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CHAPTER 4

SOIL MANAGEMENT AND FERTILITY PRACTICES FOR ANNUAL RYEGRASS

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Introduction

In Texas, annual ryegrass (*Lolium multiflorum* Lam.) is grown primarily in the eastern one-third of the state from the East Texas Timberlands to the Blacklands and to the Coastal Prairie. Soils vary in clay content and levels of acidity or alkalinity. Ryegrass is intolerant of strongly acid soils and responds readily to nitrogen (N) and other deficient plant nutrients applied to soils ranging from moderately acid to alkaline. This chapter describes responses of annual ryegrass to limestone and plant nutrients applied to neutralize acidity and overcome nutrient deficiencies.

Macronutrients, Soil Acidity, and Limestone

Nitrogen

After strongly acid soils are properly limed for ryegrass production, adequate, timely N fertilization generally creates greater increases in forage dry matter production than does application of any other plant nutrient. Response of annual ryegrass to N depends on soil and climatic factors that affect plant growth rate and the availability and efficiency of applied N. During periods of cold temperature and high rainfall, N in soils will be used inefficiently by plants. The nitrate (NO_3^-) form of N can be leached from soils during periods of high rainfall and may be lost by denitrification from soils that remain saturated with water for prolonged periods.

Morris et al. (1994) reported 4.7 t/ac maximum dry matter yield of ryegrass at an N rate of 250 lb/ac applied as a single treatment to a cultivated acid, sandy soil in southeastern Louisiana. On a Bernard clay loam at Beaumont, Weihing and Evatt (1960) showed higher sustained forage production at each cutting by three applications of 30 lb N/ac; at seeding, late January, and early March (Table 1). Sixty lb N/ac applied on March 2 produced the highest yield, but 77% of this was harvested in May and included seed. One application of 90 lb N/ac at seeding produced more forage at the first two harvests, but without continued N treatments ryegrass yield decreased significantly during the last two harvests. Similar results were shown during an abnormally cold winter (Weihing and Evatt, 1960).

Westfall et al. (1971) reported that two urea applications, one-half before seeding and one-half after the second cutting, continued to increase ryegrass production and crude protein to the

Table 1. Oven-dry forage yields of Gulf ryegrass in response to nitrogen fertilization and management.

Nitrogen applied			Harvest date				
At seeding	Jan 29	Mar 2	Dec 8	Jan 29	Mar 2	May 12-14[1]	Total
--------------------			lb/ac				--------------------
0	0	0	237	539	374	1307	2457
0	60	0	274	542	1421	2396	4633
0	0	60	326	512	402	4247	5487
30	0	30	430	607	401	3158	4596
30	30	30	601	742	946	3049	5338
30	30	0	521	643	871	1851	3886
60	0	0	898	889	504	1634	3925
60	30	0	821	803	1002	1634	4260
90	0	0	899	1160	654	1307	4020
LSD	0.05		243	243	205	539	713

[1]Last cutting includes seed.

200 lb N/ac rate at Beaumont (Fig. 1). Data from Overton support split-applications of N for ryegrass production (Matocha, 1972). Dunavin (1975) reported increased ryegrass yields and an 8.3% improvement in N uptake efficiency when 360 lb N/ac were applied in three, 120 lb/ac applications during the season. Uptake efficiency of N decreased as the rate of N application was increased.

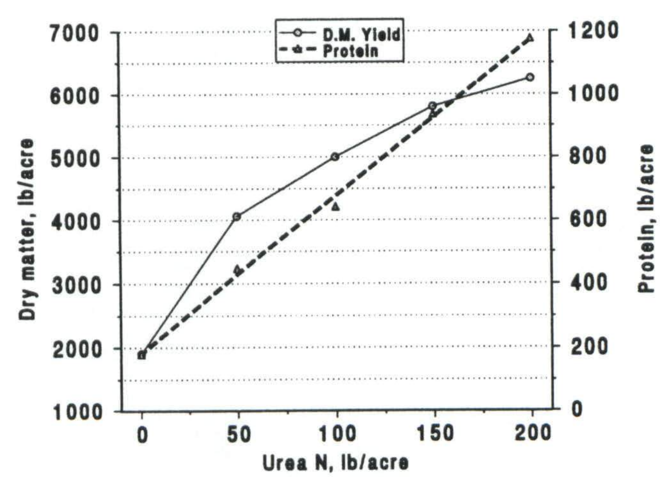

Fig. 1. Ryegrass yield and protein production response to N.

Robinson et al.

(1987) reported that N in two equal applications increased yields as the rate was increased (Table 2). Statistically significant yield increases occurred to 300 lb N/ac in 1974 and to 400 lb N/ac in 1973 and 1975 on the Olivier silt loam soil. Applying ammonium nitrate at planting and after each harvest increased forage, but production was not statistically greater than yield of ryegrass that received N in two applications on this silt loam soil. Nitrogen recovery rates were uniform, averaging 61% at N rates of 400 lb/ac or lower (Robinson, 1990). Ammonium nitrate applied at 50 lb N/ac for each regrowth produced more forage dry matter than urea at the same N rate.

