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INTEGRATION OF A THISTLE-HEAD WEEVIL AND HERBICIDE FOR *CARDUUS* THISTLE CONTROL

J.T. TRUMBLE and L.T. KOK

Department of Entomology, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061 (U.S.A.)

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ABSTRACT

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Acute and chronic effects of the herbicide 2,4-D on the thistle-head weevil, *R. conicus*, and the integration of the weevil and herbicide for *Carduus* thistle control were examined. LC_{50} values for adults prior to overwintering (males 78.6 kg/ha; females 66.8 kg/ha) were lower than for weevils (males 117.1 kg/ha; females 126.6 kg/ha) that had overwintered, but were still at least 40 times the recommended application rate of 1.68 kg/ha. Survival of adults and fecundity of ovipositing females were not significantly affected by either direct application of 2,4-D at 1.68 kg/ha plus sticker, or exposure to herbicide sprays and residue while on musk thistle rosettes. Mean numbers of eggs/ovipositing female/3 day sampling interval were not significantly different (range = 5.44—7.60), regardless of the 2,4-D dosage applied (range = 0.0—147.84 kg/ha). All ovipositing weevils produced viable eggs, but percent viability was not recorded. Thistle-infested fields sprayed with up to 2.24 kg/ha of 2,4-D resulted in death of host plants, but did not prevent survival or reproduction of *R. conicus* populations. With proper timing of herbicide application, *R. conicus* and 2,4-D can be compatibly used in an integrated control program for *Carduus* thistles.

INTRODUCTION

Interest in developing biological and integrated management techniques for *Carduus* thistles has increased substantially during the past 10 years (Kok and Surles, 1975; McCarty and Hatting, 1975; Dunn, 1978). Searches for biological control agents for *Carduus* thistles in many European countries (Zwölfer, 1965; Boldt, 1978,;Boldt and Campobasso, 1978) have led to the screening (Zwölfer, 1967; Kok, 1975; Dunn and Rizza, 1976), release and establishment of a variety of thistle-feeding insects in North America (Dunn, 1978; Goeden and Ricker, 1978; Puttler et al., 1978; Kok and Trumble, 1979).

Despite increased interest in biological approaches to thistle control, current control practices still rely heavily on the use of herbicides, especially 2,4-dichlorophenoxyacetic acid (2,4-D) (Kates et al., 1979). Thus, the effects of pesticides on beneficial insects attacking *Carduus* thistles must be evaluated prior to development of an integrated approach to pasture management for these noxious weeds. Experimentally based information permitting development of management strategies has only recently become available. Rees (1977) stated that the effects of herbicides on survival of a thistle-head weevil, *Rhinocyllus conicus* Froelich, varied with larval density; as larval population/thistle bloom increased, survival decreased. Trumble and Kok (1979a) related the respective stages of weevil and plant development to timing of herbicide application. They showed that treatment of musk thistle (*Carduus nutans* L.) with 2,4-D in the late-bud to early-bloom stage of the primary bloom prevented formation of viable seed without adversely affecting *R. conicus* larval development. Based on the impact of 2,4-D low volatile amine (LVA) on *R. conicus* adults in laboratory and field experiments, the potential for integration of the herbicide and biocontrol agent are presented in this paper.

MATERIALS AND METHODS

Herbicide treatment of R. conicus *prior to overwintering*

R. conicus adults emerging from musk thistle blooms collected in Pulaski Co., Virginia in July 1978 were separated by sex and caged with bouquets of thistle leaves. After 2 weeks, two replicates of 20 ♂ and 2 replicates of 20 ♀ were treated with adjuvent (sticker = Nufilm 17®) plus commercial 2,4-D (LVA) at rates of 0.17, 1.68, 16.80, 84.00, or 147.84 kg/ha. These rates corresponded to 0.1, 1.0, 10.0, 50.0, or 88.0 times, respectively, the manufacturer's recommended application rate. Controls were sprayed with water and adjuvent only.

