.41	0.17	26.0
sandy	11-23	5.8	3.32	82.5	24.2	2.30	0.33	0.11	17.9
loam	23-32	5.7	3.97	85.4	27.2	2.96	0.31	0.12	37.7
Good to	0- 8	6.0	5.22	86.5	33.9	3.99	0.40	0.13	19.8
fair	8-23	5.8	3.75	61.3	10.5	1.77	0.33	0.20	23.4
alfalfa	23-32	5.5	4.11	52.3	18.5	1.78	0.26	0.11	18.7
	0- 6	5.8	5.37	75.7	18.2	2.60	0.31	0.16	14.4
Series 1	6-24	5.5	4.01	49.5	10.7	1.54	0.27	0.17	19.4
	24-34	5.6	3.92	58.5	27.5	1.90	0.30	0.08	10.9
Plainfield	0- 8	6.3	5.68	87.4	54.1	4.59	0.28	0.09	15.7
sandy	8-22	5.6	4.09	48.5	12.2	1.60	0.23	0.15	15.4
loam	22-34	5.5	4.26	64.5	33.4	2.27	0.40	0.08	12.6
	0- 7	5.8	5.34	68.5	23.3	3.01	0.49	0.15	10.6
Poor alfalfa	7-24	5.5	4.21	53.2	21.4	1.66	0.48	0.10	15.4
	24-34	5.6	4.85	58.1	20.7	2.33	0.36	0.13	14.0
	0- 8	6.0	5.43	75.0	23.0	3.44	0.46	0.17	12.8
Series 2	8-23	5.2	4.06	48.0	16.7	1.35	0.49	0.11	19.7
	23-32	5.4	4.40	60.3	23.0	2.13	0.40	0.11	9.1

Table 2. (continued)

Soil type and condition and location of stand	Depth of sample	pH	Exchange capacity per 100 grams	Base sat.	$\frac{Ca+Mg}{K}$	Ca per 100 grams	Mg per 100 grams	K per 100 grams	Available P
	inches		m.e.	%		m.e.	m.e.	m.e.	p.p.m.
Plainfield	0- 7	5.2	4.19	71.0	28.7	2.41	0.46	0.10	6.8
sand	7-24	4.4	2.45	30.6	7.4	0.30	0.36	0.09	7.5
	24-36	4.8	1.51	51.0	10.0	0.33	0.37	0.07	14.3
Poor alfalfa									
	0- 6	5.7	4.53	72.8	24.4	2.57	0.60	0.12	23.3
Series 3	6-19	4.8	2.70	28.9	12.0	0.34	0.38	0.06	6.1
	19-36	4.4	1.73	31.2	4.4	0.26	0.18	0.10	14.2
	0-10	6.0	8.06	75.6	37.1	5.14	0.80	0.16	20.2
Fox sandy	10-18	4.8	9.30	52.0	29.2	3.71	0.96	0.16	23.6
loam	18-24	5.5	9.55	53.0	27.1	3.97	0.91	0.18	41.9
	24-36	5.5	4.69	49.0	19.8	1.72	0.46	0.11	13.0
Good alfalfa									
	0-10	6.2	9.48	74.7	63.4	6.15	0.82	0.11	26.3
	10-18	4.5	7.13	58.5	31.0	3.37	0.67	0.13	16.4
Series 4	18-24	5.3	8.56	55.6	28.7	4.01	0.59	0.16	24.6
	24-36	5.0	7.15	52.2	45.6	2.99	0.66	0.08	22.5
Fox sandy	0- 8	6.2	3.90	78.2	32.9	2.66	0.30	0.09	16.7
loam	8-24	5.5	2.67	62.2	12.8	1.29	0.25	0.13	12.3
	24-36	5.3	3.60	41.9	12.7	1.23	0.17	0.11	17.3
Good alfalfa									
	0- 8	5.8	4.21	72.2	29.5	2.72	0.23	0.10	22.5
Series 5	8-24	5.5	3.26	69.0	16.3	1.82	0.30	0.13	13.8
	24-36	5.3	4.83	46.6	16.3	1.55	0.57	0.13	18.7

Table 2. (continued)

Soil type and condition and location of stand	Depth of sample	pH	Exchange capacity per 100 grams	Base sat.	$\frac{Ca+Mg}{K}$	Ca per 100 grams	Mg per 100 grams	K per 100 grams	Available P
	inches		m.e.	%		m.e.	m.e.	m.e.	p.p.m.
Fox sandy	0- 8	5.5	3.46	67.6	28.1	2.02	0.23	0.08	13.0
loam	8-24	5.2	3.96	40.7	25.8	1.35	0.20	0.06	13.4
Fair to poor	24-36	5.2	3.74	45.7	16.1	1.39	0.22	0.10	12.3
alfalfa	0- 8	5.3	3.25	67.8	17.1	1.86	0.20	0.12	17.4
Series 6	8-24	4.8	2.67	67.8	19.1	1.49	0.23	0.09	13.3
	24-36	5.0	4.95	71.7	34.3	2.57	0.86	0.10	13.0
Fox sandy	0- 9	6.2	6.25	84.0	31.8	4.30	0.79	0.16	24.2
loam	9-20	5.8	3.18	68.0	11.9	1.42	0.59	0.15	13.6
	20-30	5.6	5.76	77.4	36.2	3.71	0.63	0.12	13.9
	30-36	5.5	5.63	62.0	13.5	2.68	0.57	0.24	15.6
Good alfalfa	0- 8	6.0	6.65	75.2	32.3	4.08	0.77	0.15	17.3
	8-20	5.7	3.12	61.0	16.3	1.28	0.51	0.11	14.7
Series 8	20-30	5.3	4.42	68.2	24.2	2.50	0.40	0.12	9.8
	30-36	5.2	4.78	80.1	24.5	3.07	0.61	0.15	10.7
Fox sandy	0- 6	6.0	9.35	80.8	92.3	6.24	1.14	0.08	
loam	6-18	5.2	3.46	63.3	30.2	1.55	0.57	0.07	
	18-36	4.5	6.95	32.4	17.7	1.05	1.08	0.12	
Poor alfalfa	0- 7	6.3	5.48	83.7	38.9	3.45	1.05	0.09	
Series 9	7-20	6.0	4.58	78.0	34.7	2.61	0.86	0.10	
	20-36	5.6	7.12	61.4	35.4	3.37	0.88	0.12	

Table 2. (continued)

Soil type and condition and location of stand	Depth of sample	pH	Exchange capacity per 100 grams	Base sat.	$\frac{Ca+Mg}{K}$	Ca per 100 grams	Mg per 100 grams	K per 100 grams	Available P
	inches		m.e.	%		m.e.	m.e.	m.e.	p.p.m.
Fox fine	0-11	6.0	6.55	76.6	44.7	4.53	0.38	0.11	12.7
sandy loam	11-24	5.2	5.91	48.9	17.0	2.15	0.58	0.16	10.0
	24-36	4.5	7.67	60.6	28.0	3.34	1.15	0.16	30.6
Fair alfalfa									
	0-10	6.3	10.61	72.0	57.7	6.89	0.61	0.13	28.9
Series 10	10-20	5.2	6.18	64.5	23.4	3.26	0.96	0.18	16.1
	20-36	4.5	8.25	76.6	28.6	4.29	1.85	0.18	23.9
	0-10	6.0	7.36	79.0	33.2	4.65	0.99	0.17	21.6
Fox loam	10-18	5.5	7.67	55.6	31.8	3.10	1.04	0.13	12.7
	18-30	4.8	6.78	76.3	27.7	3.68	1.31	0.18	18.2
	30-38	5.2	7.36	70.5	39.0	3.90	1.17	0.14	43.3
Good alfalfa									
	0-10	6.2	6.97	76.9	40.2	4.27	0.96	0.13	27.0
	10-18	5.8	6.44	44.7	30.9	2.09	0.69	0.09	14.9
Series 12	18-30	5.5	6.62	75.8	20.8	3.91	0.88	0.23	13.4
	30-40	5.7	4.07	38.9	18.7	1.10	0.40	0.08	14.5
	0-10	6.5	9.47	65.3	67.7	5.59	0.50	0.09	23.2
Fox loam	10-26	5.0	5.82	39.2	14.2	1.80	0.33	0.15	9.4
Fair to poor	26-38	4.6	6.27	35.6	27.0	1.75	0.40	0.08	13.5
alfalfa	0- 7	6.0	6.26	66.5	40.5	3.75	0.30	0.10	13.9
Series 13	7-20	4.5	4.47	40.5	17.1	1.38	0.33	0.10	18.0
	20-32	4.8	7.31	75.4	49.1	4.17	1.23	0.11	8.1

Table 2. (continued)

Soil type and condition and location of stand	Depth of sample	pH	Exchange capacity per 100 grams	Base sat.	$\frac{Ca+Mg}{K}$	Ca per 100 grams	Mg per 100 grams	K per 100 grams	Available P
	inches		m.e.	%		m.e.	m.e.	m.e.	p.p.m.
	0-11	6.0	11.62	68.2	35.0	6.88	0.82	0.22	32.4
Fox silt loam	11-22	6.2	13.45	83.3	42.1	9.26	1.69	0.26	63.0
	22-36	5.7	14.23	83.4	65.0	9.40	2.30	0.18	20.6
	36-42	5.5	7.89	69.2	26.3	4.15	1.10	0.20	34.3
Good alfalfa									
	0-10	5.9	11.70	67.3	31.5	6.92	0.64	0.24	23.9
	10-20	5.7	13.41	70.0	46.0	7.50	1.69	0.20	22.6
Series 14	20-34	5.5	11.65	74.5	47.2	6.28	2.21	0.18	11.2
	34-42	5.8	7.02	66.5	32.2	3.46	1.05	0.14	23.5
Coloma sandy	0- 9	6.3	2.83	68.5	11.9	1.19	0.59	0.15	14.7
loam	9-24	5.0	2.16	51.0	8.2	0.83	0.15	0.12	12.6
	24-36	5.0	1.95	71.3	11.6	0.92	0.36	0.11	12.8
Good alfalfa									
	0- 9	6.0	3.04	60.2	11.2	1.42	0.26	0.15	10.7
Series 15	9-24	5.6	2.64	56.5	7.8	1.09	0.23	0.17	11.7
	24-36	5.5	2.15	68.3	11.2	1.10	0.25	0.12	16.1
Coloma sandy	0-10	6.0	3.97	81.0	34.3	2.83	0.26	0.09	11.6
loam	10-24	5.4	2.24	65.2	15.6	1.27	0.29	0.10	10.0
	24-36	5.8	2.50	75.5	17.9	1.54	0.25	0.10	15.7
Poor alfalfa									
	0- 9	6.0	4.28	85.8	32.4	3.33	0.23	0.11	28.9
Series 16	9-24	5.6	2.73	60.0	14.0	1.24	0.29	0.11	30.0
	24-36	5.8	2.56	85.1	20.8	1.82	0.26	0.10	53.4

Table 2. (continued)

Soil type and condition and location of stand	Depth of sample	pH	Exchange capacity per 100 grams	Base sat.	(Ca+Mg)/K	Ca per 100 grams	Mg per 100 grams	K per 100 grams	Available P
	inches		m.e.	%		m.e.	m.e.	m.e.	p.p.m.
Coloma sandy loam	0- 6	4.8	3.14	38.2	11.0	0.91	0.19	0.10	
	6-20	4.7	2.16	44.8	11.1	0.74	0.15	0.08	
Poor alfalfa	20-32	5.0	1.83	60.0	21.0	0.83	0.22	0.05	
	0- 6	5.1	3.57	44.0	16.4	1.16	0.32	0.09	
Series 17	6-20	5.2	3.01	44.8	14.0	1.05	0.21	0.09	
	20-36	5.4	2.14	59.8	9.7	0.88	0.28	0.12	
Bellefontaine sandy loam	0- 8	6.2	12.62	84.5	81.3	9.65	0.92	0.13	
	8-18	5.5	5.85	63.5	36.2	2.65	0.97	0.10	
	18-30	4.9	6.27	76.5	21.8	3.42	1.07	0.21	
Good alfalfa	30-42	5.4	4.40	88.6	31.5	2.65	1.13	0.12	
	0- 8	5.8	9.33	77.5	50.6	5.96	1.13	0.14	
	8-18	5.2	4.82	68.8	26.6	2.44	0.76	0.12	
Series 18	18-30	5.0	8.18	66.6	31.0	4.32	0.96	0.17	
	30-42	5.5	4.09	81.4	32.3	2.21	1.02	0.10	
Bellefontaine sandy	0-10	5.8	6.20	44.2	38.1	2.24	0.42	0.07	
	10-20	5.6	6.85	50.4	33.5	2.91	0.44	0.10	
loam Poor alfalfa	20-28	5.5	6.27	62.5	31.2	2.70	1.06	0.12	
	0- 8	5.7	5.80	56.6	53.7	2.46	0.76	0.06	
Series 19	8-18	5.2	5.91	45.6	29.0	1.97	0.64	0.09	
	18-30	5.3	6.32	55.0	48.6	2.53	0.87	0.07	

Table 2. (continued)

Soil type and condition and location of stand	Depth of sample	pH	Exchange capacity per 100 grams	Base sat.	$\frac{Ca+Mg}{K}$	Ca per 100 grams	Mg per 100 grams	K per 100 grams	Available P
	inches		m.e.	%		m.e.	m.e.	m.e.	p.p.m.
Bellefontaine	0- 7	5.6	7.40	61.1	87.3	4.52	0.72	0.06	
sandy loam	7-17	5.8	6.30	82.8	42.3	4.21	0.88	0.12	
	17-30	5.9	5.60	79.0	39.2	3.20	1.11	0.11	
Poor alfalfa									
	0- 6	5.8	8.32	84.5	77.1	5.82	1.12	0.09	
Series 20	6-20	5.5	6.95	71.7	34.5	3.87	0.97	0.14	
	20-30	5.8	5.21	78.0	32.8	2.71	1.23	0.12	
	0- 8	6.5	11.25	63.0	36.5	6.30	0.63	0.19	34.2
Warsaw loam	8-18	6.0	8.80	70.0	59.7	5.35	0.62	0.10	43.3
	18-27	5.5	11.70	42.2	34.2	3.84	0.96	0.14	28.8
	27-42	5.4	7.60	32.0	19.2	1.82	0.49	0.12	18.7
Poor alfalfa									
	0- 8	6.3	12.53	73.5	45.5	8.30	0.80	0.20	31.5
Series 21	8-18	5.7	7.31	50.5	40.0	3.05	0.55	0.09	46.5
	18-27	5.3	4.83	41.6	16.5	1.28	0.53	0.11	46.1
	27-42	5.0	5.21	38.6	15.7	1.26	0.63	0.12	26.2
	0-12	7.2	17.70	97.0	28.6	14.92	1.66	0.58	44.8
Warsaw loam	12-20	7.1	12.24	96.5	41.1	10.55	0.97	0.28	28.5
	20-28	6.8	7.60	69.5	34.2	4.70	0.44	0.15	18.4
	28-42	6.5	4.83	67.5	24.1	2.93	0.20	0.13	14.9
Good alfalfa									
	0-12	6.8	13.62	77.3	28.2	9.12	1.04	0.36	15.4
Series 22	12-18	6.8	9.50	86.6	44.6	6.89	1.15	0.18	9.8
	18-24	6.5	7.22	84.0	30.8	4.99	0.89	0.19	9.2
	24-36	6.2	4.26	51.2	9.9	1.62	0.36	0.20	23.4

Table 2. (continued)

Soil type and condition and location of stand	Depth of sample	pH	Exchange capacity per 100 grams	Base sat.	$\frac{Ca+Mg}{K}$	Ca per 100 grams	Mg per 100 grams	K per 100 grams
	inches		m.e.	%		m.e.	m.e.	m.e.
	0- 8	5.1	11.40	49.4	69.5	4.98	0.58	0.08
Warsaw loam	8-24	4.6	10.30	28.2	28.1	2.32	0.49	0.10
	24-36	4.5	4.15	30.8	15.0	0.83	0.37	0.08
Poor alfalfa								
	0- 7	5.5	12.23	48.6	65.1	5.21	0.65	0.09
Series 23	7-20	5.0	8.94	56.9	45.2	3.75	1.22	0.11
	20-30	5.2	5.63	56.0	25.9	1.98	1.09	0.08
Emmet sandy	0- 8	6.5	6.91	76.4	32.1	4.40	0.73	0.16
loam	8-20	6.0	4.81	78.3	36.7	2.48	1.19	0.10
	20-30	5.5	3.21	65.4	34.0	1.37	0.67	0.06
Good alfalfa								
	0-12	6.5	7.95	70.3	40.7	4.36	1.12	0.11
Series 26	12-22	6.0	2.92	70.5	24.7	1.06	0.92	0.08
	22-32	5.5	3.44	56.5	31.3	1.15	0.73	0.06
Emmet sandy	0- 7	6.0	5.62	83.9	93.4	3.52	1.15	0.05
loam	7-25	5.3	2.97	66.3	48.2	1.32	0.61	0.04
Poor alfalfa								
	0- 6	6.2	4.83	82.0	65.0	3.07	0.83	0.06
Series 27	6-21	5.5	3.15	68.5	53.3	1.24	0.89	0.04

Table 2. (concluded)

Soil type and condition and location of stand	Depth of sample	pH	Exchange capacity per 100 grams	Base sat.	$\frac{Ca+Mg}{K}$	Ca per 100 grams	Mg per 100 grams	K per 100 grams
	inches		m.e.	%		m.e.	m.e.	m.e.
Kalkaska sand	0- 6	5.5	4.42	87.0	63.0	2.40	1.38	0.06
	6-24	5.3	3.34	77.5	63.7	1.40	1.15	0.04
Fair to poor alfalfa	24-36	5.8	1.80	82.2	48.4	0.72	0.73	0.03
	0- 8	5.5	4.32	76.0	60.0	2.08	1.12	0.07
Series 29	8-20	5.5	3.70	70.8	51.7	1.42	1.15	0.05
	20-36	5.3	2.60	55.2	24.0	0.35	0.59	0.06
Mancelona sandy loam	0- 6	6.0	6.07	67.2	67.0	3.20	0.82	0.06
	6-18	5.7	5.21	76.9	79.2	2.61	1.35	0.05
	18-36	6.0	4.37	75.3	24.3	2.11	1.05	0.13
Poor alfalfa								
	0- 8	6.3	5.48	80.5	54.1	3.12	1.21	0.08
Series 31	8-16	6.0	2.95	72.3	63.4	2.72	1.08	0.06
	16-36	5.8	3.87	61.8	38.8	1.50	0.83	0.06
Onaway sandy loam	0- 8	6.5	7.80	87.2	55.7	6.00	0.69	0.12
	8-18	5.9	5.11	83.7	22.8	3.24	0.86	0.18
	18-24	5.5	3.94	51.3	12.5	1.08	0.79	0.15
Good alfalfa								
	0- 7	6.5	8.12	86.5	45.9	5.85	1.03	0.15
Series 32	7-20	6.0	6.21	76.6	28.8	3.62	0.98	0.16
	20-30	5.6	4.15	59.0	18.1	1.61	0.75	0.13

Table 3. The statistical analysis of some chemical characteristics of the top soil from 26 good and poor alfalfa fields in western Michigan

Statistic	Condition of stand	K+	Ca+	Mg+	Base sat.	Ca+Mg/K ratio	P++
		m.e.	m.e.	m.e.	%		p.p.m.
Mean	good	0.18	5.20	0.76	77.1	36.2	22.1
	poor	0.10	3.60	0.65	69.4	50.4	18.7
Mean deviation	good	0.06	2.03	0.26	5.9	11.6	6.0
	poor	0.03	1.30	0.30	11.1	18.2	7.3
Standard deviation	good	0.10	2.80	0.33	7.9	15.9	7.8
	poor	0.04	1.78	0.35	13.5	21.1	8.4
Significance between means		3.5**	4.1**	1.1	0.7	2.6*	1.2

*Significant to the 5% point.
**Significant to the 1% point.
+Expressed in milliequivalents per 100 grams soil.
++Average of only 15 fields.

Of the elements for which analyses were made, only exchangeable potassium and calcium were significantly different upon comparing good with poor alfalfa fields. Soils supporting good legume growth were slightly higher in replaceable magnesium and available phosphorus, and had greater per cent base saturation and lower Ca+Mg/K ratios than samples from poor legume stands. A significant difference between means at the 5 per cent point was found for the Ca+Mg/K ratio.

In general the soil below the surface layer designated as "profile" in the samples studied contained smaller quantities of plant nutrients as indicated by the mean value of the profile determinations in Table 4. As the content of calcium, magnesium, and potassium fell off in the lower portion of the solum, the reaction, base saturation, and Ca+Mg/K ratio decreased likewise. The total exchange capacity of the profile samples decreased with increasing depth, but not in proportion to the lowered base content. The amount of nutrients in the surface soil absorbed by alfalfa plants as compared with those taken up from the lower portions of the profile is not known, but Millar (20) has shown that alfalfa roots can absorb appreciable quantities of plant food at depths below the surface layer. However, it would seem that for most purposes an analysis of the top soil will give about as accurate a picture of the fertility of sandy soils as an entire profile analysis.

Potassium

As shown in Table 4, there is a notable difference in the exchangeable potassium of surface and profile samples when comparing soils from good

Table 4. **Partial chemical analysis of some sandy soils as related to depth of sampling and condition of legume stand**

Sample depth	K*		Ca*		Ca+Mg/K		Base saturation**	
	Good	Poor	Good	Poor	Good	Poor	Good	Poor
Plainfield sandy soils								
Top soil	0.15	0.13	3.39	3.20	25.2	30.7	83.9	74.8
Profile	0.14	0.11	2.49	1.91	21.6	21.0	71.2	56.6
Fox sandy loam soils								
Top soil	0.13	0.09	4.56	3.39	41.2	44.1	76.1	74.9
Profile	0.14	0.09	3.21	2.41	28.0	32.5	65.0	63.4
Fox loam and silt loam soils								
Top soil	0.19	0.10	5.68	4.67	35.0	54.1	72.8	65.9
Profile	0.17	0.10	5.03	3.07	35.5	35.9	70.0	53.7
Coloma sandy soils								
Top soil	0.15	0.10	1.32	2.06	11.6	23.5	64.3	62.1
Profile	0.14	0.09	1.09	1.47	10.3	18.2	62.6	62.0
Bellefontaine sandy loam soils								
Top soil	0.14	0.10	7.80	3.76	65.9	64.1	81.0	61.6
Profile	0.14	0.07	4.18	3.26	38.9	45.6	75.9	64.3
Emmet sandy loam soils								
Top soil	0.14	0.06	4.38	3.29	40.9	79.2	73.3	83.0
Profile	0.10	0.05	3.08	2.29	34.8	65.0	69.6	75.2
Warsaw sandy loam and loam soils								
Top soil	0.47	0.14	12.02	6.20	28.4	54.2	87.1	58.6
Profile	0.26	0.12	6.96	4.19	30.2	36.9	78.7	48.7

*Expressed in milliequivalents per 100 grams soil.
**Expressed in per cent.

and poor alfalfa fields. With the exception of the Warsaw soils, the potassium level of soils supporting luxuriant stands was about 0.15 milliequivalents per 100 grams as compared with 0.10 milliequivalents for the poor fields. On the basis of the removal of from 40 to 70 pounds of potassium during the growing season by alfalfa grown on sandy soils, it is evident that a level of 75 to 80 pounds of exchangeable potassium in sandy soils is insufficient to start or maintain a legume stand.

Calcium, Reaction, and Base Saturation

The exchangeable calcium content of soils having good legume stands was distinctly higher than that of soils from poor fields in the case of the Fox, Bellefontaine, Emmet and Warsaw soils. All fields sampled that supported a good alfalfa growth showed a reaction of pH 6.0 or higher, while 7 of the 14 fields having poor legume stands tested below pH 6.0.

The per cent base saturation was higher in samples from the Plainfield, Bellefontaine, Warsaw, and Fox loam and silt loam soils on which alfalfa grew well than in soils from fields where growth was inferior. The Coloma and Fox sandy loam soils presented little difference in per cent base saturation for good or poor locations, while the opposite relation was noted for the Emmet soils. In general it appears that sandy soils having 70 to 75 per cent base saturation, when adequately supplied with available potassium, will produce flourishing stands of alfalfa. Vanderford (32), in a greenhouse study on the effect of lime levels on legumes, found increases in yield until a condition of 100 per cent base saturation was reached, but these increases were not of a uniform magnitude.

Under field conditions, it is not advisable to attempt to lime sandy soils to complete base saturation.

Numerous experiments have been carried out by workers concerning the effect of lime on the availability of potassium for plants. Many conflicting data have been published. Peech and Bradfield (24) consider this situation as the result of failure to evaluate properly the conditions under which the experiments were carried out. They believe that additions of lime to acid soils containing neutral salts will decrease the potassium concentration in the soil solution, depending on the initial degree of base saturation. In the absence of neutral salts in acid soils, potassium will be liberated by moderate applications of lime.

Ca+Mg/K Ratio

Upon comparing the data in Table 4, the Ca+Mg/K ratio was found to be definitely lower for soils from the better legume stands in the case of the Coloma, Emmet, Warsaw, and Fox loam and silt loam soils, and slightly lower in the Plainfield, Bellefontaine, and Fox sandy loam samples. For the sandy soils studied, it appears that a ratio higher than 25 to 30 is indicative of the inability of a soil to produce good alfalfa stands, while in the sandy loam and loam soils, Ca-Mg/K ratios of 45 to 50 or higher are synonomous with poor legume growth.

Phosphorus

The data in Table 3 indicate that the dilute acid soluble phosphorus content of soils from good and poor legume stands is almost the same. Truog (31) set an arbitrary limit of 50 pounds per acre of available phosphorus as the amount necessary for general farming on the sandy soils of Wisconsin. In this study, the mean of the phosphorus determination of all soils from good alfalfa fields was about 45 pounds per acre in the surface layer.