In most regions of East Texas, ryegrass is overseeded on Coastal bermudagrass (*Cynodon dactylon* [L.] Pers.) pasture after the nocturnal temperatures have declined below 60 °F in October. Ryegrass provides cool-season grazing, particularly during late winter and early spring. Clover is often seeded with the ryegrass. The ryegrass-clover combination requires careful management of N fertilizer application.

Table 2. Nitrogen application influences on yield of Gulf ryegrass grown on an Olivier silt loam.

	Forage dry matter			
N rate	1973	1974	1975	Average
lb/ac	---tons/ac---			
0	1.62 g[1]	2.55 g	2.98 f	2.38 g
100[2]	2.33 f	3.46 f	4.56 de	3.45 f
200[2]	3.19 de	3.88 ef	4.08 e	3.72 ef
300[2]	3.38 cde	4.97 cd	5.30 bc	4.55 d
400[2]	4.33 ab	5.19 bc	5.70 abc	5.07 bc
500[2]	4.14 ab	5.57 bc	6.33 a	5.34 ab
25/harvest[3]	2.93 ef	4.40 de	4.22 e	3.85 ef
50/ "	4.01 bc	5.80 ab	5.98 ab	5.27 ab
100/ "	4.01 bc	6.28 a	6.32 a	5.54 a
25/harvest[4]	3.17 de	4.42 de	4.25 e	3.95 e
50/ "	3.73 bcd	5.03 cd	5.22 cd	4.66 cd
100/ "	4.83 a	5.86 ab	6.33 a	5.67 a

[1] Means within a column followed by the same letter are not significantly different at the 5% probability level according to Duncan's Multiple Range Test.

[2] N was applied as ammonium nitrate, one-half at planting and one-half in late winter.

[3] N was applied as ammonium nitrate at the indicated rates at planting and after each harvest except the last, 5 times in 1973 and 7 times in other years.

[4] N was applied as urea at the indicated rates at planting and after each harvest except the last, 5 times in 1973, and 7 times in other years.

Results reported by Evers et al. (1993) showed that the highest dry matter yield in a ryegrass-clover system occurred when the initial 60 lb N/ac was applied at the time 80% of first true clover leaves were expanded. This treatment was followed by 60 lb N/ac in January, and 60 lb N/ac after the first harvest in March (Fig. 2). Total production was 2.1 t of dry forage/ac. Delaying the first 60 lb N/ac application until January raised ryegrass dry matter yield by 1700 lb/ac while lowering clover dry matter yield by 700 lb/ac (Fig. 3). Ryegrass yield was maximized and clover minimized at 180 lb N/ac applied in three equal increments, beginning at first true clover leaf, then in January, and again in March. This treatment also maximized the pounds of ryegrass plus clover dry matter produced per pound of N applied.

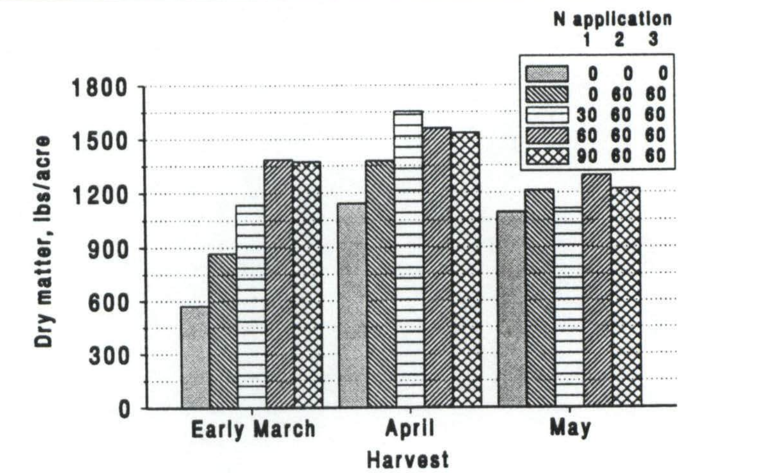

Fig. 2. Three year avg. Marshall ryegrass + Yuchi arrowleaf clover yield by harvest time and N application. N applied at: (1) 1st clover leaf; (2) January; (3) After 1st harvest (March).

Analysis of the top 6 inches of soil for nitrate N is inadequate for predicting the N needed for ryegrass, especially on acid, sandy soils. Nitrate N moves readily with water and is easily removed from the surface soil by fall and winter rains, especially in sandy soils in the Coastal Plain, Gulf Coastal Prairie, and Gulf Coast Flatwoods. On sandy soils in high rainfall regions of Texas and the southern United

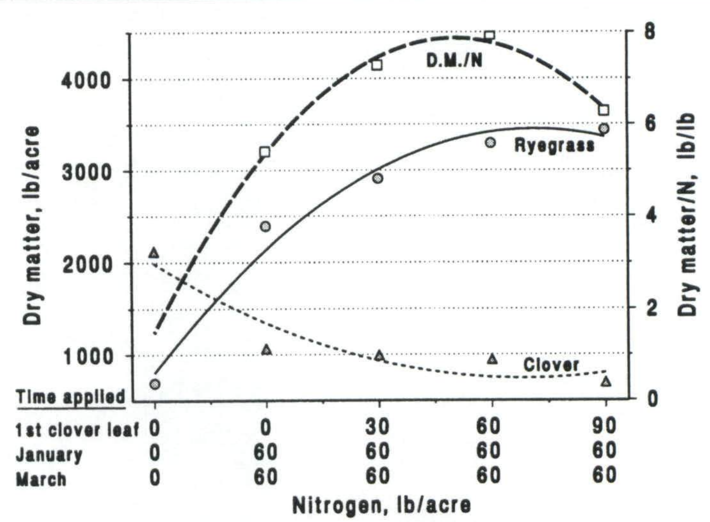

Fig. 3. Effect of N rate and time of application on Marshall ryegrass and Yuchi arrowleaf clover yields and D.M. per pound of N.

