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Effect of a Weevil, *Rhinocyllus conicus*, on Musk Thistle (*Carduus thoermeri*) Seed Production[1]

MELVIN K. MCCARTY and WILLIAM O. LAMP[2]

Abstract. **Three musk thistle (*Carduus thoermeri* Weinm.) sites that were infested with a weevil (*Rhinocyllus conicus* Froel.) and a fourth non-infested site were evaluated for numbers of insects and seeds per seed head. At four successive weekly intervals, seed heads were sampled just after flowering. Initial sampling was in 1978 and was repeated in 1979. Weevil incidence in heads blooming during the first week was 6.7/head in 1978 and 28.0 in 1979. At infested sites, production of fully developed seeds averaged 28% less than at the non-infested site in 1978 and 78% less in 1979. Heads that were in bloom during the fourth sampling week had an infestation rate less than one weevil/head in both years. Fully developed seeds germinated well (96 to 99%) and were not affected by date of bloom. Because many heads bloomed during the third and fourth weeks, a large number of viable seeds were still produced at infested sites.**

Additional index words. **Carduus nutans L., seed production.**

INTRODUCTION

Musk thistle (*Carduus thoermeri* Weinm.)[3] is a serious weed over much of the United States (1). It is primarily a biennial or winter annual, but may under some circumstances act as an annual (5, 6). It is solely dependent on seed for propagation and thus is vulnerable to any organism that interferes with seed production. Studies in Europe (14) revealed that a number of insects were capable of affecting musk thistle seed production. A head weevil (*Rhinocyllus conicus* Froel., Coleoptera: Curculionidae) was selected for introduction into Canada and the United States for biological control of *Carduus* species (2, 3, 4, 10). By feeding on receptacle tissue, its larvae prevent development of some or all of the seeds within a head (14).

Considerable work has been done on describing seed production, seed quality, viability, and germination of musk thistle under natural conditions and as influenced by mowing or herbicide treatment (7, 9). Recent studies have been reported concerning the effect of *R. conicus* on seed production and thistle stand reduction (11, 13). These studies did not, however, compare thistle seed production at *R. conicus*-infested and non-infested sites.

In 1978 and 1979, we monitored musk thistle seed production at four locations that had various levels of weevil infestation. Certain plant characteristics, as well as weevil populations, seed production, and seed characteristics are reported.

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[2]Res. Agron., U.S. Dep. Agric., Agric. Res. Serv., Lincoln, NE 68583 and Res. Assoc., Illinois Natural History Survey, 607 E. Peabody, Champaign, IL 61820.

[3]This plant has been called *C. nutans* L. Recent taxonomic treatments from Eurasia treat *C. nutans* as a group of closely-related but distinct species. Experimental data suggest some biological validity to this concept. Personal consultation with S.M.A. Kazmi, Peshawar, Pakistan (Revision der Gattung Carduus, Teil II, Mitt. Bot. Munchen, Band V, p. 279–550, 1964) supports this view. On this basis, the materials under study in this paper are called *Carduus thoermeri* Weinm. (cf. J. do Amaral Franco *in* T. G. Tutin et al., *Flora Europaea* 4:222–223, 1976).

MATERIALS AND METHODS

Study sites. Four sites were selected for evaluation in central Nebraska (Valley and Greeley Counties) during 1978 and 1979. Weevils infested musk thistles at three of the sites: Holmes (pasture near Arcadia and site of the first established weevil population in Nebraska in 1972), Homestead (an abandoned homestead site about 4 km southeast of Holmes where weevils were found in 1975), and Natural Resources District or NRD (a 1975 release site about 16 km northeast of Holmes). The fourth site, Scotia, located about 36 km southeast of the other sites, had no weevil population and served as a reference for seed production and viability.

Thistle development. Development of the thistles at the four sites was monitored during late May and June so that sampling of seed heads could begin shortly after first flowering. In addition, head development was followed for 25 labeled plants at the NRD site in 1979. Weekly observations of the stage of head development and location on the plant were recorded.