Relation Between Condition of Legume Stand and
Chemical Composition of Plants

A partial chemical analysis of alfalfa plants from good and poor alfalfa stands in western Michigan is presented in Table 5. Calcium, magnesium, and potassium were determined separately on the leaves and stems, while analyses for nitrogen were made on the entire top of the plant. No attempt was made to analyze the roots. Six poor stands and four satisfactory stands were selected on five representative soil types. All poor fields exhibited medium to strong potash starvation symptoms, except series 7, where the alfalfa had failed to produce a stand. The alfalfa at series 5, 10, 12, and 22 was vigorous and healthy.

The per cent nitrogen in the alfalfa tops varied considerably, and no definite correlation was found between the nitrogen and potash plant content. Millar (22) found a low positive correlation between the per cent nitrogen and potassium in a large number of legume hay samples grown in Michigan. Total protein was undoubtedly higher in those stands having normal growth and consequently greater yield.

In general, the alfalfa from poor fields tended to be higher in calcium and magnesium than that from good stands, with the leaves containing the greater amount of each element. The inverse relation between the

Table 5. Partial chemical analysis* of alfalfa sampled from good and poor alfalfa stands in southwestern Michigan in June, 1941

Soil type and number***	Condition of stand	Part of plant	Nitrogen**	CaO	MgO	K_2O
			per cent	per cent	per cent	per cent
Plainfield sand Series 3	Poor alfalfa stand K deficiency symptoms	Leaves	3.55	3.01	0.42	0.95
		Stems		1.35	--	1.12
Fox sandy loam Series 5	Fair alfalfa stand	Leaves	3.78	3.45	0.55	1.42
		Stems		1.28	0.45	1.55
Fox sandy loam Series 6	Fair to poor alfalfa stand K deficiency symptoms	Leaves	4.02	3.35	0.60	0.87
		Stems		1.35	0.49	0.68
Fox sandy loam Series 7	Young alfalfa stand failed Stunted growth	Leaves	3.35	3.44	0.65	1.04
		Stems		1.48	0.57	0.90
Fox fine sandy loam Series 10	Good alfalfa stand	Leaves	3.88	2.78	0.49	1.68
		Stems		1.23	0.40	1.73
Fox sandy loam Series 11	Poor alfalfa stand K deficiency symptoms	Leaves	3.75	3.84	0.62	0.61
		Stems		1.82	0.55	0.75

Table 5. (continued)

Soil type and number***	Condition of stand	Part of plant	Nitrogen**	CaO	MgO	K_2O
			per cent	per cent	per cent	per cent
Fox loam	Good alfalfa stand	Leaves	4.26	2.25	0.55	1.72
Series 12		Stems		0.72	0.38	1.89
Warsaw loam	Poor alfalfa stand	Leaves	3.90	2.87	0.46	0.90
Series 21	K deficiency symptoms	Stems		0.80	0.36	0.67
Warsaw loam	Good alfalfa stand	Leaves	2.54	2.69	0.41	2.47
Series 22		Stems		0.65	0.30	2.50
Warsaw sandy loam	Poor alfalfa stand	Leaves	3.95	2.83	0.62	0.80
Series 23	K deficiency symptoms	Stems		1.15	0.54	1.07

*Chemical analyses made on alfalfa tops.
**Analyses made on leaves and stems together.
***Data for each series given in Table 1.

calcium and potassium content of alfalfa has been shown to occur in a number of experiments by investigators (2) and (30) in studies on the mineral content and requirements of legumes. Since it has been shown that the exchangeable calcium and magnesium content of the soil from poor stands was no higher, and in some cases lower, than the soil from good locations, the higher content of these elements in potassium deficient alfalfa must be explained on the basis that a low supply of available potassium in the soil upset the physiological balance of cation absorption and a larger proportion of calcium and magnesium was taken into the plants. According to Pierre and Bower (26) the absorption of one cation is generally depressed by a high concentration of others.

The correlation between the potash content of alfalfa and the condition of the stand was high as seen by the scatter diagram in Figure 1. The average potash content of the leaves of plants from poor fields was 0.86 per cent as compared with 1.82 per cent in the legumes from the four normal fields. Likewise the per cent K_2O in the stems of deficient plants averaged about 0.87 in contrast to 1.92 in alfalfa stems from good fields. The fact that the stems of legumes are higher in potassium than the leaves is generally known.

Tissue tests were made for potassium in alfalfa on locations 3, 6, 11, 12, 21, and 22 in the middle of May 1941, or about one month before samples were taken for chemical analysis. Though the deficiency symptoms were not as marked as a month later, the plants from series 3, 6, 11, and 21 gave a low test for potash, while the test of vigorous alfalfa plants from locations 12 and 22 showed high or adequate potassium.

Figure 1. Scatter diagram showing relation between per cent potash in alfalfa leaves and the condition of stand

The average potassium content of legume hays grown on the lighter soils of Michigan has been found by Millar (22) to be about 1.34 per cent. This value is slightly below that of an average of 1.55* for the normal alfalfa and considerably above that of 0.75* for the alfalfa from deficient fields.

Calcium-Potassium Ratios as Related to Condition of Stand

In Table 6 the relation between the potassium content of soils and plants and the condition of legume stand is clearly evidenced. The average replaceable potassium of soil profiles from good fields was 0.17 milliequivalents per 100 grams and 0.09 milliequivalents from the soils of deficient stands. This ratio of about 2:1 compares favorably with a 2:1 ratio of the potash content of alfalfa from good stands as compared with poor fields. The equivalent cation ratios for calcium:potassium are given in Table 6 for both plants and soils.

In greenhouse pot studies of the Ca:K ratios for alfalfa, Hunter, Toth, and Bear (15) concluded that though alfalfa can adjust itself to wide variations in soil Ca:K ratios, making normal growth between 1:1 and 100:1, soils having the ratio of 4:1 or less gave optimum development for the period of study. The work from the New Jersey station indicated that an abrupt drop in yield took place when the calcium content fell below 1 per cent, or when the ratio Ca:K exceeded 4 to 1. The data in

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*Average of per cent potassium of leaves and stems.

Table 6. The relation of condition of stand to potassium content and equivalent Ca:K ratios in soils and plant tissue

Series number	Condition of stand	K_2O in plant* %	Exch. K per 100 gm. soil** m.e.	Equivalent Ca:K ratio plant	Equivalent Ca:K ratio soil***
3	Poor	1.03	0.09	6:1	11:1
6	Poor	0.78	0.09	7:1	20:1
7	Poor	0.97	0.09	6:1	--
11	Poor	0.68	0.08	12:1	--
21	Poor	0.79	0.13	6:1	30:1
23	Poor	0.94	0.08	6:1	39:1
5	Fair	1.49	0.12	4:1	16:1
10	Good	1.71	0.15	3:1	27:1
12	Good	1.81	0.15	2:1	22:1
22	Good	2.49	0.25	2:1	28:1

*Average of leaves and stems of plants collected in 1941.

**Average of replaceable K of profile samples taken in 1940.

***Average of replaceable Ca and K of profile samples taken in 1940.

this paper are in excellent agreement with the critical limits set for the calcium and potassium content of alfalfa. However, it appears that the equivalent cation ratio of the soil can vary widely only if the exchangeable potassium content is above a critical level. In the sandy soils of Michigan, this critical limit seems to be between 0.10 and 0.15 milliequivalents per 100 grams of soil.

SECTION II. GREENHOUSE STUDIES

In order to more clearly ascertain the correlation between the condition of legume stands and the supply of certain plant nutrients in soils, greenhouse studies were carried out under controlled conditions of moisture and plant food. It is generally considered that the cropping of soils in greenhouse pots is more intensive than under actual field trials with soil temperatures and moistures at a much higher level. This is evidenced by the fact that soils deficient in phosphorus in the field will often produce several crops of alfalfa in the greenhouse without showing the characteristic symptoms of phosphorus deficiency. It is quite possible that the response of alfalfa to certain chemical elements might be somewhat different under field conditions. However, in the greenhouse, an investigation of plant growth can be made with most factors under control on a large number of soils with a minimum of time and expense. It is thought by many workers that intensive greenhouse pot culture simulates long time field cropping.

It is known that certain so-called minor elements are essential for plant growth. Willis and Piland (35) together with many other workers have found that boron prevents alfalfa "yellows" and often greatly increases the yield of legumes. Experiments at the Florida Station (17) on an acid sandy soil have shown that minor elements in the presence of lime and fertilizer caused appreciable increases in the growth of pasture plants. As the work of Millar and Gillam (23) showed that commercial fertilizers do not contain enough Mg, Mn, and Cu to take care of plant needs, these and other minor nutrients were included with calcium, potassium, and phosphorus as treatments in this greenhouse work.

Experimental Plans

Samples for greenhouse study were taken from 18 alfalfa fields, the soils being represented as follows: Fox 5, Warsaw 2, Plainfield 1, Emmet 5, Kalkaska 2, Mancelona 1, and Onaway 2. The soil types, their series number and location, and the kind of legume stand in the field are given in Table 1. Each soil sample was obtained by compounding 40 to 50 individual plow layer portions taken at random over the field. After sieving the soils through a one-half inch mesh galvanized screen, they were thoroughly mixed. To those soils that tested below pH 6.5, finely divided calcium carbonate was added to raise the reaction to a point between 6.5 and 7.0. The plant nutrients and the rates at which they were added on an acre basis are given in Table 7. All fertilizer and minor element compounds were added as chemically pure salts in solution, except phosphate, to partially wet soils in one and two gallon glazed jars. All treatments were replicated four times. Simple block or split plot designs were used and the yield results were analyzed statistically.

The soil in the pots was allowed to dry, was remixed, and brought to optimum moisture. Inoculation was provided for in cases where it was questionable whether nitrogen fixing bacteria were present. The soils were kept at optimum moisture during the course of the experiment by weighing the pots at frequent intervals. Generally, after three or four

Table 7. Rates and kinds of lime, fertilizer materials, and minor elements applied to soils for greenhouse studies

Series number	pH of soil before potting	Pounds per acre of lime and fertilizer and minor element salts
3	5.5	1000 $CaCO_3$, 160 KCl, 50 $MgSO_4 \cdot 7H_2O$, 15 $Na_2B_4O_7 \cdot 10H_2O$, 25 $MnSO_4 \cdot 2H_2O$
5	5.4	2000 $CaCO_3$, 160 KCl, 178 $Ca(H_2PO_4)_2$, 50 $MgSO_4 \cdot 7H_2O$, 10 $Na_2B_4O_7 \cdot 1)H_2O$, 5 $MnSO_4 \cdot 2H_2O$, 5 $CuSO_4 \cdot 5H_2O$, 350 KCl for 2nd stand.
6	5.3	Same as for series 5
10	6.0	1000 $CaCO_3$, other additions same as series 5
11A	6.0	1000 $CaCO_3$, 160 KCl, 200 $Ca(H_2PO_4)_2 \cdot 2H_2O$, 50 $MgSO_4 \cdot 7HO$, 15 $Na_2B_4O_7 \cdot 10H_2O$, 10 $CuSO_4 \cdot 5H_2O$
11B	6.0	1000 $CaCO_3$, 320 KCl, 100 $MgSO_4$ $7H_2O$, 50 $MnSO_4 \cdot 2H$ O, 10 $CuSO_4 \cdot 5H_2O$, 25 $Na_2B_4O_7 \cdot 10H_2O$, 10 $ZnSO_4$
12	6.0	1000 $CaCO_3$, other additions same as series 5
21	5.8	1000 $CaCO_3$, other additions same as series 5
22	6.0	1000 $CaCO_3$, other additions same as series 5
24	5.7	1000 $CaCO_3$, 160 KCl, 75 $MgSO_4 \cdot 7H_2O$, 25 $MnSO_4 \cdot 2H_2O$, 25 $Na_2B_4O_7 \cdot 10H_2O$, 10 $Co(CH_2COO)_2 \cdot 4H_2O$, 15 $ZnSO_4$
25	5.5	1000 $CaCO_3$, 400 KCl, 75 $MgSO_4 \cdot 7H_2O$, 15 $ZnSO_4$, 30 $Na_2B_4O_7 \cdot 10H_2O$, 20 $Co(CH_3COO)_2 \cdot 4H_2O$, 25 $MnSO_4$ $2H_2O$
26	6.5	100 $MgSO_4 \cdot 7H_2O$, 400 KCl, 150 $Ca(H_2PO_4)_2 \cdot 2H_2O$, 30 $Na_2B_4O_7 \cdot 10H_2O$, 50 $MnSO_4 \cdot 2H_2O$, 25 $CuSO_4 \cdot 5H_2O$, 15 $Co(CH_3COO)_2 \cdot 4H_2O$
27	6.0	1000 $CaCO_3$, 400 KCl, 100 $MgSO_4 \cdot 7H_2O$, 15 $ZnSO_4$, 20 $Na_2B_4O_7 \cdot 10H_2O$, 20 Co(CH COO)$_2 \cdot 4H_2O$, 25 $CuSO_4 \cdot 5H_2O$

Table 7. (continued)

Series number	pH of soil before potting	Pounds per acre of lime and fertilizer and minor element salts
28	5.7	1500 $CaCO_3$, 200 KCl, 100 $MgSO_4 \cdot 7H_2O$, 10 $ZnSO_4$, 25 $Na_2B_4O_7 \cdot 10H_2O$, 30 $MnSO_4 \cdot 2H_2O$, 15 $CuSO_4 \cdot 5H_2O$
29A	5.5	1000 $CaCO_3$, 200 KCl, 100 $MgSO_4 \cdot 7H_2O$, 15 $ZnSO_4$, 30 $Na_2B_4O_7 \cdot 10H_2O$, 60 $MnSO_4 \cdot 2H_2O$, 15 $CuSO_4 \cdot 5H_2O$, 15 $Co(CH_3COO)_2 \cdot 4H_2O$
29B	5.5	1000 $CaCO_3$, 400 KCl, 100 $MgSO_4$ $7H_2O$, 25 $CuSO_4$ $5H_2O$, 20 $Co(CH_3COO)_2$ $4H_2O$
30	5.8	1000 $CaCO_3$, 350 KCl, 75 $MgSO_4$ $7H_2O$, 10 $ZnSO_4$, 25 $Na_2B_4O_7$ $10H_2O$, 15 $CuSO_4$ $5H_2O$, 10 $Co(CH_3COO)_2$ $4H_2O$
31	6.0	1000 $CaCO_3$, 200 KCl, 100 $MgSO_4$ 7H O, 25 $Na_2B_4O_7$ $10H_2O$, 50 $MnSO_4$ $2H_2O$, 15 $CuSO_4$ $5H_2O$, 10 $Co(CH_3COO)_2$ $2H_2O$
32	6.5	400 KCl, 100 $MgSO_4$ $7H_2O$, 50 $MnSO_4$ $2H_2O$, 40 $Na_2B_4O_7$ 10 H_2O, 25 $CuSO_4$ $5H_2O$, 15 $Co(CH_3COO)_2$ $4H_2O$
33	6.0	1000 $CaCO_3$, 200 KCl, 75 $MgSO_4$ $7H_2O$, 30 $Na_2B_4O_7$ $10H_2O$, 50 $MnSO_4$ $2H_2O$, 15 $ZnSO_4$, 15 $CuSO_4$ 5 H_2O

cuttings the alfalfa roots were removed and the cultures were refertilized* and replanted to alfalfa.

Yield of Alfalfa as Affected by Treatment

Plainfield loamy sand---series 3---As indicated in Table 8 little response was obtained on Plainfield loamy sand from additions of calcium or boron alone, but calcium together with potassium gave substantial increases in yield of tops and roots, especially at the time of the third cutting. A further addition of manganese resulted in a still greater increase in yield of both tops and roots.

Fox sandy loam---series 5---On Fox sandy loam soil, significant increases in yield were obtained, as evidenced in Table 9, for all cuttings of both stands. In the first stand calcium and potassium resulted in yields no larger than did calcium alone, while calcium with phosphorus resulted in smaller yields than did calcium alone. However, where the three elements calcium, phosphorus, and potassium were applied the yields were increased and where magnesium, boron, manganese and copper were added to this treatment, increases in yield of 50 to 60 per cent resulted in the second and third cuttings. In the second stand calcium caused very little increase in yield but calcium and potassium resulted in increases up to 1000 per cent, while respective additions of magnesium, boron and magnesium, and boron, magnesium, manganese and copper caused in each case further increases in yield of tops and roots. Per cent nitrogen dropped off slightly with increases in yield and the protein content in grams varied directly with yields.

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*P was left out of the fertilizer treatments for the second stand of series 5, 6, 10, 12, 21, and 22.

Table 8. The mean yield of tops and roots of alfalfa grown in greenhouse pots on a Plainfield loamy sand* as affected by various fertilizer and minor element treatments

Treatments**	Tops cuttings			Roots
	1st	2nd	3rd	
	gms.	gms.	gms.	gms.
1. Check	4.4	2.1	4.3	5.4
2. B	4.4	2.2	5.3	7.2
3. Ca	4.3	2.1	4.9	7.9
4. Ca+K	5.0	2.7	7.4	14.6
5. Ca+K+Mg	4.9	2.8	7.6	15.0
6. Ca+K+Mg+Mn	5.4	3.3	8.2	15.8

*Data for series 3 given in Table 1.
**Kind and rate of treatments listed in Table 7.

Plate 1. Third cutting of alfalfa grown on Plainfield sand. Treatments listed above.

Table 9. Effect of different fertilizer treatments on the mean yield, per cent nitrogen, and protein content* of alfalfa grown in greenhouse pots on a Fox sandy loam soil*** from a good alfalfa stand.

Treatments****	FIRST STAND							
	First cutting		Second cutting		Third cutting		Roots	
	Mean yield per pot	Nitrogen	Mean yield per pot	Nitrogen	Mean yield per pot	Nitrogen	Mean yield per pot	Nitrogen
	grams	per cent	grams	per cent	grams	per cent	grams	per cent
Check	7.4	2.9	4.6	3.4	2.4	4.6	22.5	2.2
Ca	9.2	2.4	6.0	3.4	3.0	4.5	25.6	2.2
Ca+K	9.6	3.2	5.9	3.2	2.9	4.3	28.5	2.1
Ca+P	7.7	3.4	4.5	3.6	1.9	4.4	23.0	2.4
Ca+K+P	10.3	3.1	6.1	3.2	3.1	4.3	29.6	2.0
Ca+K+P+Mg+B+Mn+Cu	12.5	2.9	9.0	3.1	5.2	3.7	35.2	2.0
F value	26.2**		35.0**		29.0**			
Difference to be significant at 5% point	1.1		0.8		0.6			
Treatments****	SECOND STAND							
Check	1.3	2.9	0.8	3.6			3.0	2.5
Ca	1.6	3.7	0.7	3.7	No data collected		3.2	2.6
Ca+K	13.1	3.1	9.8	3.3			24.4	2.2
Ca+K+Mg	14.8	3.2	10.5	3.2			26.8	2.0
Ca+K+Mg+B	15.9	3.2	11.2	3.0			29.3	1.8
Ca+K+Mg+B+Mn+Cu	18.3	2.9	12.6	3.1			32.0	1.8
F value	159.3**		504.6**					
Difference to be significant at 5% point	1.8		0.7					

*All data based on oven dry plant material.
**Significant to 1% point.
***Data for Series 5 given in Table 1.
****Kind and rate of treatments given in Table 7.

Table 10. Per cent increase in the yield of alfalfa tops and roots grown in greenhouse pots on a Fox sandy loam soil* on comparison of various fertilizer and minor element treatments

Comparison of treatments**	First Stand: Tops, Cuttings, 1st	2nd	3rd	Roots
	per cent			per cent
Ca/No treatment	24.9	28.8	22.8	13.7
Ca+K/No treatment	30.2	27.1	20.0	26.7
Ca+P/No treatment	5.1	-2.0	-20.8	2.2
Ca+K+P/No treatment	40.0	31.4	29.2	31.5
Ca+K+P+Mg+B+Cu+Mn/No treatment	69.0	94.7	117.8	56.5
Ca+K/Ca	4.4	-1.0	-2.5	11.3
Ca+P/Ca	-15.6	-23.9	-35.5	-10.0
Ca+K+P/Ca	12.3	2.0	5.1	15.7
Ca+K+P/Ca+K	7.5	3.3	8.0	3.8
Ca+K+P/Ca+P	33.2	34.2	63.4	28.7
Ca+K+P+Mg+B+Cu+Mn/Ca+K+P	21.0	48.2	68.6	18.9
	Second Stand			
Ca/No treatment	30.0	-12.5		6.6
Ca+K/No treatment	950.0	1125.0		713.3
Ca+K+Mg/No treatment	1080.0	1212.5		793.3
Ca+K+Mg+B/No treatment	1175.0	1300.0	No	876.6
Ca+K+Mg+B+Cu+Mn/No treatment	1371.0	1475.0	data	966.6
Ca+K/Ca	708.0	1300.0	collected	662.5
Ca+K+Mg/Ca	808.5	1400.0		737.5
Ca+K+Mg/Ca+K	12.3	7.2		9.8
Ca+K+Mg+B/Ca+K+Mg	8.0	6.7		9.3
Ca+K+Mg+B+Cu+Mn/Ca+K+Mg	24.2	20.0		19.7
Ca+K+Mg+B+Cu+Mn/Ca+K+Mg+B	15.0	12.5		9.2

*Data for series 5 given in Table 1.

**Kind and rate of treatments listed in Table 7.

Fox sandy loam---series 6---The alfalfa in all cuttings of the first and second stand showed a significant response to treatment. This is shown by the results reported in Table 11. The data in Table 12 show that calcium resulted in only a small increase in yield, while alfalfa grown in pots treated with calcium and potash made up to 60 per cent better growth at the third cutting of the first stand. Phosphorus appeared to depress the yields. The combination of magnesium, boron, manganese and copper definitely helped to maintain legume yields when used with calcium and potassium. In the second stand potassium was very efficient in increasing the growth of alfalfa. Its effect was especially marked in the roots. Magnesium caused further increases in yield, as did also boron and manganese and copper. Nitrogen and protein relations were the same as reported for series 5.

Fox fine sandy loam---series 10---On Fox fine sandy loam as shown in Table 13 significant increases in yield were obtained as a result of all treatments which included potassium. As shown in Table 14 the increase in yield of tops ranged as high as 127 per cent of the yield of the untreated pots in the first stand and 406 per cent in the second stand. Calcium alone did not cause a significant increase in yield in either stand. Calcium plus phosphorus caused significant increases in yield in the first and third cuttings of the first stand but not in the second cutting. Applications of both phosphorus and potash in addition to calcium, however, resulted in yields decidedly higher than did either element alone. A further addition of magnesium, boron, manganese, and copper caused slight increases in the yields obtained in the first two cuttings of the first stand and a significant increase in the third cutting.

Table 11. **Effect of different fertilizer treatments on the mean yield, per cent nitrogen, and protein content* of alfalfa grown in greenhouse pots on a Fox sandy loam soil*** from a good alfalfa stand**

Treatments****	First cutting		Second cutting		Third cutting		Roots	
	FIRST STAND							
	Mean yield per pot	Nitrogen	Mean yield per pot	Nitrogen	Mean yield per pot	Nitrogen	Mean yield per pot	Nitrogen
	grams	per cent	grams	per cent	grams	per cent	grams	per cent
Check	6.3	2.8	4.5	3.3	2.0	4.3	19.8	2.8
Ca	5.8	2.8	4.7	3.5	2.2	4.2	18.5	2.6
Ca+K	8.5	3.0	5.7	3.2	3.1	4.1	25.4	2.2
Ca+P	8.3	2.9	5.4	3.4	2.5	4.0	23.2	2.2
Ca+K+P	10.4	3.1	6.4	3.4	2.4	4.2	27.0	2.3
Ca+K+P+Mg+B+Mn+Cu	11.9	2.8	7.7	3.2	4.9	3.8	33.1	1.9
F value	61.0**		7.9**		13.1**			
Difference to be significant at 5% point	0.9		1.2		0.9			
Treatments****	**SECOND STAND**							
Check	1.2	2.8	0.7	3.6	No data collected		3.2	2.6
Ca	1.0	3.8	1.0	3.2			2.9	2.7
Ca+K	10.8	2.7	7.7	3.1			20.1	2.2
Ca+K+Mg	14.8	3.0	9.5	3.2			23.2	2.3
Ca+K+Mg+B	15.9	2.6	11.7	2.8			25.8	2.1
Ca+K+Mg+B+Mn+Cu	16.2	2.9	12.3	3.0			28.5	2.0
F value	78.6**		817.2**					
Difference to be significant at 5% point	2.4		0.6					

*All data based on oven dry plant material.

**Significant to 1% point.

***Data for Series 5 given in Table 1.

****Kind and rate of treatments given in Table 7.

Table 12. Per cent increases in the yield of alfalfa tops and roots grown in greenhouse pots on a Fox sandy loam soil* on comparison of various fertilizer and minor element treatments

Comparison of treatments**	First Stand			
	Tops			Roots
	Cuttings			
	1st	2nd	3rd	
	per cent			per cent
Ca/No treatment	-7.8	4.4	11.3	-6.6
Ca+K/No treatment	35.0	27.2	57.1	28.3
Ca+P/No treatment	31.3	22.1	26.8	17.2
Ca+K+P/No treatment	66.0	42.2	19.0	36.4
Ca+K+P+Mg+B+Cu+Mn/No treatment	88.5	70.6	147.3	67.2
Ca+K/Ca	46.5	22.0	41.0	37.3
Ca+P/Ca	42.9	17.0	13.7	25.4
Ca+K+P/Ca	80.2	36.3	7.0	45.9
Ca+K+P/Ca+K	23.0	11.8	-24.3	6.3
Ca+K+P/Ca+P	26.1	16.3	-6.0	16.4
Ca+K+P+Mg+B+Mn+Cu/Ca+K+P	13.1	20.0	107.8	22.6
	Second Stand			
Ca/No treatment	-14.5	42.9		-9.4
Ca+K/No treatment	801.0	1000.0		528.1
Ca+K+Mg/No treatment	1130.0	1257.1	No	625.0
Ca+K+Mg+B/No treatment	1230.0	1571.4	data	706.3
Ca+K+Mg+B+Mn+Cu/No treatment	1250.0	1657.1	collected	790.6
Ca+K/Ca	954.0	670.0		593.1
Ca+K+Mg/Ca	1340.0	850.0		700.0
Ca+K+Mg/Ca+K	36.6	23.4		15.4
Ca+K+Mg+B/Ca+K+Mg	8.1	23.2		11.2
Ca+K+Mg+B+Cu+Mn/Ca+K+Mg	9.8	29.5		22.9
Ca+K+Mg+B+Cu+Mn/Ca+K+Mg+B	1.5	5.1		10.4

*Data for series 6 given in Table 1.

