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INTRODUCTION

The introduction of Kentucky 31 tall fescue into south Missouri in the 1940s made possible a steady increase of beef cow numbers beginning in 1950. That increase peaked in 1975 when a record number of 2,759,000 beef cows calved on Missouri farms. By this date an area estimated to be in excess of four million acres, previously in weedy, brushy pastures and low quality scrub timber, had been planted to tall fescue.

Soil samples from these new pastures were tested by county soil testing laboratories, established in the 1940s, and results were used in making fertilizer recommendations as discussed by Kroth and Meinke (7). Fertilizer recommendations were made on the basis of the soil samples representing an acre furrow slice, 0-7 inches, or 2,000,000 lbs of soil. The assumption made was that forage produced for pasture was a crop needing the same treatment as though it were in a rotation with corn or soybeans.

Kroth et. al. (8), however, showed topdressing small quantities of P_2O_5 and K_2O annually to forage crops would produce as high forage yields as when the soils were brought up to "soil test" following the standard "plow down" fertilizer recommendations. Limestone needs for pastures were determined in the same manner. Frequently eight tons of limestone per acre were recommended, which, because of the shallow stony soils of south Missouri, would be mixed in the surface few inches or spread on the soil surface when applied to established stands.

Limestone recommendations were based on the assumption that a pH of 6.5-7.0 was the range necessary for maximum nutrient availability and crop growth and that this pH needed to extend throughout the plow layer. Unnoticed was the work of Brown and Munsell (3) reported in 1933, that one ton/A of limestone top-dressed every eight years would be adequate for permanent pastures. However, the work of Fisher (4), who summarized limestone experiments conducted by the Department of Agronomy, University of Missouri, over a 15 year period showed that optimum yields of the major crops were produced in the pHs* range of 4.5-5.8 instead of the higher range of 6.5-7.0 as previously thought.

The incidence of grass tetany in southwest Missouri in 1968 stimulated interest in the causes of this malady, Brown et. al. (2). Low soil Mg coupled with high levels of exchangeable K and Ca in the surface one or two inches of soil from topdressed KCl and calcitic limestone could prevent the uptake of the Mg by grass plants. This would result in forage low in Mg thereby supplying inadequate Mg for animal health. The need for determining the actual lime requirement of

*pH determined in 1:1 soil:0.01M $CaCl_2$ suspension.

tall fescue and the effect of top-dressed limestone and potassium and phosphorus fertilizers on the chemical composition of tall fescue forage caused the establishment of this study.

OBJECTIVES

1. Determine the quantity of top-dressed limestone necessary for optimum tall fescue forage production.
2. Evaluate the effects of rate of top-dressed limestone and time and rate of top-dressed K_2O on yield and mineral content of tall fescue forage and soil test values.
3. Evaluate the effects of rate of top-dressed limestone and time and rate of applying P_2O_5 on yield and mineral content of fescue forage and soil test values.

CONCLUSIONS

1. Three T/A calcium limestone top-dressed on tall fescue is adequate to produce high quality forage free of weedy plants and grasses that are tolerant of acid soil. Estimated effectiveness is eight to ten years.
2. Eight T/A calcium limestone mixed uniformly through the acre seven inches increased forage yields an average of 0.33 T/A over the top-dressed treatments during a five year period.
3. Effect of limestone top-dressed in May 1973 on pHs moved down faster than expected: 3T/A into the second inch by November 1975 and to the sixth inch by March 1979; 6T/A into the sixth inch by 1975 with pronounced changes by March 1979.
4. Limestone top-dressed on tall fescue had no appreciable effect on uptake of K by spring grown forage from top-dressed K_2O, also had no effect on K content of November sampled forage.
5. Mg content of spring grown forage was reduced by top-dressed limestone, often below the 0.2% Mg considered to be safe from grass tetany. Top-dressed limestone tended to reduce Mg content of November sampled forage but the level was well above 0.2%.
6. Top-dressed limestone maintained higher Ca levels in both March and November sampled forages than the 8T/A plow down treatment. Toward the end of the study the Ca values for the 8T/A plowdown treatment were statistically higher than the zero limestone treatment but lower than those of the top-dressed limestone treatments.
7. The cation ratio $\frac{K}{Ca+Mg}$ would not be a good indicator of tetany prone forage when limestone and K_2O are top-dressed on pastures.
8. Treatment 5, where all the NPK fertilizers were equally divided between early May and August applications, produced the best distribution of grazeable forage.
9. Applying K_2O in late fall or early spring increased the K content of fescue forage. This K^+ combined with Ca^{++} from top-dressed limestone reduced Mg

content of March sampled forage below 0.2% through 1976 for the 3T/A and through 1978 for the 6T/A treatments.

10. Application of NPK in early May would produce a more uniform distribution of grazeable forage during June and July than the accepted time of early spring.
11. Fescue forage produced after August and early fall rains can be below 0.2% P, the level accepted as nutritionally acceptable for beef cattle. Periods of low fall rainfall could produce this low P forage level regardlesss of the P_2O_5 soil test value of the 0-1 inch depth.
12. Three T/A limestone top-dressed would permit red clover to grow with tall fescue in a pasture mixture. This application could be effective for as long as eight to ten years.
13. The pHs of the 0-1 inch depth of the 8T/A limestone treatment (1. 1T/acre inch) was reduced to 5.0 after seven years due to the acidifying effect of 160 lbs N applied annually. This suggests that grass pastures that have been heavily fertilized with N could be acid enough in the surface 1-2 inches to prevent establishment of red clover.
14. Top-dressed limestone at rates higher than 3T/A would fix P of top-dressed P_2O_5 longer than necessary there by tending to produce forage nutritionally deficient in P, especially under low soil moisture conditions.

PROCEDURES

The study site was a Gerald silt loam (fine, mixed, mesic umbric fragiaqualf), naturally low in Mg, on the University of Missouri's Southwest Center, Lawrence County. Initial soil test values for the 0-7 and 8-14 inch depths are given in Table 1.

Limestone treatments were: 0,3T, 6T, top-dressed and 8T/A plowed down, three replications, the 8T/A would have been the recommended treatment for this soil. Each lime block was 50 ft by 35 ft, large enough to accommodate five NPK subplots 10 ft and 35 ft in size. The limestone blocks were laid out, 4T/A limestone disced into the surface of blocks to get the 8T/A treatment, the entire experimental area plowed and the remaining 4T limestone disced into the plowed surface of the blocks getting the 8T/A plowed down, on 3/8/72. The objective was to get the eight tons of limestone worked into the 0-7 inches as uniformly as possible, 1. 1T per acre inch. Certified Kentucky 31 fescue, 11 lbs/A, was planted in all blocks with a grain drill using 60+30+30* starter fertilizer on 4/7/72. An excellent stand was obtained, weeds were controlled with 1 qt./A 2,4-D on 5/25/72. The subplots were delinated, 3T and 6T/A limestone were top-dressed on the appropriate blocks, 5/22/73, and the 5 NPK treatments were top dressed 5/24/73. The five different subtreatments included different rates and times of applying NPK to evaluate their effects on cutting and total yields, plant mineral content and soil test values. The first differences in time of applications of the NPK top-dressing began in December 1973 so that meaningful yield data could be taken in 1974. The NPK subtreatments are given in Table 2.

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*All references of this type indicate N + P_2O_5 + K_2O in lbs. per acre.

Table 1. Initial Soil Test Values of Limestone Topdressing Study, Southwest Center.*

Depth Inches	OM %	pHs*	Neutralizable acidity Me/100 gms.	P_2O_5 P_1	P_2	Ca	Mg	K	CEC Me/100 gms.
				Lbs/2,000,000 lbs. of soil					
0-7	2.6	4.7	6.1	22	20	2025	151	154	12.0
8-14	2.0	3.9	12.1	10	10	1200	257	135	16.4

*pH measured in 1:1 soil: 0.01 M $CaCl_2$ suspension. P_1, P_2 indicate Bray's weak and strong extractants respectively. Exchangeable K determined by ammonium acetate extraction.

Table 2. Rate and Time of Application of NPK Treatments for Each of Four Limestone Blocks.

Treatment No.	Rate and Time of Application: December	After 1st Harvest	August
1	80+50+150	0	80+0+0
2	80+25+75	0	80+25+75
3	80+50+75	0	80+0+75
4	80+0+0	0	80+50+175
5	0	80+25+75	80+25+75

A total of 160 lbs. N, 50 lbs. P_2O_5 and 150 lbs. K_2O per acre per year were the quantities of nutrients selected to evaluate the effect of limestone on fescue yields. Previous work had indicated these amounts of nutrients were adequate to produce forage yield permissible by the available soil moisture in Southwest Missouri, Kroth, et. al. (8). Yields evaluating the effect of limestone and NPK treatments were first taken in 1974. Three forage harvests as hay were made each year. Average harvest dates were: 1st cutting May 9; 2nd cutting July 18; 3rd cutting November 20. The grab samples used for dry matter determination of the 3rd cutting were saved in 1974, 1975, 1977 for grinding and Ca, Mg, P, K analyses. Also random samples were taken from 6-8 places from each plot in March when forage was 5-6 inches high in 1976, 1977, 1978 for mineral analyses. Chemical analyses were also made on samples from the 1st cutting of 1974. Plots were harvested for forage yields with a five foot flail type forage harvester and over-sized burlap bags. Grab samples of about one pound were taken from each bag for moisture determination.

