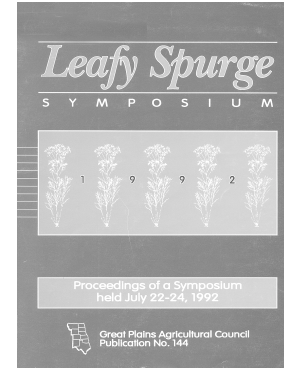


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1992 Leafy Spurge Symposium and Proceedings

Edited by ROBERT A. MASTERS, SCOTT J. NISSEN, and GEIR FRIISOE

Introduction / Business meeting minutes

ROBERT A. MASTERS / MARK THOMPSON and ROBERT A. MASTERS

President, Leafy Spurge Task Force, 1992. USDA-ARS, 344 Keim Hall, University of Nebraska, Lincoln, Nebraska 68583, (402) 472-1546

The 11th Annual Leafy Spurge Symposium of the Leafy Spurge Task Force, Soil and Crops Committee, Great Plains Agriculture Council was held July 22 through 24, 1992 at the Cornhusker Hotel and Convention Center in Lincoln, Nebraska. The purpose of the Symposium was to provide a forum for scientists to discuss current research findings, for state and federal agriculture department personnel to discuss noxious weed policy issues, and for producers to express their concerns and experiences with leafy spurge management. A total of 114 individuals from Texas, North Dakota, South Dakota, Nebraska, Montana, Wyoming, Idaho, Oregon, Colorado, Kansas, Minnesota, and Manitoba and Ontario, Canada attended the Symposium.

The Symposium began in the afternoon with a plenary session where invited speakers discussed the history and role of the Leafy Spurge Task Force and the role of USDA-ARS in leafy spurge research. Three concurrent sessions (Research Reports, Regulatory Affairs, and Producer's Forum) were held during the morning of the second day of the Symposium followed by a general session in the afternoon where experts presented "state-of-science" reviews on leafy spurge taxonomy, biology, physiology, and management strategies. The final day of the Symposium started with an information interchange and poster display session. Jamie Bishop concluded the Symposium with presentation on the need for public involvement in the effort to manage leafy spurge.

This Proceedings of the 11th Annual Leafy Spurge Symposium contains summaries of presentations made during the Symposium. These summaries were prepared by those giving the presentations.

I would like to thank Jamie Bishop, Geir Friisoe, John Kitchell, Gene Lehnert, Scott Nissen, Barte Smith, and Doug Smith for their outstanding assistance with the planning

and coordination of the 11th Leafy Spurge Symposium. Their input and dedication contributed in a significant way to the success of the Symposium. I would also like to thank Jim Pester for his help in preparing these Proceedings.

The next Leafy Spurge Symposium will be held in July 1993 in Colorado. Dr. George Beck is the Symposium Coordinator and can be reached at (303) 491-7568 for more information.

Minutes of the Leafy Spurge Task Force business meeting

Cornhusker Conference Center, Lincoln, Nebraska, July 23, 1992

1. Introduction

The meeting was called to order by President, Bob Masters.

2. Report by Donald Anderson, Administrative Advisor

D. Anderson called attention to issues for consideration during the business meeting. 1) Consider changing the meeting date to reduce conflict with research activities. 2) Establish program committee to facilitate meeting organization and activities.

3. Timing of Future Symposia

Those attending the meeting discussed several alternative times for future Symposia. A date in June through early July was not desirable because of conflicts with field research activities and data summarization. Holding the Symposia in the fall or winter was in conflict with those with teaching appointments and with various professional society annual meetings that typically occur during this time period. Those attending the business meeting determined that late July through early August was the best time to hold the Leafy Spurge Task Force Symposium.

4. Critique of 1992 symposium

Bob Masters asked those attending the business meeting to critique the 1992 Symposium and discuss what elements should be included in the agenda of future meetings. The agenda for the 1992 Symposium included concurrent sessions for researchers, regulatory personnel, and producers and a general session where "state-of-the-science" information was presented on various aspects of leafy spurge taxonomy, biology, and control. This format was used in an effort to increase participation of regulatory personnel and producers attending the Symposium. Attendance and participation by regulatory personnel were good, but not by producers. Business meeting attendees indicated that there was not enough time for discussion during the Symposium and that the purpose of the Symposium was to provide a forum for researchers to get together and exchange ideas and information. In keeping with the purpose of the meeting it was not necessary to structure the meeting agenda to accommodate non-scientists. Bob Masters indicated that if non-scientists were invited to attend then there should be an attempt to develop an agenda that was of interest and value to them. He suggested that the Task Force members consider establishing a schedule of planning Symposiums every 3 years with a broad agenda con-

taining elements of interest to scientists and non-scientists and in the intervening years conduct Symposium with the sole intent of facilitating interaction among scientists conducting research with leafy spurge. The group discussed the merits of this proposal. George Beck moved that the 1994 and 1995 Leafy Spurge Task Force meetings be research oriented and that meeting held in 1996 be designed to accommodate the concerns of scientists and non-scientists. Don Galitz seconded the motion and the motion was passed unanimously by the business meeting attendees. Scott Nissen suggested having a poster session at future meetings. Dave Biesboer suggested that having sessions at the meeting where scientists would be given 5 to 10 minutes to present research might stimulate discussion interaction. He felt that the future Task Force meetings should be less structured and more informal.

5. Future Leafy Spurge Task Force symposiums

The 1993 Leafy Spurge Task Force Symposium will be held in Colorado. Scott Nissen motioned that the Symposium be held in Bozeman, Montana in 1994. This motion was seconded by Cal Messersmith and passed unanimously. Chuck Quimby stated that Neal Spencer would be responsible for coordinating the Symposium in 1994. Chuck Quimby motioned that the Symposium be held in Fargo, North Dakota in 1995. Seconded by George Beck and passed unanimously. Don Galitz was volunteered to coordinate the Symposium in 1995.

6. Executive committee for 1993

The officers for 1993 are:

George Beck, Chairman, Neal Spencer, Vice-Chairman, and Don Galitz, Secretary.

7. Motion

A motion was made to adjourn the business meeting, was seconded, and approved.

(Notes of the business meeting transactions were taken by Mark Thompson and summarized for submission by R.A. Masters, President, Leafy Spurge Task Force, July 23, 1992.)

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History of GP(A)C-14 and its effect on leafy spurge control

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Coordination of regional leafy spurge control efforts began with the Leafy Spurge Symposium, June 26 to 27, 1979, in Bismarck, ND. This was followed by the Northern Regional Leafy Spurge Conference, December 17 to 18, 1979, in Billings, MT. A coordinating committee of directors of the state Agricultural Experiment Stations (AES) and USDA-ARS was formed at these ad hoc meetings to assure that an effective research and extension program would be established by the key states. The greatest initial interest was in North Dakota, Montana, and Wyoming, with supporting interest from Nebraska and South Dakota.

Several ad hoc group efforts occurred prior to approval of the GPC-14 Research Committee by the Great Plains Agricultural Council (GPAC). First, the coordinating committee of administrators appointed the Regional Leafy Spurge Working Committee (ad hoc) of research and extension scientists to form a coordinating structure; the committee was chaired by Russ Lorenz, USDA-ARS, Mandan, ND. Second, a newsletter, “*Leafy Spurge News*”, was started in 1980 by the Montana AES. The newsletter continues today with Russ Lorenz as editor. Third, a five-state research project was submitted to the Old West Regional Commission and was funded from March 1981 to February 1982. North Dakota was the lead state and the project included Montana, Nebraska, South Dakota, and Wyoming.

The leafy spurge effort moved from ad hoc to recognized status when the GPAC approved Research Committee GPC-14 Leafy Spurge Control in the Great Plains in June 1981. Don Anderson, Associate Director of the North Dakota AES, was named administrative advisor and continues in that role. The first meeting was held June 29 to 30, 1981, in Fargo, ND.

The objectives of GPC-14 established in 1981 were: a) to develop and evaluate techniques for weed control and land management to control leafy spurge in the field; b) to demonstrate through extension and other educational efforts the methods of leafy spurge control and land management to improve the productivity of agricultural and public lands; c) to increase the knowledge of leafy spurge biology and physiology through basic

and applied research; and d) to coordinate the leafy spurge research and extension program efforts of the cooperating agencies.

Meetings of GPC-14 have been held annually in late June or July since the organizational meeting. The meetings always have included presentations of the latest research and extension information with some time devoted to field tours. The meeting objectives are focused on leaders in research, extension, and land management organizations (e.g., U.S. Forest Service, Bureau of Land Management), although local weed control officers and some producers regularly attend. Annual attendance has been 60 to 120.

The GPAC was reorganized administratively in 1986 into major topic committees. The GPC-14 Research Committee then became a Task Force under the Crops and Soils Committee. The GPAC asked that objectives become more specific for all task forces.

The current objectives, presented through the administrative advisor and approved by GPAC in 1991, are to: a) provide an economic analysis of present and future losses caused by leafy spurge and cost benefit analysis of biocontrol program; b) determine the status of leafy spurge weed problems and biological control work already in progress; c) select and set up specific sites in each state for establishment of field insectaries and future redistribution sites; d) collection of biocontrol agents for distribution to insectary sites; e) evaluate colonization of biocontrol organisms at release sites from previous years; f) development of predictive model for determining optimum collection times for field-insectary-reared biological control organisms; g) develop laboratory and greenhouse mass production of biocontrol organisms of leafy spurge; h) development of a leafy spurge training manual and instructional material; i) preparation of an information packet, audio visual material, and press releases for documentation and education of the public; and j) collect, maintain, and propagate a collection of native species of *Euphorbia* for use by researchers to screen new potential biological control agents. These objectives emphasize activities in biological control research, but under-represent the integrated control efforts that are continuing such as use of herbicides and cultural control including competitive forage species and grazing management of goat, sheep, and cattle.

GPAC-14 has been an effective task force for coordinating leafy spurge research and information exchange programs in North America. Although this committee can't dictate programs and activities in specific states, the regular information exchange has minimized duplication of effort and has resulted in more rapid evaluation of progress than occurs in normal scientific channels. Probably no other widespread weed research program in North America has as much coordination of activities as this leafy spurge control effort.

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The role of USDA-ARS in leafy spurge research

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USDA-ARS, Biological Control of Weeds Laboratory, Bozeman, MT 59717

Thank you, Dr. Masters. I would like to express thanks to Dr. Shearman for his welcome to Nebraska for this GPAC Task Force 14 meeting, and a special thanks to the Nebraska Leafy Spurge Working Task Force for helping to sponsor the meeting. This is one “working” group that really works!

I am to speak today on the Role of the Agricultural Research Service (ARS) in Leafy Spurge Research. First, I bring you greetings from our National Program Leader for Weed Science, Dr. Joe Antognini. He wanted to be here, but the administrators of the National Program Staff gave him another assignment this week; he is representing ARS at a meeting on Sustainable Agriculture in Memphis, TN. Joe has to go to many meetings. He is currently President of the Weed Science Society of America, and last week he met with the WSSA Board in Denver to plan the February 1993 meeting there. I am sure he would want me to invite all of you to plan to attend that meeting.

We are fortunate to have Joe Antognini as our National Program Leader in Weed Science. He strongly supports research on leafy spurge. A year ago last April, he obtained official permission to organize an ARS-sponsored workshop to establish ARS priorities for leafy spurge research. The meeting, held in Minneapolis, was helpful in focusing the ARS program for leafy spurge. We published a brief report about the meeting in the Leafy Spurge Newsletter. If you want more detail and didn't get a copy of the Proceedings, please request one from Norm Rees, who was secretary of the meeting. As further evidence of his interest in leafy spurge, Dr. Antognini attended and spoke at a workshop/field day on biocontrol of leafy spurge held in Bozeman, MT on July 7 just two weeks ago.

What is ARS currently doing in this leafy spurge arena? Much of the research will be specifically reported on by ARS scientists attending this meeting, so it is more appropriate for you to get the details from them. So my remarks will tend toward generalities with only a little detail. If I don't provide enough detail, perhaps you will be kind enough to ask questions of the scientists involved.

I was told that it would be inappropriate for me to mention specifics about ARS budgets for FYs '93 and '94 because Congress has not yet passed the '93 appropriation and the '94 budget has a long way to go yet. With a national election in the offing, one

guess may be as good as another. My personal opinion is that regardless of who gets elected, most federal agencies will experience flat budgets or actual reductions. How all this will affect ARS with a FY '92 budget of about \$640 million and 2600 scientists is an open question.

But for leafy spurge, I think the picture is bright. The Agricultural Research Service has responded to the wishes of the legislative branch and places specific emphasis on leafy spurge research. Research on that one weed species now commands about one-eighth of the total weed science budget in ARS or about \$1.9 million. I think that is remarkable when you think about all the weed problems in the country. About 12 SYs are assigned to leafy spurge. More scientists than that (around 18) are involved but some of them only work on leafy spurge as part of their responsibility.

ARS laboratories involved, some of which are reporting research here, include the Sheep Research Station at Dubois, ID, the Foreign Disease and Weed Science Lab at Frederick, Maryland, our Biological Control of Weeds Research Unit at Bozeman and Sidney, MT, and part of an SY (Robert Kramer) working on microorganisms of the rhizosphere at Columbia, MO.

Others include five ARS scientists, physiologists and biochemists, at Fargo, ND, who have been assigned to work on the anatomy, physiology, and biochemistry of leafy spurge. Their task is to take species apart and learn all we can about it. Leafy spurge is a very successful weed and by learning the "whys" and "hows," perhaps as Russ Lorenz says, an "Achilles heel" can be found or who knows what uses may be made of it. I know that others here are interested in this aspect of leafy spurge.

I want to specifically mention some of the work of the ARS lab here in Lincoln, specifically that of Bob Masters, our moderator, who is a member of the Wheat, Sorghum, and Forage Research Unit under the Research Leadership of Ken Vogel; this Unit cooperates with the Department of Agronomy, University of Nebraska (UNL). Dr. Masters, Dr. Scott Nissen (Plant Physiologist, UNL), and Dr. Tony Caesar, Res. Plant Pathologist from our lab in Bozeman won a grant from ARS's Office of International Affairs (\$14,000), U. of Neb. Office of International Programs (\$2000) and UNL Research Council (\$2,500) to support foreign travel in Europe and Russia for the purpose of collecting plants and plant diseases across this wide area. I should mention that they received the support of Dr. Richard Soper, National Program Leader for Biocontrol and Acting Director of the Office of International Affairs. Dr. Soper has also been a strong supporter of leafy spurge research. The travelers sampled leafy spurge populations and collected specimens from 57 locations in Europe and 35 locations in Ukraine and Russia. This effort will greatly help in meeting several of the objectives expressed in our 1991 Minneapolis workshop: 1) establishment of a world collection of spurge at Lincoln that would contain plants representing the genetic diversity found in European and North American leafy spurge; 2) determine Eurasian origins or other American biotypes through DNA comparisons (the ramifications for biocontrol matchups and just a better understanding of our target weed are self-evident); and 3) conduct an intensive search for plant pathogens as potential biocontrol agents. These microbial natural enemies can contribute greatly to the biocontrol of spurge. The mission of these world travelers was met very successfully in all regards. Also, they have some interesting stories to tell about their adventures.

This is a good time to mention another of our ARS labs, the Biological Control Lab-Europe in Montpellier, France, under the leadership of Dr. Lloyd Knutson. This lab was very instrumental in helping the team I just mentioned make their trip through furnishing a vehicle, serving as a launch point, and a retrieval point. The BCL-E also contracted with a former employee, Massimo Cristofaro, to serve as a guide on the Eastern European phase of the odyssey.

By the way, the Biological Control Laboratory - Europe is very active in leafy spurge research and right now they are focusing their effort in Asia. This is part of their effort to coordinate and cooperate with the International Institute of Biological Control (Commonwealth Agricultural Bureaux) in Delemont, Switzerland so that duplication of effort is minimized and a maximum number of biocontrol agents are made available to North America. Luca Fornasari of the BCL-E is in China now collecting two new *Aphthona* species and will come to Bozeman in August 1992 to work with Norm Rees and Dr. Jeff Littlefield of Montana State University (MSU) on host-range testing of these agents in the MSU quarantine. We are ready with Euphorbiaceous plants in hand because APHIS has helped us get some of the native species required and provided funds and because Robert Nowierski of MSU has provided funds through the Montana Noxious Weed Trust Fund for the hiring of a plant-culturing specialist.

I have just learned that Dr. Sam Yang of the Frederick, MD lab has just returned from China where he collected plant pathogens as potential biocontrol agents for leafy spurge. These travels in China are facilitated by an ARS-sponsored laboratory there that was arranged by Dr. Soper.

I think that you can see that these projects are cooperative efforts as most of our projects are! ARS is obliged by law to conduct research that supports the programs of action agencies. But it is a 2-way street. Our agency receives funding or in-kind support from many agencies for leafy spurge research: the Animal and Plant Health Inspection Service, Forest Service, SCS (Resource Conservation and Development), and the Cooperative Extension Service; USDI agencies, e.g., BLM, BIA, USFWS, NPS, BOR; the Corps of Engineers (DOD); several state Agricultural Experiment Stations, including the University of Nebraska, University of Wyoming, Montana State University, North Dakota State University, Colorado State University, and Utah State University; several state departments of agriculture including North Dakota, Montana, Wyoming, Nebraska, and South Dakota; and various other state agencies; various county weed boards and county weed officers in several states; and the unique Montana Noxious Weed Trust Fund.

In our biological control program, cooperation with Agriculture Canada has been of paramount importance. Dr. Peter Harris of that agency is the "Father of North American Weed Biological Control Research." In July, 1989, Dr. Harris invited several of us to Spruce Woods Provincial Park in Manitoba to view some of his work with the black dot spurge flea beetle, *Aphthona nigricutis*. I was just on my way to Bozeman to my new job as Research Leader of the newly established Rangeland Weeds Lab. So it was especially exciting for me to see the possibilities. As a result of Dr. Harris' cooperation and extensive cooperation among research and action groups in this country, we are now seeing the beginnings of similar effects at several locations in several states. Other *Aphthona* species have proved to be important. When I arrived in Bozeman in August 1989, I learned of a 1987 ARS release by Norm Rees and Bob Pemberton near Bozeman of *Aphthona flava*

originating from the ARS lab then in Rome, Italy. In the past two years, the control there has been spectacular. In a cooperative field day on July 7 sponsored by ARS and many of the action agencies previously listed, we showed off what we call the first example of a large scale success in biological control of leafy spurge in the United States. We also held a lottery among public land managers and county weed officers for 36,000 beetles.

But, it isn't all that rosy. Neal Spencer of our Research Unit in Sidney, MT has over 170 release sites of the various *Aphthona* species in eastern Montana and North Dakota; about 70% are established. Part of Norm Rees' research is an interagency cooperative pilot test already underway for three years and funded by ARS at \$59,000/yr for the next three years to investigate patterns and timing of releases of *Aphthona* species and effects on vegetation. On our way to Lincoln, we visited research sites in Montana, North Dakota and Nebraska. In the sandhills of southeastern North Dakota, there is no establishment and there is about 70% establishment in the sandhills of Nebraska. Why??? What is the difference? We don't know yet, but we are trying to find out.

Well, where do we go from here? 1) Grazing by sheep/goats and utilization of spurge as hay will continue to be extremely important. 2) Developing basic information on the anatomy, physiology, biochemistry, including DNA fingerprinting and triterpenoid profiling is essential to understanding our target weed and in the development of control strategies. 3) With respect to biological control, we're just getting warmed up: a great arsenal of natural enemies can and will be unleashed. This will include plant pathogens, both introduced and augmented extant species. We are excited about the possibility of a new regional Bioscience Facility at Montana State University for which significant funding has already been received; this will include a plant pathogen quarantine which will complement the one already existing in Frederick, Maryland. Many more insect agents are already in the pipeline, e.g., six additional species have been released in Canada and will soon be cleared for the U.S. Neal Spencer and Andrea Prevost of our Sidney lab have written the Environmental Assessments and submitted permits for approval to APHIS for five of those six and the sixth will soon be completed. Neal Spencer has provided an information sheet on those species which is available at Cindy Heiser's display table (North Dakota Dept. of Agriculture). I have already mentioned others coming soon from China to our quarantine lab in Bozeman. We are also interested in the possibilities of research on mass rearing of some of the insects used as biocontrol agents. 4) Chemical control is still important and should be used as a repeated spot treatment when complete exclusion is the objective. 5) Strategies are being developed to revegetate leafy spurge-infested rangelands with introduced cool-season grasses by Tom Whitson and Mark Ferrell at the University of Wyoming and native warm-season grasses by Bob Masters and Scott Nissen in Nebraska. 6) Integration of all these techniques offers the most hope and yet is what we know the least about. Team research will be required to put the pieces together for understanding of the many interactions taking place. An example of this is a cooperative Bureau of Land Management, Colorado State University, and ARS study on sheep grazing, biocontrol with insects, and herbicides being conducted by George Beck of CSU; this is a precedent-setting long-term study with a commitment for funding by BLM for ten years. 6) Technology transfer will have to go hand in hand with research. "Service" is part of our name and is what we are about. We are proud of our agency and just hope that we can continue to be of "service" in this great cooperative cause for agriculture and the environment.

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Uptake and translocation of polyamines and inhibitors in hypocotyl segments of leafy spurge

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Introduction

Work continues in this laboratory on the role of the diamine, putrescence (*Put*), and the polyamines, spermidine (*Spd*) and spermine (*Spm*), in the development of leafy spurge. These compounds (which will be collectively called polyamines) are ubiquitous and are believed to be involved in the growth and development of plants; possibly at the level of cell division (Slocum and Flores 1991). Some scientists consider these polyamines as possible plant growth regulators. However, their role in plants has not been established with certainty. The objective of this research is to assess the role of the polyamines in the organogenesis of leafy spurge, and whether alteration of the polyamine pathway (Figure 1) may be a weak point for control of the weed. The metabolic relationship to ethylene, a known plant growth regulator, is shown in Figure 1.

These polyamines and several inhibitors of enzymes involved in the biosynthesis of the polyamines (Figure 1) were tested for their effects on organogenesis. The inhibitors used in this report were: DFMO (alpha-difluoromethylornithine), a specific inhibitor of ornithine decarboxylase (ODC) which catalyzes the conversion of ornithine to putrescine; DFMA (alpha-difluoromethyl arginine), a specific inhibitor of arginine decarboxylase (ADC) which catalyzes the conversion of arginine to agmatine, a precursor of putrescine; and MGBG (methylglyoxal-bisguanylhydrazone, a non-specific inhibitor of S-adenosylmethionine, which is a precursor to both spermidine and ethylene. The modifying effects of the natural auxin, IAA (indole-3-acetic acid), were included. The results include a brief summary of results reported at a USDA-ARS meeting in Minneapolis in 1991, but have not been presented to this symposium. Also included are the interactions of MGBG, *Spm* and IAA, as well as the rates of uptake and translocation of radio labeled polyamines and DFMO from the agar-solidified medium.

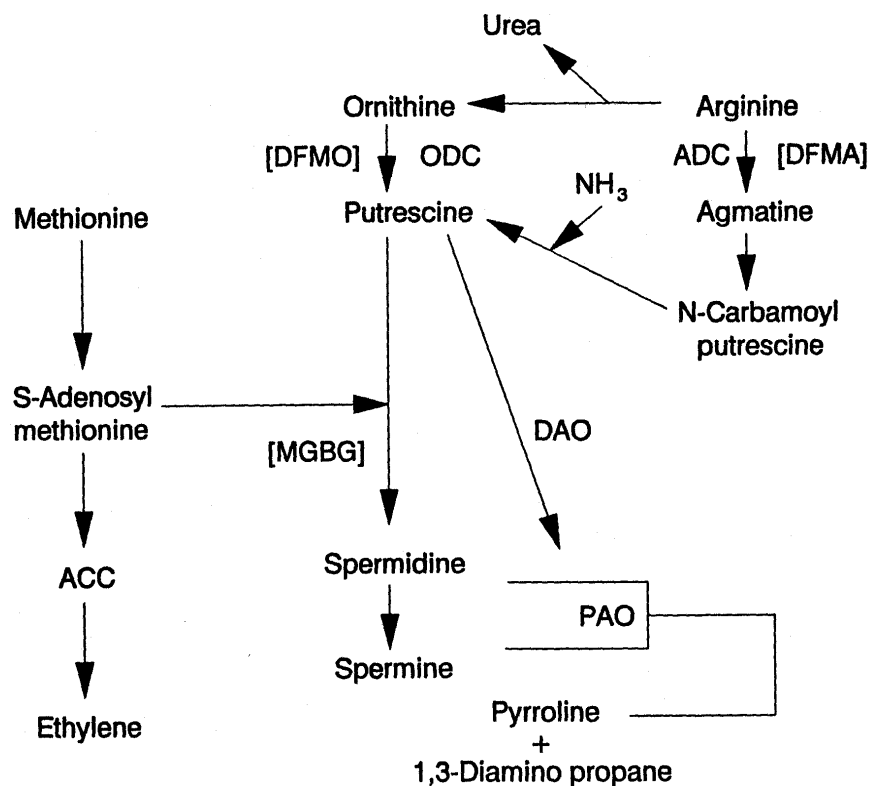


Figure 1. Polyamine biosynthesis and degradation.

