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Germination and Early Seedling Development of Musk and Plumeless Thistles

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INTRODUCTION

Musk thistle (*Carduus nutans* L.) was added to the Nebraska noxious weed list in 1959. Past studies have concentrated on describing botanical characteristics that may be used to identify musk and other thistles (2). By correct timing of herbicide applications, musk thistle can be controlled with 1 to 2 lb/A 2,4-dichlorophenoxyacetic acid (2,4-D), 0.25 or 0.5 lb/A 4-amino-3,5,6-trichloropicolinic acid (picloram), or 2 lb/A 2-methoxy-3,6-dichlorobenzoic acid (dicamba) (1).[2]

Musk thistle may behave as a biennial or a winter annual under Nebraska conditions (2). With information on life cycle, growth habit and method of control, weed agencies in Nebraska and other states are putting forth a concentrated effort to control musk thistle. However, musk thistle is spreading into previously uninfested areas by means

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Cooperative investigations of the Crops Research Division, Agricultural Research Service, U.S. Department of Agriculture, and the Nebraska Agricultural Experiment Station, Lincoln.

[2] (Picloram and dicamba are not registered for this use on pasture or cropland at the time this is written. They should not be used in these areas until proper registration occurs.)

of wind-borne achenes. Little is known about the requirements for achene germination and early establishment of musk thistle seedlings.

Plumeless thistle (*Carduus acanthoides* L.) is very similar to, and often confused with, musk thistle. However, characters such as leaf shape, pubescence on the underside of the leaf, and flower head size may be used to readily separate the two species (2). Plumeless thistle has recently been considered a problem weed and was added to the Nebraska noxious weed list in 1967.

The present study was conducted to determine the effects of some simulated environmental variables on the germination of musk and plumeless thistle achenes. The two species appear to occupy a somewhat similar role in the natural vegetation, and a direct comparison of germination characteristics was sought. The factors studied and their hypothesized relation to the germination process are given in Figure 1.

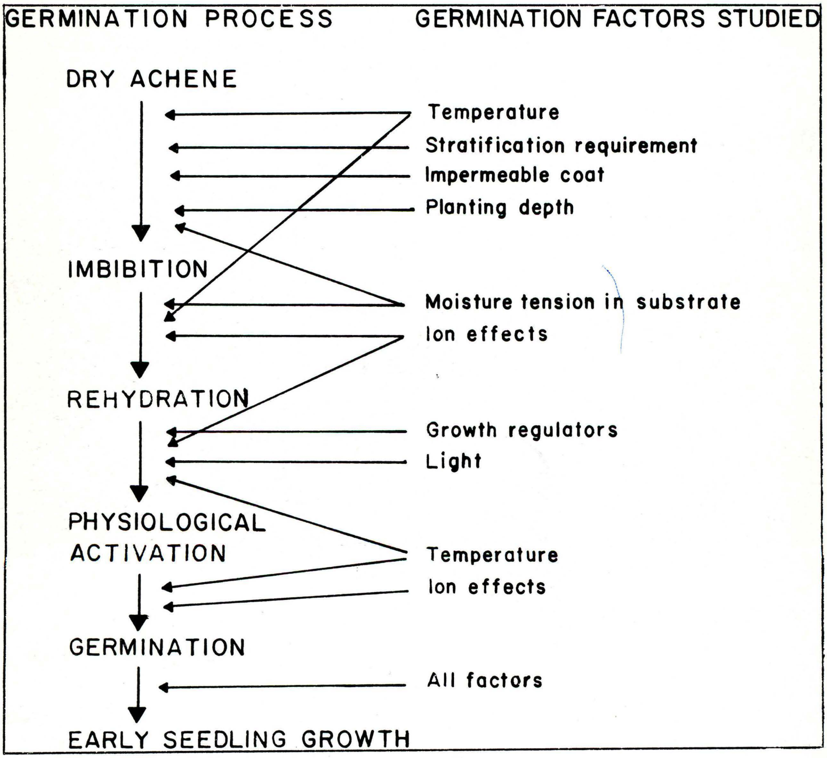

Figure 1. Factors investigated in these studies that might affect percentage germination in musk and plumeless thistles, and the steps in the germination process that might be most affected.

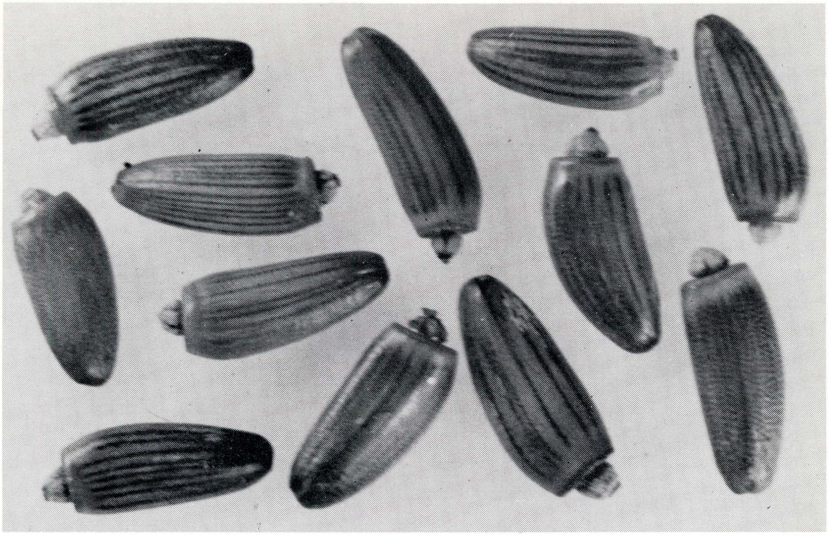

Figure 2. Musk thistle achenes.

MATERIALS AND METHODS

Description of Achenes

The achenes of musk thistle used in these studies were about 2 by 4 mm., weighed 0.4 g./100 and displaced 0.004 cc./achene. They are light tan with dark brown striations on the longitudinal axis

Figure 3. Plumeless thistle achenes.

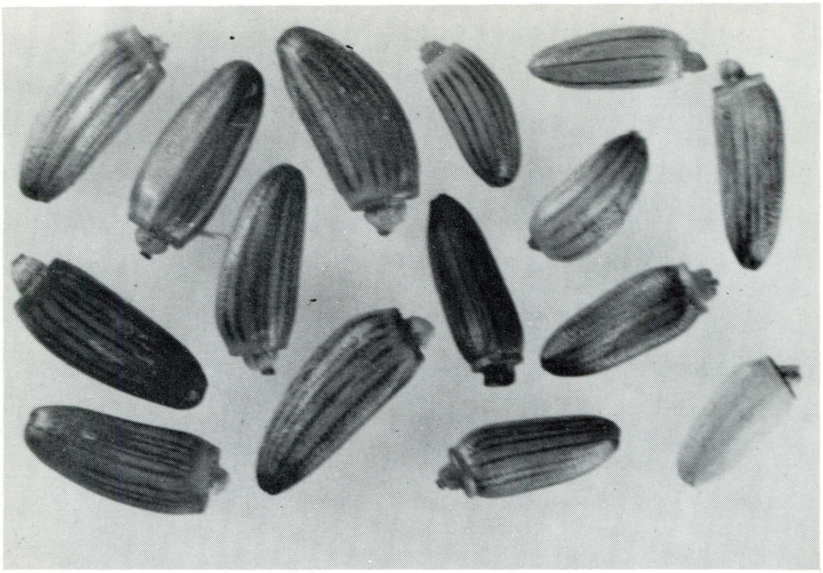

Figure 4. Comparison of musk and plumeless thistle achenes. The 7 larger achenes on the left are musk thistle and the 8 smaller achenes on the right are plumeless thistle.

(Figure 2). The achenes are attached to long strands of a nonbranched pappus. The lack of branching of the pappus is used to characterize the entire *Carduus* genus which is termed "plumeless".

Plumeless thistle achenes were 1 by 3 mm., weighed 0.2 g./100 and had a volume of 0.0024 cc./achene. Plumeless thistle achenes (Figure 3), except for being smaller and lighter in color, are much like those of musk thistle. The striations on the longitudinal axis are not so prominent as in musk thistle (Figure 4). It is assumed that the achenes of both species are carried long distances by wind.

