

Alternative Nitrogen Fertilizers for Tall Fescue Pastures

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Tall fescue grows on more than 12 million acres and provides forage for more than 4 million beef cattle in Missouri. About one-half of all tall fescue acres receive some nitrogen (N) fertilizer in spring. Most of these applications are made in March or early April. Another time in which tall fescue acres are fertilized with N is in late-summer for autumn stockpiling.

In past years, ammonium nitrate and urea have been the most popular sources of N for spring and late-summer fertilization. Ammonium nitrate is widely considered the “safest” source of N for forage production, particularly for late-summer applications, as the N in ammonium nitrate is much less likely to be lost to volatilization than is urea. However, ammonium nitrate has become a homeland security issue for the fertilizer industry because it can be used as an explosive. Additionally, few new ammonium nitrate plants have been constructed in the United States over the last 20 years, and given the current economic and security climate, domestic production is likely to decline over the next 10 to 20 years. These factors make ammonium nitrate more expensive than other N sources.

Given the pricing structure and potential problems with ammonium nitrate, urea is becoming more widely used as a N source for forage production. This is due to urea’s wider availability and lower cost per N unit when compared to ammonium nitrate. In fact, in many rural parts of Missouri, the only source of N available for pastures is urea. While urea is a common source of N fertilizer for row crop applications in spring, its use for fertilization of pastures is problematic due to excessive nitrogen volatilization. Up to 40% of the N applied to pastures as urea can be lost due to volatilization if rainfall does not occur within 48 hours of an application. Given these problems, farmers are looking for a reliable and inexpensive source of N for pastures.

Some old and new technologies might help alleviate these problems. The most promising solutions are to use a non-volatilizing N source such as ammonium sulfate or to treat urea fertilizer with a volatilization inhibitor. Ammonium sulfate is a sulfur rich (24% S), cost competitive, non-volatilizing source of nitrogen. In addition, several companies have developed products reported to reduce or eliminate volatilization of urea under field conditions. While the technology behind these “urea stabilization products” varies, there has been little “head-to-head” testing under typical field conditions. Technologies that allow safe application of urea would alleviate concerns from farmers and the fertilizer industry, but research is needed to determine which of these products would be most useful for fertilizing pastures in Missouri.

Over the past three years, we have conducted experiments to examine the best alternative to ammonium nitrate fertilizer for spring and late-summer N applications to tall fescue pastures. Specifically, we have compared ammonium nitrate to ammonium sulfate, urea, coated urea products, and mixtures of ammonium sulfate with urea and mixtures of ammonium sulfate with ESN polymer coated urea as a source of nitrogen for tall fescue.

Procedures:

Experiment 1 (Spring applied N treatments).

Treatments: Established tall fescue was fertilized with 75 lb/acre N in mid-March at the Southwest Research and Education Center near Mount Vernon, MO and at the Bradford Research and Extension Center near Columbia, MO. Products were tested in 2005, 2006, and 2007 at Mt. Vernon and in 2006 and 2007 at Columbia. The sources of N are listed in Table 1 and include several urea based products already on the market, mixtures of some of these products, as well as untreated urea, ammonium sulfate, and ammonium nitrate as checks. The 75 lb/acre N rate was selected because it is a common fertilization rate for producers. Soil P and K levels were maintained at levels recommended by the University of Missouri Soil Testing Laboratory.

Experiment 2 (Late-summer applied N treatments).

Treatments: Established tall fescue was fertilized with 75 lb/acre N in mid-August at the same locations (but different plot areas) as described above for Experiment 1. The same sources of N were used as in Experiment 1. Our focus for this experiment was on autumn growth for stockpiling or deferred grazing.

Design: Each treatment in both experiments is replicated five times in a randomized complete block design. Individual plots are 10 ft. x 35 ft.

Measurements. For the spring N application (Experiment 1) forage yield was measured in late May, late July and early October in 2005, 2006, and 2007. For the late-summer application (Experiment 2) yield was measured in late November or early December. Forage yield was determined by clipping a 4-ft. x 25-ft. strip in each plot using a Hege sickle-bar harvester.