States, ryegrass interseeded in a hybrid bermudagrass sod in October has produced excellent forage when fertilized with 180 lb N/ac in three increments of 60 lb/ac, beginning three weeks after seeding and germination of the ryegrass, in late January, and again in March.

With ryegrass seeded in a prepared seedbed in September, 30 lb N/ac may be needed at planting, followed by 50 lbs in mid-November or after the first grazing, 60 lb in February, and another 50 lbs in early April. Where clover is seeded with ryegrass in a bermudagrass sod, maintaining adequate clover and ryegrass production is difficult. In N-deficient soils, winter forage production is limited and clover will provide more forage than the ryegrass. The first 60-70 lb/ac increment of applied N will increase ryegrass and decrease clover growth. Delaying fertilization of this mixed stand with N until January will give clover a better chance, but early forage production will decline. In southern latitudes of the Coastal Plain states, N rates up to 300-400 lb/ac, applied one-half at seeding and one-half in late January, have produced excellent ryegrass yields on prepared seedbeds in clay and clay loam soils.

Soil Acidity and Limestone

Strongly acid soils inhibit growth of bacteria that convert N in the form of ammonium (NH_4^+) to NO_3^-. Pearson (1958) presented data that showed a 256% increase in NO_3^--N produced in two weeks at pH 6.2 compared to pH 5.0. Fertilizers containing NH_4^+-N are strong acidifiers of low-buffer-capacity soils (sandy, low organic matter soils). Soil acidity caused by nitrification of NH_4^+ fertilizers is shown in Table 3. Acidity generated by applied NH_4^+ will be lower when ammonia (NH_3) is lost through volatilization and when NH_4^+ is taken up by plants. Acidity created by NH_4^+ fertilizers will also be lower when NH_4^+ is fixed in clays, immobilized in soils by microorganisms, or if plants take up more anions than cations. Lower-than-normal levels of acidity result when soil NO_3^- is denitrified.

Haby and Nelson (unpublished data) found that soil pH was lowered from 5.4 to 4.5 in the surface 6-inch depth of a Bowie fine sandy loam due to application of fertilizers containing NH_4^+ without limestone during the six years from 1988 to 1994 (Fig. 4). The increase in acidity due to N declined as the limestone rate was raised. The 2 t/ac rate of limestone, applied twice from 1988 to 1994, maintained soil pH at 7.0 or above at all rates N applied.

Limestone quality is an important consideration when planning to lime acid soils. Quality of limestone is determined by its fineness and its neutralizing value. Neutralizing value is also called calcium carbonate equivalent (CCE). Calcium carbonate equivalent is an estimate of the amount of acidity a given limestone will neutralize. Pure calcium carbonate has a CCE of 100

Table 3. Soil acidity caused by ammonium N fertilizers during the biological nitrification reaction.[1]

N source	Formula	N content	Residual acidity (Maximum value)	Residual acidity (Accepted value)	Residual acidity (Accepted value)
		%	lb $CaCO_3$/lb of N applied	lb $CaCO_3$/lb of N applied	lb $CaCO_3$/100 N of N applied
Anhydrous ammonia	NH_3(gas)	82	3.6	1.8	180
Urea	$(NH_2)_2CO$	46	3.6	1.8	180
Ammonium nitrate	NH_4NO_3	34	3.6	1.8	180
Urea-ammonium nitrate	$(NH_2)_2CO$-NH_4NO_3	32	3.6	1.8	180
Ammonium sulfate	$(NH_4)_2SO_4$	21	7.2	5.4	540
Monoammonium phosphate	$NH_4H_2PO_4$	10	7.2	5.4	540
Diammonium phosphate	$(NH_4)_2HPO_4$	18	5.4	3.6	360

[1]Sources: Adams, 1984; Kincheloe, 1986.
[2]Values represent the amount of 100% effective limestone required to neutralize the acidity produced by ammonium nitrogen biologically converted to nitrite in the soil.

and is the standard for evaluating other liming materials. The fineness of grind determines the speed at which a given limestone will react in an acid soil. Together, the CCE and the fineness determine the effective calcium carbonate equivalent (ECCE, Table 4). Particle size effectiveness is estimated by passing ground limestone through 8 and 60-mesh sieves. Particles retained on an 8-mesh sieve are considered ineffective for neutralizing soil acidity because of the small total surface area of

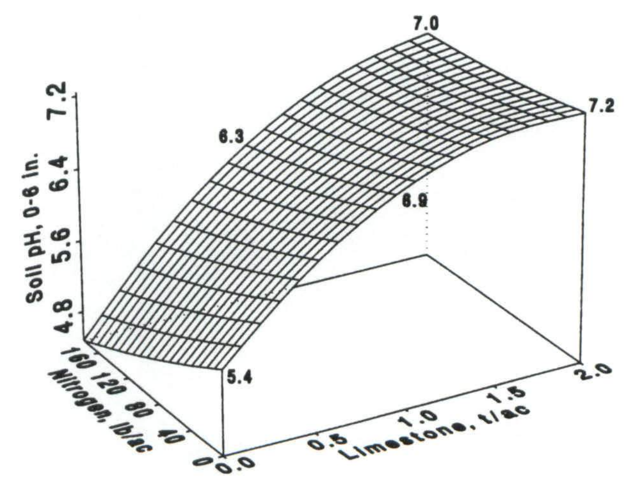

Fig. 4. Influence of limestone and N rates on pH in the 0-6 in. depth of a Bowie fine sandy loam after 6 yr. of N treatments.