Materials and methods

Hypocotyl segments (1 cm long) of aseptically-grown leafy spurge seedlings were placed on B5 nutrient medium (Gamborg *et al.* 1968) at full strength or 0.1 strength salts and vitamins. Sucrose was used at 2% (w/v) and 0.7 % (w/v) agar in all media. Eight hypocotyl segments were placed onto the agar-solidified medium. *Put*, *Spd*, DFMO, DFMA, MGBG, and IAA were also dissolved in the agar media. Radio labeled [¹⁴C]-*Put*, [¹⁴C]-*Spd*, [¹⁴C]-*Spm* or [3H]-DFMO were used to determine uptake into hypocotyl segments laid horizontally or supported vertically in the agar. The hypocotyl segments were blotted, and weighed prior to being analyzed for [¹⁴C] by combustion and [¹⁴C]-CO₂ analysis.

Results

I. Brief summary of results reported at the USDA-ARS coordination planning meeting, Minneapolis, MN, April 23-25, 1991:

In full strength B5 medium, putrescine at 1 to 5 mM had no significant effect on root formation, while 0.5 mM appeared to stimulate roots. DFMO (0.5 mM) strongly inhibited root formation, while DFMA (0.5 mM) did not. The addition of *Put* (0.5 mM) only partially reversed the effects of DFMO.

IAA (1.1 μ M) greatly increased root formation; usually 3 to 5 times the number (per hypocotyl segment) as controls. When both DFMA and DFMO (0.5 mM) were applied together, root formation was inhibited. The inhibition was reversed by the addition of 1.1 M IAA, but not to the level achieved when IAA was used alone (without the inhibitors).

When the B5 salts and vitamins were diluted to one-tenth the normal concentration (sucrose remaining constant at 2% w/v) *Put* at 1 mM inhibited root formation. IAA (1.1 μ M) reversed the inhibitory action of *Put*, so the number of roots per hypocotyl segment was similar to those treated with IAA alone.

II. The effects of MGBG:

In full strength B5 medium, MGBG (like *Put*) had no effect on root or shoot formation. However, as with *Put*, MGBG strongly inhibited organogenesis in hypocotyl segments grown on the diluted B5 medium. Both root and shoot formation were inhibited completely (Table 1). IAA did not reverse this inhibition, as it did with *Put*.

Table 1. Effects of MGBG and IAA on organogenesis in leafy spurge hypocotyl segments.^{a,b}

Treatment	Concentration	No. organs/segment	
		Shoots	Roots
Controls	0	1.3	0.4
MGBG	0.2 mM	0	0
IAA	1.1 μ M	0.3	2.0
IAA + MGBG	1.1 μ M	0	0.03

^aMethylglyoxal-bis-guanylhydrazone (MGBG) and indole-3-acetic acid (IAA).

^bHypocotyl segments were placed in 0.1 X B5 culture media for 28 days.

Because MGBG is an inhibitor of *Spd* biosynthesis, the presumption was that treatment of the hypocotyl segments with *Spd* would reverse the action of the inhibitor. However, the addition of 0.5 mM *Spd* did not reverse the inhibition by MGBG (Table 2), but *Spd* inhibited both shoot and root formation in the 0.1 x B5 medium.

Table 2. Effects of MGBG and spermidine on organogenesis in leafy spurge hypocotyl segments.^{a,b}

Treatment	Concentration	No. organs/segment	
		Shoots ^c	Roots ^c
Controls	0	1.2 \pm 0.1 ^d	0.4 \pm 0.04 ^d
MGBG	0.1	0.6 \pm 0.1 ^{d,e}	0.1 \pm 0.02 ^{d,e}
Spermidine	0.5	0.05 \pm 0.03 ^e	0 ^e
MGBG + Spermidine	0.1 + 0.05	0 ^e	0.1 \pm 0.03 ^e

^aMethylglyoxal-bis-guanylhydrazone (MGBG).

^bHypocotyl segments were placed in 0.1 x B5 culture media for 28 days.

^cMean values and standard errors.

^dCombined results of 3 experiments.

^eDiffers from controls (P < 0.01).

The results of one experiment on uptake and translocation of radio labeled *Put*, *Spd*, *Spm* and the ODC inhibitor, DFMO, from 0.1 x B5 medium are shown in Table 3. These results are from hypocotyls laid horizontally onto the medium.

Table 3. Uptake of (¹⁴C)-polyamines and (³H)-DFMO in leafy spurge hypocotyl segments. ^{a,b}

	4 hours	1 day	7 days	29 days
	nM/g			
Putrescine	–	3.1	7.7	14.1
Spermidine	3.5	5.2	4.5	–
Spermine	3.1	5.0	5.9	–
DFMO	–	0.6	14.6	37.6

^a Values are expressed in nmoles per gram fresh weight calculated as equivalents of the parent compound. DFMO is α -difluoromethylornithine.

^b Hypocotyl segments were placed in 0.1 X B5 culture media for 28 days.

Other experiments were done in which the hypocotyl segments were placed vertically into the agar and the upper half of the hypocotyls were separated from the portion that was in contact with the medium. This was done to avoid errors due to radioactive compounds adhering to the exterior of the hypocotyls, and to determine the extent of movement of radioactivity within the tissues. In media with one-tenth the normal salt concentration, at 28 days, uptake and translocation of [¹⁴C]-polyamines and [³H]-DFMO expressed as nanomoles of parent compound equivalents per mg fresh weight were 11 to 13 nmol of *Put* equivalents, 7.5 to 26 nmol of *Spd*, 2.5 to 10 nmol of *Spm*, and 15 to 26 nmol of DFMO.

Only one experiment has been completed with full strength B5 medium with the hypocotyls oriented vertically. In that experiment, lesser amounts of all four compounds were translocated than for hypocotyls oriented similarly in the diluted media. In that experiment, at 28 days, equivalents recovered for *Put*, *Spd*, *Spm* and DFMO were 2, 2.5, 3.5 and 6 nmol per mg fresh weight, respectively.

Discussion

Putrescine has been shown to stimulate cell division and growth of plant tissues (Slocum and Flores 1991). In leafy spurge, the application of exogenous putrescine as high as 5 mM concentration in B5 nutrient medium has no obvious effect on the formation of roots on isolated hypocotyl segments when the B5 medium contains full strength salts and vitamins. The inhibition by *Put* in the diluted medium is difficult to rationalize. Putrescine has been shown to accumulate under potassium deficiency (T.A., Smith, chapter 1 in Slocum and Flores 1991). Preliminary results indicate that more *Put* may be taken up by hypocotyl segments grown in the dilute medium than in full strength medium, and may accumulate to a higher (phytotoxic?) level under those circumstances.

DFMO inhibits root formation strongly. Since DFMO inhibits the ODC pathway in the biosynthesis of putrescine from ornithine (Slocum and Flores 1991), the implication is that depletion of putrescine results in the failure of root formation. However, the addi-

tion of *Put* in the B5 medium did not reverse the inhibitory effects of DFMO in leafy spurge hypocotyl segments. The results of the uptake experiments indicate that *Put* did penetrate into the tissues, was translocated, and appeared to be present in sufficient quantities so as to overcome the inhibition by DFMO and/or DFMA.

DFMA did not inhibit root formation, in contrast to DFMO, implying that the ornithine pathway may be tied more closely to the control root formation than the arginine pathway.

IAA reversed (at least partially) the nearly total inhibition of root formation induced by treatment with both DFMO and DFMA applied together. It is tempting to speculate that IAA stimulates the formation of putrescine and bypasses the block of *Put* biosynthesis via the two major pathways (catalyzed by ADC and ODC). Preliminary results (not shown) indicate that *Put* levels are elevated during the times of organ formation, but roots are also formed in the absence of detectable *Put* (hypocotyl segments treated with DFMO and DFMA). Further work is underway to resolve these contradictions.

Because MGBG inhibits *Spd* biosynthesis (Slocum and Flores 1991) and MGBG inhibited both root and shoot formation in leafy spurge (grown in the diluted medium), it was presumed that the introduction of *Spd* to the medium should overcome this inhibition. However, this did not occur. In fact, *Spd* itself proved to be inhibitory to organogenesis (similar to *Put*). This contradiction remains under investigation.

Unlike treatment with *Put*, the addition of IAA did not reverse the inhibition induced by MGBG (as it did with hypocotyl segments treated with DFMO and DFMA). Therefore, the mechanism of IAA-*Spd* interaction differs from that for IAA-*Put* interactions.

All of the polyamines and DFMO were taken up readily by the hypocotyl segments. The quantities of radiolabeled equivalents recovered in the tissues were calculated as nmol per mg fresh weight. This is several fold greater than reported for the concentration of endogenous polyamines in other plant tissues (Slocum and Flores 1991) and in leafy spurge hypocotyl segments, as noted in preliminary determinations by this laboratory. Although it seems likely that the parent compounds are readily available within the hypocotyl tissues, polyamines are metabolized in plants (Slocum and Flores 1991). Their metabolism in leafy spurge is expected and they may form conjugates or become bound to plant constituents, as well as forming breakdown products, such as pyrroline and 1,3-diaminopropane.

Conclusions

The role of polyamines in leafy spurge organogenesis is not clear. Putrescine is not phytotoxic in media with a high salt concentration, but is phytotoxic in low salt medium. Spermidine is also phytotoxic in the low salt medium. Although organogenesis was inhibited by the inclusion of inhibitors of the enzymes involved in the biosynthesis of both compounds, the addition of exogenous *Put* and *Spd* did not reverse the action of these inhibitors. It is possible that neither *Put* nor *Spd* are required for organogenesis in leafy spurge. Exogenously applied *Put*, *Spd*, *Spm* and DFMO appear to be taken up readily by

hypocotyl segments. Further work on endogenous levels of polyamines, conjugates and bound forms is underway to aid in the clarification of their role in the control of plant growth.

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Starch degradative enzymes in the roots of leafy spurge

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Introduction

The accumulation of storage reserves is an important aspect for survival of perennial species including leafy spurge. Proteins, lipids and carbohydrates are storage materials. In leafy spurge, storage carbohydrates form the bulk of reserve material in the perennial roots. Seasonal fluctuations in non-structural storage carbohydrates have been observed in roots of leafy spurge and in many other species. The yearly pattern of non-structural carbohydrates in leafy spurge roots is a rapid accumulation of starch in late summer to autumn followed by a winter phase in which starch is slowly degraded.

The distinct changes in quantities of starch suggest seasonal alterations in the activities of the enzymes involved in degradation of starch. The pathway of starch breakdown and the seasonal pattern of activity of these enzymes was investigated in leafy spurge roots to determine if there are changes which can account for the pattern of starch accumulation.

The pathway of starch breakdown in other species involves a number of enzymes. α -amylase is an endoamylase which cleaves 1,4- α -glucose linkages of native starch granule producing branched oligosaccharides, maltose, and maltodextrins. The small molecular weight dextrins are further degraded by α -amylase, β -amylase, debranching enzymes and starch phosphorylase. Alpha-glucosidase and maltose phosphorylase degrade maltose to release glucose. The presence of these enzymes in leafy spurge roots and the seasonal pattern of activity were determined.

Starch degradation

The yearly pattern of total amylase activity was determined in crude extracts of leafy spurge roots. In this assay, the production of maltose by α -amylase and β -amylase from

starch is determined colorimetrically. This assay underestimates the activity of α -amylase by ignoring the other products of its action on starch but is a useful assay to determine the total amount of amylase activity in crude extracts. There are marked seasonal changes in the activity of total amylase. Total amylase activity is lowest in the summer during the growing season and highest in fall and winter.

The activity of α -amylase in crude extracts containing both α -amylase and β -amylase was done using a carbohydrate substrate specific for α -amylase. A similar pattern of α -amylase activity was observed with enzyme activity lowest in the summer during the growing season and highest in the fall growing season and winter months. However, the magnitude of the change in α -amylase activity is less than that for the total amylase activity. This suggests that the observed changes in total amylase activity were also due to an increase in β -amylase activity.

Characterization of leafy spurge root-amylase

The properties of leafy spurge root α -amylase were determined for comparison to other species. Heat stability, calcium requirement for activity and the number of multiple forms of the enzyme were determined. Leafy spurge root α -amylase is not heat stable in the presence or absence of calcium. Activity is reduced by approx. 50% in the presence of a calcium chelator EGTA, indicating a requirement for Ca^{+2} .

Separation of proteins by SDS-PAGE followed by activity gels allow the characterization of enzyme molecular weight. A protein extract from leafy spurge roots reveals the presence of a band with molecular weight of 44 kD similar to that of barley. Separation of proteins by isoelectric focusing (IEF) followed by activity gels allows the visualization of multiple forms of α -amylase which differ in their isoelectric point. Several bands of activity are visible which can be divided into two groups based on their isoelectric points. Group 1 with pI ranging from 5.0 to 5.3 and group 2 with pI from 6.0 to 6.9 are visible. The forms of leafy spurge α -amylase have similar Pi to that of barley aleurone. The gel also shows that all forms of the enzyme are coordinately regulated and that there are no seasonal changes in particular isoforms.

Leafy spurge root α -amylase has properties of both barley aleurone and spinach leaf enzyme. It is, however, antigenically, distinct and does not cross-react with antibodies to barley α -amylase.

Maltose metabolism

The cleavage of maltose by α -glucosidase and maltose phosphorylase is the final step in the complete degradation of starch. Both enzymes are detectable in leafy spurge roots, but there are no significant seasonal differences in the activity of either α -glucosidase or maltose phosphorylase.

Conclusions

Seasonal changes in starch content are correlated with changes in activity of α - and β -amylases. Alpha-amylase from leafy spurge roots has some characteristics of barley and spinach leaf enzymes but is antigenically distinct. Multiple forms of α -amylase are present, and all forms appear to be coordinately regulated. α -glucosidase and maltose phosphorylase activities are present in leafy spurge roots but do not show any seasonal changes in activity.

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Storage reserves in the roots of leafy spurge

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Introduction

Many persistent weeds are perennial species in which the aerial parts die back annually leaving underground organs which must survive the winter and support the growth of new shoots in the spring. There are a number of types of perennial organs including corms, tubers, bulbs, rhizomes and roots which develop from shoots, roots or leaf bases. Despite their diverse developmental origins, these organs have in common the ability to accumulate abundant storage materials which are then mobilized to support regrowth of buds. Knowledge of the metabolism of storage compounds in perennial organs can provide information which may be useful in the application of management schemes.

In leafy spurge, the extensive root system is the perennial organ and possesses abundant carbohydrate and nitrogenous reserves. Carbohydrates comprise the bulk of storage reserves and are present in roots as starch and sucrose. Nitrate, amino acids and proteins are potential stores of nitrogen. We have been interested in the seasonal dynamics of storage reserves and in the environmental cues which regulate their metabolism.

Nitrogenous reserves

An examination of the free amino acid and soluble protein content in roots indicates that these compounds undergo extensive changes prior to the onset of winter. These compounds are present in relatively low quantities during the growing season, May to September. There is a dramatic increase in both amino acids and protein in October which is maintained through the winter until spring when shoots emerge. The specific amino acids and proteins which account for these changes were investigated further. Changes in aspartic acid, asparagine, glutamine, proline, and arginine accounted for most of the increase in free amino acids. These particular amino acids are common storage compounds because of low carbon to nitrogen ratio. The remaining amino acids showed little or no seasonal changes.

Extracts from leafy spurge roots were examined for the presence or storage proteins. Changes in specific proteins were determined by isolating soluble proteins from roots and separating them by SDS-Polyacrylamide gel electrophoresis. A protein with a molecular weight of 26 KD is present in roots which shows a seasonal pattern of accumulation and degradation. It is present in greatest quantities in extracts from September to January and absent or present in reduced quantities in other months. This protein is present only in the roots and is not visible in protein extracts from seeds or leaves. The seasonal pattern of accumulation of this protein suggests that it is a reserve of nitrogen which can be degraded to provide nitrogen to the root and buds.

Carbohydrate storage reserves

Seasonal changes in non-structural storage carbohydrates have been observed in roots of leafy spurge and in other perennial species. In general, there is a rapid accumulation of non-structural carbohydrates in roots after seed dispersal until top growth dies back followed by a decline in spring as buds emerge. Further changes occur in non-structural carbohydrates during winter months when polymeric reserves are depleted and lower molecular weight compounds accumulate.

In leafy spurge roots, starch accumulates in late summer and fall and is depleted during the winter months. In contrast, sucrose content is low in the season and in the fall and accumulates in winter months. The breakdown of starch provides energy for the root during the winter months and is a source of carbon for sucrose synthesis. Starch breakdown and accumulation of sucrose occur in other organs, such as potato tubers, and may aid in survival of low temperatures during the overwintering period.

The distinct changes in quantities of starch and sucrose suggest seasonal changes in the activities of enzymes responsible for synthesis and degradation of these compounds. We have investigated the enzymes involved in starch degradation in leafy spurge roots and the yearly pattern of activity of these enzymes. The complete degradation of starch to glucose requires the action of several enzymes. The activity of two enzymes, α -amylase and β -amylase, increases significantly in the fall and winter months concomitant with the decline in starch content. The activity of other enzymes in the pathway did not change significantly throughout the year.

Conclusions

Leafy spurge roots contain abundant stores of carbohydrates and nitrogen which are important in the overwintering and regeneration of new shoots in the spring. The storage reserves are present in roots in relatively low quantities during the growing season and accumulate in fall when top growth dies. Breakdown of starch and protein and synthesis of certain amino acids and sucrose occur in the winter months indicating that leafy spurge roots are not dormant at this time.

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Integrated control of leafy spurge (*Euphorbia esula*) with ‘Bozoisky’ Russian wildrye (*Psathyrostachys juncea*) and ‘Luna’ pubescent wheatgrass (*Agropyron intermedium* var. *trichophorum*)

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Introduction

Herbicide research to control leafy spurge in Wyoming began in 1952 with 2,4-D, (Vore & Alley 1982). Picloram, available beginning in 1963, has proven to be the most reliable and effective herbicide for control of leafy spurge with a single application. However, control can be maintained for only three to five years. After this time, retreatment is necessary to maintain adequate leafy spurge control. Adequate control is a level where cattle are able to effectively utilize desirable forage growing in competition with leafy spurge. Hein (1988) found leafy spurge canopy cover exerted the greatest influence on grazing behavior and forage utilization by cattle. Leafy spurge canopy cover of 10% or less and shoot control of 90% or more were necessary to achieve 50% forage utilization by cattle in Montana. In North Dakota, moderate and high-density leafy spurge infestations were avoided until early fall when the milky latex in the spurge disappeared (Lym and Kirby 1987). Cattle only used 2% of the available forage when leafy spurge cover was less than 20%.

Although herbicides play an important part in the control of leafy spurge, alternative methods are available and may be used where persistent herbicides cannot be tolerated. One such method is plant competition. Grass competition has long been recognized as a method of leafy spurge control. Crested wheatgrass was used in Saskatchewan, Canada to decrease the rate of vegetative spread, limit density, reduce seed production, and suppress top growth of leafy spurge. If 2,4-D was applied to such stands twice a year the hay was safely removed for feed, and seed production was prevented (Selleck 1959a and b). Leafy spurge growth may also be suppressed by planting an early emerging crop such as crested

wheatgrass, that will compete with it for early soil moisture (Morrow *et al.* 1979). The purpose of this research was to determine the potential of perennial grass competition as an alternative to repetitive herbicide treatment for control of leafy spurge.

Materials and methods

Research was conducted near Devil's Tower, Wyoming to evaluate the effects of two perennial grass species on leafy spurge. Two applications of glyphosate (Roundup, Monsanto) at 1.5 and 1 quart of product per acre were broadcast with a tractor mounted sprayer delivering 13.5 gpa at 20 psi before seeding grasses in 1989. The first application was May 18, 1989 and the second application was July 19, 1989. Soils were classified as a silt loam with 1.8% organic matter and pH of 6.3. The herbicide, 2,4-D was applied at a rate of 1 lb ai/A on August 9, 1989 to control annual broadleaf weeds. An application of Ally at 0.25 oz/A plus 2 lb ai/A of 2,4-D low volatile ester was made May 14, 1990 to control annual mustards. Plots (33 by 174 ft) were arranged in a randomized complete block design with two factors and four replications. Factors were grass varieties and tillage (tilled or not tilled). Plots were tilled with a rototiller and packed on August 7, 1989 and grasses were seeded with a Tye drill, with 1/4 inch depth bands, on August 8, 1989. Evaluations of percent grass stand, grass number per 20 feet of row, grass yield, percent leafy spurge control, and percent downy brome infestation were taken September 12 and 13, 1991.

'Luna' pubescent wheatgrass and 'Bozoisky' Russian wildrye were selected on the basis of productivity, ability to establish in low moisture areas and ability to compete with leafy spurge. Luna was seeded at a rate of 11 pounds of pure live seed per acre and Bozoisky at a rate of 7 pounds of pure live seed per acre. Row spacing was 8 inches for both varieties.

Results and discussion

Grass stands in rototilled plots were 94% and 93% for Luna and Bozoisky, respectively (Table 1). Grass stands in no-till plots were 86% and 69% for Luna and Bozoisky, respectively. The rototilled plots also had significantly more plants per 20 ft of row than the no-till plots.

Leafy spurge control was excellent at 95% or better in both rototilled and no-till plots (Table 1). Downy brome infestation was considerably greater in the no-till plots. Bozoisky had 21% infestation in the rototilled plots compared to 73% infestation in the no-till plots. Luna had 6% infestation in the rototilled plots compared to 20% infestation in the no-till plots.

Grass production was very good for both the rototilled and no-till plots due to good early season moisture. Luna yielded 3068 lbs/A in the tilled plots and 2181 lbs/A in the no-till plots (Table 1). Bozoisky yielded 1463 lbs/A in the rototilled plots and 1046 lbs/A in the no-till plots.

Table 1. ‘Luna’ pubescent wheatgrass and ‘Bozoisky’ Russian wildrye grass stand, leafy spurge control, downy brome control, grass yield, and number of grass plants from rototilled (RT) and non-tilled (NT) plots.

Grass species	Grass stand		Leafy spurge control		Downy brome control		Grass yield		Number of grass plants	
	RT	NT	RT	NT	RT	NT	RT	NT	RT	NT
			%				— lbs/A —		no./20 ft row	
‘Luna’ pubescent wheatgrass	94	86	99	99	6	20	3068	2181	34	25
‘Bozoisky’ Russian wildrye	93	69	99	95	21	73	1463	1046	37	21
LSD (P<0.05)	5		3		8		716		5	

Grasses planted August 8, 1989.

Evaluations made on September 13, 1991.

Grass characteristics. Luna pubescent wheatgrass is considered to be better adapted to droughty, infertile and saline soils than intermediate wheatgrass. Luna was developed in New Mexico by the USDA-SCS (Onsager 1987). Excellent grass stands were established in both the tilled and no-till plots and provided excellent control of leafy spurge. This grass yielded more than Russian wildrye.

Russian wildrye is a cool-season perennial bunchgrass that has been widely used in the western U.S. and Canada. Once established, it has excellent drought and cold tolerance. The species is characterized by dense basal leaves that are high in nutritive value and palatable to grazing animals. Also, its nutritive value during the late summer and early fall is better than many other grasses, including crested and intermediate wheatgrass. Bozoisky, the cultivar used in this study, was recently obtained from the former Soviet Union. It has been significantly more productive and easier to establish on semi-arid range sites than other Russian wildryes (Onsager 1987). This grass established excellent stands in the tilled plots and fair in the no-till plots and provided excellent leafy spurge control, regardless of tillage treatment.

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Leafy spurge control in North Dakota - 1991

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Evaluation of spray additives with picloram, screening of non-registered herbicides, and various glyphosate plus 2,4-D combinations for leafy spurge control have been the primary emphasis of the research program in 1991 from treatments applied in 1990.

Compounds that appeared to increase picloram absorption in greenhouse and previous field trials were field evaluated. The additives MAPEG 400 MO, X-77, L-77, LI-700, Tetronic 504, and Triton CS-7 at 0.5% (v/v) increased leafy spurge control when applied with picloram compared to the herbicide applied alone but not with picloram plus 2,4-D regardless of application date. Several additives evaluated in the greenhouse will be field tested in 1991, including Scoil, Sunit II, Raider, Raider L (pH), and BAS-090.

Many labeled and unlabeled herbicides were evaluated for leafy spurge control in greenhouse and field experiments. Imazethapyr (Pursuit), imazaquin (Scepter), and BAS-514 averaged greater than 80% control with no grass injury when applied in September. Control was similar when the herbicides were applied alone or with an additive or in combination with 2,4-D. DPX-V9360 (Accent) and imazethapyr (Pursuit) applied with X-77 or 2,4-D plus X-77 provided greater than 80% leafy spurge control, but grass injury ranged from 40 to 80%.