**Kind and rate of treatments listed in Table 7.

Table 13. **Effect of different fertilizer treatments on the mean yield, per cent nitrogen, and protein content* of alfalfa grown in greenhouse pots on a Fox fine sandy loam soil*** from a fair alfalfa stand**

Treatments****	FIRST STAND							
	First cutting		Second cutting		Third cutting		Roots	
	Mean yield per pot	Nitrogen	Mean yield per pot	Nitrogen	Mean yield per pot	Nitrogen	Mean yield per pot	Nitrogen
	grams	per cent	grams	per cent	grams	per cent	grams	per cent
Check	6.4	3.5	4.1	3.5	1.5	4.4	15.5	2.6
Ca	7.2	3.3	4.2	3.6	1.8	4.5	18.0	2.5
Ca+K	9.0	3.1	5.3	3.4	2.4	4.1	22.0	2.5
Ca+P	7.9	3.0	4.6	3.5	2.0	4.3	19.6	2.6
Ca+K+P	8.6	3.3	5.7	3.3	2.6	4.2	24.6	2.3
Ca+K+P+Mg+B+Mn+Cu	8.8	3.1	5.9	3.4	3.4	3.9	23.5	2.1
F value	5.1**		11.5**		18.0**			
Difference to be significant at 5% point	1.3		0.7		0.5			
Treatments****	SECOND STAND							
Check	2.4	3.6	1.6	4.2	No data collected		3.1	2.8
Ca	2.0	4.0	1.2	4.0			3.2	2.6
Ca+K	7.5	3.4	4.8	3.7			13.6	2.4
Ca+K+Mg	8.0	3.1	5.2	3.7			14.4	2.3
Ca+K+Mg+B	10.0	3.2	7.8	3.5			16.5	2.3
Ca+K+Mg+B+Mn+Cu	9.5	2.9	8.1	3.5			14.8	2.3
F value	79.7**		314.0**					
Difference to be significant at 5% point	1.2		0.5					

*All data based on oven dry plant material.
**Significant to 1% point.
***Data for Series 10 given in Table 1.
****Kind and rate of treatments given in Table 7.

Table 14. Per cent increase in the yield of alfalfa tops and roots grown in greenhouse pots on a Fox fine sandy loam soil* on comparison of various fertilizer and minor element treatments

Comparison of treatments**	First Stand: Tops, Cuttings 1st	2nd	3rd	Roots
	per cent			per cent
First Stand				
Ca/No treatment	12.5	3.0	21.7	16.1
Ca+K/No treatment	40.8	28.0	58.3	41.9
Ca+P/No treatment	23.4	11.6	31.6	26.4
Ca+K+P/No treatment	34.5	38.0	73.5	58.5
Ca+K+P+Mg+B+Mn+Cu/No treatment	37.0	43.3	127.0	51.6
Ca+K/Ca	29.6	24.2	30.0	22.0
Ca+P/Ca	13.8	8.1	8.2	8.9
Ca+K+P/Ca	19.5	33.9	42.5	36.7
Ca+K+P/Ca+K	-4.4	7.6	9.5	11.8
Ca+K+P/Ca+P	9.0	23.8	4.0	25.5
Ca+K+P+Mg+B+Mn+Cu/Ca+K-P	2.1	4.0	30.8	-4.5
Second Stand				
Ca/No treatment	-18.6	-25.0		3.2
Ca+K/No treatment	214.0	200.0		339.1
Ca+K+Mg/No treatment	231.3	225.0		364.5
Ca+K+Mg+B/No treatment	317.0	387.5	No	432.3
Ca+K+Mg+B+Mn+Cu/No treatment	281.5	406.3	data	377.4
Ca+K/Ca	282.0	300.0	collected	325.0
Ca+K+Mg/Ca	308.0	333.3		350.0
Ca+K+Mg/Ca+K	6.7	8.4		5.9
Ca+K+Mg+B/Ca+K+Mg	25.8	50.0		14.6
Ca+K+Mg+B+Mn+Cu/Ca+Mg+K	15.1	55.8		2.8
Ca+K+Mg+B+Mn+Cu/Ca+Mg+K+B	-8.4	4.0		-10.3

*Data for series 10 given in Table 1.

**Kind and rate of treatments listed in Table 7.

In the second stand, magnesium caused slight increases in yield, ranging in percentage from 5.9 in the roots to 8.4 in the tops. An addition of boron caused significant increases in yield in both cuttings and in the yield of roots, the increases amounting to 25.8, 50.0, and 14.6 per cent respectively. No significant increases in yield were caused by applications of manganese and copper.

Fox sandy loam---series 11---According to the results reported in Table 15, the application of boron to a Fox sandy loam soil caused slight increases in the yield of the first and third cuttings of alfalfa and a significant increase in the yield of the second and fourth cuttings. An application of calcium increased the yield slightly at the second cutting and significantly in the last two cuttings.

Potassium in addition to calcium caused significant increases in the yield of all four cuttings but no further increases in yield were obtained by adding phosphorus or magnesium to the fertilizer. Copper, however, when added in combination with magnesium, potassium, and calcium caused significant increases in the yields of the first three cuttings.

Fox loam---series 12---As indicated by the results presented in Table 16, calcium did not significantly increase alfalfa yields on Fox loam. In fact, decreases in yield resulted in five out of six cases, considering both tops and roots. Potash in addition to calcium caused significant increases in yield in all cases but an addition of phosphorus to the calcium-potash treatment did not cause further increases in yield large enough to be significant. Phosphorus and calcium, without potassium, did not result in yields significantly larger than those obtained from treatment with calcium alone.

Table 15. The mean yield of tops of alfalfa grown on a Fox sandy loam* as affected by various fertilizer and minor element treatments

Treatment***	Cuttings			
	1st	2nd	3rd	4th
	grams	grams	grams	grams
Check	5.9	2.4	5.0	3.2
B	6.2	2.6	5.5	5.1
Ca	5.9	2.6	6.9	5.9
Ca+K	8.2	3.7	10.2	8.7
Ca+K+P	7.6	3.8	9.8	8.3
Ca+K+Mg	7.3	3.4	10.7	8.9
Ca+K+Mg+Cu	9.3	4.4	12.0	9.8
F value	15.0**	24.0**	43.4**	38.5**
Difference to be significant at the 5% point	0.9	0.2	1.2	1.4

*Data for series 11 given in Table 1.

**Significant at the 1% point.

***Kind and rate of treatments listed in Table 7.

Table 16. Effect of different fertilizer treatments on the mean yield, per cent nitrogen, and protein content* of alfalfa grown in greenhouse pots on a Fox loam soil*** from a good alfalfa stand

Treatments***	FIRST STAND TOPS First cutting Mean yield per pot	First cutting Nitrogen	Second cutting Mean yield per pot	Second cutting Nitrogen	Third cutting Mean yield per pot	Third cutting Nitrogen	Roots Mean yield per pot	Roots Nitrogen
	grams	per cent	grams	per cent	grams	per cent	grams	per cent
Check	7.3	2.9	4.9	3.6	1.9	4.3	16.3	2.4
Ca	8.4	2.9	3.7	3.7	1.7	4.6	17.2	2.4
Ca+K	11.1	2.8	5.2	3.3	2.7	4.3	25.4	2.0
Ca+P	9.1	2.7	3.6	3.8	2.2	4.2	19.8	2.4
Ca+K+P	10.1	3.1	5.4	3.4	3.2	4.2	26.0	2.0
Ca+K+P+Mg+B+Mn+Cu	10.4	3.2	5.8	3.4	4.7	4.2	28.6	1.9
F value	10.4**		8.3**		23.5**			
Difference to be significant at 5% point	1.2		1.0		0.6			
Treatments****	**SECOND STAND**							
Check	1.3	3.9	0.8	4.1	No data collected		2.6	2.5
Ca	0.9	4.0	0.5	4.3			2.0	2.5
Ca+K	6.6	3.5	4.4	3.7			13.5	2.1
Ca+K+Mg	6.9	3.4	5.2	3.6			14.0	2.0
Ca+K+Mg+B	7.8	3.3	6.5	3.6			15.3	1.9
Ca+K+Mg+B+Mn+Cu	9.3	3.5	8.0	3.4			16.1	2.0
F value	49.5**		262.9**					
Difference to be significant at 5% point	1.5		0.6					

*All data based on oven dry plant material.
**Significant to 1% point.
***Data for Series 12 given in Table 1.
****Kind and rate of treatments given in Table 7.

The combination of magnesium, boron, manganese, and copper did not increase yields in the first two cuttings of the first stand but caused an increase in the third cutting, according to Table 17, of 47.5 per cent.

In the second stand calcium again failed to affect yields. Potassium applications caused very marked increases in yield. Magnesium and boron, considered singly, both caused significant increases in yield in the second cutting but not in the first, and probably not in the root yields. The combination of boron, manganese, and copper caused significant increases in yield in the top growth from both cuttings and probably in the roots. According to the data, much of the increase was due to the manganese and the copper.

Warsaw loam---series 21---In the experiment with Warsaw loam from a poor alfalfa field, Table 18, calcium failed to cause significant increases in yield in either stand as did also potash, applied in addition to calcium in the first stand. Phosphorus applied with calcium caused a significant increase in the yield of the third cutting but not of the first two cuttings. A combination of potash and phosphorus, applied with calcium increased the yields in the first and third cuttings of the first stand. The group of elements, magnesium, boron, manganese, and copper was effective in increasing yields, as shown in Table 19, 10.6, 8.4, and 10.0 per cent, respectively, in the three cuttings of the first stand. The increases, considering as a basis the yields obtained from the pots treated only with calcium, phosphorus, and potassium, were significant in the first and third cuttings but not in the second.

In the second stand potash again caused very marked increases in yield. Magnesium caused slight increases in yield and boron caused a significant

Table 17. Per cent increase in the yield of alfalfa tops and roots grown in greenhouse pots on a Fox loam soil* on comparison of various fertilizer and minor element treatments

Comparison of treatments**	First Stand			
	Tops			Roots
	Cuttings			
	1st	2nd	3rd	
	per cent			per cent
Ca/No treatment	15.0	-16.0	-9.2	-5.5
Ca+K/No treatment	51.0	14.3	44.1	55.8
Ca+P/No treatment	24.4	-16.5	17.3	21.4
Ca+K+P/No treatment	37.0	25.0	68.2	59.9
Ca+K+P+Mg+B+Mn+Cu/No treatment	37.7	32.1	148.0	75.4
Ca+K/Ca	31.5	36.3	66.4	47.6
Ca+P/Ca	8.3	0.5	29.5	15.1
Ca+K+P/Ca	19.2	48.7	85.4	51.2
Ca+K+P/Ca+K	-9.2	9.0	16.5	2.4
Ca+K+P/Ca+P	10.0	49.8	43.4	31.3
Ca+K+P+Mg+B+Mn+Cu/Ca+K+P	0.4	6.0	47.5	10.0
	Second Stand			
Ca/No treatment	-32.0	-37.5		-23.1
Ca+K/No treatment	433.0	450.0		419.2
Ca+K+Mg/No treatment	450.0	550.0	No	438.5
Ca+K+Mg+B/No treatment	525.0	712.5	data	488.2
Ca+K+Mg+B+Mn+Cu/No treatment	693.0	900.0	collected	519.2
Ca+K/Ca	674.0	780.0		575.0
Ca+K+Mg/Ca	710.0	940.0		600.0
Ca+K+Mg/Ca+K	4.6	18.2		3.7
Ca+K+Mg+B/Ca+K+Mg	13.5	25.0		9.3
Ca+K+Mg+B+Mn+Cu/Ca+K+Mg	34.0	53.9		15.0
Ca+K+Mg+B+Mn+Ca/Ca+K+Mg+B	18.3	23.1		5.2

*Data for series 12 given in Table 1.

**Kind and rate of treatments listed in Table 7.

Table 18. **Effect of different fertilizer treatments on the mean yield, per cent nitrogen, and protein content* of alfalfa grown in greenhouse pots on a Warsaw loam soil*** from a poor alfalfa stand**

Treatments****	FIRST STAND							
	First cutting		Second cutting		Third cutting		Roots	
	Mean yield per pot	Nitrogen	Mean yield per pot	Nitrogen	Mean yield per pot	Nitrogen	Mean yield per pot	Nitrogen
	grams	per cent	grams	per cent	grams	per cent	grams	per cent
Check	10.9	3.1	6.5	3.2	3.8	4.5	32.0	2.2
Ca	9.5	3.1	6.3	3.3	3.9	4.3	28.5	2.5
Ca+K	9.4	3.7	6.3	3.1	3.9	4.1	31.0	2.2
Ca+P	9.6	3.6	6.5	3.3	4.6	4.2	30.0	2.2
Ca+K+P	12.3	3.0	6.9	3.0	5.9	3.7	37.3	1.8
Ca+K+P+Mg+B+Mn+Cu	13.7	2.8	7.4	3.0	6.5	4.0	41.6	1.6
F value	26.6**		4.0*		50.2**			
Difference to be significant at 5% point	1.1		0.7		0.5			
Treatments****	**SECOND STAND**							
Check	2.1	3.7	2.5	---			3.8	2.4
Ca	2.4	3.8	3.3	3.4	No data collected		4.5	2.6
Ca+K	8.6	3.3	10.8	3.3			16.1	2.1
Ca+K+Mg	10.1	3.5	12.4	3.5			18.5	2.3
Ca+K+Mg+B	14.4	3.7	13.9	3.5			21.2	2.0
Ca+K+Mg+B+Cu+Mn	14.5	3.1	11.7	3.5			23.5	1.9
F value	74.3**		48.6**					
Difference to be significant at 5% point	1.8		2.1					

*All data based on oven dry plant material.
**Significant to 1% point.
***Data for Series 21 given in Table 1.
****Kind and rate of treatments given in Table 7.

Table 19. Per cent increase in the yield of alfalfa tops and roots grown in greenhouse pots on a Warsaw loam soil* on comparison of various fertilizer and minor element treatments

Comparison of treatments**	First Stand			
	Tops			Roots
	Cuttings			
	1st	2nd	3rd	
	per cent			per cent
Ca/No treatment	-13.2	-3.0	3.2	-10.2
Ca+K/No treatment	-14.0	-2.2	2.0	-3.1
Ca+P/No treatment	-12.6	0.8	21.0	-6.2
Ca+K+P/No treatment	13.7	6.1	56.0	16.6
Ca+K+P+Mg+B+Mn+Cu/No treatment	25.2	15.2	71.9	30.0
Ca+K/Ca	-0.8	0.8	-1.2	8.8
Ca+P/Ca	0.7	4.0	17.0	5.3
Ca+K+P/Ca	30.7	9.6	51.0	30.9
Ca+K+P/Ca-K	31.6	8.7	53.1	20.3
Ca+K+P/Ca-P	29.5	5.3	29.0	24.3
Ca+K+P+Mg+B+Mn+Cu/Ca+K+P	10.6	8.4	10.0	11.3
	Second Stand			
Ca/No treatment	61.3	35.0		18.4
Ca+K/No treatment	306.0	343.0		323.7
Ca+K+Mg/No treatment	377.0	404.0		386.8
Ca+K+Mg+B/No treatment	575.0	465.0	No	458.0
Ca+K+Mg+B+Mn+Cu/No treatment	573.0	368.0	data	518.4
Ca+K/Ca	152.0	288.0	collected	257.8
Ca+K+Mg/Ca	196.0	274.0		300.0
Ca+K+Mg/Ca-K	17.4	14.0		14.9
Ca+K+Mg+B/Ca+K+Mg	42.0	12.0		14.6
Ca+K+Mg+B+Mn+Cu/Ca+K+Mg	43.5	-5.0		26.0
Ca+K+Mg+B+Mn+Cu/Ca+K+Mg+B	-1.0	-15.1		10.9

*Data for series 21 given in Table 1.

**Kind and rate of treatments listed in Table 7.

increase in yield in the first cutting but not in the second. The data presented in Table 18 indicate no benefit, at least in yield of tops, from the application of manganese and copper. There may have been a slight increase in the yield of roots as a result of the addition of these two elements.

Warsaw loam---series 22---On Warsaw loam soil, taken from a field where there was a good stand of alfalfa, there was no response as shown in Table 20 to any of the treatments at the first cutting of the first stand. At the second and third cuttings there was no response to calcium, potassium, and phosphorus, but the further addition of magnesium, boron, manganese, and copper resulted in highly significant increases in yield. Since this soil produced good alfalfa in the field it is not surprising that the response to fertilizer should be less in the first stand than that obtained on soils where the field crop had been very poor.

After alfalfa was replanted on this soil there was still no response to calcium but a very marked response to potash and a statistically significant response to magnesium. Boron caused a significant increase in the yield of the second cutting and probably of the roots. Manganese and copper did not cause a further increase in yield.

Emmet loamy sand---series 24---This soil produced a poor stand of alfalfa in the field. Likewise the yields produced in the greenhouse were low. There were, however, several significant increases in yields resulting from the various treatments, as shown by the data in Tables 22, 23, and 24. Calcium alone caused significant increases in the yield of the fourth cutting of the first stand and in both cuttings of the second stand but caused a

Table 20. Effect of different fertilizer treatments on the mean yield, per cent nitrogen, and protein content* of alfalfa grown in greenhouse pots on a Warsaw loam soil*** from a good alfalfa stand

Treatments****	FIRST STAND TOPS							
	First cutting		Second cutting		Third cutting		Roots	
	Mean yield per pot	Nitrogen	Mean yield per pot	Nitrogen	Mean yield per pot	Nitrogen	Mean yield per pot	Nitrogen
	grams	per cent	grams	per cent	grams	per cent	grams	per cent
Check	12.7	3.1	7.0	3.4	4.5	4.4	36.2	2.5
Ca	12.6	3.1	6.6	3.3	4.6	4.3	35.4	2.5
Ca+K	12.8	3.7	7.3	3.1	4.7	3.8	35.5	2.5
Ca+P	11.5	3.6	6.3	3.5	3.7	4.1	34.0	2.8
Ca+K+P	12.2	3.0	6.8	3.2	4.4	3.9	37.8	2.1
Ca+K+P+Mg+B+Mn+Cu	13.3	2.8	8.2	3.3	6.4	3.5	45.0	1.8
F value	1.41		5.67**		26.10**			
Difference to be significant at 5% point	1.5		0.8		0.7			
Treatments****	SECOND STAND							
Check	4.8	3.7	4.3	4.0	No data collected		6.6	2.5
Ca	4.4	4.0	4.8	4.4			6.8	2.5
Ca+K	15.4	3.0	14.4	3.3			23.1	2.2
Ca+K+Mg	17.7	3.1	15.8	3.1			28.5	2.3
Ca+K+Mg+B	19.0	3.2	17.9	3.1			33.2	2.3
Ca+K+Mg+B+Mn+Cu	19.8	3.3	18.0	3.2			35.0	2.1
F value	198.4**		890.8**					
Difference to be significant at 5% point	1.6		0.7					

*All data based on oven dry plant material.
**Significant to 1% point.
***Data for Series 22 given in Table 1.
****Kind and rate of treatments given in Table 7.

Table 21. Per cent increase in the yield of alfalfa tops and roots grown in greenhouse pots on a Warsaw loam soil* on comparison of various fertilizer and minor element treatments

Comparison of treatments**	First Stand: Tops, Cuttings 1st	2nd	3rd	Roots
	per cent			per cent
Ca/No treatment	-1.0	-5.6	0.5	-2.2
Ca+K/No treatment	0.5	4.2	2.9	-1.9
Ca+P/No treatment	-9.6	-10.6	-18.7	-6.1
Ca+K+P/No treatment	-3.5	-3.1	-5.0	4.4
Ca+K+P+Mg+B+Mn+Cu/No treatment	4.5	16.0	42.0	16.0
Ca+K/Ca	1.5	10.5	2.2	0.3
Ca+P/Ca	-8.6	-5.2	-19.0	-4.0
Ca+K+P/Ca	-2.5	2.5	-5.4	6.7
Ca+K+P/Ca-K	-4.0	-7.0	-7.5	6.4
Ca+K+P/Ca+P	6.6	8.3	17.0	11.2
Ca+K+P+Mg+B+Mn+Cu/Ca+K+P	8.4	20.0	49.4	11.1
	Second Stand			
Ca/No treatment	-7.7	11.7	No data collected	3.0
Ca+K/No treatment	221.0	234.9		250.0
Ca+K+Mg/No treatment	268.0	267.4		332.0
Ca+K+Mg+B/No treatment	295.0	316.3		403.0
Ca+K+Mg+B+Mn+Cu/No treatment	312.5	318.6		430.3
Ca+K/Ca	248.0	200.0		339.7
Ca+K+Mg/Ca	300.0	229.2		319.1
Ca+K+Mg/Ca+K	14.6	9.7		23.4
Ca+K+Mg+B/Ca+K+Mg	7.3	13.3		16.5
Ca+K+Mg+B+Mn+Cu/Ca+K+Mg	12.0	13.8		22.8
Ca+K+Mg+B+Mn+Cu/Ca+K+Mg+B	4.4	0.6		5.4

*Data for series 22 given in Table 1.

**Kind and rate of treatments listed in Table 7.

Plate 2. Second stand, second cutting of alfalfa grown on a Fox sandy loam, series 5. Treatments 1. Check, 2. Ca, 3. Ca+K, 4. Ca+K+Mg, 5. Ca+K+Mg+B, 6. Ca+K+Mg+B+Mn+Cu.

Plate 3. Second stand, second cutting of alfalfa grown on a Warsaw loam, series 22. Treatments 1. Check, 2. Ca, 3. Ca+K, 4. Ca+K+Mg, 5. Ca+K+Mg+B, 6. Ca+K+Mg+B+Mn+Cu.

Table 22. The mean yield of tops and roots of alfalfa grown in greenhouse pots on an Emmet loamy sand soil* as affected by various fertilizer and minor element treatments

Treatment**	First Stand					Second Stand		
	Tops				Roots	Tops		Roots
	Cuttings					Cuttings		
	1st	2nd	3rd	4th		1st	2nd	
	grams				grams	grams		grams
No treatment	4.8	3.6	1.4	0.9	4.5	1.9	1.5	3.5
Ca	5.2	3.8	1.5	1.2	4.3	2.1	1.9	3.2
Ca+B	5.9	4.4	1.9	1.5	4.8	2.3	2.2	3.8
Ca+B+Mg	6.5	5.2	2.5	1.7	5.4	2.9	2.1	4.0
Ca+B+Mg+Mn	5.6	5.5	2.6	1.6	5.6	2.5	2.3	3.6
Ca+B+Mg+Mn+Co+Zn	5.0	4.8	2.1	1.3	4.4	2.3	2.3	3.5
Ca+K	5.5	4.9	2.4	1.4	7.4	2.5	2.4	4.2
Ca+K+B	5.6	5.5	3.0	1.6	8.0	2.7	2.5	4.6
Ca+K+B+Mg	6.7	6.4	3.4	1.9	9.2	2.8	3.0	5.3
Ca+K+B+Mg+Mn	5.8	5.7	3.2	1.8	7.6	3.1	2.9	5.0
Ca+K+B+Mg+Mn+Co+Zn	6.4	6.0	3.3	1.8	8.6	2.9	3.2	5.6

*Data for series 24 given in Table 1.

**Kind and rate of treatments listed in Table 7.

Table 23. The analysis of variance of the yield of tops and roots of alfalfa grown on an Emmet loamy sand soil (series 24) as listed in Table 22

Source	DF	FIRST STAND									
		Tops								Roots	
		First cutting		Second cutting		Third cutting		Fourth cutting			
		SS	MS	SS	MS	SS	MS	SS	MS	SS	MS
Total	39	23.35		30.33		15.93		2.64		127.08	
Blocks (Bk)	3	0.66	0.22	0.14	0.05	0.03	0.01	0.18	0.06	0.83	
Fertilizers (F)	1	1.33	1.33	9.12	9.12**	8.37	8.37**	0.46	0.46**	105.30	105.30**
Bk x F	3	1.26	0.42	0.41	0.14	0.01	0.003	0.02	0.01	2.77	0.92
Minor elements (M El)	4	3.67	0.92	10.37	2.59**	5.15	1.29**	1.32	0.33**	8.68	2.17*
F x M El	4	6.60	1.65	1.54	0.39	0.92	0.08	0.23	0.06	4.80	1.20
Bk x M El	12	8.26	0.69	4.87	0.41	0.49	0.12	0.18	0.02	2.03	0.17
Bk x F x M El	12	1.57	0.13	3.88	0.32	0.96	0.08	0.25	0.02	2.67	0.22
Difference to be significant at 5% point***		0.7 0.6		0.4 0.6		0.1 0.3		0.1 0.1		1.0 0.5	

Table 23. (continued)

Source	DF	SECOND STAND									
		Tops								Roots	
		First cutting		Second cutting		Third cutting		Fourth cutting			
		SS	MS	SS	MS	SS	MS	SS	MS	SS	MS
Total	39	5.98		7.76						27.34	
Blocks (Bk)	3	0.07		0.05						0.49	
Fertilizers (F)	1	1.45	1.45**	3.96	3.96**					16.77	16.77**
Bk x F	3	0.18	0.06	0.04	0.01	No data collected		No data collected		1.09	0.36
Minor elements (M El)	4	1.63	0.41*	1.83	0.46					4.69	1.17
F x M El	4	0.62	0.16	0.44	0.11					1.85	0.46
Bk x M El	12	0.83	0.07	1.04	0.09					0.81	0.07
Bk x F x M El	12	1.20	0.10	0.40	0.03					1.64	0.14
Difference to be significant at 5% point***		0.3 0.3		0.1 0.2						0.6 0.3	

*Significant to 5% point.

**Significant to 1% point.

***Upper value is difference required between fertilizer means; lower value is difference required between minor element means.