At each date, sub-samples of forage harvested from each plot were retained for forage quality analyses {crude protein (CP) and *in vitro* true digestibility (IVTD)}. Samples were dried at 122° F in a forced-air oven before being ground to pass a 1-mm screen. Crude protein and IVTD were measured using near infrared reflectance spectroscopy.

Results:

Experiment 1

Forage Yield. Our data show that only the initial harvest responded to N applied in March. Between 60 and 80% of the annual dry matter was harvested at the initial sampling date in May and few treatment differences were measured in the two subsequent harvests; thus yields are only shown for the initial harvest each year (Table 2). We hypothesized that the “coated urea” products might have yielded greater than uncoated urea products in the summer or autumn after application because of their slow N release activity. But typically, this was not the case.

Ammonium sulfate ranked in the top producing group at nearly all harvests and locations, but only produced more forage than ammonium nitrate in 2007 at Mt. Vernon. Tall fescue fertilized with ammonium sulfate produced over 1000 lb/acre more forage than that fertilized with urea in the spring of 2005 and 2007 at Mt. Vernon. Urea and ammonium nitrate produced equal amounts of forage in every case except that yields from plots fertilized with urea produced about 500 lb/acre less than ammonium nitrate in 2007. In each case precipitation was not recorded for 3 to 6 days after fertilizers were applied in mid-March. Thus, some volatilization of N as ammonia from the urea probably occurred.

Treating urea with Agrotain or using a coated urea product like Nurea or ESN would have theoretically prevented or slowed urea volatilization. These different products however, were not equal. Adding Agrotain to the urea, likely prevented volatilization and thus provided greater yields in the spring of 2007 at Mt. Vernon. However, yields from tall fescue fertilized with untreated urea and those fertilized with Agrotain treated urea were equal at all other times. Forage yields from tall fescue fertilized with Nurea were never different from those fertilized with untreated urea. Fertilizing with ESN polymer coated urea nearly always lead to poorer spring yields than just using untreated urea.

We should note that in Columbia ample precipitation was recorded each year within 5 days of the fertilizer application to get urea into the soil solution. An extended dry period after application may have resulted in more volatilization of urea and thus a comparative advantage for the “coated urea” products.

Thus far, our data show that a spring application of 75 lb/acre N increased yields by an average of 2354 lb/acre over the unfertilized control or about 31 lb of additional forage for each lb of N fertilizer applied. Ground moisture affected this relationship drastically as the range was 1800 to over 3500 lb/acre or 23 to 46 lb of additional forage for each lb of N fertilizer applied.

Forage Quality. When plots were fertilized in March, IVTD was rarely affected by the form of the fertilizer used. Only twice out of 15 harvests (3 harvests per year over 5 site-years) did treatments affect the digestibility of forage. In these two cases, the top ranking group was comprised of one third to one half of the treatments. Further, the unfertilized control showed the greatest IVTD in one of these instances. We ignored these small differences as they are not entirely germane to the research. Harvest month did affect IVTD of forage and the data are presented in Table 3. The general response was that forage harvested in spring was of lower digestibility than the regrowth harvested in summer and autumn.

The response of CP to fertilizer form was affected by year, location, and harvest month; these data are presented by harvest for each location and year. For plots fertilized in March, only the first harvest in May showed treatment effects in the first year (Table 4). There were no residual effects of the treatments on summer or autumn CP levels. The greatest concentration of CP was shared by four treatments that did not differ and had a 25% greater concentration of CP than the unfertilized control. ESN was a component in three of those four treatments and may have provided a constant supply of N longer in the spring to keep CP levels higher than the other treatments. It is noteworthy that all fertilizer forms increased CP concentrations over that of the unfertilized control.

In year, two another location was included in the experiment. Contrary to the first year, there were residual effects of fertilizer treatments on summer and autumn CP concentrations although at times these effects are perplexing to understand (Table 5). At the May harvest, no one treatment contained the highest level of CP at either location, but similar to the first year, treatments that had ESN as a component were in the top ranking group and they contained on average 20% greater CP concentrations than the unfertilized control. Treatments with polymer coatings such as ESN and Nurea were in the top ranking group in autumn at Mt. Vernon. In the summer and autumn at Columbia, the unfertilized control contained the greatest concentration of CP. This may be an artifact of poor forage yields. Fertilizer N was not used for DM production by the plants but instead stored for later use as metabolites.