Achenes collected from plumeless thistle plants near Bennet, Nebraska, in 1965 and a nursery on East Campus, University of Nebraska in 1966 were used in studies conducted in 1967 and 1968. Experiments were duplicated in a germinator having 20 to 30 C. alternating temperature for 8-hour light and 16-hour dark periods respectively.

We recorded germination 5, 7 and 10 days after initiation of the studies. At the 10-day evaluation, we also recorded length of the seedling radicles and hypocotyls and fresh weights. We removed the seedlings from petri dishes and blotted them dry with tissue paper before weighing. Seedling growth in the greenhouse was oven-dried before weighing topgrowth.

Stratification

Each stratification experiment was 160 days in duration. We exposed musk and plumeless thistle achenes to wet or dry storage conditions at 2 temperatures, 0 or 5 C. Achenes in germination towels were soaked in distilled water for 8 hours before putting them in cold, wet storage. One hundred achenes in each of 40 towels imbibed moisture at room temperature for 8 hours before they were placed in cold storage. We placed dry achenes in open beakers in the same cold storage temperatures and others in beakers were stored at room temperature. At each sampling period, we removed achenes from each treatment: (1) cold wet, (2) cold dry, and (3) room temperature dry. The dry achenes were wrapped in 100-unit lots in germination towels, moistened with distilled water and placed in the germinator along with those stored under cold conditions. Achenes were tested for viability at approximately weekly intervals for 4 weeks, then at monthly intervals for 4 months.

Different Constant Temperatures

We placed musk and plumeless thistle achenes in moistened towels. These were placed in chambers at 0, 5, 15, 25, 28 or 35 C in the dark to evaluate the effect of different constant temperatures. Germination was recorded after 5, 10, 15 and 20 days. At the end of the 10-day period, we transferred achenes in the 0 and 5 C. chambers to 28 C. and left them for 10 more days. Two studies with 6 replications each were conducted.

Light Requirement

The effect of light was determined by comparing germination in petri dishes wrapped in aluminum foil with that in unwrapped dishes. The effect of 30 p.p.m.w. gibberellic (GA) and indoleacetic (IAA) acids on achenes germinating in the light or dark was compared by the same technique. Achenes left in "light" received 8 hours exposure to fluorescent lights and 16 hours in the dark in the germinator.

Depth of Planting

Two studies were conducted in the greenhouse. The soil was a 3 to 2 part mixture of Sharpsburg silty clay loam and sand packed to attain a bulk density of 1.1. Achenes were planted on the surface and in the soil at 0.5-cm. increments to a depth of 6 cm. In one experiment, 20 achenes were planted per 2-inch diameter plastic pot. In another study, rows of 20 achenes each were planted at the appropriate depth. The achenes were equidistantly spaced 1 inch apart in 4- by 18- by 24-inch flats. Each depth of planting was replicated 6 times. Emergence was recorded periodically after planting.

Growth Regulators

Concentrations of 0, 8, 16, 32, 63, 125 and 250 p.p.m.w. of GA, IAA or kinetin were used as the germination media. The effects of 0, 3, 6, 13, 25, 50, 75 and 100 p.p.m.w. of 2,4-D, picloram and dicamba were also studied.

Achene Coat

Scarification with coarse sandpaper, removal of approximately 1 mm. of the radicular end of the achene tip, or exposure to concentrated sulfuric acid for 0, 0.5, 1, 2, 3, 4 and 5 minutes constituted the achene coat treatments. After exposure to the acid, the achenes were placed in cheesecloth and immediately washed for 3 to 5 minutes with running tapwater.

Effect of pH

Solutions with pH values of 2.2, 3, 4, 5, 6, 7, 8, 9 and 10 were prepared by adding NH_4OH or HCL to distilled water. Confirmation of the pH was accomplished by using a glass electrode pH meter. The change in pH of these non-buffered solutions toward neutrality was about 0.4 pH units in 10 days.

Salinity

The effect of sodium chloride on germination was evaluated using water media containing 0, 250, 500, 1,000, 5,000, 10,000, 15,000 or 20,000 p.p.m.w. The reaction of seedlings to sodium chloride in the soil was evaluated by planting 20 achenes, each in 2-inch diameter pots containing 0, 50, 100, 150, 300, 450, 600, 900, 1,500 or 2,000 p.p.m. NaCl. The appropriate amount of salt on wt/wt basis was incorporated into air dry Sharpsburg silty clay loam soil containing 23 m.e. Na/100 g. by mixing for 1 hour on a rotating mixer. The achenes were planted 1 cm. deep and sprinkler irrigated as needed. We recorded emergence and survival periodically and we harvested, oven dried and weighed seedlings after 21 days.

Moisture Stress

Various levels of moisture tension were simulated in 5 experiments using d-mannite (mannitol). We formulated osmotic pressure medias ranging from 0 to 20 atmospheres at 2 atmosphere increments using the formula given by Powell and Pfeifer (3) but as modified by Scifres and McCarty (4).

RESULTS AND DISCUSSION

Stratification

After-ripening is a common phenomenon in seeds. This requirement may be due to physiological or structural immaturity or a combination of the two. There was no significant change in percentage germination of musk thistle achenes after 16 days cold treatment (Figure 5). However, after 21 days of storage, percent germination of achenes stored at 0 C. under moist conditions decreased. At 5 C. wet, no significant change occurred until after 27 days. Germination of achenes stored at 0 C. was consistently lower than that of those stored at 5 C.

The same general trend was true for germination of plumeless thistle achenes (Figure 6). However, the reaction to moist prechilling was more rapid than in musk thistle. Germination of plumeless thistle declines most rapidly at 5 C., which was consistently lower than at 0 C.

Neither species has an after-ripening requirement. In a dry condition, achenes of neither species were damaged by low temperatures for up to 160 days. However, after imbibition, both species were injured by low temperatures. Most of the achenes that did not germinate after cold, moist, preconditioning deteriorated rapidly when transferred to conditions optimum for germination.

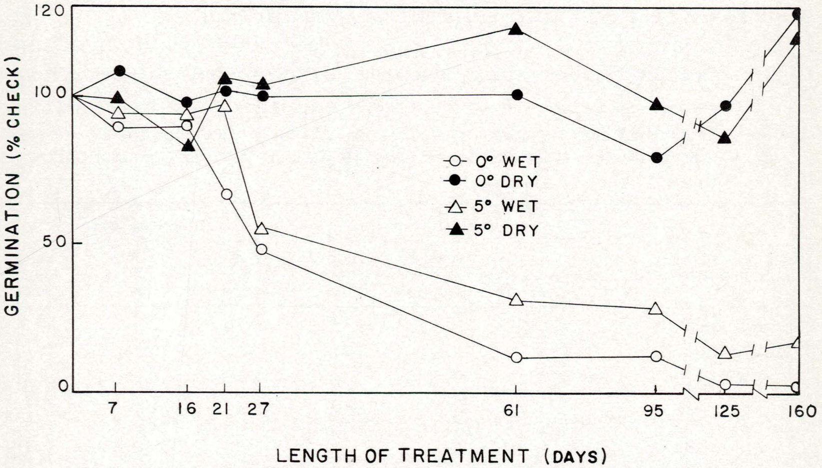

Figure 5. Germination percentage of musk thistle achenes after stratification in a wet or dry environment at 0 or 5 C.

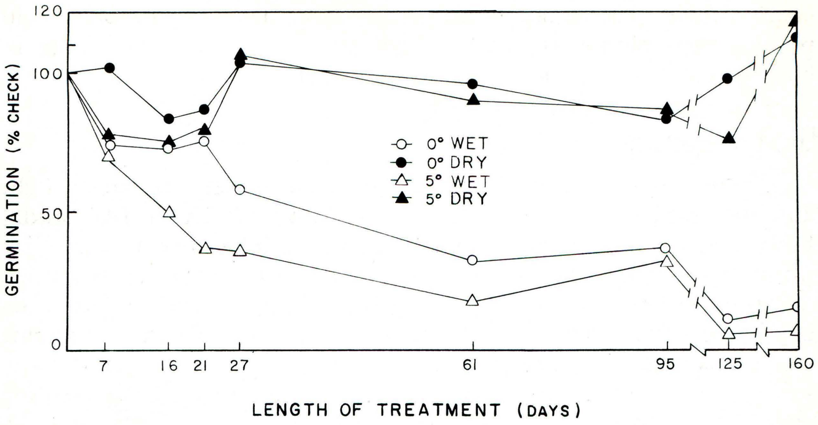

Figure 6. Germination percentage of plumeless thistle achenes after stratification in a wet or dry environment at 0 or 5 C.

