S-Triazine Herbicides Combined with Nitrogen Fertilizer for Increasing Protein on Shortgrass Range

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Highlight: *Three s-triazine herbicides (atrazine, simazine, and cyanazine) applied annually at 1.1 and 3.4 kg/ha to shortgrass range in northcentral Colorado, consistently increased protein concentration in range herbage for 3 years, 1970–72. Overall, herbage yields were not affected. Spring applications were slightly more effective than fall applications. Atrazine and simazine were about equally effective. However, herbage treated with simazine retained protein better into fall and winter than that treated with atrazine. Cyanazine was the least effective. Increases in protein from the three herbicides were additive to increases from N fertilizer applied at 22 and 45 kg N/ha, except in a drought year. During drought, 3.4 kg of atrazine or simazine combined with 45 kg N reduced herbage yields and yields of protein. The most practical treatment was a combination of 1.1 kg simazine and 22 Kg N/ha. Averaged over 3 years, this combination increased protein concentration 43% and yield of protein 35% in September.*

Over the past 20 years, *s*-triazine herbicides have been used effectively for weed control in a variety of crops, especially corn. The *s*-triazines control most annual grasses and many broadleaf weeds. Many of the *s*-triazines also increase N content of plants. Because protein concentration of range forage is often below nutrient requirements of cattle in the fall and winter months, increased concentration may increase livestock production.

Furtick (1958) was among the first to report increased protein concentration of forage crops by herbicide applications. De Vries (1963) found that simazine (2-chloro-4, 6-bis(ethylamino)-*s* triazine) significantly increased N uptake by corn. Ries et al. (1968) reported increased N concentration and fresh weight of several forage grasses and legumes. Ries (1968) and Ries et al. (1968) suggested that species tolerant to simazine showed increased N only at high rates of application; whereas the N concentration of susceptible species was increased only by low rates of simazine, especially under conditions of suboptimal temperature and soil N.

Allinson and Peters (1970) found that simazine increased protein concentration of several tolerant forage species without decreasing dry matter yields, but susceptible species showed the greatest increases. Over all species tested, the greatest increases in protein concentration were accompanied by the greatest decreases in yield. Eastin and Davis (1967) reported that 1.1 kg/ha of atrazine (2-chloro-4-ethylamino-6-isopropylamino-*s* triazine) increased total-N and nitrate-N concentration of several tropical field crops, but also decreased yields whether the species were tolerant or resistant to atrazine and whether in the field, soil, culture, or nutrient solution. They also pointed out the general inverse relationship between increased N concentration of plants and reduced yields. Kay (1971) found both increased plant protein and herbage yield of intermediate wheatgrass (*Agropyron intermedium* (Host) Beauv.) from atrazine over a period of 4 years. However, the increase in yield accompanied a considerable decrease in annual grasses. Houston and van der Sluijs (1973) found that annual applications of 3.4 kg/ha of atrazine in combination with 45 kg N/ha, applied in May or June, increased protein yield on rangeland during the summer an average of 142 to 148%. Their work was conducted on the same range site as the present study.

The mechanism by which triazine compounds influence plant protein, nitrate-N, and yield are not well understood. It is known that many physiological processes in the plant are altered by triazines. Differential metabolism of triazines appears to govern the susceptibility of the plant. This differentiation is related to ability of the plant to degrade the phytotoxic parent molecule (Shimabukuro, 1967). Also involved are the rates of absorption, translocation, and accumulation of the compounds (Sheets, 1961).

Triazine-treated plants have shown increased total-N and nitrate-N and increased nitrate reductase activity (Ries et al., 1967). Increased nitrate reductase activity is usually associated with increased protein formation and decreased nitrate-N (Hageman et al., 1961). Because reduction of nitrate depends on photosynthesis and respiration (Salisbury and Ross, 1969), which are inhibited by triazine accumulation (Smith and Buchholtz, 1962),

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the triazines appear to affect a great many plant reactions.

The present study compares the effects of atrazine, simazine, and cyanazine (2-(4-chloro-6-ethylamino-*s*-triazine-2-ylamino)-2-methylpropionitrile) combined with N fertilizer on protein yield, and nitrate-N concentration of shortgrass range in northcentral Colorado. The three *s*-triazine herbicides differ not only in chemical structure, but also in solubility. Cyanazine is the most soluble (water solubility 171 ppm), atrazine is intermediate (solubility 70 ppm), and simazine is the least soluble (5 ppm).