Year 3 had several similarities to year 2. The treatments with ESN as a component were again in the group with the greatest concentration of CP at both locations in May (Table 6). These groups averaged 12 to 25% higher CP levels than the unfertilized control. At Mt. Vernon, no treatments differed in summer or autumn while at Columbia, the unfertilized control was one of two and eleven treatments with the greatest CP concentration in July and October, respectively.

Soil pH_s. It is well documented that using ammonium sulfate decreases soil pH more rapidly than most other sources of N. Thus we were interested in measuring the change in soil pH as successive applications of these different N sources were applied to the same plots. The final soil pH for each location is shown in Table 7. Only at Mt. Vernon did soil pH respond to the fertilizer treatments where plots fertilized with ammonium sulfate had lower pH than most of the other N sources. However, the magnitude of the response shows that soil pH did not change markedly. For instance, the amount of lime needed to bring the plots fertilized with ammonium sulfate to be equal with the untreated control would be about 50 ENM units which have a value of approximately \$2.00/acre. Soil pH in plots fertilized with urea treated with Agrotain was greater than almost every other treatment. Perhaps the slow release technology of Agrotain provides a microenvironment with a continuous amount of highly alkaline ammonia in the soil solution.

Experiment 2

Forage Yield. For N applied in late-summer, many of the products yielded similarly and in most cases 10 or more of the products or product combinations showed equal yields (Table 4). Urea, ammonium nitrate, and ammonium sulfate had comparable yields in two of four site-years. Tall fescue fertilized with urea yielded 35 and 22% less than that fertilized with ammonium nitrate during the autumn of 2005 at Mt. Vernon and the autumn of 2007 at Columbia, respectively. In both of these years, no rain fell with 5 to 7 days of fertilizer application and only a small amount of rain (less than 0.51 inch) fell within 12 days of fertilizer application. Additionally, temperatures were typically in the upper 80's or low 90's for the two weeks following application. This is a classic example of the risk associated with using urea as the N source for late-summer applications to pasture. Treating urea with Agrotain or using Nurea provided enough protection from volatilization that forage yields were equal to ammonium nitrate in all cases. However, polymer coated urea (ESN) yielded less than most other treatments. The ESN polymer coated urea has not shown much promise as a substitute for urea or ammonium nitrate for spring or late-summer N applications. We have yet to analyze the forage quality or soil fertility of samples collected in the autumn.

Forage Quality. When plots were fertilized in mid-August for autumn growth, the response of IVTD to fertilizer form depended on year and location. In year 1, eleven treatments made up the top group and the four that were not included all contained ammonium sulfate (Table 9). In year two, there were no treatment differences at Mt. Vernon, while at Columbia, seven treatments averaged 77.4% IVTD. This result was 3 percentage units greater than the unfertilized control. In year 3, fertilizer treatments did not affect the digestibility of forage.

Crude protein response depended on year and location also. At Mt. Vernon in year 1, treatments did not affect CP concentration in forage (Table 10). In year 2, ten treatments were included in the top ranking group at Mt. Vernon and had a nearly 25% greater CP concentration than the unfertilized control. At Columbia, the top ranking group was comprised of 4 treatments that all contained ESN

and this group had a nearly 20% higher CP concentration than the control. In year 3, ten treatments comprised the top ranking group and averaged 22% greater CP concentration than the unfertilized control.

Conclusions:

1. Using untreated urea is risky. Fertilizing tall fescue with untreated urea worked as well as ammonium nitrate in 4 of 5 site-years in spring. However, for late-summer applications, untreated urea yielded less than ammonium nitrate about half the time.
2. Urea treated with Agrotain provided growth responses equal to ammonium nitrate.
3. Yield of forage receiving ESN by itself or in mixtures with urea or ammonium sulfate often lagged behind other products.
4. Of the 13 times when crude protein was affected by treatment during experiment 1, ESN either by itself or in mixtures was in the top ranking group.
5. Ammonium sulfate was a consistently good product, with yields equal to or in a few cases, better than those from urea or ammonium nitrate.
6. IVTD was rarely affected by fertilizer form during the spring, summer, and autumn of experiment 1. In experiment two, approximately half of the treatments made up the top ranking group when fertilizer form affected forage digestibility.