Glyphosate plus 2,4-D (Landmaster BW) provided greater than 65% leafy spurge control when applied alone and 95% control when applied with picloram. Grass injury was variable due to location and application date (35 to 80%).

2,4-D mixed amine (Hi-Dep) and 2,4-D alkanolamine were evaluated for leafy spurge control. Leafy spurge control 12 months after application averaged 10% or less regardless of formulation. 2,4-D plus picloram provided similar leafy spurge control regardless of 2,4-D formulation.

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Leafy spurge control in North Dakota - 1992

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Imazethapyr, imazaquin, nicosulfuron, and quinclorac: have been evaluated for leafy spurge control since 1989 at North Dakota State University. All four herbicides provided the highest leafy spurge control and the least grass injury when fall-applied, but control varied by location. The herbicides were applied with additives that included, X-77 at 0.5% (v/v), Scoil at 1 qt/A, and BAS-090 at 1 qt/A.

Imazethapyr was applied at 2 and 4 oz/A with Scoil and X-77 and control averaged 40 to 60% 9 months after treatment (MAT), respectively. Control increased 10 to 15% when Scoil was the adjuvant with imazethapyr at 2 oz/A but not at 4 oz/A.

Imazaquin was applied at 2 and 4 oz/A with Scoil and X-77 and leafy spurge control averaged 90% regardless of rate or additive at Chaffee. At Hunter, control by imazethapyr at 2 and 4 oz/A with X-77 was 34 and 38%, respectively, and with Scoil increased to 84 and 87%, respectively.

Nicosulfuron was applied at 1 and 2 oz/A with X-77 and Scoil. At Chaffee, control averaged 75% regardless of rate or additive. At Hunter, control averaged 60% when nicosulfuron was applied at 1 oz/A with Scoil, but declined when applied at 2 oz/A.

Quinclorac was applied at 16 and 24 oz/A with Scoil and BAS-090. Control 12 MAT was greater than 90% regardless of application rate and additive which was similar to picloram plus 2,4-D at 8 plus 16 oz/A at all locations. Control increased from 49 to 82% when quinclorac at 16 oz/A was applied for 2 years consecutively. Quinclorac at 16 oz/A plus picloram at 8 oz/A alone or with BAS-090 provided greater than 90% control after 2 years of sequential treatments.

Two other compounds were evaluated alone and with various herbicides for leafy spurge control. These compounds were XRM-5255 (picloram acid formulated as a water soluble powder) and picloram isooctyl ester plus triclopyr butoxyethyl ester (1:2) (Access, commercial formulation). XRM-5255 was applied alone at 4, 8, and 16 oz/A or with 2,4-D at 16 oz/A. Leafy spurge control was lower with XRM-5255 compared to picloram potassium salt (Tordon 22K) whether applied alone or with 2,4-D. Picloram ester applied alone or with other compounds did not control leafy spurge as well as picloram potassium salt.

Several additives and 2,4-D formulations to increase leafy spurge control with picloram have been evaluated. The additives include MAPEG 400 MO, X-77, Silwett L-77, Li-700, Tetronic 1504, GAFAC RS610, Scoil, and BAS-090. In general, control was similar regardless of additive or 2,4-D formulation. Two 2,4-D formulations, 2,4-D mixed amine and 2,4-D alkanolamine, were evaluated alone and with picloram for leafy spurge control.

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Leafy spurge control in a tallgrass prairie natural area

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Introduction

The Nature Conservancy owns and manages Bluestem Prairie, a 2,500 acre tallgrass prairie nature preserve located in Clay County, Minnesota. The Minnesota Department of Natural Resources Scientific and Natural Areas Program provides assistance in management of the gene. The prairie is located about 15 miles east of Moorhead, MN.

Bluestem Prairie is one of the finest tallgrass prairie remnants in Minnesota and contains a diversity of habitats and most species common to prairie including Greater Prairie Chicken. The prairie contains 13 plant and animal species listed by the state as either special concern, threatened or endangered and contains a plant species that is on the federal threatened species list.

Leafy spurge occurs on the prairie and is of major concern to The Nature Conservancy because of the potential threat this aggressive and persistent plant poses to the biological diversity of Bluestem Prairie. The other concern of The Nature Conservancy was developing a strategy that would effectively control leafy spurge and not threaten the natural qualities of the prairie that needed to be protected and maintained.

In 1987, experts in biological and chemical control and local agricultural inspectors and other land managers working on leafy spurge were invited to Bluestem Prairie to view the leafy spurge infestation. These individuals were asked to recommend a control strategy that would not compromise the natural values of the prairie, but would address The Nature Conservancy's primary objective of eliminating leafy spurge from Bluestem Prairie. The question posed to the visitors was, "What strategy would lead to elimination without harm to the biological diversity of the site?"

A lot was learned that day, but in the end the recommendations could be condensed to three practices that used in combination might lead to leafy spurge eradication. These practices were early detection, annual applications of picloram (Tordon 22K), and continuous monitoring. Armed with these recommendations, a strategy was developed to maximize leafy spurge control and minimize adverse effects of the herbicide on native flora and fauna.

Methods

Volunteers and contract employees searched the property for leafy spurge patches. A preliminary search was conducted in 1985 and 1986 and a more thorough search of the entire property was conducted in 1987 and 1988. Since 1988, about half of the prairie was surveyed each year. In addition, new patches were identified and documented during treatment of known patches or when other management activities were being conducted.

All patches were permanently marked with steel posts and each patch was assigned a number and tagged with an aluminum marker. Permanently marking patches made re-treatment more efficient. The marked patches were surveyed each year and treated with herbicide if viable plants, seedlings, and new shoots were found.

The first treatment of newly found patches were generally a broadcast treatment with a backpack sprayer. Herbicide treatments were applied to large patches with a John Deere AMT 8 foot boom sprayer using coarse flat fan nozzles and herbicide delivered at a pressure of 30 psi. Follow-up spot treatments of individual or scattered plants were usually made with a backpack sprayer.

Picloram was applied at the maximum labeled rate of 2 lbs picloram/acre. A spray solution contained 2.5 ounces of herbicide and 0.2 ounces of blue dye in 1 gallon of water. The dye made treated plants easier to see, improved treatment efficiency, and enabled safer chemical application because the applicator could easily detect exposure to the spray solution.

Prescribed fire was used to enhance chemical control efforts. Fire effectively removed plant litter in the most heavily infested leafy spurge areas. Benefits to burning include the following.

- 1) Increased visibility of leafy spurge plants, especially small shoots.
- 2) Enabled more chemical to reach the leafy spurge foliage and roots, instead of being intercepted in the litter layer.
- 3) Improved detection and treatment of leafy spurge growing in association with woody species by stimulating regrowth of the weed. This stimulation resulted from suppression of the woody species and release of leafy spurge from competition.
- 4) Possible enhancement of seed germination followed by “flushes” of seedling growth. These flushes of seedlings could serve to deplete viable leafy spurge seed from the soil seedbank.

Results and discussion

A total of 344 leafy spurge patches have been found since searching activities began in 1985. The patches cover about 18 acres or 0.7% of Bluestem Prairie. Patches were found throughout the prairie and assuming even patch distribution, there is one known leafy spurge patch for every 7 acres of grassland. Clearly, without aggressive control, the prairie ecosystem and the biological diversity and uniqueness of the site would be lost. The current distribution of leafy spurge patches on Bluestem Prairie (color coded by year

the patch was located) is illustrated in Figure 1. A total of 204 leafy spurge patches were found after two thorough surveys were completed by 1988 (Figure 2). An average of 32 new patches per year have been found since the survey in 1988 and the total patch count on Bluestem Prairie continues to rise at a disturbing rate (Figure 3).

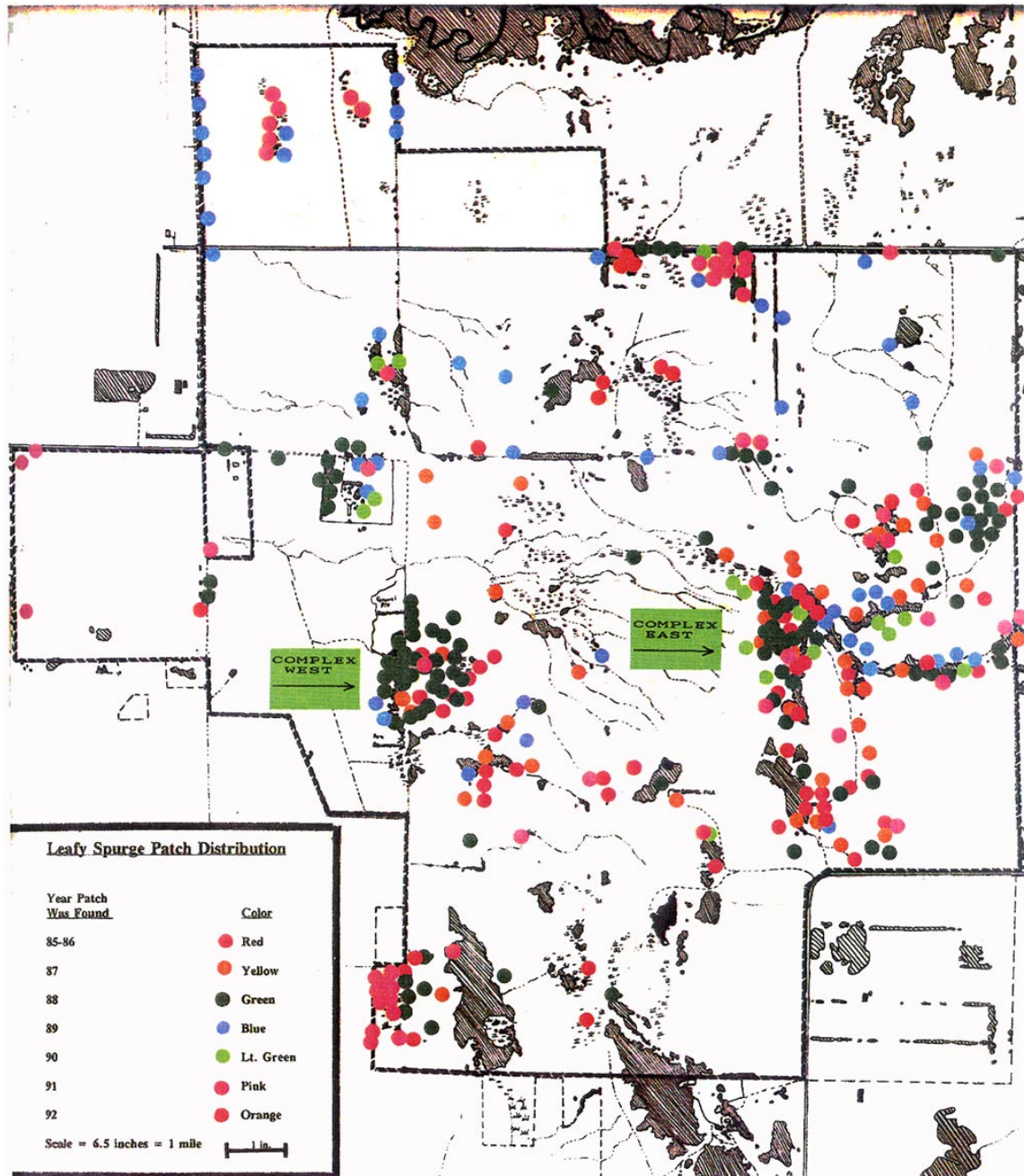


Figure 1. Bluestem Prairie leafy spurge patch distribution color coded by year the patch was found.

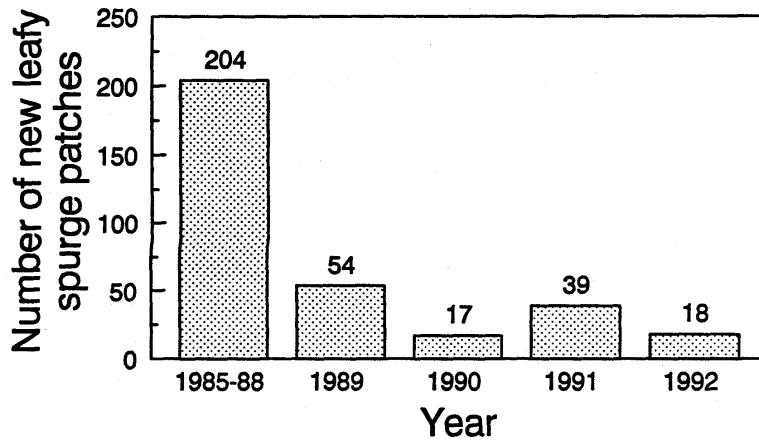


Figure 2. Number of new leafy spurge patches found each year on Bluestem Prairie.

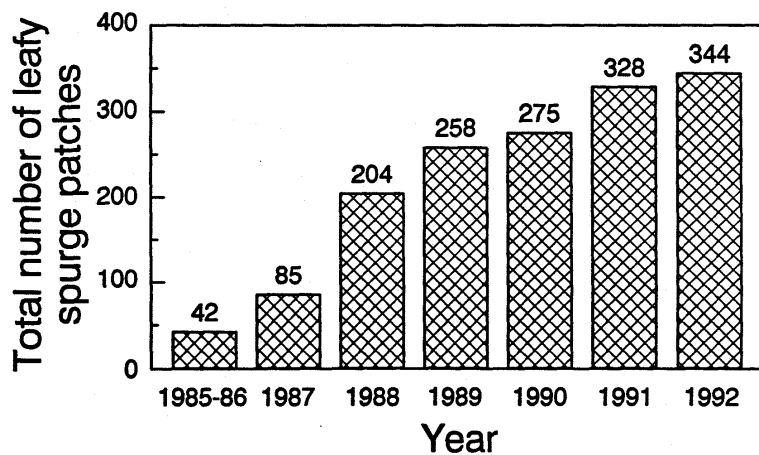


Figure 3. Total number of known leafy spurge patches on Bluestem Prairie. The total in 1991 includes 14 patches found on 180 acres of additional land.

Comprehensive survey of the property enables detection of small patches. These surveys have been and continue to be absolutely essential to The Nature Conservancy's management program to eliminate leafy spurge. Early detection of leafy spurge patches stops additional seed production, thereby, decreasing new patch establishment rate, reduces the amount of herbicide needed because most patches are small, and increases level of control because plants in small patches usually have less extensive root systems and can be eliminated more easily than older, well established patches.

Applying picloram in the manner described has been effective. There has been a substantial decrease in the number of leafy spurge stems per patch as number of treatments has increased (Figure 4). There was an estimated average of 530 stems per patch before the first herbicide treatment, but after 8 treatments, average stem count per patch dropped to 30 stems.

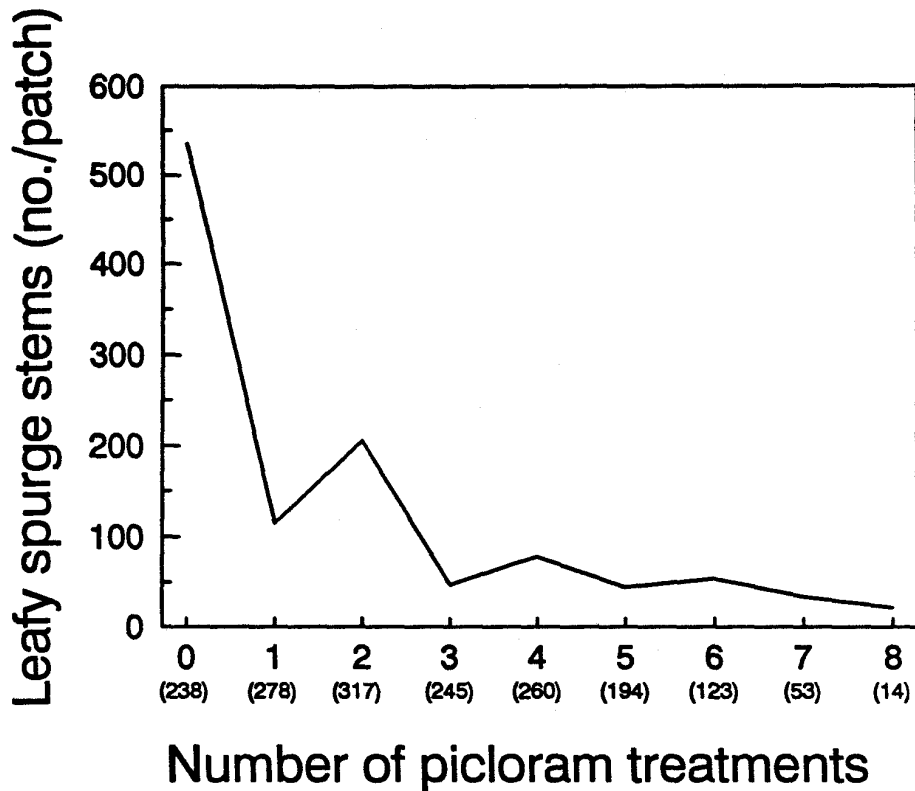


Figure 4. Mean number of leafy spurge stems per patch receiving from 0 to 8 consecutive annual applications of picloram (TORDON 22K) on Bluestem Prairie. Values in the parenthesis are number of patches used to calculate number of leafy spurge stems per patch.

Excellent control with picloram can be achieved, but as posed earlier, “Is elimination of leafy spurge patches possible?” In 1992, 69 of the 344 patches (20%) had no plants present when checked for treatment from mid-June to mid-July (Table 1). It is unlikely that these 69 patches have been eliminated. About 2 to 5% of the patches have been eliminated, based on number of consecutive years that a patch has had no leafy spurge present (Table 1). This is an underestimate of the success of the weed control strategy, because the percentages were calculated using all 344 patches. This total patch number reflects an average of 32 new patches per year that have been identified; therefore, many patches have received just 1 or 2 treatments and elimination should not be expected after such a few number of treatments.

Amount of herbicide applied per patch and time spent treating each patch were measured. The average amount of herbicide applied per patch dropped from about 3 oz in 1988 to 0.4 oz in 1992 (Table 2). Time spent treating decreased each year since the leafy spurge eradication program was implemented. Time treating included time spent traveling between patches, spraying time, and time spent searching for plants. The decrease in treatment time was partly due to decreased travel time between patches caused by an increase in the number of patches identified. As the control program has matured, the time spent searching for plants within a patch increased, while time spent spraying decreased.

Table 1. Percent of total number of leafy spurge patches that had 0 plants present for 1, 2, 3, and 4 consecutive years.

Consecutive years	Years	Patches with no plants -----%-----
1	1992	20
2	1991 through 1992	7
3	1990 through 1992	5
4	1989 through 1992	2

Table 2. Mean ounces of picloram (Tordon 22K) applied per patch and time spent treating each patch from 1988 to 1992.

Year	Picloram applied	Patches with no plants
	----- oz/patch -----	----- % -----
1988	3	63
1989	1.2	33
1990	1	34
1991	1.2	26
1992	0.4	18

Conclusions

Several conclusions can be drawn from these results with leafy spurge control on Bluestem Prairie.

1) The decision to use picloram to control leafy spurge in manner described minimized the adverse effects of both picloram and leafy spurge on the native prairie community.

2) Extensive surveys for new patches is essential to the eradication program. Patches must be found when they are small and the survey should be repeated annually because many small, non-flowering patches can be easily missed. In addition, leafy spurge seed remains viable for up to 8 years and can contribute to reestablishment of patches.

3) Diligent leafy spurge control by neighbors is critical to control program success because leafy spurge seeds are readily dispersed and easily establish new catches. Many new patches were and are being found each year despite virtually 100% elimination of seed production on Bluestem Prairie.

4) Leafy spurge patches must be permanently marked to enable thorough and efficient treatment each year. Without markers, the ability to locate, and retreat many patches would not be possible until a few surviving plants reestablish the patch and increase its visibility.

5) Patches can be eliminated using picloram, but it takes time and persistence. Excellent control, but not eradication, is achieved after the first treatment.

6) Time spent treating and picloram applied per patch decreased as did the overall cost of the control program with follow-up treatments. Continued cost benefit and ultimate success of the control will hinge on eventually halting establishment of new patches.

The Nature Conservancy's leafy spurge control program has been successful at controlling the patches that have been sprayed annually for a number of years. Preliminary evidence suggests that elimination of small patches may be occurring within Bluestem Prairie. Picloram is very persistent and does damage some native plant species even when used properly. Picloram is classified as a restricted use herbicide and must be applied by an EPA certified applicator. There are restrictions in where this herbicide can be used particularly on sites where the depth to ground water is shallow. The herbicide must be applied in accordance with the label. Herbicides are a tool of last resort in The Nature Conservancy's natural areas management program and are appropriate technology to reach the management objective of leafy spurge eradication. In the next few years, it is hoped that there will be a decrease in the number of new patches found and that herbicide treatments will eradicate leafy spurge from the Bluestem Prairie.

Another aspect that warrants additional attention is a need to increase monitoring and application of control measures on lands adjacent to Bluestem Prairie. This coupled with increased efforts to educate other landowners and the general public about the threat leafy spurge poses to native plant communities is essential to the success of The Nature Conservancy's control program.

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Can plant pathogens alone control leafy spurge?

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Introduction

Leafy spurge (*Euphorbia esula* L.) is a perennial weed of the grasslands of North America. Biological control with plant pathogens is being investigated to reduce the use of chemicals for control of leafy spurge. Several fungal pathogens have been identified as potential biocontrol agents for leafy spurge. This paper reports on the efficacy of four fungal pathogens to control leafy spurge growing in pots and the number of pathogen applications required to kill the leafy spurge.

Materials and methods

Four fungi, *Alternaria angustiovoidea* Simmons from North Dakota (2), *Myrothecium verrucaria* (Albertini & Schwein.) Ditmar:Fr from China (4), and one isolate each of *Fusarium* and *Rhizoctonia* from Nebraska were selected for inoculation studies. *Alternaria angustiovoidea* was grown on potato-carrot agar (PCA) and the other three pathogens were grown on potato-dextrose agar (PDA). The media were amended with penicillin (30 mg/L) and streptomycin sulfate (100 mg/L).

Cultures of *A. angustiovoidea* and *M. verrucaria* were grown in darkness at 20° C and 30° C respectively for a week and then were given a 12-hour photoperiod (40 $\mu\text{E s}^{-1} \text{m}^{-2}$) daily for another week for conidia production. Conidia of *A. angustiovoidea* were suspended in 0.5% sucrose solution plus 0.1% Tween 20 (10 conidia/ml) and those of *M. verrucaria* were in 2% sucrose solution plus 0.1% Tween 20 (10 conidia/ml) and then atomized onto leafy spurge until run off.

Plants inoculated with *A. angustiovoidea* were incubated in 20° C dew chambers for 48 hours and those inoculated with *M. verrucaria* were incubated in 30° C dew chambers for 16-18 hours. New plant shoots in the pots were inoculated with the same pathogen

every two to three weeks until no new shoots emerged from the underground root buds or from the stem portions not killed by the pathogens.

Fusarium and *Rhizoctonia* isolates were grown on PDA for three to four days and then 30 g of wheat kernels were placed on each PDA plate. One week later, the wheat kernels, overgrown with mycelium, were placed on the soil near stems of leafy spurge in a single pot, covered with soil, and top watered. The pots were repeatedly inoculated until no new shoots emerged.

Leafy spurges used in this study were propagated from root buds (1-30 root buds per pot) in greenhouse mixed soil in 20-cm diameter round plastic pots or (7 x 7 cm) square plastic pots. Leafy spurge plants, from young seedlings to flowering plants were used for the inoculation studies. Ten pots were used for each pathogen and this test was repeated one time.

Results

All four fungi tested infected and killed leafy spurge established in pots in the greenhouse. The *Alternaria* and *Myrothecium* infected above ground shoots and *Fusarium* and *Rhizoctonia* infected the crown area and roots. Injury or death of the aboveground shoots enhanced regrowth of new shoots from the healthy underground root buds. Most new shoots emerged from the pot perimeters, from drainage holes at bottom of the pots, or wherever there were healthy root buds. The number shoots depended on the number of viable root buds, the vigor of the plants at time of inoculation, and the degree of stem injury.

Leafy spurge flowers were very susceptible to *A. angustiovoidea* and *M. verucaria*. Inoculated flowers turned brown and died before seed production. However, stem portions of the flowering plant might not be killed by the pathogens and new shoots also grew from portions of such stems.

Examination of underground portions of the dead leafy spurge plants four weeks after the plants were killed by the pathogens showed the roots were dead.

One application of the pathogen was sufficient to kill the plants. When there were only one or two young shoots and no viable underground root buds in a pot. However, when there were many viable underground root buds in a pot, two to ten applications of the pathogen were required to kill the plants. Older and healthier plants were more difficult to kill and required greater numbers of pathogen applications.