Experimental Area and Methods

The study was conducted at the U.S. Department of Agriculture Central Plains Experimental Range located 20 km northeast of Nunn, Colorado. The soil is Ascalon sandy loam. The long-time average annual precipitation is 31 cm (12.2 inches), with 73% occurring from May through September.

The vegetation is typical of short-grass range. Blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.) is the dominant species. Other important species are plains pricklypear (*Opuntia polyacantha* Haw.), scarlet globe-mallow (*Sphaeralcea coccinea* (Pursh) Rydb.), red threeawn (*Aristida longiseta* Steud.), sand dropseed (*Sporobolus cryptandrus* (Torr.) A. Gray), woody buckwheat (*Eriogonum effusum* Nutt.), and sun sedge (*Carex heliophylla* Mack.).

The three *s*-triazine herbicides were each applied at 0, 1.1, and 3.4 kg active ingredient/ha in factorial combination with ammonium nitrate fertilizer at rates of 0, 22, and 45 kg N/ha. The herbicides were applied as an 80% wettable powder in aqueous solution containing 0.15% of nonionic surfactant at a volume of 187 liters/ha (20 gallons/acre) with a compressed air sprayer. The fertilizer was broadcast on the surface in pellet form.

All treatment combinations were replicated four times in May 1970 and repeated on the same plots in 1971 and 1972. Fall treatments were applied on a separate block of plots in November 1970 and repeated on the same plots in 1971. Plot size was 4.6 m by 15.2 m (15 ft × 50 ft).

Total herbage was harvested at ground level in June, July, August, and September each year. Herbage samples were oven dried at 55°C, weighed, and ground through a 1-mm screen. Total-N concentrations were determined by standard Kjeldahl procedure. Nitrate-N concentrations were determined by the xylenol method (Sabatka et al., 1972) for all spring-applied treatments harvested in June and July 1972.

Table 1. Monthly precipitation (cm) for the cropyears (September through August) of 1969, 1970, 1971, and 1972, cropyear totals, and 34-year mean at Central Plains Experimental Range, Nunn, Colorado.

	Month												Crop-year
Year	S	O	N	D	J	F	M	A	M	J	J	A	Total
1969	1.0	2.4	1.7	0.5	0.3	0.7	0.6	4.0	5.7	11.8	4.4	3.5	36.8
1970	3.1	7.1	0.3	T	0.1	0.1	3.3	3.4	2.1	2.9	4.0	0.6	27.0
1971	3.8	2.9	0.4	0.6	1.1	0.8	2.3	7.2	4.2	3.1	1.5	0.6	28.5
1972	5.4	0.4	0.1	T	0.9	T	1.0	1.5	3.1	8.3	4.5	9.7	34.9
34-Year mean[1]	2.6	2.0	0.7	0.4	0.7	0.6	1.5	2.6	5.5	6.2	4.7	3.8	31.3

[1] 1939–1972.

Precipitation was above average in the summer and fall of 1969 before the first spring treatment and below average in the spring and summer of 1970 (Table 1). Precipitation was near average in the first three quarters of the cropyear of 1971. Summer moisture was below average. Precipitation in the cropyear of 1972 was essentially the reverse of 1971. Moisture was below average in the fall, winter, and spring, and above average in the summer.

Results

Since spring applications produced similar to slightly greater increases in protein concentration and protein yield than fall applications, the following discussion of treatment responses is limited to the spring applications.

Triazine Effects

All three herbicides significantly increased protein concentrations in range herbage during the summer for the 3 years of study (Table 2). Cyanazine was the least effective of the three triazine herbicides. It increased average protein concentration 14%. Atrazine was the most effective. It increased average protein 21%.

The 3.4-kg/ha rate of all compounds produced significantly higher concentrations of protein than the 1.1-kg rate—an increase of 24% as compared with 10%. The single most effective herbicide treatment for increasing protein was 3.4 kg/ha of atrazine. This treatment increased protein concentration an average of 29% over the 3 years.

Protein concentrations of herbage were highest in June and steadily decreased during the summer, reaching lowest levels in September (Table 2). The interaction between herbicide treatments and months of harvest was significant. At the June harvest, protein concentrations were significantly greater for atrazine than for simazine or

Table 2. Crude protein concentrations (%), herbage yields (kg/ha), and yields of crude protein (kg/ha), 1970–72. Herbicides were applied in May each year on the same plots.