Table 4. Calculation of the effective calcium carbonate equivalent (ECCE) of a limestone sample.

Mesh	Limestone fraction	Effectiveness factor	Fineness factor	Neutralizing value	ECCE
>8	.05	x 0	= 0		
<8 to >60	.40	x .50	= .20		
<60	.55	x 1.00	= .55		
		Sum	= .75	x 100	= 75

these large particles. Particles passing an 8-mesh sieve that are retained on a 60-mesh are considered 50% effective. Limestone particles passing the 60-mesh sieve are 100% effective at neutralizing soil acidity if the limestone has a neutralizing value of 100. The fineness factor is the product of the sieved limestone fraction multiplied by its effectiveness factor. The sum of the fineness factors multiplied by the neutralizing value, or CCE, of the limestone equals the ECCE. Some states, including Texas, use a 20-mesh sieve in the series. The effectiveness factors then become 0, 0.2, 0.6, and 1.0 for materials retained on the 8 mesh, less than 8 but larger than 20 mesh, less than 20 but larger than 60 mesh, and less than 60 mesh, respectively.

Limestone mixed into the soil is more effective at neutralizing acidity than when it is left on the soil surface. Incorporation is not always practical. Haby et al. (1994) showed results of pH change due to application of limestone with a neutralizing value of 100 to a Darco loamy sand (Grossarenic Paleudult) as ECCE 62 and 100 materials at rates of one and 2 t/ac (Fig. 5). Two and one-half years later, the limestone with an ECCE of 100 maintained the surface soil 0.4 pH unit above soil treated with limestone characterized as ECCE 62. Soil pH increase due to one ton of ECCE 100 limestone was greater

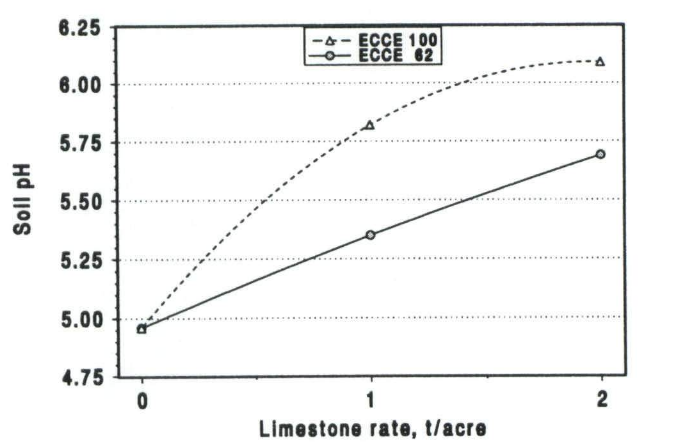

Fig. 5. Effect of limestone rate and effective $CaCO_3$ equivalence (ECCE) on soil pH in the 0-6-inch depth 2.5 years after treatments were applied on the surface of a Darco loamy fine sand.

than the pH increase caused by two tons of ECCE 62 limestone. This indicates the ECCE 100 limestone was at least twice as effective at neutralizing soil acidity as was the ECCE 62 material when both were surface applied and not incorporated into the soil.

Ryegrass Response to Limestone on Acid Soils

Early studies on annual ryegrass in Alabama showed no forage yield response to lime on sandy soil at pH 5.1 (Adams, 1968). In more recent research in Louisiana, annual ryegrass production was increased by liming a Providence silt loam soil (Morris et al., 1987). Soil pH in the lime check plots dropped below 4.9 due to continued annual N rates of 375 lb N/ac.

Data from Hillard et al. (1992) showed a positive response of Marshall ryegrass to limestone for three seasons in a four-year liming study begun in 1983 (Table 5). On the Lilbert loamy fine sand with an initial pH of 4.7, 0.3 t of ECCE 62 limestone/ac incorporated into this soil raised pH to 4.8 and ryegrass dry matter yield increased by 0.87 t/ac. Yield was increased by 1.3 tons dry forage/ac at the 1.7 t/ac limestone rate that raised surface soil pH to 6.2 by 1985.

Table 5. Soil pH and Marshall ryegrass response to limestone incorporated into a Lilbert loamy fine sand[1].