Discussion

Leafy spurge is a perennial weed that is very difficult to kill because of shoot regrowth root buds on roots. Established potted plants that were repeatedly killed back to the soil, could recover by sprouting new shoots from the underground buds. Applications of four different fungal pathogens were effective in top kill but had to be repeated as new growth occurred. Plant vigor and age affected regrowth and subsequent number of appli-

cations. Frequent retreatment will probably not be economical under field conditions. As a result the pathogens under study are not feasible for use on rangeland.

Plant pathogens, to be effective against leafy spurge, must be translocatable to the roots to inhibit shoot growth to promote and spread from plant to plant. These pathogens could be potentially part of an integrated pest management system that includes insects and chemicals.

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Effects of glyphosate and *Alternaria angustiovoidea* on *Euphorbia esula*

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Alternaria angustiovoidea isolates were collected on leafy spurge (*Euphorbia esula*) in Nebraska and North Dakota. These isolates were cultured at Frederick, MD, and evaluated in a series of greenhouse experiments in 1991 to determine control potential on leafy spurge alone, with an invert oil carrier, or following a pretreatment of glyphosate at .05 and .1 lb/Acre (0.056 and 0.11 kg/ha). The Nebraska and North Dakota isolates alone caused 96% and 98% injury to leafy spurge following 48 hours in a high humidity dew chamber. These isolates also reduced the height of leafy spurge by 40% and 80% respectively 28 days after treatment. The Nebraska isolate reduced dry weight of stems and roots slightly but at 120 days the North Dakota isolate reduced the dry weight of stems and roots 70% and 77% respectively. Field experiments were conducted in 1991 and 1992 using the Nebraska isolate at subirrigated meadow and sand hills pasture sites in Nebraska. Selected sites received applications of glyphosate at 1 lb/acre (1.1) prior to pathogen treatment. The 1991 field experiments also included an invert oil emulsion carrier for *A. angustiovoidea*. In the 1992 field experiment, the isolate was applied alone with a nonionic surfactant in water or in a crop oil and water solution. Glyphosate alone at 1 lb/A reduced leafy spurge cover 65% and 60% in the subirrigated meadow and sand hills pastures respectively. Flowering of leafy spurge was reduced 60% and 70% at the same sites. Glyphosate at 1 lb/A as a pretreatment followed by two applications of *A. angustiovoidea* in an invert emulsion reduced leafy spurge cover 70% in the subirrigated meadow. This combination reduced flowering 80% at both locations. In 1992, glyphosate alone or combined with *A. angustiovoidea* caused 50% injury to leafy spurge evaluated at four weeks after application.

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Diseases of leafy spurge in the northern Great Plains

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Commencing in summer 1991, efforts were undertaken to find, identify and characterize the pathogenicity of native, preferably soilborne pathogens of leafy spurge. The invasive and tenacious nature of the root system of leafy spurge, and consideration of the failure of previous efforts in the application of foliar plant pathogens to substantially decrease leafy spurge stand density, led on this approach. As a result of the discovery by two scientists in our unit, Norm Rees and Chuck Quimby, of the early occurrence of symptoms of senescence in a stand of leafy spurge near Bozeman, Montana, and the subsequent appearance of more pronounced symptoms, the soilborn plant pathogen *Rhizoctonia solani* was isolated and identified. County weed supervisors in Montana were contacted to request that local personnel be alert for symptoms similar to those of the initial discovery of the disease. Investigations of other stands of leafy spurge where stunting of the leafy spurge occurred confirmed the wide-spread occurrence of *Rhizoctonia solani* in Montana, Colorado and North Dakota, causing a variety of symptoms on leafy spurge (Table 1.) All binucleate strains of *Rhizoctonia* were found to be of anastomosis group 4. Furthermore, above-ground symptoms on leafy spurge were associated with the presence of binucleate *Rhizoctonia* spp.

Stands that had attained a dense monoculture were observed to be decreasing in density. This “all points bulletin” approach resulted in the discovery of another pathogen of leafy spurge, the bacterium *Agrobacterium tumefaciens*. Field investigations led to the discovery of several airborne pathogens of leafy spurge.

As described above, the discovery of *Rhizoctonia solani* led to the discovery of other pathogens. At several sites where disease had especially severe effect on leafy spurge, complex relationships with pathogens of diverse taxonomy were seen and are under study. The die out of leafy spurge in circular patches at one site, associated with characteristic mushroom “fairy rings”, is being investigated. High populations of a strain of *Rhizoctonia solani* are present in the soil at the site. A preliminary study has shown that the strain is moderately virulent on leafy spurge, compared with other strains from the Northern Plains area isolated from this weed. However, there is an apparent interaction with a basidiomycetous fungus also present in the soil at this site. The resulting interac-

tion is the most effective that we have seen in eradicating leafy spurge. Furthermore, the *R. solani* has been shown to be highly effective at preventing reestablishment of leafy spurge from seed through preemergence damping off. In contrast, a *R. solani* strain with pronounced virulence when tested singly on leafy spurge has been somewhat less effective in eliminating leafy spurge in the field due possibly to the presence of the antagonistic bacterium *Erwinia herbicola* in the vascular system of the leafy spurge plants at the site where *R. solani* was found. Figure 1 summarizes a preliminary study of comparative virulence on leafy spurge among several strains of *Rhizoctonia* spp.

Table 1. Origin, field symptoms observed, number of strains isolated, nuclear condition, and anastomosis grouping (AG) of *Rhizoctonia* spp. isolated from leafy spurge.

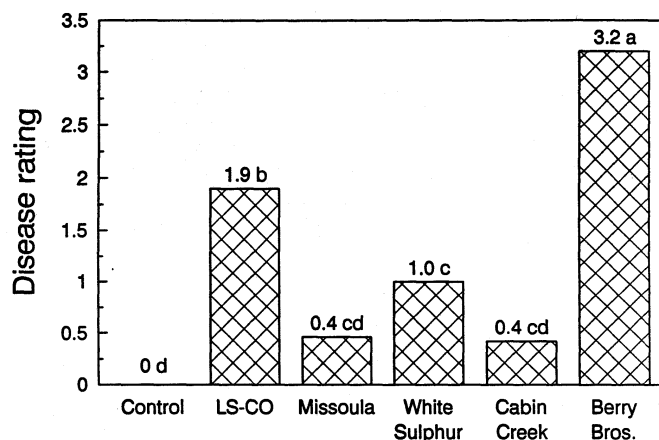
Location	Symptoms			Number of strains	Strain traits
	Dead root buds	Crown rot	Stem rot		
Ft. Benton, Montana	+	+	-	2	1 - binucleate 1 - AG-4
White Sulphur Springs, Montana	+	+	+	2	1 - binucleate 1 - AG-4
Bozeman Montana	-	+	-	1	AG-4
Missoula, Montana	+	+	+	2	1 - binucleate 1 - AG-4
Sidney, Montana	+	+	-	1	AG-4
Fallon County, Montana	+	-	+	4	3 - binucleate 1 - AG-4
Colorado	-	+	+	1	1 - binucleate
North Dakota	+	-	-	1	1 - binucleate

Symptom present (+) and symptom absent (-).

Thus, there are several highly important interactions which have been discovered in relation to biocontrol of leafy spurge, indicating that such interactions may profoundly affect the efficacy of such biocontrol agents as *R. solani*, should they be applied in the field through an augmentative approach.

Previous studies have indicated that for canola, potato, and sugar beets, AG-4 is typically less virulent, less prevalent or both, relative to the anastomosis groups that are the principal cause of disease on these crops, which were AG-2, AG-3, and AG-2-2, respectively (1,2,4). This trend has also been noted on other crops and locations (3), where, for example, AG-4 was more commonly isolated from soil in carnation fields than other anastomosis groups, but was weakly pathogenic compared to AG-2-2. Collectively, these results provide evidence that the use of AG-4 as a biological control agent of leafy spurge would be unlikely to present a threat to major crops grown in the Northern Plains, compared to some other anastomosis groups of *R. solani*.

Studies are continuing to assess both comparative virulence and host ranges of the strains of AG-4 described in the present study.



Sites where *Rhizoctonia solani* isolates were collected

Figure 1. Virulence of *Rhizoctonia solani* isolates as determined with pathogenicity tests on stems of six-week-old leafy spurge. Means followed by the same letter are not significantly different according to Waller and Duncan's k-ration LSD.

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Leafy spurge propagation and herbicide-insect interaction for leafy spurge control

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Propagation of leafy spurge in the greenhouse for insect biocontrol agents was evaluated. Leafy spurge plants grew best at 27°C, fertilized when 20 days old using a balanced fertilizer at a rate of 70 kg N/ha weekly or 135 kg N/ha biweekly in a potting media at pH 7 and a 16-hour photoperiod. Leafy spurge can be propagated to a size adequate for use in chemical and/or biocontrol experiments in approximately 6 weeks.

Aphthona spp. larvae failed to complete development to pupation when propagated with greenhouse-grown leafy spurge. Delayed development may be due to an imbalance or deficiency in the root nutrient content. Greenhouse-grown leafy spurge had a similar starch reserve to field grown plants but only 50% of the water-soluble carbohydrate (sucrose) content. Greenhouse-grown plants that were senesced naturally or artificially had similar carbohydrate concentrations to field grown plants.

It has been hypothesized that biocontrol agents brought from Europe may not establish on North American biotypes. *Aphthona* spp. was exposed to one Austrian and six North American biotypes. No feeding preference was observed and eggs were found in pots of each biotype. Larvae development and adult emergence will be monitored. The effect of herbicide treatment on insect feeding was evaluated. The treatments were 2,4-D at 140 g/ha, picloram + 2,4-D at 70 plus 150 g/ha, and girdling the stem to deplete the latex. *Aphthona nigriscutis* and *A. czwalinae* were placed in separate cages and feeding behavior was monitored for 2 weeks. Insects fed on the herbicide treated plants until the leaves desiccated and only stems remained. Eggs have been found in pots of treated, girdled, and control plants. Larvae development and adult emergence will be monitored.

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Effect of leafy spurge biotypes on biocontrol insects and insect-herbicide interaction for leafy spurge control

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The effect of leafy spurge biotypes on *Spurgea esulae* and *Aphthona* spp. survival and growth was evaluated. The leafy spurge biotypes included plants from Austria, Manitoba, Montana, Nebraska, North Dakota, South Dakota, and Wyoming. These experiments are in progress and data presented are from initial evaluations and are not the final results.

S. esulae galls were collected from the field and placed in a cage with 6 plants of each biotype in a randomized complete block design. The adults emerged, laid eggs, and galls formed. The percentage of tips galled per biotype and the number of larvae per gall were averaged over two trials. The largest percentage of galled tips (68%) were on the Wyoming biotype and no galled tips were found on the Montana biotype. The most larvae per gall (14) occurred on the Nebraska biotype and the least (3) on the North Dakota biotype.

Survival and growth of *A. cyparissiae*, *A. czwalinae*, *A. flava*, and *A. nigricutis* on leafy spurge biotypes was evaluated. Seven leafy spurge biotypes in six-inch pots were placed in a cage with approximately 50 adults of each species in separate trials. Plants were rotated within the cage every 3 days and replaced after 9 days for a total of 3 replications. Feeding was monitored. No feeding preference was observed except there was slightly less feeding by *A. flava* on the Nebraska biotype. Eggs were found in pots of each biotype, but there was poor adult emergence.

The effect of herbicide treatments on *S. esulae* was evaluated. The treatments were 2,4-D at 16 oz/A, picloram plus 2,4-D at 4 plus 16 oz/A, and imazethapyr at 2 oz/A. The leafy spurge top-growth died and gall counts in the herbicide treated plots declined from an average of 30 to 0/4 ft² 1 month after treatment (MAT) compared to 46/4 ft² in the untreated control. Galls were again found on regrowth of treated leafy spurge 3 MAT and averaged 3 galls/4 ft² compared to 8 galls/4 ft² in the control. The number of stems galled were similar 12 MAT regardless of treatment and averaged 4 galls/4 ft².

The effect of herbicide applied to leafy spurge on *Aphthona* spp. establishment was evaluated. *Aphthona* spp. was released in the middle of four 2500 ft² quadrants. The herbicide treatment of picloram plus 2,4-D at 4 plus 16 oz/A was applied to quadrants one and two the first year, quadrants two and three the second year, and so on. Adult movement at four sites was monitored. Adults were distributed equally between the sprayed and unsprayed quadrants.

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Exploration in Europe, Ukraine, and Russia for leafy spurge and associated pathogens

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The objective of the exploration trip was to collect leafy spurge genotypes and associated plant pathogens from plant populations in Europe, Russia, and Ukraine. The two highlights of the foreign exploration were the successful accomplishment of the exploration objective and establishment of productive working relationships with a number of highly qualified foreign scientists. We traveled over 4100 miles from May 19 through June 5 by van in western Europe, Hungary, and Czechoslovakia during the first leg of the trip and collected leafy spurge (*Euphorbia esula* and *Euphorbia virgata*) and associated pathogens from 57 locations.

Leafy spurge was relatively rare in Europe and was found primarily along roadsides and occasionally along railroad right-of-ways. The reason for the scarcity and restricted distribution may have been influenced by the long history of intensive management of all rural lands (croplands, pastures, and forests) in the European countries. Roadsides and railroad right-of-ways possessed two common characteristics that appeared to be conducive to *Euphorbia* occurrence: (1) open, high light environment and (2) absence of frequent site disturbance (cultivation or mowing). In Europe, cypress spurge (*Euphorbia cyparissias*) was very common with distribution limited to roadsides and forest edges.

Leafy spurge was more common in Russia and Ukraine than in Europe. Leafy spurge was collected from June 14 through 26 at 35 locations in southern and central Russia and eastern Ukraine from roadsides, abandoned construction sites, pastures, and nature preserves. On certain sites leafy spurge densities were very high, despite the presence of many natural enemies (insects and pathogens). Another euphorb identified as *Euphorbia steposa* was quite common and was often found growing in association with leafy spurge in southeastern Ukraine and southern Russia.

There was a great amount of variation in leaf shape and size and plant height of the *Euphorbia* spp. specimens collected. At several collection sites in Europe, Russia and Ukraine there was a continuum of plant types from the narrow-leaved *virgata*-type to the tall, robust, broadleaved *esula*-type of leafy spurge. This enormous variability in morphological traits underscores the need for basic research to determine information on the ge-

netic variability among leafy spurge genotypes in North American and Eurasia (Nissen *et al.* 1992).

Numerous plant and pathogen specimens were collected. Plants are currently being propagated and maintained along with several North American leafy spurge biotypes in a nursery by cooperators with the USDA-ARS and University of Nebraska in Lincoln, Nebraska (Table 1). These plants will be used in research to determine the Eurasian origins of North American leafy spurge and will be made available to other scientists interested in working with leafy spurge. Pathogens are currently housed at the USDA-ARS pathogen quarantine facility at Frederick, Maryland where their use for biocontrol of leafy spurge will be evaluated. The personnel associated with the USDA-ARS European Biological Control Laboratory in Montpellier, France and cooperating scientists in Czechoslovakia, Russia, Ukraine were extremely helpful and critically important to the success of this foreign exploration (Table 2).

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Nissen, S. J., R. A. Masters, D. J. Lee, and M. L. Rowe. 1992. Comparison of restriction fragment length polymorphisms in chloroplast DNA of five leafy spurge (*Euphorbia* spp.) accessions. *Weed Science* 40:63-67.

Table 1. Listing of locations where various Euphorbs were collected in Europe, Ukraine, and Russia during 1992.

Country	Nearest city to collection site	Country Code	Site Code	Plant material collected	
				Root/Crown	Seed
Austria	Alland	A	1	+	-
Austria	Mayerling	A	2	+	-
Austria	Sattelbach	A	3	+	-
Austria	Sattelbach	A	4	+	-
Austria	Alland	A	5	+	-
Austria	Stattersdorf	A	6	+	-
Austria	Herzogenburg	A	7	+	+
Austria	Walpersdorf	A	8	+	+
Austria	Nussdorf	A	9	+	-
Austria	Krems	A	10	+	+
Austria	Krems	A	11	+	-
Austria	Krems	A	12	+	+
Austria	Guntersdorf	A	13	+	-
Czechoslovakia	Iza	C	1	+	+
Czechoslovakia	Zeletava	C	2	+	-
Czechoslovakia	Hdalov	C	3	+	-
Czechoslovakia	Opocnice	C	4	+	-
Czechoslovakia	Kosicky	C	5	-	+
Czechoslovakia	Predmerice	C	6	+	-
Czechoslovakia	Tyniste	C	7	+	-
Czechoslovakia	Bolehost	C	8	-	+
Czechoslovakia	Opocno	C	9	+	+
Czechoslovakia	Opocno	C	10	+	-
Czechoslovakia	Bohuslavice	C	11	+	-
Czechoslovakia	Ceska-Skalice	C	12	+	-
Czechoslovakia	Lanzov	C	13	+	-
Czechoslovakia	Markvartice	C	14	-	+
Czechoslovakia	Vysocany	C	15	+	-
France	Salon	F	1	+	-
France	Montferrier	F	2	-	+
Germany	Bad Tolz	G	1	+	-
Germany	Dieninger	G	2	+	-
Germany	Wallgau	G	3	+	-
Germany	Krun	G	4	+	-
Germany	Mittenwald	G	5	+	-
Hungary	Gyongos	H	1	+	-
Hungary	Fuzesabony	H	2	+	-
Hungary	Tizafured	H	3	+	-
Hungary	Debrecen	H	4	+	+
Hungary	Debrecen	H	5	+	-
Hungary	Debrecen	H	6	+	+
Hungary	Debrecen	H	7	+	+
Hungary	Nyriegyhada	H	8	-	+
Hungary	Tokaj	H	9	+	-
Hungary	Biri	H	10	+	+
Hungary	Puspokladany	H	11	+	-
Hungary	Kisujszallas	H	12	+	-
Hungary	Komarno	H	13	+	-
Hungary	Acs	H	14	+	-
Italy	Pisa	I	1	+	+
Italy	Pisa	I	2	-	+

Table 1. (Continued.)

Country	Nearest city to collection site	Country Code	Site Code	Plant material collected	
				Root/Crown	Seed
Italy	Pisa	I	3	+	+
Italy	Pisa	I	4	+	+
Italy	Pisa	I	5	+	-
Italy	Pisa	I	6	+	+
Italy	Pisa	I	7	+	+
Italy	Pisa	I	8	+	-
Russia	Sambek	R	1	-	+
Russia	Sambek	R	2	-	+
Russia	Aksay	R	3	-	+
Russia	Aksay	R	3	-	+
Russia	Kayalnizkaia	R	4	-	+
Russia	Preyradnoie	R	5	-	+
Russia	Moskovskoe	R	6	-	-
Russia	Shpakovskoie	R	7	+	-
Russia	Shpakovskoie	R	8	-	+
Russia	Tatarka	R	9	+	+
Russia	Nikolievka	R	11	+	+
Russia	Nikolievka	R	12	-	+
Russia	Romanovka	R	13	-	+
Russia	Romanovka	R	14	-	+
Russia	Sherbedino	R	15	-	+
Russia	Romanovka	R	16	-	+
Russia	Balashov	R	17	-	+
Russia	Balashov	R	18	-	+
Russia	Arkadak	R	19	-	+
Russia	Arkadak	R	20	-	+
Russia	Arkadak	R	21	-	+
Ukraine	Merefa	U	1	-	+
Ukraine	Pervomaisky	U	2	+	-
Ukraine	Krasnopavlovka	U	3	+	-
Ukraine	Losovaia	U	4	+	-
Ukraine	Samoilovka	U	5	+	-
Ukraine	Varvarovka	U	6	-	-
Ukraine	Pavlograd	U	7	+	-
Ukraine	Synelnikovo	U	8	-	+
Ukraine	Synelnikovo	U	9	-	+
Ukraine	Zaporoschie	U	10	-	+
Ukraine	Orehov	U	11	-	-
Ukraine	Rosovka	U	12	+	-
Ukraine	Shirokino	U	13	+	-
Ukraine	Novoazovsk	U	14	-	+

Collected (+) and not collected (-).

Table 2. List of contacts that assisted in collection of euphorbs during travel in Europe, Russia, and Ukraine.

Name	Address	Telephone
Dr. Lloyd Knutson, Director	USDA-ARS European Biological Control Laboratory BP 4168 Agropolis 34092 Montpellier Cedex 5, France	Tel. (33)67045600 Fax (33)67045620
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Dr. Gyula Oros, Biologist	Plant Protection Institute Hungarian Academy of Sciences Budapest-II, Herman Otto u. 15. H-1022, Hungary	Tel. (37)11769555 Fax (37)11769729
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Biological control of leafy spurge using angora goats

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Introduction

Leafy spurge infests over 1 million ha in the Northern Great Plains. North Dakota alone has approximately 0.5 million ha infested. Land value depreciation in North Dakota is estimated at \$137 million, while foregone business activity is estimated at \$75 million (Thompson *et al.* 1990).

Herbicides have been the traditional choice for controlling leafy spurge, however, long term control has been elusive with any method. Due to herbicides ineffectiveness, sensitivity of use in fragile or sensitive habitats, and potential for groundwater contamination, biological control measures are being studied. These include various species of insects, pathogens, sheep, and goats. Sheep and goats will graze leafy spurge, which has a nutritional composition approaching alfalfa (Fox *et al.* 1991).

This research project was initiated in 1991 on the Sheyenne National Grasslands in southeastern North Dakota. The Grasslands are managed for multiple use including cattle grazing by the U.S. Forest Service. Extremely large infestations of leafy spurge occur in several areas within the Grasslands, limiting their usefulness for cattle, wildlife, and recreation.

The primary objective if this project was to determine annual changes in leafy spurge and associated plant communities following repeated goat grazings. We will also examine the nutritional and botanical composition of diets selected by the goats.

Methods

Five 8m² exclosures were established, each containing four perpendicular transects. Grazed outside transects are compared with nongrazed inside transects using measure-

ments of density, cover, and yield for leafy spurge, native forbs, shrubs, and grasses along with leafy spurge height.

Goat diets were collected following a video tape evaluation and analyzed for nutrient composition. Fecal collections were also made at the same time as the diets were collected. These underwent microhistological analysis for botanical composition and relative preference analyses. This is of major interest to cattlemen and Forest Service officials.

Results

Only data for 1991 has been analyzed and summarized. Herded angora goats readily grazed leafy spurge throughout the growing season. Leafy spurge cover was reduced from 34% to 15% through goat grazing. Goat grazing prevented leafy spurge from flowering and producing seed.

Nutritive quality of diets generally declined over the grazing season. Percentage dietary crude protein declined from 20% to 16% between June and September. Percentage phosphorus in diets declined from .45% to .38% from start to finish of the grazing season. Diet digestibility declined from 78% to 70% between early and late season collections. Crude protein and phosphorus percentages of diets exceeded nutrient requirements of angora goats throughout the grazing season.

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Leafy spurge interactions with cattle, sheep and goats

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We are attempting to determine why cattle generally avoid leafy spurge and why goats appear to graze it more readily than sheep in southeast Idaho. In contrast to goats, cattle and sheep are more likely to develop an aversive response to leafy spurge the first time that leafy spurge enters their rumen. Blood cortisol levels are elevated in sheep when spurge is first placed in their rumen. This suggests that sheep experience physiological stress with their first ruminal exposure to leafy spurge. However, when sheep are pre-exposed to leafy spurge (i.e., when leafy spurge is placed in their rumen on several days before a test for aversion) they do not exhibit an aversive response from leafy spurge at a later time. In conjunction, blood cortisol levels don't tend to elevate at a later leafy spurge exposure when sheep are pre-exposed to leafy spurge. These findings may partially explain why sheep seem to require an adjustment period before they will begin grazing significant amounts of leafy spurge.

After leafy spurge is fermented for 12 hours with either goat or sheep ruminal digesta, the mixture of sheep digesta and leafy spurge elicits a greater aversive response from sheep than the fermented mixture of goat digesta and spurge. This finding suggests that ruminal activity in goats degrades an aversive compound in leafy spurge to a greater degree than ruminal activity in sheep. Alternatively, sheep may produce an aversive compound from leafy spurge in their rumen; whereas, goats do not. Unfortunately, when we transferred ruminal digesta (with its compliment of microbes) from goats into cattle, these cattle experienced the same aversive response to leafy spurge as did cattle that did not receive goat digesta.

Finally, in an attempt to identify an aversive compound in leafy spurge, we injected a diterpene that has been found in leafy spurge (Ingenol 3,20-Dibenzoate) into the jugular blood of sheep and found that it did not elicit an aversive response from sheep.

