Effect of a Nitrification Inhibitor on the K, Ca, and Mg Composition of Winter Wheat Forage[1]

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ABSTRACT

Winter wheat (*Triticum aestivum* L.) is an important forage for cattle in much of the Southern Great Plains. However, death losses in wheat pastures due to grass tetany of nursing and pregnant older cattle, and frothy bloat of younger cattle, often occur. Forages from fields moderately or heavily fertilized with N are generally more hazardous than forages from unfertilized fields. As regards grass tetany, high rates of N fertilization are particularly hazardous when soil K is high. The objective of the present study was to determine the effect of the nitrification inhibitor nitrapyrin (N-serve) on the relative uptake of K, Ca, and Mg by winter wheat growing in pots in the greenhouse. When nitrapyrin was added, the plants took up less NO^{-3}-N because nitrapyrin inhibited nitrification of the added NH^{+4}. The plants also had lower concentrations of K, Ca, and Mg. However, the depression effect was greater for the divalent cations Ca and Mg, than for the monovalent cation K, so the K/(Ca + Mg) ratio was increased. Therefore, when nitrapyrin was added, the forage was more likely to cause grass tetany. Nitrapyrin also decreased plant organic acid concentrations and this probably decreased Mg and Ca uptake. The concentration of K was higher and Mg and Ca was lower during periods of rapid growth. Therefore, the forage was more likely to cause tetany during these periods. Nitrapyrin was effective in delaying nitrification, and this could be useful for supplying N to wheat later in the growing season. However, other steps might have to be taken to avoid an increased incidence of grass tetany.

Additional index words: **Aconitic acid, Ash alkalinity, Carbohydrates, Grass tetany, Hypomagnesemia, N, Organic acids, *Triticum aestivum* L., N-Serve.**

WINTER wheat (*Triticum aestivum* L.) is an important forage for cattle in much of the Southern Great Plains. The forage is generally of excellent quality and cattle gains are usually quite high, often exceeding 1 kg/day. Hazards can also exist, however. Grass tetany and frothy bloat are frequently observed among cattle grazing wheat pasture. Death losses of 1% are common, and losses of 5% or greater are observed in some years.

Wheat forage from fields moderately or heavily fertilized with N is generally more hazardous than forage from unfertilized fields (2, 3, 4, 5, 8, 12, 16, 17). One reason is that when soil K is high, the K concentration of wheat forage is increased very significantly by N fertilization, while there is little or no effect on the Ca and Mg concentrations (3, 4). This results in an increase in the equivalent K/(Ca + Mg) ratio in the forage. Wheat pastures having greater than 2.2 may cause grass tetany (6, 7). Ratios of 4 or greater are often found in N fertilized wheat forage (17).

Wilcox and Huff (23) proposed that NH^{+4} is the predominant source of N available for uptake by grasses in the spring. They suggest that the absorption of NH^{+4} would result in greatly reduced uptake of Mg and Ca by plants, and would have little effect on the uptake of K.

Cox and Reisenauer (1) carried out flowing culture solution experiments with wheat, using a constant level of NO^{-3}-N, and three rates of NH^{+4}-N. The NH^{+4}-N decreased the concentrations of Mg and Ca in the plants, with little effect on the K concentrations. They postulated that plants grown with the NH^{+4}-N source would have lower concentrations of organic acids, and that this should preferentially decrease the concentrations of divalent cations, as compared to monovalent cations.

Lamond and Murphy (10) studied the effect of N source and nitrapyrin on concentrations of K, Ca, and Mg in wheat and tall fescue. Additions of N resulted

[1] Contribution from USDA, SEA, AR, in cooperation with the Texas Agric. Exp. Stn., Texas A&M Univ., College Station, TX 77843. Received 17 Feb. 1981.

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in higher concentrations of K, Ca, and Mg in the plants, especially at the early sampling dates. Plots receiving NH_3 plus nitrapyrin generally had the lowest concentrations of K, Ca and Mg. There was less effect of the form of N on K/(Ca + Mg) milliequivalent ratios, but NH_3 plus nitrapyrin generally gave the highest ratios.