Limestone rate	pH 1983	DM 1984	pH 1985	DM 1986	pH 1987	DM 1987
t/ac		t/ac		t/ac		lb/ac
0	4.7	1.39	4.5	1.72	4.5	0.32
0.3	4.8	2.26	4.7	2.29	4.5	0.49
1.7	5.7	2.69	6.2	3.71	4.6	2.71

[1]Hillard et al., 1992

In the third and fourth years after liming, the higher limestone rate increased yields by more than 2.0 tons of dry forage/ac compared to unlimed plots. In 1987, soil pH in plots treated with 1.7 tons of limestone/ac had declined to 4.6, but dry matter yield remained 2.4 t/ac higher than in the unlimed plots. The quantity of NH_4^+-N applied in this study theoretically required 4,069 lb $CaCO_3$/ac to completely neutralize the additional acidity produced if all applied NH_4^+ was nitrified. In this soil, pH was buffered near 4.5, thereby temporarily resisting further decline in all plots. Hillard's (1992) data are supported by Rechcigl (1992) in Florida, who reported annual ryegrass yield increased 226% due to incorporation of 1.0 t of 90% CCE limestone/ac into a Pomona fine sand that had an initial pH of 4.7. Optimum yields of ryegrass were obtained at pH 5.5. Eichhorn and Bell (1993) reported a ryegrass yield increase of 310% to 4.4 t of dry matter/ac after incorporation of 1 t of ECCE 100 limestone into the surface of a pH 4.0, Mahan-Darley fine sandy loam in northern Louisiana. Yield increased by 344% at the 2 t/ac rate of limestone. Soil pH was raised to 4.4 and 4.9 by the 1 and 2 t/ac limestone rates, respectively. Exchangeable soil aluminum was significantly lowered in these yield studies. Bailey (1991) reported that liming acid soils increases the rate of mineralization of soil organic phosphorus (P), decreases fixation of inorganic P into unavailable forms, prevents co-precipitation of iron and aluminum phosphates on root membranes, and that calcium (Ca) stimulates P uptake by plant roots.

Hillard et al. (1992) reported that dry matter yield of Marshall ryegrass in a Lilbert loamy fine sand (Plinthic Paleudult) was related to the concentration of extractable soil aluminum (Fig. 6). Robinson et al. (1993) lowered soil Al from 111 ppm in a Stough fine sandy loam (Fragiaquic Paleudult) with an initial pH of 4.6 to 36 ppm at pH 5.2 and increased yield of Marshall ryegrass from 2.1 to 10.2 grams/pot in a greenhouse study. Rengel and Robinson (1989) reported that transport of Al from roots to shoots was slow. Most of the Al remained in roots. Larger shoot concentrations of Al were found in Wilo and Urbana varieties than in the more Al-tolerant varieties, Marshall and Gulf. Increases in Al concentrations in the nutrient solutions decreased uptake of Ca, magnesium (Mg), and potassium (K).

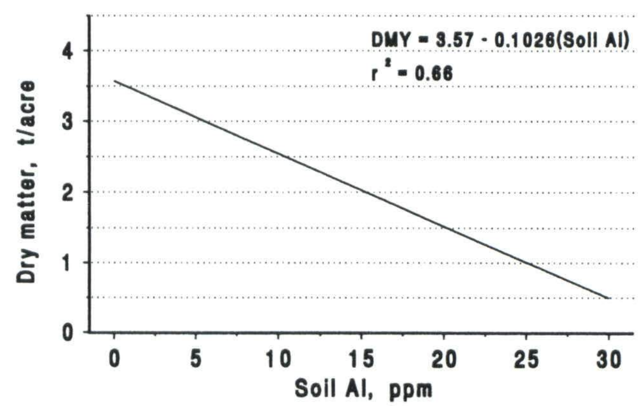

Fig. 6. The relationship between Marshall ryegrass yield and 1 M KCl extractable aluminum in a Lilbert loamy fine sand.

Analysis of the surface 6 inches of soil for lime requirement will predict the limestone rate needed to raise soil pH into the range of 6.0 for ryegrass production. Soil pH should be maintained above 5.5. When possible, limestone should be incorporated into the soil for maximum efficiency. Limestone should be applied 6 or more months ahead of seeding ryegrass. Limestone with an ECCE rating closer to 100 will be more effective at neutralizing soil acidity and will maintain a higher soil pH longer than limestone with a lower ECCE. A light disking to incorporate the limestone is better than leaving it on the soil surface.

Ryegrass Response to Phosphorus

Hillard et al. (1992) showed the response of Marshall ryegrass to the interaction of P and limestone (Fig. 7). Ryegrass yield increases due to applied P were greater at zero limestone than at the 1.7 t/ac limestone rate. Limestone treatment increased the availability of soil P to the plants. Although there was no interactive effect of limestone and P on yield, Rechcigl (1992) verified the response of ryegrass (cv Gulf) to applied P. Bailey (1991), Chen and Barber (1991), Hillard et al. (1992), and Rechcigl (1992) reported that liming acid soils made soil P more available. Soltanpour et al. (1974) found that liming an acid Ultisol (pH 5.2) after fertilizing with P decreased soil-solution P and P uptake by plants at all lime and P rates. In contrast, P availability was increased if the soil was limed first, then treated with P, provided the soil was not limed above pH 6.2. Hillard et al. (1993) showed the effect that increasing soil aluminum concentrations had on decreasing ryegrass yields with escalating rates of applied P in unlimed Lilbert surface soil. Ryegrass response to applied P was highest at the zero level of applied aluminum. At high aluminum rates, the plants were stunted and did not recover as P rates increased. In a critical review, Haynes (1982) indicated that liming has been reported to increase, decrease, or not affect the phosphate that can be extracted from acid soils.

