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Effects of rates and ratios of calcium, magnesium, and potassium on composition and yield of Ladino clover.

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by

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INTRODUCTION

Dairying is one of the major agricultural enterprises in Massachusetts. One of the prerequisites of successful dairying is an economical source of high quality forage. Legumes are considered an important source of calcium which is needed for healthy animals and production of milk. In New England the consistent production of high yield and quality forage requires scientific use of commercial fertilizers because the soils are generally low in the major and minor elements. This is especially true for those forage plants which have a growth habit requiring high fertility levels such as ladino clover and alfalfa.

In a survey of farms using currently accepted fertility practices Walrath et al (18) reported that the analysis of hay showed "evidence of a lack of balance between calcium and magnesium and potassium." The specific purpose of this investigation was to study the problem of maintaining stands of ladino clover with enough K for good yields and a balanced mineral composition. When legumes absorb high concentrations of K (3 per cent or more), the amount of Ca and Mg taken up will be necessarily lowered. However, the desired balance is a high Ca-Mg content with K ranging from 1.25 to 1.5 per cent. The difficulty in producing a forage of this composition is the tendency of legumes to accumulate K in luxury amounts. Luxury absorption of K by plants as explained by Bear and Prince (2) is the "substitution of K for Ca and Mg in the functions that are common to all three cations in the plant."

The method of solving the problem was suggested by cation balance (2,7,16,20,21), anion-cation ratio (12,17), the relative mobility of K and Ca, and Ehrenberg's potash-lime law (5). If the sum of the cations approximates a constant, decreasing one will cause an increase in the others. Although K is more motile than Ca and Mg, increasing the Ca or Mg content of the soil will bring about an increase in Ca or Mg and a lowered K content in the forage. This was summed up by Ehrenberg in 1919 by his law, $Ca \cong \frac{1}{K}$. Furthermore, Bear and Prince in 1945 (2) suggested that since the uptake of Ca and K was at different rates in alfalfa, it would seem advisable to use Ca and K differently, i.e. apply a higher initial amount of Ca with some K initially and K as needed thereafter.

Thus one procedure was to increase the Ca-Mg in the soil, in an effort to prevent luxury absorption of K. A second method was to apply some K initially and add small increments as needed. A third method was to apply the K, Ca, and Mg in an exchangeable form as it was believed that the K would not be released by the clay micelle in large enough quantities to allow the plant to use it in luxury amounts. It was assumed that, in general, the requirement and growth response of alfalfa and ladino clover to plant nutrients are similar.

EXPERIMENTAL PROCEDURE

A greenhouse pot experiment was conducted in which ladino clover was grown on Merrimac fine sandy soil subjected to the following treatments:

1. Various rates of exchangeable Ca and Mg as bentonites were combined with exchangeable K - bentonite in varying rates and ratios as shown in table 3.
2. Various rates of Ca, Mg, and K were supplied as calcite, dolomite, and muriate of potash as shown in table 4.
3. Two rates of dolomite and calcite were added to soils which had already received Ca, Mg, and K bentonites. These data are shown in table 5.

4. Factorial Experiment: Composed of cultures containing calcite and dolomite added to soil containing potassium bentonite compared with other cultures which contained Ca and Mg bentonite added to the soil and to which muriate of potash was added periodically in varying amounts. These data are shown in table 6.

On the 28th of December five stolens of five different clones of ladino clover were transplanted to glazed porcelain pots (without drains) containing 3,000 grams of soil. Treatments were duplicated. Distilled water was used throughout the experiment. Harvest dates were March 28, April 26, June 5, and July 6. The harvested clippings were dried at 70° C., weighed, and stored for analysis.

Soil from the A horizon of a Merrimac fine sandy loam which had been out of cultivation about twenty years was used. It was acid in reaction and very low in available plant nutrients (table 1).

Table 1

Some chemical characteristics of soil used in this experiment

pH	Per cent organic matter	Exchangeable cations in m.e. per 100 grams soil				
		Ca	Mg	K	H	Total Base Exchange Capacity
4.8	6.0	1.0	0.120	0.125	2.60	3.84

Data were obtained by the normal ammonium acetate method (11).

The effect of various lime rates on the pH of this soil was determined by mixing 300 grams of soil with increasing amounts of dolomitic limestone. The soil was watered frequently, and the pH was determined by a Beckman pH meter at intervals during a period of 270 days. The rates and resulting pH are shown in table 2.

Table 2

Soil reaction as affected by varying applications of dolomitic limestone*

Treatment (pounds per acre)	Resulting pH at end of 270 days
3,000	5.6
6,000	6.5
12,000	6.9
18,000	7.2
24,000	7.5

* Lee dolomite-composition, 30% CaO and 20% MgO. Fineness of lime-11% through 20-mesh and on a 50-mesh, 21% through 50-mesh and on a 100-mesh, and 68% through a 100-mesh.

All pots received superphosphate (20 per cent P_2O_5) at the rate of 1000 pounds per acre, supplying 0.5 m.e. of Ca per 100 grams of soil. Boron, as $Na_2B_4O_7$, was applied once at the rate of 20 pounds per acre. At frequent intervals $(NH_4)_2HPO_4$, supplying N and P at the rate of 5.3 pounds and 13.5 pounds per acre respectively, was applied to promote vigorous plant growth.

A modification of Albrecht's (1) colloidal clay culture procedure was used in preparing a series of soils which was labeled exchangeable or clay series. In this investigation the cation-bearing colloid was mixed with the soil to produce a soil of a known base exchange capacity. Hydrogen bentonite (pH 2.0) was produced by electro-dialysing (13) a one per cent suspensoid of sodium bentonite (Wyoming) in a cell in which the hydrogen bentonite migrated to and was collected on a rotating ceramic drum. The hydrogen bentonite was titrated with calcium hydroxide, potassium hydroxide, and magnesium oxide. The calcium bentonite contained 58 m.e. of Ca per 100 grams; the magnesium bentonite contained 58 m.e. of Mg per 100 grams; and the potassium bentonite contained 56 m.e. of K per 100 grams. These clays were added by spreading the soil and folding in weighed portion. This was allowed to age until such time as additional clay could be added without puddling the soil. Clay was added in this manner until the soil-clay mixture contained the desired amount of Ca, Mg, and/or K in m.e. per 100 grams of soil (hereinafter the treatments will be identified as 2-1-0.125, 4-2-0.125, etc., according to the Ca-Mg-K ratio in m.e. per 100 grams of soil respectively as shown in table 3).

Table 3

Clay series cultures: exchangeable Ca, Mg, and K-bentonites added to Merrimac fine sandy loam and base exchange capacity of the clay series cultures used for growth of ladino clover

Treatment No.	Exchangeable cations in m.e. per 100 grams of soil			Total B.E.C.*
	Ca	Mg	K	
1	1.5	0.12	0.125	3.84
2	2.0	1.00	0.125	6.12
3	2.0	1.00	0.250	6.34
4	2.0	1.00	0.500	6.77
5	4.0	2.00	0.125	11.07
6	4.0	2.00	0.250	11.30
7	4.0	2.00	0.500	11.72
8	6.0	3.00	0.500	16.66
9	8.0	4.00	0.500	21.63

* B.E.C. refers to base exchange capacity per 100 grams of soil.

Soil was also treated with varying rates of lime and potash and labeled the lime series (table 4).

Table 4

Lime series cultures: amounts of dolomitic limestone added initially to Merrimac fine sandy loam and the rates of muriate of potash added periodically to the lime series cultures used for growth of ladino clover.