Different Constant Temperatures

This segment of the study involved the germination response of achenes to different constant temperatures. The achenes received no preconditioning and were stored at room temperature after harvest. Achenes of both species had highest germination at 28 C. (Table 1). Storage for 10 days at 5 C., then transferring the achenes to 28 C., resulted in the best developed musk and plumeless thistle seedlings.

Musk thistle achenes did not germinate at 35 C. and only 2 percent of the plumeless thistle achenes responded. Although the seedlings of plumeless thistle under 35 C. were poorly developed, they seemed to be more heat tolerant than those of musk thistle.

Seven days of cold storage did not greatly affect viability of musk thistle achenes. There was a decrease in plumeless thistle achenes.

Table 1. Percentage germination and amount of early seedling growth of musk and plumeless thistle achenes after 10 days at different constant temperatures.[a]

	Musk thistle			Plumeless thistle		
Temperature C.	% germ.	Total fresh wt. mg.	Avg. length mm.	% germ.	Total fresh wt. mg.	Avg. length mm.
0 moist, then 28[b]	20 b	75 b	17 b	18 b	72 b	18 b
5 moist, then 28[b]	53 c	383 d	30 c	36 c	169 c	28 c
15	47 c	87 b	2 a	44 c	87 b	2 a
25	57 c	157 c	21 b	46 c	173 c	20 bc
28	65 c	184 c	21 b	72 d	194 c	16 b
35	0 a	0 a	0 a	2 a	8 a	2 a

[a] Average of two experiments. Means followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

[b] Stored at 0 or 5 C. for 10 days, then transferred to 28 C. and left for 10 days.

Musk thistle achenes appeared to be more resistant to brief cold periods than plumeless thistle. Germination at 28 C. was higher in both species than at the lower temperatures.

Light Requirement

There was a trend for higher germination under alternating light and increased germination with the addition of GA or IAA under both light levels with musk thistle (Table 2). The same was true for plumeless thistle except IAA did not substitute for light in this species.

Seedling fresh weights increased when GA was added to petri dishes of musk thistle achenes. This was independent of light. The same trend was true with plumeless thistle achenes, although GA was not statistically more effective than distilled water. Individual seedling weights were unaffected by light level or additions of growth regulators.

Table 2. Percentage germination and growth of musk and plumeless thistle seedlings for 10 days as affected by light and two growth regulators at 30 p.p.m.w.[a]

Light	Growth regulator	% germination	Fresh weight mg.		Length mm.	
			Total	Avg/ seedling	Radicle	Hypocotyl
			Musk thistle			
+	. . .	63 ab	810 b	28 ab	38 a	26 cd
+	GA	71 a	1042 a	38 ab	36 a	33 b
+	IAA	70 a	883 ab	25 b	44 a	23 d
—	. . .	58 b	830 b	29 ab	32 a	35 b
—	GA	65 ab	1070 a	32 a	31 b	42 a
—	IAA	60 ab	888 ab	38 ab	35 a	30 bc
			Plumeless thistle			
+	. . .	88 ab	640 b	15 a	34 ab	31 d
+	GA	88 ab	680 ab	16 a	28 b	40 c
+	IAA	90 a	620 b	14 a	35 a	29 d
—	. . .	75 c	670 ab	17 a	36 a	49 b
—	GA	83 b	710 a	16 a	32 ab	57 a
—	IAA	61 d	550 c	18 a	37 a	54 ab

[a] Average of two experiments. Means followed by the same letter within each column under each species are not significantly different at the 5% level using Duncan's multiple range test.

Depth of Planting

Achenes of both species required maximum contact with the soil to germinate (Figures 7 and 8). Emergence was more rapid and more seedlings emerged when the achenes were covered by as little as 0.5 cm. soil. Musk thistle appeared capable of emerging from deeper plantings than did plumeless thistle (Figure 9). Seedlings of plumeless thistle had not emerged from the 3-cm. depth at the time of this photograph, while about half of the musk thistle had.

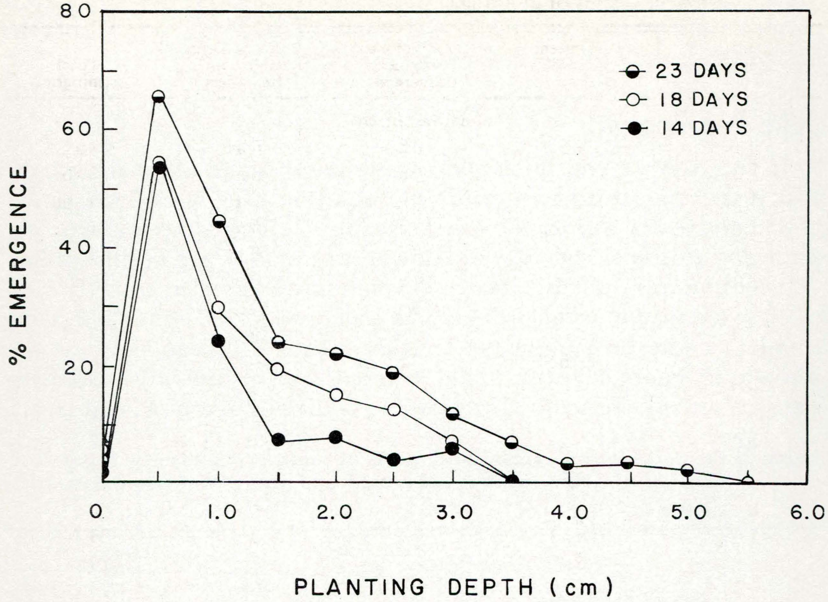

Figure 7. Emergence of musk thistle seedlings from various planting depths in a Sharpsburg silty clay loam soil and sand mixture with a bulk density of 1.1 in the greenhouse.

Even when moisture was adequate, the achenes required some soil cover before a high percentage of achenes germinated. The flats were sprinkler irrigated and the few surface planted achenes that germinated were at least partially covered with soil before they sprouted. The soil layer retains enough moisture to initiate and supply the imbibition process. But unless the achene has maximum contact with the soil, it cannot absorb adequate moisture from it to sustain the germination process.

At depths greater than 3.0 cm. some achenes germinated but failed to emerge (Table 3). Upon completion of the first depth of planting experiment the contents of each pot was spread in a thin layer 0.5 to 1 cm. deep on a germination blotter. Subsequent germination was recorded. The number that germinated at this time was quite low and variable. This short period of burial in the soil and possible damage to the achene coat apparently were partially effective in reducing germination. These data indicate that deep plowing or other tillage that will bury achenes 6 cm. or more, might reduce infestations of both species.

Table 3. Germination and emergence of musk and plumeless thistle achenes at different depths of planting.[a]

Planting depth cm.	% emergence after 23 days	% germinated but not emerged	% germination after replanting 1 cm. deep	Total germination
		Musk thistle		
0.5	83 a	0 a	0 a	83 a
1.0	78 a	0 a	0 a	78 ab
1.5	65 ab	3 a	0 a	68 abc
2.0	58 abc	3 a	3 a	64 abc
2.5	40 abcd	0 a	0 a	40 abcd
3.0	15 cd	0 a	0 a	15 cd
3.5	5 d	0 a	0 a	5 d
4.0	15 cd	3 a	0 a	18 cd
4.5	23 bcd	0 a	0 a	23 bcd
5.0	0 d	3 a	3 a	6 d
5.5	0 d	18 a	3 a	21 cd
6.0	0 d	18 a	15 a	33 abcd
		Plumeless thistle		
0.5	70 a	0 a	5 a	75 a
1.0	83 a	0 a	3 a	86 a
1.5	70 a	0 a	0 a	70 a
2.0	68 a	0 a	8 a	76 a
2.5	40 ab	3 a	3 a	46 a
3.0	70 a	3 a	8 a	81 a
3.5	43 ab	3 a	0 a	46 a
4.0	8 b	25 a	8 a	41 a
4.5	0 b	23 a	10 a	33 a
5.0	0 b	18 a	5 a	23 a
5.5	0 b	5 a	3 a	8 b
6.0	0 b	20 a	23 a	43 a

[a] Means within a column followed by the same letter are not significantly different at the 5% level. Data represent one experiment.

