

**Russian Knapweed germination and grazing/herbicide trials
Final Report
GC 272-03-Z1138**

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INTRODUCTION

Russian knapweed (*Centaurea repens*) is a perennial noxious weed that is native to Eurasia (Bottoms and Whitson 1998). It has become particularly troublesome in the semiarid intermountain west, colonizing saline and non-saline riparian habitats as well as other areas having seasonal shallow water tables.

Russian knapweed reproduces by seed and creeping rootstock and has proven to be a difficult weed to manage on infested rangelands. One author describes Russian knapweed as the most persistent and difficult perennial knapweed to control (Lacey 1989). After initial establishment by seed, established infestations of knapweed tend to maintain and spread via adventitious roots rather than through the continued establishment of new seedlings (Watson 1980). Chemical control of established infestations typically requires re-treatment within 3-5 years to maintain adequate control (Bottom and Whitson 1998). Picloram, clopyralid, and imazapic are three chemicals that show promise for Russian knapweed control. However, rootstock control remains illusive. McInnis et al. (2003) reported increased herbicide effectiveness (rootstock control) on hoary cress (*Cardaria draba*) re-growth following a mechanical mowing treatment. In that case it was observed that hoary cress re-growth was more uniform in structure and development following treatment and was likely weakened by biomass removal improving the effectiveness of herbicide control on rootstock.

The purpose of the germination trial was to determine the response of Russian knapweed seed to light, decreasing water potential and increasing salinity. The objective of the coordinated grazing (goats)/herbicide trial was to determine if treatment combinations would improve rootstock control of Russian knapweed. The field plots are designed to continue through a grass stand establishment phase.

METHODS

Germination trial

Russian knapweed seed was collected (2002) from plants growing in riparian and other low landscape positions within the sagebrush steppe of northeastern Oregon. Watson (1980) reported that knapweed seed production was subject to high rates of seed abortion. Field observations made in 2001 and 2002 suggest that viable seed production is sensitive to summer soil moisture. Knapweed populations were field tested to avoid populations dominated with unfilled seed. Collected seed was stored in plastic grain sacks for 3 mo

before being removed from the seed heads, cleaned, and separated to avoid shriveled seed for germination studies.

All germination experiments (68°F) were set up in completely randomized designs with four replications. Preliminary germination trials indicated that the germination experiments would run 40 days and require a fungicide treatment. Russian knapweed seed were rinsed in a 5% sodium hypochlorite solution, followed by three distilled water rinses prior to the start of each germination trial. The experimental unit consisted of 50 seeds placed on two sheets of filter paper (Whatman No. 1) in a 100 by 15-mm Petri dish. All experiments were designed to contrast germination under light (500 $\mu\text{Em}^{-2}\text{s}^{-1}$ spectral light) and dark conditions.

In the first set of experiments seeds were exposed to four levels of osmotic potential [polyethylene glycol concentrations (PEG)]: 0, -0.5, -1.0 and -1.5MPa. Osmotic potentials were verified with a Wescor C-51 thermocouple psychrometer. Hardegree and Emmererich (1990) reported that filter paper selectively absorbs water from PEG solution, thus decreasing the effective osmotic potential that the seed would be exposed to on the filter paper surface. Using the correction equations given in this paper, the actual osmotic potentials were determined to be unchanged.

In the second set of experiments seeds were exposed to five levels of increasing salinity. NaCl and CaCl₂ were mixed to achieve electrical conductivities of 0, 4, 8, 12 and 16 dSm^{-1} and a sodium absorption ratio of 2. Electrical conductivities were verified with a conductivity meter. The salt solution gradient approximated 0, -0.12, -0.23, -0.35 and -0.47 MPa (Richards 1954).

Germination counts were taken daily for 40 d. Germination was considered to have occurred at radical emergence. All germinated seed were removed at each count and treatment solutions were renewed as needed.

Differences among treatment effects were tested by analysis of variance. Mean separation was achieved with least significant difference (LSD) comparisons. Simple linear regressions ($R^2 > 0.85$) were performed to predict rates of germination and the initial date of germination. Differences among the initial date of germination and germination rate estimates were determined using analysis of variance with LSD comparisons. All reported results are significant at $P \leq 0.05$ unless otherwise stated.