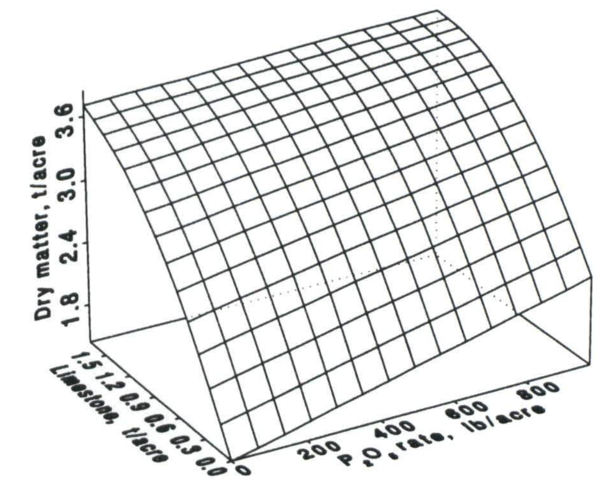

Fig. 7. Response of annual ryegrass to interactions of phosphorus and limestone 3 years after application to a Lilbert fine sandy loam.

There remains some controversy regarding ryegrass response to lime and P application on acid soils. Much of the research that showed ryegrass response to lime application was done on very strongly acid soils, i.e., those below pH 4.8. Hillard (1989) verified that aluminum rapidly accumulates to toxic concentrations at or below this pH level on a Lilbert soil series (Fig. 8). High concentrations of aluminum ions and aluminum hydroxides complex P and make it less available to the plant. Liming these strongly acid soils reverses this P fixation process, making P more available. When less acidic soils such as those with pH near 5.5 are limed, ryegrass shows little response to the lime treatment because there was no toxic concentration of aluminum to suppress its growth or complex available P.

The P fertilizer needs of ryegrass can be determined adequately by analysis of the surface soil. Unless high rates of manure have been applied, the majority of the plant available P will be concentrated within this surface depth. At very low soil test P levels, rates of 120 lb P_2O_5/ac will be needed to produce optimum yields. As the soil test level of P increases, lower rates of P will be needed. Much higher rates of P will be needed if the soil pH is below 5.0 and toxic levels of Al are present. In this case, if the soil is not limed, fertilization with P will be uneconomical for production of ryegrass. Lime should be applied and incorporated several months before fertilizing with P.

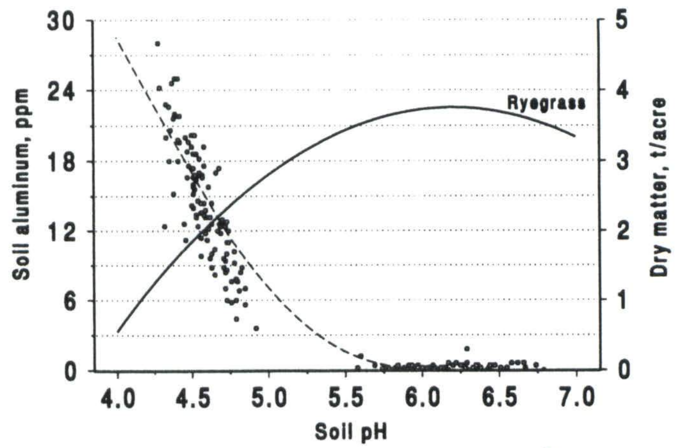

Fig. 8. Effect of soil pH on 1 M KCl extractable Al^{3+} and the yield of annual ryegrass on a Lilbert fine sandy loam.

Ryegrass Response to Potassium

The K requirement of annual ryegrass is the least researched of the macronutrient elements. Kelling and Matocha (1990) stated that only a few studies relate mineral composition to yields and those data are not sufficient to develop separate nutrient criteria for annual and perennial ryegrasses (*Lolium perenne* L.). Nemeth (1975) reported the yield of perennial ryegrass was directly related to the amount of K removed from three different soils by extraction of each for 10 minutes. Haby et al. (1994) reported linear response of annual ryegrass to potash applied in late February. Yield increase was not high, averaging 5 lb dry matter/lb K_2O, up to 150 lb K_2O/ac. On a prepared seedbed, variety comparisons indicate that TAM 90 ryegrass responded significantly to applied potash up to 150 lb/ac at low or high limestone rates (Fig. 9, Haby and Nelson, unpublished). Ryegrass yield and nutrient content data from Hillard (1989) show that K uptake by ryegrass varied by year and ranged from 42 to 61 lb K/t (51-73 lb K_2O/t) of dry forage. Forage produced at the higher limestone rates contained lower levels of K, probably due to a dilution effect caused by higher yields that stressed the ability of the soil to supply K. Because of the high potash requirement of hybrid bermudagrass, addition of potash for overseeded ryegrass becomes even more important to prevent thinning of the stand of bermudagrass and its susceptibility to winter-kill.