Table 1. Nitrogen fertilization treatments tested at the Southwest Research and Education Center near Mount Vernon, MO and the Bradford Research and Extension Center near Columbia, MO. Each source is applied to deliver 75 lb/acre N. In addition, rate mixtures of ammonium sulfate/ESN, ammonium sulfate/urea and urea/ammonium sulfate/ESN are included.

Fertilizer Source	For mixture treatments	
	Rate applied (lb/acre S)	% N derived from ESN and/or Urea
Ammonium nitrate		
Urea	-	-
Ammonium sulfate	-	-
Urea treated with Agrotain	-	-
ESN polymer coated urea	-	-
Nurea	-	-
Nurea with 10% polymer N	-	-
Ammonium sulfate (10S)/urea	10	88
Ammonium sulfate (20S)/urea	20	75
Ammonium sulfate (40S)/urea	40	53
Ammonium sulfate (10S)/ESN	10	88
Ammonium sulfate (20S)/ESN	20	75
Ammonium sulfate (40S)/ESN	40	53
Equal N from urea, ammonium sulfate and ESN	28.6	67
Unfertilized control	-	-

Table 2. Forage yield in late May of tall fescue fertilized with different N sources at the Southwest Research and Education Center near Mount Vernon, MO and the Bradford Research and Extension Center near Columbia, MO. Each fertilizer was applied in mid-March to deliver 75 lb/acre of actual N to the same plots each year. The highest yielding treatment within a year and location is in bold type. Treatments that are not significantly different than the highest yielding treatment are marked with an asterisk.

Fertilizer Source	----- Mt. Vernon -----			--- Columbia ---	
	2005	2006	2007	2006	2007
	-----lbs/acre-----				
Ammonium nitrate	8080	3972*	3647	4601	4826*
Urea	7779	3680*	3139	4037*	4716*
Ammonium sulfate	8832	3987	4183	4407*	4915
Urea treated with Agrotain	8298*	3873*	3787*	4186*	4686*
ESN polymer coated urea	7133	2114	3371	2738	3673
Nurea	8140*	3408*	3400	4195*	4564*
Nurea with 10% polymer N	7366	3624*	3401	3918*	4308
Ammonium sulfate (10S)/urea	7925*	3716*	3577	3899*	4537*
Ammonium sulfate (20S)/urea	7572	3920*	3744	4303*	4397*
Ammonium sulfate (40S)/urea	7809*	3842*	3490	3548	4646*
Ammonium sulfate (10S)/ESN	7042	2285	3599	3375	3872
Ammonium sulfate (20S)/ESN	6674	2610	3670	3149	4104
Ammonium sulfate (40S)/ESN	7611	3493*	3765*	3803	4702*
Equal N from urea, ammonium sulfate and ESN	7498	3236	3829*	3988*	4831*
Unfertilized control	4231	1653	1565	1688	2166
LSD (0.05)	1023	626	420	790	553
<u>Orthogonal Contrasts</u>					
Urea vs. ammonium nitrate	NS	NS	0.009	NS	NS
Urea vs. ammonium sulfate	0.03	NS	<0.001	NS	NS
Ammonium sulfate vs. ammonium nitrate	NS	NS	0.007	NS	NS
Urea vs. urea treated with Agrotain	NS	NS	0.001	NS	NS
Urea vs. Nurea	NS	NS	NS	NS	NS
ESN mixtures vs. urea mixtures	0.02	<0.001	NS	0.02	0.04
Unfertilized control vs. all others	<0.001	<0.001	<0.001	<0.001	<0.001

Table 3. Concentration of IVTD in forage harvested from plots fertilized with different N sources at the Southwest Research and Education Center near Mount Vernon, MO and the Bradford Research and Extension Center near Columbia, MO. Each fertilizer was applied in mid-March to deliver 75 lb/acre of actual N to the same plots each year. Values are means of 15 treatments because treatment effects were not significant. Within a column, values with different letters differ at the 0.05 alpha level.