Grazing/herbicide trials

Experimental plots were established near Burns, Oregon. The fenced perimeter of the study area contains 6 acres and lies within a heavy infestation of Russian knapweed that occupies several hundred acres. Soil within the study area is described as a fine-loamy, mixed, superactive, frigid Vitritorrandic (Calcic) Haploxeroll.

Preliminary trials were conducted in the large infestation in 2002 to verify the willingness of boer goats to select knapweed as a major component of their diet. In spring 2003, a

split plot experimental design (3 Blocks) was established to evaluate the effectiveness of fall herbicide treatments (control, picloram @ 1qt/a, clopyralid @1.33pt/a and imazapic @ 12oz/a) following one growing season in which the knapweed received 3 different levels of grazing treatment. The grazing treatments consisted of no grazing, grazing once and grazing twice in a single growing season. A second experiment (same design) was established at the same time to evaluate the herbicide treatments after the grazing treatments were continued for 2 growing seasons.

treatments

Pre-treatment Stem Density(6/03) - Stem density was determined from 0.2m² plots. Each treatment cell (36) within the experiment was sampled using 2 randomly placed plots in the center of the cell (n = 72). Treatment cell differences were not detected within the area established for the 2-year grazing experiment. Russian knapweed stem density (m²) was 44 ± 4 (Mean ± Standard deviation), hoary cress (*C. draba + pubescens*) density (m²) was 83 ± 8. Within the area established for the 1-year grazing experiment, treatment cell differences were not detected for Russian knapweed but block 2 did contain more hoary cress stems than blocks 1 and 3. Russian knapweed stem density (m²) was 53 ± 2. Hoary cress stem densities (m²) were 90 stems in blocks 1 & 3 compared to 117 stems in block 2 (LSD = 25).

Grazing Once (6/03) – Biomass in the control plots (20 plots; 0.25m²) was 2500 ± 400 lbs/a (Mean ± 95% CI). Russian knapweed and hoary cress comprised 92 and 8% of the biomass, respectively. Four hundred doe and kid goats were placed within the treatment one plots on June 17 for 5 days. The biomass (20 plots; 0.25m²) at the end of the grazing treatment was 1100 ± 200 lbs/a (Mean ± 95% CI). Russian knapweed contributed 99% of the biomass within the experimental plots. The grazing treatment achieved 55% utilization.

Grazing Twice (6 & 8/03) – Control plot biomass (20 plots; 0.25m²) was 2400 ± 300 lbs/a (Mean ± 95% CI). Russian knapweed made up 97% of the plot biomass. The difference between the June and August biomass estimates do not represent a measurable decline in biomass. The experimental plots that were grazed in June contained 1700 ± 300 lbs/a (Mean ± 95% CI) prior to the August grazing (20 plots; 0.25m²). This represents a 600 lb growth increase in mean biomass between the June and August grazing treatments. The biomass contained in the experimental plots was 100% Russian knapweed. The second phase of this treatment placed 400 doe and kid goats on the designated treatment plots for a second grazing period (August 26 - 28) of 3 days. The biomass (20 plots; 0.25m²) at the end of the second grazing treatment was 500 ± 100 lbs/a with 100% of the biomass being Russian knapweed. The second grazing period achieved 70% forage utilization.

Herbicide Application - Herbicide treatments were applied in mid October 2003 to the one-year grazing blocks. Herbicide treatments were control, picloram @ 1qt/a, clopyralid @ 1.33pt/a and imazapic @ 12oz/a.

Grass density, biomass and the biomass of knapweed and hoary cress were measured in August 2004. Each attribute was measured using two 0.25m² plots located randomly within each treatment cell. Differences among treatment effects were tested by analysis of variance. Mean separation was achieved with least significant difference (LSD) comparisons. All reported results are significant at $P \leq 0.05$ unless otherwise stated.

RESULTS

Germination trial

Russian knapweed germination was completely inhibited at all levels of water stress imposed by PEG (data not shown). Germination at 0.0 MPa was greater under continuous dark conditions when contrasted against a continuous light environment (Table 1). Differences in light versus dark germination among knapweed seed occurred 12 days into the experiment. At the end of the germination trial (40 d), Russian knapweed germination under dark conditions was one and a half times greater than under light conditions (62% versus 39%).