Applying a nitrification inhibitor will result in higher concentrations of ammonium in the soil and cause wheat plants to take up more N as ammonium. We hypothesized that this would result in a lower concentration of cations which could affect the K/(Ca + Mg) equivalent ratio. Therefore, the objective of this study was to determine the effect of nitrapyrin [2-chloro-6-(trichloromethyl) pyridine] on the K, Ca, and Mg concentrations in wheat forage.

MATERIALS AND METHODS

A greenhouse study was initiated using Pullman clay loam (fine, mixed, thermic Torrertic Paleustolls) which is a predominant soil in the Southern High Plains. Table 1 shows selected data for the soil and a complete description is given by Mathers et al. (11). The pots were filled with 12 kg of air dry soil which was sampled from the 0 to 15-cm depth. Treatments included a check, 75, 150, and 225 ppm N as either NH_4NO_3, $(NH_4)_2SO_4$, or urea. The $(NH_4)_2SO_4$ and urea were added alone or in combination with nitrapyrin at the rate of 1 mg for each 50 mg N. Treatments were replicated three times for a total of 48 pots which were weighed periodically and watered to 25% (W/W). The fertilizer and nitrapyrin (N-serve[3]) were added in solution. Pots were filled with three increments of soil and water or fertilizer solution. Each increment contained 4 kg of soil to which 1 liter of water or fertilizer solution was added. This way we expected to get a rather uniform distribution of fertilizer and nitrapyrin throughout the pot.

Fifteen seeds of 'Tascosa' winter wheat were planted in each pot on 26 Sept. 1977. After emergence, the stand was thinned to six plants/pot. Forage was harvested six times; 32, 53, 80, 102, 144, and 189 days after planting. The forage was oven dried at 65 C, ground, and analyzed for N, K, Ca, Mg, P, NO^{-3}-N, trans-aconitic acid, and ash alkalinity. Samples were digested with sulfuric acid and hydrogen peroxide in a block digestor (19) and analyzed for N and P by the Technicon[3] Auto Analyzer Industrial Method No. 334-74W/B+ revised March 1977. Potassium, Ca, and Mg concentrations were determined on the same digest by absorption spectrophotometry. Nitrate N was determined on the Auto Analyzer (9). Ash alkalinity was determined after ignition of a sample at 550 C for 2 hours (22). Aconitate was determined by polarography (15).

RESULTS AND DISCUSSION

The total yield and uptake of N, K, Mg, Ca, P, and aconitate for the six clippings are presented in Table 2. The yields were not affected by N source or nitrapyrin. The average yields for the urea, $(NH_4)_2SO_4$, and NH_4NO_3 treatments were 46.0, 45.8, and 47.7 g/pot, respectively. Treatments with nitrapyrin yielded 44.1 g/pot, as compared to 45.9 for the same treatments without nitrapyrin. Nitrapyrin did not have a large effect on N uptake, although for the $(NH_4)_2SO_4$ treatments there was generally slightly less N uptake from the nitrapyrin treated soils. There was less uptake of K, Mg, and Ca from nitrapyrin treated soils with the exception of K uptake from the urea treated soils which showed no difference. No consistent effect of nitrapyrin on P uptake was observed, except that P values (Fig. 1j) tended to be lower in the early cuttings from nitrapyrin treatments.

The effect of nitrapyrin was much greater when the N source was $(NH_4)_2SO_4$ than when the N was added as urea (Table 2). This was particularly true for K uptake and for all cation uptake values at the lower N levels. The reason for this difference is believed to be due to the manner in which the fertilizer and nitrapyrin were added. Since the soil was added to pots in lots of 4 kg followed by 1 liter of fertilizer and

[3] Mention of a trade name does not constitute a recommendation for use by the USDA.

Table 1. Chemical and physical properties of Pullman clay loam.

Depth	Ammonium acetate extractable Na	K	Ca	Mg	CEC†	
cm	meq/100 g					
0–12	0.16	1.28	9.0	2.7	18.4	
12–23	0.33	1.15	13.7	3.5	19.6	
	pH	O.M.‡	Sand	Silt	Clay	Texture
		%				
0–12	6.5	1.58	39.2	31.6	29.2	Clay loam
12–23	6.5	1.29	31.6	29.6	38.8	Clay loam

† Cation exchange capacity.
‡ Organic matter.