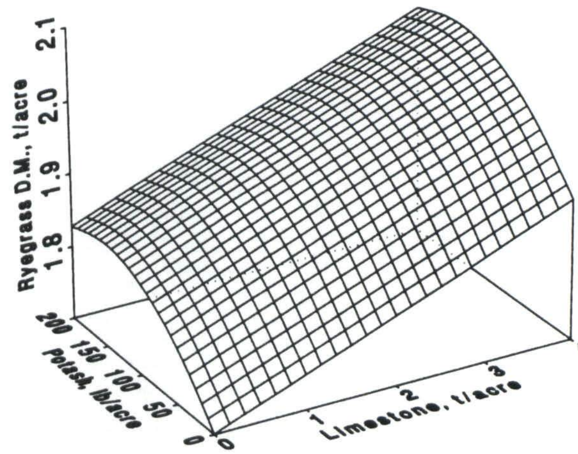

Fig. 9. Two year mean yield response of TAM 90 ryegrass to limestone and potash (K_2O) treatments.

Based on Hillard's (1989) data, 4 tons of ryegrass dry matter/ac will contain 240 lb K. Robinson et al. (1987) showed that K removal in ryegrass cut for hay increased from 114 lb/ac to 270 lb/ac as yield was increased by N applications. Potassium removal averaged 51 to 52 lb/t of ryegrass at all N rates between 100 and 500 lb/ac. Soil test K levels in the East Texas Coastal Plain Ultisols are usually rated in the very low to medium category. According to Maynard & Loosli (1962), less than 2% of the K in forages consumed by cattle is removed from pasture as animal tissue K. A 500-pound calf grown on ryegrass pasture will remove only 1.5 lb of K/ac. At this recycling rate for K, once the grazing system has been in place for several years, only a small amount of fertilizer K is needed/ac each year. In an established, long-term ryegrass and bermudagrass grazing system using recycled K, addition of 50 lb K_2O/ac when the soil test reveals very low or low levels of K should be adequate to supply the K needs of the ryegrass. Additional K may be needed for the bermudagrass. This annual K rate will help overcome unequal redistribution of excreted K and K leached deeper into the subsoil.

Ryegrass response to potash on soils that test in the medium K category becomes questionable in long-term, established grazing systems. When cattle prices are low, one management plan may include omitting K fertilization for ryegrass on medium testing soils for one season. When cattle prices are high, application of 25 to 30 lb K_2O/ac/season to a soil with a medium level of extractable K will help maintain an adequate supply of K in the soil. Certain soils such as Houston Black clay and Victoria clay contain high extractable K levels and should not need added K to maintain ryegrass yields for several years in grazing systems.

Secondary Nutrients

Calcium

The Ca supply to plants is a concern in highly leached, acid, sandy soils such as Ultisols. Inadequate Ca supply is a consideration in soils where excessive levels of other cations such as K^+, sodium (Na^+), or ammonium (NH_4^+) salts have been used, or where Mg in serpentine soils inhibits Ca uptake by plants (Haby et al., 1990). Calcium is primarily supplied as limestone to alleviate actual or potential phytotoxicities of Al^{3+}, iron (Fe^{2+}), manganese (Mn^{2+}), and hydrogen (H^+). Only without toxic amounts of these ions can the need for Ca be determined in soils (Doll & Lucas, 1973). In unlimed soil from the Lilbert series adequately fertilized with N, P, and K in a greenhouse study, Hillard et al. (1993) found that applied Ca decreased ryegrass production at all levels of applied Mg. When this same soil was limed, Ca had no effect on yield at low rates of Mg and decreased ryegrass yields at high rates of Mg and at low rates of P. In a strongly acid soil, Ca should be supplied as limestone. Although it will help remove Al from the soil by leaching, supplying Ca in the form of gypsum, a neutral salt, will not neutralize soil acidity.

The Ca needs of most classes of cattle, except weaned calves on a high rate of gain and superior lactating cows, can be obtained from ryegrass produced on acid soils that have been adequately limed and maintained at a soil pH approaching 6.0 or greater. Hillard et al. (1992) reported Ca levels in ryegrass ranging from 0.40 to 0.69 in the unlimed and limed plots the first year after treatment. By the fourth season, soil pH in the unlimed plots was 4.5 and had declined to pH 4.6 in limed plots. Ryegrass Ca levels were 0.14 and 0.40 for these treatments, respectively. Weaned bull, steer, and heifer calves that weigh more than 700 pounds on a 2 lb/day rate of gain, and mature, lactating cows can obtain adequate dietary levels of Ca from ryegrass growing in properly limed soils (NRC, 1984).

Magnesium

Magnesium is important as a plant nutrient and to prevent hypomagnesemic tetany (grass tetany) in ruminants grazing cool-season grasses such as ryegrass. Grass tetany is most likely to occur with beef cows during initial stages of lactation when grazing forages containing less than 0.2 percent Mg (Underwood, 1966). Supplemental feeding of Mg should be offered when lactating cows are grazing Mg-deficient ryegrass. Magnesium is at its lowest level in ryegrass in late fall and winter (Hillard, 1989). Cherney and Robinson (1985) found that ryegrass exposed to day/night temperatures of 41/32 ^{o}F for two weeks consistently contained less than the critical Mg level of 0.2%, while that grown at 70/55 ^{o}F always contained >0.2% Mg. They indicated that grass tetany potential in ryegrass is higher after cold, wet periods and that young regrowth tissue can increase that potential. Hillard (1989) found that the highest level of Mg in ryegrass limed with a 4% Mg limestone was 0.13%. The highest Mg level in ryegrass grown in unlimed soil was 0.09% the first season after treatment.

