Atrazine and Simazine Increase Yield and Quality of Range Forage[1]

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Abstract. Application of 2-chloro-4-(ethylamino)-6-(isopropylamino)-*s*-triazine (atrazine) to intermediate wheatgrass *(Agropyron intermedium* (Host) Beauv.) increased forage yields, plant protein, and nitrate over a 4-year period. Atrazine or 2-chloro-4,6-bis(ethylamino)-*s*-triazine (simazine) applied to a sward of red brome *(Bromus rubens* L.), Arabian grass *(Schismus arabicus* Nees.), and red-stem filaree *(Erodium cicutarium* (L.) L'Her.) increased dry-matter yields sixfold and also increased protein and nitrate nitrogen. Nitrate in plants treated with atrazine increased to near-toxic levels for livestock.

Introduction

GROWTH and protein concentration have been increased in many crops by applying sub-herbicidal rates of the triazines — 2-chloro-4-(ethylamino)-6-(isopropylamino)-*s*-triazine (atrazine) and 2-chloro-4,6-bis-(ethylamino)-*s*-triazine (simazine). These crops include ryegrass *(Lolium perenne* L.), alfalfa *(Medicago sativa* L.), dry beans *(Phaseolus vulgaris* L.), rice *(Oryza sativa* L.), oats *(Avena sativa* L.), corn *(Zea mays* L.), wheat *(Triticum aestivum* L.), and rye *(Secale cereale* L.) (6, 7). Protein in seedling rye plants increased as much as 79%.

The mechanism by which simazine and atrazine effect an increase is not fully understood. It has been shown, however, that nitrate level and nitrate reductase activity in plants increased within a few hours of simazine application (7). Nitrate reductase activity was up to eight times as great in treated plants as in control plants.

Both atrazine and simazine appear to be potential agents for chemical fallow, and for weed control in both new and established range seedings (2,3,5). The present study was done to determine whether these compounds might also increase total forage production and protein concentration on rangeland.

Methods

Yield, protein, and nitrate concentration increased after triazines were applied in two separate studies in different geographic areas of California.

The first study was near the town of Likely, in the extreme northeast corner of the state. Mean annual precipitation is about 10.5 inches. Annual precipitation in the 4 years reported was 12.23, 8.16, 9.20, and 8.36 inches. The elevation is 4,760 ft. Big sagebrush *(Artemisia tridentata* Nutt.) grew on the site before it was burned in 1957, and seeded to Greenar intermediate wheatgrass *(Agropyron intermedium* (Host) Beauv.) in 1958.

To remove the downy brome *(Bromus tectorum* L.) in Greenar intermediate wheatgrass, atrazine at 1 lb/A was sprayed annually in the middle of October to one-half of each treatment in a fertilizer trial. Ammonium nitrate at 80 lb/A nitrogen was applied immediately after the atrazine. Wheatgrass yields and the protein and nitrate contents of the wheatgrass plants were measured during flowering in each growing season from 1967 through 1970. Yields were measured by clipping the wheatgrass to 2 inches at flowering, from an area of 9 sq ft in each treatment. The entire sample was oven-dried, ground, and a single subsample was drawn for laboratory measurements. Protein was determined by the "Improved Kjeldahl method for nitrate-free samples method 2.036" (1), and nitrate was determined by the phenoldisulfonic acid method (1, 4).

The second study was in the Temblor Range near Fellows, California. This is in the interior coast range at the southern end of the San Joaquin Valley. Mean annual rainfall is about 8 inches, and the elevation is 2,500 ft. Rainfall was 6.58 inches in the fallow year and 12.45 inches in the year samples were taken. The vegetation is red brome *(Bromus rubens* L.), Arabian grass *(Schismus arabicus* Nees.), and red-stem filaree *(Erodium cicutarium* (L.) L'Her.). Atrazine and simazine were applied at 1 and 2 lb/A on November 9, 1967, as a fallow treatment (2). Increases in yield, protein, and nitrate of the resident vegetation were measured at the end of the second growing season following herbicide application (May 12, 1969), after the triazines were no longer present at herbicidal levels. The vegetation was clipped to ground level from an area of 4 sq ft in each treatment and oven-dried. The sample was ground, and a single subsample was drawn for laboratory use.

Filaree seeds were collected from the check plot and from the 2-lb/A atrazine treatment at the end of the second growing season, and were stored 10 months at room temperature. The seeds then were weighed and planted in flats in the greenhouse to check on the possible effects on seedling vigor of the increased protein and nitrate in the seeds. When the seedlings were 32 days old, they were dug, washed, and dried; the length of roots and tops was measured, and the entire seedling was weighed.

Both studies involved four replications in a split-plot design. Results were evaluated by analysis of variance and Duncan's multiple-range test.

Results

Mean wheatgrass yields were nearly doubled by nitrogen alone, and nearly quadrupled with nitrogen plus atrazine. The addition of atrazine to nitrogen did not further increase yields over nitrogen alone in 1968 (a very dry spring (Table 1). The unfertilized treatments were not affected by the atrazine in any year. Control of downy brome was 100% in all atrazine treatments. Downy brome production in 1968 was essentially zero in any treatment because of the dry spring.