Measurement, herbicide,[1] and rate (kg/ha)	Month of harvest				Average
	June	July	Aug.	Sept.	
Crude protein (%)					
Control	11.9 e[2]	9.9 j	9.4 k	8.9 l	10.0 e
C 1.1	13.1 d	10.3 ij	9.9 j	9.3 kl	10.6 d
S 1.1	13.1 d	10.9 fgh	10.3 ij	10.0 j	11.1 c
A 1.1	13.8 c	11.2 fg	10.6 hi	10.1 j	11.4 c
C 3.4	15.1 b	12.1 e	10.9 fgh	10.3 ij	12.1 b
S 3.4	14.7 b	12.1 e	11.3 f	11.0 fgh	12.3 b
A 3.4	15.8 a	13.0 d	11.8 e	10.8 gh	12.9 a
Average	13.9 a	11.4 b	10.6 c	10.1 d	
Herbage yield (kg/ha)					
Average	490 b	520 a	465 c	470 bc	
Protein yield (kg/ha)					
Average	62.6 a	57.6 a	48.3 b	44.8 b	

[1] C-cyanazine, S-simazine, and A-atrazine.
[2] Interaction means or row or column averages followed by the same letter are not significantly different at the 5% level.

cyanazine. However, protein concentrations decreased more slowly with simazine during the summer than that with cyanazine and atrazine. By September, protein concentrations were greatest for simazine and atrazine and least for cyanazine.

The triazine compounds alone did not affect average herbage yields or protein yields. Herbage yields increased from June to July and then decreased, whereas protein yields steadily decreased from June through September (Table 2).

In June 1972, after three annually repeated applications, the 1.1-kg rate of atrazine and the 3.4-kg rate of all three triazine compounds temporarily increased nitrate-N significantly above the untreated control (Table 3). The low rate of atrazine nearly doubled the concentration of nitrate-N. The high rate of all three triazines increased nitrate-N more than 200%. By July 1972, none of the triazines had any effect on nitrate-N. These concentrations of nitrate-N reveal an improvement in the nitrogen status of plants (Hylton et al., 1970) without creating the hazard of nitrate poisoning for cattle.

Table 3. Nitrate-N concentrations (ppm) of herbage in June and July, 1972. Herbicides were applied in May of 1970, 1971, and 1972 on the same plots.

Herbicide[1] and rate (kg/ha)	Date of harvest	
	June 1972	July 1972
Control	170 cde[2]	60 e
C 1.1	200 bcd	80 de
S 1.1	290 bc	50 e
A 1.1	300 b	100 de
C 3.4	480 a	100 de
S 3.4	440 a	100 de
A 3.4	480 a	80 de

[1] C-cyanazine, S-simazine, and A-atrazine.
[2] Interaction means followed by the same letter are not significantly different at the 5% level.

Effective precipitation decreased during the course of the study, culminating in a severe drought in 1972. This influenced protein concentrations, herbage yields, and protein yields. Average protein concentrations increased significantly each year of the study. Protein concentrations averaged over all herbicide treatments and months of harvest were 9.0, 10.6, and 14.9%, respectively, in 1970, 1971, and 1972. Average herbage yields decreased significantly from 625 kg/ha in 1970, to 460 in 1971, and 375 in 1972. Average yield of protein was about the same in 1970 and 1972, 56 and 55 kg/ha respectively, but significantly less in 1971, 49 kg/ha.

Table 4. Herbage yields (kg/ha) and yields of crude protein (kg/ha) in 1972. Herbicides were applied in May of 1970, 1971, and 1972 on the same plots.

Measurement, herbicide,[1] and rate (kg/ha)	Month of harvest			
	June	July	Aug.	Sept.
Herbage yield (kg/ha)				
Control	360	395	390	360
C 1.1	340	465	415	350
S 1.1	330	480	415	385
A 1.1	330	435	410	360
C 3.4	290	380	395	380
S 3.4	285	380	395	315
A 3.4	260	410	400	320
Average	315 b[2]	420 a	405 a	355 b
Protein yield (kg/ha)				
Control	63.2	51.0	47.0	37.2
C 1.1	63.8	59.9	51.9	37.8
S 1.1	63.9	66.8	55.8	44.1
A 1.1	67.4	62.3	55.0	40.6
C 3.4	62.1	57.9	52.5	44.8
S 3.4	62.1	74.7	56.7	40.2
A 3.4	57.2	67.0	58.4	40.6
Average	62.8 a	62.8 a	53.9 b	40.7 c

[1] C-cyanazine, S-simazine, and A-atrazine.
[2] Row averages followed by the same letter are not significantly different at the 5% level.