Table 3. Precipitation Southwest Center 1972-1978.

Precipitation In Inches	1972	1973	1974	1975	1976	1977	1978	19-year Average
January	.46	3.85	1.97	3.32	.50	1.46	1.52	1.55
February	.83	1.06	1.76	3.66	.91	1.74	1.34	1.66
March	1.24	9.64	5.55	7.10	3.56	3.49	4.88	3.64
April	4.01	6.26	3.02	3.42	5.78	3.78	4.31	4.05
May	2.16	4.07	5.70	2.58	4.12	3.53	7.11	4.67
June	1.27	5.23	7.57	5.49	4.62	8.11	5.34	5.13
July	3.24	1.72	1.98	.68	5.20	2.84	3.68	2.94
August	3.96	.90	6.77	6.05	3.29	7.12	2.80	3.64
September	9,07	9.29	4.52	5.29	2.25	9.90	4.10	5.15
October	4.91	4.16	4.53	1.51	3.60	1.52	.58	3.22
November	7.91	7.86	5.07	2.92	.65	2.24	5.88	3.40
December	2.10	4.34	2.67	2.78	.71	2.41	2.48	2.51
Total Inches	41.19	58.38	51.11	44.80	35.09	48.14	44.02	41.56

Chemical analyses were made on all forage samples by the Missouri Agricultural Experiment Station Chemical Laboratory according to accepted procedures. Samples were oven dried at 60°C and saved for later processing. Fall sampling was done in November after growth had stopped; it was intended that these samples would represent grazeable forage produced after late August or September rains.

Soil samples by one inch depths to a depth of six inches were taken from all plots of treatment 5 on all four lime treatments fall of 1975. The seventh inch was not sampled for economic reasons as previous studies had shown its value was similar to that of the sixth inch. (6). Eight to ten cores were taken from each plot, each core cut into six one-inch segments and each segment placed in its appropriate sample bag. All 60 plots of the study were sampled at the close of the experimental period following the same procedure. Final soil samples could not be taken the fall of 1978 due to lack of late fall rains so these samples were taken in the spring of 1979. Results of tests on samples from treatment 5 for 1975 and 1979 are given in Table 20. Results of all final tests for all treatments are given in Appendix Table 2.

Soil samples were tested by the methods outlined by Brown et. al. (1). Soil extractants were calibrated to give results in pounds of nutrients per 2,000,000 lbs. of soil (seven inch furrow slice, one acre in area). When a sample represents an acre inch instead of an acre seven inches the result is interpreted as nutrient concentration in pounds per 2,000,000 lbs. of soil. Since this sample represents only one inch of the acre furrow slice the test results need to be divided by seven to get the actual pounds of nutrient in the acre inch sampled.

Soil samples from the 8-14 inch depth were taken from all lime blocks, compositing samples from the three replications into one sample. Results of these tests are given in Table 21. In restrospect soils of each NPK treatment should have been sampled from the 8-14 inch depth to determine the effect of these, as well as the limestone treatments, below the plow layer.

RESULTS AND DISCUSSION

Forage Yields

The effect of limestone and annually top-dressed NPK treatments on yields of tall fescue by cuttings and total annual production over the five years of the study are given in Appendix Table 1. Since there was very little interaction between NPK and limestone treatments only the single effects of these treatments will be discussed.

Limestone Effects. The effects of limestone on yields of tall fescue by cuttings and total yield are given in Table 4.

Table 4. Effect of Limestone on Yields of Tall Fescue.

	Yields Tons/A 5 Yr. Ave.			
Lime Treatments	Cut 1	Cut 2	Cut 3	Total
O	1.28a*	.55ab	1.07b	2.90b
3T T_pD	1.32a	.49b	1.10b	2.91b
6T T_pD	1.37a	.51ab	1.16b	3.04b
8T PwDn	1.38a	.60a	1.32a	3.31a

* Values followed by the same letter are not significantly different - Duncan's New Multiple Range Test. Statistical significance in succeeding tables is indicated by this method of lettering.

The results show that thoroughly mixing the 8T/A evenly through the plow layer, 1.1T per acre inch of depth, significantly increased the average yield by .33T/A over the average yields of the top-dressed lime treatments. The increase in yield came in the third cutting, the reason for this increase can not be determined from the data of this study, See Appendix Table 1. The top-dressed limestone had no significant effect on the mass of material on the other plots but the material on the zero lime plots contained quantities of blackberry vines, sour dock and weedy grasses. On the other hand the 3T and 6T/A top-dressed plots produced fescue forage only. From this data it was concluded limestone at 3T/A would be profitable by insuring high quality fescue forage. The length of time this lime would be effective could not be determined by this study but possibly 8 to 10 years.

NPK Treatment Effects. The five different combinations of rate and time of application were selected to test their effect on yields, forage composition and soil test values. The results of these treatment combinations on yield by cuttings and total average yields for the study are given in Table 5. These data show that for total yields all treatment combinations except treatment 4 were significantly equal to treatment 5. Apparently applying all of the P_2O_5 and K_2O in August, treatment 4, tended to reduce yields. Final soil test values show that the surface inch of plots getting treatment 4 have the highest P_2O_5 and exchangeable K soil test values of the study, Appendix Table 2.

Table 5. Effect of Different Time and Rate of NPK Applications on Yield of Tall Fescue.

	Tons/A 5 Yr. Ave.			
Treat. Number*	Cut 1	Cut 2	Cut 3	Total
1	1.56a	.41b	1.04d	3.01ab
2	1.45b	.41b	1.15cb	3.02ab
3	1.55a	.42b	1.09cd	3.06ab
4	1.35c	.42b	1.20b	2.96b
5	.77d	1.02a	1.35a	3.14a

* See Table 2.

The relatively high yield produced at the second cutting by treatment 5 was a surprise. Delaying the spring (December) application until the 9th or 10th of May would tend to produce more forage for grazing during late May and June than when the fertilizers were applied in December or early spring as is generally thought. Brown, et. al. (2) also reported this increased yield due to delayed fertilizer application. Apparently early spring application of N especially, would deplete soil moisture in April and early May which would be used in late May and June if the fertilizer application were delayed until the second week in May. See Appendix Table 1.

The average yield of 3.0T/A is what Kroth et. al. (8) concluded was the yield expectations of forage crops that could be produced by the average available soil moisture during the growing season in southwest Missouri. Hence, it was concluded that the NPK rates used in this study had been adequate to evaluate the effect of limestone on tall fescue production.

Year Effects. The effect of years on cutting and total yields are given in Table 6. The highest cutting and total yields came in 1977 when rainfall amount and distribution were nearly ideal for forage production in southwest Missouri, Table 3, and Appendix Table 1.

Table 6. Effect of Years on Cutting and Total Yields of Tall Fescue

Cuttings	Tons/A					
	1974	1975	1976	1977	1978	Avg.
1	1.30c	1.46b	1.18e	1.52a	1.23d	1.34
2	.26e	.39d	.57c	.82a	.64b	.54
3	1.23b	1.21b	.68d	1.81a	.88c	1.16
Total	2.79	3.06	2.43	4.15	2.75	3.04

Mineral Content of Tall Fescue Forage

Potassium - Spring Samplings. The effects of limestone treatments on K content of spring grown fescue forage are given in Table 7. The data show that mixing 8T/A through out the plow layer tended to reduce the uptake of K in comparison to the other limestone treatments, in 1977. A good rainfall distribution may be the explanation of the rather high K content this year. The lower K values for 1974 show the dilution effect due to maturity of the forage, i.e. harvested as hay rather than grazeable March forage.

Table 7. Effect of Limestone on Potassium Content of Tall Fescue Forage

Limestone Treatment	March Samplings				November Samplings		
	1974*	1976	1977	1978	1974	1975	1977
	%K						
0	2.03a	2.31a	2.97a	2.60ab	2.04a	1.90a	2.07a
3T/A TD	1.96ab	2.24a	2.95a	2.66a	1.98a	1.97a	2.18a
6T/A TD	1.98ab	2.20a	2.82b	2.54ab	2.05a	1.97a	2.04a
8T/A PwDn	1.93b	2.17a	2.70c	2.49b	1.96a	1.89a	2.07a

* Sampled in May as first cutting hay.

The effects of NPK applications on K content of spring grown fescue forage are given in Table 8. Applying all of the yearly K_2O in December, treatment 1, resulted in high K concentration in the spring grown forage. When the K_2O was evenly divided between December and August applications, treatments 2,3, K content was reduced somewhat. Applying all of the K_2O in August, treatment 4, also tended to reduce K in the next spring's growth. The lowest concentration of K in spring growth occurred when the K_2O was split equally between May 10 (after first cutting) and August, treatment 5, producing the highest forage yield and removing most of the applied K in the second and third cuttings. Apparently by 1978 enough K^+ had accumulated in the surface inch of soil that time of applying K_2O no longer had an appreciable effect of the K content of March grown forage. The data of Table 9 show that K content of fescue forage was influenced more by time of top-dressing K_2O than the method of limestone application.