Treatment No.	Dolomite added (lbs. per acre)	Muriate of potash added (pounds per acre) Initially	After 1st harvest	After 2nd harvest	After 3rd harvest
10	3,000	60	60		
11	6,000	60	60		
12	6,000	60	60	60	60
13	12,000	60	60	60	60
14	6,000	120	120	120	120
15	6,000	240		120	120
16	6,000	240		240	
17	3,000	240		240	
18	12,000	240		240	
19	18,000	240		240	
20	12,000	120	120	120	120
21	18,000	120	120	120	120
22	24,000	120	120	120	120
23	12,000 ($CaCO_3$)	240		240	

Treatments combining exchangeable soils with added amounts of lime are shown in table 5.

Table 5

Rates of calcitic and dolomitic limestone added to Merrimac fine sandy loam containing known amounts of exchangeable Ca, Mg, and K.

Treatment No.	Exchangeable cations in m.e. per 100 grams of soil			Lime added (pounds per acre)	
	Ca	Mg	K	Calcite	Dolomite
32	2.0	1.0	0.25	1035	1833
33	2.0	1.0	0.25	2070	3665
34	2.0	1.0	0.50	1035	1833
35	2.0	1.0	0.50	2070	3665
36	4.0	2.0	0.25	2070	3665
37	4.0	2.0	0.50	2070	3665

Combinations of Ca, Mg, and K supplied as bentonites and dolomite, calcite, and muriate of potash were applied as shown in table 6.

Table 6

Factorial cultures: various rates of nonexchangeable calcitic and dolomitic limestone added to Merrimac fine sandy loam containing exchangeable K - bentonite and amounts of nonexchangeable KCl applied periodically to soil containing exchangeable Ca and Mg bentonites

Treatment No.	M.e. per 100 grams of soil		M.e. per 100 grams of soil or lbs. per acre	
	Ca	Mg	Total K	Included
3	2 exch.	1 exch.	0.25 exch.	0.125 originally in soil
24	2 exch.	1 exch.	0.25 KCl	60 K_2O initially plus 60 after 1st cutting
27	2 nonexch.	1 nonexch.	0.25 exch.	
32	2 nonexch.	1 nonexch.	0.25 KCl	60 K_2O initially plus 60 after 1st cutting
4	2 exch.	1 exch.	0.50 exch.	
25	2 exch.	1 exch.	0.50 KCl	240 K_2O initially plus 120 after 2nd cutting
28	2 nonexch.	1 nonexch.	0.50 exch.	
30	2 nonexch.	1 nonexch.	0.50 KCl	240 K_2O initially plus 120 after 2nd cutting
7	4 exch.	2 exch.	0.50 exch.	
26	4 exch.	2 exch.	0.50 KCl	240 K_2O initially plus 120 after 2nd cutting
29	4 nonexch.	2 nonexch.	0.50 exch.	
31	4 nonexch.	2 nonexch.	0.50 KCl	240 K_2O initially plus 120 after 2nd cutting

ANALYTICAL METHODS

The ladino clover was ground in a micro-mill, and a weighed sample was wet ashed and analyzed for Ca, Mg, P, K, and Na. The Ca, Na, and K contents were determined by a Perkin-Elmer flame photometer (15). Phosphorus content was determined by Sherman's (14) method and Mg content by following the procedure of Drosdoff and Nearpass (4).

RESULTS

Clay series

The addition of Ca-Mg-K as bentonites to the soil increased the B.E.C.[1] from approximately 4 to 6 to 11 to 16 to 21 m.e. per 100 grams of soil and produced a general increase in yield as shown in figure 1 and 1A. Forage grown on the soil of high B.E.C. had nearly twice as much K as Ca, as did the forage grown on the treatments containing low B.E.C. at the K rate of 0.50. However, the generally upward trend of yield was broken in these treatments which supplied Ca-Mg-K as 4-2-0.25 and 4-2-0.50. A possible explanation of the above composition and yield trends may be drawn from some theories of Mattson (9) set forth in the following paragraphs.

The untreated replicates had low base exchange capacity, 3.84 m.e. (1.5 Ca, 0.12 Mg, and 0.125 m.e. K). Plant material containing 1.99 per cent[2] Ca (very high), 0.15 per cent of Mg, and 0.65 per cent of K (very low) was produced by this soil. This untreated soil, the 2-1-0.125, and 2-1-0.25 Ca-Mg-K treatments produced poor yields. The high Ca content of the forage agrees with Mattson's theory that "... soils having a low exchange capacity should supply the plant relatively better with divalent than with monovalent cations."

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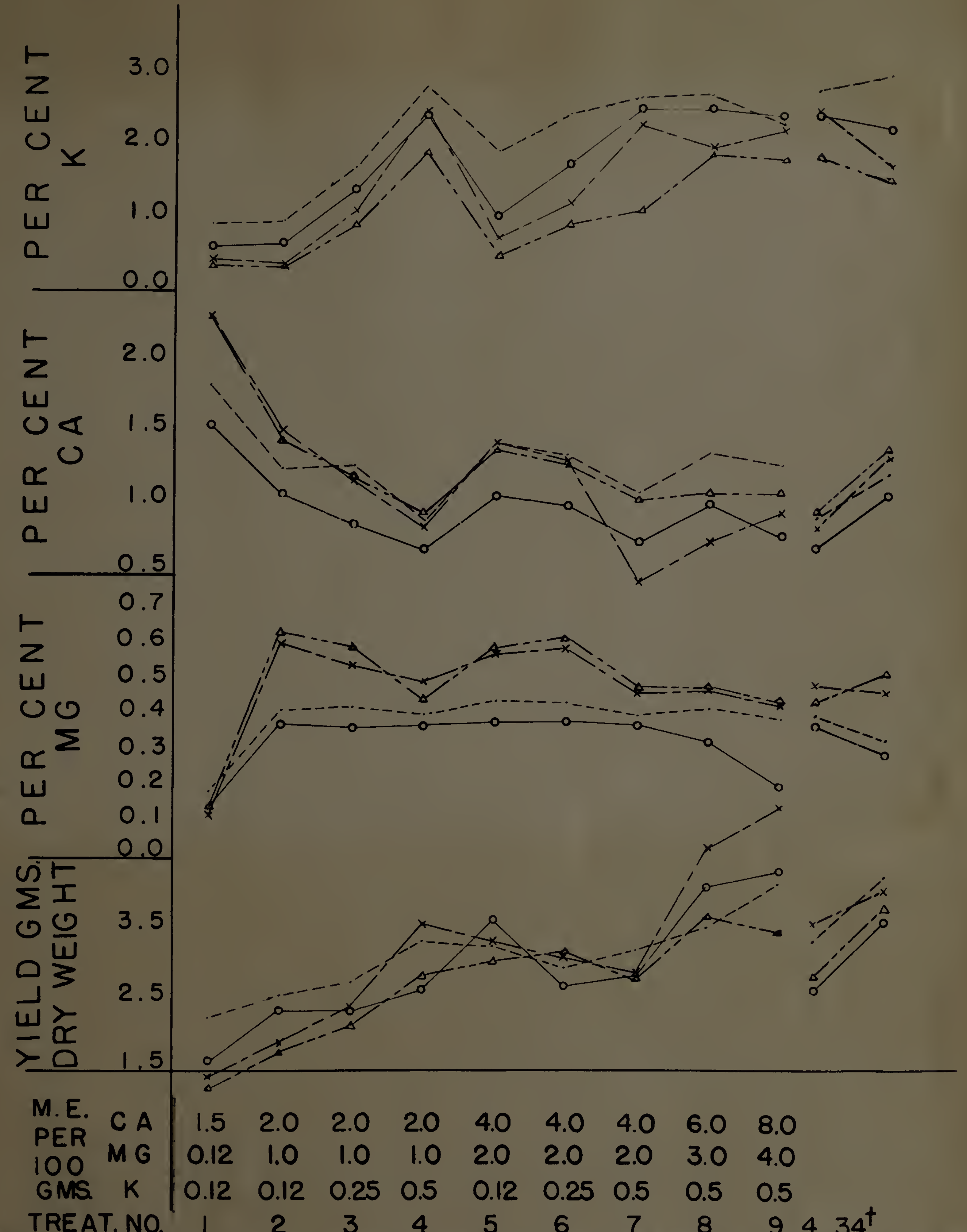
1. In this investigation the amount of the acidoid was increased as the supply of cations increased. This brought about a higher concentration of acidoid in contact with the plant roots.
2. Average of all four cuttings was used in this discussion.