Table 24. Per cent increase in the yield of alfalfa tops and roots grown in greenhouse pots on an Emmet loamy sand soil* on comparison of various fertilizer and minor element treatments

Comparison of treatments**	First Stand Tops Cuttings 1st	2nd	3rd	4th	First Stand Roots	Second Stand Tops Cuttings 1st	2nd	Second Stand Roots
	per cent				per cent	per cent		per cent
Ca/No treatment***	7.9	7.0	3.3	29.6	-5.1	10.5	26.7	-8.6
Ca+K/No treatment***	15.8	38.0	65.5	46.0	63.0	31.6	60.0	19.4
Ca+K/Ca	7.3	29.0	60.0	12.5	71.4	19.1	26.3	30.7
Ca+K+B/Ca+B	-5.5	25.6	53.4	6.8	67.9	17.4	13.6	21.1
Ca+K+B+Mg/Ca+B+Mg	3.0	23.0	35.0	13.1	68.6	-3.4	42.9	32.1
Ca+K+B+Mg+Mn/Ca+B+Mg+Mn	3.5	3.2	21.0	6.0	37.4	24.0	26.1	37.9
Ca+K+B+Mg+Mn+Co+Zn/Ca+B+Mg+Mn+Co+Zn	28.0	14.0	59.5	39.0	93.2	26.1	39.1	57.7
<u>Ca Fertilizer</u>								
B/Check****	15.0	16.0	12.8	25.0	10.5	9.5	15.8	11.6
B+Mg/Check****	26.2	36.8	67.0	41.8	26.1	38.1	10.5	25.2
B+Mg+Mn/Check****	8.0	44.0	90.5	37.5	29.1	19.1	21.1	14.2
B+Mg+Mn+Co+Zn/Check****	-3.7	25.7	38.2	6.2	2.9	9.5	21.1	11.8
B+Mg/B	9.5	18.2	30.0	13.4	14.2	26.1	-4.5	4.6
B+Mg+Mn/B	-6.0	24.6	35.4	10.0	16.8	8.7	4.5	-4.6
B+Mg+Mn/B+Mg	-14.5	5.3	4.0	-3.0	2.3	-13.8	9.5	-8.8
B-Mg-Mn-Co-Zn/B-Mg-Mn	-10.0	-12.6	-20.2	-22.6	-20.0	-8.0	0.0	-2.1

Table 24. (continued)

Comparison of treatments**	First Stand					Second Stand		
	Tops				Roots	Tops		Roots
	Cuttings					Cuttings		
	1st	2nd	3rd	4th		1st	2nd	
	per cent				per cent	per cent		per cent
Ca+K Fertilizer								
B/Check****	1.3	12.8	23.0	18.5	8.1	8.0	4.2	10.8
B+Mg/Check****	20.8	30.5	40.7	42.5	24.1	12.0	25.0	26.5
B+Mg+Mn/Check****	4.0	15.4	31.2	29.5	3.4	24.0	20.8	20.5
B+Mg+Mn+Co+Zn/Check****	15.0	21.4	37.8	31.3	15.9	16.0	33.3	34.9
B+Mg/B	19.2	16.0	14.5	20.2	14.7	3.7	20.0	14.1
B+Mg+Mn/B	2.7	2.2	7.0	9.2	-4.4	14.8	16.0	8.6
B+Mg+Mn/B+Mg	-13.6	-11.5	-6.6	-9.0	-16.7	10.7	-3.3	-4.8
B+Mg+Mn+Co+Zn/B+Mg+Mn	10.5	-3.5	5.0	1.2	12.1	-6.5	10.3	12.0

*Data for series 24 given in Table 1.

**Kind and rate of treatments listed in Table 7.

***No fertilizer or minor element treatment.

****Check refers to fertilizer treatment alone under the respective fertilizer heading.

reduction in the root yields of both stands. Potassium applied in addition to calcium increased, significantly all yields except the first cutting of the first stand. The increases ranged in percentage from 7.3 to 71.4 (Table 24).

Boron when applied in addition to calcium caused significant increases in yield in all cases except the first cutting of the second stand and where it was applied in addition to calcium and potash it caused significant increases in all cases except the first cutting of the first stand and the two top growth yields of the second stand.

Magnesium resulted in increased yields in all cases except one, the second cutting of the second stand in the no potash group. Most of the increases in yield were significant.

Manganese was apparently not needed on this Emmet loamy sand soil. There were more cases of decreases than of increases in yield as a result of the addition of the element to the fertilizer mixtures.

Cobalt and zinc added together to the fertilizer mixtures caused decreases in yield 9 out of 16 times.

Emmet sandy loam---series 25---According to the data shown in Table 25, this Emmet sandy loam, which produced a fair stand of alfalfa in the field responded quite markedly to various mixtures of calcium and magnesium with potassium both with and without certain combinations of the minor elements. However, very slight increases in yield were obtained from additions of calcium and magnesium. Apparently the potassium was the most needed element. Where potassium was omitted from the mixtures, boron caused an increase in yield amounting to as much as 25 per cent on

Table 25. The mean yield of tops and roots of alfalfa grown in greenhouse pots on an Emmet sandy loam soil* as affected by various fertilizers and minor elements, and the per cent increase in yield upon comparison of treatments***

Treatment**	Tops Cuttings 1st	Tops Cuttings 2nd	Tops Cuttings 3rd	Roots	Comparison of treatments	Tops Cuttings 1st	Tops Cuttings 2nd	Tops Cuttings 3rd	Roots
	grams			grams	Ca+Mg Fertilizer	per cent			per cent
No treatment	5.3	2.8	2.0	6.8	B/Check	9.3	12.5	9.1	25.0
Ca+Mg	5.4	3.2	2.2	6.4	Co+Cu/Check	11.1	18.8	27.3	4.7
Ca+Mg+B	5.9	3.6	2.4	8.0	B+Co+Cu/Check	-1.9	-3.1	13.6	23.1
Ca+Mg+Co+Cu	6.0	3.8	2.8	6.7	B+Cu+Zn/Check	33.3	31.3	36.4	48.4
Ca+Mg+B+Co+Cu	5.3	3.1	2.5	7.8	B+Co+Cu/B	-10.2	-13.9	4.2	-2.5
Ca+Mg+B+Cu+Zn	7.2	4.2	3.0	9.5	B+Co+Cu/Co+Cu	-11.7	-18.4	-10.7	16.4
					B+Cu+Zn/B	22.0	16.7	25.0	18.7
					Mg+K Fertilizer				
Mg+K	7.7	6.9	3.7	16.5	B/Check	2.6	-14.5	8.1	-36.4
Mg+K+B	7.9	5.9	4.0	10.5	Co+Cu/Check	-14.3	-13.0	5.4	9.7
Mg+K+Co+Cu	6.6	6.0	3.9	18.1	B+Co+Cu/Check	-10.4	-29.0	2.7	-23.7
Mg+K+B+Co+Cu	6.9	4.9	3.8	12.6	B+Cu+Zn/Check	2.6	2.9	16.2	-30.1
Mg+K+B+Cu+Zn	7.9	7.1	4.3	11.5	B+Co+Cu/B	-12.7	-17.0	-5.0	20.0
					B+Co+Cu/Co+Cu	4.5	-18.3	-2.6	-30.4
					B+Cu+Zn/B	0.0	20.3	7.5	9.5

Table 25. (continued)

Treatment**	Tops Cuttings 1st	Tops Cuttings 2nd	Tops Cuttings 3rd	Roots	Comparison of treatments	Tops Cuttings 1st	Tops Cuttings 2nd	Tops Cuttings 3rd	Roots
	grams			grams	Ca+Mg+K Fertilizer	per cent			per cent
Ca+Mg+K	8.7	7.1	4.9	13.0	B/Check	-12.6	-9.9	-10.2	-7.7
Ca+Mg+K+B	7.6	6.4	4.4	12.0	Co+Cu/Check	-15.0	-14.1	0.0	-0.8
Ca+Mg+K+Co+Cu	7.4	6.1	4.9	12.9	B+Co+Cu/Check	-9.2	-16.9	-4.1	-0.8
Ca+Mg+K+B+Co+Cu	7.9	5.9	4.7	12.9	B+Cu+Zn/Check	-2.3	2.8	8.2	25.4
Ca+Mg+K+B+Cu+Zn	8.5	7.3	5.3	16.3	B+Co+Cu/B	3.9	-7.2	6.8	7.5
					B+Co+Cu/Co+Cu	6.8	-3.3	-4.1	0.0
					B+Cu+Zn/B	11.8	14.1	20.5	35.8

*Data for series 25 given in Table 1.

**Kind and rate of treatments listed in Table 7.

***Check refers to fertilizer treatment alone under respective fertilizer heading.

the roots, but where potassium was present, no increase in yield resulted from the boron treatment. Likewise cobalt and copper caused increases in yield where potassium was not present but not where that element was applied.

A combination of boron, copper, and zinc caused marked increases in yield, ranging from 31.3 to 48.4 per cent where no potassium was applied. In the presence of potassium these elements caused rather large increases in yield in two cases, slight increases in four cases and decreases in yield in two cases. In other words, wherever potassium was applied, the value of the minor elements seemed to be lessened or nullified.

Emmet sandy loam---series 26---On this Emmet sandy loam, as shown by the data presented in Table 26, magnesium produced a significant increase in yield in the fourth cutting and perhaps in the roots. The addition of potassium to the fertilizer treatment resulted in yields which were significantly greater than those obtained where only magnesium was applied. Boron had no effect on yields, but a further addition of phosphorus did cause still greater yields. The increases were significant in all four cuttings. Manganese caused a significant increase in yield only in the fourth cutting. Copper and cobalt, applied together, in addition to magnesium, potassium, and boron caused a significant reduction in yield in the first cutting, a significant increase in the second and slight increases in the third and fourth cuttings and in the yield of roots.

Emmet sandy loam---series 27---Several elements caused increases in yield on this soil according to the data reported in Table 27. It is interesting to note that only a fair crop of alfalfa was produced in the

Table 26. The mean yield of tops and roots of alfalfa grown on an Emmet sandy loam* as affected by various fertilizer and minor element treatments

Treatment***	Tops cuttings 1st	2nd	3rd	4th	Roots
	grams				grams
No treatment	9.8	7.1	4.9	5.8	9.7
Mg	9.5	6.6	5.0	6.6	11.5
Mg+K	10.4	8.8	6.4	8.5	13.6
Mg+K+B	10.7	8.3	6.2	8.6	13.8
Mg+K+B+P	13.4	10.9	9.0	9.8	15.1
Mg+K+B+Mn	10.6	8.5	6.3	10.3	13.8
Mg+K+B+Cu+Co	9.8	9.3	6.5	9.0	14.1
F value	39.2**	84.4**	28.7**	54.8**	24.9**
Difference to be significant at 5% point	0.6	0.5	0.7	0.7	

Per cent increase in yield on comparison of above treatments

Comparison of treatments***	Tops cuttings 1st	2nd	3rd	4th	Roots
	per cent				per cent
Mg/No treatment	-2.8	-2.9	2.0	13.8	18.5
Mg+K/No treatment	6.1	24.0	30.6	46.6	40.2
Mg+K+B/No treatment	9.2	16.9	26.5	48.3	40.2
Mg+K+B+P/No treatment	36.7	53.5	83.7	69.0	55.7
Mg+K+B+Mn/No treatment	8.2	19.7	29.9	77.6	42.3
Mg+K+B+Mn+Cu+Co/No treatment	0.0	30.9	32.7	55.2	45.4
Mg+K/Mg	9.5	33.3	28.0	28.8	18.3
Mg+K+B/Mg+K	3.0	-5.7	-3.1	1.2	1.5
Mg+K+B+P/Mg+K+B	25.2	31.4	45.2	14.0	11.0
Mg+K+B+Mn/Mg+K	1.9	-3.4	-1.6	21.2	1.5
Mg+K+B+Mn/Mg+K+B	-1.0	2.4	1.6	19.8	1.5
Mg+K+B+Cu+Co/Mg+K	-5.8	5.7	1.6	5.9	3.7
Mg+K+B+Cu+Co/Mg+K+B	-8.4	12.0	4.8	4.7	2.2

*Data for series 26 given in Table 1.
**Significant at the 1% point.
***Kind and rate of treatments listed in Table 7.

Table 27. The mean yield of tops and roots of alfalfa grown in greenhouse pots on an Emmet sandy loam soil* as affected by various fertilizers and minor elements, and the per cent increase in yield upon comparison of treatments***

Treatment**	Tops Cuttings 1st	2nd	3rd	Roots	Comparison of treatments	Tops Cuttings 1st	2nd	3rd	Roots
	grams			grams	No Fertilizer	per cent			per cent
No treatment	3.3	3.4	2.8	9.3	B/No treatment	-6.1	-2.9	7.1	3.2
B	3.1	3.3	3.0	9.6	B+Co "	6.0	17.6	17.9	0.0
B+Co	3.5	4.0	3.3	9.3	B+Co+Cu/"	12.1	26.5	25.0	-7.5
B+Co+Cu	3.7	4.3	3.5	8.6	B+Zn/ "	45.5	38.2	43.0	36.6
B+Zn	4.8	4.7	4.0	12.7	B+Co/B	12.9	21.2	10.0	-3.2
					B+Co+Cu/B	19.4	30.3	16.7	-10.1
					B+Co+Cu/B+Co	5.7	7.5	6.0	-7.5
					B+Zn/B	54.8	42.4	33.3	32.3
					Ca+Mg Fertilizer				
Ca+Mg	3.2	3.4	3.2	8.5	B/Check	34.4	67.6	43.8	24.7
Ca+Mg+B	4.3	5.7	4.6	10.6	B+Co/Check	-9.4	14.7	9.4	-17.5
Ca+Mg+B+Co	2.9	3.9	3.5	7.1	B+Co+Cu/Check	9.6	6.0	0.0	-28.0
Ca+Mg+B+Co+Cu	3.5	3.6	3.2	6.1	B+Zn/Check	21.9	41.2	31.2	-22.3
Ca+Mg+B+Zn	3.9	4.8	4.2	6.6	B+Co/B	-32.6	-31.6	-23.9	-33.0
					B+Co+Cu/B	-18.6	-36.8	-30.5	-42.5
					B+Co+Cu/B+Co	20.7	-7.7	-8.6	-14.1
					B+Zn/B	-9.3	-15.8	-9.7	-37.7
					Ca+Mg+K Fertilizer				
					B/Check	-9.8	-2.0	4.9	2.3
Ca+Mg+K	4.1	4.9	4.1	8.9	B+Co/Check	4.9	6.1	46.3	22.2
Ca+Mg+K+B	3.7	4.8	4.3	9.1	B+Co+Cu/Check	12.2	10.2	19.5	28.1
Ca+Mg+K+B+Co	4.3	5.2	4.7	10.9	B+Zn/Check	9.7	22.4	36.6	10.1
Ca+Mg+K+B+Co+Cu	4.6	5.4	4.9	11.4	B+Co/B	16.2	8.3	9.3	19.9
Ca+Mg+K+B+Zn	4.5	6.0	5.6	9.8	B+Co+Cu/B	24.3	12.5	14.0	25.5
					B+Co+Cu/B+Co	7.0	3.9	4.3	4.6
					B+Zn/B	21.6	25.0	30.2	7.7

*Data for series 27 given in Table 1.
**Kind and rate of treatments listed in Table 7.
***Check refers to fertilizer treatment alone under respective fertilizer heading.

field on this sandy loam. In the presence of calcium and magnesium, boron caused marked increases in alfalfa yields. Such was not the case, however, where the calcium and magnesium were omitted or where potassium was applied. The results obtained from zinc were somewhat the reverse from those obtained from boron. Zinc, in addition to boron caused increases in yield where calcium, magnesium, and potassium were applied and where all three were omitted but not where calcium and magnesium only were applied. A similar situation resulted with respect to cobalt. Perhaps the explanation for the failure of zinc and cobalt to cause increases in yield in the presence of calcium and magnesium and the absence of potassium is that the yields of the pots which received only boron in addition to calcium and magnesium were too high, or in other words were in error. Copper caused slight but probably not significant increases in yield in 9 out of 12 cases. Again the three cases of decreased yields occurred on the pots where calcium and magnesium but not potassium were applied.

Emmet sandy loam---series 28---On a fourth Emmet sandy loam, in which alfalfa under field conditions did rather poorly, marked increases in yield were obtained as a result of application of calcium and magnesium and a combination of calcium, magnesium, and potassium. Increases in yield also occurred from application of boron, either alone or with calcium and magnesium or with calcium, magnesium, and potassium. In any combination, manganese seemed to depress yields, while further additions of copper and zinc tended to raise them again. Perhaps if the copper and zinc had been added without the manganese they would have proved more advantageous.

Kalkaska loamy sand---series 29---With the Kalkaska loamy sand represented by series 29, which produced a very poor crop in the field, some very interesting results were obtained, as shown by Tables 31, 32 and 33. Calcium and magnesium, applied together without other treatment did not appreciably affect alfalfa yields but an addition of potassium caused very marked increases in yield, 56.6 per cent in the second cutting of the first stand to 191.7 per cent in the second cutting of the second stand. Boron, applied alone or in combination with calcium and magnesium, or calcium, magnesium, and potassium, caused consistent and in most cases significant increases in yield. The addition of manganese and copper to the treatments increased the yields in only 9 out of 24 cases and reduced the yields in 12 cases. Cobalt, added to each of the fertilizer mixtures, caused increases in yield in all instances except that of the second cutting in the second stand where the potassium was included, and in the first cutting of the first stand where calcium, magnesium, and potassium were omitted. In some cases the increases were not significant.

Kalkaska loamy sand---series 30---As shown by the results presented in Tables 34 and 35, this soil was badly in need of potassium for alfalfa but apparently did not need the other elements applied. Very little response was obtained from additions of calcium and magnesium,but where potassium was added yields were increased from 25.7 per cent to 144.0 per cent. The increase due to potassium ranged from 13.4 to 117.8 per cent. No consistent increases in yield were obtained from any of the minor elements. Many of the increases obtained were insignificant.

Table 28. The mean yield of tops and roots of alfalfa grown in greenhouse pots on an Emmet sandy loam soil* as affected by various fertilizer and minor element treatments

Treatment**	First Stand					Second Stand			
	Tops				Roots	Tops			Roots
	Cuttings					Cuttings			
	1st	2nd	3rd	4th		1st	2nd	3rd	
	grams				grams	grams			grams
No treatment	5.1	2.8	1.0	1.1	2.9	2.8	1.1	1.6	3.2
B	6.3	3.8	1.5	1.5	3.5	3.4	1.4	1.9	4.0
B+Mn	5.9	3.7	1.3	1.3	3.1	3.0	1.3	1.8	3.3
B+Mn+Cu+Zn	6.0	4.1	1.7	1.7	3.3	3.8	1.8	2.1	3.9
Ca+Mg	6.7	3.4	1.1	1.0	3.6	2.9	1.5	1.7	4.3
Ca+Mg+B	7.3	4.4	1.4	1.5	3.2	3.8	1.9	2.1	5.8
Ca+Mg+B+Mn	7.1	4.2	1.4	1.5	3.8	3.7	2.1	2.4	4.9
Ca+Mg+B+Mn+Cu+Zn	7.1	4.7	1.8	1.9	4.2	4.9	2.6	2.5	4.9
Ca+Mg+K	8.8	6.2	2.9	2.4	7.1	5.6	5.7	7.7	12.7
Ca+Mg+K+B	9.0	6.9	3.4	3.0	8.3	5.3	5.8	8.1	13.2
Ca+Mg+K+B+Mn	7.4	6.0	2.9	2.8	6.7	5.4	5.7	7.5	11.7
Ca+Mg+K+B+Mn+Cu+Zn	7.4	6.5	3.3	3.1	7.7	6.7	6.1	7.8	11.8

*Data for series 28 given in Table 1.

**Kind and rate of treatments listed in Table 7.

Table 29. The analysis of variance of the yield of alfalfa tops and roots for series 28 as listed in Table 28

Source	DF	FIRST STAND Tops First cutting SS	MS	Second cutting SS	MS	Third cutting SS	MS	Fourth cutting SS	MS	Roots SS	MS
Total	47	63.44		86.17		36.33		24.94		185.02	
Blocks (Bk)	3	0.26		0.78		0.06		0.06		0.26	
Fertilizers (F)	2	42.80	21.40**	69.54	34.77**	31.75	15.88**	18.43	9.22**	172.88	86.44**
Bk x F	6	1.10	0.18	0.24	0.04	0.29	0.05	1.24	0.21	0.34	0.06
Minor Elements (M El)	3	4.38	1.46**	7.68	2.56**	2.75	0.92**	3.25	1.08**	2.88	0.96**
F x M El	6	8.07	1.35	1.80	0.30	0.39	0.07	1.09	0.18	5.99	0.99
Bk x M El	9	2.88	0.32	1.00	0.11	0.35	0.04	0.68	0.08	1.37	0.15
Bk x F x M El	18	3.95	0.22	5.13	0.28	0.74	0.04	0.19	0.01	1.30	0.07
Difference to be significant at 5% point***		0.4		0.2		0.2		0.4		0.2	
		0.4		0.4		0.2		0.2		0.3	
SECOND STAND											
Total	47	74.45		191.21		362.76				736.71	
Blocks (Bk)	3	0.26		0.24		0.09				0.08	
Fertilizers (F)	2	54.42	27.21**	182.98	91.49**	357.00	178.50**	No		721.45	360.73**
Bk x F	6	1.02	0.17	0.66	0.11	0.23	0.04	data		0.37	0.06
Minor Elements (M El)	3	11.86	3.95**	3.28	1.09**	1.31	0.44*	collected		8.13	2.71**
F x M El	6	2.62	0.44	0.93	0.16	1.46	0.24			3.73	0.62
Bk x M El	9	2.12	0.24	0.90	0.10	0.43	0.05			0.43	0.05
Bk x F x M El	18	2.15	0.12	2.22	0.12	2.24	0.12			2.52	0.14
Difference to be significant at 5% point***		0.4		0.3		0.2				0.3	
		0.3		0.3		0.3				0.3	

*Significant to 5% point.
**Significant to 1% point.
***Upper value is difference required between fertilizer means;
Lower value is difference required between minor element means.

Table 30. Per cent increase in the yield of alfalfa tops and roots grown in greenhouse pots on an Emmet sandy loam soil* upon comparison of various fertilizer and minor element treatments

Comparison of treatments**	First Stand					Second Stand			
	Tops				Roots	Tops			Roots
	Cuttings					Cuttings			
	1st	2nd	3rd	4th		1st	2nd	3rd	
	per cent				per cent	per cent			per cent
Ca+Mg/No treatment	30.5	18.7	5.0	-8.7	14.3	4.6	29.0	6.3	34.6
Ca+Mg+B/B	15.5	16.5	-5.0	-1.6	-8.0	12.5	36.3	10.5	45.9
Ca+Mg+B+Mn/B+Mn	20.0	13.8	2.0	9.5	21.6	25.0	68.0	33.3	48.9
Ca+Mg+B+Mn+Cu+Zn/B+Mn+Cu+Zn	18.0	14.5	7.4	11.8	26.5	30.0	46.5	19.0	42.8
Ca+Mg+K/No treatment	71.0	118.0	180.8	115.6	146.1	128.5	404.4	381.3	300.8
Ca+Mg+K+B/B	42.4	82.5	128.5	100.0	141.3	56.3	323.6	326.3	230.8
Ca+Mg+K+B+Mn/B+Mn	25.8	65.0	119.0	96.5	114.4	81.0	352.0	316.6	258.0
Ca+Mg+K+B+Mn+Cu+Zn/B+Mn+Cu+Zn	23.5	56.4	94.0	82.3	131.8	77.2	240.9	271.4	241.3
Ca+Mg+K/Ca+Mg	31.0	83.0	173.8	136.6	97.9	90.5	291.4	353.0	197.7
Ca+Mg+K+B/Ca+Mg+B	23.2	56.5	140.4	103.4	162.2	39.0	210.7	285.8	126.7
Ca+Mg+K+B+Mn/Ca+Mg+B+Mn	5.0	45.0	114.8	79.3	76.3	44.5	169.0	212.5	140.5
Ca+Mg+K+B+Mn+Cu+Zn/Ca+Mg+B+Mn+Cu+Zn	11.7	36.5	80.8	63.2	83.2	36.5	132.7	212.0	139.1

Table 30. (continued)

Comparison of treatments**	First Stand					Second Stand			
	Tops				Roots	Tops			Roots
	Cuttings					Cuttings			
	1st	2nd	3rd	4th		1st	2nd	3rd	
	per cent				per cent	per cent			per cent
No Fertilizer									
B/No treatment***	23.0	34.8	46.4	33.5	20.7	20.5	22.2	18.8	25.2
B+Mn/No treatment***	15.0	29.5	29.0	18.0	6.9	7.1	11.1	12.5	3.1
B+Mn+Cu+Zn/No treatment***	16.6	46.0	16.6	51.0	13.8	34.0	57.8	31.3	8.7
B+Mn/B	-6.3	-3.8	-11.6	-11.6	-11.4	-11.2	-9.0	-5.3	-17.6
B+Mn+Cu+Zn/B	-5.0	8.5	13.3	13.3	-5.7	11.0	29.1	10.5	-13.2
B+Mn+Cu+Zn/B+Mn	1.2	11.4	28.4	28.4	6.5	25.0	42.0	16.7	5.3
Ca+Mg Fertilizer									
B/Check****	8.7	32.0	35.7	43.9	-11.2	30.0	29.3	23.5	35.7
B+Mn/Check****	5.5	24.0	28.6	41.5	6.3	28.3	44.8	41.2	14.0
B+Mn+Cu+Zn/Check****	5.1	41.0	73.8	85.4	16.8	66.6	79.3	47.1	15.2
B+Mn/B	-2.6	-6.1	-5.3	-1.7	19.6	-1.2	12.0	14.3	-16.0
B+Mn+Cu+Zn/B	-3.0	6.9	28.0	29.0	31.5	28.0	38.7	19.0	-15.1
B+Mn+Cu+Zn/B+Mn	-0.4	14.0	35.2	31.0	9.9	30.0	25.0	4.2	1.0
Ca+Mg+K Fertilizer									
B/Check****	2.3	12.7	19.1	23.7	17.7	-5.2	2.6	5.2	3.3
B+Mn/Check****	-15.3	-1.8	0.9	7.2	-5.3	-2.5	-0.5	-2.6	-7.0
B+Mn+Cu+Zn/Check****	-15.8	4.9	14.8	27.8	8.1	19.3	6.6	1.3	-7.5
B+Mn/B	-15.3	-12.9	-15.3	-13.2	-19.5	2.8	-3.0	-7.4	-10.8
B+Mn+Cu+Zn/B	-16.0	-6.8	-3.5	3.4	-8.0	26.0	3.9	-3.7	-10.5
B+Mn+Cu+Zn/B+Mn	-0.5	7.0	13.8	19.2	14.2	22.6	7.1	4.0	0.4

*Data for series 28 given in Table 1.
**Kind and rate of treatments listed in Table 7.
***No fertilizer or minor element treatment.
****Check refers to fertilizer treatment alone under the respective fertilizer heading.