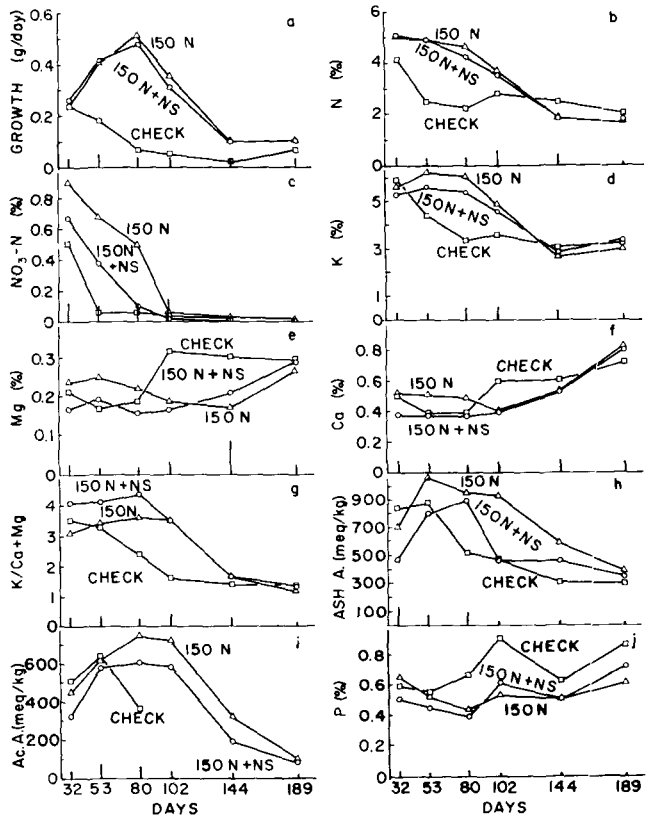

Fig. 1. Growth and composition of wheat forage grown in the greenhouse with and without nitrapyrin (NS) treatments using $(NH_4)_2SO_4$ as the N source. Growth rate was calculated on an 18-day period allowing 14 days after planting for emergence. There was insufficient plant material from the check treatment for aconitic acid analysis after the third harvest. Length of marks on the base line of the graphs indicate the L.S.D. for points above it.

Table 2. Total yield and nutrient uptake from six cuttings of wheat forage.

Treatment†	Yield	N	K	Mg	Ca	P	Ac.A.‡
	g	uptake (mg)					
Check	15.4	440	660	36	80	105	–
75U	30.4	1,080	1,560	69	148	174	860
76U+	31.7	1,130	1,580	68	147	206	830
150U	42.6	1,650	2,150	95	227	199	1,390
150U+	43.0	1,650	2,220	91	204	225	1,280
225U	65.1	2,160	2,640	144	303	268	1,780
225U+	58.4	2,210	2,710	110	244	249	1,670
75AS	28.5	1,050	1,430	64	149	161	–
75AS+	27.2	980	1,300	57	129	153	–
150AS	43.5	1,730	2,230	97	226	228	1,460
150AS+	41.7	1,600	1,980	78	181	209	1,120
225AS	65.2	2,360	2,910	135	304	325	1,790
225AS+	62.6	2,180	2,610	110	259	280	1,390
75AN	30.0	1,100	1,550	66	150	179	–
150AN	44.2	1,740	2,340	99	226	234	1,450
225AN	69.0	2,420	3,070	163	329	336	1,910
L.S.D.	2.8	68	96	17	14	16	83

† U = UREA; AS = Ammonium Sulfate; AN = Ammonium Nitrate; + = Added Nitrapyrin; 75, 150, 225 = ppm N.
‡ Aconitic Acid.

Table 3. Concentration of NO_3-N in forage.