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Leafy spurge overview and summary of federal regulatory efforts

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Leafy spurge is a herbaceous deep rooted perennial plant that was introduced into the United States (U.S.) sometime during the early 1800's to the late 1890's. More specifically ballast material from ocean going ships in the early recorded history of the U.S. was off-loaded onto the eastern coast prior to returning to Europe, loaded with raw materials. During the time frame of 1870-1880 immigrants from Russia came to North America and brought with their personal belongings, seed grains, to begin a new life on this continent. Larger shipments of wheat seed were made from Russia as additional land in North America was placed into farming. Included with these grains were varying amounts of leafy spurge seed. During this same time seed from grasses that had served settlers well in northern Europe and Russia was introduced into the plains to improve rangeland production. Smooth brome from Russia proved to be a more cold-hardy variety and was widely spread throughout the plains states. Included in this massive seed distribution program was a significant amount of seed from leafy spurge. Similar accounts have been made from importation of seeds from the European continent.

The question is obvious, if leafy spurge is a weed, why was the seed allowed to come into the U.S.? Leafy spurge is not a plant of economic importance in those parts of the world. Natural control mechanisms prevent this plant from becoming a weed with the devastating impact as we know it here in the U.S. This natural control, which is long term, is an important component of a management strategy against leafy spurge.

The Animal Plant Health Inspection Service (APHIS), received and accepted a proposal from R. Lorenz in 1986 which accepted the agency into a biological control based management program designed to reduce leafy spurge populations below economic levels. The program is a cooperative effort with scientists from the Cooperative States Research Service and Agriculture Research Service. Federal resources in 1988 significantly increased the activity and direction of this program. Six species of insects which attack leafy spurge at several locations on the plant have been introduced from foreign collections. These include four flea beetles whose larvae feed on the root system. A stem boring beetle that feeds both in the stem and roots. Finally, a shoot tip gall midge which reduces the amount of seed that a plant can produce. The results of the flea beetles are

very encouraging in that releases in 1989 are now well established with significant impact on leafy spurge populations. Several new species of flea beetles are currently being screened for future release. A clear winged moth, whose larvae are root borers, is a very exciting new possibility since these insects are also strong fliers.

A new and important component for success in biological control of leafy spurge is the active participation of the personnel within each state. Redistribution of these insects to new sites in each state is necessary for the establishment of these insects throughout the infested areas. The organization within each state must provide a plan for distribution and release of these insects following guidelines developed over the last five years by scientists working in the field. This work when accomplished by state organizations will allow current Federal resources to be utilized in introducing and establishing new species for future release.

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Regional and interstate efforts to coordinate leafy spurge and noxious weed work

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The need for coordinated and cooperative efforts in Noxious Weed Management has never been greater. The response to that need has been tremendous. Much of the credit can be given to the formulation of an informal working group called the Western Weed Coordinating Committee, (WWCC).

The WWCC got its start in 1989 at a meeting held in Billings, Montana. The attendance was by invitation and was limited to 45 participants. The composition of the attendees was focused on federal agencies and State Departments of Agriculture weed program leaders. The primary objective of this informal gathering was to get those state and federal agencies involved in weed management together in one place to get to know each other. More formal objectives developed later include to:

- 1) Identify barriers to more effective management of noxious weeds and develop actions and opportunities to remove those barriers.
- 2) Serve as a catalyst for improvement of cooperation across state and international boundaries.
- 3) Communicate information on noxious weed management and coordinate successes.
- 4) Improve the awareness of the need for good weed management.

The WWCC is still in existence and grows in size and strength with each passing year, with the most recent meeting in Sparks, Nevada drawing over 75 participants. This meeting was attended by such divergent agencies as the Department of Defense, Department of Energy, U.S. Fish and Wildlife Service and the Bonneville Power Administration.

Achievements of the WWCC to date include:

- 1) Development of an Information and Education Catalog which provides information on available posters, pamphlets, videos, etc. that focus on noxious weeds.
- 2) Development of a noxious weed short course for federal land managers. This course has been on line for two years and has served personnel from 10 states. The state of Montana and the USDA Forest Service were the initial cooperators in the development of this course.
- 3) Development of State memorandum of understanding. With the passage of Section 15: Amendments to the Federal Noxious Weed Act, WWCC provides a liaison between states and federal agencies that are writing memorandums of understanding and developing cooperative agreements at the local level.
- 4) Development of a directory of State and Federal Agency noxious weed personnel.

The WWCC has provided a much needed forum for the exchange of information between states, between federal agencies and between state and federal agencies.

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Noxious weed seed free forage and their use in federal lands

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Over the past 10 to 12 years, numerous individuals and organizations have been pushing for stronger weed management program within the state of Montana. One program that has come up repeatedly was a state wide clean hay program to help manage and minimize the spread of noxious weeds. The Montana Noxious Weed Seed Free Hay (MNWSFH) program was developed to meet that challenge and has shown great success in meeting the need for noxious weed seed free forage.

The MNWSFH program has been functioning since 1989. The program has been administered by the Montana Extension Service and coordinated by Gene Surber, Gallatin County Extension Agent and Larry Hoffman, Lewis and Clark County Extension Agent. Initial strong interest in the program has leveled off since 1990 with the major buyers of NWSFH being recreational areas and wildlife areas.

Currently the USDA Forest Service is expanding the prevention segment of its Noxious Weed Program within several forests in the Northern Region, as well as other areas. The enforcement mechanism used is the issuance of closure orders which in effect prohibit the transport or use of any hay or feeds in a designated area, unless it meets specific standards. In the northern region, the requirement is that the agronomic products be certified noxious weed seed free. Similar closure orders are being utilized in the Intermountain and Rocky Mountain Regions.

A number of states including Nebraska, Wyoming, Colorado, Idaho, Utah and others have also developed Noxious Weed Seed Free Hay programs with varying degrees of success. Wyoming has led an effort to formulate a regional hay certification program; however, most states seem to prefer to establish their intrastate program before expanding to an inter-state program. Overall the market for noxious weed seed free hay appears to be expanding with the Federal Government being the biggest buyer of this commodity.

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Noxious weeds control – A Cowboy State priority

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Noxious weed control in Wyoming has been a priority for more than 50 years.

In its inception, the control was done by the private landowner, and there were scattered counties with established Boards of Directors. Most of the weed control done was to stem the tide of Leafy Spurge in the early to mid 1930's. It wasn't until the legislature enacted the Wyoming Weed and Pest Control Act in 1973, that 23 Districts were established. The 1973 legislation provided for a uniform method of weed and pest control statewide.

Under the Wyoming Weed and Pest Control Act, a designated and prohibited list of noxious weeds was adopted. Currently there are 19 weeds including Field bindweed, Canada thistle, leafy spurge, perennial sowthistle, quackgrass, hoary cress, perennial pepperweed, ox-eye daisy, skeletonleaf bursage, Russian knapweed, yellow toadflax, dalmation toadflax, scotch thistle, common burdock, plumeless thistle, dyers woad, houndstongue, and spotted knapweed. Noxious weeds listed as prohibited in another state are also considered prohibited in Wyoming.

Each district has the opportunity to have a weed or pest not on the statewide list, declared as a locally noxious weed or pest. In Crook County the locally designated list includes Russian wheat aphid, grasshoppers, mormon crickets, mountain pine beetle, dogs, ground squirrels, and wild licorice.

As a part of the Weed and Pest Control Act, provisions were made for a County Weed and Pest Control District Board of Directors of 5 to 7 members, and a mill levy to fund the program.

An integral part of the program is a provision for a cost-share plan. Each district is allowed to set the amount of cost-share allowed to the taxpayer landowner. In Crook County for instance, a cost-share of 70 percent is paid by the district for chemicals, up to \$3,500 per year.

In an effort to stem the expanding leafy spurge infestation, the legislature established the Leafy Spurge Act, with an additional mill levy funding in 1978. There were also provisions or general fund appropriations for this program.

Here again, the cost-share provisions were an integral part of the program. Each district levying the full one mill was eligible for funding through the Wyoming Department of Agriculture Leafy Spurge Control Program appropriation. In the beginning there was up to a million dollars available for leafy spurge control per biennium. This has been reduced to \$265,000 in the last few years, but efforts are under way to increase this funding.

The cost-share participation for this program was set at no less than 80-20 by the legislation, to include both chemicals and labor. In Crook County, a landowner doing his own application work, receives the chemical at no cost, and is required to pay only a 5 percent administration fee.

This legislation was set up for a six year period, with provisions for six year extensions, and the second six year program was approved in 1984.

In 1990 the Leafy Spurge Act was changed to the Special Management Program. This change was made to allow the weed and pest control districts to establish special management program districts, for any weed or pest on the designated and prohibited list.

Under the special management program, the general fund appropriation is still made, with the funds being allocated on a priority basis for leafy spurge control. It is hoped that through the use of a chemical registration surcharge, that this program will become self-sufficient, with no need for general fund appropriations.

The statutory provisions of the law place enforcement with the individual weed and pest control districts, and any cases not resolved the hearing process by the board of directors, are placed under the jurisdiction of the district courts for disposition. This procedure is not often used since the court costs and attorneys' fees are borne by the weed and pest control district program funding. Budgets are tight enough without spending the control program funds in this manner.

Under the special management program, the districts are encouraged to use the integrated weed and pest management system. This allows the latitude for innovative plans that include biological insect, sheep and goats, and competitive grass seeding in addition to the usual chemical and cultural control practices for leafy spurge control and suppression.

With the county mill levy valuations being reduced, more of the innovative control methods are becoming the rule, rather than the exception. It's estimated that 2.9 million dollars are spent annually by the weed and pest districts for chemical purchases in Wyoming. With districts Crook and Campbell counties spending \$225,000 to \$230,000 on chemicals annually.

The special management program statutes require all state agencies controlling lands to follow the same laws as private landowners. This part of the statute may be tested in the coming year, because of a funding cut of 86 percent for weed and pest control during the next biennium, by the Director of School Trust Lands. There has been a decision recently, to sell any leafy spurge infested lands to the lessee, and make these infested acres become the responsibility of private landowners.

An estimated 70,000 acres of leafy spurge infested land occur in Wyoming. Of this total, 35,000 acres are in Crook County. These acres include private, state and federal

land. The federal lands are divided between three separate agencies, the National Forest Service, the National Park Service, and the Bureau of Land Management.

Compliance under the Carlson-Foley Act has been a nightmare. Each federal agency has its own philosophy, policy, and procedures. For example, one agency in 1991, decided to use the money budgeted for weed control, to inventory the weed species on 1340 acres under its jurisdiction. Consequently the leafy spurge was allowed to flourish and send an abundant crop of seeds down the Belle Fourche River, to add to the problem headaches of landowners down stream. Thanks to this decision, new infestations were found along the river this year, in Wyoming, and in an irrigated area of western South Dakota.

Hopefully, the memorandum of understanding being developed under the National Undesirable Plants Management Act passed by congress in 1990, will preclude the occurrence of this scenario in the future.

In conclusion, despite some of the pitfalls and stumbling blocks, Wyoming has one of the strongest Weed and Pest Control Laws, and “NOXIOUS WEED AND PEST CONTROL,” is a “COWBOY STATE PRIORITY!”

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South Dakota leafy spurge control program

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The South Dakota Weed and Pest Department is overseen by a 13 member commission composed of 7 designated members and 6 appointed members. This commission is responsible for formulating the policy for the prevention, suppression, control, and eradication of noxious weeds in South Dakota. Weed and Pest programming is developed by the State Weed and Pest Coordinator and carried out by the State Weed and Pest Supervisor and 3 Area Weed and Pest Supervisors. Control programs on the county level are developed by a local Weed and Pest Board in which many have township representatives to relay local concerns to the Board. The local programs are administered by a County Weed and Pest Supervisor who normally oversees several seasonal employees.

A very conservative estimate of the acres of leafy spurge in South Dakota includes 150,466 acres. Of that acreage, 79,713 is located in pasture and range, 43,808 in noncrop, and 26,945 in crop land.

Other weeds declared as noxious in South Dakota include: field bindweed, Canada thistle, perennial sow thistle, Russian knapweed, hoary cress, and purple loosestrife.

South Dakota state law places the responsibility for noxious weed control on the owner of the property. The responsibility for and the cost of controlling weeds on public property is assumed by the agency that manages such lands.

Upon failure of obtaining voluntary control, both the County and the State have enforcement authority. Enforcement operations include the County or State either contracting with a commercial applicator or treating the infestation with their own equipment. State laws are in place to protect the enforcers from any trespass or crop damage liabilities. All costs for enforcement activities are certified to the county auditor, billed to the landowner, and, if not paid by November one, extended onto the tax roll of that property and all property owned by that landowner.

State quarantine laws have been established and are used with cases that have “slipped through the system” and are an immediate threat to spread an existing or create a new infestation. Movement of quarantined articles is restricted until approved measures are taken to prevent the spread of noxious weeds. In some cases the quarantined articles are destroyed on the premises. Combine inspections are also conducted under quarantine laws to ensure noxious weeds are not transported into the state.

An integrated pest management approach to noxious weed control is practiced in South Dakota. Included in this approach is a biological control program. The first leafy spurge biological control agents were released in South Dakota in 1988. Since that time 86 releases in 27 counties have been made. Three species of *Aphthona* sp. flea beetles are the main thrust of the biological control of leafy spurge. Cooperative block programs are the backbone of controlling large infestations of leafy spurge. Some block programs encompass entire townships or more. Local landowners serve on the project steering committee with Weed and Pest personnel acting in an advisory capacity.

Participation at the 100% level is required for a successful block control program and enforcement operations are conducted to eliminate reinfestation. South Dakota currently has both interstate and intrastate cooperative block control projects. Nursery inspections are made to ensure that noxious weeds are not being marketed or inadvertently marketed for ornamental purposes.

Seed inspections are conducted to ensure seed being sold does not contain weed seeds in excess of what is listed on the label or omitted from the label altogether.

South Dakota has taken a “get tough” policy on noxious weeds. We have laws with a lot of teeth and we are using them to their fullest extent. South Dakota still has a manageable level of leafy spurge and we intend to make sure that it stays that way.

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Noxious weed control in Nebraska under a new weed law

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Nebraska Weed Control Legislation has come full circle in the past hundred or so years of weed control enforcement. We started in 1873 with a Canada thistle law that required cutting or mowing to prevent seed from ripening under a penalty of a fine of from \$10 to \$40. Any person could go on another's land to cut; without danger of a trespass suit; however, a double barrel shotgun may have dissuaded a few people. A \$20 fine was issued if you were convicted of selling hay or seed that contained Canada thistle seed.

1922 - Landowners had to start controlling all vegetation to the middle of the road, and railroads had to start controlling weeds on their right-of-ways. The overseer of the county roads could charge railroads \$2 per day per man, \$1.50 per day per team of horses, \$2 per day per mowing machine, and .25-cents an hour for hand scythe.

1929 - Metropolitan cities had to start controlling weeds and worthless vegetation.

1937 - Weed eradication districts were established. Bindweed and Puncture Vine were added to the noxious weed list. I wonder if puncture vine was added because of crop loss or flat tires.

1959 - The Nebraska Weed Control Association was formed. At the time of organization, only voluntary districts were formed. After considerable hard work, this group developed a goal to weed control compulsory in each county of the state and to promote the profession and professionalism of weed control.

1962 - The 1873 Canada Thistle Law was still in force. A barberry eradication program had been added and designated noxious weeds were: field bindweed, puncture vine, leafy spurge, Canada thistle, and musk thistle. All counties were mandated to be included in a weed district. The Nebraska Director of Agriculture was given the responsibility to enforce the Weed Act.

1965 - A new Weed Act was written by the Nebraska Department of Agriculture with advice provided by weed scientists from the U.S. Department of Agriculture and the Weed Science Society of America. This amended version is what we have today.

1975 - The word eradication was removed from the Weed Law; 12 weeds were removed from the statute; and the Director designated musk thistle, canada thistle, plumeless thistle, and leafy spurge as noxious. All counties must have a Weed Control Superintendent and be certified annually by the Director.

1980 - Due to budget cuts, field staff for Noxious Weed Control on the State level was reduced.

1983 - A 15-day fine and 10-day force control notice was established. The 15-day notice provided for a fine of \$50 per day, up to 15 days for failure to control noxious weeds. The 10-day notice provided for force control measures to be taken by the landowner. The cost of control was to be assessed to real estate taxes and draw interest at the same rate as unpaid real estate taxes.

1986 - The Noxious Weed Budget was eliminated at the Department of Agriculture. Nebraska did not have any noxious weed enforcement programs. We had a state statute on the books with no enforcement, no training, and no certification.

The Nebraska Weed Control Association and the newly formed Nebraska Leafy Spurge Working Task Force joined forces and became lobbyists, legislators, and to some a pain in the neck. We showed slides, gave talks, suggested changes to numerous legislative bills. We got on a first-name basis with some of the senators. We spent more time at the capitol than at home, trying to catch senators between sessions; but we managed to hold the law together. At this point we had 93 counties which could enforce the law under 93 different ideas or "how to's". We had to sell ourselves to the counties and convince them to accept a standard set of rules and regulations dealing with enforcement of the Weed Law. We did it!

We needed to define and designate training. Back to the legislature. We got it. We continued to push to get the Department of Agriculture back into weed control. We got it, even though our governor vetoed the bill, the legislature overrode the veto. Our new Weed Act went into effect November 1, 1989. We now have a State Program Supervisor, six field men to assist and monitor country program, a mandatory training program for superintendents, a force control or fine option of up to \$1,500 per violation, and a quarantine program. We also have a mandated State Noxious Weed Advisory Committee that helps advise the Director of Agriculture in noxious weed matters. This committee represents rural, urban, public, and private sectors.

The Director of the Department of Agriculture establishes which plants are noxious, which control measures are to be used, and approves the training for the weed control superintendents.

Each County Board is required to employ one or more Weed Control Superintendents to inspect, compile data, consult, render assistance, and give direction for effective weed control in their county.

The County Control Authority is the County Board of Commissioners/Supervisors, or a separate independently elected Weed Board.

Overseeing the County Weed Control programs is the Director of the Department of Agriculture and six Agricultural Inspectors who monitor and evaluate the county programs. Funding for the county program is derived at the local level through a mill levy

system approved by the County Board. If a Control Authority fails or refuses to carry out a suitable program, the Director of the Nebraska Department of Agriculture is required to instruct the County as to needed changes. Continued refusal or failure, results in the State Attorney General filing a suit against the County Control Authority.

Funding for the State program is raised through a registration of economic poisons of \$40; of this fee, \$10 goes to the Economic Poisons Registration Fund and \$30 goes to the Noxious Weed Cash Fund. These funds are matched by funds from the general fund. None of these funds go to county funds and Nebraska has no provision for cost share.

At the county level, Nebraska weed laws designate the landowner or controller as the responsible party. After the superintendent has inspected the property and determined that there is an uncontrolled infestation, the Weed Control Authority may issue a 10-day force control notice, a 15-day fine notice, or both. The fine notice is a fine of \$100 per day for a maximum of 15 days for each day of noncompliance per legal. The 10-day notice allows the Control Authority to control the infestation after the end of the ten days. If the amount is unpaid after 60 days, the charges are certified at the County Treasurer's Office and become a part of the land taxes and bear interest at the same rate as unpaid taxes.

February 20, 1992 - The Nebraska Weed Control Association adopted a Certification Standard for Noxious Weed Free Forage. The State Department of Roads has agreed to purchase certified hay for mulch on roadsides. The success of this new program in Nebraska is yet to be determined. In Nebraska both County Weed Superintendents and State Inspectors collect data on acres of land infested with noxious weeds. Reports indicate a variance in acreage that we hope to stabilize with standardized methods of estimating acreages. Nebraska differs in total acreage reported by the weed superintendent reports and the state inspectors. The superintendent reports indicate a total of 669,646 acres of spurge in 1990 while the state survey shows 411,405 acres. In 1991, the superintendent reports indicated 578,710 acres compared to the state survey of 409,671 acres. It will be interesting to compare notes for 1992. Meetings such as this, and organizations such as the Nebraska Leafy Spurge Working Task Force, have spread the word about the impact that leafy spurge has on our society. Leafy spurge has almost become a common buzz word around farm shows, sale barns, and coffee shops. There is an awareness by most, but not all. Sometimes you have to get a person's attention through enforcement action before you can educate him/her. I'm sometimes asked what I do as a Weed Control Superintendent. I tell them, "I sell an educational program, and if they don't buy it, I'll fine 'em!" Unfortunately, it's not as easy as it sounds. We have to deal with attorneys and county boards who, for some reason, do not have control high on their list of priorities. The Department of Agriculture does have a challenge encouraging these counties to improve their programs.

The future of our programs depend on how we as professionals conduct ourselves, our programs, and how we sell ourselves to our constituents.

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A county approach to leafy spurge control in rural and urban areas

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The Lancaster County Leafy Spurge Control Program includes efforts in; (1) information dissemination and education, (2) inspection and identification, (3) control of infestations on public lands, (4) marking and controlling infestations on roadsides, (5) prevention of weed propagule dissemination by crops and articles, and (6) issuing of notices for control.

The information and education effort has included mailing information to all landowners with noxious weed infestations, providing information on identification and control at public meetings, dissemination of newsletter articles about leafy spurge, and delivering a message to commercial pesticide applicators during mandatory certification training programs.

Annual inspections are made of known infestations and new infestations are documented as they are encountered or are reported to us. Information on leafy spurge distribution within Lancaster County is maintained in a database on computer. Investigations into using this database in a geographic information system to assist in noxious weed management are being conducted.

A roadside spraying program was initiated in 1989. Special signs have been purchased and are used to mark roadside infestation sites. Efforts are being made to prevent initiation of new infestations by restricting the movement of crops that are contaminated with leafy spurge. A letter has been sent to alert excavation contractors and utility companies about the movement of leafy spurge during their earth moving activities. The signs and letters have resulted in good cooperation from the public. Crop and hay inspections are made on request and prior to issuing quarantine notices.

Notices requesting control of leafy spurge within 10 days were sent to private landowners and letters were sent to public agencies responsible for land infested with noxious weeds that had not been treated. A total of 96 notices were sent out and 94 infestations were controlled on 552 acres. Public agencies treated 196 infestations on 348 acres following receipt of letters requesting noxious weed control. Letters will be sent this fall that will contain information on recommendations to control noxious weeds in the fall.

The Lancaster County Leafy Spurge Control Program has resulted in increased public awareness and a willingness of private landowners and public agencies to provide control in both the rural and urban areas. One problem has been weed control in urban areas because of the large number of relatively small land parcels. However, once people are aware of the problem, they respond in a positive, regardless of whether they are urban or rural landowners.

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The new Colorado weed law – HB90-1175

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The Colorado Weed Management Act, HB90-1175, was passed during the 1990 legislative session, signed by Governor Romer, and became effective on July 1, 1990. This bill requires that all persons in Colorado manage designated noxious weeds using integrated management systems. The bill recognizes two types of land; unincorporated land, or that land under the jurisdiction of counties, and incorporated land, or that land under the jurisdiction of cities or towns. Thus, two types of weed management districts can be formed; weed districts for unincorporated land governed by county commissioners and weed districts for incorporated land governed by towns or cities.

Several key definitions occur in the bill:

Advisory commission: comprised of individuals appointed by the local governing bodies to advise on matters of undesirable plant management.

Undesirable plant management: the planning of an integrated program to manage designated undesirable plant species.

Integrated undesirable plant management: the planning and implementation of a coordinated program using a variety of management methods including:

Education, preventive measures, good land stewardship, cultural control, biological control, mechanical, and chemical control; the purpose of integrated undesirable plant management is to achieve healthy and productive plant communities by the least environmentally damaging means.

Alien plant: any plant species not indigenous to Colorado or native to the plant community in which it is found.

Native plant: any plant species that is indigenous to Colorado.

Undesirable plant: any noxious plant species designated as undesirable by HB90-1175 or by the local governing body.

Noxious plant: any alien plant, or parts thereof, that meets one or more of the following criteria:

- aggressively invades or is detrimental to economic crops or native plant communities;
- is poisonous to livestock;
- is a carrier of detrimental insects, diseases, or parasites;
- its presence is detrimental to the environmentally sound management of natural or agricultural ecosystems.

Weed: is any noxious plant species.

HB90-1175 provides for the protection of native plant communities and agroecosystems from undesirable plant encroachment. HB90-1175 further protects native Colorado plants in that native plants cannot be designated as noxious or undesirable.

The statewide undesirable plants as designated by HB90-1175 include:

Euphorbia esula - the leafy spurge complex

Centaurea repens - Russian knapweed

Centaurea diffusa - diffuse knapweed

Centaurea maculosa - spotted knapweed

Other non-native plants can be designated as noxious or undesirable by local governing bodies.

Each county or city/town must adopt an undesirable plant management plan on or before January 1, 1992 for all the unincorporated lands under county jurisdiction or for all the incorporated lands under city/town jurisdiction. Each local governing body shall appoint an advisory commission and commission members must be residents of the respective county or city/town. Local governing bodies may cooperate with one another through written intergovernmental agreements to form multi-county, multi-city/town, or multi-county-city/town weed districts.