† with the addition of 1035 pounds of calcite and 1833 pounds of dolomite per acre

Figure 1. Clay series - the composition of ladino clover in percentages of Ca, Mg, and K and the yield of dry matter in grams per pot resulting from the application of Ca-Mg-K-bentonites to Merrimac fine sandy loam.

First cutting.- - - -
Second cutting o——
Third cutting x—·—
Fourth cutting △—·-·—

Figure 1A

Clay series: showing the effect of increased exchangeable calcium, magnesium, and potassium on growth:

Pot No. 2 Check (1.5-0.12-0.125 Ca-Mg-K)

Pot No. 7 6.77 B.E.C. (2-1-0.50 Ca-Mg-K)

Pot No. 14 11.72 B.E. C. (4-2-0.50 Ca-Mg-K)

Pot No. 18 21.63 B.E.C. (8-4-0.50 Ca-Mg-K)

Thus, Mattson's theory and the poor yields (concentration effect) may account for the abnormal composition of the forage.

Those treatments which supplied 6-3-0.50 and 8-4-0.50 Ca-Mg-K produced a soil with a high base exchange capacity of 16.16 and 21.63 m.e. respectively. Forage from these treatments contained approximately 2.38 per cent K (high), 1.03 per cent Ca (low), and 0.40 per cent Mg. Yields were extremely high at these rates and ratios. This composition may be explained by Mattson's (9) statement that soils high in B.E.C. should supply a higher proportion of monovalent than divalent ions to the plant because the divalent ions are held with greater energy than are monovalent ions as the strength of the soil acidoid (quantity) is increased. The high K content of the forage from treatments (nos. 2, 3 and 4) in which the soils were relatively low in B.E.C. (6 m.e. of which 0.50 m.e. was K) can best be explained by the relative mobility of Ca-K or their activity coefficients (19).

Intermediate B.E.C. was produced by treatments 4-2-0.125 to 4-2-0.50. It has been stated (9) that within this intermediate range both monovalent and divalent cations will be taken up in nearly equal amounts. The composition resulting from these treatments varied greatly in per cent of Ca and K. In this group of treatments increasing K did not increase the yields. A possible explanation of this reversal in trend is that by changing from a low B.E.C. to a high B.E.C., by means of adding more clay increments to the soil, the acidoid of the soil may have been approaching the strength of the acidoid of the colloids in the ladino clover roots. Since Mattson (9) has reported that the acidoid of red clover roots is as high or higher than that of bentonite (clay), increasing the amounts of soil acidoid may have caused it to approach an equilibrium with the ladino clover root acidoid. If equilibrium between clay and root acidoid was approached, it may have caused the decreased growth. This is reasoned from Mattson's (9) statement that there can be no equilibrium established between the soil and a growing plant. A simpler explanation may be that the Ca-Mg was too low to balance that amount of K.

The data indicated that supplying Ca-Mg-K as bentonites at the 4-2-0.125 ratio produced the highest yield with the most desirable composition, although the K content of the third and fourth cuttings was below the "critical limits" (2) for alfalfa. Field experience has indicated that the ladino clover might perish at this level, especially if grass were included. Mattson (9) has shown that grasses will absorb relatively more K and less Ca while legumes, with a stronger acidoid, absorb greater amounts of Ca-Mg and less K - yet fairly large amounts of K are required for desirable legume yields.

From figure 1 it can be noted that the K content of the ladino clover generally decreased with each successive cutting, in agreement with results found by Bear and Prince (2). The reciprocal relationship between K and Ca (also Mg but to a lesser degree) was shown to be similar to Ehrenberg's (6) potash-lime law $Ca \approx \frac{1}{K}$.

Although Moser (10) found no "best" Ca-Mg ratio for optimum growth of plants and Hunter (6) reported that varying Ca-K ratio from 1-1 and up to and including 32-1 in soil increased the yield of alfalfa, the data presented in this discussion shows that certain Ca-Mg-K ratios produced more ladino clover than others. However, in these treatments supplying exchangeable Ca, Mg, and K, no combination used gave composition and yield which were considered optimum. In conclusion, then, this method of preventing luxury consumption of K and at the same time producing desirable yields by adding increasing amounts of exchangeable Ca and Mg, did not accomplish the desired results.

Additional data calculated from figure 1 are shown in the following tables 7, 8, and 9.

Table 7

The effects of various rates of exchangeable Ca-Mg-K-bentonites added to Merrimac fine sandy loam on the total yield of ladino clover in grams per pot and pounds per acre; the milliequivalents of Ca, Mg, and K per 100 grams of dry matter; and the total milliequivalents of Ca, Mg, and K removed by four cuttings.

Treatment No.	Exchangeable cations in m.e. per 100 grams of soil			Total yields[1] dry matter		m.e.[2] per 100 gms. dry matter	Total m.e.'s removed
	Ca	Mg	K	gms/pot	lbs./A.		
1	1.5	0.12	0.125	6.50	4,333	128.4	8.35
2	2.0	1.0	0.125	8.37	5,581	128.0	10.75
3	2.0	1.0	0.250	9.65	6,435	130.8	12.62
4	2.0	1.0	0.500	12.41	8,278	132.2	16.41
5	4.0	2.0	0.125	12.66	8,444	138.1	17.48
6	4.0	2.0	0.250	11.95	7,234	149.0	17.81
7	4.0	2.0	0.500	11.76	7,834	136.2	16.02
8	6.0	3.0	0.500	16.08	10,721	150.8	24.25
9	8.0	4.0	0.500	17.52	11,689	142.2	24.92

1. Total of all four cuttings
2. m.e. of Ca, Mg, and K

Table 8

The sum of Ca, Mg, and K for each cutting expressed as milliequivalents per 100 grams of dry plant material as effected by various rates of Ca-Mg-K-bentonites added to Merrimac fine sandy loam

Treatment No.	1st	2nd	3rd	4th cutting
1	131.7	107.5	138.2	136.2
2	124.0	102.5	136.9	132.2
3	143.9	109.6	134.3	135.3
4	153.3	130.5	149.5	135.3
5	163.3	114.6	141.6	132.8
6	173.1	129.6	149.7	143.5
7	161.5	135.9	123.8	123.5
8	178.0	147.0	130.6	146.9
9	159.2	122.7	144.2	142.5

Table 9

Ca, Mg, and K removed by ladino clover from Merrimac fine sandy loam as effected by various rates of Ca-Mg-K-bentonites

Treatment No.	Pounds per acre		
	Ca	Mg	K
1	82.83	5.65	27.96
2	77.58	27.84	38.18
3	73.34	31.10	87.76
4	71.22	36.20	208.17
5	115.32	42.68	94.97
6	94.29	38.61	127.14
7	66.83	34.22	178.36
8	105.95	44.54	237.88
9	86.04	49.21	307.07