Growth Regulators and Herbicides

The responses of both species to growth regulators and to three compounds possessing herbicidal properties were studied. Neither GA nor kinetin severely depressed germination of either thistle species (Figure 10). However, 250 p.p.m.w. IAA reduced percentage germination of both species.

GA only slightly changed fresh weight of musk or plumeless thistles regardless of concentration (Table 4). It slightly suppressed radicle lengths in both species at concentrations up to 125 p.p.m.w. of GA. At 250 p.p.m.w. there were no differences. Conversely, the hypocotyls of musk thistle were increased in length when GA was in the distilled water germination media. Plumeless thistle had the same trend.

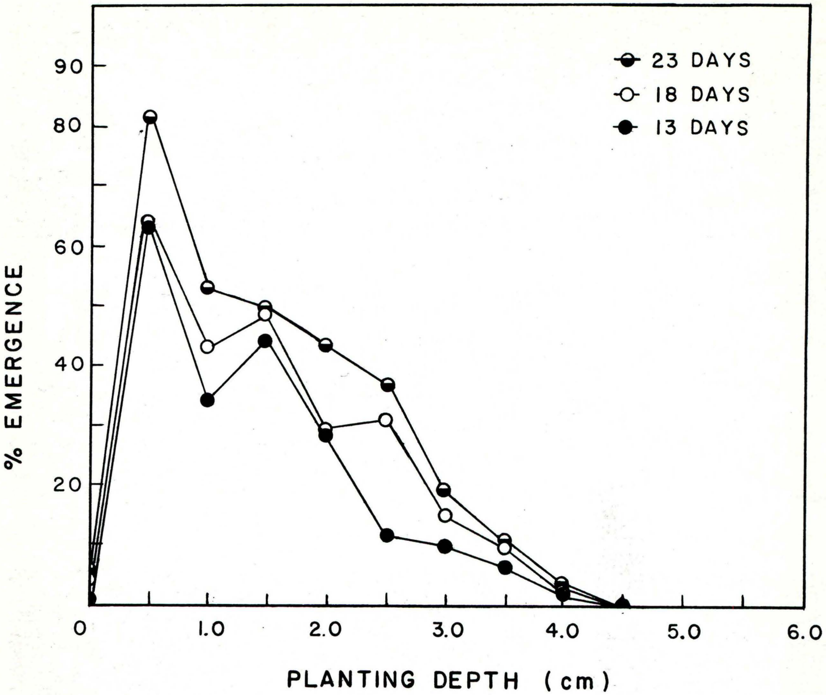

Figure 8. **Emergence of plumeless thistle seedlings from various planting depths in a Sharpsburg silty clay loam soil and sand mixture with a bulk density of 1.1 in the greenhouse.**

Sixteen p.p.m.w. or more of IAA in the germination media decreased the fresh-weight of musk thistle seedlings (Table 5). Plumeless thistle was not affected until concentrations of 125 p.p.m.w. or more were used. Musk thistle radicle lengths were shorter when 8 p.p.m.w. or more IAA was used, than those in distilled water and greatly reduced when 125 or 250 p.p.m.w. were used. Hypocotyl length reductions were not significant until a concentration of 63 p.p.m.w. was reached. The lengths of plumeless thistle seedlings were not reduced until 125 p.p.m.w. IAA was included in the media.

Seedlings of both species responded to kinetin in a manner similar to that of GA (Table 6). There was no reduction in total fresh weights of either species nor in individual weights of plumeless thistle seedlings. All concentrations inhibited root elongation in both species. Only the highest concentrations reduced the hypocotyl lengths of musk thistle but there was a tendency to stimulate hypocotyl elongation at 8 and 16 p.p.m.w. kinetin in both species.

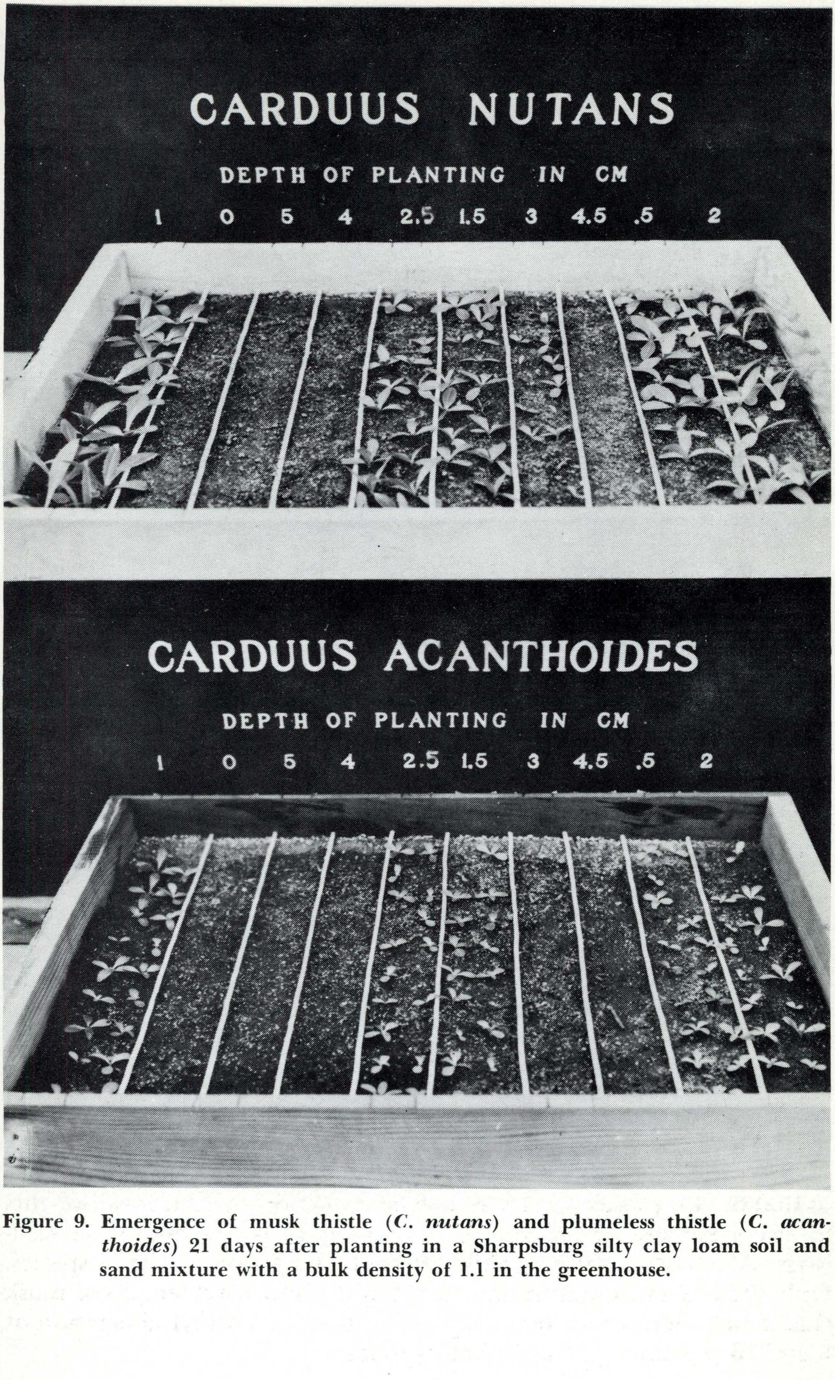

Figure 9. Emergence of musk thistle (*C. nutans*) and plumeless thistle (*C. acanthoides*) 21 days after planting in a Sharpsburg silty clay loam soil and sand mixture with a bulk density of 1.1 in the greenhouse.