Table 31. The mean yield of tops and roots of alfalfa grown in greenhouse pots on a Kalkaska sand soil* as affected by various fertilizer and minor element treatments

Treatment**	First Stand					Second Stand		
	Tops				Roots	Tops		Roots
	Cuttings					Cuttings		
	1st	2nd	3rd	4th		1st	2nd	
	grams				grams	grams		grams
No treatment	1.9	2.7	1.5	1.2	3.6	1.9	1.2	1.9
B	2.2	3.6	2.0	1.5	5.1	2.2	1.4	2.4
B+Mn+Cu	2.3	3.6	1.8	1.3	5.0	2.1	1.4	2.0
B+Mn+Cu+Co	2.3	3.9	2.0	1.6	5.4	2.5	1.8	2.7
Ca+Mg	2.0	3.1	1.7	1.1	4.0	2.0	1.4	2.2
Ca+Mg+B	2.5	3.8	2.2	1.3	5.3	2.7	1.7	2.5
Ca+Mg+B+Mn+Cu	3.0	3.9	2.2	1.7	5.1	2.8	2.2	2.6
Ca+Mg+B+Mn+Cu+Co	4.6	5.3	3.1	1.8	6.0	3.3	2.6	3.1
Ca+Mg+K	3.5	4.2	2.9	1.9	8.7	2.8	3.5	3.8
Ca+Mg+K+B	4.1	5.6	4.0	2.4	10.7	3.4	4.4	4.2
Ca+Mg+K+B+Mn+Cu	3.4	4.5	3.1	2.1	10.6	3.0	5.3	4.7
Ca+Mg+K+B+Mn+Cu+Co	3.5	4.8	3.8	2.2	11.1	3.7	5.1	6.7

*Data for series 29 given in Table 1.

**Kind and rate of treatments listed in Table 7.

Table 32. The analysis of variance of the yield of alfalfa tops and roots for series 29 as listed in Table 31

Source	DF	Tops: First cutting SS	Tops: First cutting MS	Tops: Second cutting SS	Tops: Second cutting MS	Tops: Third cutting SS	Tops: Third cutting MS	Tops: Fourth cutting SS	Tops: Fourth cutting MS	Roots SS	Roots MS
FIRST STAND											
Total	47	43.90		37.56		33.97		8.86		346.67	
Blocks (Bk)	3	0.12	0.04	0.24	0.08	0.05	0.02	0.07	0.02	0.07	
Fertilizers (F)	2	16.95	8.48**	14.27	7.14**	22.72	11.36**	5.42	2.7**	305.50	152.75**
Bk x F	6	0.49	0.08	0.46	0.08	0.23	0.04	0.16	0.03	0.98	0.16
Minor Elements (M El)	3	5.81	1.94**	11.78	3.93**	6.10	2.03**	1.47	0.49	28.00	9.33**
F x M El	6	10.98	1.83	6.60	1.10	1.94	0.32	0.80	0.13	0.75	0.12
Bk x M El	9	3.78	0.42	1.99	0.22	1.13	0.13	0.43	0.05	4.49	0.50
Bk x F x M El	18	5.77	0.32	2.22	0.12	1.80	0.10	0.51	0.03	6.88	0.88
Difference to be significant at 5% point***		0.2 0.5		0.2 0.3		0.2 0.3		0.1 0.2		0.3 0.6	
SECOND STAND											
Total	47	167.10		106.08		No data collected		No data collected		87.81	
Blocks (Bk)	3	1.12		0.53						0,12	
Fertilizers (F)	2	88.20	44.10**	89.79	44.89**					63.71	31.86**
Bk x F	6	2.15	0.36	0.25	0.04					0.18	0.03
Minor Elements (M El)	3	52.55	17.52**	9.65	3.22**					15.11	5.04
F x M El	6	6.12	1.02	2.95	0.49					7.56	1.26**
Bk x M El	9	1.00	0.11	0.49	0.06					0.33	0.04
Bk x F x M El	18	15.91	0.89	2.42	0.13					0.80	0.04
Difference to be significant at 5% point***		0.5 0.8		0.2 0.3						0.2 0.2	

*Significant to 5% point.
**Significant to 1% point.
***Upper value is difference required between fertilizer means;
Lower value is difference required between minor element means.

Table 33. Per cent increase in the yield of alfalfa tops and roots grown in greenhouse pots on a Kalkaska loamy sand soil* upon comparison of various fertilizer and minor element treatments

Comparison of treatments**	First Stand					Second Stand		
	Tops				Roots	Tops		Roots
	Cuttings					Cuttings		
	1st	2nd	3rd	4th		1st	2nd	
	per cent				per cent	per cent		per cent
Ca+Mg/No treatment***	8.0	16.1	13.3	-2.0	11.9	8.0	12.5	11.5
Ca+Mg+B/B	10.0	5.0	14.0	-12.0	3.9	22.8	17.9	5.3
Ca+Mg+B+Mn+Cu/B+Mn+Cu	19.0	7.7	23.5	27.0	3.5	32.6	58.9	30.0
Ca+Mg+B+Mn+Cu+Co/B+Mn+Cu+Co	103.4	37.0	54.4	10.8	10.2	32.5	43.1	16.8
Ca+Mg+K/Ca+Mg	70.4	35.0	72.1	66.7	118.8	36.0	159.3	75.9
Ca+Mg+K+B/Ca+Mg+B	55.4	50.0	78.7	88.2	101.4	25.0	163.6	67.0
Ca+Mg+K+B+Mn+Cu/Ca+Mg+B+Mn+Cu	15.0	12.0	40.4	26.0	106.4	10.0	139.3	81.7
Ca+Mg+K+B+Mn+Cu+Co/Ca+Mg+B+Mn+Cu+Co	-24.0	-10.0	22.4	20.9	85.7	12.3	98.1	113.6
Ca+Mg+K/No treatment***	84.0	56.6	95.0	63.0	144.7	47.0	191.7	96.2
Ca+Mg+K+B/B	85.0	57.3	103.8	65.5	109.2	53.5	210.7	75.8
Ca+Mg+K+B+Mn+Cu/B+Mn+Cu	47.3	24.3	73.6	60.0	113.6	45.9	280.4	136.2
Ca+Mg+K+B+Mn+Cu+Co/B+Mn+Cu+Co	54.4	23.3	88.9	33.8	104.6	48.5	183.3	149.5

Table 33. (continued)

Comparison of treatments**	First Stand					Second Stand		
	Tops				Roots	Tops		Roots
	Cuttings					Cuttings		
	1st	2nd	3rd	4th		1st	2nd	
	per cent				per cent	per cent		per cent
No Fertilizer								
B/No treatment***	19.0	35.0	30.0	26.1	43.4	17.3	16.7	21.8
B+Mn+Cu/No treatment***	24.0	36.0	20.0	13.1	38.5	10.5	16.7	2.6
B+Mn+Cu+Co/No treatment***	20.0	32.8	35.0	41.3	51.1	32.0	50.0	37.2
B+Mn+Cu/B	4.5	0.5	-7.5	-10.3	-3.4	-5.5	0.0	-15.8
B+Mn+Cu+Co/B	1.0	8.0	4.0	12.2	5.4	12.2	28.6	12.6
B+Mn+Cu+Co/B+Mn+Cu	-3.0	7.0	12.5	25.2	9.1	19.0	28.6	33.8
Ca+Mg Fertilizer								
B/Check****	21.0	22.0	30.9	13.6	33.6	33.5	22.2	14.9
B+Mn+Cu/Check****	46.9	26.0	30.9	46.7	28.1	36.0	64.8	19.5
B+Mn+Cu+Co/Check****	126.9	71.5	83.5	60.0	48.8	61.7	90.7	43.6
B+Mn+Cu/B	21.5	6.7	0.0	29.4	-3.8	2.0	34.8	4.0
B+Mn+Cu+Co/B	87.0	41.0	40.4	41.2	11.2	21.2	56.0	25.0
B+Mn+Cu+Co/B+Mn+Cu	54.0	32.0	40.4	9.0	16.1	19.0	15.8	20.2
Ca+Mg+K Fertilizer								
B/Check****	20.0	35.5	35.9	28.0	22.6	22.6	24.3	9.2
B+Mn+Cu/Check***	-0.8	7.8	7.0	10.6	20.9	10.0	52.1	23.5
B+Mn+Cu+Co/Check****	1.0	14.4	30.8	16.0	26.3	33.5	45.7	74.5
B+Mn+Cu/B	-9.7	-20.4	-27.2	-13.5	-1.4	-10.3	22.4	13.2
B+Mn+Cu+Co/B	-8.5	-15.5	-3.9	-9.4	3.0	9.0	17.4	60.0
B+Mn+Cu+Co/B+Mn+Cu	1.4	6.0	22.4	4.9	4.5	21.4	-4.3	41.3

*Data for series 29 given in Table 1.
**Kind and rate of treatments listed in Table 7.
***No fertilizer or minor element treatment.
****Check refers to fertilizer treatment alone under the respective fertilizer heading.

Table 34. The mean yield of tops and roots of alfalfa grown in greenhouse pots on a Kalkaska loamy sand* as affected by various fertilizer and minor element treatments

Treatment**	Tops: Cuttings 1st	2nd	3rd	4th	Roots
	grams				
No treatment	7.4	3.7	2.5	3.9	5.5
Ca+Mg	8.2	4.0	2.8	3.7	5.8
Ca+Mg+B	8.0	3.8	3.0	4.0	7.2
Ca+Mg+B+Co+Cu	8.4	4.0	3.2	4.2	6.2
Ca+Mg+B+Co+Cu+Zn	8.4	4.2	3.8	4.7	6.8
Ca+Mg+K	9.3	7.2	6.1	8.0	10.1
Ca+Mg+K+B	9.3	7.0	6.4	8.5	10.8
Ca+Mg+K+B+Co+Cu	9.7	7.1	7.1	8.9	12.1
Ca+Mg+K+B+Co+Cu+Zn	9.2	6.8	7.0	9.3	12.3

*Data for series 30 given in Table 1.
**Kind and rate of treatments listed in Table 7.

Analysis of variance of the yield of tops

Source	DF	First cutting SS	Second cutting SS	Third cutting SS	Fourth cutting SS
Total	31	17.67	76.77	104.37	178.00
Blocks (Bk)	3	0.06	0.20	0.59	0.18
Fertilizers (F)	1	14.58**	73.21**	96.26**	167.45**
Bk x F	3	0.62	0.13	0.83	0.56
Minor elements (M El)	3	0.68	0.96**	4.43**	4.21
F x M El)	3	0.53	0.98	0.52	0.27
Bk x M El	9	0.41	0.19	1.28	2.68
Bk x F x M El	9	0.79	0.10	0.46	2.65

**Significant to 1% point.

Table 35. Per cent increase in the yield of alfalfa tops and roots grown in greenhouse pots on a Kalkaska loamy sand soil* on comparison of various fertilizer and minor element treatments

Comparison of treatments**	Tops Cuttings 1st	2nd	3rd	4th	Roots
	per cent				per cent
Ca+Mg/No treatment***	10.8	8.1	12.0	-5.1	5.5
Ca+Mg+K/No treatment***	25.7	94.6	144.0	105.1	83.6
Ca+Mg+K/Ca-Mg	13.4	80.0	117.8	116.2	74.1
Ca+Mg+K+B/Ca+Mg+B	16.3	84.2	133.3	112.5	50.0
Ca+Mg+K+B+Co+Cu/Ca+Mg+B+Co+Cu	15.5	77.5	121.9	111.9	95.2
Ca+Mg+K+B+Co+Cu+Zn/Ca+Mg+B+Co+Cu+Zn	9.5	61.9	84.2	97.9	80.9
Ca+Mg Fertilizer					
B/Check****	-2.5	-5.0	7.1	8.1	24.1
B+Co+Cu/Check****	2.4	0.0	14.3	13.5	6.9
B+Co+Cu+Zn/Check****	2.4	5.0	35.7	27.0	17.2
B+Co+Cu/B	5.0	5.3	6.7	5.0	-13.9
B+Co+Cu+Zn/B	5.0	10.5	26.7	17.5	-5.6
B+Co+Cu+Zn/B+Co+Cu	0.0	5.0	18.7	11.9	9.7
Ca+Mg+K Fertilizer					
B/Check****	0.0	-2.8	4.9	6.3	6.9
B+Co+Cu/Check****	4.3	-1.0	16.4	11.3	19.8
B+Co+Cu+Zn/Check****	-1.1	-5.6	14.8	16.3	21.8
B+Co+Cu/B	4.3	1.4	10.9	4.7	12.0
B+Co+Cu+Zn/B	-1.1	-2.9	9.4	9.4	13.9
B+Co+Cu+Zn/B+Co+Cu	-5.2	-4.2	-1.4	4.5	1.7

*Data for series 30 given in Table 1.

**Kind and rate of treatments listed in Table 7.

***No fertilizer or minor element treatment.

****Check refers to fertilizer treatment alone under the respective fertilizer heading.

Mancelona sandy loam---series 31---Very poor alfalfa was produced on this soil in the field. For that reason one would expect a response to treatment and such was the case. Calcium and magnesium applied together, caused significant increases in the yields of all cuttings except the third in the second stand. The increases in root growth were both significant. An addition of potassium to the mixture caused further increases in yield, significant in all cases except in the first cutting of the first stand. The total production of tops and roots for the six cuttings amounted to 14.7 and 6.3 grams respectively on untreated pots, 18.2 and 8.0 grams respectively on pots which received only calcium and magnesium, and 25.3 and 16.0 grams respectively on pots which received potassium in addition to calcium and magnesium. As indicated by the table, the increase in yield caused by the potassium was greater in the second than in the first stand. Especially was this true of the root growth.

Boron seemed to be deficient on this Mancelona soil. Where the element was applied alone it caused significant increases in all yields, both tops and roots. Where calcium and magnesium was applied, the same result was obtained in the first stand but not in the second. Where calcium, magnesium, and potassium were applied as a basic treatment, the boron increased six yields significantly and caused decreases in two others.

In most of the 24 cases recorded in Table 36, manganese and copper caused reductions in yield.

Onaway sandy loam---series 32---Alfalfa on this soil, which produced a good crop in the field, did not respond to magnesium, as shown in Tables 39 and 40, but did give small increases as a result of applications of potassium.

Table 36. The mean yield of tops and roots of alfalfa grown in greenhouse pots on a Mancelona sandy gravelly loam soil* as affected by various fertilizer and minor element treatments

Treatment**	First Stand				Second Stand			
	Tops			Roots	Tops			Roots
	Cuttings				Cuttings			
	1st	2nd	3rd		1st	2nd	3rd	
	grams			grams	grams			grams
No treatment	5.0	2.2	1.5	3.7	2.9	2.0	1.1	2.6
B	5.5	2.8	1.8	4.3	3.3	2.4	1.3	3.2
B+Mn+Cu	4.7	2.7	1.7	3.5	2.7	2.1	1.1	2.7
Ca+Mg	6.2	2.6	1.9	4.5	3.7	2.5	1.3	3.5
Ca+Mg+B	7.0	3.4	2.3	6.4	3.7	2.4	1.4	3.2
Ca+Mg+B+Mn+Cu	6.6	3.4	2.5	4.3	3.2	2.2	1.4	3.3
Ca+Mg+K	6.4	3.7	2.4	6.3	4.2	4.4	4.2	9.7
Ca+Mg+K+B	6.7	3.3	2.2	7.3	4.9	5.0	5.0	11.0
Ca+Mg+K+B+Mn+Cu	6.8	3.8	2.7	6.7	4.2	4.4	4.3	8.9

*Data for series 31 given in Table 1.

**Kind and rate of treatments listed in Table 7.

Table 37. The analysis of variance of the yield of alfalfa tops and roots for series 31 as listed in Table 36.

Source	DF	Tops						Roots	
		First cutting		Second cutting		Third cutting			
		SS	MS	SS	MS	SS	MS	SS	MS
FIRST STAND									
Total	35	24.84		11.67		6.21		64.73	
Blocks (Bk)	3	0.46		0.26		0.10		0.05	
Fertilizers (F)	2	19.01	9.51**	7.05	3.53**	3.90	1.95**	45.50	22.75**
Bk x F	6	0.52	0.09	0.06	0.01	0.17	0.03	0.41	0.07
Minor Elements (M El)	2	1.74	0.87**	1.46	0.73**	0.65	0.33**	12.37	6.19**
F x M El	4	1.26	0.32	1.59	0.39	0.70	0.18	2.60	0.65
Bk x M El	6	0.72	0.12	0.32	0.05	0.28	0.05	0.16	0.03
F x Bk x M El	12	1.13	0.09	0.93	0.08	0.41	0.03	3.64	0.30
Difference to be significant at 5% point***		0.3 0.3		0.1 0.2		0.2 0.2		0.3 0.5	
SECOND STAND									
Total	35	15.94		49.77		89.53		382.77	
Blocks (Bk)	3	0.17		0.15		0.68		0.21	
Fertilizers (F)	2	12.03	6.01**	44.65	22.33**	85.22	42.61**	371.32	185.66**
Bk x F	6	0.08	0.01	0.98	0.16	0.63	0.10	0.22	0.04
Minor Elements (M El)	2	2.14	1.07	1.04	0.52*	0.60	0.30	4.08	2.04
F x M El	4	0.44	0.11	0.58	0.15	1.01	0.25	5.47	1.37
Bk x M El	6	0.42	0.07	0.91	0.15	0.74	0.12	0.13	0.02
F x Bk x M El	12	0.66	0.06	1.46	0.12	0.65	0.05	1.34	0.11
Difference to be significant at 5% point***		0.1 0.2		0.4 0.3		0.3 0.2		0.2 0.3	

*Significant to 5% point.
**Significant to 1% point.
***Upper value is difference required between fertilizer means;
Lower value is difference required between minor element means.

Table 38. Per cent increase in the yield of alfalfa tops and roots grown in greenhouse pots on a Mancelona sandy gravelly loam soil* on comparison of various fertilizer and minor element treatments

Comparison of treatments**	First Stand				Second Stand			
	Tops			Roots	Tops			Roots
	Cuttings				Cuttings			
	1st	2nd	3rd		1st	2nd	3rd	
	per cent			per cent	per cent			per cent
No Fertilizer								
B/No treatment***	11.0	28.8	16.3	16.4	14.3	20.3	18.2	21.0
B+Mn+Cu/No treatment***	-6.5	21.9	8.1	-3.4	-6.7	5.1	0.0	2.9
B+Mn+Cu/B	-15.8	-5.4	-7.0	-17.1	-18.0	-12.6	-15.3	-15.0
Ca+Mg Fertilizer								
B/Check***	12.2	30.0	18.5	43.0	0.8	-3.0	7.7	-7.2
B+Mn+Cu/Check****	7.0	32.0	30.0	-3.9	-12.2	-13.0	7.7	-3.4
B+Mn+Cu/B	-4.5	1.5	10.0	-32.8	-12.8	-10.3	0.0	3.1
Ca+Mg+K Fertilizer								
B/Check****	4.1	-8.0	-10.3	15.6	16.1	14.2	19.0	12.6
B+Mn+Cu/Check****	5.8	3.4	10.0	-2.0	-0.5	0.0	2.4	-8.7
B+Mn+Cu/B	1.5	14.2	24.2	-15.2	-14.3	-12.5	-14.0	-18.9

Table 38. (continued)

Comparison of treatments**	First Stand				Second Stand			
	Tops			Roots	Tops			Roots
	Cuttings				Cuttings			
	1st	2nd	3rd		1st	2nd	3rd	
	per cent			per cent	per cent			per cent
Ca+Mg/No treatment**	24.8	18.5	24.6	22.6	24.9	26.6	18.2	31.4
Ca+Mg+B/B	26.0	19.5	26.6	50.6	10.5	2.1	7.7	0.8
Ca+Mg+B+Mn+Cu/B+Mn+Cu	42.4	28.1	50.0	22.0	17.4	4.8	27.3	22.2
Ca+Mg+K/Ca+Mg	3.0	43.6	27.5	40.2	14.5	76.0	223.1	182.6
Ca+Mg+K+B/Ca+Mg+B	-4.2	0.0	-3.4	13.3	32.0	107.2	257.1	243.0
Ca+Mg+K+B+Mn+Cu/Ca+Mg+B+Mn+Cu	3.9	12.7	9.0	43.0	29.8	102.3	207.1	169.7
Ca+Mg+K/No treatment***	28.0	70.0	58.0	71.9	43.0	122.8	281.8	271.4
Ca+Mg+K+B/B	20.2	19.5	22.5	70.6	45.8	111.6	284.6	245.7
Ca+Mg+K+B+Mn+Cu/B+Mn+Cu	45.0	44.5	64.8	74.5	52.0	112.0	290.9	229.6

*Data for series 31 given in Table 1.
**Kind and rate of treatments listed in Table 7.
***No fertilizer or minor element treatment.
****Check refers to fertilizer treatment alone under the respective fertilizer heading.

Plate 4. Second stand, second cutting of alfalfa grown on a Kalkaska sand, series 29. Treatments 1. Check, 2. Ca, 3. Ca+K.

Plate 5. Second stand, second cutting of alfalfa grown on a Mancelona sandy loam, series 31. Treatments 1. Check, 2. Ca, 3. Ca+K.

Table 39. The mean yield of tops and roots of alfalfa grown in greenhouse pots on an Onaway sandy loam soil* as affected by various fertilizer and minor element treatments

Treatment**	Tops: Cuttings 1st	2nd	3rd	Roots
	grams			grams
No treatment	4.1	5.3	5.9	10.5
Mg	4.2	5.2	5.9	10.5
Mg+B	4.6	6.2	6.6	9.9
Mg+B+Mn	4.9	5.9	6.9	10.8
Mg+B+Mn+Cu+Co	4.7	5.8	6.5	12.0
Mg+K	5.6	5.9	7.2	11.4
Mg+K+B	5.7	6.4	7.9	12.2
Mg+K+B+Mn	6.6	7.7	8.4	16.8
Mg+K+B+Mn+Cu+Co	6.3	6.8	8.2	11.7

*Data for series 32 given in Table 1.

**Kind and rate of treatments listed in Table 7.

Table 40. Per cent increase in the yield of alfalfa tops and roots grown in greenhouse pots on an Onaway sandy loam soil* on comparison of various fertilizer and minor element treatments

Comparison of treatments**	Tops Cuttings 1st	2nd	3rd	Roots
	per cent			per cent
Mg/No treatment	2.4	-1.9	0.0	0.0
Mg+K/No treatment	36.6	11.3	22.0	8.6
Mg+K/Mg	33.3	13.5	22.0	8.6
Mg+K+B/Mg+B	23.9	3.2	19.7	23.2
Mg+K+B+Mn/Mg+B+Mn	34.7	30.5	21.7	55.6
Mg+K+B+Mn+Cu+Co/Mg+B+Mn+Cu+Co	34.0	17.2	26.2	-2.5
Mg Fertilizer				
B/Check****	9.5	19.2	11.9	-5.3
B+Mn/Check****	16.7	13.5	16.9	2.9
B+Mn+Cu+Co/Check****	11.9	11.5	11.0	14.3
B+Mn/B	6.5	-4.8	4.5	9.1
B+Mn+Cu+Co/B	2.2	-6.5	-1.5	21.2
B+Mn+Cu+Co/B+Mn	-4.1	-1.7	-5.8	11.1
Mg+K Fertilizer				
B/Check****	1.8	8.5	9.7	7.0
B+Mn/Check****	17.9	30.5	16.7	47.4
B+Mn+Cu+Co/Check****	12.5	15.3	13.9	2.6
B+Mn/B	15.8	20.3	6.3	37.7
B+Mn+Cu+Co/B	10.5	6.3	3.8	-1.4
B+Mn+Cu+Co/B+Mn	-4.5	-11.7	-2.4	-30.4

*Data for series 32 given in Table 1.

**Kind and rate of treatments listed in Table 7.

***No fertilizer or minor element treatment.

*****Check refers to fertilizer treatment alone under the respective fertilizer heading.

Boron caused an increase in yield in seven out of eight cases, with the decrease occurring in one of the root yields. Manganese also caused increases in yields in all cases except that of the second cutting where potash was not applied. Copper and cobalt, applied together caused reductions in seven out of eight yields.

Onaway sandy loam---series 33---This Onaway sandy loam supported a good crop of alfalfa in the field. In the greenhouse jars, calcium and magnesium did not significantly increase yields, as shown by Table 41. Potassium in addition to calcium and magnesium, however, caused increases in yield which ranged from 20 per cent (Table 43) in the first cutting of the second stand to 204.9 per cent in the root growth of the first stand.

Boron caused significant increases in yields in all cases.

Manganese caused significant increases in yields in six of nine cases. There was one decrease and two insignificant increases. Probably the element was actually beneficial.

Copper and zinc actually reduced yields where potassium was applied but increased them where it was omitted from the mixture.