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Table 1. Effects of fertilizer nitrogen (N) and 1 lb/A atrazine on yield and quality of wheatgrass.[a]

Treatment	1967	1968	1969	1970	Mean
			Dry forage yield (lb/A)		
Check	870 a	350 a	600 a	430 ab	560 a
Check + Atrazine	620 a	470 ab	830 ab	200 a	530 a
N_{80}	1200 ab	720 c	1310 bc	660 bc	970 b
N_{80} + Atrazine	2450 b	670 bc	2690 c	1940 d	1940 c
			Protein (%)		
Check	4.6 a	8.2 a	6.6 a	7.7 a	6.8 a
Check + Atrazine	5.8 a	12.9 b	10.1 b	17.5 b	11.6 b
N_{80}	9.6 b	14.7 c	13.6 c	16.2 b	13.5 c
N_{80} + Atrazine	9.6 b	16.9 d	12.2 c	15.7 b	13.6 c
			Nitrate (ppm)		
Check	100 a	0 a	100 a	30 a	60 a
Check + Atrazine	80 a	60 ab	270 a	760 c	290 ab
N_{80}	470 ab	570 b	320 a	170 ab	380 b
N_{80} + Atrazine	800 b	1130 c	830 b	670 bc	860 c

[a]Values are means of four replications. Means followed by the same letter within columns are not significantly different at the .05 probability level as determined by Duncan's multiple-range test.

The mean protein levels averaged over 4 years were increased by either nitrogen or atrazine (Table 1). Increases were greater from nitrogen than from atrazine. Nitrogen plus atrazine did not further increase protein over those with nitrogen alone except in the dry spring of 1968.

The mean nitrate levels averaged over 4 years were increased by nitrogen but not significantly by atrazine alone. Addition of atrazine to nitrogen, however, increased nitrate above that with nitrogen alone.

In the Temblor Range experiment, forage yields were increased sixfold by atrazine at 1 lb/A but were only doubled by simazine at the same rate (Table 2). Doubling the simazine rate produced further increases, but doubling the atrazine rate reduced yields to half those induced by the lower rate.

Protein was increased significantly only by 1 lb/A atrazine (Table 2). Nitrate nitrogen was increased by atrazine at both 1 and 2 lb/A. Total protein per acre was increased by all treatments, but most effectively by 1 lb/A atrazine.

Table 2. Effect of triazine herbicides on yield and nitrogen concentration of range forage.[a]

Herbicide	Rate	Dry forage yield	Protein		Nitrate
	(lb/A)	(lb/A)	(%)	(lb/A)	(ppm)
Check	1	1,360 a	8.7 a	120 a	10 a
Simazine	1	3,260 ab	9.3 a	300 b	640 ab
Simazine	2	5,270 b	8.5 a	450 c	240 a
Atrazine	1	8,880 c	12.9 b	1,140 d	1180 bc
Atrazine	2	4,590 ab	11.1 ab	510 c	2060 c

[a]Means followed by the same letter are not significantly different at the .05 probability level as determined by Duncan's multiple-range test.

Filaree seeds collected from plots treated with atrazine at 2 lb/A (0.0072 oz/100 seeds) were significantly heavier than seeds from the check (0.0062 oz/100 seeds). Top length, root length, and total seedling weight were all greater with seedlings from seeds produced by atrazine-treated plants (Table 3). The increase in seedling size was not apparent until after the plants were 2 weeks old.

Discussion

A portion of the increases in yield of wheatgrass must be attributed to the complete control of downy brome.

Table 3. Response of filaree seedlings grown from seed produced on soil treated with atrazine at 2 lb/A.[a]

	Seedling length			Seedling weight
	Top	Root	Total	
		(in)		(oz)
Check	1.14 a	2.28 a	3.42 a	0.00088 a
Atrazine	1.50 b	3.46 b	4.69 b	0.00159 b

[a]Means followed by the same letter are not significantly different at the 0.1 probability level as determined by Duncan's multiple-range test.

Even so, the lack of competition from downy brome does not explain the increases in protein and nitrate, except possibly that more nitrate was available in the soil.

Species composition in the second experiment was shifted to filaree from predominantly grass (red brome and Arabian grass). These grasses root only to a depth of 18 to 24 inches, whereas filaree roots to a maximum depth of 30 to 36 inches. In the unusually wet year (1969) the extra rooting depth probably contributed greatly to forage increases. However, depth of rooting does not account for the large increases in total dry matter from 1,360 lb/A on the check to 8,880 lb/A on the 1-lb/A atrazine treatment. By contrast, in an adjacent fertilizer trial with filaree and grass, forage yield from plots receiving 80 lb/A nitrogen was 4,000 lb/A.

Nitrate concentrations in the second experiment approached the critical level for livestock poisoning—2078 ppm (9) as a result of atrazine treatment at 2 lb/A.