Table 4. Growth and development of musk and plumeless thistle seedlings for 10 days after germination as affected by gibberellic acid (GA).[a]

GA concentration p.p.m.w.	Fresh weight mg.		Length mm.	
	Total	Avg/seedling	Radicle	Hypocotyl
		Musk thistle		
0	975 ab	29 ab	42 a	23 b
8	1045 a	30 ab	37 ab	32 a
16	987 ab	28 b	38 a	33 a
32	1173 a	33 a	29 bc	36 a
63	1085 a	29 ab	23 cd	35 a
125	803 b	27 b	17 d	30 a
250	978 ab	28 b	44 a	33 a
		Plumeless thistle		
0	620 b	13 b	39 a	15 c
8	620 b	15 ab	36 a	21 ab
16	647 ab	15 ab	34 a	20 ab
32	663 ab	17 a	27 b	22 ab
63	625 d	15 ab	20 c	18 bc
125	688 a	13 b	13 c	19 bc
250	715 a	16 a	32 ab	24 a

[a] Average of two experiments. Means within a column under each species followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

Table 5. Growth and development of musk and plumeless thistle seedlings for 10 days after germination as affected by indoleacetic acid (IAA).[a]

IAA concentration p.p.m.w.	Fresh weight mg.		Length mm.	
	Total	Avg/seedling	Radicle	Hypocotyl
		Musk thistle		
0	1058 a	26 a	47 a	20 a
8	935 ab	25 ab	35 b	19 a
16	882 b	22 b	34 b	19 a
32	683 c	22 b	34 b	18 a
63	617 c	18 c	20 c	13 b
125	325 d	13 d	10 d	9 c
250	102 e	5 e	1 d	6 d
		Plumeless thistle		
0	573 a	12 b	32 ab	15 a
8	580 a	13 a	35 a	14 a
16	542 a	12 b	33 ab	13 a
32	550 a	12 b	27 ab	12 a
63	537 a	12 b	26 b	13 a
125	362 b	9 c	17 c	8 b
250	57 c	3 d	3 d	5 c

[a] Average of two experiments. Means within a column under each species followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

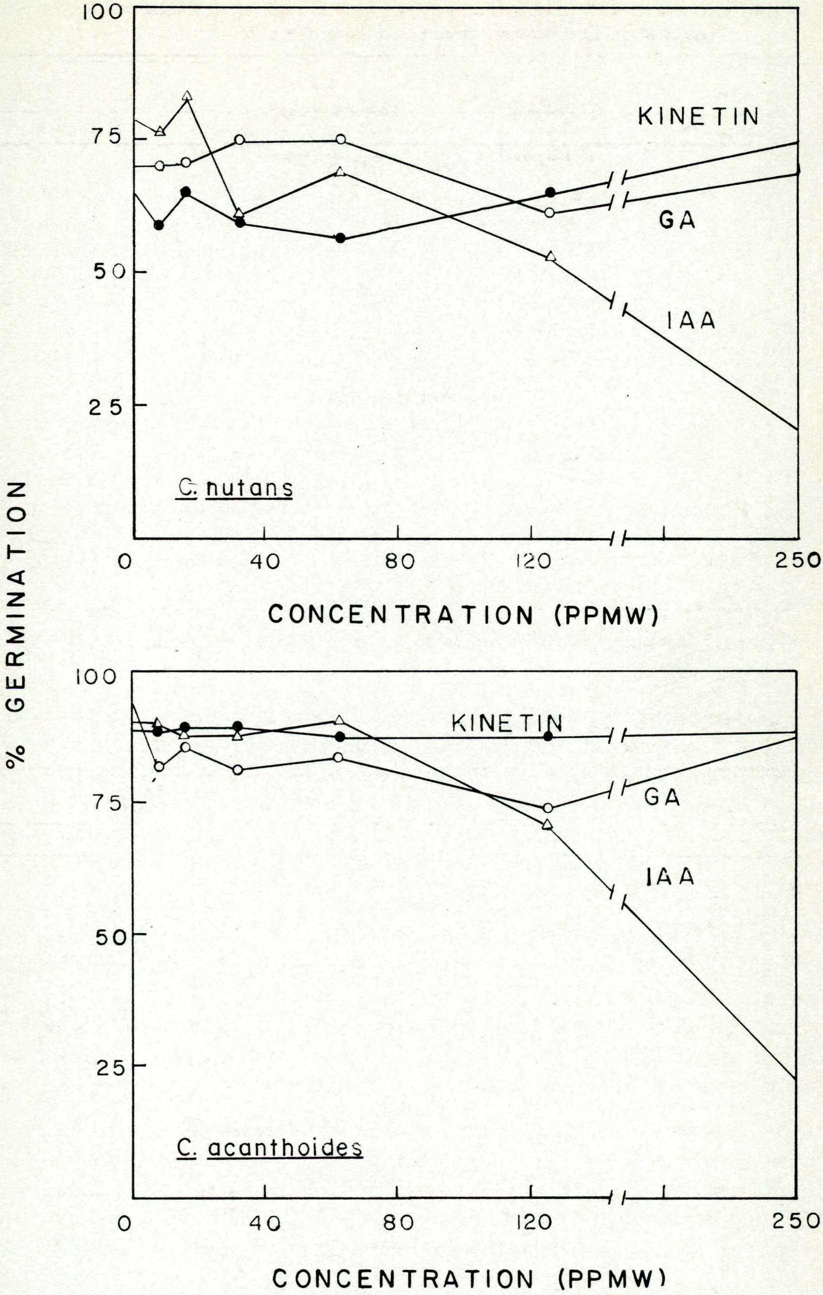

Figure 10. Germination of musk and plumeless thistles in media containing various concentrations of three growth regulators.

Table 6. Growth and development of musk and plumeless thistle seedlings for 10 days after germination as affected by kinetin.[a]

Kinetin concentration p.p.m.w.	Fresh weight mg.		Length mm.	
	Total	Avg/seedling	Radicle	Hypocotyl
		Musk thistle		
0	937 a	28 a	40 a	20 abc
8	757 ab	26 ab	23 b	23 a
16	863 ab	27 ab	14 c	22 ab
32	697 b	23 bc	7 d	19 bc
63	732 ab	26 ab	5 d	18 cd
125	768 ab	24 bc	3 d	16 de
250	825 ab	22 c	2 d	13 e
		Plumeless thistle		
0	645 a	15 a	42 a	25 cd
8	625 a	14 a	19 b	31 a
16	635 a	14 a	12 c	30 ab
32	625 a	14 a	5 e	30 ab
63	615 a	14 a	4 cd	26 bcd
125	630 a	14 a	3 de	27 ab
250	655 a	15 a	2 e	24 cd

[a] Average of two experiments. Means within a column under each species followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

All concentrations of 2,4-D reduced the germination of both species (Figure 11). The achenes fractured but the seedlings did not emerge at 2,4-D concentrations up to 50 p.p.m.w. At 75 and 100 p.p.m.w., they did not fracture. Thus, only the higher herbicide concentrations prevented germination. However, weights and elongation of seedlings were reduced in both species regardless of herbicide concentration (Table 7).

All treatments with picloram, dicamba or 2,4-D in both species severely reduced radicle growth (Tables 8 and 9). Instead of developing well-defined radicles, large amounts of callose tissue were formed at the radicle-hypocotyl junction. Numerous root hairs arose from the callose tissue. Only a small tip at the lower end of the callose tissue could be distinguished as a radicle (Table 8 and 9).

In all cases, plumeless thistle germination was more sensitive than musk thistle (Figure 11). To reduce the germination of musk thistle by 50 percent after 10 days, it required about 13 p.p.m.w. of 2,4-D, 25 p.p.m.w. of dicamba, or 75 p.p.m.w. of picloram. To reduce the germination of plumeless thistle by 50 percent, only 3 p.p.m.w. of 2,4-D, 13 p.p.m.w. of dicamba, or 25 p.p.m.w. of picloram were required. There was no difference in the response of seedling growth to the herbicides.