The advisory commissions of each district shall develop integrated management plans for designated undesirable plants for areas within their jurisdiction and recommend management criteria. The advisory commissions may designate additional undesirable plants for the area within their jurisdiction, but additional designated undesirable plants are subject to approval by the local governing body. The advisory commissions may recommend to their respective local governing bodies those landowners designated to submit individual integrated weed management plans. Local governing bodies have the sole and final authority over all advisory commission recommendations and actions.

Local governing bodies, or agents thereof, have the right to enter onto private lands for inspections if the landowner/occupant request such an inspection; if a neighbor requests such an inspection; or if the local governing body or its agent has made a visual observation of an undesirable plant infestation from a public right-of-way. No entry onto private lands is permitted until the landowner/occupant is notified of the pending inspection either orally or by certified mail. If entry is then denied by the landowner/occupant, a warrant for inspection can be obtained.

When the local governing body notifies a landowner/occupant of an undesirable plant infestation on their property, the local governing body must work with the affected landowner/occupant to provide advice on the best available integrated management plan. Within 10 days of notification of an undesirable plant infestation, the landowner/occupant shall comply with the notification terms; or acknowledge the terms, submit an acceptable plan and schedule for its completion; or request an arbitration panel. The arbitration panel will be comprised of a weed management specialist or weed scientist, a similar type of landowner/occupant, and a third member chosen by the first two. The landowner/occupant receiving the notification can challenge any single arbitration panel member and that member will be replaced. However, the decision of the arbitration panel is final.

If after due process, a landowner/occupant fails to comply with HB90-1175, the local governing body can enter and invoke the integrated undesirable plant management plan and assess the entire costs associated with the plan plus an additional 15%. The assessment shall be a lien upon the property in question, but shall not exceed 20% of the value of the entire contiguous parcel of land in any year. No local governing body shall provide for or compel undesirable plant management, or assess associated costs to private landowners/occupants until the local governing body has done the same or more on adjacent land under their jurisdiction.

Any Colorado department, agency, or state board that controls or supervises land must comply with the local governing body's undesirable plant management within the area of the local governing body's jurisdiction. State land will be treated as identical to private land under HB90-1175. Any local governing body is authorized under HB90-1175 to enter into written cooperative agreements with state or federal agencies.

The Federal Noxious Weed Act P.L. 93-629 Section 15, Management of Undesirable Plants on Federal Lands was signed into law by President Bush on November 27, 1990. P.L. 93-629 Section 15 requires all federal agencies to manage state designated undesirable plants in cooperation with affected states. The federal law requires all federal agencies to enter into written cooperative agreements with affected states that outline undesirable plants to be managed, means used to manage those plants, and means of implementing the plan. P.L. 93-629 Section 15 specifies that federal agencies are not required to do more than the affected state.

Weed laws, whether at the state or federal level, are powerful preventive tools that foster cooperation among all persons for weed management. They simply are vehicles to promote weed management. Effective weed management and reduction in weed populations only can be met when all persons involved are working together to achieve this common goal.

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The taxonomy and biology of leafy spurge

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The problem

Leafy spurge (*Euphorbia esula* L.), a polymorphic complex of taxa most likely composed of a single highly variable species, is a weed that has tremendous economic impact in the United States. Leafy spurge currently infests much of the open rangeland of the upper Great Plains, mainly in the prairie states of North Dakota, South Dakota, Montana, Minnesota, Nebraska, Idaho, and Wyoming (Nobel *et al.* 1979). The ever-spreading presence of this weed on highway right-of-ways (Koukkari 1980) and in protected natural areas (Biesboer 1985) of Minnesota is a major problem that is becoming of greater concern each year.

In North Dakota, the cost of leafy spurge to agriculture and other agencies in the state has been well documented (Messersmith and Lym, 1983; Leistriz *et al.* 1991). Leistriz; *et al.* (1991) recently detailed the monetary losses of North Dakota to leafy spurge infestation. Primary loss of seasonal carrying capacity of pastureland and decreased land values for ranchers coupled with secondary effects such as business losses to households, retail trade, agriculture, services, etc. resulted in an estimated loss to the state of \$105 million in 1989. Economic losses are detailed for other states mostly in various state publications and reports and also show that their losses run into the millions of dollars as well. Unfortunately, the battle to control leafy spurge is being lost. During a span of nine years (1973-82) the number of acres infested by leafy spurge in North Dakota has doubled (Watson 1985). Today, leafy spurge infestations in the United States may range from 2.5 to 3.0 million acres (estimated by the authors).

The number of acres infested with spurge in Minnesota is difficult to determine because recent weed survey data is not available for the state. Based upon some recent estimations, about 800,000 acres of land have leafy spurge (Leo Holm, Agricultural Engineer, Minnesota Department of Transportation, pers. comm., and University of Minnesota, Herbarium information). Populations of leafy spurge appear to be increasing rapidly in the mid-West. Within Minnesota, leafy spurge infestation has reached a serious, if not critical level.

Origin and distribution

Except for Australia, leafy spurge is found throughout the world. The species probably originated in a region that includes eastern Europe and western Asia. It can be found as far north as Scandinavia and as far south and west as Italy and Spain. During the 1800's it was documented as a species found in Massachusetts (1827), New York (1876) and Michigan (1881) (Britton 1927) and by 1913 it was found growing in the western prairie regions of Canada and the United States (Dunn 1979).

The mode of introduction of leafy spurge to the United States has been hypothesized by Dunn (1985) to have occurred independently in several ways: 1) as seeds present in the soil of the ballast of cargo ships carrying goods from Europe in the 1700's and 1800's; 2) in the seed stocks of Mennonites that emigrated to the prairie states from Russia in the decade of 1870 to 1880; 3) in smooth brome grass seed (*Bromis inermis* L.) that seedsmen introduced to Canada and the northern United States from Russia and Hungary forage crop; and 4) probably by Mennonites settling in Minnesota who imported many bushels of oats from Russia that were probably contaminated with leafy spurge seeds (Batho 1931). In any case, leafy spurge has become firmly established in the United States and is still spreading.

Morphology and evolution

Leafy spurge belongs to a family of dicotyledonous plants called the Euphorbiaceae. The Euphorbiaceae is a large family encompassing morphologically diverse forms of herbs, shrubs and trees comprising approximately 7000 species in 300 genera. The family is distributed throughout the world with the exception of polar regions. The genus *Euphorbia*, a large genus of about 1600 species, is characterized by plants that exude latex when injured and a more or less regular bisexual cyathium. The cyathium is an inflorescence condensed to form what appears to be a single flower. The inflorescence is formed by the compression of internodes, the absence of petals on individual flowers, and the reduction of each staminate flower to a single stamen. A perianth-like arrangement of 5 bracts occurs in most cyathia separated by 4 horn-like bodies that represent the combined stipules of the subtending bracts. In the middle of the cyathium is a solitary pistillate flower with a tricarpellate ovary on a long stalk. The tips of the bracts alternate with 4 or 5 glandular nectaries.

The fruit of many euphorbs is a triple, woody, and capsular schizocarp. Upon ripening, the fruit divides into three sections, each containing a seed, which is explosively dehisced. Earliest reference to the genus *Euphorbia* dates from the period of Hippocrates who was born about 465 B.C. The botanists and physicians of antiquity were interested in the few known species of *Euphorbia* primarily for the purgative value of their latex. The common name of spurge was probably derived from this use of a latex producing plant.

As previously mentioned, a great amount of morphological variation occurs in the genus *Euphorbia*. Many are herbaceous (as typified by *E. esula*), especially species found in the New World, but shrubs and woody plants do occur in the group. Chief interest has

focused on the many unusual succulent species found in the Old World. Many of these forms have converged morphologically to resemble the Cactaceae. As in the cacti, *Euphorbia* illustrates almost spherical forms, ridged axes, cylindrical forms, coralline forms, dwarf and arborescent forms and are often well-armed with thorns.

Studies of the phytochemistry and starch grain morphology of the non-articulated cells found in *Euphorbia*. (Biesboer and Mahlberg 1981) coupled with other data such as basic chromosome number and general morphology suggest that a large herbaceous subgenus of 500 members, the subgenus *Esula*, is primitive within the genus. In other words, herbaceous species such as *E. esula* have given rise to the many diverse forms present in this complex genus. Evolution has probably occurred along two lines originating in the subgenus *Esula*, namely an herbaceous line having trinucleate pollen and a basic chromosome number of $x=7$ and a succulent line having binucleate pollen and a basic chromosome number of $x=10$.

The name *Euphorbia esula* L. is the name generally used by North American botanists to identify leafy spurge. Its correct name is *Euphorbia podperae* Croiz. (Richardson 1968), but since it is not a name of common usage in North America, the plant will probably always continue to be referred to as *esula*. It is suggested, based on studies by Dunn and Radcliff-Smith (1980), that most of the individual populations of leafy spurge in the United States are hybrids between *E. esula* and *E. waldsteinii* (Sojak) Radcliffe-Smith (*E. virgata*).

Phenology and development

We have carefully studied the phenology and development of leafy spurge in Minnesota. Leafy spurge is an herbaceous, deep-rooted perennial weed. Plants range in size from about 0.3 m to 1.0 m in height and develop from a usually woody crown located just below the surface of the soil. Each crown can produce from one to more than twenty upright shoots, which contributes to the almost shrub-like appearance of older plants. In Minnesota, we have found stem densities in the range of about 120 to 290 stem s/m^2 in many populations. The leaves of the plant are quite variable in length but are generally narrow, lanceolate to ovate, slightly broader beyond the middle of the leaf, sessile and have a characteristic blue-green appearance. In Minnesota, shoots emerge rapidly in late April and thus the species is among the earliest to be seen growing in the spring. In fact, reddish buds or short shoots can be found under the snow in winter. This early development and rapid growth gives leafy spurge a tremendous competitive advantage over other more desirable species. Stem elongation is very rapid as daily temperatures increase from May through June. Stems remain green during summer but become yellowish-red to red during fall senescence. Dead stems are rather persistent and can remain standing for a year or more after senescence.

The specialized inflorescence or flower cluster of leafy spurge is called a cyathium. It is insect pollinated and produces copious amounts of pollen and nectar. Insects belonging to 8 different orders and representing 60 species in 39 families could serve as pollinators of leafy spurge (Best *et al.* 1980).

Seedlings are particularly hardy and can emerge from the soil when temperatures are near freezing. Seedlings are easy to recognize because they are a deep red or purplish in color due to anthocyanin production in the hypocotyl. As the winter season progresses, some seeds will appear to dry up and die but their roots will persist and produce adventitious buds, especially near the hypocotylar end of the shoot (Raju 1975). The main seedling shoot usually does not survive and will be replaced by one or more adventitious shoots that will mature into flowering stalks.

All organs of leafy spurge produce a milky white 'sap', called latex, from specialized groups of cells called non-articulated laticifers. If a leafy spurge plant is injured, the latex can be seen to flow readily from injured surfaces. The latex of many euphorbiaceous species contains rubber, alkanes, C₂₈ - C₃₀ triterpenes and their esters, various polyfunctional polycyclic diterpenes and cryptic irritants starch, and many proteins. Some of these compounds have been isolated from leafy spurge latex but many have not. The latex of leafy spurge has been noted to produce contact dermatitis in susceptible individuals. Cattle will not consume leafy spurge because it causes severe irritation of the mouth and digestive system. It may also cause scours, and occasionally results in death (Selleck *et al.* 1962). However, sheep and goats can be made to accept and graze on spurge and some researchers suggest that these animals may be used as a means to control leafy spurge (Lacey *et al.* 1984).

Inflorescences (clusters of flowers) are produced on the main axes of the plant during May to the end of July. The flowering process, and subsequent seed development, occur again in the fall, but usually from axillary branches. Seed development and maturation continue for 4-6 weeks following the appearance of the last flowers. The plant usually ceases to grow during the hottest and driest weeks of July and August.

Fruits ripen and seeds are dispersed generally from late June into August and then again for a short span of time during the fall. According to results from a study conducted in Saskatchewan (Selleck *et al.* 1962), mature plants produced about 200 to 252 seeds per plant and the yields ranged from 27 to 3800 kg seed/ha. Highest yields occurred when native grasses were mowed. The effects of mowing relate directly to the excision of stem apices that in turn enhance the development of lateral branches and a subsequent increase in the total number of inflorescences produced on each plant.

Reseeding is initially affected by the explosive dehiscence of the seed capsule. Seed may be ejected up to 4.6 m from the parent plant and be distributed fairly uniformly from 0.3 to 0.4 m from the plant (Hanson and Rudd 1933). Leafy spurge seeds can float and initial infestations of land previously devoid of the species often occurs along stream or river where seeds have floated into a new habitat. The number of seeds that germinated from a given population is relatively high. In the laboratory, we have found that 50 to 80% of the seeds collected from various populations in Minnesota will germinate after reaching the brown to gray color indicative of mature seeds. Seeds may remain dormant in the soil for approximately 5 to 8 years following dehiscence (Selleck *et al.* 1962).

An important aspect of the biology of leafy spurge, in addition to production of large numbers of seeds, is the capacity of the plant to produce adventitious shoot buds directly from roots and crown. In young seedlings, shoot buds will develop within 10 to 15 days on the proximal portion of the hypocotyl and on the young primary and lateral roots. All

of these buds appear to have the potential to produce new shoots. The same is true of the buds located on the crown. If the above ground stem of the plant is killed by herbicides or mowing, these underground buds will be released, perhaps from the inhibition of prior apical dominance, to produce new shoots. The root system, which consists of both long and short roots, can give rise to shoot buds anywhere along its length.

The mature plant may have an extensive root system. For example, long roots have been excavated from a depth of 4.8 in (Selleck *et al.* 1962). Both the cultivation of the soil, which cuts or disturbs the root system, and mowing may actually increase the number of stems in an infestation. This was demonstrated by determining the density of leafy spurge before and after tilling the soil (Selleck *et al.* 1962). Shoot density increased from 134 shoot/m² in an undisturbed control patch of leafy spurge to 316 shoots/m² after tilling. Shoots can continue to emerge through 90 cm of overlying soil for 5 successive years after removal of the major portion of the root system by excavation (Coupland *et al.* 1955).

Leafy spurge is difficult to control for a number of reasons. Although root buds have not yet been studied extensively in leafy spurge, they have been studied in other perennial species. For example, the common milkweed (*Asclepias syriaca*) also produces crown and root buds in a manner similar to leafy spurge (Stamm-Katovich *et al.* 1988). Uptake of the herbicide glyphosate in *Asclepias syriaca* in dormant buds proximal to the crown is minimal compared to those distal to the crown (Waldecker and Wyse 1985). These proximal buds will allow regrowth of the plant after herbicide treatment. The root system of leafy spurge extends very deeply into the ground and translocation of herbicides to deep buds is probably quite limited. Finally, the large number of seeds placed into the seed bank by leafy spurge populations ensures that plant replacement by seedling recruitment can occur on an annual basis.

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Biological control of leafy spurge with insects

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The Animal Plant Health Inspection Service, (APHIS) biological control based management program against leafy spurge (LS) continues with enhanced enthusiasm now that results from earlier releases of insects are available. Currently four species of flea beetles, *Aphthona flava*, *A. cyparissiae*, *A. czwalinae*, *A. nigriscutis*, a stem borer, *Oberea erythrocephala*, and shoot tip gall midge, *Spurgia esulae* have been established in the United States. All except the gall midge are univoltine and will require establishment of field insectary sites (FIS) throughout all states infested with LS. Production of these insects in these FIS has progressed such that redistribution to new sites is now possible. One objective of the program is to set up as many as five FIS for each species of insect in all states. Current follow up sampling is in progress to determine the number of FIS maybe available for redistribution efforts in 1993.

Simultaneously, soil samples are being taken for analysis to investigate the possibility of correlation between soil types and successful establishment of each species. Additionally, soil temperatures, air temperatures, and moisture are being monitored. This information should be useful in developing guidelines for predicting when insects will be available for collection when the FIS are transferred to the individual states.

Studies to determine the compatibility of herbivores and insects are now in the second year. Plots 15.5m x 15.5m randomly selected for treatments with insects and insects/sheep were set up in 1990. Early data from this year suggest that LS populations decreased in each treatment. Plots with the insect/sheep treatments did not have any growth of LS in about one-half of each plot. Characteristic circular patterns of LS reduction appear in these study plots.

Releases of *A. nigriscutis* in 1989, which have been monitored closely, show outstanding results. An area surrounding the release point of about 30 x 10m area was seen in 1991. Native grasses were seen in the core area. In 1992 the area of little or no LS had increased to 60 x 30m in size. The stem density of LS at the release point was 350/m² in 1989. Grasses have revegetated this area and LS distribution scattered. Insect populations at these study areas will continue to be monitored to provide information necessary to

determine the number that are available for redistribution. To date over 20,000 insects have been collected from this site.

All states with releases made in 1989-1990 are being surveyed for possible insectary sites that can be utilized for collections and distribution in 1993.

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Flea beetle (Coleoptera: Chrysomelidae) pilot study on leafy spurge (*Euphorbia esula*)

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Life cycle and impact of the plant

Leafy spurge (*Euphorbia esula* L.) is an aggressive, persistent, deep-rooting perennial plant of Eurasian origin. It has become dominant on rangelands and pastures, displacing useful forage plants in North America. Leafy spurge reproduces both by vegetative regrowth and the production of large quantities of seeds which are often distributed by birds, wildlife, man, and water. This plant is able to maintain high energy reserves through an extensive root system, ranging from a massive network of small roots near the soil surface, to deep penetrating tap roots. This ability to maintain high root reserves permits the plant to recover quickly from physical and most chemical damage.

In Europe, there are 105 native *Euphorbia* species which belong to the subgenus *Esula*, the group to which the target leafy spurge belongs. An additional 4 species belong to the subgenus *Chamaesyce*. In North America, 21 native species belong to the subgenus *Esula*, 26 species belong to the subgenus *Agaloma*, 3 species to *Poinsettia* and 57 species to *Chamaesyce*. Two species (*E. garberi* and *E. deltoides*) belonging to the subgenus *Chamaesyce*, currently have federal protection under the endangered or threatened species act.

In 1979, estimated losses in the United States, in terms of expenditures for controlling leafy spurge and loss of productivity at \$10.5 million annually, while others reported that although the problem is most severe on undisturbed lands, it can reduce crop yields from 10 - 100% on cultivated cropland areas. Economist in North Dakota recently concluded that in North Dakota, one million acres of leafy spurge had depreciated land values by \$137 million and had a total economic impact of \$105 million in that state for 1989.

Life history and habits of the flea beetles

Adult flea beetles feed on leafy spurge leaves and bracts, while the larvae feed on the root hairs and yearling roots. Larval feeding damages the roots and reduces the plant's ability to take up nutrients and moisture. Moderately attacked plants show retarded flowering periods. Continued pressure by the flea beetles first reduces the average plant height and then, as the insect population increases further, plant density drops and native vegetation returns.

Most *Aphthona* flea beetle species have one generation per year on leafy spurge; adults are present between late June and early September when eggs are laid in the soil near leafy spurge roots. Larvae hatch and immediately begin to feed on leafy spurge roots. As they grow they move to larger roots where they feed both externally and internally. A portion of the leafy spurge control that has already been documented from flea beetle release sites may be due to the secondary invasion of soil borne plant pathogens. Mature larvae over winter in the soil and pupate in late spring or early summer.

The copper spurge flea beetle, *A. flava*, is amber colored, while the brown dot spurge flea beetle, *A. cyparissiae*, and the black dot spurge flea beetle, *A. nigriscutis*, are brown and can be separated by a black dot between the forward section of the two elytra on the latter species. Work by Peter Harris in Canada suggests that the black dot flea beetle prefers sandy soils with low humus content, while the brown dot flea beetle does better in higher humus and moisture content soils. Although these 3 species of flea beetles are similar in action, there are some characteristics which tend to separate them.

The Copper Flea Beetle was first released near Bozeman in 1985, and in North Dakota and Idaho in 1986. It established at 4 of the 8 Montana sites, and at a single North Dakota site. The brown dot flea beetle was first released in Montana in 1987 and established at 2 sites. Most 1989 releases of the black dot flea beetle appear to have established in 1990 in Idaho, Montana, Nebraska and North Dakota.

The pilot study

A large scale experiment was begun in 1990 to observe the various conditions which affect the efficiency of selected flea beetles to suppress leafy spurge. The first phase of the experiment had the following objectives:

1. To study the efficacy of various numbers and patterns of releases of *Aphthona nigriscutis* as to its effects on populations of the leafy spurge plant, flowering periods, growth patterns, and spurge density.
2. To study the effects and interactions of different associated plant communities on the efficacy of the beetle in suppressing populations of leafy spurge.
3. To study the effects of different leafy spurge densities on the efficacy of the beetle.
4. To study the direct and indirect effects of different soil types and composition on the efficacy of *A. nigriscutis*.
5. To determine factors that affect how fast *A. nigriscutis* populations can increase and expand.

6. To monitor the changes in plant community constituents, density, and biomass production as leafy spurge competition is reduced.
7. To determine the optimum size of release for *A. nigriscutis*. From this information, protocols for the sizes of future release for various *Aphthona* species may be established.
8. To determine the optimum period for releasing adults.
9. To locate detrimental factors for *A. nigriscutis* establishment, and population dynamics, and to investigate how best to avoid or manipulate such factors.
10. To compare efficiency of sweep sampling of the flea beetle on leafy spurge with D-VAC sampling.
11. To determine effectiveness of the beetle in relation to weather conditions, elevation, site conditions, etc.
12. To investigate the effect of host plant genetics (biotype) on the efficacy of *A. nigriscutis* against leafy spurge.

In addition to these objectives, effects of cattle grazing, and previous use of herbicides is also being evaluated.

This research was and is being conducted by the USDA/ARS in cooperation with Bureau of Land Management (BLM), U.S. Forest Service (USFS), USDA/APHIS, Resource Conservation and Development (RC&D), Agriculture Canada, and Montana State University (MSU). Six sites were selected in Colorado, Idaho, Montana, Nebraska and North Dakota.

In the first phase, from three (in Colorado and Idaho) to seven (Montana (2), Nebraska and North Dakota) treatments and duplicate checks were randomly assigned at each site, such that topography, vegetation, soil conditions, etc. were similar throughout the site study area, and particularly between each treatment and its check. Treatments are generally separated by a minimum of one kilometer and 200 to 300 meters separates a treatment and its check. Transects radiate outward from the center in each of 8 directions, north, northeast, east, southeast, south, southwest, west and northwest. Plant composition, canopy cover, spurge plant height, spurge density and number of flowering stems are sampled and recorded from each of the 1/10th meter north, east, west, and south test loci. The four remaining transects are used for clipping samples (biomass) at each 1/10 meter locus.

The second phase was established in 1992 with the addition of 3 new treatments at each of 3 of the sites (Montana, Nebraska, North Dakota). *Aphthona cyparissiae*, *A. flava* and *A. nigriscutis* were released to duplicate the original "treatment #4", such that the results can be compared to the original study.

At most locations, 1992 surveys of the 1990 releases revealed that flea beetles were established and effective in more than 66% of the plots. Depressed plant height, retarded flowering and diminishing plant populations are observed, but no insects have been recovered from any of the North Dakota plots, and many results are not as was expected indicating that we are either not measuring all of the appropriate parameters, or we are not giving the proper credit to the proper conditions.

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Chemical control of leafy spurge – a summary

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Introduction

Leafy spurge is an aggressive invader of rangeland, crops, and non-crop areas. It is very difficult to control and eradication may be impossible particularly for large infestations. Several herbicides are currently registered for leafy spurge control each providing a level of control depending upon rate, application timing, and frequency of application. No single herbicide is ideally suited to use in every habitat for leafy spurge control. The user should integrate herbicides into management system where herbicide choice, rate, application timing, and frequency of application are tailored to the environmental situation. The most commonly used herbicides to control leafy spurge are picloram, dicamba, 2,4-D, and glyphosate, whereas fosamine, sulfometuron, and dichlobenil are used less often.

One of the most important aspects of using a herbicide to control leafy spurge, or other creeping perennials, is to apply the herbicide such that the target plant is stressed but desirable plant species are not injured and thus allowed to compete effectively with the weed. Unpublished research conducted at Colorado State University indicates that picloram at 0.5 lb/A provided better long-term leafy spurge control than picloram at 2.0 lb/A. Control averaged 83 and 52% with picloram at 0.5 and 2.0 lb/A, respectively approximately 2 years after treatments were applied. Crested wheatgrass injury was less with the low rate of picloram (3 v. 66%) and most likely effective grass competition allowed by the 0.5 lb rate aided long-term control.

Optimum timing to apply picloram, dicamba, or 2,4-D for effective leafy spurge control is in spring when the weed is in the flowering growth stage (Lym and Messersmith 1985a). Fall applications of these herbicides to leafy spurge regrowth appropriate, but control is not always equivalent to spring applications. Control longevity varies with herbicide and rate. Once leafy spurge topgrowth control falls to 70% or less, infestations re-surge rapidly (Table 1) (Lym and Messersmith 1985a, 1985b; Lym and Whitson 1990).