Year	-----Mt. Vernon-----			-----Columbia-----	
	2005	2006	2007	2006	2007
Harvest month	-----% of DM-----				
May	67.1b	74.4b	71.3b	72.6c	71.9c
July	81.3a	79.6a	78.7a	77.2b	80.8a
October	79.7a	74.6b	71.8b	82.9a	78.9b

Table 4. Concentrations of CP in 2005 of forage harvested from plots fertilized with different N sources at the Southwest Research and Education Center near Mount Vernon, MO and the Bradford Research and Extension Center near Columbia, MO. Each fertilizer was applied in mid-March to deliver 75 lb/acre of actual N to the same plots each year. The treatment with the greatest CP within a column is in bold type. Treatments that are not significantly different than the highest treatment are marked with an asterisk.

Harvest month	-----Mt. Vernon-----		
	May	July	October
Fertilizer Source	-----% of DM-----		
Ammonium nitrate	9.0	9.9	9.9
Urea	9.0	11.1	10.2
Ammonium sulfate	9.5	10.8	11.0
Urea treated with Agrotain	9.4	10.1	9.6
ESN polymer coated urea	10.4	10.0	10.6
Nurea	9.4	9.7	10.2
Nurea with 10% polymer N	8.9	10.5	11.2
Ammonium sulfate (10S)/urea	9.4	10.5	10.6
Ammonium sulfate (20S)/urea	9.7*	10.1	10.5
Ammonium sulfate (40S)/urea	9.4	10.4	11.0
Ammonium sulfate (10S)/ESN	9.9*	10.4	10.3
Ammonium sulfate (20S)/ESN	9.5	10.4	10.7
Ammonium sulfate (40S)/ESN	9.6*	11.2	11.4
Equal N from urea, ammonium sulfate and ESN	9.4	11.4	11.1
Unfertilized control	7.5	11.3	10.7
LSD (0.05)	1.0	NS	NS
<u>Orthogonal Contrasts</u>			
Urea vs. ammonium nitrate	NS	NS	NS
Urea vs. ammonium sulfate	NS	NS	NS
Ammonium sulfate vs. ammonium nitrate	NS	NS	NS
Urea vs. urea treated with Agrotain	NS	NS	NS
Urea vs. Nurea	NS	NS	NS
ESN mixtures vs. urea mixtures	NS	NS	NS
Unfertilized control vs. all others	<0.001	NS	NS

Table 5. Concentration of CP in 2006 of forage harvested from plots fertilized with different N sources at the Southwest Research and Education Center near Mount Vernon, MO and the Bradford Research and Extension Center near Columbia, MO. Each fertilizer was applied in mid-March to deliver 75 lb/acre of actual N to the same plots each year. The treatment with the greatest CP within a column is in bold type. Treatments that are not significantly different than the highest treatment are marked with an asterisk.

Harvest month	-----Mt. Vernon-----			-----Columbia-----		
	May	July	October	May	July	October
Fertilizer Source	-----% of DM-----					
Ammonium nitrate	9.8	10.1	8.6	8.4	9.8	11.5
Urea	9.1	10.5	9.0	8.4	10.6	12.0*
Ammonium sulfate	10.7*	9.4	9.3	9.0	10.5	11.3
Urea treated with Agrotain	9.7	9.8	9.2	8.1	11.3	11.5
ESN polymer coated urea	11.0*	10.0	11.1	11.5	11.4	11.7
Nurea	9.7	9.3	8.9	8.2	11.0	11.6
Nurea with 10% polymer N	10.0	9.8	11.1	8.2	10.7	11.5
Ammonium sulfate (10S)/urea	10.0	10.4	9.3	8.5	10.6	11.7
Ammonium sulfate (20S)/urea	10.3	10.3	9.5	8.1	11.4	12.1*
Ammonium sulfate (40S)/urea	9.7	10.2	9.7	8.3	10.9	11.8
Ammonium sulfate (10S)/ESN	11.2	9.9	11.0*	10.4*	10.7	11.4
Ammonium sulfate (20S)/ESN	11.1*	9.7	10.1*	9.8	11.5	11.6
Ammonium sulfate (40S)/ESN	10.5*	10.0	9.2	9.5	10.1	11.6
Equal N from urea, ammonium sulfate and ESN	11.1*	10.0	10.4*	9.2	9.4	11.8
Unfertilized control	8.7	10.6	9.2	8.7	13.8	12.6
LSD (0.05)	1.0	NS	1.3	1.4	1.7	0.7
<u>Orthogonal Contrasts</u>						
Urea vs. ammonium nitrate	0.001	NS	NS	NS	NS	NS
Urea vs. ammonium sulfate	NS	0.03	NS	NS	NS	0.02
Ammonium sulfate vs. ammonium nitrate	NS	NS	NS	NS	NS	NS
Urea vs. urea treated with Agrotain	NS	NS	NS	NS	NS	NS
Urea vs. Nurea	0.04	0.02	<0.001	NS	NS	NS
ESN mixtures vs. urea mixtures	0.001	NS	NS	<0.001	NS	NS
Unfertilized control vs. all others	<0.001	NS	NS	NS	<0.001	<0.001