Lime series

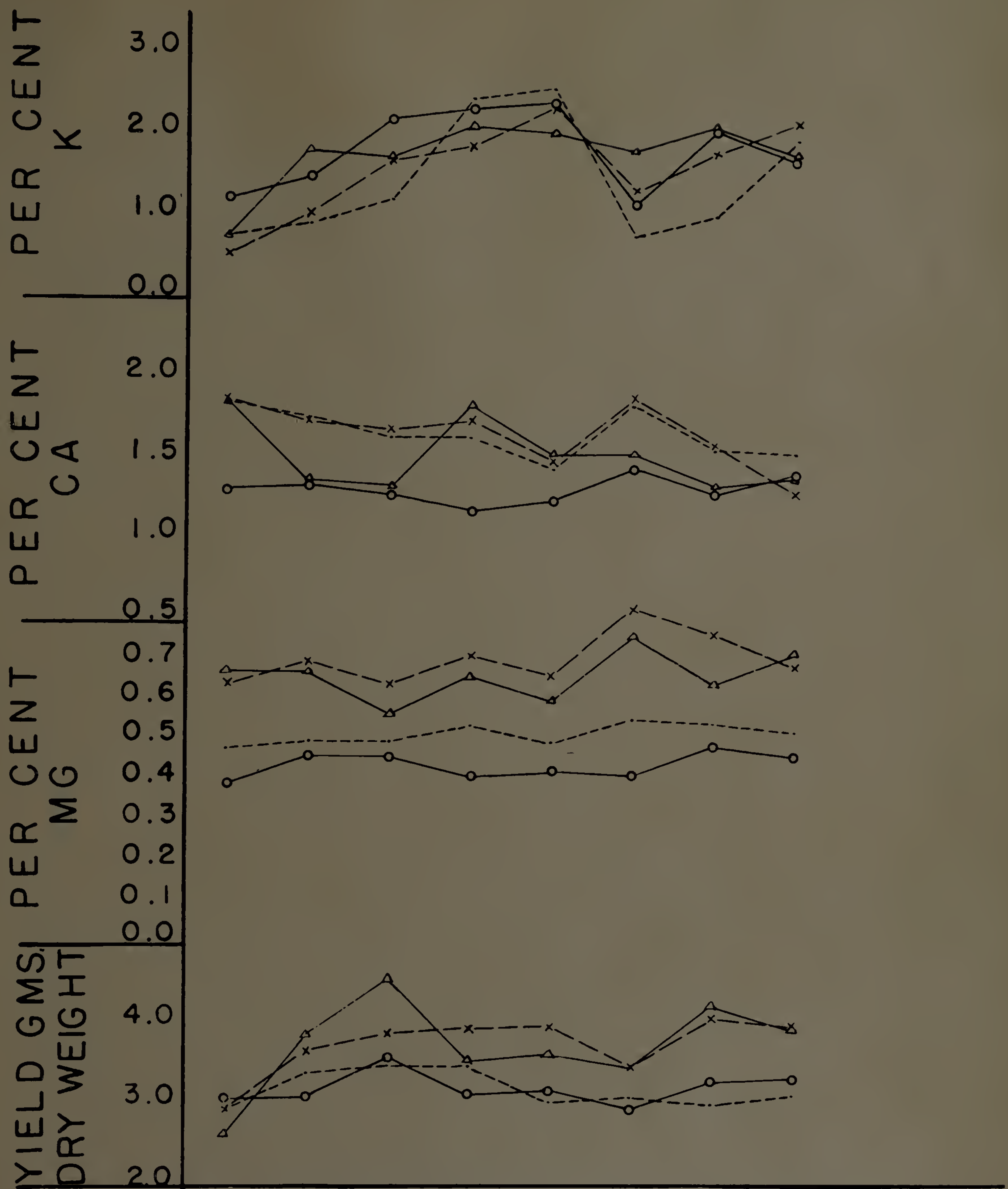
Treatments using 6,000 dolomite (in this series all applications were pounds per acre and hereinafter treatments will be referred to as 6,000 dolomite, 120 K_2O, etc.) with the following rates of K_2O produced these percentages of K in ladino clover (average of four cuttings) calculated from figure 2:

(a)	60 K_2O initially and 60 K_2O after each cutting	1.37 per cent
(b)	120 K_2O initially and 120 K_2O after each cutting	1.73 per cent
(c)	240 K_2O initially and 120 K_2O after 2nd and 3rd cuttings	2.18 per cent
(d)	240 K_2O initially and 240 K_2O after 2nd cutting	2.37 per cent

The K content of ladino clover was increased as K_2O was increased. Hence, on this soil with 6,000 dolomite luxury absorption of K can be prevented only by applying small amounts of K_2O initially and after each cutting.

Treatments designated as (a) and (b) above produced a high yield of forage with 1.54 and 1.50 per cent of Ca (high) respectively. The Mg content showed a similar trend (fig. 2). Bear and Wallace (3) suggested that 60 K_2O was the amount needed to produce one satisfactory cutting of alfalfa. The results of this experiment agree with their findings; however, 120 K_2O (b above) would be recommended for a grass-ladino mixture because grasses are known to absorb more K than legumes as explained by Mattson's root acidoid theory (see clay series). The above observations were based on the total of the four cuttings.

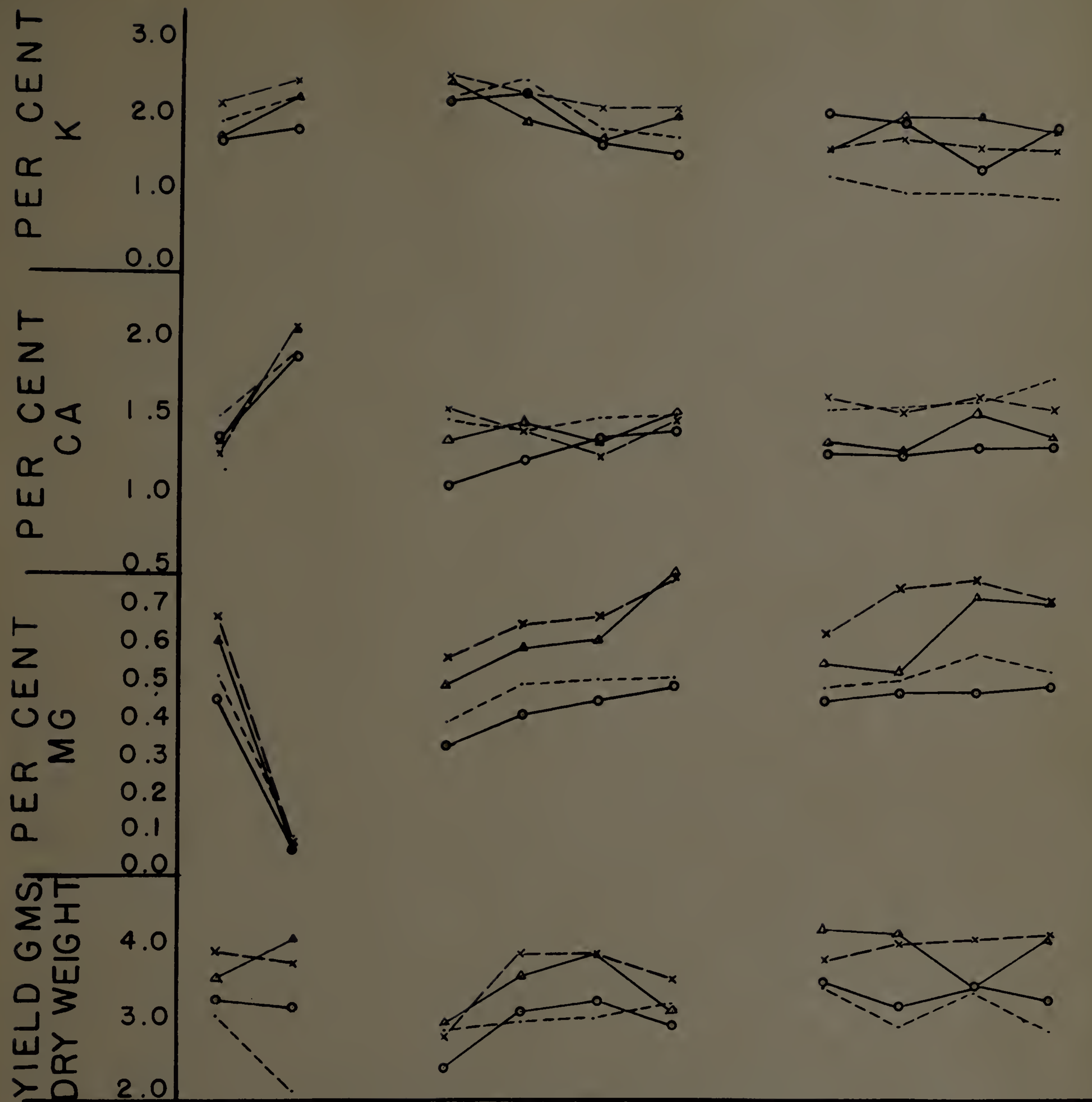
In treatments using 6, 12, 18, and 24,000 dolomite and 120 K_2O initially and 120 K_2O after each cutting, the K content was generally below 2 per cent and the Ca content between 1.35 and 1.65 (fig. 3). These treatments produced forage with a more desirable (lower) K content than did treatments using comparable lime levels with 240 K_2O initially and 240 K_2O after second