Table 8. Effect of NPK Rate and Time of Application on Potassium Content of Tall Fescue Forage

NPK Treat. No	March Samplings				November Samplings		
	1974*	1976	1977	1978	1974	1975	1977
	%K						
1	2.29a	2.43a	3.03a	2.70a	1.94b	1.72b	1.95c
2	2.14b	2.37b	3.01a	2.62ab	2.02ab	2.01a	2.12ab
3	---	2.33b	2.89b	2.52b	---	1.77b	2.07bc
4	1.65d	2.17c	2.80b	2.55ab	2.02ab	2.08a	2.23a
5	1.81c	1.86d	2.58c	2.48b	2.04a	2.08a	2.10abc

* Sampled in May as first cutting hay. Treatment 3 not sampled in 1974.

Postassium-November Samplings. Limestone treatments had no effect on K concentration of tall fescue forage produced after August or September rains and harvested in November, Table 7. However time of applying K_2O had an effect, Table 8; the December applied K_2O had been removed by the two previous harvests leaving a low K value in the fall grown forage, treatment 1. The other treatments applied some K_2O in August resulting in relatively high K concentration in the fall grown forage. In most cases forage K concentration is lower in the November harvested forage reflecting the more advanced maturity of the growth. Dry soil conditions in the fall could also reduce nutrient uptake; higher forage K resulted in 1977 when August and September rainfall was larger than normal, Table 3 and 8. Time of K_2O applications also influenced K concentration of fescue forage more than limestone applications, Table 9.

Magnesium - Spring Samplings The effects of limestone treatments on magnesium content of spring grown fescue forage are given in Table 10. The 3T and 6T/A top-dressed treatments statistically reduced the Mg content of the forage in 1974 and 1977 and the 6/A treatment in 1978. These Mg levels were below the 0.20% Mg thought necessary to prevent grass tetancy, Brown et. al.

Table 9. Effect of Limestone, NPK Treatments and Time of Sampling on Potassium Content of Tall Fescue Forage.

		March Samplings				November Samplings		
Limestone Levels	NPK Treat. No	1974*	1976	1977	1978	1974	1975	1977
		---%K---						
0	1	2.35a	2.50a	3.11a	2.80a	1.98ab	1.80efghi	2.12abc
	2	2.25ab	2.50a	3.11a	2.68abc	2.02ab	2.11abc	2.07abc
	3	---	2.44ab	3.04abc	2.52abc	---	1.66hi	2.03abc
	4	1.66e	2.26def	2.88abcdefg	2.55abc	2.03ab	2.05bcde	2.15ab
	5	1.84d	1.87h	2.73efgh	2.47abc	2.11ab	1.90cdefg	2.00abc
3T/A TpD	1	2.28ab	2.40abc	3.11a	2.78a	1.93ab	1.72ghi	2.00abc
	2	2.11bc	2.37abcde	3.07ab	2.65abc	2.00ab	2.06abcd	2.27a
	3	---	2.35bcde	3.00abcd	2.60abc	---	1.80efghi	2.12abc
	4	1.60e	2.26def	2.91abcdef	2.63abc	2.02ab	2.12abc	2.30a
	5	1.86d	1.84h	2.66gh	2.65abc	1.97ab	2.16ab	2.22a
6T/A TpD	1	2.28ab	2.38abcd	2.98abcde	2.57abc	1.90b	1.61i	1.80c
	2	2.17bc	2.30cde	3.02abcd	2.58abc	2.04ab	1.97bcdefg	2.00abc
	3	---	2.26def	2.79cdefgh	2.53abc	---	1.84defghi	2.05abc
	4	1.62e	2.16f	2.78defgh	2.53abc	2.13ab	2.13abc	2.25a
	5	1.86d	1.88h	2.55hi	2.48abc	2.12a	2.30a	2.12abc
8T/A PwDn	1	2.27ab	2.44ab	2.92abcde	2.68abc	1.94ab	1.79fghi	1.87bc
	2	2.03c	2.29cde	2.84bcdefg	2.55abc	2.02ab	1.89cdefg	2.15ab
	3	---	2.25ef	2.73efgh	2.42bc	---	1.76ghi	2.07abc
	4	1.72de	2.02g	2.63h	2.48abc	1.91ab	2.03cdef	2.23a
	5	1.71de	1.83h	2.38i	2.32c	1.96ab	1.96cdefg	2.05abc

* Sampled in May as first cutting hay. Treatment 3 not sampled in 1974.

(2). It is possible these low values were due to the low exchangeable Mg resulting from the top-dressed lime treatments. These low levels will be pointed out when soil test values are discussed, Appendix Table 2. Mixing 8T/A through the plow layer maintained a satisfactory Mg level in the forage apparently because of the 2% $MgCO_3$ in the limestone used in the study.

Table 10. Effect of Limestone on Magnesium Content of Tall Fescue Forage

Limestone Treatment	March Samplings 1974*	1976	1977	1978	November Samplings 1974	1975	1977
	%mg						
0	.173b	.201b	.213b	.213b	.223a	.247b	.241b
3T/A TD	.159c	.187b	.203c	.211b	.203b	.231b	.254b
6T/A TD	.164bc	.185b	.196c	.196c	.200b	.237b	.252b
8T/A PwDn	.189a	.221a	.231a	.233a	.228a	.278a	.275a

* Sampled in May as first cutting hay.

The effects of NPK treatments on the Mg content of spring grown fescue forage are given in Table 11. Treatments 1 and 5 statistically reduced Mg content below the other treatments. The high K level due to December application of all the annual K_2O of treatment 1 may have supressed the uptake of Mg. In the case of treatment 5, the higher yields, thus produced may have removed most of the exchangeable Mg from the soil the previous summer and fall as final soil test values from plots getting top-dressed limestone had low Mg soil test values at the close of the study, Table 20.

Table 11. Effect of NPK Rate and Time of Application on Magnesium Content of Tall Fescue Forage

NPK Treat. No	March Samplings 1974*	1976	1977	1978	November Samplings 1974	1975	1977
	%Mg						
1	.166c	.183c	.209b	.214ab	.223a	.248a	.267a
2	.175b	.200b	.218ab	.213ab	.213ab	.245a	.258ab
3	---	.204b	.224a	.218a	---	.255a	.257ab
4	.188a	.214a	.218ab	.219a	.213ab	.248a	.242b
5	.156d	.190c	.183c	.203b	.207b	.246a	.253ab

* Sampled in May as first cutting hay. Treatment 3 not sampled in 1974.

The effects of limestone and NPK treatments are re-emphasized in Table 12. Top-dressed limestone tended to produce fescue forage below the .2% Mg in most years. NPK treatments 1 and 5 tended to produce lower Mg contents than the other three treatments at all limestone levels.

Table 12. Effect of Limestone, NPK Treatments and Time of Sampling on Magnesium Content Tall Fescue Forage.

Limestone Levels	NPK Treat. No	March Samplings 1974*	March Samplings 1976	March Samplings 1977	March Samplings 1978	November Sampling 1974	November Sampling 1975	November Sampling 1977
		%Mg						
0	1	.167cdefg	.190efg	.207efghi	.207bcde	.220bcd	.240efghi	.243bc
	2	.177bcd	.200cde	.217cdefghi	.207bcde	.217bcde	.230ghi	.237bc
	3	---	.203cde	.220bcdefg	.220abcd	---	.247defgh	.237bc
	4	.190b	.213bcd	.230abcde	.223abc	.233ab	.263abcde	.240bc
	5	.157efgh	.197de	.190ij	.210bcde	.223abcd	.257bcdef	.247bc
3T/A TpD	1	.160defgh	.173gh	.203fghi	.217abcde	.213bcdef	.230ghi	.267abc
	2	.177defgh	.190efg	.203ghi	.210bcde	.200def	.230ghi	.247bc
	3	---	.193ef	.227abcde	.22abcd	---	.243defghi	.253abc
	4	.170cdef	.203cde	.210efghi	.217abcde	.210bcdef	.233fghi	.260abc
	5	.147h	.177fgh	.173ij	.190e	.190f	.220i	.243bc
6T/A TpD	1	.153fgh	.163h	.193hij	.193de	.210bcdef	.243defghi	.263abc
	2	.173bcde	.193ef	.213defghi	.200cde	.207cdef	.253cdefgh	.270abc
	3	---	.193ef	.207fghi	.203cde	---	.243defghi	.240bc
	4	.180bc	.197de	.197ghi	.193de	.190f	.220i	.227c
	5	.150gh	.177fgh	.170j	.190e	.193ef	.227hi	.257abc
8T/A PwDn	1	.183bc	.207cde	.233abcd	.240a	.247a	.280ab	.293a
	2	.190b	.217bc	.240ab	.233ab	.227abc	.267abcd	.280ab
	3	---	.227ab	.243a	.227abc	---	.287a	.293a
	4	.213a	.243a	.237abc	.243a	.220bcd	.277abc	.240bc
	5	.170cdef	.213bcd	.200ghi	.220abcd	.220bcd	.280ab	.267abc

* Sampled in May as first cutting hay. Treatment 3 not sampled in 1974.

Magnesium - November Samplings. Limestone at 8T/A mixed through the plow layer maintained a significantly higher Mg content in the November samplings than the other treatments except for the no lime treatment in 1974, Table 10. The reason for this exception is not clear. It is apparent NPK treatments had very little effect on the Mg content of fescue forage harvested in November, Table 11. Table 12 also shows that limestone levels, even when combined with NPK treatments, were the dominant factors in effecting the Mg content of fescue forage harvested in November.