Table 6. Concentration of CP in 2007 of forage harvested from plots fertilized with different N sources at the Southwest Research and Education Center near Mount Vernon, MO and the Bradford Research and Extension Center near Columbia, MO. Each fertilizer was applied in mid-March to deliver 75 lb/acre of actual N to the same plots each year. The treatment with the greatest CP within a column is in bold type. Treatments that are not significantly different than the highest treatment are marked with an asterisk.

Harvest month	-----Mt. Vernon-----			-----Columbia-----		
	May	July	October	May	July	October
Fertilizer Source	-----% of DM-----					
Ammonium nitrate	11.4*	10.1	10.7	9.5	11.9	14.9
Urea	10.2	10.2	9.9	9.0	11.8	15.3*
Ammonium sulfate	11.2*	9.5	9.7	10.6	11.9	13.5
Urea treated with Agrotain	11.0*	10.3	10.6	9.2	11.8	15.9*
ESN polymer coated urea	12.2	10.1	10.7	11.9	12.0	15.3*
Nurea	9.5	10.2	10.1	9.7	12.1	15.6*
Nurea with 10% polymer N	10.6	10.4	10.5	8.8	12.9*	14.8
Ammonium sulfate (10S)/urea	10.1	10.1	10.0	9.4	12.4	16.4*
Ammonium sulfate (20S)/urea	10.3	10.5	10.4	9.6	11.8	15.0*
Ammonium sulfate (40S)/urea	10.5	10.0	10.5	9.4	12.1	15.3*
Ammonium sulfate (10S)/ESN	12.0*	10.2	9.6	11.6*	11.5	15.9*
Ammonium sulfate (20S)/ESN	11.7*	10.2	10.4	11.1*	12.1	16.8
Ammonium sulfate (40S)/ESN	11.8*	9.6	9.0	10.2	12.0	16.2*
Equal N from urea, ammonium sulfate and ESN	11.8*	10.1	9.3	10.1	11.8	14.9
Unfertilized control	8.9	10.0	9.4	10.1	13.6	15.5*
LSD (0.05)	1.0	NS	NS	1.0	0.9	1.7
<u>Orthogonal Contrasts</u>						
Urea vs. ammonium nitrate	0.007	NS	NS	NS	NS	NS
Urea vs. ammonium sulfate	0.03	NS	NS	0.001	NS	0.02
Ammonium sulfate vs. ammonium nitrate	NS	NS	NS	0.03	NS	NS
Urea vs. urea treated with Agrotain	NS	NS	NS	NS	NS	NS
Urea vs. Nurea	NS	NS	NS	NS	NS	NS
ESN mixtures vs. urea mixtures	<0.001	NS	NS	<0.001	NS	NS
Unfertilized control vs. all others	<0.001	NS	NS	NS	<0.001	NS

Table 7. Final soil pH of plots treated with different sources of N fertilizer for three (Mt. Vernon) or two (Columbia) successive springs. Each fertilizer source was applied in mid-March to deliver 75 lb/acre of actual N to the same plots each year.