K_2O INT.	60	60	120	240	240	60	120	240
LBS. 1ST	60	60	120			60	120	
PER 2ND		60	120	120	240	60	120	240
ACRE 3RD		60	120	120		60	120	
DOLOMITE	3	6	6	6	6	12	12	12
TREAT. NO.	10	12	14	15	16	13	20	18

Figure 2. Lime series - the composition of ladino clover in percentages of Ca, Mg, and K and the yield of dry matter in grams per pot resulting from the application of various rates of dolomite initially and various rates of muriate of potash periodically to Merrimac fine sandy loam.

First cutting - - - -
Second cutting o——
Third cutting x- - -
Fourth cutting △——



K_2O INT.	240	240	240	240	240	240	120	120	120	120
LBS. 1ST							120	120	120	120
PER 2ND	240	240	240	240	240	240	120	120	120	120
ACRE 3RD							120	120	120	120
DOLOMITE	12	12†	3	6	12	18	6	12	18	24
TREAT. NO.	18	23	17	16	18	19	14	20	21	22

† $CaCO_3$

Figure 3. Lime series - the composition of ladino clover in percentages of Ca, Mg, and K and the yield of dry matter in grams per pot resulting from the application of various rates of dolomite initially and various rates of muriate of potash added periodically to Merrimac fine sandy loam.

First cutting ----
Second cutting o——
Third cutting x----
Fourth cutting △——

cutting. Yields were nearly equal for both groups of treatments.

More lime was required to produce forage of a desirable composition when high and infrequent applications of K_2O were used. This is shown by comparing the forage produced by 12,000 and 6,000 dolomite at the same high K_2O rates (240 initially and 240 after 2nd cutting). The 12,000 dolomite produced forage of more desirable composition (equal in Ca but lower in K) than 6,000 dolomite. The forage produced with 12,000 dolomite removed 15 per cent less K than that with 6,000 dolomite. The yield was nearly identical in these two treatments. For the farmer who wishes to use heavy, infrequent applications of K because of labor cost, labor peaks, or wet soils, the higher rate of lime offers a real saving in K removal by the forage.

The luxury absorption of K by treatments supplying 240 K_2O and lower rates of lime (15, 16, 17, and 18) is shown in figures 2 and 3. With these treatments the amount of K removed by the plant from the soil ranged from 188 to 216 pounds per acre (table 12). Generally, this was less K than was removed from the clays with 0.50 m.e. of K per 100 grams of soil (table 9). These data show that nonexchangeable forms of lime with high K_2O applications, more effectively limited luxury absorption of K by ladino clover than did exchangeable forms of Ca-Mg with high rates of exchangeable K (table 9).

With the exception of a lower yield for calcite in the first cutting, there was no appreciable difference in yields produced by dolomite and calcite in this investigation. The composition was high in Ca and K but extremely low in Mg (average of less than 0.1 per cent. Since the forage produced on soil treated with this high calcitic lime showed no visible signs of Mg-deficiency and produced good yield, the need for Mg is not apparent to the farmer without analysis. Unless the farmer is certain that his soil contains sufficient available Mg to produce ladino clover of good composition and yield, it would be advisable for him to use a liming material containing Mg. The sum of the cations in this treatment showed the cation constancy as was described by Van Itallie (20, 21) (tables 10 and 11).

The composition of ladino clover in percentages of Ca, Mg, and K; the milliequivalents of Ca, Mg, and K per 100 grams of dry matter; and the dry weight in grams per pot; are shown in the appendix for the clay and lime series for each cutting. Additional data calculated from figures 2 and 3 are shown in the following tables 10, 11, and 12.

Table 10

The effect of various rates of dolomitic limestone added initially and muriate of potash added periodically to Merrimac fine sandy loam on the total yield in grams per pot and pounds per acre; the milliequivalents of Ca, Mg, and K per 100 per grams of dry matter; and the total milliequivalents of Ca, Mg, and K removed by four cuttings

Treatment No.	Dolomite added (lbs./A)	Muriate of potash (lbs./acre) added				Total yield dry matter[1]		m.e.[2] per 100 grams dry matter	Total m.e.'s removed
		Initially	after 1st harvest	after 2nd harvest	after 3rd harvest	gms pot	lbs acre		
10	3,000	60	60			11.72	7,817	151.0	17.69
11	6,000	60	60			9.39	6,263	163.1	15.29
12	6,000	60	60	60	60	14.14	9,431	161.0	24.73
13	12,000	60	60	60	60	12.97	8,651	170.4	22.08
14	6,000	120	120	120	120	15.39	10,265	162.1	24.91
15	6,000	240		120	120	14.16	9,445	177.2	26.16
16	6,000	240		240		13.69	9,131	182.1	24.92
17	3,000	240		240		11.28	7,523	175.7	19.73
18	12,000	240		240		14.40	9,605	168.9	24.27
19	18,000	240		240		12.66	8,444	190.9	24.04
20	12,000	120	120	120	120	14.66	9,778	169.7	25.82
21	18,000	120	120	120	120	15.29	9,838	169.0	25.82
22	24,000	120	120	120	120	14.73	9,825	173.4	25.53
23	12,000[3]	240		240		13.38	8,924	174.6	23.33

1 Total of all four cuttings
2 M.e. of Ca, Mg, and K
3 $CaCO_3$

Table 11

The sum of Ca, Mg, and K for each cutting expressed as milliequivalents per 100 grams of dry plant material as effected by various rates of dolomitic limestone applied initially and various rates of muriate of potash applied periodically to Merrimac fine sandy loam