Knapweed germination was greatest between days 25 and 32 of the experiment regardless of the light treatment (Table 2). Approximately 40% of all germination occurred during the 8-day period. The rate of knapweed germination during the first 36 days of the experiment was two times greater in a darkened environment when compared to a lighted environment (1.0 versus 0.5 germinations/day). Light and dark treatment did not influence the number of days required before germination was detected. Germination required approximately 1 week (7 days) of exposure at near saturated conditions and continued for the next 25 days if moisture conditions were maintained before a decline in germination became evident and the experiment was terminated.

Germination of Russian knapweed seed decreased with increased salt concentration. In a dark environment (40 d germination totals), germination in the non-saline control was greater than 8, 12 and 16 dSm⁻¹ (62% versus 49, 31 and 23%). Germination at 4 dSm⁻¹ (57%) was intermediate to germination amounts observed in non-saline and 8 dSm⁻¹ treatments. These results suggest that Russian knapweed germinates across a wide spectrum of salt concentration, if sufficient moisture is present. Saline soils are defined as having salt concentrations above 4 dSm⁻¹ (Miller and Donahue 1990). Cumulative germination after 36 days of the experiment was reduced 10% for each treatment increase in dSm⁻¹ (germination count = $31.7 - 1.3(\text{dSm}^{-1})$, $R^2 = 0.86$). The rate of germination during the first 36 days of the experiment increased 40% as salinity was reduced from 16 to 12 dSm⁻¹ (0.3 versus 0.5 germinations/day) and 12 to 8 dSm⁻¹ (0.5 versus 0.7 germinations/day). The rate of germination increased 20% with salinity reductions from 8 to 4 and 4 to 0 dSm⁻¹ (0.7 versus 0.8 and 0.8 versus 1.0 germinations/day).

Under continuous light conditions, germination was greatest in the non-saline control (39%). Germination at 4 and 8 dSm⁻¹ was similar, but 44% less than the control. Germination at 12 and 16 dSm⁻¹ had the least amount of germination and averaged 84%

less germination than the control. Cumulative germination after 36 days of the experiment was reduced 8% for each treatment increase in dSm^{-1} (germination count = $17.1 - 1.0 (\text{dSm}^{-1})$, $R^2 = 0.79$).

Grazing/herbicide trial

Grass Response - Grass density increases were observed following grazing and herbicide treatment. Grazing treatments resulted in an increase of 2.5 grass plants per 0.25m^2 in grazed versus no graze comparisons. Similarly, herbicide treatments resulted in increases of 3.7 grass plants per 0.25m^2 in herbicide versus control comparisons. In both cases the grass density increases were generic and could not be attributed to specific grazing intensities or herbicide treatments. Interactions between the grazing and herbicide treatments were not detected.

Grass biomass increases were associated with individual herbicide treatments. Clopyralid treatments were associated with a grass biomass increase of 550 lbs/a over the control (1200 lbs/a). Grass biomass in the clopyralid plots was also greater than that observed with imazipac (1400 lbs/a; $P \leq 0.05$) and picloram (1500 lbs/a; $P \leq 0.1$) plots.

Knapweed and Hoary Cress Response - Knapweed biomass reductions were associated with individual herbicide treatments. Picloram and clopyralid treatments reduced knapweed biomass compared to imazipac and control (860 and 500 lbs/a versus 2600 and 2700 lbs/a). The control provided by imazipac on knapweed was visibly spotty with areas of moderate control intermixed with areas of little or no effect. Knapweed biomass reductions in the first growing season following the grazing treatment were not detected.

Hoary Cress biomass reductions were associated with specific herbicide treatments. The imazipac treatment reduced hoary cress biomass when compared to the growth response following the picloram, clopyralid and control treatments (97 lbs/a versus 610, 720 and 880 lbs/a).