Calcium - Spring Samplings. The data in Table 13 show the zero lime treatment produced fescue forage with the statistically lowest Ca content throughout the length of the study. After five years the Ca content of the forage produced by the 3T/A treatment dropped below the 6T/A treatment. On the other hand the 8T/A treatment dropped below the values of the 3T and 6T/A

Table 13. Effect of Limestone on Calcium Content of Tall Fescue Forage

Limestone	March Samplings				November Samplings		
Treatment	1974*	1976	1977	1978	1974	1975	1977
	%Ca						
0	.316b	.420c	.528c	.392d	.357b	.395c	.377d
3T/A TD	.349a	.559a	.675a	.481b	.435a	.494ab	.473b
6T/A TD	.370a	.569a	.689a	.505a	.434a	.512a	.495a
8T/A PwDn	.368a	.503b	.619b	.453c	.430a	.486b	.447c

* Sampled in May as first cutting hay.

top-dressed treatments in 1976 and 1977 and by 1978 its value was between those of the 3T/A and zero limestone treatments. The high Ca contents produced by the top-dressed limestone reflects high Ca^{++} levels possible in the surface inch of the soil of these plots, which, combined with high K^{+} concentration from top-dressed K_2O, could retard uptake of Mg by tall fescue. The reduction of Ca concentration in fescue forage produced on the 8T/A treatment with time reflects the neutralization of the $CaCO_3$ by the 160 lbs N top-dressed annually and consequent reduction of Ca^{++} in the 0-1 inch layer of the soil of these plots, see 1979 soil sampling, Table 20, and Appendix Table 2.

Table 14. Effect of NPK Rate and Time on Calcium Content of Tall Fescue Forage

NPK	March Samplings				November Samplings		
Treat.	1974*	1976	1977	1978	1974	1975	1977
No	%Ca						
1	.337b	.467b	.628b	.464a	.409ab	.498a	.461a
2	.334b	.516a	.655a	.456ab	.417ab	.462bc	.456a
3	---	.516a	.633b	.458ab	---	.482ab	.447a
4	.387a	.531a	.639ab	.471a	.428a	.473ab	.437a
5	.346b	.535a	.583c	.439b	.402b	.444c	.440a

* Sampled in May as first cutting hay, Treatment 3 not sampled 1974.

The effect of top-dressed NPK on Ca content of spring produced forage is not clear, however, a tendency for summer applied NPK, treatment 5, to reduce Ca content is apparent, Table 14. Possibly the summer applied K_2O produced a very high K^+ concentration in the 0-1 inch depth, which, combined with the somewhat higher Mg^{++} level of that depth, Appendix Table 2, was able to reduce the uptake of Ca^{++} from a relatingly low Ca^{++} level in the 0-1 inch depth.

Calcium - November Samplings. The effects of limestone applications on Ca content of fescue forage in November are given in Table 13. The same relationships occurred as in the spring samplings, i.e., the 3T and 6T/A treatments produced the higher Ca contents, the zero lime blocks having the lower levels and the 8T/A blocks intermediate levels. The Ca content of the forage on the 8T/A blocks reduced with time reflecting the lower Ca^{++} concentration in the 0-1 inch depth of the soil of these blocks, Table 20 and Appendix Table 2.

The effects of NPK treatments on Ca content of fescue forage sampled in November are given in Table 14. Treatment 5 tends to reduce the Ca content, 1975, possibly due to the K_2O being applied in the summer and hence having a higher K^+ level in the 0-1 inch depth of soil, Table 20. However the 1977 November sampling showed no difference between NPK treatments on Ca content of the forage. Results of this study do not give an explanation for the difference between November Ca contents of forages in 1975 and 1977.

Table 15 shows that limestone treatments had the greater effect on Ca content of November sampled forage than the NPK treatments.

Phosphorus - Spring Samplings. The effect of limestone treatments on P content of spring sampled fescue forage are given in Table 16. There is evidence that the high H^+ level (low pHs) of the zero limestone blocks and the high Ca^{++} level of the top-dressed blocks tended to reduce P content of this forage. These results would be attributed to the formation of unavailable iron and calcium compounds in the 0-1 inch depth of the soil of these blocks. On the other hand, the more favorable condition existing in the surface inch of the 8T/A treated blocks, i.e. low Fe^{+++} and Ca^{++} concentrations would tend to make P more available to fescue plants.

The effects of NPK treatments on P content of spring sampled fescue forage are given in Table 17. These data show that December applied P_2O_5 would be more available to spring produced forage, treatment 1, than when applied the previous summer, treatments 4,5. The 1978 data indicate that by this date (6 annual applications of 50 lbs P_2O_5/A) had increased the P_2O_5 level in the 0-1 inch depth of the soil of the plots to the point that additional P_2O_5, regardless of lime application, would not effect the P content of the forage, Table 20 and Appendix Table 2. The data for 1974 especially shows the effect of December (spring) applied P_2O_5, treatment 1, on the P content of the forage before a build up of P_2O_5 in the 0-1 inch depth of the soil of the plots, treatments 4,5, Table 17. A forage P content of less than 0.2% is considered P deficient from the standpoint of animal nutrition.[1] This condition occurred with treatments 4,5, in 1974.

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[1]Personal communication from Dr. J. Malcolm Asplund, Professor Animal Nutrition, Animal Husbandry Department, University of Missouri-Columbia, Columbia, MO 65211

Table 15. Effect of Limestone, NPK Treatments and Time of Sampling on Calcium Content of Tall Fescue Forage.

Limestone Levels	NPK Treat. No	March Samplings 1974*	March Samplings 1976	March Samplings 1977	March Samplings 1978	November Samplings 1974	November Samplings 1975	November Samplings 1977
		%Mg						
0	1	.290e	.393b	.520fg	.393fg	.333d	.410ef	.390efg
	2	.333cde	.423b	.560ef	.393fg	.390bc	.383ef	.380fg
	3	---	.427b	.530ef	.410fg	---	.427de	.370g
	4	.347cd	.420b	.547ef	.390fg	.370cd	.393ef	.367g
	5	.293e	.437b	.483g	.373g	.333d	.360f	.380fg
3T/A TpD	1	.343cd	.520a	.677ab	.470abcde	.437ab	.523ab	.497ab
	2	.323de	.570a	.703a	.463bcde	.430ab	.473bcd	.490abc
	3	---	.547a	.670abc	.490abc	---	.483bc	.483abcd
	4	.363bcd	.570a	.687a	.510abc	.453a	.513abc	.457abcd
	5	.367bcd	.587a	.637bcd	.470abcde	.420ab	.477bcd	.437cde
6T/A TpD	1	.343cd	.560a	.687a	.517a	.420ab	.557a	.493ab
	2	.347cd	.560a	.713a	.507abc	.427ab	.510abc	.503a
	3	---	.563a	.697a	.497abc	---	.527ab	.490abc
	4	.410ab	.590a	.707a	.513a	.453a	.503abc	.493ab
	5	.380bc	.573a	.640bcd	.490abc	.437ab	.463d	.497ab
8T/A PwDn	1	.370bcd	.393b	.630cd	.477abcde	.447a	.500bc	.463abcd
	2	.333cde	.510a	.643bcd	.460cde	.420ab	.480bcd	.450abcd
	3	---	.527a	.633cd	.437def	---	.490bc	.443bcd
	4	.426a	.543a	.617d	.470abcde	.437ab	.483bc	.430def
	5	.343cd	.543a	.570e	.423efg	.417ab	.467bcd	.447bcd

* Sampled in May as first cutting hay. Treatment 3 not sampled in 1974.

Table 16. Effect of Limestone on Phosphorus Content of Tall Fescue Forage.

Limestone Treatment	March Samplings 1974*	1976	1977	1978	November Samplings 1974	1975	1977
	%P						
0	.198b	.268ab	.274b	.273a	.162c	.143b	.189d
3T/ATD	.192b	.257b	.269b	.268ab	.168bc	.152b	.215c
6T/ATD	.198b	.259b	.270b	.255b	.173b	.159b	.229b
8T/APwDn	.211a	.281a	.300a	.275a	.204a	.181a	.251a

*Sampled in May as first cutting hay.

Table 17. Effect of NPK Rate and Time of Application on Phosphorus Content of Tall Fescue Forage

NPK Treat. No	March Samplings 1974*	1976	1977	1978	November Samplings 1974	1975	1977
	%P						
1	.233a	.292a	.293a	.272ab	.166c	.145b	.207c
2	.216b	.276b	.292a	.269ab	.181b	.165a	.227b
3	---	.294a	.297a	.274a	---	.148b	.207c
4	.163d	.238c	.261b	.256b	.191a	.170a	.243a
5	.187c	.231c	.250c	.269ab	.169c	.164a	.222b

* Sampled in May as first cutting hay. Treatment 3 not sampled in 1974.

The data in Table 18 show that the effect of summer applied P_2O_5, treatments 4,5, is a reduction in the P content of spring grown fescue forage regardless of the limestone treatments, in 1974, 1976, and 1977. By 1978 the P_2O_5 content of the 0-1 inch depth of soil had possibly become high enough, Table 20, that additional P_2O_5 top-dressed in December had no statistical effect on P content of spring grown fescue forage.