The increase in size and weight of filaree seedlings grown from seeds produced on plants treated with atrazine might have resulted from the larger seed size. However, Schweizer and Ries (8) reported an increase in weight of oats seedlings from seeds grown on simazine-treated plants, although seed weight was the same as weight of seeds from untreated control plants. Also, the differences in seedling size or weight did not appear until 14 days after planting in both this study and that of Schweizer and Ries (8). If the increase in seedling size was due to the larger seed, it should have been apparent immediately after germination.

Atrazine and simazine at sub-herbicidal levels show potential for increasing the quantity and quality of range forage at low cost. However, increased levels of nitrate are a potential hazard to livestock.

Acknowledgments

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Response of Weeds and Soybeans to Vernolate and Other Herbicides[1]

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Abstract. Vernolate (*S*-propyl dipropylthiocarbamate) injected into a sandy loam soil controlled a higher percentage of early weeds in soybeans *(Glycine max* (L.) Merr.) in 2 years out of 3 when compared with incorporated vernolate at the same rate by conventional methods. Late season weed control was enhanced by split applications of herbicides applied postemergence in sequence with vernolate. Chloroxuron (3-[*p*-(*p*-chlorophenoxy)phenyl]-1,1-dimethylurea) applied early postemergence plus 3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea (linuron) or 2,4-bis-(isopropylamino)-6-(methylthio)-*s*-triazine (prometryne) applied in split applications as late and layby treatments gave the best weed control. Prometryne caused chlorotic veination in the upper leaves of the plants each year. In 1970, when prometryne was applied in sequence with incorporated vernolate, soybean plants were injured 30% compared with only 8% injury when the same herbicide was applied in sequence with injected vernolate at the same rate. The average seed yields were higher from injected vernolate at 1.12 kg/ha than from incorporated vernolate at 2.24 kg/ha. There was no difference in yield when vernolate was incorporated or injected at the same rate. Seed yields from the 3-year average were lower from plots treated with prometryne than from plots treated with linuron or 2-*sec*-butyl-4,6-dinitrophenol (dinoseb). Generally, the soybean seed quality was lower and seed size smaller when herbicide treatments failed to control weeds throughout the growing season.

Introduction

Chemical control of sicklepod *(Cassia obtusifolia* L.), tall morningglory *(Ipomea purpurea* (L.) Roth), and ivyleaf morningglory *(I. hederacea* (L.) Jacq.) in soybeans *(Glycine max* (L.) Merr.) is difficult. No single herbicide treatment will adequately control these weed species throughout the growing season. In the sandy Coastal Plain of Georgia, *S*-propyl dipropylthiocarbamate (vernolate) controlled yellow nutsedge *(Cyperus esculentus* L.) better when injected into the soil than when incorporated by conventional methods (5, 6). EPTC (*S*-ethyl dipropylthiocarbamate) applied as a subsurface treatment in Mississippi resulted in better weed control than when applied to the surface and rotary hoed (8). Yellow nutsedge, sicklepod, and Texas millet *(Panicum texanum* Buckl.) were affected more by EPTC, vernolate, and *S*-propyl butylethylthiocarbamate (pebulate), when applied at a depth of 3.8 cm than when applied at 1.9 cm (4). Studies on soybeans in Mississippi[3] and South Carolina (7) showed that broadleaf weed control from preplant treatment with vernolate plus postemergence treatment of 3-[*p*(*p*-chlorophenoxy)phenyl]-1,1-dimethylurea (chloroxuron) was better than when either herbicide was applied alone.

The objectives of this investigation were to compare subsurface application of vernolate with conventional surface incorporation and to determine the effects of vernolate plus other herbicides applied postemergence on the control of weeds, on crop tolerance, and on other agronomic characteristics of soybeans.

Materials and Methods

Field experiments were conducted from 1968 to 1970 on a Cecil sandy loam with an organic-matter content of approximately 1.9%. Hill soybeans were planted 3 cm deep on May 3, 1968, April 30, 1969, and May 1, 1970. Vernolate treatments were (a) 2.24 kg/ha applied to the soil surface and incorporated, (b) 2.24 kg/ha injected, and (c) 1.12 kg/ha injected. An untreated check also was included. Vernolate was incorporated with a power-driven rotary tiller into the top 5 cm of the soil on April 19, 1968, April 28, 1969, and April 30, 1970, and injected 5 to 8 cm deep on the day of planting with knife-injector blades spaced 7.6 cm apart (5). The herbicide treatments applied postemergence in 1968 were (a) untreated check, (b) chloroxuron at 1.68 kg/ha, (c) 3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea (linuron) at 1.12 kg/ha, (d) 2-*sec*-butyl-4,6-dinitrophenol (dinoseb) at 2.52 kg/ha, and (e) 2,4-bis(isopropylamino)-6-(methylthio)-*s*-triazine (prometryne) at 2.24 kg/ha. Plots that received the postemergence treatments in 1968 were cultivated May 28, and herbicides were applied as directed postemergence sprays on June 10. Chloroxuron was applied at 1.12 kg/ha as an early postemergence to all plots, except the untreated check, on May 21, 1969 and May 18, 1970. Linuron at 0.56 kg/ha, dinoseb at 1.68 kg/ha, and prometryne at

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