Herbage yields were reduced in June 1972 by the 3.4-kg rate of application of all three herbicides, and protein yields were reduced by the high rate of atrazine (Table 4). Herbage yields were reduced also in September by the high rate of both simazine and atrazine, and in June 1971. The low rate of simazine and the high rate of cyanazine produced the highest herbage and protein yields in 1972.

Nitrogen Fertilizer Effects

Nitrogen fertilizer alone increased protein concentrations, herbage yields, protein yields, and nitrate-N concentration (Table 5). Increases were in direct proportion to the amounts of N applied. The 22 kg N/ha increased average protein concentration 17%, and the 45 kg N/ha increased it 25%. The 22- and 45-kg rates of N increased average herbage yields 14 and 18%; yields of protein 30 and 44%; and nitrate-N concentration in June 1972 by 106 and 150%, respectively. The

Table 5. Crude protein concentrations (%), herbage yields (kg/ha), yields of crude protein (kg/ha), and nitrate-N concentrations (ppm), 1970–72. N was applied in May each year on the same plots.

Measurement and nitrogen rate (kg/ha)	Month of harvest				
	June	July	Aug.	Sept.	Avg
Crude protein (%)					
0	12.3	10.0	9.2	8.7	10.1 c[1]
22	14.3	11.6	10.8	10.4	11.8 b
45	15.2	12.5	11.7	11.1	12.6 a
Herbage yield (kg/ha)					
0	450	470	415	435	440 b
22	505	520	475	485	495 a
45	525	560	510	495	520 a
Protein yield (kg/ha)					
0	50.9	46.4	37.5	35.7	42.6 c
22	65.9	58.7	50.3	47.4	55.6 b
45	71.0	67.8	57.1	51.5	61.9 a
Nitrate-N (ppm)[2]					
0					180 c
22					370 b
45					450 a

[1] Column averages followed by the same letter are not significantly different at the 5% level.
[2] Nitrate-N concentrations shown are for June 1972 harvest.

Table 6. Herbage yields (kg/ha) and yields of crude protein (kg/ha) in 1972. N was applied in May of 1970, 1971, and 1972 on the same plots.

Measurement and nitrogen rate (kg/ha)	Month of harvest			
	June	July	Aug.	Sept.
Herbage yield (kg/ha)				
0	290	400	380	340
22	340	440	420	370
45	305	465	410	345
Protein yield (kg/ha)				
0	52.1	51.2	44.7	33.4
22	71.3	66.1	57.7	45.2
45	65.1	71.2	59.3	43.6

increases in nitrate-N concentration were temporary. In July 1972, N fertilizer had no effect on concentration of nitrate-N.

Herbage yields were reduced in the drought year of 1972 by 45 kg N/ha to levels below those produced by 22 kg N/ha in 3 of the 4 months of harvest (Table 6). Protein yields were reduced similarly in the first and last months of harvest.

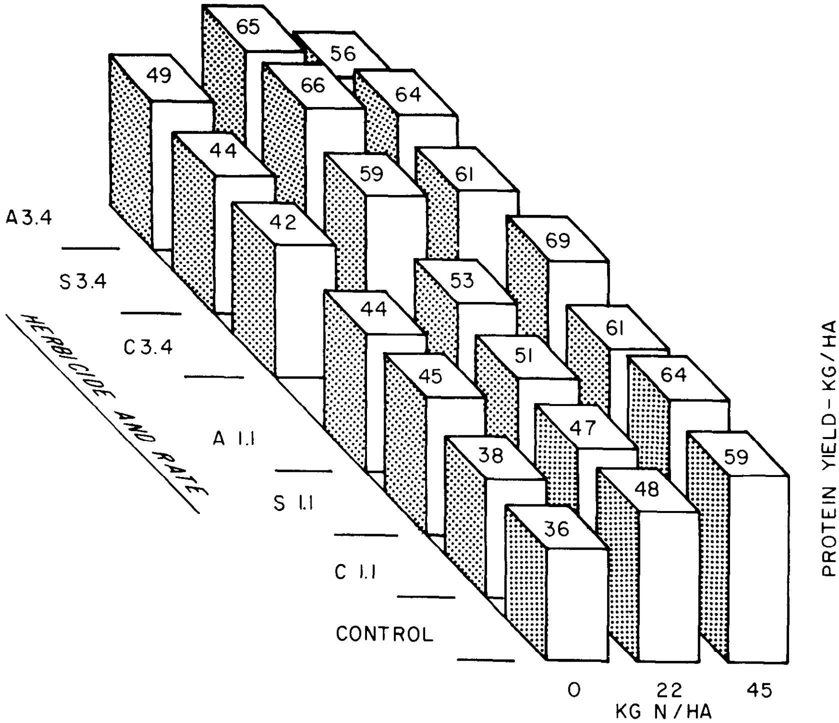

Fig. 1. *Average protein yields of herbicide and nitrogen fertilizer combinations, 1970–7 Treatments were applied in the spring each year on the same plots.*

Combination Effects

The interaction between herbicide treatments and rates of N was not significant during 1970 and 1971 for either protein concentrations, herbage yields, protein yields, or nitrate-N concentrations. Therefore, the individual effects of the herbicide and N treatments were essentially additive.