Seed production and weevil populations. Twenty-five seed heads were sampled at each site weekly for 4 weeks (the majority of the period of bloom). Each head was bagged at the early postbloom stage. A muslin bag with a heavy drawstring closure was used, based on previous experience. The postbloom stage insured that florets were normally pollinated. Heads were selected randomly from the thistle population, and generally heads came from different plants. Bagged heads were harvested after 2 weeks to allow seeds to mature on the plant.

The individual heads were dissected and the following data were obtained: receptacle diameter, number of weevil pupation chambers, and seed yield. The seeds were graded into four size classes using a seed blower[4] and counted. Gummy seeds were rinsed in carbon tetrachloride before being graded. Seeds not so rinsed were saved for germination tests in a 5 C low-humidity chamber. Because of the difficulty in removing non-viable, shriveled seeds from weevil pupation chambers, seeds in the smallest size class were only counted from the Scotia site.

Seed production and weevil densities were statistically compared between sites and week of bloom by analysis of variance for each year, and Duncan's multiple range test separated significant differences.

Seed characteristics. Seed germination was tested in a germinator at alternating 25 C and 15 C temperatures for the 14-h light and 10-h dark periods, respectively. Samples for test consisted of petri dishes with 25 seeds each on filter paper moistened with a 0.01% sodium hypochlorite-distilled water solution. Each seed sample was weighed before the test. Germinated seeds were counted after 7 to 10 days.

Two sets of germination tests were done for both the 1978 and 1979 seeds. First, 16 samples of each seed size class for each year were tested to determine differences among size classes. Each sample consisted of seeds from each site and week of bloom. Second, two samples of seed size class IV (fully developed) from each of five heads from each of the 16 site and week-of-bloom categories were tested for differences among sites and weeks.

Seed characteristics were statistically compared between sites and week-of-bloom by analysis of variance for each year, and Duncan's multiple range test was used to separate significant differences.

[4]South Dakota Seed Blower, model B. Manufactured by B. L. Erickson Products, Brookings, SD. (Tradename, cited for identification of implement used, is not necessarily endorsed by the U.S. Dep. Agric. over similar products.).

Table 1. Receptacle diameter of musk thistle heads during the period of bloom from four sites in central Nebraska. Each number is an average of 25 heads.

Year	Site	Receptacle diameter on sample date[a]				
		6/21	6/28	7/5	7/12	$\bar{X}$
		(mm)				
1978	Scotia	26	24a	20b	20a	22
	Holmes	25	20c	19c	18b	20
	Homestead	26	23b	22a	17b	22
	NRD	26	23ab	20b	19a	22
	$\bar{X}$	26	23	20	19	22
		6/26	7/3	7/10	7/17	$\bar{X}$
1979	Scotia	29a	25a	22	19a	24
	Holmes	28a	24a	21	19a	23
	Homestead	25b	22b	23	19a	22
	NRD	24b	19c	21	15b	20
	$\bar{X}$	27	23	22	18	22

[a]Means within columns and years followed by the same letters are not significantly different ($P<0.05$, Duncan's multiple range test).

RESULTS AND DISCUSSION

Thistle development. Growth of musk thistle was fairly

Table 2. Number and location of musk thistle heads on plants reaching full bloom during each week of the blooming period. Figures are totals from 25 plants at the NRD site during 1979. A similar pattern was noted at other sites and during 1978.

Location on plant	Heads in bloom				
	6/20–6/26	6/27–7/3	7/4–7/10	7/11–7/17	Total
	(no./25 plants)				
Terminal of main stem	21	3	0	0	24
Terminal of upper three branches	7	48	19	0	74
Terminal of lower branches	0	10	35	21	66
Axillary on branches	0	1	53	46	100
Total	28	62	107	67	264

uniform at the four widely separated sites. Date of first bloom and rate of development were essentially the same (data not shown). Receptacle diameters, a measure of potential seed production, were similar among sites with two notable exceptions (Table 1). In 1978, the Holmes site produced significantly smaller seed heads than the Scotia site on three of the sample dates. In 1979, the NRD site produced significantly smaller heads than did the Scotia site on three of the sample dates. Although not always significant, the Scotia site usually produced the largest heads, and thus was expected to produce the most seeds. At this site, total seed production (viable and non-viable) averaged 656 and 629 seeds/head during 1978 and 1979, respectively.