Phosphorus - November Samplings. The data in Table 16 shows the effects of limestone treatments on P content of fescue forage sampled in November. Blocks receiving no limestone produced forage below the nutritionally satisfactory level of 0.2% P in 1974, 1975, and 1977. Lack of P uptake is attributed to soluble Fe^{+++} effectively fixing the applied P so as to make it unavailable for fescue plants. Also the high Ca^{++} from the top-dressed 3T and 6T/A treatments in the 0-1 inch depth made the P relatively unavailable especially in 1974 and 1975. On the other hand the more favorable condition regarding P availability occurred in the 0-1 inch depth of the plots getting the 8T/A mixed through the plow layer allowing for a greater uptake of P by fescue.

Table 17 shows the effect of time of application of P_2O_5 on P content of November harvested fescue forage. December applied P_2O_5, treatment 1, resulted in lower P content the following November than when phosphorus was applied in August, treatment 4. However all NPK treatments produced forage below the 0.2% level in 1974 and 1975, but higher than .2% in 1977. Since the

Table 18. Effect of Limestone, NPK treatments and Time of Harvest on Phosphorus Content of Tall Fescue Forage.

Limestone Levels	NPK Treat. No	March Samplings 1974*	March Samplings 1976	March Samplings 1977	March Samplings 1978	November Samplings 1974	November Samplings 1975	November Samplings 1977
		%P						
0	1	.237a	.300abc	.293bc	.287a	.153g	.133f	.187hi
	2	.223ab	.283cde	.293bc	.277abc	.163efg	.147def	.187hi
	3	---	.300abc	.297b	.260abc	---	.137f	.177i
	4	.163fg	.230h	.250fgh	.260abc	.177cdef	.157cde	.203fghi
	5	.170efg	.227h	.237h	.263abc	.153g	.140ef	.190hi
3T/A TpD	1	.230a	.280def	.277cde	.273abc	.160efg	.140ef	.210efgh
	2	.200bcd	.263fg	.277cde	.267abc	.173defg	.160cd	.217defgh
	3	---	.283cde	.290bc	.260abc	---	.137f	.203fghi
	4	.150g	.230h	.260efg	.250bc	.180cde	.163cd	.253abc
	5	.187cdef	.227h	.243gh	.277abc	.160efg	.160cd	.210efgh
6T/A TpD	1	.230a	.280def	.280bcd	.247c	.157fg	.140ef	.200ghi
	2	.213abc	.267efg	.283bc	.257abc	.177cdef	.170bc	.233cdef
	3	---	.283cde	.277cde	.260abc	---	.147def	.217defgh
	4	.153g	.233h	.253fg	.250bc	.190bcd	.163cd	.253abc
	5	.193cde	.230h	.257fg	.263abc	.167efg	.173bc	.240cde
8T/A PwDn	1	.237a	.307ab	.320a	.280abc	.193bcd	.167bc	.230cdefg
	2	.227a	.290bcd	.313a	.277abc	.210ab	.183ab	.270abc
	3	---	.310a	.323a	.283ab	---	.173bc	.230cdefg
	4	.183def	.257g	.280bcd	.263abc	.217a	.197a	.277a
	5	.197cde	.240h	.263def	.273abc	.197abc	.183ab	.247bcd

* Sampled in May as first cutting hay. Treatment 3 not sampled in 1974.

rainfall data for August and September in 1975 and 1977, Table 3, are similar one must expect that rainfall distribution was better in 1977 causing the 0-1 inch depth to be moist longer than in 1975 permitting a greater P uptake as well as a higher third cutting yield in 1977 than in 1975, Table 6. Kroth and Meinke (7) point out that P and K uptake from the 0-1 inch depth is dependent on favorable moisture and temperature conditions; in August and September moisture would be the most crucial and forage low in P could be produced even though a high P_2O_5 (P_2) soil test value occurred in the 0-1 inch depth, Appendix Table 2.

The P contents of November sampled fescue forage as influenced by both limestone and NPK treatments are given in Table 18. Treatment 4, where all the top-dressed P_2O_5 is applied in August gave the highest P content of the November produced forage containing 0.2% P or above in 1977. All but three of the other values of the November samples (1974, 1975) were below this nutritionally acceptable standard. These data again point up the possibility that unless unnecessarily high P_2O_5 soil test values for the 0-1 inch depth are maintained fescue forage produced in September and October could be nutritionally deficient in P.

The possibility exists that nutritional problems experienced by cattlemen with tall fescue in the fall and winter may be due to a P deficiency resulting from low rainfall and relatively low P_2O_5 level in the 0-1 inch depth rather than some characteristic of tall fescue itself. However if P is deficient in fall grown fescue forage it would be more economical, as well as more efficient use of P_2O_5 fertilizer, to feed a mineral supplement containing P rather than raising the 0-1 in P_2O_5 soil test to an inefficiently high level. Kroth and Meinke (7) have shown that a P_2O_5 (Bray P_2) soil test value for the 0-3 inch depth of 45 lbs/2,000,000 of soil maintained by annual applications of 30 lbs P_2O_5/A would produce the optimum grazeable cool season forage yield of 3T/A/yr.

This present study top-dressed 50 lbs /P_2O_5/A/yr to supply adequate P to test the effect of the limestone treatments. The 50 lbs P_2O_5/A/yr resulted in higher than necessary P_2O_5 soil test values for the 0-3 inch depth; for treatment 5 and 3T/A top-dressed limestone, these values in 1975 and 1979 were 64 and 124 lbs P_2O_5(P_2)/2,000,000 lbs of soil respectively, Table 20. These values are considered to be unnecessarily high due to excess top-dressed P_2O_5. The P_2O_5(P_2) soil test value of 45 lbs/2,000,000 lbs of soil for the 0-3 inch depth as found by Kroth and Meinke (7) could produce P deficient forage in dry falls. As mentioned, this deficiency would better be met by feeding mineral P rather than applying expensive P_2O_5 fertilizer to raise the 0-1 inch depth P_2O_5 soil test value which would not necessarily guarantee that forage so produced would be adequate in P. Good rainfall distribution was experienced in 1977 producing forage with suitable P level Table 18. Indications are that fescue forage harvested in November 1978 could have been P deficient, due to low October rainfall, Table 3. Forage yield should be the criteria for adequate soil P_2O_5 rather than the P level of forage produced in dry falls.

Relationships of Mineral Content and Incidence of Grass Tetany

A brief summary of the literature review by Brown et. al. (2) is as follows: 1. A high concentration of K^+ relative to the concentration of Mg^{++} in the soil could result in forage with high K and low Mg contents; 2. High Ca^{++} concentration relative to Mg^{++} concentration could result in forage with high Ca and low Mg contents; 3. Grazeable forage with less than 0.2% Mg on a dry matter basis can be conducive to grass tetany; 4. The forage cation ratio, $\frac{K}{Ca+Mg}$, expressed in me. of cation per 100 grams of dry matter, with a value greater than 2.2 could indicate possibility of grass tetany.

Table 19. Effect of Limestone, NPK Treatments and Time of Sampling on the Cation Ratio, $\frac{K}{Ca+Mg}$, of Tall Fescue Forage.

Limestone Treatment	N P K No.	March Harvests 1974*	March Harvests 1976	March Harvests 1977	March Harvests 1978	November Harvests 1974	November Harvests 1975	November Harvests 1976
0	1	2.17a	1.81a	1.85a	1.95a	1.13c	1.14b	1.37a
	2	1.83b	1.70	1.73a	1.86a	1.12d	1.42a	1.38a
	3	-----	1.64a	1.74a	1.67b	-----	1.02d	1.38a
	4	1.26d	1.49b	1.60b	1.72a	1.20b	1.26a	1.44a
	5	1.58c	1.25d	1.76a	1.75a	1.11d	1.24a	1.30a
3 T/A TpD	1	1.94a	1.52b	1.58b	1.70a	1.04d	.99e	1.10c
	2	1.74b	1.37d	1.51b	1.67b	1.17c	1.23a	1.29a
	3	-----	1.39c	1.47b	1.56c	-----	1.04c	1.20a
	4	1.20d	1.28d	1.44c	1.56c	1.15c	1.20a	1.33a
	5	1.57d	1.07e	1.47b	1.74a	1.12d	1.31a	1.36a
6 T/A TpD	1	1.97a	1.47b	1.52b	1.57c	1.04d	.86b	1.00e
	2	1.72b	1.34d	1.45b	1.59c	1.17c	1.08c	1.08d
	3	-----	1.31d	1.37d	1.56c	-----	1.02d	1.18a
	4	1.11d	1.21e	1.38d	1.56c	1.27a	1.25a	1.32a
	5	1.57c	1.11e	1.42d	1.58c	1.13d	1.40a	1.17a
8 T/A PwDn	1	1.80b	1.77a	1.47b	1.57c	1.17c	.95e	1.01e
	2	1.79b	1.35d	1.40d	1.54c	1.35a	1.05c	1.21a
	3	-----	1.28d	1.35d	1.53c	-----	.93e	1.14b
	4	1.20d	1.09e	1.34d	1.46d	1.38a	1.10b	1.39a
	5	1.61c	1.04d	1.35d	1.51c	1.29a	1.06c	1.18a

* Sampled in May as first cutting hay. Treatment 3 not sampled in 1974.

The work of Kroth and Meinke (7) showed that top dressing fertilizer P_2O_5 and K_2O resulted in high concentrations of these nutrients in the 0-1 inch depth of the fertilized soil. These nutrients, especially K^+ can be quickly absorbed by plants when temperature and soil moisture permit, George and Thill (5). This present study confirms the work of Kroth and Meinke and also shows that top-dressed limestone results in high levels of Ca in fescue forages, Table 12, as well as high Ca soil test values for the 0-1 inch depth of the top-dressed soil, Table 20.