DISCUSSION

Germination trial

Continuous light has been observed to inhibit germination in a number of species (Bewley and Black 1994, Bradbeer 1988) and is generally associated with species that favor seed burial or shaded environments. Our results suggest a knapweed germination strategy that favors seed burial and/or shaded environments for germination. Results from the moisture tests indicate that seeds require exposure to moisture conditions near field capacity for approximately 7 days for germination to begin and that exposure to that environment for 25 to 32 days yielded the highest daily rate of germination. Knapweed germination decreased with exposure to increased salt concentrations. However for practical purposes most sites classified as saline would result in only a moderate reduction in germination.

In the sagebrush steppe, knapweed populations are maintained primarily through vegetative reproduction (creeping root system). Seed development is sensitive to summer soil moisture and appears to result in spotty viable seed production. Knapweed seed is suited to germinate in riparian, wet meadow, sodic meadow and meadow environments. In the wettest years germination could expand to alluvial fans and toe slopes where topographic attributes concentrate soil moisture. However, successful knapweed germination is probably limited to areas where wetted soil conditions are maintained for extended periods of time and community structural characteristics afford an opportunity for seed coverage by litter or soil.

Grazing/herbicide trial

The control plots ended the 2003 and 2004 growing seasons with 2400 and 2700 lbs/a of standing knapweed biomass.

Plots that were grazed once ended the 2003 growing season with 1700 lbs/a of standing knapweed biomass. The grazing treatment removed approximately 1400 lbs/a of biomass in June. Re-growth on these experimental plots during July and August contributed 600 lbs/a. Forage utilization under this treatment was 55%.

Plots that were grazed twice in 2003 ended the growing season with 500 lbs/a of standing knapweed biomass. The first grazing period removed 1400 lbs/a of biomass in June, re-growth on the plots in July and August contributed 600 lbs/a (total biomass = 1700 lbs/a). The second grazing period removed 1200 lbs/a from the plots. Approximately 2600 lbs/a of knapweed and hoary cress biomass was removed using this treatment strategy. Forage utilization under this treatment was 55% in the first grazing period and 70% in the second grazing period.

The nutrient content of Russian knapweed and hoary cress was relatively high in June but declined with maturity (Table 3). Goats grazed a steady knapweed diet throughout the summer of 2002 and 2003. They gained weight and did not appear to exhibit any visible toxic effects.

Vegetation response near the end of the first full growing season (2004) demonstrated a grass a weed response. Grazing was associated with increased grass density. Grass biomass increases were greatest and knapweed biomass was lowest on plots receiving the clopyralid treatment. A similar but less robust response was observed with the picloram treatment. Imazapic yielded the greatest reductions in hoary cress. These results are preliminary. Data collection will continue in 2005.

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Table 1. Cumulative knapweed germination in a light versus dark environment at 0.0 MPa.

<u>Day</u>	<u>Dark</u>	<u>Light</u>	<u>LSD</u> (0.05)
	----- % -----		
4	0	0	--
8	3.0	1.6	--
12	8.0	3.2	3.0
16	13.4	5.2	3.9
20	23.4	10.4	4.4
24	31.0	13.6	3.7
28	43.0	21.0	3.7
32	55.2	30.4	8.0
36	60.4	35.6	10.1
40	61.4	39.2	8.3

Table 2. Knapweed germination during each 8-day periods in light and dark environments.

<u>Day</u>	<u>Dark</u>	<u>Light</u> ¹	<u>Mean</u> ²
	----- % -----		
0- 8	3.0a	1.7a	3.0d
9-16	10.4a	3.4b	7.5c
17-24	17.4a	8.4b	15.0b
25-32	24.2a	15.0b	18.6a
33-40	6.2a	8.6a	8.1c

¹ Letter differences across treatment columns are different at P<0.05.

² Mean period (8-day) comparisons are vertical (P<0.05).

Table 3. Knapweed and hoary cress nutrient content in June and August 2003.

Nutrient	June		August	
	Knapweed	Hoary Cress	Knapweed	Hoary Cress
	----- % -----	----- % -----	----- % -----	----- % -----
Crude Protein	18.5	15.3	7.4	7.4
ADF ¹	32.2	22.8	44.4	32.0
NDF ²	43.4	33.9	63.3	45.8
TDN ³	58.0	62.0	54.0	58.0

¹ADF = acid detergent fiber

²NDF = neutral detergent fiber

³TDN = total digestible nutrients