Table 41. The mean yield of tops and roots of alfalfa grown in greenhouse pots on an Onaway sandy loam soil* as affected by various fertilizer and minor element treatments

Treatment**	First Stand					Second Stand			
	Tops				Roots	Tops			Roots
	Cuttings					Cuttings			
	1st	2nd	3rd	4th		1st	2nd	3rd	
	grams				grams	grams			grams
No treatment	8.3	3.4	1.9	1.4	3.0	3.5	4.4	5.4	4.4
Ca+Mg	9.4	3.6	2.0	1.5	3.1	3.5	4.6	5.7	4.6
Ca+Mg+B	10.7	4.4	2.6	2.0	3.8	4.5	5.5	6.3	5.3
Ca+Mg+B+Mn	9.8	5.7	3.6	2.5	5.2	4.6	5.6	6.0	6.2
Ca+Mg+B+Mn+Cu+Zn	11.3	6.5	4.0	2.8	5.5	5.5	7.3	7.1	9.0
Ca+Mg+K	12.3	8.9	5.4	2.9	9.4	4.2	6.0	8.0	7.1
Ca+Mg+K+B	13.2	10.0	6.6	3.5	10.5	4.7	6.8	9.0	8.3
Ca+Mg+K+B+Mn	15.3	10.4	8.7	5.3	16.6	7.3	9.6	10.3	10.9
Ca+Mg+K+B+Mn+Cu+Zn	14.4	9.7	6.5	4.8	12.1	6.1	8.6	8.6	16.3

*Data for series 33 given in Table 1.

**Kind and rate of treatments given in Table 7.

Table 42. The analysis of variance of the yield of alfalfa tops and roots for series 33 as listed in Table 41.

Source	DF	Tops: First cutting SS	Tops: First cutting MS	Tops: Second cutting SS	Tops: Second cutting MS	Tops: Third cutting SS	Tops: Third cutting MS	Tops: Fourth cutting SS	Tops: Fourth cutting MS	Roots SS	Roots MS
FIRST STAND											
Total	31	130.81		211.72		153.90		49.51		624.26	
Blocks (Bk)	3	0.16		0.04		0.05		0.35		1.11	
Fertilizers (F)	1	95.91	95.91**	179.55	179.55**	111.37	111.37**	29.26	29.26**	486.72	486.72**
Bk x F	3	0.08	0.03	0.12	0.04	0.38	0.13	0.08	0.03	1.83	0.61
Minor Elements (M El)	3	18.78	6.26**	17.78	5.93**	26.39	8.80**	16.14	5.38**	95.24	31.75**
F x M El	3	0.71	0.24	7.45	2.48	7.15	2.38	2.17	0.72	35.98	11.99
Bk x M El	9	2.02	0.22	5.90	0.66	4.12	0.46	1.21	0.13	1.82	0.20
Bk x F X M El	9	13.15	1.46	0.88	0.10	4.44	0.49	0.30	0.03	1.56	0.17
Difference to be significant at 5% point***		0.2 1.0		0.2 0.7		0.4 0.7		0.2 0.3		0.9 0.5	
SECOND STAND											
Total	31	44.07		87.72		83.63		No data collected		406.58	
Blocks (Bk)	3	0.18		0.33		0.46				1.06	
Fertilizers (F)	1	9.35	9.35**	32.81	32.81**	59.68	59.68**			149.65	149.65**
Bk x F	3	0.32	0.11	0.75	0.25	4.12	1.37			0.73	0.24
Minor Elements (M El)	3	25.18	8.39**	37.49	12.50**	7.95	2.65**			218.55	72.85**
F x M El	3	7.63	2.54	11.22	3.74	8.40	2.80			28.64	9.55
Bk x M El	9	1.13	0.12	3.52	0.39	1.91	0.21			1.71	0.19
Bk x F X M El	9	0.28	0.03	1.60	0.18	1.11	0.12			6.24	0.69
Difference to be significant at 5% point***		0.4 0.3		0.6 0.6		1.3 0.4				0.6 0.7	

**Significant to 1% point.

***Upper value is difference required between fertilizer means;
Lower value is difference required between minor element means.

Table 43. **Per cent increase in the yield of alfalfa tops and roots grown in greenhouse pots on an Onaway sandy loam soil* on comparison of various fertilizer and minor element treatments**

Comparison of treatments**	First Stand					Second Stand			
	Tops				Roots	Tops			Roots
	Cuttings					Cuttings			
	1st	2nd	3rd	4th		1st	2nd	3rd	
	per cent				per cent	per cent			per cent
Ca+Mg/No treatment***	13.5	6.0	9.3	7.1	1.7	0.0	4.5	5.6	4.6
Ca+Mg+K/No treatment***	48.2	165.0	189.0	107.3	209.9	20.0	36.4	48.1	61.4
Ca+Mg+K/Ca+Mg	31.0	150.0	163.5	93.5	204.9	20.0	30.4	40.4	54.5
Ca+Mg+K+B/Ca+Mg+B	25.0	139.0	156.0	76.3	178.1	4.4	23.7	42.9	56.6
Ca+Mg+K+B+Mn/Ca+Mg+B+Mn	52.0	83.7	140.0	107.9	222.3	58.7	71.4	71.7	75.8
Ca+Mg+K+B+Mn+Cu+Zn/Ca+Mg+B+Mn+Cu+Zn	27.0	48.8	62.1	82.9	119.5	10.9	17.8	35.2	79.9
Ca+Mg Fertilizer									
B/Check****	14.0	22.0	27.0	33.0	22.8	29.0	19.6	10.5	15.2
B+Mn/Check****	4.5	58.0	79.0	65.0	67.5	32.6	21.3	5.3	34.8
B+Mn+Cu+Zn/Check****	20.0	83.0	99.0	86.8	78.9	60.0	60.1	24.6	93.1
B+Mn/B	-5.7	35.0	40.8	26.3	36.4	2.8	1.4	-4.8	17.0
B+Mn+Cu+Zn/B	5.5	50.1	56.2	40.0	45.7	23.6	33.8	12.7	70.4
B+Mn+Cu+Zn/B+Mn	12.0	14.0	11.0	5.0	6.8	20.2	32.0	18.3	45.8

Table 43. (continued)

Comparison of treatments**	First Stand					Second Stand			
	Tops				Roots	Tops			Roots
	Cuttings					Cuttings			
	1st	2nd	3rd	4th					
	per cent				per cent	per cent			per cent
Ca+Mg+K Fertilizer									
B/Check***	7.1	12.3	23.6	21.0	12.0	13.9	13.3	12.5	16.9
B+Mn/Check***	25.0	16.0	62.8	81.0	77.1	76.5	60.4	28.8	53.5
B+Mn+Cu+Zn/Check***	17.0	8.4	22.0	65.6	28.8	47.0	43.3	20.0	130.7
B+Mn/B	14.0	3.3	31.8	50.0	58.1	55.0	41.5	14.4	31.3
B+Mn+Cu+Zn/B	9.7	-3.3	-1.1	36.2	15.0	29.1	26.4	6.7	96.7
B+Mn+Cu+Zn/B+Mn	-9.5	-6.4	-25.0	-8.6	-27.3	-16.7	-10.1	-6.8	49.4

*Data for series 33 given in Table 1.

** Kind and rate of treatments listed in Table 7.

***No fertilizer or minor element treatment.

****Check refers to fertilizer treatment alone under the respective fertilizer heading.

SECTION III. A STUDY OF SOME POTASSIUM-DEFICIENT FIELD-BEANS SOILS IN MICHIGAN

In the past few years, especially during dry summer months, a large number of areas of field beans showing a certain characteristic yellowing of the leaves have been noticed in the "Thumb" section of Michigan. Cook (9) has shown by means of plant tissue tests and fertilizer applications that these deficiency symptoms were due to a lack of soil potassium. Muriate of potash, applied as a sidedressing after the starvation symptoms had appeared, greatly increased the yield of beans and produced plants of normal color.

Upon the observation of such potassium deficiency symptoms rather generally over the area in the summer of 1941, it was decided a study should be made of those soils on which beans showing such symptoms were growing. Plant and soil samples were to be collected for chemical analysis, and muriate of potash was to be used as a side-dressing to discover if the yield of field beans could be increased by an addition of potassium at the first appearance of signs of potassium starvation in the growing plants.

Location and Sampling of Fields

Fields where beans exhibited deficiency symptoms and fields of normal appearing beans on the same soil type were selected wherever possible. The choice of fields was made by driving through the area and sampling as many different soil types as were found. Twelve fields on six different soils were included in the investigation. These soils, together with their assigned series number, their location, and the condition of the bean fields, are listed in Table 1.

On the bean fields selected for study, both plant and soil samples were taken during the period of July 21st to July 23rd. The plant samples were composed of from ten to twenty bean plants collected at random along several rows. The plant tissue was dried and ground in the laboratory. Three samples of soil were taken in each field in close proximity to the area from which the plants were gathered. These samples consisted of top soil or plow layer portions and at least 10 to 15 inches of the B horizon. The soil was dried and then passed through a 2 millimeter sieve. Analyses for the potash content of the bean plants were made by ashing the samples as in Section I and determining potassium as sodium potassium cobaltinitrite. Exchangeable potassium in the soils was run according to Volk's (33) method.

Muriate of potash was applied as a sidedressing on the fields of ten farms at the rate of 100 pounds per acre using a hand drill. Two rows of beans were fertilized and the next two rows were left as a check plot. This unit was replicated at least four times in the field. The potash was placed on the inside of the pair of fertilized rows to avoid influencing the growth of plants in adjacent check rows. The fertilized bean rows varied in length from 100 to 200 feet.

Weather Conditions During the Growing Season

Very little rain fell in the "Thumb" area during the month of July and the first of August. About the middle of July potassium deficiency symptoms in field beans were first observed in certain sections of east central Michigan. This study was not carried out until a week later when signs of potash starvation appeared more generally throughout the region. Very definite symptoms developed resulting in some cases in entire fields of small yellow beans. At the time of sampling the bean plants were stunted in growth. The lower leaves, especially at the tips, had turned yellow and the chlorosis had worked back between the main veins of the leaves. In extreme cases, these lower leaves were entirely yellow and the margins were turning brown, while the uppermost leaves showed slight to medium signs of potassium starvation.

From the 20th of July to the first of August when daily temperatures were constantly high and rainfall was very light throughout the area, many bean blossoms on plants in both normal and deficient fields were blasted and few pods were set. The field beans on potassium deficient soils that were planted early in the spring were most seriously affected. Since these beans were nearly mature, they failed to recover and produce more blossoms in August. Very few pods were present at harvest time on these stunted plants. Those beans that were planted late in June on soils low in potassium did not suffer as much as those planted earlier since they were not as fully developed. These beans put forth new growth and blossoms during the month of August. Field beans planted on soils adequate in available potassium produced a good crop despite the period of low rainfall in July. These plants likewise made new growth and blossomed in August when light rains fell.

The Potassium Content of Soils and Bean Plants

In Table 44 the data show a very good correlation between the field condition of beans and the exchangeable potassium in the plow layer, the plant tissue test for potash, and the total content of potassium in the dried plant material. Medium to serious potash deficiency occurred in the bean plants when the exchangeable potassium content of the surface soil fell below 0.10 to 0.15 milli-equivalents per 100 grams of soil in the lighter soils and below 0.15 to 0.20 milli-equivalents in the heavier soils. From a consideration of the latter group, it appears that the bean plants starved for potassium do not obtain any large amount of that element from the subsoil. The normal bean plants had percentages of K_2O of 1.90 and above, while the per cent K_2O of all potash deficient plants sampled was below 1.20, except for those from two locations showing a medium deficiency.

Effect of Sidedressing on Yield

Observations in early September of those bean fields treated with muriate of potash indicated that there would be a significant difference in yield between fertilized and check plots at only two locations. The potash deficient plants sidedressed with KCl developed much better color in the following two months and were somewhat larger than the plants on the untreated strips. The effect of sidedressing field beans at the H. Armbruster farm is shown by data in Table 45. The data indicate that the addition of potash approximately doubled the yield in all but one replicate.

Table 44. Partial chemical analysis of field bean plants and soils sampled in July 1941 in the "Thumb" area of Michigan

Soil type and number*	Field symptoms	Soil sample depth	Exchangeable K per 100 grams air dry soil	Plant tissue test for K	K_2O in field bean plants
		inches	m.e.		per cent
Miami loam		0-12	0.08		
	Serious	12-20	0.09		
Series 34	potash	0- 6	0.07	Low	0.62
	deficiency	6-18	0.07		
		0- 7	0.06		
		7-24	0.03		
		0- 6	0.22		
Conover	No	6-17	0.19		
loam	potash	0- 6	0.18	High	1.92
	deficiency	6-16	0.14		
Series 35		0- 7	0.29		
		7-15	0.21		
		0- 8	0.06		
Oshtemo		8-18	0.03		
loamy sand	Serious	0- 8	0.05		
	potash	8-20	0.04	Low	0.57
Series 36	deficiency	0- 6	0.04		
		6-18	0.03		
Kawkawlin		0-10	0.09		
sandy		10-40	0.05		
loam	Medium	0- 9	0.07	Low	0.71
	potash	9-30	0.08		
Series 37	deficiency	0- 8	0.11		
		8-25	0.14		
Brookston		0- 8	0.37		
silt	No	10-18	0.31		
loam	potash	0- 9	0.37	High	2.94
	deficiency	10-30	0.41		
Series 38		0- 8	0.45		
		10-24	0.47		
Gilford		0-12	0.05		
sandy	Serious	12-30	0.03		
loam	potash	0- 7	0.03	Low	0.73
	deficiency	7-30	0.02		
Series 39		0-11	0.07		
		11-25	0.04		

Table 44. (continued)

Soil type and number*	Field symptoms	Soil sample depth	Exchangeable K per 100 grams air dry soil	Plant tissue test for K	K_2O in field bean plants
		inches	m.e.		per cent
Miami loam		0- 7	0.08		
	Serious	7-16	0.21		
	potash	0- 8	0.07	Low	1.15
Series 40	deficiency	8-25	0.12		
		0- 7	0.06		
		7-25	0.13		
Brookston		0- 8	0.36		
silt	No	8-22	0.23		
loam	potash	0-10	0.36	High	1.92
	deficiency	10-18	0.29		
Series 41		0- 9	0.38		
		10-27	0.26		
Gilford		0- 9	0.04		
sandy	Medium	9-20	0.02		
loam	potash	0- 9	0.08	Medium	1.82
	deficiency	9-22	0.02		
Series 42		0-10	0.04		
		10-20	0.03		
		0- 6	0.22		
Miami loam	No	6-20	0.12		
	potash	0- 7	0.18	High	2.94
Series 43	deficiency	8-20	0.29		
		0- 9	0.21		
		9-22	0.24		
		0-10	0.17		
Brookston	Serious	10-18	0.12		
loam	potash	0-12	0.13	Low	0.59
	deficiency	12-20	0.20		
Series 44		0- 6	0.10		
		6-16	0.11		
		0- 9	0.15		
Conover	Medium	9-22	0.14		
loam	potash	0- 8	0.10	Low	1.74
	deficiency	8-24	0.11		
Series 45		0- 7	0.17		
		8-25	0.12		

*Data for each series given in Table 1.

Table 45. The yield of field beans on a Brookston loam at the H. Armbruster farm as affected by sidedressing with KCl in late July 1941

Rows	Treatment	Yield in pounds per acre
1- 2	KCl	1006
3- 4	Check	649
5- 6	KCl	921
7- 8	Check	461
9-10	KCl	893
11-12	Check	329
13-14	KCl	470
15-16	Check	385
17-18	KCl	761
19-20	Check	263

It is believed that the application of fertilizer was not early enough at most locations to increase the yield, though the appearance of the plants was improved. Had appreciable amounts of rain fallen in the area before the end of July, the effect of sidedressing on the yield of beans might have been greater.

SECTION IV. THE POTASSIUM EQUILIBRIUM IN SOME MICHIGAN SOILS

Release Studies

The potassium requirement of legumes, especially alfalfa and clovers, are known to be high. Investigators (3), (5), (34) have found that a ton of alfalfa contains from 25 to 50 pounds of potassium, varying with the time of cutting and the purity of the hay. Ames and Boltz (2) noted one instance where three cuttings from an alfalfa field one season removed 206 pounds of potassium per acre. The power of sandy soils to supply potassium to plants is generally regarded as low even though a total chemical analysis of such soils shows a fairly high potassium content. The inability of a sandy soil or sandy loam to provide a continuous supply of available potassium could well be a critical factor in the production of a good alfalfa crop.

It is evident from recent soil investigations that the release of potassium from the weathering of potash bearing primary minerals by hydrolysis cannot entirely account for the amounts of available potassium which some soils are able to supply when subject to intensive cropping, artificial leaching, or alternate freezing and thawing. Hoagland and Martin (14) have presented greenhouse data in which the potassium taken up by the plant was greater than the accompanying decrease in the exchangeable form indicating that release of non-replaceable potassium had taken place during the growth of the crop. Experiments by Bray and

and DeTurk (6), in which soils were artificially leached with acids and salt solution to markedly lower the level of available potassium, have shown that the rate of release of potassium over a period of six months was too great to attribute to the gradual hydrolysis of primary minerals. In a study on the effect of freezing and thawing of saturated soils on the amount of exchangeable potassium, Fine, Bailey, and Truog (12) found that releases of potassium from the non-replaceable form occurred in two-thirds of the soils studied.

A number of explanations have been extended to cover the character of the release and fixation of potassium in its several defined forms in soils. Wood and DeTurk (36), Bartholomew and Janssen (4), Page and Williams (24), Hoagland and Martin (14), Jofee and Kolodny (16), and Bray and DeTurk (6) have used the concept of an equilibrium to relate amounts of water soluble, replaceable, and non-replaceable or fixed potassium found in soils. Some investigators have suggested explanation of the equilibrium release of potassium on compounds of varying solubility present in the soil, on the formation of stable secondary minerals, or on the formation of potassium phosphate complexes. Other workers have interpreted bacterial fixation and the release of potassium in a double buffer system involving two types of base exchange reactions as more suitable concepts to explain the potassium equilibrium.

Few studies have been made concerning the release and fixation of potassium in sandy soils under laboratory and greenhouse conditions. A more comprehensive study of the equilibrium between the various fractions of soil potassium under different levels of cropping and fertilization is needed in representative soil types in western Michigan. Such an investigation would be helpful in supplementing field data concerning time of application and the amounts of potash fertilizers to be used in a legume program, as well as gaining information of a particular soil type with a view to estimating fertility reserves.

Experimental Procedure

This study was designed to determine the rate of increase in the concentration of water soluble and exchangeable potassium and to follow the equilibrium between the various fractions in five soil types from western Michigan. These soils were brought to a low fertility level in two ways. In the first procedure, the soils were cropped using alfalfa grown in greenhouse pots, while in the second method the soils were artificially leached with a neutral salt solution.

Alfalfa was planted on the five soils in one gallon glazed pots. Nine jars of each soil type were set up. The soil types, their original pH values and the amount of lime applied to each are given in Table 46. Every soil was then given a fertilizer increment of 250 pounds superphosphate, 75 pounds magnesium sulfate, 25 pounds manganese sulfate, 15

Table 46. The soils, their original pH, and the lime applied to each

Series number	Soil type	pH	Pounds of $CaCO_3$ per acre
3	Plainfield sand	5.5	1000
10	Fox fine sandy loam	6.0	500
25	Emmet sandy loam	5.5	1000
33	Onaway sandy loam	6.0	500
29	Kalkaska sand	5.5	

pounds borax, and 10 pounds copper sulfate on an acre basis.

Three pots of each soil were selected at random after the first, second, and third alfalfa clippings. The roots were removed and a composite sample of soil taken from all three jars. These samples were brought to optimum moisture and stored at a uniform temperature of about 20 degrees C. A portion of each soil was air dried to determine the level of potassium at the beginning of the storage period. At intervals, samples of the moist soil were dried and analyzed. Water soluble potassium was extracted with boiled distilled water using a soil-water ratio of 1 to 10. The soil suspension was shaken for 30 minutes and filtered under suction. Exchangeable K was determined on the same sample according to the procedure in Section I. Using the same sample the acid soluble fraction was found by boiling 10 gms. of soil with 100 cc. 1 N nitric acid in a reflux condenser for 10 minutes and washing on a filter with several portions of boiling 1N HNO_3. Potassium was determined using Volk's (33) method.

Artificial leaching of the soils was accomplished by allowing three liters of neutral normal ammonium acetate to percolate through one kilogram of soil. The funnels were connected with a suction pump to maintain a constant percolation rate of about one drop per second. Occluded ammonia was removed by leaching with distilled water. The soils were then partially dried, mixed, and stored at optimum moisture and uniform temperature. Exchangeable and water soluble potassium before and during storage were determined as with the soils planted to alfalfa.

Rate of Release of Potassium as Affected by Cropping and Leaching

The mean yield per pot of alfalfa clippings for each soil type at each cutting listed in Table 47 indicate that after three cuttings the differences in yield between soils were reduced to a minimum except for alfalfa grown on the Onaway soil.

Table 47. Mean yield per pot of oven dry alfalfa grown on five sandy soils

Series number	Soil type	Cuttings 1st	2nd	3rd
		grams	grams	grams
3	Plainfield sand	6.6	5.5	4.6
10	Fox fine sandy loam	9.5	6.1	4.2
26	Emmet sandy loam	8.9	6.9	4.3
33	Onaway sandy loam	12.5	9.3	7.5
29	Kalkaska sand	9.1	6.0	5.4

In Figures 2, 3, and 4, the increase of salt soluble (replaceable + water soluble) potassium in five soils on storage after one, two, and three cuttings of alfalfa is shown. The release of potassium for these same soils on storage after leaching with a salt solution is given in Figure 5. The data show that continued cropping tends to reduce the level of exchangeable potassium for the soils studied. The rate of release of potassium from the soil after any cutting is most rapid during the first two months of incubation, and as the soils are more heavily cropped the rate of increase over the entire storage period becomes greater, as indicated in a comparison of Figures 2 and 4. The presence of potassium deficiency symptoms on the second cutting of alfalfa grown on the Kalkaska and Plainfield soils, and severe starvation signs on the third cutting of alfalfa grown on all five soils would indicate that further cropping would not lower the potassium level much below that found in the soils immediately after three crops of alfalfa were removed.

A general pattern of release of potassium for the five soils is apparent upon comparing the data in Figures 2, 3, 4, and 5. The Fox, Onaway and Emmet soils, having original replaceable potassium contents of 49, 48, and 33 p.p.m. respectively, were cropped to approximately the same potassium level and show very similar increases on incubation. The single exception to this trend is the rapid release shown by the Onaway soil in Figure 4 over the first three months of storage. The Kalkaska and Plainfield soils, being of a more sandy nature, had lower original exchangeable potassium levels of 23 and 24 p.p.m., and were cropped to lower values than the other soils. Of the two sandy soils, the Kalkaska released potassium more rapidly after one and two cuttings of alfalfa, but its release rate was lower than that of the Plainfield soil after three cuttings were removed. The Plainfield and Kalkaska samples returned upon storage after each cutting to a potassium content higher than the original. Only on incubation after the first cutting did the exchangeable potassium of the Emmet soil rise above the original level. The potassium level in the Fox and Onaway soils did not rise above a maximum of 36 p.p.m. over a storage of eight months.

The effect of leaching with a neutral salt and subsequent incubation on the five soils is given in Figure 5. The leaching procedure reduced the K content to a considerably lower level than the growth of three cuttings of alfalfa. At the beginning of the storage period, the

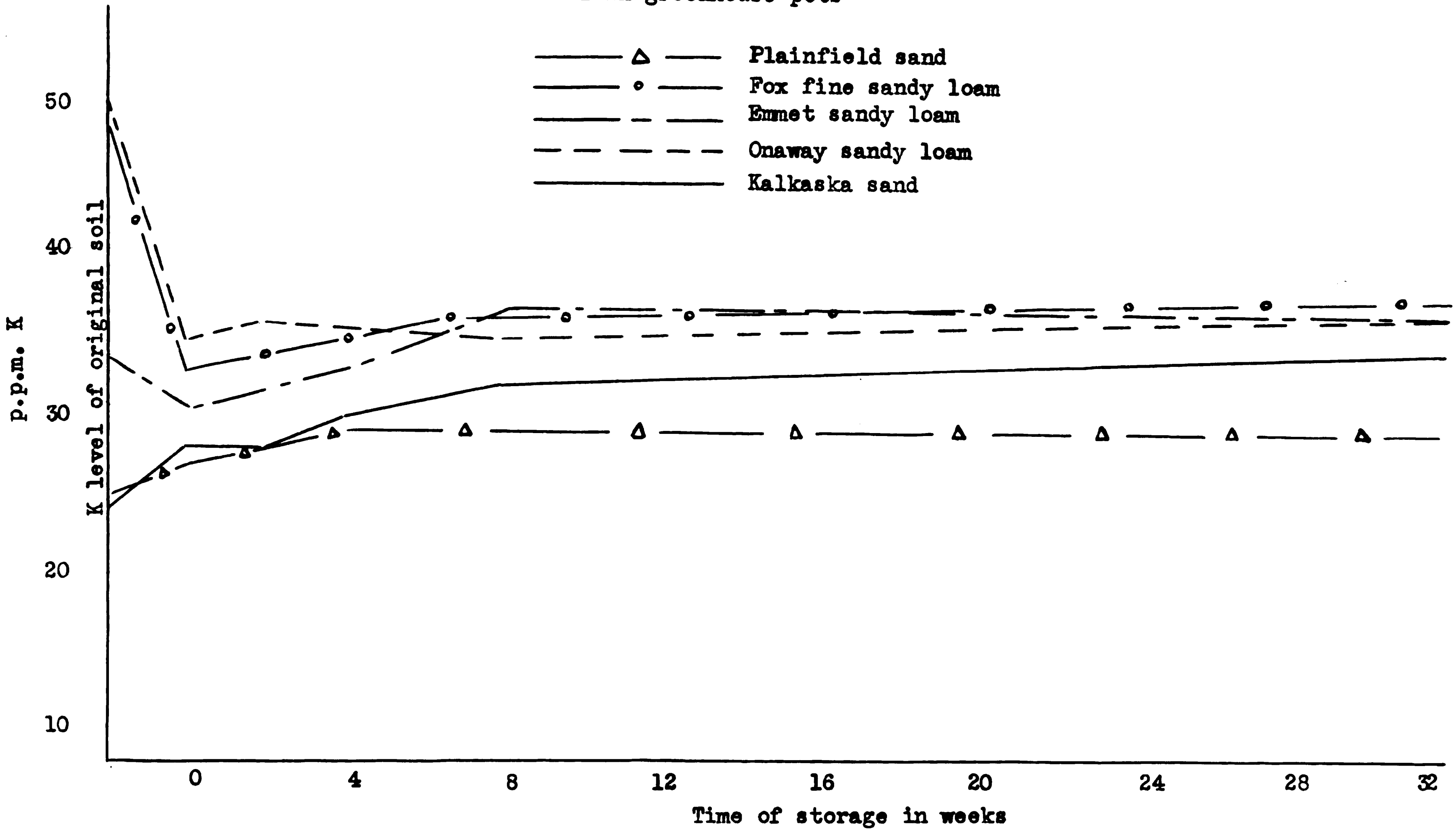


Figure 2. The release of exchangeable potassium over a period of eight months in five Michigan soils after one cutting of alfalfa from the soil in greenhouse pots

Figure 3. The release of exchangeable potassium over a period of eight months in five Michigan soils after two cuttings of alfalfa from the soil in greenhouse pots.