Table 10 shows the effect of top-dressed limestone on the Mg content of tall fescue. In all cases of the March sampled forages the 6T/A held the Mg content of the forage below 0.2%; the Mg content of the forage from the 3T/A treated blocks was significantly higher than the 6T/A blocks only in 1978. This is evidence that the Ca^{++} from the 0-1 inch depth tended to hinder Mg uptake by spring produced forage.

The effect of top-dressed K_2O on Mg content of fescue forage is given in Table 11. The direct effect of high K^+ activity, treatment 1, may have caused reduced Mg content of March sampled forage in 1974, 1976, and 1977. However the similar Mg reduction produced by treatment 5, was probably due to an indirect effect caused by the increased yields of this treatment. Table 5 shows treatment 5, with all top dressed nutrients evenly divided between May and August applications, produced the highest total yield as well as the highest yields for cutting 2 and 3. Treatment 5, Table 11, shows lowered Mg content; below 0.2% for 1974, 1976, 1977 spring samplings. This low Mg content is explained by the naturally low Mg^{++} of the soil having been further lowered through removal by the higher yield of cuttings 2 and 3 of treatment 5. Table 11 shows forage Mg contents above 0.2% for all November samplings. The final soil test values of the study, Appendix Table 2, show Mg values for treatment 5 well below the initial value of 151 lbs/2,000,000 of soil, Table 1.

The effects of limestone and top-dressed K_2O on the cation ratio $\frac{K}{Ca+Mg}$ are given in Table 19. The only ratio equaling 2.0 was that from treatment 1 on the zero limestone blocks in 1974 when the forage was harvested as hay. Table 9 shows treatment 1 in 1974 produced forage with a high K content, Table 12 shows a low Mg content, and Table 15 a low Ca content; these values resulting in the $\frac{K}{Ca+Mg}$ ration of 2.17. The Ca and Mg values could be lower in this mature forage, due to dillution, than in the other samples taken in March, resulting in the higher ratio of 2.17.

The cation ratios for the March samplings of other years show the effect of treatment 1 with all of the K_2O top-dressed the previous December. Also the top dressed limestone, supplying large quantities of Ca^{++}, produced low cation ratios indicating the forage would not be tetany prone. This is in contrast to the other criteria based on the 0.2% Mg forage content. Table 10 indicated top-dressed limestone would produce spring grown fescue forage with less than 0.2% Mg, hence likely to cause tetany, other conditions being favorable, Brown et. al. (2).

The cation ratios of November harvested forage were well below the critical level of 2.2, reflecting the generally higher Ca and Mg content of fall harvested forage found in this study, Tables 12 and 15.

It is apparent from this study that the cation ratio $\frac{K}{Ca+Mg}$ is a poor indicator of possible incidence of grass tetany where relatively high rates of limestone have been top-dressed on grass pastures coupled with top-dressed K_2O in late fall or early spring.

Results of Soil Tests

Results of the effect of top-dressed NPK on yields of forage crops by Kroth et. al. (8) indicated that annual applications of 160+40+140 would supply all the nutrients necessary to produce forage permissible by soil moisture. To insure adequate P_2O_5 and K_2O for this study 50 lbs P_2O_5 and 150 lbs K_2O per acre per year were chosen. Consequently an increase in P_2O_5 and exchangeable K soil test values, due to excess P and K over fescue needs, was expected. As explained previously the total annual rates of NPK of 160+50+150 were divided into five different rate and time treatments to evaluate the effect of these variables on forage yields, forage composition and soil test values.

Treatment 5. The effect of treatments with time on soil test values was followed with treatment 5, the treatment that gave promise of producing the highest and best distributed yields of the study. Soil samples by one inch depths to a depth of six inches were taken from all plots getting treatment 5 including all limestone blocks in November 1975. All plots of the study were then sampled in the same manner in the spring of 1979; dry weather the fall of 1978 prevented sampling at that time. The results of tests of soil samples for treatment 5 for both sampling dates are given in Table 20.

pHs. The top-dressed limestone blocks were established in May 1973. The data of Table 20 show that the effect of 3T/A limestone had changed the first inch, with some change in the second inch, by November 1975 but by March 1979 the effect had moved to the sixth inch, the pHs ranging from 6.3 to 5.5 by March 1979. On the other hand the effect of 6T/A limestone had moved to the sixth inch by 1975, with pronounced changes for the entire six inches by March 1979, the pHs ranging from 7.1 to 5.9. This rate of change in pHs was greater than expected.

Evenly mixed 8T/A limestone through the acre seven inches effectively changed the pHs of the plow layer. However the 160 lbs N/A/yr had neutralized much of this limestone in the first inch, with some effect in the second inch by November 1975, a pHs of 5.4 and 6.3 in the first and second inches respectively. By March 1979 these pHs values had changed to 5.0 and 6.1. The implications of these pHs values for red clover establishment in tall fescue stands will be given later. The array of pHs values for all limestone and NPK treatments by separate one inch depths is given in Appendix Table 2.

P_2O_5. The data of Table 20 show that the P_1 and P_2 test values changed considerably between 1975 and 1979 for the first inch, the P_2 values changing from 20 lbs initially, to 147 lbs by 1975 and to 307 lbs/2,000,000 of soil by 1979. Changes for the second inch were far less, most of the P not used by the plants staying in the surface inch. The absence of downward movement of P beyond the surface inch is quite evident as shown by the array of P_2O_5 soil test values given in Appendix, Table 2.

The very high P_2O_5 values of the first inch for treatment 4, Appendix Table 2, where all of the annual P_2O_5 is applied in August, is noted. Apparently less P was made available to forage plants from treatment 4 than from the other treatments. Table 17 does show higher November P content of fescue forage for Treatment 4

Table 20. Effect of Limestone on Soil Test Values at Different Depths - Treatment 5

		1975 Sampling							1979 Sampling						
				P_2O_5							P_2O_5				
Limestone Treatment	Depth Inches	OM %	pHs	P_1	P_2	ExK	Mg	Ca	OM %	pHs	P_1	P_2	ExK	Mg	Ca
				-------------Lbs/2,000,000 lbs soil-----------------							-----------------Lbs/2,000,000 lbs soil----------				
0	1	3.6a	4.1f	141a	184a	419bc	123cdefgh	633e	5.6a	4.6m	242a	288b	564a	134d	623k
	2	2.4b	4.2f	36c	40d	269d	100fghij	900e	3.0b	4.3m	81c	97c	385c	81hij	637k
	3	2.2b	4.7e	17d	17d	167fg	113efghi	1500d	2.9b	4.6l	30d	34de	273d	113defg	1223j
	4	2.4b	5.0cde	17d	18d	115g	123cdefgh	1967cd	219b	4.9kl	21d	28de	148e	114defg	1706ghi
	5	2.6b	5.1cd	17d	15d	112g	127cdefg	2167c	2.9b	5.2jk	18d	26de	203de	105efg	2050ghi
	6	2.7b	5.1cd	13d	14d	97g	140cde	2133c	2.8b	5.3jk	16d	25de	131e	144defg	2157gh
3T/A TpD	1	3.6a	6.0b	110b	147bc	492a	153c	3333b	5.5a	6.3def	174b	307ab	504ab	213b	3840b
	2	2.7b	4.8de	22cd	26d	285d	67k	1667cd	2.4b	6.1efgh	33d	42de	211de	119def	2797ef
	3	2.6b	4.9de	18d	19d	149fg	67k	1800cd	3.2b	6.0gh	18d	24de	94e	93fghi	2660ef
	4	2.6b	5.1cd	12d	18d	113g	77jk	2133c	3.0b	5.8hi	16d	22de	79e	76hij	2683ef
	5	2.4b	5.2cd	13d	15d	99g	97ghijk	2000cd	3.0b	5.8hi	14d	20de	79e	74hij	2743ef
	6	2.7b	4.9de	11d	12d	88g	93hijk	1700cd	2.8b	5.5ij	14d	12e	75e	65j	2437fg
6T/A TpD	1	3.7a	6.3ab	103b	153b	466ab	147cd	4467a	5.4a	7.1a	212a	343a	453bc	189c	4783a
	2	2.4b	5.1cd	27cd	36d	239de	70jk	1933cd	2.8b	6.6bcd	33d	41de	197de	92ghi	3313cd
	3	2.3b	5.0cde	14d	15d	138fg	70jk	1733cd	2.6b	6.4cde	19d	24de	95e	72 hij	2923de
	4	2.5b	5.0cde	13d	15d	112g	90ijk	1833cd	3.0b	6.1efgh	14d	23de	75e	68ij	2840ef
	5	2.4b	5.2cd	14d	17d	94g	100fghij	2000cd	3.3b	6.1efgh	17d	21de	79e	73hij	2943de
	6	2.5b	5.1cd	10d	11d	92g	113efghi	1867cd	3.0b	5.9gh	13d	21de	72e	79hij	2743ef
8T/A PwDn	1	3.4a	5.4c	95b	125c	387c	250a	2133c	5.0a	5.0k	228a	280b	446bc	259a	1843hi
	2	2.4b	6.3ab	21cd	28d	196ef	193b	3167b	2.9b	6.1efgh	57c	71cd	235de	224b	3097de
	3	2.3b	6.6a	12d	17d	106g	127cdefg	3533b	2.8b	6.7bc	21d	29de	105e	181c	3613bc
	4	2.5b	6.5a	12d	21d	98g	113efghi	3533b	2.5b	6.8ab	12d	24de	77e	129de	3640bc
	5	2.5b	6.5a	15d	12d	98g	117efghi	3433b	2.5b	6.8ab	13d	19de	78e	106efg	3837b
	6	2.5b	6.4a	11d	15d	94g	130cdef	3300b	2.5b	6.7bc	13d	17e	74e	97fghi	3677bc

over other treatments, but in some years these amounts were below the accepted nutritional level for cattle. Also treatment 4 produced March forage with as low a P content as any of the other treatments excepting treatment 5, in 1977.