Treatment†	1st Cutting	2nd Cutting	3rd Cutting	4th Cutting
	NO_3-N (%)			
Check	0.50	0.05	0.05	0.02
75U	0.91	0.70	0.03	0.04
75U+	0.84	0.59	0.01	0.03
150U	0.95	0.73	0.51	0.18
150U+	0.91	0.72	0.42	0.02
225U	0.89	0.77	0.69	0.62
225U+	0.79	0.63	0.58	0.32
75AS	0.95	0.71	0.04	0.03
75AS+	0.78	0.34	0.01	0.02
150AS	0.89	0.67	0.49	0.05
150AS+	0.66	0.37	0.09	0.01
225AS	0.90	0.77	0.66	0.58
225AS+	0.66	0.51	0.37	0.46
75AN	0.96	0.77	0.03	0.04
150AN	0.87	0.74	0.52	0.04
225AN	0.94	0.83	0.70	0.57
L.S.D.	0.13	0.11	0.12	0.14

† U = UREA; AS = Ammonium Sulfate; AN = Ammonium Nitrate; + = Added Nitrapyrin; 75, 150, 225 = ppm N.

nitrapyrin solution, we believe that this resulted in more separation of the nitrapyrin from urea than from the $(NH_4)_2SO_4$. Since the ammonium and nitrapyrin would move less distance in the soil than urea as reported by Touchton et al. (20, 21), the nitrification of urea was probably inhibited to a lesser extent than the $(NH_4)_2SO_4$. The NO^{-3}-N concentrations in the forage for the various clippings are shown in Table 3 and support this view. The NO^{-3}-N concentrations in the forage from the nitrapyrine-treated pots receiving $(NH_4)_2SO_4$ were substantially less than when nitrapyrin was not added. When urea was the source of N, there was a much smaller effect of the nitrapyrin and the NO^{-3}-N concentrations in the forage were similar to those found when the N source was NH_4NO_3. Values are not shown for the fifth and sixth clippings because no measurable concentrations of NO^{-3}-N were present in any of the treatments.

Since the effect of nitrapyrin was limited for the urea treated pots, the principal presentation of results and discussion will deal only with the $(NH_4)_2SO_4$ treatment. Also, since the trends were similar for all N rates, only the data for the 150-ppm level will be presented and discussed in detail. Figure 1 is a composite that presents the growth and concentration of various elements and constituents as a function of time. Data points are the times of harvest.

Growth Rates. The growth rates were calculated by dividing the yield for each harvest by the number of days contributing to the harvest. For the first harvest, we subtracted 14 days from the total number of days (planting to forage harvest) because there was practically no top growth during this period of seed germination and seedling emergence. Thus, the first growth rate (Fig. 1a) is based on 18 days after emergence instead of the 32 days from planting to forage harvest. The rate of growth was the same whether or not nitrapyrin was added (Fig. 1a). The growth rate increased during the first three croppings and then decreased at a significant rate. The growth rate of the check treatment declined from the start because of insufficient N.

N Concentration. The N concentration of the forage was quite high during the early growth periods when N was adequate (Fig. 1b). There was no significant effect of nitrapyrin. Since growth rates and N concentrations were similar in forages produced with and without nitrapyrin, we can use the plant composition data to study the effects of nitrapyrin on uptake of other constituents.

Nitrate Concentration. Applied N increased the NO^{-3}-N concentration in the forage. When nitrapyrin was added with the N, NO^{-3}-N concentrations in the forage were much lower than on similar N treatments without nitrapyrin (Fig. 1c). This indicates that the nitrapyrin slowed the rate of NH^{+4} nitrification. Therefore, the plants on nitrapyrin treatments absorbed a higher percentage of their N requirement as NH^{+4} than those not receiving nitrapyrin. Nitrogen became limiting following the third harvest and there was no appreciable NO^{-3}-N in the forage in subsequent forage samples.

K, Mg, and Ca Concentration. The K concentrations were exceedingly high in the forage harvested early (Fig. 1d). There was a close relationship between the K concentration and the rate of growth. The K concentrations were high when growth rates were high, and they declined sharply as growth rates slowed significantly. There was also an effect of the nitrapyrin. The nitrapyrin treatments produced forage that was lower in K concentration. This is believed to be the result of the plants taking up more of their N as NH^{+4}, which would tend to compete with K uptake.