Therefore, continual monitoring of sites is important to determine when to reinstate control measures to maintain acceptable leafy spurge control.

Table 1. Longevity of leafy spurge control.

Original control	Years without treatment		
	1	2	3
-%		%	
>95	85	70	<20
80	60	<20	0
70	<30	0	0
60	20	0	0

From Lym and Whitson (1990).

Leafy spurge control with various herbicides

Picloram, 2,4-D, and picloram plus 2,4-D. The traditional approach to control leafy spurge with picloram is to apply relatively high rates (1.0 to 2.0 lb ai/A) as a single application in spring or fall. Indeed, higher picloram rates provided better control than single applications of picloram at 0.25 or 0.5 lb (Table 2). However, high picloram rates are expensive in any given year and grass injury may occur. Lym and Messersmith (1990) found that annual applications of picloram or picloram plus 2,4-D at reduced picloram rates for 3 consecutive years provided 85% or better leafy spurge control 1 year after herbicide treatment (Table 3). Leafy spurge control may not always be equivalent among locations with similar treatments. Unpublished research conducted at Colorado State University indicated that 3 consecutive years of picloram plus 2,4-D at 0.25 + 1.0 lb ai/A applied in spring at the true flowering growth stage provided 59% leafy spurge control at the end of the third year. Drought conditions prevailed at this site for the duration of the experiment and most likely impacted results.

2,4-D. When 2,4-D is applied alone, biannual applications are recommended and typically represent a maintenance program to restrict vegetative spread and reduce seed set.

Table 2. Leafy spurge control with spring-applied picloram in North Dakota.

Herbicide	Rate — lb ai/A —	Months after treatment		
		3	12	24
			%	
Picloram	0.25	56	30	---
	0.5	58	63	3
	1	76	74	21
	2	93	96	82
LSD (P<0.05)		12	11	26

Lym and Messersmith (1985a).

Dicamba and dicamba plus 2,4-D. Sandoz prescribes a programmed approach to controlling leafy spurge with dicamba where 2.0 lb ai/A of dicamba are applied in spring at the flowering growth stage for 3 consecutive years. Lym and Messersmith (1985b) found that a single application of dicamba at 4.0 lb ai/A provided equivalent leafy spurge control to biannual applications of dicamba at 1.0 lb ai/A over a 27-month period (data not shown). High rates (6.0 to 8.0 lb/A) applied once provided 80 to 90% leafy spurge control for 1 year but reinfestation occurred (Lym and Messersmith 1985a) and the risk of grass injury exists with high dicamba rates (Lym and Whitson 1990). Although applying dicamba at reduced rates over time may not provide better control than a higher rate applied once, grass safety and decreased herbicide expense in any given year are advantages of the programmed approach.

Table 3. Leafy spurge control from annual applications of picloram or picloram combined with 2,4-D at two locations in North Dakota.

Herbicide	Rate -- lb ai/A --	August		June	
		1982	1983 %	1985	1986 %
Picloram	0.25	39	48	48	50
	0.38	65	62	75	72
	0.5	65	71	90	69
Picloram + 2,4-D	0.25 + 1.0	52	66	85	73
	0.38 + 1.0	69	72	91	82
	0.5 + 1.0	71	75	94	88
LSD (P<0.05)		18	14	16	17

From Lym and Messersmith (1986). Treatments began in August 1981 at Dickinson, ND and in June 1982 at Valley City, ND.

Final treatments were applied in 1984. Data averaged over locations.

Lym and Messersmith (1985a) found that biannual applications of dicamba at 1.0 lb or dicamba plus 2,4-D at 0.5 + 2.0 or 1.0 + 2.0 provided 70% or better leafy spurge control 27 months after treatment (Table 4). Unpublished research conducted at Colorado State University indicated that 3 consecutive annual applications at the true flowering stage of dicamba plus 2,4-D at 1.0 + 2.0 lb ai/A provided only 54% control at the end of the third year; however, these treatments were most likely influenced by drought.

Table 4. Leafy spurge control with annual applications of dicamba or dicamba combined with 2,4-D in North Dakota.

Herbicide	Rate -- lb ai/A --	Months after treatment				
		3	12	15	24	27
Dicamba	0.5	47	49	38	45	33
	1.0	50	57	70	58	73
Dicamba + 2,4-D	0.5 + 2.0	68	69	84	65	70
	1.0 + 2.0	53	58	65	68	71
LSD (P<0.05)		15	NE	23	NE	NE

From Lym and Messersmith 1985a. Treatments applied biannually.

Non-estimable (NE) due to insufficient number of similar experiments.

Glyphosate and glyphosate tank-mixes. Fall applied glyphosate at 0.75 lb ai/A generally provides 80 to 90% leafy spurge control 1 year after application (Lym and Messersmith 1985a), but a follow-up 2,4-D treatment is needed the following spring to control leafy spurge seedlings (Lym and Messersmith 1990). Leafy spurge control ranged from 3 to 24% and 18 to 32% 12 months after treatment with glyphosate and glyphosate tank mixes when applied in August or September, respectively. In a five-state regional project, grass injury ranged from 0 to 3% with August applications and from 23 to 28% with September applications (Table 5) (Lym *et al.* 1991). Whitson *et al.* (1989) demonstrated that a single season of sequential glyphosate applications followed by seeding perennial grasses, resulted in 88 to 93% leafy spurge control four years after seeding.

Table 5. Leafy spurge control and grass injury 9 and 12 months after treatment (MAT) with glyphosate and glyphosate tank mixes.

Herbicide	Rate -- lb ai/A --	August application				September application			
		9 MAT		12 MAT		9 MAT		12 MAT	
		Con- trol	Grass Injury %	Con- trol	Grass Injury %	Con- trol	Grass Injury %	Con- trol	Grass Injury %
Glyphosate	0.38	36	31	3	0	62	66	18	28
Glyphosate + 2,4-D	0.38 + 0.65	65	27	17	3	73	68	12	25
Glyphosate + Picloram	0.38 + 0.5	93	31	24	0	98	78	32	23
Picloram	0.5	91	13	21	0	96	17	30	17
LSD (P<0.05)		6	5	NS	NS	6	5	NS	NS

From Lym, R.G., K.G. Beck, P.K. Fay, M. Ferrell, and M. Peterson (1991).
NS is non-significant at P<0.05.

Fosamine. Leafy spurge control with fosamine has been inconsistent. Fosamine is typically applied at 6 to 8 lb ai/A in spring when leafy spurge is in the true flower growth stage. Fosamine will provide the best control when soil moisture is abundant and relative humidity is high (Whitson *et al.* 1989).

Sulfometuron and sulfometuron tank-mixes. Sulfometuron and sulfometuron tank-mixes were evaluated in a six-state regional study. Leafy spurge control averaged 11 and 14% 12 months after treatment with sulfometuron at 0.09 and 0.19 lb ai/A, respectively, when spring-applied and 40 and 59% when fall-applied (Table 6). Control was improved when sulfometuron was tank-mixed with picloram at either timing. Generally, fall-applied sulfometuron or sulfometuron plus dicamba or picloram provided satisfactory leafy spurge control, but grass injury was severe. Sulfometuron or sulfometuron tank-mixes are usable in non-crop settings where leafy spurge control is desired and grass injury can be tolerated such as around livestock holding areas, along railroad rights-of-way, and around power stations.

Table 6. Great Plains regional summary of leafy spurge control and grass injury 3 and 12 months after treatment (MAT) spring and fall applications.

Herbicide	Rate -- lb ai/A --	Spring application				Fall application			
		3 MAT		12 MAT		3 MAT		12 MAT	
		Con- trol	Grass Injury	Con- trol	Grass Injury	Con- trol	Grass Injury	Con- trol	Grass Injury
		%		%		%		%	
Dicamba	2.0	32 de	5 cd	6 d	0 a	79 c	10 b	54 c	0 b
Picloram						92			
	0.5	57 bc	5 cd	54 b	0 a	abc	21 b	54 c	0 b
Picloram								80	
	1.0	90 a	5 cd	78 a	0 a	99 ab	27 b	abc	1 b
Sulfometuron	0.09	17 e	12 bcd	11 d	15 a	86 bc	84 a	40 c	88 a
Sulfometuron						94			
	0.19	24 de	30 ab	14 d	31 a	abc	85 a	59 bc	90 a
Sulfometuron + dicamba	0.09 + 2.0	41 cd	31 ab	26 cd	19 a	100 a	80 a	89 ab	86 a
Sulfometuron + picloram	0.09 + 0.5	68 b	24 ab	63 ab	13 a	100 a	85 a	92 a	89 a
Sulfometuron + 2,4-D	0.09 + 1.0	54 bc	22 abc	22 cd	17 a	90 abc	76 a	46 c	57 a
Sulfometuron + 2,4-D	0.19 + 1.0	68 b	38 a	42 bc	29 a	99 ab	89 a	72 abc	93 a
2,4-D	1.0	33 de	2 d	13 d	0 a	21 d	3 b	14 d	0 b

Means in the same column followed by the same letter are not significantly different according to Student-Newman-Kuels mean separation test (P<0.05).

Recommendations for various habitats

Open rangeland/pastures. On rangeland or pastures that are situated away from live or ephemeral water channels or where high ground water does not exist, picloram, picloram plus 2,4-D, dicamba, or dicamba plus 2,4-D are logical herbicide choices. Lym and Messersmith (1990) found that picloram plus 2,4-D at 0.25 + 1.0 lb ai/A spring-applied was the most cost-effective treatment in North Dakota (data not shown) yielding a net return of \$115 and \$44 per acre in eastern and western North Dakota, respectively, and averaged 80% leafy spurge control across all locations.

Near water. Fosamine, 2,4-D amine, and glyphosate are registered to apply near water. Alternative leafy spurge control measures, such as biological control, are appropriate considerations for leafy spurge management near water.

Among trees. Glyphosate and 2,4-D amine can be applied safely near trees because of limited soil activity and if drift onto tree foliage is avoided. Shelterbelts may be prime areas to develop leafy spurge insect predator insectaries and may represent a safer, more effective control strategy than herbicide use among trees.

Non-crop areas. Picloram, picloram plus 2,4-D, dicamba, and dicamba plus 2,4-D can be used to control leafy spurge in non-crop areas. Sulfometuron also can be used in non-crop areas to control leafy spurge if fall-applied and grass injury can be tolerated.

Conclusion

Many effective herbicides are available to incorporate into a leafy spurge management system. Herbicides are only part of a good weed management system and herbicides are most effective when they are used in such a manner that the weed is stressed and desirable plants are not injured.

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Managing leafy spurge with livestock

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Introduction

The goal of our research is to discover ways to manipulate either the grazing animal or the leafy spurge plant and cause leafy spurge to become a preferred forage.

Managing leafy spurge by livestock grazing is potentially the best solution for this and other exotic weeds on rangelands. Livestock grazing may not always provide a feasible solution, but when it will it has two definite advantages over other methods of controlling weeds. First, the use of pesticides and introduction of exotic insects and pathogens for biocontrol may have negative environmental or perceptual consequences. Second, instead of simply eliminating a plant that is considered a problem, grazing livestock could convert leafy spurge from a pest to forage. However, the use of livestock for grazing leafy spurge will require more dedication and greater managerial skills than other methods of weed control.

Regardless of the objective, successful grazing management requires an understanding of the factors that influence selective grazing and plant response to defoliation. Therefore, this paper will begin with a short review of some general principles that affect grazing management. Then we will present some specific results from research at the U.S. Sheep Experiment Station on grazing leafy spurge.

Leafy spurge and other plants classified as weeds on rangelands were usually introduced from another continent. Therefore, they have few natural enemies or pathogens and may be adapted to unexploited niches in natural communities. Secondly, these weed species are not consumed by herbivores either domestic or wild; vertebrate or invertebrate. This implies that for some reason they are not palatable to these animals. Rangeland weeds might be considered ecologically competitive plants that no one wants to eat.

When we talk about using livestock to control weeds the goal is to manipulate the patterns of defoliation and place a target plant at a competitive disadvantage. To use any type of biological control effectively we must understand the grazing behavior of the herbivore and the ecology of the target plant species. In other, words we need to understand both the target and the bullet.

There are two approaches that can be used either separately or in combination to place a weed at a competitive disadvantage to the other plants in the community.

- 1) Use grazing management to increase the probability the target plant will be defoliated at a phenological stage and/or frequency and intensity that is most detrimental to it.
- 2) Modify grazing behavior to cause animals to have a strong relative preference for the target weed.

Grazing management will do little to modify the selective grazing behavior except as the more preferred species are removed because of high grazing pressure and the animals are forced to graze less palatable species.

Grazing management

The principles of grazing management for controlling weeds are the same principles used regardless of the management objective i.e., proper: stocking rate, season of use, kind or mix of livestock, grazing distribution, frequency and intensity of grazing (grazing system). However, because of the low productivity of rangeland, controlling weeds with grazing management alone may require a greater intensity of management than is economically justifiable. Therefore, it is important to discover ways to modify the animals grazing behavior to induce it to have a high degree of preference for the target weed.

When using grazing management to place a weed at a competitive disadvantage to other plants in the community it is important to understand how plants are adapted to defoliation. Grazing resistance refers to mechanisms used by a plant to survive in the presence of defoliation. Plants resist the negative affects of defoliation by tolerance, and avoidance. Tolerance mechanisms increase growth following defoliation; while avoidance mechanisms reduce the probability and severity of defoliation. Most weed species rely on avoidance mechanism to resist grazing. These include spines or other physical deterrents, and aversive phytochemicals. The key to management of perennial herbaceous weeds by grazing may be simply to induce livestock to graze them. When they are grazed they may not have the tolerance mechanisms to replace lost photosynthetic material and may be out competed by other plants in the community, such as the grasses, that have well developed tolerance mechanisms. Ideally, grazing should be planned so that defoliation occurs when it is most detrimental to the target plant and at the point in its phenological development that it has the greatest preference compared to other species in the community.

Modifying grazing behavior

Grazing management manipulates patterns of defoliation by controlling the timing of grazing or by using high grazing pressures to force an animal to graze plants that are otherwise avoided. In contrast management of grazing behavior attempts to modify patterns of defoliation by directly manipulating preferences using diet training. Behavior is adap-

tive and survival is the motivating force for all behavior. This point will be important in evaluating the potential for modifying diet selection.

Animal behavior has both innate and learned components, but to consider these two facets independently from each other or the environment in which the behavior is performed is an unwarranted simplification.

Innate behaviors are responses that are not highly dependent on specific learning experiences. For instance, although diet selection appears plastic, the presences of innate stimulus filters may predetermine which plants are perceived as potentially palatable food items for a given kind of livestock. Certain general phenomenon such as food neophobia and diet sampling are innate. These behaviors can have an influence on diet selection. Food neophobia is the tendency of herbivores to avoid foods they have not previously encountered. It is obvious that such a behavior would inhibit the ability to induce livestock to consume a new weed. Conversely, the tendency of herbivores to explore and sample their environment could cause animals that were conditioned to consume a specific weed to discover other plants that are more desirable and thus stop eating the target weed. Species specific differences in an animal's ability to detoxify phytotoxins can cause one kind of animal to receive a positive post ingestive consequence from a particular weed while another kind of animal receives negative feedback from the same plant.

Learning is a process by which behavior is acquired or changed by reacting to a situation. The degree to which diet selection is learned will decide the degree to which we can hope to influence this behavior. New responses are always being acquired and old ones lost on a daily basis usually without our knowledge. Through learning an organism can deal with a variable and changing environment where programmed and specific modes of response may be maladaptive.

A principle of learning is that an established response decreases if the stimulus is repeatedly presented without a consequence. This process is known as extinction. Extinction is just as important an adaptive mechanism as conditioning, because a continued response to cues that are no longer significant is not in the animals' best interest.

It appears likely that animals exhibit associative learning, because the brain has evolved to enable animals to distinguish events that reliably and predictably occur together from those that are unrelated. In other words, the brain has evolved as a detector of causal relationships in the environment.

Summarizing the aspects of animal behavior that influence diet selection it appears that diet selection is under the influence of innate and learned behaviors. Innate behaviors will place limits on the degree that diet selection can be modified by learned behaviors. Learning is a somewhat permanent change in behavior resulting from experience. The learned behavior will eventually cease when the stimulus no longer reliably predicts a future consequence. The existence of observational learning and sensitive periods for learning may present special opportunities for modifying diet selection. Efforts to modify diet selection that lowers an animals fitness compared to a diet that does not contain the target species is destined for failure because behavior is adaptive and survival is the motivating force for all behavior.

Results from grazing studies

Many studies on using sheep and goats to graze leafy spurge have been conducted at the U.S. Sheep Experiment Station since 1989. These studies have involved small pasture grazing trials and pen feeding trials. In the grazing trials animals graze small spurge infested pastures for periods of 1 to 2 weeks by which time pastures are generally 70% utilized. Data collected include bite counts to determine diet selection, and frequent biomass estimates of available forage and level of utilization. Trials have included studies on the effect of previous experience, species of livestock (sheep vs. goats) and location on the palatability and preference for leafy spurge.

Previous experience

The objective of the study was to decide if exposure of young lambs to leafy spurge would increase the consumption of this plant. Orphan lambs were exposed to leafy spurge from birth to 11 weeks of age as a water soluble extract mixed with milk replacer and as freshly harvested plants. Ewe-reared lambs were exposed to leafy spurge by grazing them on a leafy spurge infested pasture. Three studies were conducted to determine the effect of early exposure on preference for leafy spurge.

Study 1 investigated the consumption of vegetative and flowering leafy spurge paired with arrowleaf balsamroot by orphan lambs during a 30-minute feeding period. Experienced lambs consumed a higher percentage leafy spurge than naive lambs. The interaction of leafy spurge phenophase and previous experience showed that experienced lambs preferred leafy spurge despite phenophase (70% of intake) and naive lambs only preferred leafy spurge when it was vegetative.

Study 2 investigated the preference for leafy spurge on pastures with high or low leafy spurge biomass. Experienced compared to naive lambs had a higher percentage of bites and preferred leafy spurge in the high spurge biomass pasture, but not in low biomass pastures. Naive lambs avoided leafy spurge in both pastures.

Study 3 was a pasture trial that investigated spurge consumption by orphan and ewe-reared lambs. Percent bites and time spent grazing leafy spurge were not affected by previous exposure, but herbage removal was greater in pastures grazed by experienced compared to naive lambs (876 vs. 685 g/lamb, respectively). Experienced ewe-reared lambs had a higher rate of biting on leafy spurge than naive or orphan lambs. These studies indicate that previous experience will be an important factor affecting the use of sheep as a biological control agent for leafy spurge.

Sheep vs. goats

Preference for leafy spurge by sheep and goats has not been directly compared. In this study mature animals with no previous experience grazing leafy spurge were used.

Innate differences in preference for leafy spurge by sheep compared to goats was tested using paired confinement feeding trials and pasture trials.

In the paired feeding trials leafy spurge was paired with either arrowleaf balsamroot or crested wheatgrass. There was a significant interaction between kind of livestock and plant species paired with leafy spurge. Sheep avoided leafy spurge despite the other species of forage it was paired with. Goats avoided leafy spurge when paired with crested wheatgrass (33% of intake) but preferred spurge when it was paired with arrowleaf balsamroot (80% of intake). Averaged across both species of other forages offered, goats consumed 57% of their intake from leafy spurge during the 30-minute feeding trial compared to 28% for sheep.

In a pasture trial goats took 74% of their bites from leafy spurge compared to 16% for sheep. Pastures were grazed until total biomass utilization was 77%. Goat utilization of leafy spurge was 21 and 69% at mid and end of trial compared to 5 and 54% for sheep. Work is continuing to determine the effect of previous experience on preference for leafy spurge by sheep and goats.

Trials completed June 1992 suggest that differences between sheep and goats in their preference for leafy spurge may be moderated by the physiological condition of the ewe. Utilization of leafy spurge biomass was 42% greater for lactating compared to dry ewes. While the lactating nannies had a utilization rate only 10% higher than lactating ewes. We hypothesize that hormonal differences between dry and lactating ewes are ameliorating the aversive consequences of leafy spurge in these animals.

Results from confinement feeding studies and aversion trials help provide an explanation for the difference in preference for leafy spurge between sheep and goats. When leafy spurge is used as an aversive agent in a classical food aversion trial sheep are averted to a novel feed but goats are not. This suggests the presence of a phyto-chemical in leafy spurge that stimulates the emetic system and causes this aversion. Another study that investigated the affect of the percent spurge in a ground forage diet showed that as percent leafy spurge increased intake decreased. The slope of the line that predicted intake from spurge concentration was greater for sheep than goats. This shows that sheep are more responsive than goats to aversive phyto-chemicals in leafy spurge. Furthermore, we believe that these yet unidentified phyto-chemicals cause cattle to avoid leafy spurge to a greater degree than sheep. Identification and understanding of the phyto-chemicals in leafy spurge that cause this plant that otherwise is a nutritious forage to be classified as a noxious weed will be the key to manipulating livestock preference for it.

Effect of location

Anecdotal evidence suggests that livestock preference for leafy spurge varies among populations of this plant. Chromatographic analysis, DNA sequences and morphological differences support the observation that large variation exists among accessions of leafy spurge. Reports from Montana and North Dakota (ND) suggest that sheep will readily eat large amounts of leafy spurge on range and pasture land. In contrast, we observe that sheep in southeast Idaho (ID) are reluctant consumers of the weed. An experiment was conducted to decide if spurge palatability differed between ND and ID and if characteris-

tics that separated palatable from unpalatable accessions could be identified. This information could be used to identify leafy spurge populations that would be susceptible to control by sheep grazing. The objective of this project was to determine if differences in preference and utilization of leafy spurge growing in different locations could be shown and if the plants could be differentiated by gas chromatography.

Ten sheep from each state were placed on small, spurge-infested pastures in southeast ID and central ND. The trials were conducted in early- and mid-June in ID and ND, respectively. The alternative forages were primarily crested wheatgrass in ID and smooth brome in ND. Standing crop, number of grazed and ungrazed spurge stems and diet composition was recorded at the beginning, middle and end of each trial. At the start of the trials, the percent grass in the standing crop was 61 and 74 in ID and ND, respectively, while the percent spurge was 30 and 24 in ID and ND, respectively. Sheep grazed pastures until approximately 50% of the initial standing crop was removed.

Sheep grazed a greater percent of spurge stems in ND compared to ID (P) but utilization of spurge stems was not affected by the origin of the sheep. By the end of a trial sheep grazed 99% of the spurge stems in North Dakota compared to 70% in Idaho. In Idaho, sheep did not consume large amounts of leafy spurge until the second half of a trial. This showed that at this location significant utilization will not occur until other forages have been consumed. Relative preference for leafy spurge further demonstrated the importance of location on palatability of spurge. With one exception, sheep avoided spurge in Idaho but in North Dakota the contribution to the diet was about equal to its availability in the standing crop. The interaction of location x origin x trial for relative preference substantiated previous work at the Sheep Station that showed how experience can affect preference for leafy spurge. North Dakota sheep showed a strong preference for leafy spurge during the first half of the ID trial. We hypothesize this may have been caused by their familiarity with spurge that was presumably low in aversive phytochemicals.

We conclude that differential grazing of leafy spurge by sheep on sites in Idaho and North Dakota is a result of differences in palatability or post ingestive consequences of spurge growing on these sites. Gas chromatography of latex from these two accessions showed differences between peaks at 3.15, 33.43 and 36.98 minutes. This suggests that this procedure can be used to differentiate among spurge accessions of different palatability.

Conclusions

These studies show how innate and learned behavior will interact with the nutritional and anti-quality characteristics of the target plant to influence diet selection. Previous experience was shown to influence sheep preference for leafy spurge, by presumably modifying the animal's neophobic response to a novel food. However, experience alone did not decrease the apparent negative post-ingestive feedback that sheep receive when they consume leafy spurge. The presence of phytochemicals that cause negative post-ingestive consequences was shown by using leafy spurge to produce a conditioned food aversion. The ability to modify leafy spurge palatability, presumably by altering aversive

phyto-chemicals in the plant, was suggested by the change in preference between locations in Idaho and North Dakota. Finally, the ability to alter preference genetically was shown by the difference between sheep and goats. We conclude that, under conditions of free choice, preference for leafy spurge will be determined by the concentration of yet unidentified phyto-chemicals or the animal's ability to ameliorate the aversive affects of these chemicals. Furthermore, if animals are to be used to graze leafy spurge without intensive management and fencing that force them to graze the plant then it will be necessary to manipulate either the plant or the animal such that leafy spurge becomes a preferred forage. Presently the lack of information on the chemical compounds in leafy spurge that cause aversion is the main obstacle in advancing to our goal of manipulating either the grazing animal or the leafy spurge plant so that it becomes a preferred forage.