Plant uptake of Mg was augmented by increased uptake of P (Fig. 10, Hillard, 1989). Rengel and Robinson (1990) showed that the Mg level in ryegrass was increased by fertilization with magnesium chloride, especially in plants grown in unlimed soil. Aluminum in acidic solutions inhibited uptake of Mg by ryegrass roots (Rengel and Robinson, 1989). Aluminum depressed plant growth more at the high than at the low temperature in solution containing 2.4 ppm Mg but not in solutions of 24.3 ppm Mg (Rengel and Robinson, 1990). Increasing the Al concentration increased the K/Ca+Mg ratio of shoots, thus increasing the grass tetany potential of ryegrass forage. Hillard (1989) found that increasing application rates of limestone that contained 4% Mg lowered the K/Ca+Mg ratio. This ratio was consistently lower in harvests of ryegrass collected later into the production season.

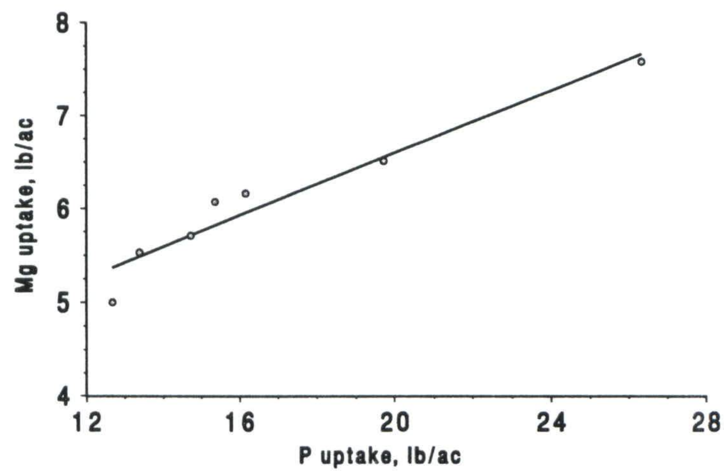

Fig. 10. Correlation of the mean uptake levels of P and Mg in annual ryegrass (cv Marshall) tissue in 1986. (r^2= 0.86)

Nowakowski et al. (1975) reported that Mg increased yield of ryegrass at the third cutting under the high N treatment on a severely Mg deficient Cottenham series sandy loam soil. Response was greater when ammonium sulphate was the N source due to the competitive uptake of NH_4^+ with Mg^{2+}. A significant yield response to Mg was obtained when the ryegrass dry matter contained 0.07% Mg or less, and there were distinct Mg-deficiency symptoms.

In acid soils that are deficient in Mg, application of a high-Mg limestone will temporarily correct this deficiency. Supplemental Mg can be applied to Mg-deficient, limed soils and alkaline soils as the mineral langbeinite (potassium magnesium sulfate, $K_2SO_4 \cdot 2MgSO_4$), magnesium sulfate, or magnesium chloride.

Sulfur

The majority of studies on ryegrass response to sulfur (S) have been conducted on perennial ryegrasses (Gilbert and Robson, 1984, I and II; Gilbert and Robson, 1984, I). These studies involved mixed stands of ryegrass and clover. Their data indicated that increasing the N supply vastly increased the responsiveness of ryegrass to S application by stimulating growth in a S deficient soil. This increased growth decreased S concentration of ryegrass. It is anticipated that annual ryegrass would respond similarly. However, Morris et al. (1994) reported that yield of Marshall ryegrass was not increased by S application, although S content was increased, on a Tangi silt loam (thermic Typic Fragiudult) in a region that averages 62 inches of precipitation annually. This soil had not received fertilizer S since clearing the forest about 45 years earlier.

A soil test of the surface 6 inches of sandy soils for sulfate S is inadequate for determining potential crop response to applied S in a high rainfall region. Sulfate forms of S are mobile in the soil and can be leached as water moves through these soils. In addition, S accumulates in the B-horizon. If the B-Horizon is at a depth accessible by plant roots, annual grasses can obtain S at depths not normally sampled for soil analysis. When this zone of accumulation, or B-horizon is below the rooting depth of annual grasses, these forages are expected to respond to S applied in a readily available form. A more accurate estimation of the potential response of ryegrass to S requires that soil samples be collected for analysis from the normal rooting depth. For annual ryegrass in an unrestricted root environment, this depth may be 12-15 inches. Collect samples by separate 6-inch increments to 18 inches for S and nitrate-N analyses. When the B horizon (zone of clay accumulation) is within this depth, sample it separately from the surface horizons.

Micronutrients

There is little known about response of ryegrass to micronutrients. Search of the Agricola database produced no papers. In general, soil levels of zinc, iron, copper, manganese and boron are known to become more readily available as soil acidity increases. When an acid soil is limed, these plant nutrients become less available to plants. Soil levels of extractable molybdenum increase when soil pH is raised by lime addition. Under conditions where the surface soil has been limed to pH 6.0 or higher, micronutrient deficiencies could be possible. However, the ryegrass plant extends its root system deeper than 6 inches and can extract nutrients from unlimed soils below this depth.

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