The terminal head of the main stem on each plant was the first to bloom (Table 2). Terminal heads on the upper three branches were the most common heads in bloom during the second week of bloom. Axillary heads on the branches, the most numerous of all head locations, were dominant during the third and fourth weeks of bloom. Although receptacle diameters, and thus potential seed production per head, decreased with sample date (Table 1), the majority of heads were blooming during the third week. Thus, these heads, located primarily on terminals of lower branches or axillaries of branches, were the major source of seed production. Very few heads bloomed after 4 weeks during both 1978 and 1979. The hot, dry weather in central Nebraska was responsible because thistles rapidly reached senescence during mid-July. By comparison, thistles in more mesic eastern Nebraska continue flowering until mid-August (8).

Weevil populations. R. conicus infested seed heads at all sites except the Scotia site (Table 3). At Holmes, the initial establishment site in 1972, heads generally had more weevils than at the other sites. Weevils were first observed at the Homestead site in 1975, arriving there by dispersal from the nearby Holmes site. The NRD site was a release site in 1975.

Table 3. Number of weevil pupation chambers in the musk thistle heads that had bloomed just before the sampling dates indicated from four sites in central Nebraska. Each number is an average of 25 heads.

Year	Site	Weevils/head on sample date[a]				
		6/21	6/28	7/5	7/12	$\bar{X}$
		(no./head)				
1978	Scotia	0.0a	0.0a	0.0a	0.0a	0.0
	Holmes	8.3c	1.8c	0.2a	0.5b	2.7
	Homestead	5.3b	0.9b	0.1a	0.1a	1.6
	NRD	6.6bc	2.2c	0.9b	0.2a	2.5
	$\bar{X}$ of 3 infested sites	6.7	1.6	0.4	0.3	2.3
		6/26	7/3	7/10	7/17	$\bar{X}$
1979	Scotia	0.0a	0.0a	0.0a	0.0a	0.0
	Holmes	44.0d	16.0b	6.0c	1.8b	16.9
	Homestead	29.4c	16.6b	7.4c	1.6b	13.8
	NRD	10.5b	2.0a	2.2b	0.4a	3.8
	$\bar{X}$ of 3 infested sites	28.0	11.5	5.2	0.2	11.5

[a]Means within columns and years followed by the same letters are not significantly different ($P<0.05$, Duncan's multiple range test).

In 1978, heads sampled the first week of bloom averaged 6.7 weevils at infested sites, but later blooming heads averaged only 0.3 to 1.6 weevils (Table 3). This ovipositional preference by *R. conicus* for early blooming heads has been documented (12). A marked increase occurred in 1979, with the Holmes, Homestead, and NRD sites averaging population densities 6.3, 8.6, and 1.5 times the level of 1978, respectively. This increase was especially great during the second and third week of bloom, suggesting that the adult weevils were increasing their proportion of oviposition onto later blooming heads. The population growth at the NRD site was much lower than at the other sites, probably because this site was a more recent release site than Holmes.

Seed production. The seeds harvested from each head were processed with a seed-blower into four size classes, I to IV (Table 4). Size class I consisted of seeds having chaffy, shrunken seed coats, which were not viable. Size class II seeds were nearly normal in appearance, but were flat and smaller in dimension. Germination rate was 2%. Size class III seeds were better filled and the germination rate averaged 38%. Size class IV seeds consisted of plump, well-filled seeds, which had a germination rate of >95%. Over a period of years we have used the class IV seeds for experimental and propagation uses (9).

Viable-seed production was estimated by summing for all size classes the germination rate multiplied by the number of seeds per head in each size class. The estimate of viable seeds in size classes I to III was only 1.8% or less of the total estimate of viable seeds. Because counts of size class IV seeds dominated the estimates of viable seeds, we used these counts for statistical comparisons.

There was a relatively small reduction in number of well-developed seeds harvested in 1978 from the three infested sites as compared to the Scotia site (Table 5). Only the Holmes site produced significantly fewer seeds than did the Scotia site throughout the period of bloom. The average production of seeds per head at the Scotia site was 482, and the average of the three infested sites was 346, or about 28% fewer seeds. The heads collected during the first week of bloom usually produced the most seeds, as a result of their larger size (Table 1).

Table 4. Characteristics of musk thistle seed size classes as separated by a seed blower[a].