To simulate maximum initial spray contact in the field, weevils were placed on compacted earth in 0.4 l containers, sprayed using a pressure-calibrated backpack sprayer, and confined on the treated surface for 30 min. Adults were then returned to cages and monitored weekly for mortality. All weevils were maintained in photoperiod chambers with a light—dark (LD) cycle of LD:16—8 until October, when they were switched to LD:8—16 as natural photoperiods decreased. Temperatures throughout this test fluctuated between 21 ± 1°C (day cycle) and 13 ± 2°C (night cycle).

After 24 weeks, no less than eight pairs of adults (♂ and ♀) were randomly selected from weevils remaining in all but the 147.84 kg/ha treatment and caged with primary blooms of musk thistle to determine if oviposition would occur. Treatments at 147.84 kg/ha resulted in too few survivors for incorporation into this experiment. Thistle bloom stems were immersed in water to retain fresheness and suitability for oviposition; blooms were replaced at least every 6 days. Eggs were removed, counted, and placed on moistened filter paper each time blooms were replaced. Viability was determined by the occurrence of egg hatch. Adults were maintained at LD:16—8 and 21 ± 1°C throughout this oviposition study.

Herbicide treatment of R. conicus *after overwintering*

Adult weevils emerging from overwintering sites were collected from musk thistle in Pulaski Co., Virginia in early May 1979. Three replicates of 20 ♂ and three replicates of 20 ♀ were treated using the same dosages and techniques as adults in the previous study. Temperature and photoperiod were maintained at 21 ± 1°C and LD:16—8, respectively. Adult mortality was monitored daily for 14 days.

To determine if fecundity was affected by 2,4-D applications, 12 replicates of two ♀ plus two ♂ from each treatment were caged in 0.2 l containers with musk thistle blooms. Eggs were removed and counted at 3 day intervals for 21 days and blooms were replaced at least every 6 days. Egg viability was monitored as in the previous experiments. Adult mortality was recorded for each sample date.

Herbicide treatment of R. conicus *on thistle rosettes*

Additional experiments were designed to document the survival and fecundity of adults on musk thistle rosettes because *R. conicus* living on thistles do not receive identical herbicide doses, and the weevils would be exposed to pesticide residues through contact and ingestion. Six replicates of 10 ♂ and 10 ♀ were placed on musk thistles rosettes, allowed to acclimate for 5 min, then sprayed with sticker plus 2,4-D (LVA) at 1.68 kg/ha. Also, six replicates of 10 ♂ and 10♀ were released on musk thistle that had been previously sprayed with the herbicide at 1.68 kg/ha and allowed to dry. Controls were treated with water plus sticker only. The rosettes used in this study were of comparable diameter (X = 26.4 ± 2.1 cm). Weevils were confined on the plants for 1 week, at which time all herbicide treated rosettes had died. Adults were then removed, placed in 0.2 l containers with musk thistle blooms, and monitored for fecundity and egg viability as in the previous experiment.

Field application of herbicide to R. conicus *infested thistles*

Two thistle sites were selected for field studies. Site 1, located in Montgomery Co., Virginia, was treated with 2,4-D at 2.24 kg/ha on 25 May 1977, 15 days after *R. conicus* adults had been released. Only plumeless thistle (*Carduus acanthoides* L.) was present at this location. Site 2, located in Pulaski Co., Virginia, was sprayed with 2,4-D at 1.68 kg/ha on 27 June 1977, at least 3 years after *R. conicus* became established. This field contained both musk and plumeless thistle. These locations were surveyed for *R. conicus* adults each spring in 1978 and 1979 to document survival under field-sprayed conditions.

Statistical analysis

Log probit analysis was computer generated using the "Probit Procedure" of SAS (Barr et al., 1976). Acute and chronic toxicity data, normalized with the arcsin transformation, and differences in fecundity between treatments were analyzed using the Student—Newman—Keuls test.