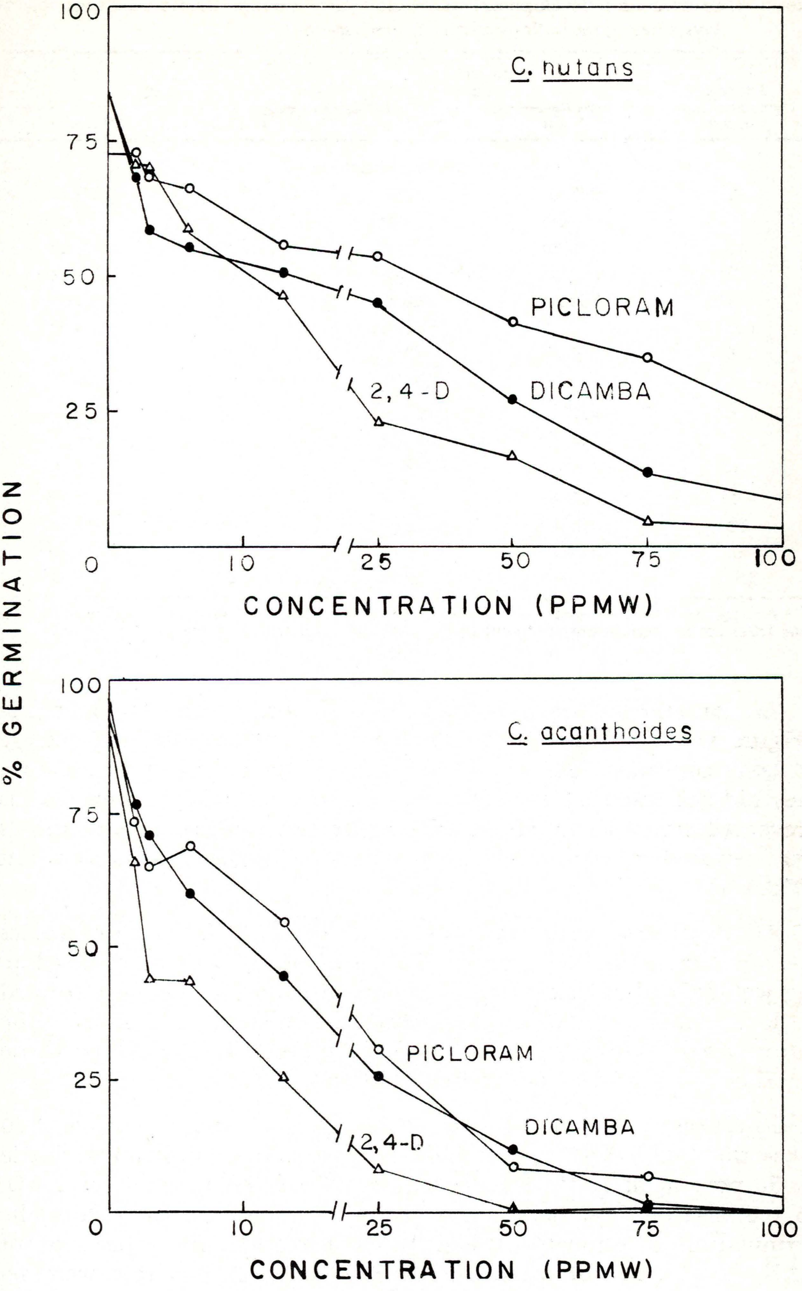

Figure 11. Germination percentage of musk and plumeless thistle achenes in concentrations of 2,4-D, dicamba or picloram.

Table 7. Growth and development of musk and plumeless thistle seedlings for 10 days after germination as affected by 2,4-D.[a]

2,4-D concentration p.p.m.w.	Fresh weight mg.		Length mm.	
	Total	Avg/seedling	Radicle	Hypocotyl
		Musk thistle		
0	1193 a	29 a	45 a	22 a
2	417 b	12 b	3 b	7 b
3	377 b	11 bc	3 b	6 bc
6	270 c	9 de	2 bc	5 cd
13	200 c	8 e	2 bc	5 cd
25	90 d	8 e	1 cd	5 d
50	73 d	9 de	1 cd	5 d
75	20 d	10 cd	1 d	4 c
100	12 d	7 f	1 d	4 c
		Plumeless thistle		
0	643 a	14 a	42 a	17 a
2	147 b	4 b	2 b	5 b
3	73 c	3 c	2 b	4 bc
6	33 cd	2 d	1 b	4 bc
13	7 d	1 e	1 b	4 bc
25	3 d	1 e	1 b	3 c
50	0 d	0 e	0 b	0 d
75	0 d	0 e	1 b	3 c
100	0 d	0 e	0 b	0 d

[a] Average of two experiments. Means within a column under each species followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

These data indicate no requirement for an exogenous source of GA or kinetin for achene germination in these species. IAA was toxic to both species. Fairly high concentrations of 2,4-D, dicamba and picloram were required to be in direct contact with the achenes before germination could be reduced by 50 percent. This indicates a low probability of killing achenes of these species with the field rates of these herbicides required for control. Herbicides with residual toxicity in the soil could kill seedlings after germination. Low rates of treatment in the field during the fall of the year controlled these species when dicamba and picloram were applied, but not 2,4-D.

Achene Coat

Mechanical disturbance of the achene coat was detrimental to the germination of both species (Tables 10 and 11). Scarification with sandpaper or removal of 1 mm. of the radicular tip resulted in the same percentage germination of musk thistle achenes (Table 10).

At 5 and 7 days after imbibition, removal of 1 mm. of the tip of plumeless thistle achenes reduced the percentage germination as compared to treatments with sandpaper (Table 10). Ten days after imbibition, germination of achenes treated with sulfuric acid equalled or exceeded that of untreated achenes. The tendency for early injury was more pronounced with plumeless thistle achenes. Treatment for 3 minutes or longer in acid reduced germination as compared to untreated achenes even after 10 days (Table 11).

Total fresh-weight production and average fresh weights per musk thistle seedling showed the effect of achene coat damage on early seedling growth (Table 12). As the intensity of damage increased, less vigorous seedlings were produced. Weights of seedlings were more indicative of damage than lengths of shoots and roots, although the trend toward lower vigor with increased damage to achenes could be noted in hypocotyl and root lengths. Seedling vigor of plumeless thistle was affected more than musk thistle (Table 13). For instance, all treatments reduced the fresh weights of plumeless thistle. As the amount of damage increased, there was a corresponding decrease in seedling vigor.

Table 8. Growth and development of musk and plumeless thistle seedlings for 10 days after germination as affected by dicamba.[a]

Dicamba conc. p.p.m.w.	Fresh weight mg.		Length mm.	
	Total	Avg/seedling	Radicle	Hypocotyl
		Musk thistle		
0	1215 a	29 a	45 a	23 a
2	435 b	13 b	5 b	8 b
3	333 c	12 b	4 bc	5 c
6	250 d	9 c	3 bcd	5 c
13	220 d	9 cd	2 cd	5 c
25	192 d	9 cd	2 cd	5 c
50	110 e	8 cd	1 cd	5 c
75	48 f	7 de	1 d	4 c
100	25 f	6 e	1 d	4 c
		Plumeless thistle		
0	827 a	18 a	43 a	17 a
2	320 b	8 b	7 b	7 b
3	177 c	5 c	3 c	5 c
6	100 d	4 cd	2 c	4 cd
13	83 d	4 cd	2 c	3 cd
25	30 e	2 d	1 c	3 cd
50	7 e	1 e	1 c	3 cd
75	1 e	1 e	1 c	2 d
100	0 e	0 e	0 c	0 d

[a] Average of two experiments. Means within a column under each species followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

Table 9. Growth and development of musk and plumeless thistle seedlings for 10 days after germination as affected by picloram.[a]

Picloram conc. p.p.m.w.	Fresh weight mg.		Length mm.	
	Total	Avg/seedling	Radicle	Hypocotyl
		Musk thistle		
0	1033 a	29 a	48 a	24 a
2	358 b	10 b	3 b	5 b
3	283 c	8 bc	2 bc	5 b
6	278 c	8 bc	2 bc	5 b
13	233 cd	9 bc	2 bc	5 b
25	207 de	8 c	2 c	5 b
50	162 ef	8 c	2 c	5 b
75	115 fg	8 c	1 c	5 b
100	83 g	7 c	1 c	5 b
		Plumeless thistle		
0	697 a	14 a	43 a	18 a
2	150 b	4 b	3 b	4 b
3	117 bc	3 bc	2 b	4 b
6	120 bc	4 b	2 b	4 b
13	107 bc	4 b	2 b	4 b
25	67 bc	4 b	1 b	4 b
50	19 bc	4 b	1 b	3 c
75	13 c	4 b	1 b	4 b
100	5 c	2 c	1 b	4 b

[a] Average of two experiments. Means within a column under each species followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

The achene coat does not retard germination of musk and plumeless thistle. Damage by removal of the achene coat, in some cases, reduced germination and seedling vigor. Achene coat deterioration under natural conditions may directly influence viability.

Table 10. Percentage germination of musk thistle achenes as affected by achene coat injury.

Treatment	Percentage germination after[a]		
	5 days	7 days	10 days
None	64 a	64 ab	66 b
Sandpaper	44 cd	48 cd	49 c
1 mm. achene tip removed	43 d	43 d	43 c
Length of H_2SO_4 treatment (min.)			
0.5	57 ab	60 ab	64 b
1	64 a	66 a	77 a
2	53 bc	58 ab	68 b
3	50 cd	54 bc	71 ab
4	52 bc	61 ab	72 ab
5	50 cd	53 bc	69 ab

[a] Means within a column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

Table 11. Percentage germination of plumeless thistle achenes as affected by achene coat injury.