However, in 1972, several interaction effects of herbicide and N combinations were significant. In 1972, most herbicide treatments increased protein concentrations about the same with or without N fertilizer. The 3.4-kg/ha rate of atrazine increased protein concentrations most in the absence of N, and progressively less as the rate of fertilizer increased. Average herbage yields decreased 10 to 20% with 3.4 kg/ha of all three herbicides when combined with 45 kg N/ha. Atrazine caused the largest decrease.

The combined effects of herbicide and N treatments on protein yields over the 3 years are shown in Figure 1. The highest average yield of protein was produced by 1.1 kg/ha of atrazine and 45 kg N/ha. This combination treatment increased protein yields 92% over the untreated control, 57% over atrazine alone, and 17% over N alone. The combination treatment of 3.4 kg of atrazine and 45 kg N reduced protein yield below that produced by the N alone.

Discussion and Conclusions

Two of the three triazine herbicides studied, atrazine and simazine, consistently increased crude protein concentration of range herbage. Both of these herbicides were more effective than cyanazine.

The triazine herbicides produced the greatest increases in protein concentration at the first harvest after application. The increases became progressively smaller during July and August, but remained nearly constant from August to September.

Atrazine was more effective than simazine during the early part of the growing season. However, atrazine lost its effectiveness more rapidly during the growing season than did simazine. By the last harvest of the growing season, the effects of atrazine and simazine were about equal.

Increased protein concentration of herbage during the early part of the summer is probably of little value for livestock. Increased protein concentration in September and into the winter is more valuable because this is when the protein concentration usually falls below minimum requirements. The slower decrease in protein concentration during the summer and fall and higher protein yield in September suggest that simazine would provide the mos protein during the time of greates need.

The reduction in herbage yields i June 1971 and 1972 and Septembe 1972 from 3.4 kg of simazine wer undesirable because of decrease grazing capacity. Other dat (unpublished) show that rates of 1.7 t 2.2 kg AI/ha of atrazine decreas cool-season grasses on this range Simazine similarly affects plan composition. In view of this, the 1.1-k rate of simazine is more desirable tha the 3.4 kg rate.

The N fertilizer also increase protein concentrations, increased yield of protein, and equally important, als increased herbage yields. The N effect were additive to the effects of th triazine herbicides for increasin protein concentrations and yields.

The reduction in herbage yields fro the high rate of fertilizer in the drough year of 1972 was undesirabl Decreased stands of several specie (unpublished data) accompanied th reductions in yields. Since fertilize applied at 22 kg N/ha increased herbag and protein yields in all year fertilization should be restricted to th lower rate.

Increases in nitrate-N concentratio of range forage from applications c triazine herbicides and from N fertilizer were not of practical significance for livestock production. The highest level of nitrate-N found during the study was 600 ppm in June 1972, after 3 years of repeated applications. This concentration of nitrate-N was considerably less than the 2,000 ppm concentration considered toxic to livestock (Bradley et al., 1940).

The most effective combinations of treatments for increasing protein concentration of herbage during the study were either 3.4 kg atrazine or 3.4 kg simazine with 45 kg N. These combination treatments increased protein concentrations an average of 60%, but also reduced herbage and protein yields during drought. The treatment producing the greatest average increases in herbage and protein yield was the combination of 1.1 kg atrazine and 45 kg N. This combination treatment increased overall herbage yield an average of 30% and protein yield an average of 90%, which is somewhat less than the increase in protein yield of 126% previously reported for the same combination treatment on the same range site (Houston and van der Sluijs, 1973).

The most practical treatment for increasing protein concentrations, herbage yields, and protein yields for fall and winter use with least risk of depressing herbage and protein yields during drought years is the combination of 1.1 kg of simazine and 22 kg N/ha. In September 1972, probably the most critical month during the study for severe drought effects, this treatment combination increased protein concentration 54%, had no effect on herbage yield, and increased production of protein 48%. This treatment combination should be further evaluated in grazing studies.

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