The Mg and Ca concentrations (Fig. 1e and 1f) were also significantly affected by nitrapyrin. The effect on these cations was even greater than the effect on K. Total K, Mg, and Ca uptake in six harvests from the nitrapyrin treatments were 88, 80, and 80%, respectively, as compared to the treatments not receiving nitrapyrin. The Ca and Mg concentrations, however, responded to growth rates in an entirely different manner than K concentrations. The Mg and Ca concentrations increased markedly as growth rates decreased. This is opposite to K concentration changes

described earlier.

Our findings agree with the hypotheses presented by Wilcox and Hoff (23). They proposed that absorption of NH^{+4} would reduce Ca and Mg uptake but would have little competitive effect on the uptake of K. We showed some depression of K uptake, but a substantially larger effect on Mg and Ca. Our data also agree with the postulations of Cox and Reisenauer (1) in that the Mg and Ca concentrations were lower for the nitrapyrin treatment. As will be indicated later, the nitrapyrin also decreased organic acid concentrations, which Cox and Reisenauer (1) believed should preferentially decrease the concentrations of divalent cations, as compared to monovalent cations.

K/(Ca + Mg) Equivalent Ratio. The K/(Ca + Mg) meq ratios are shown in Fig. 1g. The nitrapyrin treatment had ratios of four or greater during the early growth periods as compared to three or greater for the treatments without nitrapyrin. This resulted because the nitrapyrin depressed Ca and Mg uptake more than K uptake. A ratio of 2.2 is considered hazardous and the expected incidence of tetany increases as the ratio increases. The forage produced in nitrapyrin treated soil would be more likely to induce grass tetany than forage produced on soil without nitrapyrin. The K/(Ca + Mg) ratios dropped dramatically during later harvests and showed a close relationship to the growth rates (compare Fig. 1a and 1g). The sharp drop was due to a decrease in K and increases in Ca and Mg concentrations.

Ash Alkalinity and Aconitate Concentrations. Ash alkalinity has been found to be closely related to organic acid concentrations, as measured by the concentrations of cations minus anions (14, 22). In the present study, the dominant organic acid is aconitic. (Compare Fig. 1h and 1i.) Previous studies (13, 17, 18) have shown that organic acid concentrations closely follow K concentrations. This was the case in the present study. Nitrapyrin decreased organic acid concentrations, which no doubt was due largely to a decrease in K concentration. The organic acids were decreased more in the later cuttings than can be accounted for by decreased K concentrations.

P Concentrations. The P concentrations were highest in the check treatment, and this is undoubtedly due to the much lower growth rates (Fig. 1j). When nitrapyrin was added, the P concentrations tended to be lower during the early growth period.

CONCLUSIONS

The use of nitrapyrin with N fertilizers produced forage that was more likely to cause grass tetany than forage produced when fertilizer N was added alone. Nitrapyrin apparently slowed the nitrification of added NH^{+4} and caused the wheat plants to take up more N in the form of NH^{+4}. This depressed the uptake of cations, but the depression effect was greater for the divalent cations, Ca^{++} and Mg^{++}, than for the monovalent cation K^{+}. This led to an increase in the meq K/(Ca + Mg) ratio which is often used as an indicator of the grass tetany potential of forage.

The potential for forage to cause tetany was also closely related to the growth rate of the wheat plants. During rapid growth, the K concentration was high but it decreased as the growth rate decreased. Concentrations of Ca and Mg were lowest during rapid growth and then increased as growth rates decreased. The decrease in K and the increases in Ca and Mg resulted in a very sharp decline in the K/(Ca + Mg) ratios as the growth rate declined. This corresponds to findings under field conditions that showed the K/(Ca + Mg) ratios were generally highest in early fall and spring when growing conditions for winter wheat is generally the most favorable. Although nitrapyrin tended to make the forage slightly less desirable from the standpoint of K/(Ca + Mg) ratios, it did precisely what it was developed for i.e., delay nitrification. The evidence presented here, however, suggests that nitrapyrin should not be used for the primary purpose of making wheat forage less likely to cause grass tetany.

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