Treatment	Percentage germination after[a]		
	5 days	7 days	10 days
None	78 a	90 a	94 a
Sandpaper	58 b	64 b	66 cde
1 mm. achene tip removed	36 c	46 de	54 e
Length of H_2SO_4 treatment (min.)			
0.5	60 b	82 a	90 ab
1	38 c	66 b	84 abc
2	28 cd	60 bc	82 abcd
3	12 d	44 e	64 de
4	16 d	48 cde	52 e
5	20 d	58 bcd	74 bcd

[a] Means within a column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

Effect of pH

Both musk and plumeless thistle achenes germinated more than 50 percent in a pH range of 3 to 9 (Figure 12). The range of pH to promote good early seedling development was the same as for germination in both species (Table 14). These data indicate the wide range of hydrogen-ion concentration tolerated by both species. This may not be indicative of the tolerance range of the juvenile plants. The pH range studied encompassed most pH ranges in soils.

Table 12. The growth and development of musk thistle seedlings for 10 days after germination when achenes were given various coat treatments.[a]

Treatment	Fresh weight mg.		Length mm.	
	Total	Avg/seedling	Radicle	Hypocotyl
None	820 a	25 a	38 abc	21 b
Sandpaper	625 b	25 a	34 c	26 a
1 mm. achene tip removed	450 c	12 d	23 d	12 c
Length of H_2SO_4 treatment (min.)				
0.5	670 b	22 ab	46 a	18 b
1	826 a	22 ab	40 abc	19 b
2	656 b	20 bc	42 ab	17 b
3	536 bc	16 cd	45 a	17 bc
4	591 bc	17 c	40 abc	19 b
5	530 bc	16 cd	36 bc	16 bc

[a] Means within a column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

Salinity

Both species tolerated up to 1,000 p.p.m.w. NaCl without decrease in germination (Figure 13). In the range of 1,000 p.p.m.w. to 20,000 p.p.m.w., percentage germination decreased significantly. Each successive increase of NaCl concentration above 1,000 p.p.m.w. caused a significantly lower germination percentage.

Seedling growth was affected in a manner similar to percentage germination (Table 15). There was a trend toward slight stimulative response of both species at low salt concentrations. Considering all criteria, musk thistle seedlings can apparently grow and develop normally for at least 10 days in solutions of NaCl up to 500 p.p.m.w. Plumeless thistle seedling developing was not hindered until 1,000 p.p.m.w.

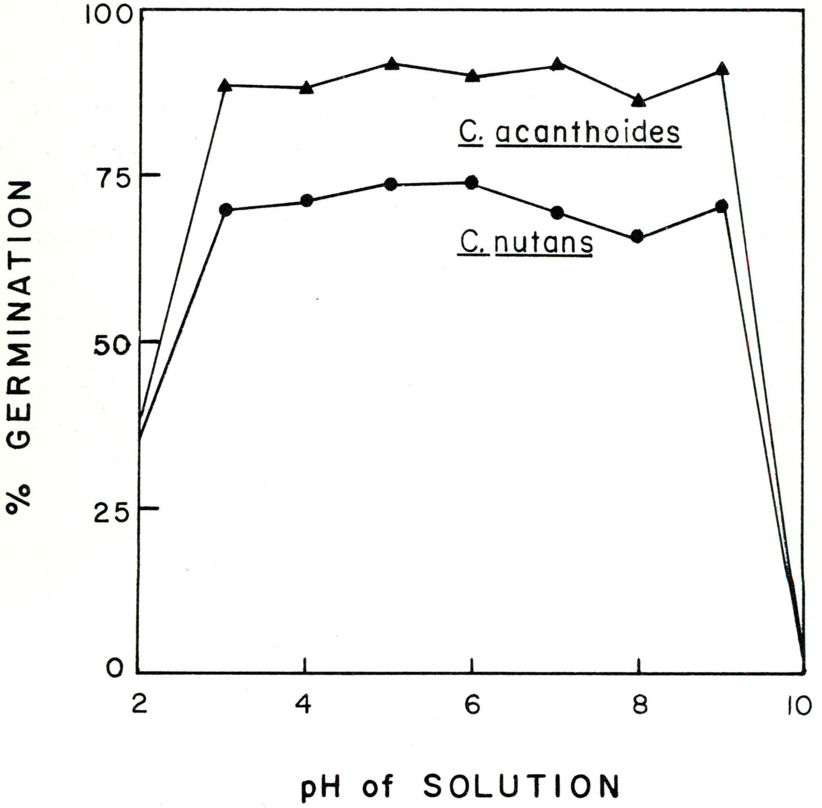

Figure 12. Percentage germination of musk and plumeless *thistle achenes 10* days after initiation of the experiments as affected by substrate pH.

Table 13. The growth and development of plumeless thistle seedlings for 10 days after germination when achenes were given various coat treatments.[a]

Treatment	Fresh weight mg.		Length mm.	
	Total	Avg/seedling	Radicle	Hypocotyl
None	606 a	12.6 a	28 a	14 a
Sandpaper	140 de	3.3 bc	23 abc	13 a
1 mm. achene tip removed	229 cd	.7 c	19 c	7 c
Length of H_2SO_4 treatment (min.)				
0.5	344 b	7.9 ab	26 ab	12 ab
1	286 bc	6.7 ab	20 bc	10 bc
2	190 de	4.8 b	21 bc	9 bc
3	140 de	4.4 b	17 c	8 c
4	102 e	4.1 b	18 c	7 c
5	129 e	3.3 bc	18 c	8 c

[a] Means within a column followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

Table 14. Growth and development of musk and plumeless thistles for 10 days after germination as affected by substrate pH.[a]

pH of media	Fresh weight mg.		Length mm.	
	Total	Avg/seedling	Radicle	Hypocotyl
		Musk thistle		
2	381 c	11 b	13 c	9 b
3	923 ab	27 a	36 b	21 a
4	891 ab	25 a	42 ab	24 a
5	926 ab	28 a	43 a	21 a
6	926 ab	25 a	43 ab	21 a
7	921 ab	27 a	41 ab	21 a
8	824 b	25 a	37 ab	23 a
9	970 a	28 a	37 ab	20 a
10	13 d	2 c	2 d	4 c
		Plumeless thistle		
2	182 d	5 b	8 c	6 c
3	568 c	13 a	37 a	14 b
4	717 a	17 a	38 a	18 a
5	627 b	14 a	50 a	14 b
6	596 bc	14 a	35 a	14 b
7	602 bc	13 a	34 ab	14 b
8	610 bc	14 a	34 ab	14 b
9	580 bc	13 a	28 b	14 b
10	8 e	6 b	3 d	3 d

[a] Average of two experiments. Means within a column under species followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

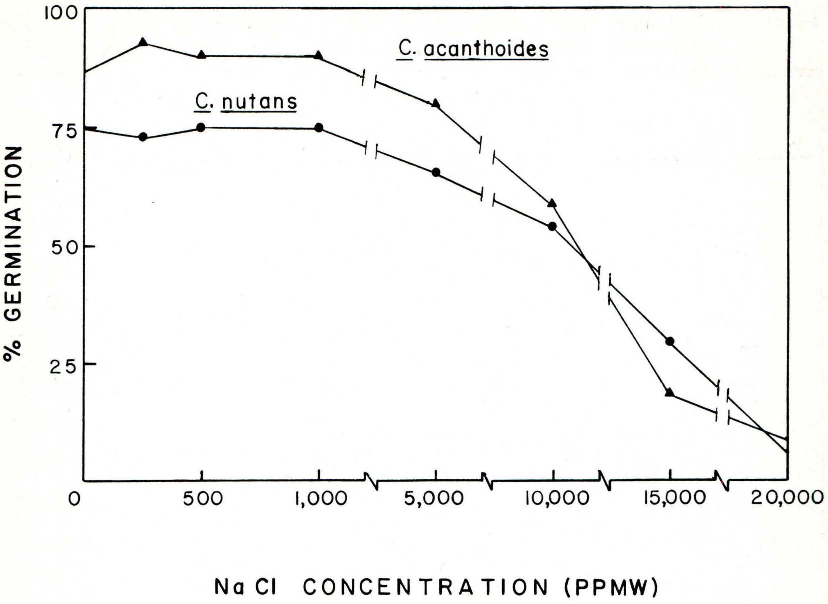

Figure 13. Average percentage germination of musk and plumeless achenes in various concentrations of sodium chloride for 10 days.