Treatment No.	First	Second	Third	Fourth cutting
10	153.2	129.8	166.0	156.8
11	171.9	143.6	198.0	177.1
12	155.8	141.3	171.3	219.0
13	191.2	161.7	195.9	215.1
14	182.1	161.4	190.7	179.0
15	171.9	154.8	179.9	202.2
16	170.4	157.4	200.8	204.2
17	167.2	206.6	188.7	180.5
18	152.5	145.0	171.4	171.3
19	156.4	161.1	181.8	159.9
20	163.5	143.1	197.9	170.2
21	153.7	159.7	191.8	166.8
22	161.6	147.0	196.9	194.8
23	163.3	160.7	185.7	178.8

Table 12

Ca, Mg, and K removed by ladino clover from Merrimac fine sandy loam as effected by various rates of dolomite applied initially and muriate of potash applied periodically

Treatment No.	Pounds per acre		
	Ca	Mg	K
10	133.7	43.0	50.8
11	110.2	40.1	55.1
12	145.2	56.6	129.2
13	146.2	59.7	100.4
14	154.0	53.4	177.6
15	143.6	52.9	195.9
16	134.2	53.0	216.4
17	108.9	36.3	188.1
18	135.4	56.7	188.3
19	136.8	58.9	173.9
20	143.7	58.7	180.9
21	156.0	65.3	160.1
22	153.2	62.9	167.0
23	194.5	8.0	206.1

Exchangeable Ca-Mg-K with additional lime

Generally, yields of ladino clover were increased (as much as 2,000 pounds per acre) when both dolomite and calcite were added to those soils which contained exchangeable Ca, Mg, and K as clay additions (table 13). The increased yield and the observation that the forage produced had a more desirable composition, (an increase of approximately 0.4 per cent Ca and a similar decrease of K), leads to the conclusion that the soil of the clay series was not balanced in Ca, Mg, and K. However, the lower lime rate, 1035 calcite and 1893 dolomite, gave higher yields (1300 to 1500 pounds per acre more) than the high rate of lime, 2070 calcite and 3665 dolomite. At the high lime rate K became a seriously limiting factor, doubling the exchangeable K supply and increased the yields (table 13). The increased Ca-absorption by these plants may be explained by the increased degree of Ca-saturation as Wiklander (19) stated: "In normal soils the complex is principally saturated with Ca which has a greater replacing power as compared to that of some of the other exchangeable ions. As a consequence of the complementary ion principle and the effect exerted by the degree of saturation, Ca should become the more difficult to displace, the lower the Ca saturation."

Factorials

Supplying K as KCl or K-bentonite at the rate of 0.25 m.e. K per 100 grams of soil produced ladino clover of desirable K content, while either KCl or K-bentonite at the rate of 0.50 m.e. K per 100 grams of soil produced forage much higher in K (well above 2 per cent).

The highest yield was produced by the treatment using 4-2-0.50 nonexchangeable Ca-Mg and exchangeable K (table 14). The use of nonexchangeable Ca-Mg with exchangeable K in a 2-1-0.50 rate and ratio also produced high yields, but a 2-1-0.25 rate and ratio did not give high yields. Although the

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Factorials

Supplying K as KCl or K-bentonite at the rate of 0.25 m.e. K per 100 grams of soil produced ladino clover of desirable K content, while either KCl or K-bentonite at the rate of 0.50 m.e. K per 100 grams of soil produced forage much higher in K (well above 2 per cent).

The highest yield was produced by the treatment using 4-2-0.50 nonexchangeable Ca-Mg and exchangeable K (table 14). The use of nonexchangeable Ca-Mg with exchangeable K in a 2-1-0.50 rate and ratio also produced high yields, but a 2-1-0.25 rate and ratio did not give high yields. Although the

0.25 m.e. rate of K supplied as KCl produced greater yields than the same rate of K-bentonite, the rate of 0.50 m.e. of K per 100 grams of soil supplied as KCl produced lower yields than K as K-bentonite, when combined with either Ca-bentonite and Mg-bentonite or dolomite. In general, nonexchangeable Ca-Mg produced more forage than did exchangeable Ca-Mg, regardless of the Ca-Mg rate and the rate and form of K.

Table 13

The yields of ladino clover resulting from adding dolomite and calcite to Merrimac fine sandy loam which contained known amounts of exchangeable Ca, Mg, and K, compared to the yields without the addition of lime

Treatment No.	Exchangeable cations m.e. per 100 gms. of soil			Liming material added (lbs. per acre)		Total yield of four cuttings (lbs. per A.)
	Ca	Mg	K	Calcite	Dolomite	
32	2.0	1.0	0.25	1035	1833	8,924 (6,450)*
33	2.0	1.0	0.25	2070	3665	7,624
34	2.0	1.0	0.50	1035	1833	10,498 (8,277)*
35	2.0	1.0	0.50	2070	3665	8,164
36	4.0	2.0	0.25	2070	3665	8,291 (7,970)*
37	4.0	2.0	0.50	2070	3665	9,985 (7,844)*

*Yields from treatments supplying exchangeable cations without additional lime

Table 14

The effect of various rates of nonexchangeable calcitic and dolomitic limestone with exchangeable K bentonite and the effect of exchangeable Ca-Mg bentonites with nonexchangeable KCl applied at different intervals to Merrimac fine sandy loam on the total yield of ladino clover in grams per pot; the milliequivalents of Ca, Mg, and K per 100 grams of dry matter; and the total milliequivalents of Ca, Mg, and K removed by three cuttings

Treatment No.	m.e. per 100 grams of soil			Total yield[1] dry matter	m.e.[2] per 100 grams dry matter	Total m.e.'s removed
	Ca	Mg	K	grams/pot		
3	2 exch	1 exch	0.25 exch	7.53	121.8	9.17
24	2 exch	1 exch	0.25 KCl	8.33	131.9	11.00
27	2 nonexch	1 nonexch	0.25 exch	8.71	142.1	12.38
32	2 nonexch	1 nonexch	0.25 KCl	9.77	136.0	13.29
4	2 exch	1 exch	0.50 exch	9.56	145.2	13.89
25	2 exch	1 exch	0.50 KCl	7.23	168.3	12.16
28	2 nonexch	1 nonexch	0.50 exch	10.17	136.2	13.79
30	2 nonexch	1 nonexch	0.50 KCl	8.31	165.6	13.76
7	4 exch	2 exch	0.50 exch	8.97	136.9	12.29
26	4 exch	2 exch	0.50 KCl	8.93	159.0	15.20
29	4 nonexch	2 nonexch	0.50 exch	11.65	152.0	17.73
31	4 nonexch	2 nonexch	0.50 KCl	9.08	170.7	15.52

1 Total of three cuttings
2 m.e. of Ca, Mg, and K

Discussion of results

The object of producing forage of desirable composition (high Ca and Mg with low K content) and reasonably high yields was accomplished in this experiment by use of dolomite and K_2O and by the addition of calcite and dolomite to soil which had previously received applications of exchangeable Ca, Mg, and K.

Treatments which failed to produce forage with desirable composition and reasonably high yields were those which consisted of high amounts of K_2O initially with insufficient lime, 0.50 m.e. exchangeable K per 100 grams of soil without additional lime, and low applications of exchangeable bases.

When the K was applied in one heavy initial amount or in two large applications, both the clay and lime series produced forage high in K in the first cutting (tables 1 and 2 appendix). This was explained by Bear and Prince (2) from the position of K in the electromotive series. They further stated that K decreased as Ca and Mg increased from the first to the last crops. In this experiment the m.e. of Ca generally decreased sharply in the second cutting and recovered in the third and fourth cuttings. Magnesium showed a similar trend. The overall data, then, agrees with the composition data of Bear and Prince (2). This uptake of nutrients may be further explained by the relative mobility of the cations K Ca Mg.