RESULTS AND DISCUSSION

Herbicide treatment of R. conicus *prior to overwintering*

Log probit graphs of the dose—response data after 14 days indicated that application of 2,4-D at 1.68 kg/ha plus sticker did not cause mortality in *R. conicus* populations prior to overwintering. The LC_{50} values for males (78.6 kg/ha) and females (66.8 kg/ha) corresponded to 46.8 and 39.8 times, respectively, the recommended dose/ha. Survival of weevils treated with up to 10 times the recommended dose/ha (16.8 kg/ha) was not significantly different from controls (Table I). Although application of 2,4-D at 84.0

TABLE I

Survival of *R. conicus* adults treated before overwintering with various concentrations of 2,4-D (LVA)

Treatment (kg/ha)	% Survival post-treatment (weeks)*				
	1	3	5	15	24
0 (control)	100.0 a	98.7 a	98.7 a	93.7 a	62.5 a
0.17	100.0 a	100.0 a	100.0 a	93.7 a	62.5 a
1.68	100.0 a	100.0 a	98.7 a	91.3 a	70.0 a
16.80	98.7 a	93.8 a	88.7 a	78.7 ab	53.7 ab
84.00	100.0 a	76.3 b	70.0 b	58.7 b	35.0 b
147.84	72.5 b	25.0 c	17.5 c	13.7 c	7.5 c

*Based on two replicates of 20 ♂ and two replicates of 20 ♀/treatment; means in columns followed by the same letter do not differ at the $P < 0.05$ level (arcsin transformation, Student—Newman—Keuls test).

kg/ha did not cause adult mortality during the first week of this test, significant reductions ($P < 0.05$) in survival were apparent during the remaining 24 weeks. Treatment of adults with 147.84 kg/ha significant reduced survival throughout this study ($P < 0.05$). However, herbicidal effects on oviposition and egg viability were not observed; all treatments contained females (n = 4—6) which produced viable eggs, but percent viability was not recorded.

The impact of 2,4-D on *R. conicus* was primarily acute, as populations treated with 16.8 kg/ha or more declined more rapidly than weevils sprayed with 1.68 kg/ha or less ($P < 0.05$) during the first 5 weeks after herbicide

TABLE II

Rate of decline of *R. conicus* populations treated before overwintering with various rates of 2,4-D (LVA)

Treatment (kg/ha)	% Mortality/week*		
	0—5 weeks	6—15 weeks	16—24 weeks
0 (control)	0.25 a	0.51 a	3.72 a
0.17	0.0 a	0.63 a	3.63 a
1.68	0.25 a	0.76 a	2.52 a
16.80	2.25 b	1.08 a	3.12 a
84.00	6.00 c	1.59 a	2.86 a
147.84	16.50 d	1.50 a	3.70 a

*Based on two replicates of 20♂ and two replicates of 20♀/treatment; means in columns followed by the same letter do not differ at the $P < 0.05$ level (arcsin transformation, Student—Newman—Keuls test).

application (Table II). Differences in rates of decline were not significant between treatments for the remaining 19 weeks.

Herbicide treatment of R. conicus *after overwintering*

LC_{50} values after 14 days for males (117.1 kg/ha) and females (126.6 kg/ha) corresponded to 69.7 and 75.4 times, respectively, the recommended dosage of 1.68 kg/ha. These values are slightly higher than corresponding values obtained from treatment of weevils prior to overwintering, and mortality data (Table III) show that 2,4-D has less impact on survival of overwintered adults. Application of 2,4-D at 84.00 kg/ha to overwintered adults initially

TABLE III

Survival of overwintered *R. conicus* adults treated with various concentrations of 2,4-D (LVA)

Treatment (kg/ha)	% Survival post-treatment (days)*				
	1	3	5	9	14
0 (control)	99.2 a	97.5 a	95.8 a	95.0 a	91.2 a
0.17	100.0 a	99.2 a	97.5 a	92.5 a	91.2 a
1.68	100.0 a	97.5 a	97.5 a	95.0 a	90.0 a
16.80	99.2 a	98.3 a	97.5 a	94.2 a	93.3 a
84.00	90.8 b	88.3 b	87.5 a	85.0 a	80.8 a
147.84	84.2 b	76.7 b	72.5 b	67.5 b	62.5 b

*Based of three replicates of 20 ♂ and three replicates of 20 ♀/treatment; means in columns followed by the same letter do not differ at the $P < 0.05$ level (arcsin transformation, Student—Newman—Keuls test).

caused significant differences ($P < 0.05$) in survival, but percentage survival beyond 3 days was not significantly different from controls. Sprays of 2,4-D at 147.84 kg/ha significantly reduced survival throughout this test ($P < 0.05$).