Musk thistle emergence and seedling growth was not severely affected by salt concentrations up to 900 p.p.m. in soil (Table 16). Plumeless thistle germination and growth was not severely affected until the salt concentration reached 2,000 p.p.m. Germination and growth response were highly variable in both experiments. Only the higher concentrations caused a significant reduction in oven-dry weights of plumeless thistle seedlings.

Moisture Stress

Increase in moisture tension caused a decrease in percentage germination of achenes of both species (Figure 14). It required 16 atm. tension on the substrate moisture before the percentage germination of musk thistle achenes was reduced 50 percent but only about 8 atm. before the same reduction occurred in plumeless thistle.

This difference in drought resistance could partially account for the relative distribution of the two species. Musk thistle at the present time is more widely distributed than plumeless thistle. The response of seedling growth to moisture tension was similar between the two species at about 6 atm. tension (Table 17). The greatest difference between the germination characteristics of the two species was in their response to moisture stress.

Table 15. Elongation and development of musk and plumeless thistles 10 days after germination in substrates of various salt concentrations.[a]

NaCl conc. p.p.m.w. (1000)	Fresh weight mg.		Seedling length mm.	
	Total	Avg/seedling	Radicle	Hypocotyl
		Musk thistle		
0	822 a	25 a	38 a	18 b
0.25	857 a	25 a	36 a	22 a
0.5	932 a	24 a	36 a	22 a
1.0	587 b	16 b	32 a	20 ab
5.0	493 b	17 b	20 b	13 c
10.0	240 c	10 c	5 c	7 d
15.0	75 d	3 d	3 c	5 d
20.0	8 d	1 e	1 c	3 d
		Plumeless thistle		
0	133 b	15 b	39 a	15 b
0.25	157 a	17 a	36 a	17 a
0.5	150 a	17 a	37 a	18 a
1.0	150 a	17 a	30 ab	17 a
5.0	90 c	12 c	26 b	12 c
10.0	40 e	8 d	7 c	6 d
15.0	47 d	2 e	2 cd	4 e
20.0	17 f	1 f	1 d	2 e

[a] Average of two experiments. Means followed by the same letter within each column under each species are not significantly different at the 5% level using Duncan's multiple range test.

Table 16. Growth of musk and plumeless thistle seedlings for 25 days as affected by NaCl concentrations in a Sharpsburg silty clay loam soil in the greenhouse.[a]

Conc. NaCl added p.p.m.	Musk thistle		Plumeless thistle	
	% germination	Oven-dry weight mg.	% germination	Oven-dry weight mg.
0	64 b	363 a	71 ab	290 a
50	88 a	350 a	79 a	380 a
100	61 b	350 a	75 a	390 a
150	68 b	263 a	78 a	290 a
300	76 ab	288 a	66 b	330 a
450	75 ab	350 a	68 b	280 a
600	74 ab	325 a	66 b	360 a
900	79 ab	275 a	69 ab	300 a
1500	56 c	175 b	75 a	350 a
2000	56 c	213 ab	59 c	200 b

[a] Means within a column followed by the same letter are not significantly different at the 5% level, using Duncan's multiple range test.

CONCLUSIONS

Musk and plumeless thistles are serious weed problems in Nebraska. They occupy a wide range of habitats. A single plant is capable of producing numerous achenes having a pappus which allows these species to spread by wind into new areas. It is apparent that the achenes of both species are capable of germinating under a wide range of environmental conditions.

Chilling achenes that had imbibed water reduced germination. Chilling the achenes which had not imbibed water increased percentage germination in both species.

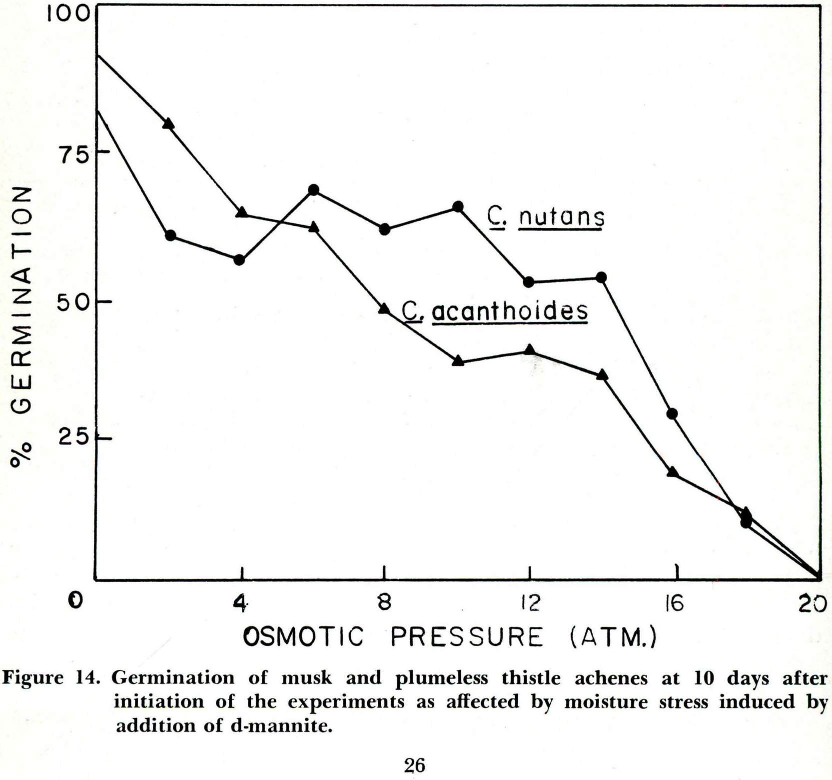

Figure 14. Germination of musk and plumeless thistle achenes at 10 days after initiation of the experiments as affected by moisture stress induced by addition of d-mannite.

Table 17. Growth and development of musk and plumeless thistles after 10 days as affected by different moisture tensions induced by addition of d-mannite.[a]

Osmotic pressure atm.	Fresh weight mg.		Length mm.	
	Total	Avg/seedling	Radicle	Hypocotyl
		Musk thistle		
0	928 a	23 a	40 a	19 a
2	442 b	15 b	31 b	13 b
4	345 b	12 c	23 c	8 c
6	370 c	12 c	17 d	8 cd
8	303 e	10 d	9 c	7 cde
10	290 e	9 de	4 f	7 def
12	190 f	7 e	3 f	5 fg
14	197 f	7 e	2 f	6 ef
16	92 g	7 e	2 f	4 gh
18	25 h	5 f	1 f	4 h
20	2 i	2 g	1 f	4 i
		Plumeless thistle		
0	585 a	13 a	37 a	13 a
2	361 b	9 b	30 b	10 b
4	205 c	7 c	21 c	7 c
6	192 c	6 cd	15 d	6 c
8	123 d	5 de	13 d	6 c
10	100 de	5 de	5 e	5 cd
12	97 de	5 de	4 e	6 cd
14	67 ef	4 e	4 e	5 cd
16	52 f	5 de	2 e	4 de
18	27 f	5 de	1 e	3 e
20	.1 g	.1 f	1 e	3 c

[a] Average of two experiments. Means within a column under species followed by the same letter are not significantly different at the 5% level using Duncan's multiple range test.

Plumeless thistle achenes had higher percentage of viability than musk thistle under most of the temperature regimes studied. Plumeless thistle achenes appeared to be more tolerant to heat.

Although germination was reduced in the dark, light was not a major contributing factor in germination in either species. GA alleviated the light requirement for germination. Exogenous auxin was not required if the achenes were germinated in alternating light and dark.

Covering the achenes with soil or other material appeared to be necessary for high germination percentage in both musk thistle and plumeless thistle. Achenes of both species apparently require prolonged contact with moisture. Emergence was faster at the shallow depth. Apparently just enough soil to cover the achene favors germination and rapid emergence of seedlings.

The achenes of both species were capable of germinating in a wide range of pH. Both species tolerated high NaCl concentrations and osmotic pressures in the germination substrate. However, musk thistle seemed to tolerate higher moisture stress and may have a better chance of becoming established under dry conditions.

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