Seed blower setting[b]	Air velocity[c]	Seed size class	Weight/seed	Germ. rate
(%)	(ft/min)		(mg ± 1 S.D.)	(%)
20	500	I	0.51 ± 0.03	0
25	575	II	1.23 ± 0.25	2
30	650	III	1.97 ± 0.33	38
30	650	IV[d]	3.23 ± 0.32	96

[a]South Dakota Seed Blower, Model B.

[b]Percentage of possible aperture opening in lid.

[c]Measured by Kurz Air Velocity Meter, Model 440.

[d]Seed remaining on screen at 30 setting.

Table 5. Number of well-developed seeds (size class IV) per musk thistle head that was blooming on indicated dates from four sites in central Nebraska. Each number is an average of 25 heads.

Year	Site	Well-developed seeds on sample date[a]				
		6/21	6/28	7/5	7/12	$\bar{X}$
		(no./25 heads)				
1978	Scotia	663a	626a	317b	323a	482
	Holmes	363b	274c	206c	128b	243
	Homestead	647a	441b	414a	51c	388
	NRD	434b	527ab	394ab	276a	408
	$\bar{X}$ of 3 infested sites	481	414	338	152	346
		6/26	7/3	7/10	7/17	$\bar{X}$
1979	Scotia	815a	665a	461a	304a	561
	Holmes	17c	75c	227b	196b	129
	Homestead	1c	34c	69c	249ab	88
	NRD	237b	252b	122c	9c	155
	$\bar{X}$ of 3 infested sites	85	120	139	151	124

[a]Means within columns and years followed by the same letters are not significantly different (P<0.05, Duncan's multiple range test).

Table 6. Characteristics of well-developed seeds (size class IV) from musk thistle heads. Germination rates and seed weights are averages of 40 samples of 25 seeds.

Year	Site	Germination rate[a]	Seed weight
		(%)	(mg/seed)
1978	Scotia	96a	2.9a
	Holmes	99b	3.2b
	Homestead	98b	3.1b
	NRD	98b	3.2b
	$\bar{X}$	98	3.1
1979	Scotia	96	3.4
	Holmes[b]	96	3.3
	Homestead[b]	98	3.2
	NRD[c]	96	3.6
	$\bar{X}$	96	3.4

[a]Means within columns and years followed by the same letters are not significantly different (P<0.05, Duncan's multiple range test).

[b]Because of insufficient seed, only 20 samples were tested.

[c]Because of insufficient seed, only 30 samples were tested.

In 1979 there was a marked increase in weevil densities (Table 3) accompanied by a sharp reduction in the number of well-developed seeds at the infested sites (Table 5). All three infested sites produced significantly fewer seeds than did the Scotia site. Overall, the Scotia site averaged 561 seeds/head and the three infested sites averaged 124 seeds or about 78% fewer seeds. At the Holmes and Homestead sites, the reduction was especially great for heads that bloomed during the first and second weeks of sampling (about 98% and 84%, respectively, of the Scotia site), reflecting the high density of weevils in those heads. Thus, a greater relative number of seed were produced from heads blooming in the third and fourth weeks. The NRD site, with fewer weevils than the other infested sites, produced seeds in the same pattern as in 1978, i.e., more seeds per head in the first and second weeks of bloom A heavy infestation of a seed-feeding caterpillar [*Homoeosoma electellum* (Hulst), Lepidoptera: Pyralidae] reduced seed production during the fourth week of bloom at the NRD site. Although this insect affects seed production, it is usually localized and not reliable from year to year.

Seed characteristics – non-infested heads. Germination rates of well-developed seeds from non-infested heads were high (96 to 99%, Table 6). The Scotia site had a significantly lower germination rate than did the infested sites in 1978, possibly because of a stimulatory effect by weevils in other heads on the plants. This trend did not occur in 1979, however. Seed weights followed the same pattern; the Scotia-site seeds were smaller than infested-site seeds in 1978, but no difference occurred in 1979.