Fecundity of overwintered weevils was reduced when treated with 2,4-D at rates of 1.68, 16.8 and 147.84 kg/ha (Table IV). However, in each of these treatments several males died within 3 days, and the corresponding females produced few or no eggs. If these females are not included in the analysis, no significant differences in mean numbers of eggs/female can be detected. In addition, if only ovipositing females are considered (Table IV), the mean numbers of eggs/female/3 day sampling interval are not significantly different between treatments. All ovipositing females in this study produced viable eggs regardless of the herbicide dosage administered.

TABLE IV

Impact of various concentrations of 2,4-D (LVA) on fecundity of overwintered *R. conicus*

Treatment (kg/ha)	$\bar{X}$ eggs/♀/21 days*	$\bar{X}$ eggs/♀/3 day interval**
0 (control)	37.58 a	6.15 a
0.17	44.54 a	7.08 a
1.68	27.23 b	5.51 a
16.80	26.68 b	5.64 a
84.00	37.83 a	7.60 a
147.84	27.61 b	5.44 a

*Based on 12 replicates of 2 ♀/treatment.
**Based on ovipositing ♀s only (n ñ 10—12 replicates of 2 ♀/treatment); means in columns followed by the same letter do not differ at the $P < 0.05$ level (Student—Newman—Keuls test).

Herbicide treatment of R. conicus *on thistle rosettes*

Exposure of *R. conicus* adults on musk thistle rosettes to 2,4-D (LVA) sprays and/or residue did not inhibit survival or reproduction. Survival at 2 weeks post-treatment was not significantly different from controls (Range = 79.2—83.7%), and LC_{50} values could not be calculated. The impact of 2,4-D on oviposition as measured by numbers of eggs/female/21 days (range = 28.2—31.4) and numbers of eggs/ovipositing female/3 day period (range = 6.2—6.8) was not significant. With the exception of the numbers of eggs/female/21 days, these values are not significantly different from comparable data in the post-overwintering study. The slightly lower values for numbers of eggs/female/21 days for adults treated on rosettes vs. controls for overwintered weevils may be attributed to the lack of oviposition by two females in each residue treatment. If these weevils are not included in the analysis, no significant differences are apparent. As in the previous oviposition tests, all ovipositing females produced viable eggs, but percent viability was not recorded.

Field application of herbicide to R. conicus *infested thistles*

Application of 2,4-D to thistle-infested fields did not prevent survival and reproduction of *R. conicus.* In spite of the death of host plants and exposure of adults to herbicide residue, larvae and adults were recovered during the spring of 1978 from both test locations. Few thistles and no weevils were found at the Montgomery Co., Virginia site in spring of 1979 because the thistle population was destroyed during the summer and fall of 1978 by repeated applications of 2,4-D and kerosene. However, adults and larvae were abundant in Pulaski Co., Virginia in spring 1979, despite an additional 2,4-D treatment at 1.68 kg/ha in June 1978.

CONCLUSIONS

Results of these tests indicate that 2,4-D does not adversely affect the survival of *R. conicus*, and can be compatibly used with the weevil in an integrated control program for *Carduus* thistles. 2,4-D treatment of musk thistle in the late-bud to early-bloom stage of the primary bloom was not detrimental to the larvae (Trumble and Kok, 1979a), and would not prevent survival or reproduction of adult *R. conicus*. Although 2,4-D treatment of rosettes does not directly affect *R. conicus*, herbicide application may seriously impair the efficacy of rosette-feeding insects such as *Ceuthorhynchidius horridus* (Panzer). *C. horridus* occurs primarily in the larval stage in the U.S.A. when thistles are in the rosette stage (Trumble and Kok, 1979b). Herbicide treatment in the late-bud to early-bloom stage of the primary bloom of musk thistle would coincide with the pupal and adult stages of *C. horridus.* The pupal stage develops underground, and the adult stage is not adversely affected by 2,4-D at 1.68 kg/ha (Trumble and Kok, 1980). Thus, 2,4-D application can be manipulated to have a minimal impact on the complex of biocontrol agents present. By timing herbicide applications to manage thistle populations without adversely affecting the biological control agents, the use of herbicides may be reduced without increasing thistle densities.

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