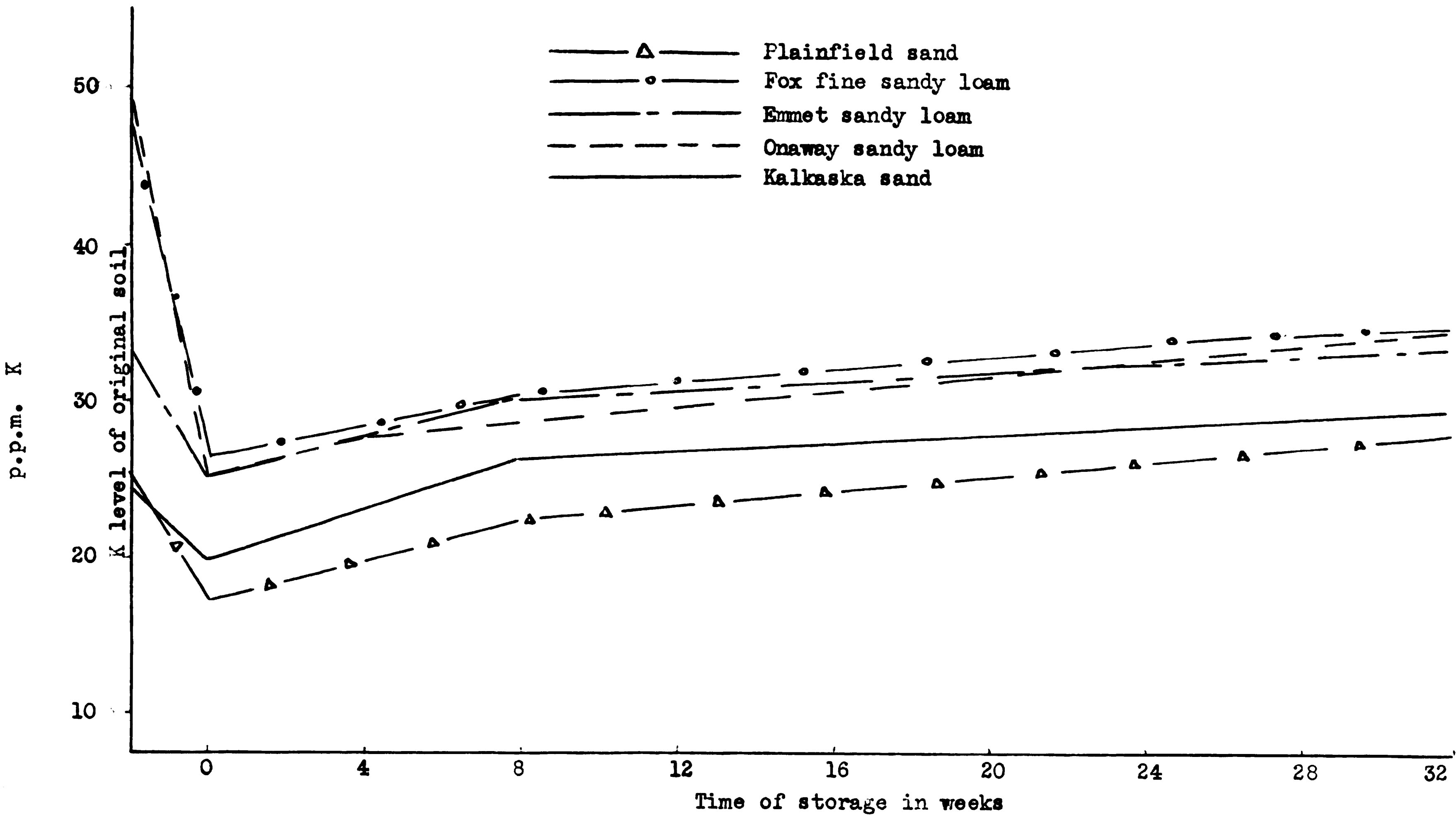


Figure 4. The release of exchangeable potassium over a period of eight months in five Michigan soils after three cuttings of alfalfa from the soil in greenhouse pots.

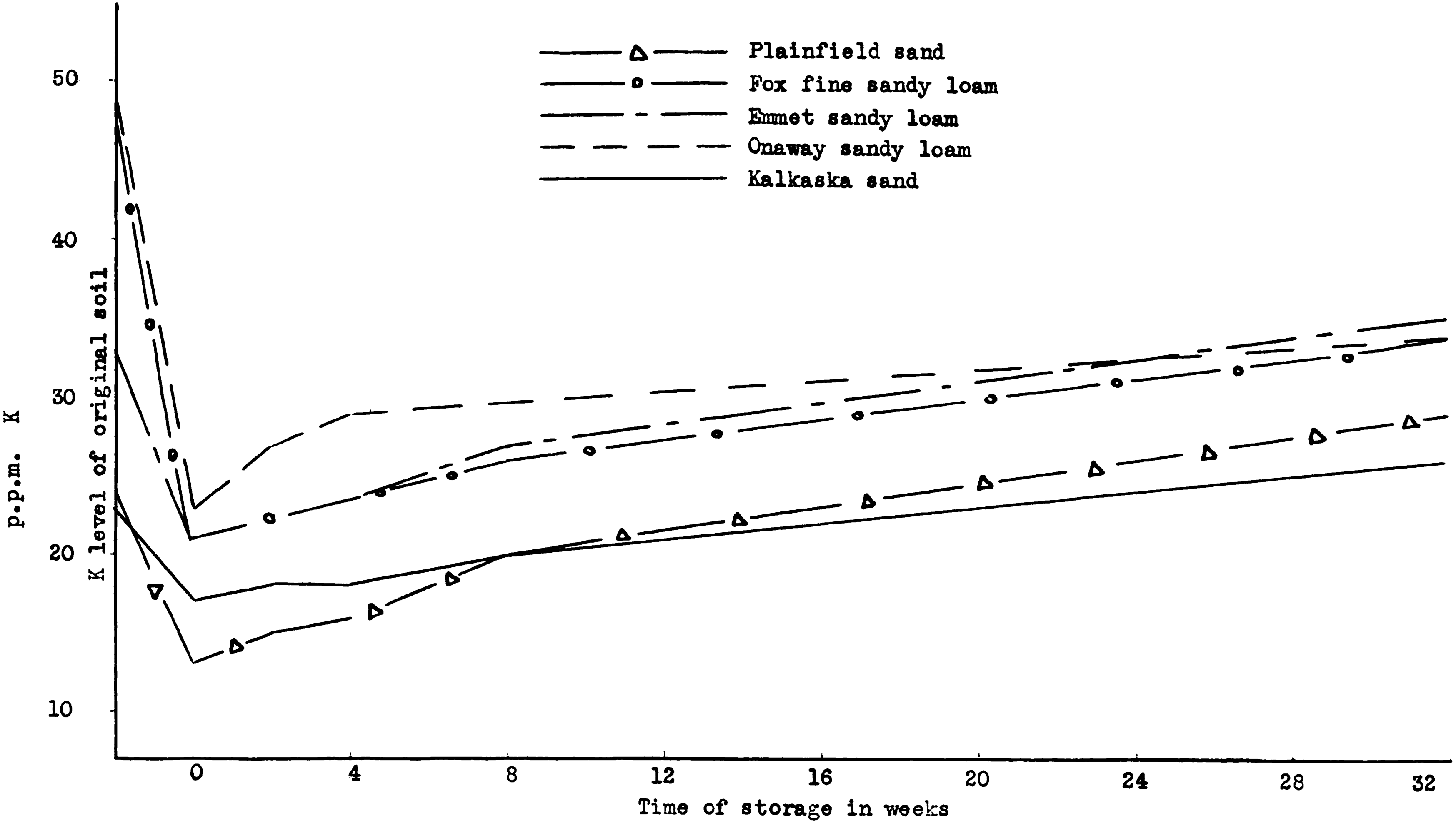
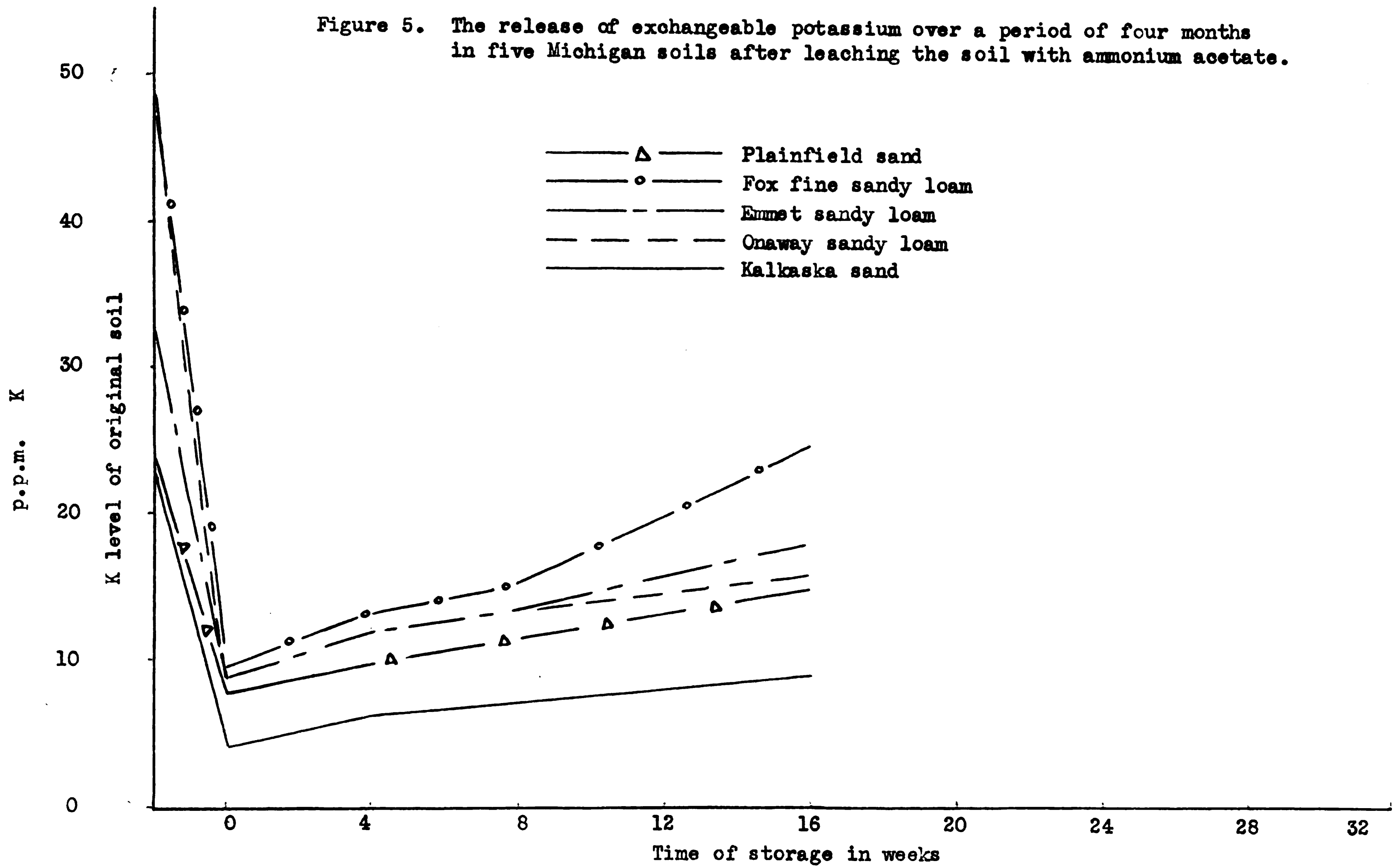


Figure 5. The release of exchangeable potassium over a period of four months in five Michigan soils after leaching the soil with ammonium acetate.



replaceable potassium of all soils was between 4 and 10 p.p.m. After four months of moist storage the potassium supply varied from 9 to 25 p.p.m. The release of potassium in the Fox sample was greatest, followed by the Emmet, Onaway, Plainfield, and Kalkaska samples.

Effect of Cropping on Equilibrium Between Four Fractions of Soil Potassium

The release of acid soluble, exchangeable, and water soluble potassium over the storage period for the five soils, as given in Table 48, can be illustrated diagramatically under equilibrium conditions as in Figure 6.

Treatment	Fixed		Available	
	Acid insoluble	Acid soluble	Exchangeable	Water soluble
1st cutting	— — —	+ +	0	+
2nd cutting	— — —	0	+	+ +
3rd cutting	0	— — —	+ +	+ + +

Figure 6. Diagramatic equilibrium between the various forms of soil potassium

After the eight month incubation the soils that had one cutting of alfalfa removed showed a gain in the acid soluble and water soluble fractions, no appreciable deviation in exchangeable potassium, and a marked loss in acid insoluble potassium calculated by difference. After two cuttings of alfalfa and incubation, the soils gained in both exchangeable and water soluble forms, decreased in acid insoluble potassium, and

Table 48. The effect of cropping with alfalfa on several forms of soil potassium and the subsequent gain or loss of those fractions upon incubation of some sandy soils in greenhouse pots

Soil type	0 week incubation			32 week incubation			Gain or loss			
	Acid sol.	Exch.	Water sol.	Acid sol.	Exch.	Water sol.	Acid insol.	Acid sol.	Exch.	Water sol.
				Pounds of potassium per acre						
One cutting of alfalfa										
Plainfield sand	180	32	20	192	28	28	-16	12	-4	8
Fox f. sandy loam	208	42	26	240	40	30	-34	32	-2	4
Emmet sandy loam	182	36	24	206	36	34	-34	24	0	10
Onaway sandy loam	192	38	26	262	38	34	-78	70	0	8
Kalkaska sand	126	34	22	130	32	34	-14	4	-2	12
Two cuttings of alfalfa										
Plainfield sand	160	22	12	135	30	25	6	-25	8	13
Fox f. sandy loam	232	35	15	236	43	25	-22	4	8	10
Emmet sandy loam	164	35	15	189	42	25	-52	25	7	10
Onaway sandy loam	178	32	20	210	39	29	-48	32	7	9
Kalkaska sand	151	23	16	124	30	28	8	-27	7	12
Three cuttings of alfalfa										
Plainfield sand	140	18	8	104	36	22	4	-36	18	14
Fox f. sandy loam	151	32	10	114	44	24	11	-37	12	14
Emmet sandy loam	222	32	10	193	44	26	1	-29	12	16
Onaway sandy loam	176	32	14	155	42	26	-1	-21	10	12
Kalkaska sand	116	20	14	89	30	22	9	-27	10	8

*Before cropping the soil types contained the following amounts of acid soluble, exchangeable, and water soluble potassium respectively in pounds per acre: Plainfield sand 194, 32, 16; Fox f. sandy loam 218, 60, 38; Emmet sandy loam 226, 40, 26; Onaway sandy loam 214, 56, 40; Kalkaska sand 180, 26, 20.

averaged little change in the acid soluble fraction. It should be noted that the acid soluble potassium increased in the sandy loams and decreased in the case of the sandy soils. After three cuttings of alfalfa both water soluble and exchangeable forms gained at the expense of the acid soluble form.

It can be concluded from this study that during the four months of growth of alfalfa before the first cutting, the more available water soluble and replaceable fractions were mainly utilized thereby drawing upon and reducing the acid soluble form. Upon eight months storage the level of the acid soluble form rose due to releases of potassium from the less soluble fraction. About two months growing period elapsed before the second cutting thus enabling the alfalfa plants to further exhaust the water soluble, exchangeable, and acid soluble supply. Upon incubation at this time the probable facts that the acid insoluble fraction released potassium less rapidly and that the potassium equilibrium had been shifted further toward the more available forms by plant removal, would substantiate the gain of water soluble and exchangeable potassium at the expense of the less soluble fractions. The marked increase in the two more available forms of potassium and decrease in acid soluble potassium was probably brought about by a further drastic removal of potassium by alfalfa plants and a lower rate of release of potassium from the acid insoluble form.

Salt Soluble and Water Soluble Potassium as Related to Cropping and Time of Storage

A better insight into the relation of water soluble to salt soluble potassium after cropping or leaching and subsequent storage can be gained from the data in Table 49. For any given treatment for any of the five soils the ratio of salt soluble to water soluble potassium decreases with time of incubation, indicating that the proportion of the more soluble form increases. For example, the ratio of all soils after one cutting at initial storage time is quite similar varying from 2.50 to 2.60. At the end of the incubation, with the exception of the Fox soil, these ratios fell to approximately 2.00. The effect of cropping was to change the ratio between the two forms of soil potassium. The data would indicate that the alfalfa plants were obtaining a proportionately larger share of potassium from the soil solution and that the equilibrium between replaceable and water soluble potassium was unable to maintain the proportion of the two forms as found in the original soil.

Fixation Studies

A considerable number of experiments have been carried out in the past ten years concerning the fixation of potassium in soils and the availability of various forms of soil potassium to plants. The fixation of potassium by soils has been observed by Hoagland and Martin (14), Wood and DeTurk (36), Joffe and Kolodny (16), Purvis and Blume (28), Lamb, Jr. (19), and others. Most of these investigators regard fixed or non-replaceable potassium as that form not extractable with a neutral salt solution, but yet more available to plants than potassium held in primary minerals. Wood and DeTurk (36) have divided the fixed fraction into the acid soluble and acid insoluble forms. Studies on fixation have been made mainly by adding soluble potassium or salts of potassium

Table 49. The effect of incubation on the ratio of salt soluble to water soluble potassium in some sandy soils which have been cropped and artificially leached

Soil type	Soil treatment	Ratio of salt soluble to water soluble K over a period of weeks					
		0	2	4	8	16	32
Plainfield sand	1 cutting	2.60	2.46	2.55	2.16		2.00
	2 cuttings	2.83	2.71	2.44	2.31		2.20
	3 cuttings	3.25	3.00	3.20	3.33		2.64
	leached	2.33	2.24	2.00	2.00	1.88	
Fox fine sandy loam	1 cutting	2.61	2.50	2.33	2.43		2.33
	2 cuttings	3.12	3.10	2.90	2.80		2.72
	3 cuttings	4.20	4.00	3.83	3.33		2.83
	leached	2.00	2.00	2.00	1.86	2.05	
Emmet sandy loam	1 cutting	2.50	2.40	2.13	2.12		2.06
	2 cuttings	3.33	3.06	3.06	2.70		2.68
	3 cuttings	4.20	4.20	3.83	3.37		2.70
	leached	2.35	2.25	2.00	2.00	2.25	
Onaway sandy loam	1 cutting	2.46	2.54	2.32	2.33		2.12
	2 cuttings	2.60	2.57	2.54	2.46		2.35
	3 cuttings	3.33	3.38	3.23	3.00		2.60
	leached	1.50	1.57	1.45	1.36	1.47	
Kalkaska sand	1 cutting	2.55	2.33	2.16	2.07		1.94
	2 cuttings	2.44	2.21	2.19	2.08		2.08
	3 cuttings	2.43	2.57	2.57	2.50		2.36
	leached	2.00	1.70	1.50	1.75	1.80	

to soils and leaching the soil at intervals with dilute acids or salt solutions after moist storage or heat or freezing treatments to determine the level of various forms of soil potassium. The picture of the mechanism of fixation is still not clear.

Experimental Procedure

The application of medium to heavy fertilizer applications to soil and the subsequent sampling to recover all potassium presents difficulties. Hoagland and Martin (14) concluded that sampling from a large lot of soil does not give as accurate results as to the fate of potassium added to a soil as does the analysis of one portion of soil which has been given an increment of potash.

A workable procedure was developed in this study, whereby solutions of KCl were added to 500 gram portions of air dry soil at the rate of 200, 500, and 1000 pounds per acre of KCl. The partially moistened soil was thoroughly mixed on waxed paper, and the mixing sheets analyzed for potassium. The amount lost was found to be within the experimental error of the method. Seven sandy soils were given the above treatments and then stored at optimum moisture and at room temperature. Fifty gram portions of soil were removed at intervals to determine the water soluble, exchangeable, and acid soluble potassium. The extraction and analytical methods used were the same as those employed in studies of release.

The Potassium Equilibrium as Affected by Addition of Muriate of Potash to the Soil

The various fractions of soil potassium are given in Table 50 for the original soils before incubation and after four months storage for the same soils to which three levels of potash were added. The rate of applying the potassium solutions can be listed as ratios of 0:1:2.5:5 or at rate of 0, 105, 263, and 525 pounds potassium per acre respectively. Work by other investigators (35) indicates that the rate of equilibrium reaction varies with time and may be different for each soil. Preliminary work in this study showed little change in the amount of potassium fixed in each soil over a period ranging from 8 to 32 weeks.

The exchangeable form in the original soils is about 1½ times that extracted by water, while the acid soluble fraction appears from 2 to 4 times greater than the water soluble and exchangeable forms combined. A value for the fixed or insoluble form is lacking since it is an arbitrary figure obtained by difference.

After an incubation period of four months, the test soils to which no potassium was added, showed in general slight increases in water soluble and replaceable potash, and in three out of four soils a small decrease in the acid soluble form. The Onaway and Emmet soils gave minor releases of potassium from the acid insoluble fraction. Upon analysis of the soil to which potassium was added, the water soluble form was found to have increased most and in the approximate ratios of 0:1:2.0-2.6:4.2-5.5. The exchangeable fraction was raised in the ratio

Table 50. The effect of added potassium on the proportion of soil potassium in four fractions after 16 weeks' incubation

Fox fine sandy loam

Fraction	Pounds K per acre in original soil	Pounds of K per acre in incubated soil after varying increments of K had been added			
		0	105	263	525
Fixed*	0	12	83	102	106
Acid soluble	246	230	168	176	180
Exchangeable	42	44	88	150	246
Water soluble	28	30	82	150	310

Onaway sandy loam

Fixed*	0	-12**	46	102	107
Acid soluble	194	194	146	112	152
Exchangeable	56	60	88	136	204
Water soluble	40	48	116	202	352

Emmet sandy loam

Fixed*	0	-5**	85	147	139
Acid soluble	244	235	150	126	164
Exchangeable	40	50	84	138	224
Water soluble	26	30	96	162	308

Emmet sandy loam

Fixed*	0	-1**	127	97	85
Acid soluble	222	214	124	180	228
Exchangeable	54	59	92	126	212
Water soluble	34	38	90	188	328

*This is considered to be the acid insoluble form.

**Negative values in the fixed or acid insoluble fraction indicate a release of potassium from that form.

of 0:1:2.0-2.7:4.7-5.3. Accordingly the rise in the two forms with increasing amounts of potassium added is rather close to the ratio at which the increments were made.

The amount of acid soluble potassium as listed in Table 50 is approximately the same for all original samples except for the Onaway soil. Little change occurred in this form over four months of moist storage when no treatment was made. With the addition of 105 pounds potassium per acre, a marked decrease in the level of this form was noted. However, the content of the acid insoluble or fixed form was necessarily increased indicating a shift in equilibrium from the more available to the less available fraction. The same general picture holds for the 263 pound increment with the exception of increases in the acid soluble fraction in two of the four soils. Adding 525 pounds K per acre to the soils changed the equilibrium still more by shifting a slightly larger amount of potassium into the acid insoluble form. It is interesting to note that the content of acid insoluble fraction is about the same whether potassium was added at the rate of 500 or 1000 pounds KCl per acre. This might indicate a possible "saturation" with respect to this fraction.

Amounts of Potassium Fixed

The gain in the water soluble and exchangeable potassium content of seven soils, together with the potassium added, and the amount of fixation is given in Table 51. Fixation from -9 to 17 pounds per acre was recorded for the 105 pound per acre addition, from 11 to 37 pounds per acre for the 263 pounds potassium increment, and from 31 to 99 pounds per acre for the 525 pound per acre addition. The Kalkaska sandy soil showed

Table 51. The recovery and correlated fixation of soluble potassium added to seven soils after 16 weeks' incubation

Pounds per acre of K added	Exchangeable K lbs./A.	Water soluble K lbs./A.	Fixation lbs./A.	Fixation per cent
Fox fine sandy loam				
0	2	2	-4	-6
105	46	54	5	3
263	108	122	33	10
525	204	282	39	4
Onaway sandy loam				
0	4	8	-12	-13
105	32	76	-3	-5
263	80	162	21	9
525	148	312	65	12
Emmet sandy loam				
0	10	4	-14	-21
105	44	70	-9	-5
263	98	136	29	9
525	144	282	59	10
Emmet sandy loam				
0	5	4	-9	-11
105	38	56	11	6
263	72	154	37	10
525	158	294	73	12
Mancelona Sandy loam				
0	0	2	-2	-3
105	28	64	13	7
263	76	150	37	11
525	164	302	59	10

Table 51. (continued)

Kalkaska sand

Pounds per acre of K added	Exchangeable K lbs./A.	Water soluble K lbs./A.	Fixation lbs./A.	Fixation per cent
0	4	2	-6	-18
105	46	54	5	3
263	98	154	11	4
525	156	338	31	6

Fox sandy loam

0	-2	4	-2	-2
105	52	36	17	16
263	122	108	33	13
525	198	228	99	19

the least tendency to fix potassium, immobilizing only 6 pounds with a 1000 pound increment of KCl on an acre basis. The Mancelona, Onaway, and Fox fine sandy loam soils had the same fixing power with a maximum of about 10 per cent when a half ton of muriate of potash per acre was added. The Fox sandy loam fixed the greatest amount of soluble potassium with the fixation between 15 and 20 per cent.