Individual averages for each week of bloom are not given in Table 6, however, the date of bloom did not significantly affect germination rate (P>0.05). Seeds from heads blooming during the first week germinated as well as seeds from later blooming heads. Seeds from heads blooming the first week in 1978, however, weighed more than seeds from later blooming heads (3.4 vs. 3.0 mg/seed, P<0.05), possibly a reflection of moisture stress. No significant difference between sample dates occurred in 1979 seed weights (P>0.05). Thus, seed characteristics were not usually affected by location of the head on the plant.

Because the female weevil oviposited preferentially on early developing heads, the terminal heads of the main stem and upper lateral branches had high larval infestations and great seed destruction. The larger proportion of potential seeds occurred, however, in the more numerous lower terminal and axillary heads that bloomed during the third and fourth week. Well-developed seeds from these later blooming heads were similar in viability to the early blooming heads, so a large number of seeds were still produced at infested sites during 1979. As weevil populations continue to grow, a larger proportion of eggs are expected to be laid on the later blooming heads, and thus the weevil would cause greater seed destruction.

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Soil Persistence of Tebuthiuron in the Claypan Resource Area of Texas[1]

RODNEY W. BOVEY, ROBERT E. MEYER, and HUGO HEIN, JR.[2]

Abstract. **Pelleted tebuthiuron {*N*-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-*N*,*N'*-dimethylurea} was applied aerially on duplicate plots at 2.2 and 4.4 kg/ha in spring, summer, fall, and winter of 1978 and 1979. Treatments were made near Bryan in the Claypan Resource Area of Texas on an area supporting a stand of mixed brush consisting mostly of oak (*Quercus*) species. Soils were sampled at eight locations in each plot at depths of 0 to 15 and 15 to 30 cm in March 1980. Bioassays using 'Tamcot' cotton (*Gossypium hirsutum* L.) and 'Caddo' wheat (*Triticum aestivum* L.) were done in the greenhouse to detect levels of tebuthiuron residues in the soil. A standard curve was developed to compare known concentrations of tebuthiuron to the unknown content from treated plots. Tebuthiuron persisted in all treated soils and ranged from 0.08 to 0.49 μg/g. Concentrations were usually greater in soil treated in 1979 than in 1978 and in soil treated with 4.4 kg/ha of tebuthiuron than 2.2 kg/ha. No consistent differences in tebuthiuron residues existed either between soil depths or among seasons of application using the bioassay.**

Additional index words. *Triticum aestivum* **bioassay,** *Gossypium hirsutum* **bioassay, herbicide residue, brush control.**

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[2]Res. Agron., Plant Physiol., and Agric. Res. Tech., Agric. Res. Serv., U.S. Dep. Agric., Range Sci., Texas A&M Univ., College Station, TX 77843.

INTRODUCTION

Tebuthiuron is an effective herbicide for control of certain brush species on rangeland in the Southwest (10, 16, 17, 18, 20, 24). Since its introduction, many investigations have reported the physiological effects of tebuthiuron on plants (4, 5, 6, 12, 21, 22, 23), but data on persistence of residues in soil are lacking.

Because tebuthiuron is a soil-applied herbicide (23), its persistence in the soil as related to weed control and tolerance of forage species is important. By observing vegetation sensitive to tebuthiuron, a rough indication of residues in the soil can be ascertained. For example, Baur (1) found that spray or pellet formulations of tebuthiuron applied at 1.1 kg/ha to bare soil 261 days (and 68 cm rainfall) before planting provided effective weed control and allowed successful establishment of ryegrass (*Lolium perenne* L.). Tebuthiuron at 3.4 kg/ha, however, prevented both weed growth and ryegrass establishment. In other studies (3), kleingrass (*Panicum coloratum* L.) production was increased by preplant treatments of tebuthiuron at 1.1 kg/ha either as a spray or as pellets compared to untreated areas, but tebuthiuron at 2.2 kg/ha prevented establishment of kleingrass. Tebuthiuron at 1.1 kg/ha increased growth of common bermudagrass [*Cynodon dactylon* (L.) Pers.], but had no effect at 2.2 kg/ha compared to untreated areas. Scifres and Mutz (19) found that aerial application of tebuthiuron pellets at 2.2 kg/ha to mixed brush stands in South Texas significantly increased grass production for 1, 2, and 3 yr after treatment, but forb production and species diversity were reduced when the herbicide was applied at 1.1 kg/ha or more.