Bear and Prince (2) suggested that "...once the supply of any given cation has become adequate to meet its specific functional need, any additional quantity of it that may be absorbed by the plant is used only in those more general cation functions." These general cation functions would include buffer action in the cell sap, neutralization of organic acids, and controlling the salt concentration in the plant. The uptake of more K than is required for its specific physiological functions within the plant causes Ca and Mg to be replaced. Since Ca and Mg are needed in greater quantities by dairy animals, a high K content is undesirable in forage crops.

Treatments which contained high Ca-Mg and low K with high yields such as 6,000 pounds of dolomite with 60 or 120 K_2O initially and 60 or 120 K_2O after each cutting are those in which K is present in amounts which allow it to fulfill (or assume) its specific physiological function but not in such amounts as would cause its substitution for Ca and Mg as explained above by Bear and Prince.

From the fact that nonexchangeable Ca-Mg-CO_3 reduces the luxury absorption of K more completely than exchangeable Ca-Mg, it must be assumed that these nonexchangeable cations effect a balancing influence on the clay micelle preventing K uptake in some manner or other. Also, they may be more available or enough so that the uptake of Ca and Mg lowered K uptake in the forage. This may be the explanation for better composition and growth in those exchangeable soils which received additional applications of calcite and dolomite. There seemed to be no similar trend in favor of either exchangeable or nonexchangeable K.

Some factors which influence the uptake of Ca, Mg, and K by plants are:

1. Soils high in B.E.C. should supply a higher proportion of monovalent than divalent ions to the plant because the divalent ions are held with greater energy than are the monovalent ions as the strength of the soil acidoid (quantity) is increased and vice versa.
2. The sum of the cations approximates a constant, and decreasing one will cause an increase in the others.
3. A high Ca-saturation on the clay micelle should allow Ca to be replaced

by some other cations, thus promoting Ca uptake by the plants. The same is true for Mg and K, but to a lesser degree.

4. The absorption of Ca, Mg, and K depends partly on the nature of the complementary ions.

5. The relative mobility or ionic activities and position in the electromotive series of the cations, K > Ca > Mg, enhances K uptake by plants.

6. Nonexchangeable Ca-Mg as dolomite represses K uptake more effectively than exchangeable Ca-Mg, especially when initially present in high amounts.

7. There seems to be an indication that a Ca-Mg ratio of 1-1 (dolomite) is to be preferred to a 2-1 Ca-Mg ratio (clay soils). Compare figure 1 with figures 2 and 3 and table 7 with 10.

Comparing the composition of ladino clover grown on exchangeable and nonexchangeable soils from a cation constancy standpoint shows that the lime series did not deviate from the normal so much as did the clay series. The cation sum included only Ca, Mg, and K. Wallace et al (17) included Na and found that from 632 determinations for alfalfa the average was 150.0. Comparing this figure with the averages found for ladino clover, 137.2 in the clay series (table 7) and 170.3 in the lime series (table 10) showed that the uptake of nutrients by ladino clover and alfalfa is similar. From the work of Marshall (8) and from the data of this experiment it must be assumed that the Van Itallie (20,21) constancy of cations is applicable to average soil fertility but can be changed by extreme variations in the ratio of exchangeable and nonexchangeable Ca, Mg, and K applications to the soil.

SUMMARY AND CONCLUSIONS

A greenhouse pot experiment using Merrimac fine sandy loam was conducted. The effects of various rates and ratios of exchangeable and nonexchangeable Ca, Mg, and K on yield and quality of ladino clover were investigated. Also, the effects of various rates and ratios of nonexchangeable Ca-Mg with exchangeable K and exchangeable Ca-Mg with nonexchangeable K applied at different times were studied. The data obtained in this experiment suggest the following conclusions:

1. Dolomitic limestone applied to the soil used has been shown to better the composition (reducing luxury consumption of K and increasing Ca and Mg uptake) and increase the yield of ladino clover when it is balanced with K. This balance was accomplished by the use of:

    a. High rates of dolomitic limestone (12,000 pounds per acre) with high rates of K_2O (120 pounds K_2O per acre initially and 120 pounds K_2O per acre after each cutting).

    b. Smaller rates of dolomitic limestone (6,000 pounds per acre) with small, frequent applications of K_2O (60 or 120 pounds K_2O per acre initially and 60 or 120 pounds per acre K_2O after each cutting.)

    c. Heavy rates of dolomitic limestone (12,000 pounds per acre) with infrequent applications of K_2O (240 pounds per acre K_2O initially and 240 pounds per acre K_2O after second cutting).

Forage produced with 12,000 dolomite and 240 K_2O initially and 240 K_2O after the second cutting removed 15 per cent less K than that produced with 6,000 dolomite at the same K_2O rate.

2. The greatest yield was harvested from the highest exchangeable treatments, but, with the exception of 4-2-0.125 Ca-Mg-K ratio, these treatments produced forage too low in Ca and Mg and too high in K content.
3. Those soils which received both exchangeable and nonexchangeable applications (as Ca-Mg-K in rates and ratios of 2-1-0.25, 2-1-0.50, 4-2-0.25, 4-2-0.50, and 3,000 and 6,000 pounds of dolomite and calcite) produced high yields of forage containing a high content of Ca and Mg with a low K content.
4. With exception of the first cutting, calcite applied to the soil used produced as good yield as dolomite. However, the composition was considered undesirable since the forage contained a high content of K and low Mg. This fact would not be apparent to farmers as the plants showed little variation in appearance throughout this experiment.
5. Plants exhibited the usual cation-equivalent constancy and decreased K content with increased Ca-Mg applications.
6. The influence of base exchange capacity on the absorption of Ca, Mg, and K by ladino clover was shown to be:
   a. Higher base exchange capacity increased the K and decreased the Ca-Mg content of the forage.
   b. Lower base exchange capacity decreased the K and increased the Ca-Mg content of the forage.
7. With this soil a Ca-Mg ratio of 1-1 (dolomite) generally produced

higher yields than did a 2-1 ratio, i.e. clay series, clay plus additional lime, and factorials.

8. Treatments which failed to produce forage of desirable composition (high Ca and Mg with low K content) and reasonably high yields were those which consisted of high amounts of K_2O initially with insufficient lime, 0.50 m.e. exchangeable K without additional lime, and low applications of exchangeable bases.

APPENDIX

The composition of ladino clover in percentages of Ca, Mg, and K; the milliequivalents of Ca, Mg, and K per 100 grams of dry matter; and the weight in grams per pot for the clay series for each cutting.