Fertilizer Source	Mt. Vernon	Columbia
	----- pH(s) -----	
Ammonium nitrate	5.92	6.92
Urea	5.86	6.92
Ammonium sulfate	5.62	6.76
Urea treated with Agrotain	6.08	7.16
ESN polymer coated urea	5.92	6.84
Nurea	5.94	6.90
Nurea with 10% polymer N	5.70	6.92
Ammonium sulfate (10S)/urea	5.80	6.94
Ammonium sulfate (20S)/urea	5.92	6.95
Ammonium sulfate (40S)/urea	5.70	6.86
Ammonium sulfate (10S)/ESN	6.04	7.02
Ammonium sulfate (20S)/ESN	5.88	6.92
Ammonium sulfate (40S)/ESN	5.56	6.86
Equal N from urea, ammonium sulfate and ESN	5.38	6.86
Unfertilized control	5.84	6.96
LSD (0.05)	0.33	NS
<u>Orthogonal Contrasts</u>		
Urea vs. ammonium nitrate	NS	NS
Urea vs. ammonium sulfate	NS	NS
Ammonium sulfate vs. ammonium nitrate	0.05	NS
Urea vs. urea treated with Agrotain	NS	NS
Urea vs. Nurea	NS	NS
ESN mixtures vs. urea mixtures	NS	NS
Unfertilized control vs. all others	NS	NS

Table 8. Autumn forage yield of tall fescue fertilized with different N sources at the Southwest Research and Education Center near Mount Vernon, MO and the Bradford Research and Extension Center near Columbia, MO. Each fertilizer was applied in mid-August to deliver 75 lb/acre of actual N to the same plots each year. The treatment with the greatest yield within a column is in bold type. Treatments that are not significantly different than the highest treatment are marked with an asterisk.

Fertilizer Source	---Mt. Vernon---		----Columbia----	
	2005	2006	2006	2007
	-----lb/acre-----			
Ammonium nitrate	1932	1918*	2700*	2483
Urea	1245	2201*	2865*	1935
Ammonium sulfate	1579*	2245*	2787*	2325*
Urea treated with Agrotain	1523*	1880*	2696*	2287*
ESN polymer coated urea	1249	1549	2117	1826
Nurea	1437*	2188*	2738*	2167*
Nurea with 10% polymer N	988	2176*	2725*	2003
Ammonium sulfate (10S)/urea	1696*	2282*	2539*	2041
Ammonium sulfate (20S)/urea	1259	2137*	2877	2018
Ammonium sulfate (40S)/urea	1903*	2327	2763*	2288*
Ammonium sulfate (10S)/ESN	1856*	1664*	2378*	2110*
Ammonium sulfate (20S)/ESN	1741*	2079*	2243	2044
Ammonium sulfate (40S)/ESN	1761*	1882*	2547*	2298*
Equal N from urea, ammonium sulfate and ESN	1822*	2312*	2819*	2212*
Unfertilized control	492	834	1721	1370
LSD (0.05)	582	668	629	430
<u>Orthogonal Contrasts</u>				
Urea vs. ammonium nitrate	0.01	NS	NS	0.01
Urea vs. ammonium sulfate	NS	NS	NS	0.05
Ammonium sulfate vs. ammonium nitrate	NS	NS	NS	NS
Urea vs. urea treated with Agrotain	NS	NS	NS	NS
Urea vs. Nurea	NS	NS	NS	NS
ESN mixtures vs. urea mixtures	NS	0.04	0.05	NS
Unfertilized control vs. all others	<0.001	<0.001	<0.001	<0.001

Table 9. Autumn concentrations of IVTD in forage harvested from plots fertilized with different N sources at the Southwest Research and Education Center near Mount Vernon, MO and the Bradford Research and Extension Center near Columbia, MO. Each fertilizer was applied in mid-August to deliver 75 lb/acre of actual N to the same plots each year. The treatment with the greatest IVTD within a column is in bold type. Treatments that are not significantly different than the highest treatment are marked with an asterisk.