The relatively low P content of fescue forage produced in the fall by treatment 4 in 1974 and 1975 even though the soil test $P_2O_5(P_2)$ value for the 0-1 inch was relatively high (mean of treatment 5 all lime levels 1975 was 152 lbs/2,000,000, Table 20), implies that dry periods could reduce forage P content.

Exchangeable K. Table 20 shows the exchangeable K soil test values increased from 1975 to 1979 on the zero lime block at all depths. The reverse was true for the two top-dressed limestone blocks, also at all depths excepting the surface inch (492 vs 504 lbs. exchangeable K per 2,000,000 lbs of soil but not significantly different) for the 3T/A limestone treatment. During the same period, 1975-1979, exchangeable Ca^{++} increased at all depths supporting the thesis that K^{+} not absorbed by fescue moved downward below the plow layer, being forced from the soil colloids by the more tenacious and numerous Ca^{++} ions from the surface applied limestone. The array of exchangeable K and Ca soil test values as effected by all K_2O treatments given in Appendix, Table 2, supports this thesis. However, it could be possible that the increased yields for cutting 2 and 3 of treatment 5 removed this K rather than being leached downward. Chemical analyses were not made of cutting 2 so quantative removal of K cannot be determined. The exchangeable K values for the 0-1 and 1-2 inch depths of the 8T/A limestone increased slightly reflecting the decreased Ca^{++} of these depths due to the fact that limestone of these depths had been neutralized, especially in the 0-1 inch depth during the 4 year period, Table 20. Again the array of exchangeable K and Ca soil test values in Appendix, Table 2 supports the interpretation that large amounts of Ca^{++} would force top-dressed K from K_2O below the plow layer if not adsorbed due to luxory consumption by the fescue.

Exchangeable Mg. Table 20 shows that for treatment 5 the zero limestone treatment Mg soil test values for most depths were reduced from the initial 151 lbs/2,000,000 of soil, Table 1, by 1975 and had some additional reduction by 1979. For the 3T/A limestone treatment soil test Mg was the same as the initial value for the 0-1 inch depth but values for the other five depths were greatly reduced by 1975. By 1979 the Mg levels of the 0-1 and 1-2 inch depths had increased somewhat due to Mg in the top-dressed limestone but the lower depths had no appreciable changes. Apparently the increased fescue growth due to the limestone treatment extracted Mg below the initial value of 151 lbs/2,000,000 lbs soil. The Ca soil test values increased at all depths but at the expense of the H^{+} rather than Mg^{++} supporting the thesis that reduced Mg was due to extraction by fescue roots. However according to Table 10 top-dressed limestone tended tc reduce Mg content of fescue forage in the spring suggesting the possibility thai Mg^{++} was replaced by Ca^{++} forcing Mg^{++} below the plow layer as suggested fo: the K^{+} ion of applied K_2O.

The Mg soil test values for the 6T/A limestone treatment follow the sam pattern as for the 3T/A treatment and do not suggest a different explanation thai that given for the 3T/A treatment. The array of Mg soil test values given i

Appendix Table 2 shows the similarities of the two top-dressed limestone treatments as related to Mg soil test values.

The Mg soil test values of the 8T/A treatment reflect the 2% Mg $MgCO_3$ in the 1.1T mixed into each acre inch of these limestone blocks. No appreciable change occurred between 1975 and 1979 with this limestone treatment showing good Mg content of fescue forage, Table 10. The array of Mg soil test values for all NPK treatments on the 8T/A limestone blocks, given in Appendix Table 2, show fairly uniform values within soil sampling depths, the 0-1 depths being the highest. These values when stressed by applications of K_2O still produced spring grown fescue forage above the critical 0.2% Mg, in contrast to the 3T/A and 6T/A treatments, Table 12.

Ca Soil Test Values. The Ca soil test values for the zero lime treatment showed no change between 1975 and 1979, Table 20. On the other hand the top-dressed limestone treatments gave large increases for the 0-1 inch depths. The Ca value for the 0-1 inch depth of the 6T/A treatment was 1000 lbs greater than the 3T/A treatment, also the 1-2 inch depth showed the effect of the 6T/A treatment. The effect of these high Ca^{++} concentrations on Mg^{++} uptake by fescue has been mentioned above. The Ca^{++} values for the 8T/A treatment remained about the same excepting for the upper two depths which declined, reflecting the reduction in pHs values of these depths due to H^+ resulting from the 160 lbs N applied annually as NH_4NO_3. The array of Ca soil test values in Appendix Table 2 shows that the effect by the other four NPK treatments on these values was the same as treatment 5.

Soil Test Value 8-14 Inch Depth. Table 21 shows the 8T/A limestone application had changed the pHs, neutralizable acidity, Ca and Mg values of the 8-14 inch depth while no changes in this depth were made by the two top-dressed limestone treatments; the 8T/A treatment had been in place for seven years, the two top-dressed treatments for six years.

Table 21. Effect of Limestone on Soil Test Values, 7-14 Inch Depth.

Limestone Treatment	OM %	pHs	Neutralizable acidity Me/100 gms.	P_2O_5 P_1	P_2	Ca	Mg	K	CEC Me/100 gms.
0	1.9	4.4	9.3	10	12	1370	185	138	13.7
3T/A TpD	1.8	4.6	10.2	8	10	1590	238	157	15.4
6T/A TpD	1.6	4.4	8.3	9	11	1500	215	127	13.2
8T/A PwDn	2.0	5.1	4.3	8	11	2500	255	118	11.9

Red Clover and Limestone

Kenstar red clover was drilled into all plots in February 1979. Spring and summer rainfall was nearly ideal for germination and growth of red clover. However red clover did not survive on the zero limestone blocks and initial growth was slow on the 8T/A blocks reflecting the low pHs of the 0-1 and 1-2 inch depths; 5.0 and 5.8 respectively, Appendix Table 2. Excellent stands and rate of growth resulted on the blocks getting the 3T/A and 6T/A applications. The implication of these results are that the 3T/A top-dressed limestone in addition to being adequate for tall fescue production, would also be adequate for red clover growing in combination with tall fescue in a grazing mixture. This limestone application should be adequate for eight to ten years, higher rates would not be expected to improve red clover growth in a red clover-fescue pasture.

The pHs values for the 0-1 and 1-2 inch depths of the 8T/A limestone treatment suggest that where relatively high N applications have been made on grass pastures, establishment of red clover in these pastures may be hindered due to the low pHs values of the surface 0-2 inch depth of these pastures.

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Appendix

Table 1. Effect of Limestone and NPK Treatments on Yields of Tall Fescue 1974-1978

Yields T/A*

Limestone Treatment	NPK Treat. No.	1974 Cut 1	1974 Cut 2	1974 Cut 3	1974 Total	1975 Cut 1	1975 Cut 2	1975 Cut 3	1975 Total	1976 Cut 1	1976 Cut 2	1976 Cut 3	1976 Total
0	1	1.51	.17	1.20	2.89abcdef	1.61	.29	.93	2.81cd	1.38	.46	.52	2.35abcde
	2	1.39	.16	1.10	2.65cdefg	1.40	.26	1.06	2.77cd	1.16	.49	.50	2.15de
	3	1.58	.18	1.03	2.78bcdefg	1.50	.28	1.06	2.84cd	1.31	.46	.47	2.24cde
	4	1.26	.18	1.25	2.69cdefg	1.30	.23	1.13	2.71d	1.09	.47	.54	2.11e
	5	.68	.59	1.43	2.71bcdefg	.81	.82	1.29	2.92bcd	.50	1.04	.79	2.34abcde
3T/A TD	1	1.70	.15	1.08	2.93abcde	1.68	.26	.77	2.70d	1.30	.35	.57	2.22de
	2	1.34	.16	1.07	2.57fg	1.49	.27	1.16	2.92bcd	1.30	.39	.60	2.30cde
	3	1.54	.17	1.02	2.73bcdefg	1.65	.26	1.14	3.05bcd	1.40	.41	.64	2.45abcde
	4	1.27	.20	1.03	2.50g	1.64	.24	1.18	3.06bcd	1.25	.44	.63	2.32bcde
	5	.63	.54	1.26	2.43g	.82	.74	1.40	2.95bcd	.45	1.03	.84	2.33abcde
6T/A TD	1	1.66	.15	1.16	2.97abc	1.76	.28	.76	2.80cd	1.33	.41	.63	2.37abcde
	2	1.47	.15	1.14	2.76bcdefg	1.69	.28	1.32	3.29abc	1.40	.42	.64	2.46abcde
	3	1.60	.16	.98	2.74bcdefg	1.82	.23	1.14	3.18abcd	1.52	.44	.64	2.60abc
	4	1.26	.14	1.19	2.60efg	1.63	.25	1.25	3.13abcd	1.29	.42	.73	2.39abcde
	5	.69	.60	1.33	2.62defg	.84	.80	1.46	3.10bcd	.58	1.07	.68	2.52abcd
8T/A PwDn	1	1.67	.21	1.35	3.23a	1.77	.35	1.06	3.18abcd	1.48	.48	.75	2.71a
	2	1.33	.21	1.28	2.96abcd	1.70	.32	1.37	3.39ab	1.45	.47	.79	2.70a
	3	1.41	.20	1.45	3.05ab	1.72	.35	1.37	3.43ab	1.48	.47	.73	2.68ab
	4	1.15	.20	1.65	3.00abc	1.46	.32	1.60	3.39ab	1.26	.49	.75	2.49abcd
	5	.77	.76	1.65	3.18a	.93	.93	1.77	3.63a	.63	1.12	.94	2.70a