Potassium Equilibrium in Soils Under Greenhouse Culture

It was decided that an experiment be set up to study the potassium equilibrium of soils at the time they were supporting plant growth. This investigation was carried out using millet grown on ten different Michigan soils in the greenhouse. Small jars were used to facilitate an intensive removal of potassium as well as other plant nutrients. Six pots of each soil were used with potassium being added as the chloride to three of the jars at the rate of 400 pounds per acre. A general nutrient addition was given all soils consisting of 400 pounds ammonium sulfate, 100 pounds magnesium nitrate, 400 pounds mono-calcium phosphate, 20 pounds manganese sulfate, 5 pounds zinc sulfate, and 5 pounds copper sulfate on an acre basis. The acid soluble, exchangeable, and water soluble fractions of potassium of the soils were determined before and after cropping using the methods of extraction and analysis as indicated under release studies. The yield of plant material was taken from each jar and the oven dry tissue analyzed for potassium. The growth of millet on six of the ten soils with and without added potash is shown in

Plate 6. With values for plant removal of potassium given in Table 52 and the contents of the various fractions before and after cropping listed in Table 53, a clearer picture can be gained of the source of potassium as used for plant growth.

Source of Potassium for Plant Growth

The yield figures in Table 52 show that the addition of potassium to the soil gave increases of from 2 to 3 times the dry weight of millet for the sandier soils and from 1 to 2 times for the heavier soils compared with yields where no potassium was added. The per cent of potassium in the plants followed a similar trend with 8 to 12 times more potassium in the plants grown on the lighter soils receiving soluble KCl and 3 to 8 times more potassium in millet grown on the finer textured soils to which potassium was added. The data in Table 53 indicate that in all soils there is a gain in the water soluble and replaceable fractions after cropping regardless of whether potassium was supplied to the soil. Likewise, it should be noted that the values for the acid soluble form were lower after cropping, and that, in general, this fraction decreased most in those pots to which potassium was added. The figures listed under the column "absorbed or fixed" refer to that potassium either absorbed by plants or fixed in an acid insoluble form in the soil. Table 54 may be considered a balance sheet listing the losses and gains for each fraction of potassium after cropping. The values for fixed or acid insoluble potassium have been calculated by difference in the following manner: (the sum of the fractions of the original soil) +

Plate 6. The effect of added potassium on the growth of millet in six Michigan soils.

Table 52. The yield, per cent potassium, and potassium content of millet as affected by the addition of potassium to some soils set up in greenhouse pots

Soil type	Jar number	No K added: Yield per jar	No K added: K in plant	No K added: K in plant per 100 grams soil	K added: Yield per jar	K added: K in plant	K added: K in plant per 100 grams soil
		gms.	per cent	mgms.	gms.	per cent	mgms.
Fox sandy loam	1	8.5	0.32	1.9	14.7	1.57	16.1
	2	10.0	0.28	2.0	13.9	1.66	16.1
	3	9.0	0.28	1.8	14.3	1.80	18.0
Plainfield sand	1	5.1	0.25	0.9	14.0	1.16	10.9
	2	6.2	0.19	0.8	13.8	1.22	11.3
	3	8.2	0.16	0.9	14.4	1.08	10.4
Emmet sandy loam	1	6.1	0.36	1.6	11.0	1.63	12.9
	2	6.2	0.36	1.6	11.3	1.79	14.6
	3	7.2	0.32	1.7	10.7	1.77	13.7
Kalkaska sand	1	5.2	0.38	1.4	11.4	1.67	13.0
	2	7.2	0.35	1.7	10.6	1.78	12.7
	3	6.6	0.31	1.4	9.7	1.90	12.6
Onaway sandy loam	1	5.0	0.65	2.3	10.5	2.51	18.8
	2	5.2	0.72	2.7	11.3	2.67	21.5
	3	6.7	0.62	3.0	11.2	2.38	18.2
Gilford sandy loam	1	4.6	0.45	1.5	13.0	1.85	17.9
	2	5.8	0.32	1.4	12.1	1.91	17.2
	3	6.0	0.36	1.6	12.5	1.99	18.5
Warsaw loam	1	5.7	0.48	2.2	10.9	1.85	16.5
	2	6.6	0.36	1.9	11.2	1.79	16.3
	3	7.0	0.32	1.8	11.6	1.87	17.6
Miami loam	1	7.3	0.35	2.3	15.0	1.52	20.3
	2	8.1	0.27	1.9	12.8	1.61	18.4
	3	9.2	0.30	2.5	13.2	1.60	21.1
Miami loam	1	6.9	0.30	1.6	10.3	1.75	14.1
	2	6.2	0.35	1.7	11.7	1.64	15.0
	3	6.5	0.30	1.5	10.4	1.80	14.6
Conover silt loam	1	9.6	0.82	6.8	12.3	1.65	17.5
	2	10.2	0.73	6.4	11.8	1.60	16.3
	3	10.3	0.67	6.0	10.9	1.79	16.8

Table 52. (continued)

Soil type	Jar number	No K added: Yield per jar	No K added: K in plant	No K added: K in plant per 100 grams soil	K added: Yield per jar	K added: K in plant	K added: K in plant per 100 grams soil
		gms.	per cent	mgms.	gms.	per cent	mgms.
Brookston loam	1	10.4	0.58	5.2	11.9	1.45	14.9
	2	11.0	0.52	5.0	11.6	1.37	13.8
	3	11.7	0.45	4.6	11.7	1.42	14.4
Wauseon loam	1	8.8	0.35	2.6	15.4	1.30	16.8
	2	8.8	0.31	2.3	13.6	1.48	16.9
	3	9.6	0.27	2.2	12.1	1.52	15.5

Table 53. The effect of cropping on the amounts of several forms of soil potassium in some soils with and without potassium treatment

Soil type	Jar number	Before cropping: Acid sol.	Before cropping: Exch.	Before cropping: Water sol.	After cropping, No K added: Absorbed or fixed	No K added: Acid sol.	No K added: Exch.	No K added: Water sol.	K added: K added	K added: Absorbed or fixed	K added: Acid sol.	K added: Exch.	K added: Water sol.
		mgms. K per 100 gms. soil			mgms. K per 100 gms. soil					mgms. K per 100 gms. soil			
Fox	1				1.3	6.8	3.2	3.2		17.8	6.0	4.8	6.5
sandy	2	10.7	1.8	2.0	1.7	7.5	2.5	2.8	20.6	17.5	6.3	5.2	6.1
loam	3				1.4	8.1	2.6	2.4		18.1	5.8	5.3	5.9
Plain-	1				3.8	5.0	1.9	1.4		13.3	7.9	5.0	5.6
field	2	9.7	1.6	0.8	4.2	4.1	2.2	1.6	19.7	12.5	8.4	5.6	5.3
sand	3				3.5	5.3	2.0	1.3		13.1	8.3	5.2	5.2
Emmet	1				3.8	4.4	2.8	3.6		17.6	5.3	5.8	7.1
sandy	2	9.9	2.7	2.0	4.2	3.7	2.3	4.4	21.2	15.8	7.3	6.0	6.7
loam	3				4.7	3.3	2.5	4.1		16.1	6.5	5.6	7.6
Kalkaska	1				2.8	5.3	1.7	1.5		18.4	5.1	3.8	4.2
sand	2	9.0	1.3	1.0	2.8	5.6	1.7	1.2	20.2	18.7	3.6	4.3	4.9
	3				2.0	6.0	1.9	1.4		19.0	3.5	4.6	4.4
Onaway	1				4.8	7.6	4.3	2.4		24.3	4.2	5.4	6.2
sandy	2	14.2	2.4	2.5	5.5	7.9	3.7	2.0	21.0	23.6	3.3	5.6	7.6
loam	3				4.7	7.9	4.2	2.3		21.9	4.3	5.2	8.7
Gilford	1				4.3	5.2	2.2	1.5		20.5	5.5	3.5	5.6
sandy	2	10.9	1.1	1.2	4.1	5.8	1.8	1.5	21.9	20.5	5.4	2.8	6.4
loam	3				3.8	5.8	2.0	1.6		21.0	4.7	2.9	6.5

Table 53. (continued)

Soil type	Jar number	Before cropping: Acid sol.	Before cropping: Exch.	Before cropping: Water sol.	After cropping, No K added: Absorbed or fixed	No K added: Acid sol.	No K added: Exch.	No K added: Water sol.	K added: K added	K added: Absorbed or fixed	K added: Acid sol.	K added: Exch.	K added: Water sol.
		mgms. K per 100 gms. soil			mgms. K per 100 gms. soil					mgms. K per 100 gms. soil			
Warsaw	1	•			0.3	18.7	4.9	2.5		26.4	11.3	8.6	4.1
loam	2	20.2	4.3	1.9	0.6	18.5	5.1	2.2	24.0	27.0	10.5	8.0	4.9
	3				1.0	17.6	5.3	2.5		26.6	10.7	8.5	4.6
Miami	1				2.8	8.8	2.4	2.1		26.0	8.2	5.8	3.7
loam	2	13.3	1.4	1.4	2.1	9.3	3.1	1.6	26.2	24.4	8.7	5.5	3.7
	3				1.6	9.2	3.0	2.3		25.8	7.5	5.6	3.4
Miami	1				2.5	8.6	2.6	1.4		16.6	6.5	8.5	6.5
loam	2	12.3	1.6	1.2	1.5	9.3	2.8	1.5	23.0	16.7	7.0	6.8	7.6
	3				1.8	9.1	2.5	1.7		21.5	7.2	7.7	5.7
Brook-	1				-0.3	13.3	5.4	1.2		25.2	6.5	9.1	4.3
ston	2	14.3	4.4	0.9	0.5	12.6	5.3	1.2	25.5	24.0	7.3	8.3	5.5
loam	3				0.0	13.0	5.1	1.5		22.2	8.0	9.5	5.4
Conover	1				-1.7	7.8	5.7	1.7		21.5	2.1	9.5	5.7
silt	2	8.0	4.2	1.3	-0.3	7.0	5.2	1.6	25.3	22.2	4.6	8.5	4.4
loam	3				0.3	6.6	5.0	1.6		21.8	5.2	7.8	4.0
Wauseon	1				1.2	7.1	2.9	1.9		22.8	5.8	5.7	3.5
loam	2	9.6	2.2	1.3	1.8	6.4	3.1	1.8	24.7	21.1	8.1	4.9	3.7
	3				1.5	7.2	2.9	1.5		23.3	6.9	5.4	3.2

Table 54. The gain or loss in some fractions of soil potassium after greenhouse cropping of some soils treated with and without potassium

Soil type	Jar number	No K added: Fixed*	Acid sol.	Exch.	Water sol.	K added: Fixed*	Acid sol.	Exch.	Water sol.
		Mgms. of potassium per 100 gms. soil							
Fox sandy loam	1	-0.6	-3.9	1.4	1.2	1.7	-4.7	3.0	4.5
	2	-0.3	-3.2	0.7	0.8	1.4	-4.4	3.4	4.1
	3	-0.4	-2.6	0.8	0.4	0.1	-4.9	3.5	3.9
Plainfield sand	1	2.9	-4.7	0.3	0.6	2.4	-1.8	3.4	4.8
	2	3.4	-5.6	0.6	0.8	0.3	-1.3	4.0	4.5
	3	2.6	-4.4	0.4	0.5	2.7	-1.4	3.6	4.4
Emmet sandy loam	1	2.2	-5.5	0.1	1.6	4.5	-4.6	3.1	5.1
	2	2.6	-6.2	-0.4	2.4	1.0	-2.6	3.3	4.7
	3	3.0	-6.6	-0.2	2.1	2.2	-3.4	2.9	5.6
Kalkaska sand	1	1.4	-3.7	0.4	0.5	5.4	-3.9	2.5	3.2
	2	1.1	-3.4	0.4	0.2	6.0	-5.4	3.0	3.9
	3	0.6	-3.0	0.6	0.4	4.1	-5.5	3.3	5.7
Onaway sandy loam	1	2.5	-6.6	1.9	-0.1	5.5	-10.0	3.0	7.7
	2	2.8	-6.3	1.3	-0.5	2.1	-10.9	3.2	5.1
	3	1.7	-6.3	1.8	-0.2	3.7	-8.9	2.8	6.2
Gilford sandy loam	1	2.8	-5.7	1.1	0.3	2.6	-5.4	2.4	4.4
	2	2.7	-5.1	0.7	0.3	3.3	-5.5	1.7	5.2
	3	2.2	-5.1	0.9	0.4	2.5	-6.2	1.8	5.3
Warsaw loam	1	-1.9	-1.5	0.6	0.6	9.9	-8.9	4.3	2.2
	2	-1.3	-1.7	0.8	0.3	10.7	-9.7	3.7	3.0
	3	-0.8	-2.6	1.0	0.6	9.0	-9.5	4.2	2.7
Miami loam	1	0.5	-4.5	1.0	0.7	4.3	-5.1	4.4	2.3
	2	0.2	-4.0	1.7	0.2	6.0	-4.6	4.1	2.3
	3	-0.9	-4.1	1.6	0.9	3.7	-3.8	4.2	2.0
Miami loam	1	0.9	-3.7	1.0	0.2	2.5	-5.8	6.9	5.3
	2	-0.2	-3.0	1.2	0.3	1.7	-5.3	5.2	6.4
	3	0.3	-3.2	0.9	0.5	2.9	-5.1	6.1	4.5

Table 54. (continued)

Soil type	Jar number	No K added: Fixed*	No K added: Acid sol.	No K added: Exch.	No K added: Water sol.	K added: Fixed*	K added: Acid sol.	K added: Exch.	K added: Water sol.
		Mgms. of potassium per 100 gms. soil							
Conover silt loam	1	-8.5	-0.2	1.5	0.4	4.0	-5.9	5.3	4.4
	2	-6.7	-1.0	1.0	0.3	5.0	-3.4	4.3	3.1
	3	-5.7	-1.4	0.8	0.3	5.0	-2.8	3.6	2.7
Brookston loam	1	-4.9	-1.0	1.0	0.3	10.3	-7.8	4.7	3.4
	2	-4.5	-1.7	0.9	0.3	10.2	-7.0	3.9	4.6
	3	-4.6	-1.3	0.7	0.6	7.8	-6.3	5.1	4.5
Wauseon loam	1	-1.4	-2.5	0.7	0.6	6.0	-3.8	3.5	2.2
	2	-0.5	-3.2	0.9	0.5	4.2	-1.5	2.7	2.4
	3	-0.7	-2.4	0.7	0.2	6.8	-2.7	3.2	1.9

*This is considered to be the acid insoluble form.

(the potassium added, if any) - (the sum of the fractions after cropping) + (the potassium removed by the plants).

As might be expected the exchangeable and water soluble potassium increased on those soils to which soluble KCl was added. To those pots where no potassium was added and on which plant growth and appearance was poor, the replaceable and water soluble forms also increased over their original values. The latter phenomenon might be explained by the release of potassium from the less available sources toward the end of the growing period forming an accumulation which was not absorbed by weakened and rather inactively growing plants.

The losses exhibited in the acid soluble form in soils to which potassium was added indicated either that plants are able to feed directly upon this form of potassium or that the equilibrium shift from the acid soluble to the more available fractions is rather rapid upon intense removal of water soluble and exchangeable potassium. The gains in the acid insoluble form with additions of potassium would appear inconsistent on the basis of an equilibrium system with the next soluble fraction. However, it could have been possible, over the period of a month or two before the plants removed any large amount of potassium, for a shift of that element to occur from the more available forms to the acid insoluble state. In the case of sandy soils where no increment of potassium was received, the above explanation will not suffice, for it appears that there is a movement of potassium from the acid soluble fraction to both more and less soluble forms. Under similar conditions and upon crop removal the fine textured soils show a distinct equilibrium trend of potassium from the less available to the replaceable and water soluble forms.

SUMMARY

Plant and soil samples were collected from normal and poor alfalfa fields located on some sandy soils in western Michigan in an attempt to find the soil factor or factors which were causing the farmers difficulty in establishing and maintaining legume stands. On the supposition that the lack of available potassium might be a partial answer to the problem, the soils and plants were analyzed for this element and other plant nutrients.

The soil samples from good and poor alfalfa fields were tested for exchangeable potassium, calcium, magnesium, available phosphorus, base exchange capacity, and reaction. The supply of available potassium and calcium was substantially higher in soils from the good fields. Little difference was noted between the amount of replaceable magnesium in soils from either type of location. Ca+Mg/K ratios of samples studied were lower from the good alfalfa fields. Although there was no significant difference between the per cent base saturation of soils sampled from normal and poor alfalfa stands, it appears that 75 per cent base saturation may be regarded as the lower limit for good alfalfa growth provided there is a plentiful supply of available potassium and phosphorus. The reaction determinations, in general, paralleled the values for per cent base saturation. The available phosphorus content, as extracted with dilute acid, was about the same for soils from good and poor fields.

The calcium and magnesium contents of alfalfa from poor fields were found to be higher than that of plants from good stands, while the per cent potash was only one-half as high. The low potassium content of the dried plants as indicated by chemical test was correlated with field observations of a stunted and yellowed growth, known symptoms of potash deficiency, and with tests made on the green tissue.

The response of alfalfa grown in greenhouse pots to various fertilizer and minor element treatments was undertaken in 18 experiments on Plainfield, Fox, Warsaw, Emmet, Kalkaska, Mancelona, and Onaway soils. These soils, of a sandy character, low in organic matter with the exception of the Warsaw samples, and subject to drought in periods of low rainfall, were collected from fields that supported good and poor stands. Though some soils which had produced a good growth of alfalfa in the field responded in the greenhouse to plant food additions on cuttings of the first stand, the increases in yield over no treatment were smaller than those obtained from clippings of the second stand. In general there was a negative correlation between the productivity of the field stand and the degree of growth response in greenhouse culture.

Potassium gave significant increases in the yield of tops of one or more cuttings of alfalfa of the first stand in 16 out of a total of 19 greenhouse experiments conducted on ten different soil types. Highly significant response in the growth of tops and roots of the second stand can be attributed to potassium in every experiment where alfalfa was replanted and refertilized. Using the yield of the second cutting of the first and second stands, where available, as an indicator of the relative need of potassium, the average per cent increase in yield of all experiments upon comparing calcium, magnesium, and potassium with calcium and magnesium or calcium and potassium with calcium is 48 for the first stand and 375 for the second stand. The individual effect of potassium on yield for the second stand on two Fox sandy loam soils rose above 1000 per cent increase.

It is evident that with heavy cropping of sandy soils, an adequate supply of potassium is needed for continued maintenance and reestablishment of legume stands.

In general, applications of lime had little effect on yield even though the reaction of some soils was below pH 5.8. Small decreases in growth were recorded in the cuttings of the first stand on four soils and in the cuttings and roots of the second stand in three experiments. In all other trials alfalfa responded slightly to additions of calcium or calcium and magnesium. Three greenhouse experiments using a Mancelona, a Kalkaska, and an Emmet sandy soil indicate that the beneficial effect of boron, manganese, zinc, copper, and cobalt was increased by the use of lime. Slightly depressed yields of alfalfa were obtained in a single trial on an Emmet sandy loam from the addition of lime to minor element treatments. A part of the injurious effect of overliming of sandy soils is probably due to the formation of insoluble compounds of lime with boron, manganese, cobalt, copper, and zinc. It is also possible that the addition of lime without potassium to these sandy soils produced a higher calcium/potassium ratio which would be less favorable for legume growth.

In eleven experiments where the individual effect of magnesium can be determined from calcium, potassium, and magnesium combinations, four showed a significant response in yield from the use of magnesium, while little or no benefit was obtained from additions of this element on seven soils. In general, those soils, namely a Fox sandy loam, two Warsaw sandy loams, and an Emmet sandy loam, that responded to magnesium had lower amounts of this element in the exchangeable form than did soils not responding significantly.

Boron was added alone or in combination with calcium, calcium and magnesium, magnesium and potassium, or calcium, magnesium, and potassium in eighteen experiments. In three trials on a Fox, an Emmet, and an Onaway sandy loam, there was no significant increase in either the yield of tops or roots upon the addition of boron alone or in combination with magnesium and potassium. Significant response in top growth of one or more cuttings was obtained on four Fox sandy loam soils, two Warsaw loam soils, three Emmet sandy loam soils, and on one sample of Kalkaska sand, Mancelona sandy loam, and Onaway sandy loam. Boron was more beneficial for increasing the growth of roots than the aerial portions of the alfalfa plant. In general, boron in combination with calcium and magnesium gave slightly higher increases in yield than when boron was added together with calcium, magnesium, and potassium.

The individual effect of manganese can be determined from the data of six experiments. Significant increases in yield of tops and especially roots were recorded only on two soils, both Onaway sandy loams with pH values of between 6.0 and 6.5. A slight response to manganese was obtained on a Plainfield sandy soil. The addition of manganese in experiments on three Emmet sandy loam soils caused slight decreases in yield. In contrast to boron, manganese appears to give a greater increase in yield when applied with calcium and potassium than when applied with calcium alone.

The individual effect of zinc can be calculated in experiments on two soils. Addition of zinc with boron and with lime, potassium, and boron gave significant increases in growth of alfalfa tops and roots on an Emmet sandy loam soil, but not with lime and boron. Little or no beneficial effect was found from the use of zinc on a Kalkaska sandy soil.

Cobalt added to an Emmet sandy loam soil and a Kalkaska sandy soil in combination with boron, lime and boron, and lime, boron, and potassium produced rather important yield increases. The use of cobalt and zinc together resulted in slight to medium increases in growth on two Emmet sandy loam soils.

Copper, as the sulfate, was added as a minor element increment to soils in 15 experiments. The effect of copper alone can be ascertained in only one trial on a Fox sandy loam soil where copper produced significant increases in growth in three out of four cuttings. In eight experiments a combination of copper and manganese was used. Good increases were found in the yield of tops and roots, especially in the second stand, when these elements were added to three Fox and two Warsaw soils. Decreases in yield resulted from the use of this combination regardless of the fertilizer treatment accompanying it on a Mancelona and a Kalkaska sandy soil. Additions of copper and cobalt were of importance in raising alfalfa yields on two Emmet soils and one Kalkaska sandy soil. Root growth was stimulated more than top growth.

The general condition of yellowed and stunted field beans, which farmers of the "Thumb" area of Michigan ascribe to dry weather, would appear from this study to be due to the combined effects of low moisture and an inadequate supply of potassium in the surface soil. Those soils low in available potash produced low yielding, potassium deficient beans. Plants grown on soils high in potash produced a good yield of beans without showing deficiency symptoms despite low rainfall during the month of July and the first part of August. However, under summer conditions of higher rainfall in 1942 when precipitation was above normal for the section, many of the bean fields that showed potash starvation signs in 1941 produced normal appearing bean plants. The data points to the fact that soil moisture is an important factor in determining whether soils low in available potassium will produce potash deficient beans. Whether the greater soil moisture supply actually increases the content of exchangeable potassium or whether under such conditions the plant roots have a greater capacity to forage for potassium has not been demonstrated.

Sidedressing potash deficient beans with 100 pounds per acre of KCl doubled the yield of beans on two of ten farms. Earlier application of this fertilizer might have produced higher yields on the other fields.

With a view to obtaining information on the release and fixation of potassium in some Michigan soils, studies were made of the equilibrium between the water soluble, exchangeable, and acid soluble fractions of soil potassium under controlled laboratory conditions.

The release of potassium was investigated after soils were brought to a low fertility level either by cropping or by artificial leaching. The rate of release of exchangeable and water soluble potassium was found to be greatest in the first period of incubation and under more intensive cropping, with the soils tending to regain the same level of replaceable potassium as existed before the experiments started. Under heavy cropping of these soils, the acid soluble fraction appeared to be the main source of replacement for the more available forms. The ratio of salt soluble to water soluble potassium was found to decrease with the time of incubation. The average amount of exchangeable and water soluble potassium released over an eight month incubation period from seven sandy soils that had supported 3 cuttings of alfalfa was 25 pounds. This figure would be far too small to support a vigorous stand of alfalfa on soils of sandy texture and low in fertility.

Laboratory studies under optimum moisture conditions on the fixation of potassium in seven sandy soils of western Michigan indicated that very little if any potash of a 200 pound per acre application of KCl was fixed in the acid soluble form. When 500 and 1000 pound per acre additions of muriate of potash were made, the per cent of fixed potassium in non-exchangeable forms averaged about 10 per cent. Such large applications, however, produced rather large amounts of the water soluble and replaceable fractions, which could be lost through excessive leaching.

The effect of the addition of potassium on its various soil forms and on plant growth was investigated on twelve Michigan soils planted to millet in small greenhouse pots. The addition of KCl to the lighter textured soils was more effective in increasing the yield of millet than when applied to the loam and silt loam soils. Little difference was noted in the yield and per cent potash of the plants on all soils treated, but the potassium content of plants grown on the heavier soils with no treatment was considerably higher due to larger yields and a higher per cent of potash. The original sandy soils contained less acid soluble and exchangeable potassium than the heavier soils, but about the same amount of the water extractable fraction.

After cropping, the acid soluble and replaceable forms of potassium in the sandy soils were lower with and without potash treatment than those fractions in the loam and silt loam soils. In every case, however, except one, the exchangeable and water soluble potassium of all soils was higher than at the beginning of the experiment. The apparent source of potassium for plant growth for the sandy soils receiving no treatment was the acid soluble form, while for the heavier soils the main supply came from the acid soluble and acid insoluble fractions. As in the case of fixation studies, the effect of the addition of potassium was to cause a reduction in the acid soluble form and a definite increase in the acid insoluble form.

The main source of soil potassium in the sandy soils for plant growth is the acid soluble fraction, which is in equilibrium with the more available forms. Soils of low fertility or soils having had poor management cannot release enough potash to supply the needs of a vigorous stand of legumes. Fertilizers high in potash are necessary to help establish and maintain alfalfa and clover stands. Since the lighter soils do not fix appreciable amounts of potassium, it would appear that the most economical way of applying this plant food would be small and frequent additions over the life of the stand. Such recommendations have already been placed before the farmers.

Experimental greenhouse studies indicate that certain minor elements, such as B, Mn, Co, Cu, and Zn, when applied with calcium and potassium increase the yield of legumes on sandy soils.

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