Year	-----Mt. Vernon-----		-----Columbia-----	
	2005	2006	2006	2007
Fertilizer Source				
Ammonium nitrate	83.1*	80.9	76.7*	83.1
Urea	82.7*	77.6	76.8*	82.8
Ammonium sulfate	81.5	77.2	76.9*	81.9
Urea treated with Agrotain	82.5*	78.3	76.0	83.0
ESN polymer coated urea	83.7*	80.2	78.5	83.7
Nurea	83.9*	81.5	75.7	82.4
Nurea with 10% polymer N	84.0	80.1	76.1	82.6
Ammonium sulfate (10S)/urea	80.6	76.7	74.4	83.2
Ammonium sulfate (20S)/urea	83.7*	79.5	76.5	83.2
Ammonium sulfate (40S)/urea	81.9*	78.1	75.5	83.3
Ammonium sulfate (10S)/ESN	82.7*	79.7	77.9*	82.5
Ammonium sulfate (20S)/ESN	81.5	78.5	77.0*	82.4
Ammonium sulfate (40S)/ESN	82.3*	79.0	76.1	82.8
Equal N from urea, ammonium sulfate and ESN	81.1	77.4	77.8*	82.8
Unfertilized control	83.7*	78.1	74.4	79.7
LSD (0.05)	2.5	NS	2.1	NS
<u>Orthogonal Contrasts</u>				
Urea vs. ammonium nitrate	NS	NS	NS	NS
Urea vs. ammonium sulfate	NS	NS	NS	NS
Ammonium sulfate vs. ammonium nitrate	NS	0.03	NS	NS
Urea vs. urea treated with Agrotain	NS	NS	NS	NS
Urea vs. Nurea	NS	0.02	NS	NS
ESN mixtures vs. urea mixtures	NS	NS	0.008	NS
Unfertilized control vs. all others	NS	NS	0.003	<0.001

Table 10. Autumn concentrations of CP in forage harvested from plots fertilized with different N sources at the Southwest Research and Education Center near Mount Vernon, MO and the Bradford Research and Extension Center near Columbia, MO. Each fertilizer was applied in mid-August to deliver 75 lb/acre of actual N to the same plots each year. The treatment with the greatest CP within a column is in bold type. Treatments that are not significantly different than the highest treatment are marked with an asterisk.

Year	-----Mt. Vernon-----		-----Columbia-----	
	2005	2006	2006	2007
Fertilizer Source				
Ammonium nitrate	10.6	13.5	10.2	12.2*
Urea	8.5	11.6*	10.5	11.8*
Ammonium sulfate	10.5	12.2*	10.6	11.7*
Urea treated with Agrotain	9.1	11.8*	10.0	11.4
ESN polymer coated urea	10.3	13.0*	12.5	12.1
Nurea	9.7	12.4*	10.1	11.1
Nurea with 10% polymer N	9.9	12.6*	10.0	11.7*
Ammonium sulfate (10S)/urea	8.5	10.3	10.3	11.3
Ammonium sulfate (20S)/urea	9.8	12.1*	10.4	11.1
Ammonium sulfate (40S)/urea	8.6	11.1	11.2	11.8*
Ammonium sulfate (10S)/ESN	9.3	13.1*	12.1*	12.5
Ammonium sulfate (20S)/ESN	8.4	11.2	12.3*	11.6*
Ammonium sulfate (40S)/ESN	9.5	12.4*	10.8	12.3*
Equal N from urea, ammonium sulfate and ESN	9.0	11.3	11.4*	11.7*
Unfertilized control	8.9	9.3	9.6	9.3
LSD (0.05)	NS	2.4	1.4	1.1
<u>Orthogonal Contrasts</u>				
Urea vs. ammonium nitrate	0.04	NS	NS	0.03
Urea vs. ammonium sulfate	NS	NS	0.001	NS
Ammonium sulfate vs. ammonium nitrate	NS	NS	0.03	NS
Urea vs. urea treated with Agrotain	NS	NS	NS	NS
Urea vs. Nurea	NS	NS	NS	NS
ESN mixtures vs. urea mixtures	NS	NS	<0.001	0.01
Unfertilized control vs. all others	NS	0.001	NS	<0.001