Treatment No.	1st cut %	1st cut m.e.	2nd cut %	2nd cut m.e.	3rd cut %	3rd cut m.e.	4th cut %	4th cut m.e.
				CALCIUM				
1	1.86	92.8	1.56	77.8	2.33	116.3	2.33	116.3
2	1.26	62.9	1.07	53.4	1.54	76.8	1.48	69.9
3	1.27	63.4	0.86	42.9	1.19	59.4	1.22	60.9
4	0.91	45.4	0.70	34.9	0.86	42.9	0.95	47.4
5	1.47	73.4	1.09	54.4	1.47	73.4	1.39	69.4
6	1.37	68.4	1.01	50.4	1.34	66.9	1.33	66.4
7	1.12	55.9	0.75	37.4	0.46	23.0	1.06	52.9
8	1.39	69.4	1.04	51.9	0.76	37.9	1.11	55.4
9	1.28	63.9	0.79	39.4	0.96	47.9	1.10	54.9
				MAGNESIUM				
1	0.19	15.6	0.15	12.3	0.12	9.9	0.12	9.9
2	0.42	34.5	0.38	31.2	0.61	50.1	0.64	52.6
3	0.43	35.4	0.37	30.4	0.55	45.2	0.60	49.3
4	0.41	33.7	0.38	31.2	0.50	41.1	0.45	37.0
5	0.45	39.0	0.39	32.1	0.58	47.7	0.60	49.3
6	0.45	39.0	0.39	32.1	0.60	49.3	0.63	51.8
7	0.41	33.7	0.38	31.2	0.47	38.7	0.49	40.3
8	0.43	35.4	0.34	28.0	0.48	39.5	0.49	40.3
9	0.40	32.9	0.21	17.3	0.44	36.2	0.45	39.0
				POTASSIUM				
1	0.91	23.3	0.68	17.4	0.47	12.0	0.39	10.0
2	1.04	26.6	0.70	17.9	0.39	10.0	0.38	9.7
3	1.78	45.5	1.42	36.3	1.16	29.7	0.98	25.1
4	2.90	74.2	2.52	64.4	2.56	65.5	1.99	50.9
5	1.99	50.9	1.10	28.1	0.80	20.5	0.55	14.1
6	2.57	65.7	1.84	47.1	1.31	33.5	0.99	25.3
7	2.81	71.9	2.63	67.3	2.42	62.1	1.18	30.2
8	2.86	73.2	2.66	68.0	2.08	53.2	2.00	51.2
9	2.44	62.4	2.57	66.0	2.35	60.1	1.90	48.6

Yield clay series in grams per pot

Treatment No.	1st cut	2nd cut	3rd cut	4th cut	Total
1	2.24	1.62	1.41	1.23	6.50
2	2.57	2.34	1.91	1.75	8.57
3	2.77	2.36	2.39	2.12	9.64
4	3.33	2.67	3.57	2.86	12.43
5	3.29	3.64	3.33	3.05	13.31
6	2.98	2.69	3.12	3.16	11.95
7	3.22	2.85	2.90	2.79	11.76
8	3.57	4.14	4.66	3.71	16.08
9	4.17	4.32	5.53	3.49	17.51

LIME SERIES

The composition of ladino clover in percentages of Ca, Mg, and K; the milliequivalents of Ca, Mg, and K per 100 grams of dry matter; and the weight in grams per pot; for the lime series for each cutting.

CALCIUM

Treatment No.	1st cut %	1st cut m.e.	2nd cut %	2nd cut m.e.	3rd cut %	3rd cut m.e.	4th cut %	4th cut m.e.
10	1.89	94.3	1.31	65.3	1.88	93.8	1.79	89.3
17	1.54	76.7	1.11	55.2	1.66	82.6	1.40	69.6
11	1.85	92.3	1.36	67.9	1.78	88.8	2.08	137.9
15	1.66	82.8	1.21	66.3	1.78	88.8	1.85	92.3
16	1.47	73.5	1.28	64.0	1.48	74.2	1.53	76.5
18	1.55	77.5	1.43	71.5	1.30	65.0	1.40	70.0
19	1.57	78.5	1.48	74.0	1.54	77.0	1.65	82.5
23	1.97	98.3	1.93	96.1	2.33	116.3	2.31	115.3
12	1.71	85.3	1.36	67.9	1.72	85.8	1.37	68.4
14	1.62	80.8	1.33	66.4	1.70	84.8	1.39	69.4
13	1.95	97.3	1.38	68.9	1.89	94.3	1.51	75.3
20	1.64	81.8	1.31	65.4	1.62	80.4	1.34	66.9
21	1.68	83.8	1.38	68.9	1.72	85.8	1.59	79.3
22	1.83	91.3	1.37	68.4	1.63	81.3	1.44	71.9

MAGNESIUM

Treatment No.	1st cut %	1st cut m.e.	2nd cut %	2nd cut m.e.	3rd cut %	3rd cut m.e.	4th cut %	4th cut m.e.
10	0.48	39.5	0.40	32.8	0.65	53.5	0.68	55.7
17	0.42	34.2	0.35	29.0	0.58	47.6	0.51	41.8
11	0.53	43.3	0.47	38.9	0.78	64.1	0.79	65.0
15	0.54	44.7	0.42	35.7	0.73	60.0	0.67	55.0
16	0.51	42.1	0.44	35.8	0.67	55.0	0.61	50.0
18	0.53	43.8	0.47	38.4	0.69	56.8	0.63	51.8
19	0.54	44.3	0.51	41.9	0.80	65.8	0.81	66.8
23	0.11	9.0	0.08	6.2	0.10	7.2	0.07	5.1
12	0.51	41.6	0.47	38.5	0.71	58.4	0.67	55.1
14	0.50	41.3	0.47	38.4	0.65	53.5	0.58	47.3
13	0.56	46.0	0.52	43.0	0.84	69.1	0.77	62.9
20	0.52	43.0	0.50	40.8	0.78	63.7	0.54	44.7
21	0.60	49.2	0.49	40.5	0.80	65.8	0.75	61.3
22	0.55	45.4	0.50	41.4	0.74	60.9	0.69	57.0

POTASSIUM

Treatment No.	1st cut %	1st cut m.e.	2nd cut %	2nd cut m.e.	3rd cut %	3rd cut m.e.	4th cut %	4th cut m.e.
10	0.76	19.4	1.24	31.7	0.73	18.7	0.46	11.8
17	2.38	61.0	2.32	59.4	2.65	67.8	2.57	65.7
11	0.79	20.2	1.35	34.5	0.72	18.4	0.63	16.1
15	2.49	63.7	2.33	59.7	1.84	47.1	2.15	54.9
16	2.60	66.5	2.41	61.6	2.40	61.5	2.05	52.5
18	1.98	50.6	1.75	44.9	2.27	58.1	1.81	46.4
19	1.86	47.6	1.62	41.5	2.26	58.0	2.14	54.9
23	2.34	59.9	1.90	48.5	2.55	65.2	2.35	60.1
12	1.00	20.2	1.51	31.2	1.07	34.5	1.87	32.0
14	1.34	34.3	2.20	56.3	1.70	43.5	1.69	43.2
13	0.79	20.2	1.22	31.2	1.35	34.5	1.25	32.0
20	1.13	28.9	2.09	53.5	1.85	47.3	2.16	55.2
21	1.12	28.6	1.47	37.6	1.77	45.3	2.12	54.2
22	1.04	26.6	1.99	50.9	1.70	43.5	1.95	49.9

Yield lime series in grams per pot

Treatment No.	1st cut	2nd cut	3rd cut	4th cut	Total
10	3.03	3.10	2.95	2.63	11.71
11	2.50	2.36	2.31	2.22	9.39
12	3.41	3.14	3.70	3.90	14.15
13	3.08	2.97	3.47	3.45	12.97
14	3.52	3.60	3.91	4.31	15.34
15	3.52	3.12	3.98	3.54	14.16
16	3.07	3.20	3.99	3.68	13.94
17	2.96	2.42	2.88	3.05	11.31
18	3.12	3.32	3.97	3.98	11.39
19	3.31	3.01	3.64	3.20	13.16
20	3.00	3.29	4.11	4.27	14.67
21	3.47	3.53	4.18	3.57	14.75
22	2.94	3.36	4.26	4.16	14.72
23	2.16	3.24	3.87	4.15	13.42

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