Table 1. Effect of Limestone and NPK Treatments on Yields of Tall Fescue 1974-1978 (continued)

Limestone Treatment	NPK Treat. No.	1977 Cut 1	1977 Cut 2	1977 Cut 3	1977 Total	1978 Cut 1	1978 Cut 2	1978 Cut 3	1978 Total
		Yields T/A*							
0	1	1.77	.63	1.50	3.87cd	1.43	.50	.85	2.77bcd
	2	1.54	.69	1.56	3.80cd	1.34	.55	.95	2.84bcd
	3	1.69	.62	1.49	3.80cd	1.28	.55	.72	2.55d
	4	1.53	.61	1.65	3.80cd	1.19	.59	.91	2.69cd
	5	.93	1.38	1.77	4.08abcd	.70	1.52	1.04	3.26ab
3T/A TD	1	1.65	.61	1.77	4.03abcd	1.31	.41	.77	2.49d
	2	1.57	.62	1.79	3.98bcd	1.32	.36	.83	2.51d
	3	1.75	.72	1.84	4.32abc	1.45	.39	.69	2.53d
	4	1.48	.67	1.92	4.08abcd	1.28	.44	.79	2.51d
	5	.94	1.23	1.78	3.96bcd	.76	1.07	1.04	2.88bcd
6T/A TD	1	1.65	.67	1.83	4.15abcd	1.35	.40	.72	2.47d
	2	1.70	.71	1.82	4.23abcd	1.35	.41	.94	2.70cd
	3	1.76	.70	1.88	4.34ab	1.31	.45	.72	2.48d
	4	1.54	.65	1.98	4.21abcd	1.27	.40	.82	2.49d
	5	.98	1.33	1.84	4.15abcd	.89	1.12	1.18	3.17abc
8T/A PwDn	1	1.70	.82	1.90	4.42ab	1.55	.58	.75	2.88bcd
	2	1.73	.81	2.00	4.54a	1.33	.55	.93	2.81bcd
	3	1.78	.80	1.91	4.50ab	1.45	.56	.81	2.82bcd
	4	1.54	.76	1.99	4.30abcd	1.25	.57	.97	2.78bcd
	5	1.02	1.47	1.99	4.48ab	.90	1.33	1.24	3.47a

* Each value the mean of three replications. Results of Ducan's New Multiple Range Test given for yearly total yields only.

Appendix

Table 2. Effect of Limestone and NPK Rate and Time of Application on Soil Test Values by One Inch Depths.*

Limestone Treatment	NPK Treat. No.	pHs** Depth Inches						P_1 Depth Inches						P_2 Depth Inches					
		1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
								LBS/2,000,000 lbs soil											
0	1	4.1	4.0	4.4	4.7	4.7	4.9	149	69	17	14	14	12	172	80	23	21	20	17
	2	4.1	4.1	4.4	4.8	5.0	5.0	222	58	25	20	16	14	250	58	27	23	21	21
	3	4.1	4.0	4.4	4.7	4.9	5.0	171	83	39	24	18	17	203	84	41	28	23	23
	4	4.1	4.2	4.3	4.8	4.8	5.0	305a	87	32	19	18	13	342b	93	36	28	24	21
	5	4.6	4.3	4.6	4.9	5.2	5.3	242bc	81	30	17	18	16	288cd	97	34	28	26	25
3T/A TpD	1	6.6	6.1	5.8	5.9	5.9	5.8	131	37	19	16	15	12	201	44	28	22	19	16
	2	6.3	5.8	5.8	5.6	5.6	5.3	201	42	20	16	12	15	260	54	26	21	17	16
	3	6.4	5.8	5.7	5.7	5.6	5.4	107	36	20	15	14	12	158	46	23	20	18	16
	4	6.5	5.7	5.5	5.4	5.5	5.3	306a	59	24	18	19	17	393a	71	26	21	20	19
	5	6.3	6.1	6.0	5.8	5.8	5.5	174fgh	33	18	16	14	14	307c	42	24	22	20	12
6T/A TpD	1	6.8	6.6	6.2	6.1	5.9	6.1	112	30	17	12	12	12	178	38	23	18	16	17
	2	6.3	6.0	5.8	5.8	5.6	7.0ab	189	39	22	14	14	12	264	51	27	19	18	15
	3	6.4	7.0ab	6.7	6.3	6.2	6.1	126	28	19	13	13	12	194	36	22	18	17	17
	4	6.6	6.5	6.1	5.8	5.6	5.3	258b	63	21	15	14	12	359b	72	27	19	19	16
	5	7.1a	6.6	6.4	6.1	6.1	5.9	212cde	33	19	14	17	13	343b	41	24	23	21	21
8T/A PwDn	1	5.0	5.6	6.6	6.8	6.7	6.7	138	38	15	12	13	13	164	40	23	20	22	19
	2	5.1	6.1	6.8	6.9abc	6.8	6.8	169	34	17	12	12	12	206	51	26	23	26	22
	3	5.0	5.9	6.7	6.7	6.7	6.8	116	34	15	11	12	12	156	45	25	21	21	24
	4	5.0	6.0	6.7	6.8	6.8	6.7	257b	54	25	17	15	13	289cd	71	35	27	26	24
	5	5.0	6.1	6.7	6.8	6.8	6.7	288cd	57	21	12	13	13	280cde	71	29	24	19	17

Appendix

Table 2. Effect of Limestone and NPK Rate and Time of Application on Soil Test Values by One Inch Depths.* - continued

Limestone Treatment	NPK Treat. No.	Exchangeable K						Mg						Ca					
		Depth Inches						Depth Inches						Depth Inches					
		1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
		LBS/2,000,000 lbs soil																	
0	1	424	307	208	180	151	126	147	78	92	93	92	97	757	700	1243	1633	1900	2023
	2	524bc	327	233	174	146	127	138	79	98	97	91	95	717	767	1326	1717	1887	2077
	3	492cde	318	225	195	161	141	137	70	80	87	84	82	673	590	1040	1600	1867	1923
	4	624a	371m	271	204	152	114	126	68	84	88	82	81	680	593	1090	1600	1957	2067
	5	564b	385	273	203	148	122	134	81	113	114	105	114	623	637	1223	1707	2050	2157
3T/A TpD	1	316	167	125	105	92	93	197	107	89	81	84	86	3500	2583	2550	2533	2590	2473
	2	500cd	220	112	106	85	90	240bcd	124	104	92	83	90	3347	2640	2690	2490	2457	2297
	3	434	193	112	95	95	91	239bcd	133	116	101	98	106	3383	2550	2500	2456	2440	2223
	4	653a	360mn	155	115	97	102	244b	119	88	78	76	68	3583	2473	2247	2373	2500	2290
	5	503cd	211	94	79	79	75	213	119	93	76	74	65	3840d	2797	2660	2683	2743	2437
6T/A TpD	1	245	132	98	87	83	86	194	102	85	82	89	103	4273c	3263	2957	2793	2790	2567
	2	395	194	115	97	92	86	206	105	87	110	88	110	4207c	3117	2833	2717	2583	2493
	3	346	180	111	92	86	86	201	101	80	75	74	75	4673ab	3083	2673	2697	2517	2343
	4	519cd	318mn	129	98	90	84	221	94	74	64	56	62	4523b	3107	2683	2550	2457	2250
	5	446	197	95	75	79	72	189	92	74	68	73	79	4783a	3313	2923	2847	2943	2743
8T/A PwDn	1	308	145	103	93	88	82	229	191	153	129	106	98	1710	2933	3267	3483	3540	3423
	2	437	202	108	95	80	82	244b	196	162	126	115	108	1947	3003	3607	3750	3823	3767
	3	380	168	98	88	83	83	221	195	158	125	108	93	1673	2850	3267	3470	3550	3450
	4	568b	295	142	100	93	97	243b	210	177	132	103	95	1880	2867	3423	3430	3563	3523
	5	446	235	105	77	78	74	259a	224	181	129	106	97	1843	3097	3613	3640	3827	3677

* pHs, P_1, P_2, Ex. K, Mg and Ca were analyzed separately - the higher significant values by Duncan's. New Range Test are given to show relationships between the wide ranges of values within the plow layer at the end of the study.

** pH determined in 1:1 soil:0.01 M $CaCl_2$ suspension.