The control of leafy spurge (*Euphorbia esula*) by the interaction of herbicides and perennial grasses

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Introduction

Although herbicides play an important part in the control of leafy spurge, alternative methods are available that may be used where persistent herbicides cannot be tolerated. Grass competition has long been recognized as a method of leafy spurge control. The purpose of this research was to determine the potential of perennial grass competition as an alternative to repetitive herbicide treatment for control of leafy spurge.

Materials and methods

This research was conducted near Devil's Tower, Wyoming to evaluate the effects of eleven perennial grass species on leafy spurge. Two applications of glyphosate (Roundup, Monsanto) at 1 quart of product per acre were broadcast with a truck-mounted sprayer delivering 15 gpa at 35 psi before seeding grasses in 1986. The first application was June 2, 1986 and the second application was July 1, 1986. Soils were classified as a silt loam with 1.8% organic matter and pH of 6.3. Pendimethalin (Prowl, American Cyanamid) at 2 quarts and fluroxypyr (Starane, Dow/Elanco) at 1.2 quarts of product per acre were applied on May 16, 1988 with a tractor mounted sprayer delivering 20 gpa at 35 psi. Plots (60 by 90 feet) were arranged in a split plot design with four replications. One half of each plot was tilled and the other half was left untilled. Plots were tilled with a rototiller on August 12, 1986 and grasses were seeded with a John Deere powertill drill on August 12, 1986. Evaluations on percent grass stand, grass yield, and percent leafy spurge control were made each year starting in 1988.

Grasses used in this study were selected on the basis of their ability to establish in low moisture areas and included 'Luna' pubescent wheatgrass, 'Ephraim' crested wheatgrass, mountain rye, 'Sherman' big bluegrass, 'RS1' hybrid wheatgrass, 'Manchar' smooth brome grass, 'Oahe' intermediate wheatgrass, 'Secar' bluebunch wheatgrass, 'Rosana' western wheatgrass, 'Bozoisky' Russian wildrye, and 'Critana' thickspike wheatgrass.

Results and discussion

Grass stands were 70% or better in 1991 for most grasses in rototilled plots and for all grasses except Sherman and Luna in the no-till plots (Table 1). Mountain rye was least competitive grass and was replaced by intermediate wheatgrass and Kentucky bluegrass, which were present before the study site was seeded (Table 1). In no-till areas, Luna and Sherman maintained adequate stands, while Critana and Oahe stands were reduced to 33% and 43% stand, respectively, by five years after seeding (Table 1).

All grasses provided good leafy spurge control in 1988, but control declined in subsequent years for many of the grasses, particularly in the no-till plots. Leafy spurge control was 80% or greater for all grasses, except mountain rye and bluebunch wheatgrass, in tilled plots in 1991. Leafy spurge control was poor to fair in grass stands in the no-till plots by five years after planting (Table 1).

Bozoisky had the highest crude protein and TDN of all grasses sampled. There were no differences in nutritive value of grasses established in tilled and no-till plots (Table 2).

Grass characteristics. Luna pubescent wheatgrass is considered to be better adapted to droughty, infertile, and saline soils than intermediate wheatgrass. Luna was developed in New Mexico by the USDA-SCS (Onsager 1987). This was one of the best varieties in the study because it maintained good grass stands in both the tilled and no-tilled areas and good control of leafy spurge.

Ephraim crested wheatgrass has been the most widely use grass for seeding rangelands of western U.S. and Canada. Crested wheatgrass is an excellent source of early season forage; however, forage quality declines rapidly during the summer and fall. Ephraim was released in 1983 by the USDA-Forest Service, Utah State Division of Wildlife Resources, and USDA-SCS in cooperation with the Utah, Arizona, and Idaho Agricultural Experiment Station. This grass is persistent and drought resistant cultivar that has good sod-forming characteristics. It is recommended for grazing and revegetation of problem sites in low precipitation zones of the Great Plains (Onsager 1987). In this study, crested wheatgrass became well established and suppressed leafy spurge in tilled areas.

Sherman big bluegrass is an early maturing grass with good drought tolerance. It is best utilized in the spring since its nutritive value drops considerably as the summer progresses. This grass established well in tilled areas and in no-till areas. Leafy spurge control decreased in the no-till areas, but remained fairly constant in the tilled areas.

RS1 hybrid wheatgrass is a hybrid developed from a cross between quackgrass and bluebunch wheatgrass. The initial cross was made by D. R. Dewey in 1962. However, over 20 years were required to combine the desired characteristics of the parental species into genetically stable and fertile breeding populations. Two germplasm releases (RS1 and RS2) were made available to plant breeders in 1980. The RS1 release appears to be best adapted to areas receiving 12 to 18 inches of precipitation and responds well to repeated clipping or grazing and appears to be very palatable. This hybrid also has considerable tolerance to salinity (Onsager 1987). This grass established well in tilled areas during this study and stands increased and maintained good leafy spurge control in the tilled plots. The grass failed to adequately establish in the no-till areas.

Table 1. The control of leafy spurge by the integration of herbicides and perennial grasses from 1988 through 1991 near Devil's Tower, Wyoming.

Grass species	Grass stand (%)								Leafy spurge control (%)								Grass yield (lbs/A)							
	Rototilled				No-till				Rototilled				No-till				Rototilled				No-till			
	1988	1989	1990	1991	1988	1989	1990	1991	1988	1989	1990	1991	1988	1989	1990	1991	1988	1989	1990	1991	1988	1989	1990	1991
'Luna' pubescent wheatgrass	90	90	94	93	70	71	74	76	97	93	93	90	84	72	75	69	497	2074	1102	1910	274	1062	727	1162
'Ephraim' crested Wheatgrass	83	96	94	84	55	14	14	20	95	90	87	89	79	56	45	55	474	1434	836	1080	218	413	466	564
Mountain rye	18	11	1	2	5	4	0	0	79	50	49	64	58	31	20	8	368	436	0	0	224	119	0	0
'Sherman' big bluegrass	74	89	89	84	79	83	80	79	96	91	90	86	89	78	65	60	594	2297	922	881	336	2119	762	894
'RS1' hybrid wheatgrass	74	85	95	90	13	10	6	5	94	89	88	88	60	33	15	11	519	2886	1281	1518	142	619	382	586
'Manchar' smooth brome-grass	80	80	78	73	18	23	16	11	92	79	78	80	68	40	25	10	294	1263	639	780	152	605	171	260
'Oahe' intermediate wheatgrass	71	91	93	91	16	53	48	43	97	91	86	86	68	51	46	39	652	3173	1235	2329	152	2053	734	1099
'Secar' blue-bunch wheatgrass	64	64	58	75	15	2	3	5	83	76	65	76	64	35	24	24	194	968	871	1447	128	169	282	242
'Rosana' western wheatgrass	76	59	61	74	26	19	18	18	91	98	88	85	65	48	34	25	464	1348	729	1222	174	397	284	122
'Bozoisky' Russian wildrye	83	90	88	88	30	10	13	13	97	93	93	94	63	44	41	28	552	1283	564	932	160	220	229	438
'Critana' thickspike wheatgrass	81	61	64	70	29	15	20	33	94	78	78	86	70	29	36	50	484	1587	695	991	210	690	449	431
LSD (P<0.05)	13	21	23	19	13	21	23	19	16	18	21	21	16	19	21	21	151	630	335	421	151	630	335	421

Grasses planted August 12, 1986.

Evaluations: Grass stand and leafy spurge control; Sept. 14, 1989, Aug. 8, 1989, Sept. 13, 1990, and June 20, 1991 and grass yield; Sept. 14, 1988, Aug. 8, 1989, Sept. 13, 1990, and Sept. 12, 1991.

Table 2. Forage quality of eleven grasses planted in a pasture to suppress leafy spurge near Devil's Tower, Wyoming in 1986.

Grass species	Crude Protein	TDN
	%	
'Luna' pubescent wheatgrass	4.1	43
'Ephraim' crested wheatgrass	4.6	45
Mountain rye	3.3	45
'Sherman' big bluegrass	3.8	40
'RS1' hybrid wheatgrass	4.3	42
'Manchar' smooth bromegrass	4.9	46
'Oahe' intermediate wheatgrass	3.8	42
'Secar' bluebunch wheatgrass	4.7	45
'Rosana' western wheatgrass	5.8	45
'Bozoisky' Russian wildrye	5.8	49
'Critana' thickspike wheatgrass	4.4	38
LSD (P<0.05)	0.8	4

Grasses sampled August 8, 1989.

Manchar smooth bromegrass was selected because of its palatability, nutritive characteristics and ease of establishment. Adequate stands were established in tilled areas and, despite a decline in stands, it provided good leafy spurge control.

Oahe intermediate wheatgrass and its pubescent form, pubescent wheatgrass were introduced from Asia as early as 1907. It is a relatively tall grass with a moderate degree of rhizome development. It is more productive, but somewhat less drought resistant, than crested wheatgrass. Because of its large seeds and vigorous seedlings it is one of the easiest range grasses to establish. The grass matures from one to two weeks later than crested wheatgrass and provides more and better quality forage during the summer period (Onsager 1987). In this study, Oahe established excellent stands in the tilled areas, but poor stand established in the no-till areas.

Secar bluebunch wheatgrass is a cool season bunchgrass that is widely distributed on the dry plains and hills of the Intermountain Region and Pacific Northwest. It has excellent nutritional value. High palatability causes this grass to be rapidly depleted under heavy grazing pressure. Secar was released in 1981 by the USDA-SCS in cooperation with the Washington, Oregon, Idaho, Montana, and Wyoming Agricultural Experiment Stations. It is an early maturing, drought resistant cultivar adapted to the lower elevations of the Pacific Northwest and similar environments (Onsager 1987). This grass did not establish very well in the study, but stands and yield were adequate to suppress leafy spurge on the tilled areas.

Rosana western wheatgrass is a rhizomatous, cool-season, perennial grass that is widely distributed in the sagebrush ecosystem and in the Central and Northern Great Plains. Western wheatgrass was developed as a hybrid between thickspike wheatgrass and beardless wildrye. It is resistant to drought and is well suited to heavy alkaline soils, but is a poor seed producer and stands are often difficult to establish from seed. Rosana established good stands in the tilled areas and very poor stands in the no-till areas.

Bozoisky Russian wildrye is a cool-season perennial bunchgrass that has been widely used in the western U.S. and Canada. Once established, it has excellent drought and cold

tolerance. The species is characterized by dense basal leaves that are high in nutritive value and palatable to grazing animals. Forage quality of this grass during the late summer and early fall is better than many other grasses, including crested and intermediate wheatgrass. This cultivar has been significantly more productive and easier to establish on semiarid range sites than other Russian wildryes (Onsager 1987). Excellent stands of Bozoisky Russian wildrye that established in the tilled areas provided the best leafy spurge control.

Critana thickspike wheatgrass is a widely distributed sod forming perennial used primarily for soil stabilization on disturbed range sites. As a forage grass, it is most productive during the early summer when the nutritional value of crested wheatgrass is low. It is similar in appearance to western wheatgrass and is more tolerant to drought, but it is less productive. Critana was released in 1971 by the USDA-SCS in cooperation with the Montana Agricultural Experiment Station. This grass originated from collections made from roadside cuts in north-central Montana and is recommended primarily for revegetation of disturbed range areas and other dry habitats (Onsager 1987). Critana establishment was good in tilled plots, but poor in the no-till plots. It maintained good leafy spurge control and good forage production in the tilled plots.

Luna and Bozoisky appear to be the best overall grasses for competition with leafy spurge. Luna became well established in both tilled and no-till plots. Bozoisky Russian wildrye provided the best leafy spurge control in the tilled plots and best late season nutritive value. These two grasses were seeded August 8, 1989 in another study that was designed to determine how grazing influences the competitiveness of these grasses with leafy spurge.

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An integrated approach to leafy spurge control: Magic, myth, or mess?

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Several control methods are available to develop an integrated leafy spurge control program. The methods include cultural (crop competition), mechanical (tillage, mowing), chemical, biological control (insects, diseases), and a variation of biological control, grazing with sheep and goats.

Integrated leafy spurge control programs are not a new or mythical practice. Craig (1957) proposed “A leafy spurge eradication program” in 1957. This program included chemicals such as atlacide, borax, and 2,4-D at 20 lb/A, intensive cultivation, grazing with sheep, and prevention. Although the integrated approach is not new, some new tools are available to incorporate into the program, such as biocontrol with insects and eventually disease organisms.

Initiation of an integrated program in the best sequence for long-term control is probably important. For instance, should insects such as *Aphthona* spp. be introduced into a leafy spurge infestation first; then after the infestation is reduced, use herbicides to remove surviving plants? Or should the herbicide be used first to weaken the plants thereby allowing the insects to reduce the infestation more rapidly? Does grazing of leafy spurge during the summer followed by a fall-applied herbicide treatment reduce an infestation faster than a spring-applied treatment followed by grazing or fall regrowth? Does grazing by sheep or goats alone reduce the infestation or only allow the use of the land? The answers to these questions remain unknown, but the research programs to answer them are underway.

Good leafy spurge control has been achieved with cultivation combined with chemical (Derscheid *et al.* 1963) and more recently with herbicides applied prior to seeding competitive perennial grasses in rangeland (Ferrell *et al.* 1992). An integrated program also can mean establishing more than one type of insect in a location such as *Aphthona* spp. and the gall midge (*Spurgesa esula*) to reduce root vigor and seed production, respectively.

However, leafy spurge control will not automatically become a magical success just because a program is integrated. For example, the combination of a gall fly plus a stem-mining larva on Canada thistle did not or only slightly reduce plant vigor over a 3-year

period (Peschken *et al.* 1992). Also, the combination of a picloram treatment followed by cattle grazing was less successful in controlling diffuse knapweed than the herbicide applied alone (Maxwell *et al.* 1992).

An integrated approach should be designed for the specific land use and location to be successful. The best approach for a Rocky Mountain meadow with wildlife foraging will probably not be the best combination in the Nebraska sandhills that are grazed by cattle. Insistence that one program is best, or only using those pieces that are politically popular will lead to a mess and poor management success.

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Leafy spurge management: Perspectives of a Nebraska sandhills rancher

S. SALZMAN

Rancher, Salzman Cattle Co., Ainsworth, NE 69210.

My biggest qualification in giving this talk is not the success I have had with leafy spurge control, but rather the lack of success I have had in the past forty years in attempts to stem the onslaught of this noxious weed. In spite of past failures, I'm very encouraged by the possible control of spurge in the future. The efforts within the scientific community that are occurring today in the various disciplines of chemical and biological control are a great beginning. I'm fully confident that we are beginning to witness the fruits of this important research.

As a member of the producer's group, I want to thank the scientists for their contribution to developing strategies to improve the control of leafy spurge. I'm very pleased that there is much work being done with many potential control or management practices in many different environments. A simple "shotgun" approach to control is not applicable to the many different environments in which leafy spurge is found. A diverse array of economic and environmentally sound management options are needed to effectively deal with leafy spurge.

I will use my ranch as an example of the complexity of problem. Ours is a typical sandhills ranch that has leafy spurge on many different range sites including; sub-irrigated hay meadows with a water table that fluctuates between 3 inches to 3 feet in depth, many groves of trees where leafy spurge thrives in the understory, and high dry sandy hills that are 30 to 70 feet above the water table. It has become apparent to me that one method of control will not adequately address these varied situations.

Our primary control practice has been to use herbicides. In the sub-irrigated meadows we spray 2,4-D twice a year. This treatment would work quite well if we were able to be consistent in applying the herbicide every year, but in extremely wet years the ground is too soft to support spray equipment so we are unable to spray before leafy spurge sets seed. Spraying in the fall of the year is very difficult because the leafy spurge is often hidden from sight by forage grasses. We spray 2,4-D to control leafy spurge that occurs in tree groves, but it is a real challenge to maneuver herbicide application equipment in the groves and to get complete coverage. We spray small patches of leafy spurge in the hills with picloram and have been very successful in eliminating these patches.

A management practice that we have adopted to reduce the spread of leafy spurge is not to feed hay to cattle on non-infested hay meadows that may be contaminated with leafy spurge seed. In the past, feeding hay on the wet meadows was a widely adopted practice and on our ranch was a very efficient vehicle for movement of seed and propagation of leafy spurge. Today we feed contaminated hay in lots and pile up the manure and let it stand for extended periods of time. This has appeared to be quite effective in decreasing the germinability of the leafy spurge seed. We look forward to using sheep or goats in the tree groves and insects and pathogens on other areas of the ranch along with the judicious use of herbicides.

The topic of my talk is suppose to be a producers perspective on leafy spurge control and the reason I have concluded our control problems and treatment efforts is to expose you to my background and to help you understand the influences that have shaped my thinking. A holistic approach to leafy spurge control is going to be a necessity if this scourge of Northern Plains rangelands is to be controlled. A necessary part of this approach will include continuing scientific research, publicity, and operator assistance in implementation of new control technology and most importantly, a different mind set. I will briefly examine each of these topics.

Scientific research needs to be continued and expanded to include new areas as the knowledge base is enlarged. I urge the scientific community not to limit their thinking and to consider new possibilities regardless of how ridiculous they might seem. An example of this that comes to my mind is something that I'm personally involved with at the present time. A year ago I analyzed the feed value of leafy spurge in hay from a sub-irrigated meadow and found it to contain 14.5% crude protein. I contacted some researchers about the possibility of starting feeding trials with cattle. Preliminary in vitro trials were run and the results were encouraging enough to continue with a limited look at the nutritive quality of leafy spurge. I am not advocating at this time that we should adopt leafy spurge as the new forage of the century, but who knows we may find that the most economical and environmentally sound treatment alternative for leafy spurge on sub-irrigated meadows is to use leafy spurge as a feed source. Another relatively unexplored area is determining the influence of livestock trampling on leafy spurge growth and development. I use these two examples to make the point that no avenue should be left unexplored.

Publicity is a very important part of the fight against leafy spurge that has been neglected. The public and state and federal legislators and research institution administrators are not going to consider leafy spurge as a pressing problem unless they are made aware of it through the news and individual contact. Producers and scientists both have the responsibility to jointly make the public aware of this problem weed. The scientific community has the responsibility to make their results available in public forums and not only in the rather narrow outlet of scientific publications. Producers need to assume more responsibility in helping publicity campaigns because their input to state and federal legislators and research administrators will have a great impact on appropriation of funds and establishment of research priorities.

Several years ago a coalition of researchers and producers formed the Nebraska Leafy Spurge Working Task Force. This group has had some significant accomplishments that include conducting quarterly meetings and an annual state-wide meeting, garnering support from various state and county organizations and private individuals to support a

graduate research position at the University of Nebraska, exhibiting posters and disseminating information on noxious weeds at numerous meetings around Nebraska, actively interacting with state and federal legislators, and working with local Weed Districts to promote control of noxious weeds. These are just a few of the Task Force's many accomplishments. I use these examples to highlight their efforts and to demonstrate what can be done to enhance public awareness. Remember that "the squeaky wheel gets the grease" and getting the word out is crucial to developing and maintaining successful research and control programs.

Research efforts, publicity, and laws are not going to get the job done if the producer community does not believe that leafy spurge is a real threat to his/her livelihood or that of his/her community. Publicity is a big help, but there is more that can be done to improve our efforts to control leafy spurge. I feel that there is a need to develop more effective and efficient information delivery systems, detailed economic analyses of control options, programs to improve producer involvement, field demonstrations of various control methods that include treatments that could be used in a producer's operation, methods to map weed distributions that can be easily applied in the field and understood months later, and last, but not least, producers need to encourage one another to continue control efforts.

One thing that could help would be government financial aid, but this must be handled correctly or it could work against development of successful weed control programs. I am very opposed to state or federal financial assistance in the form of a set dollar amount for control, but would support a cost share of a percentage of the cost of control incurred by an individual. Cost share programs should allow for the use of all viable control practices and not just herbicides.

The future looks bright for leafy spurge control, but I have concerns that we should be aware of and protect against. These concerns are the loss of herbicides, a "tunnel" vision approach to control, a mind set that strives for eradication of leafy spurge, and the occurrence of producer apathy that arises from the philosophy that research will solve this problem without his/her help. The loss of herbicides is not a scare statement, but a reality. Herbicides must be used prudently and wisely or else it will be mandated by the public that their use must be curtailed. The "tunnel" vision approach always is a possibility as various segments of the scientific community focus on parts of the problem and lose sight of the need to develop research programs that include many different disciplines. We need to continue to hold meetings, to communicate through the Leafy Spurge Newsletter, and to generate support for truly integrated research and control programs. The mind set that one leafy spurge plant is too many must be changed if mechanical, insect, and pathogenic control methods are to be successful.

The last concern I have is the lack of producer support. Producers have traditionally been very demanding that somebody should help them and this somebody includes state universities, federal agencies and whoever else is in sight. To ensure success, producers must take the bit in their mouth and help support these efforts and not focus only on their operation. I encourage and strongly recommend a conscious effort to establish more groups such as the Nebraska Leafy Spurge Working Task Force and to develop a partnership between producers and researchers.

In conclusion, I want to say thank you for the research endeavors that have been and are being made. I am confident that the problems I have expressed can and will be overcome and in the next ten years more progress will be made than has been made in the last 30 years. It has been a privilege to address this group and please remember that what I have presented today are my opinions.

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The importance of public involvement in controlling leafy spurge

J. BISHOP

Lincoln, NE 68506

Note: As a writer, I serve DowElanco, on noxious weed issues in particular. My company, Bader Rutter & Associates, is an ad agency in Milwaukee, Wis. I'm based here in Lincoln.

Let me explain how I ended up here before you. I attended a committee meeting. Now many of you are perhaps very familiar with committee meetings. You know the scene. Several people around a table draining three coffeepots. Someone says we ought to do such and such. A period of silence. These very busy people avoid eye contact. And then someone opens their mouth and begins to pontificate on the subject. That's called volunteering. So here I am.

Committees are funny things. Like Yogi Berra said: I'd like to thank the person who made this meeting necessary.

Actually, I'd like to thank the Symposium planning committee. It is truly an honor to speak to you.

So let's talk about the importance of public involvement in controlling leafy spurge, or managing leafy spurge, or living with it, or whatever term you prefer to use. For leafy spurge is noteworthy among noxious weeds for many reasons. It is the lightning rod of noxious weeds. Others may cause more economic harm. Others infest more acres. Others spread much faster. Others may destroy more land. But leafy spurge is perceived as the most harmful. It draws more interest from people, more attention of regulators, more time and animation from the research community and the energy of tax revenues. Perhaps this is so because leafy spurge is more feared than the other weeds, because it is so persistent. And such a threat.

But even the lightning rod of noxious weeds gets little attention outside our small circle. Overall public awareness is low... political support meager... and in the context of our country's many social problems, it is considered at best a minor concern.

But not to us. It is important to us. It's important to those we serve directly.

If this does not ring true for you, here are several examples.

Just a few years ago the Heritage Foundation cited funding for leafy spurge control on federal lands as a waste of money.

More recently, publicity from the Office of the President this year recommended cutting federal funds for a research project on leafy spurge. That project was to cost something like \$250,000. Compared to the annual expenses of our government, it is paltry. Yet there was spurge at the whipping post.

What does this mean in the day to day? I ran into a weed scientist at Chicago O'Hare Airport. We were acquaintances and we got to visiting about his job, and the neat things he was doing, groundbreaking stuff. Well, I said, What is your research budget? Turns out it was something like \$3,000. Hardly enough to pay for test tubes, let alone lab time, grad student research, field testing. And like many researchers, he obtained outside funding for a significant portion of his work.

There are many examples of how noxious weed research and control get short shrift. And it is my opinion that it will only get worse unless there are changes.

On the local and state level, our roads and bridges are coming apart. Fixing them costs big bucks. There are similar pressures on other services, such as education, health care, and other public works.

As Sid Salzman said in a hallway conversation just yesterday, he as mayor of Ainsworth, Nebraska, has had some difficulty explaining to his citizens why the city must spend \$2 million for a new water plant to meet new regulations. And then there's the landfills.

The point is each of these areas has a large constituency, larger than that for weed control, or some other driving regulatory requirement.

And it doesn't help that in many rural areas' populations are declining and many young people are moving out.

University budgets also are facing the budget crunch. I'm sure that you are dealing with this trend each day, for the same trends are at work in the government agencies.

In the larger scheme of things, the Los Angeles riots will pull more money into the rotting core of our major metro areas. And rural America will see fewer resources devoted to its special needs.

All these trends will compel a forced ranking of what is "perceived" as most important. And that is where the dollars will go.

We'll have to choose among essential services. I argue that in many cases, noxious weeds will not make the cut.

Continued financial pressure on agricultural operations, and in some cases landowner apathy, will simply accelerate the cycle of destruction.

But we know the core problem. Noxious weeds can destroy the land. A) they cut the flow of money from agriculture; or B) in the worst case, they take land from the tax base.

Society is the loser, forfeiting a portion of renewable wealth. ***We protect that... that is our service ... and that is our value.***

Now, before we close down the mainstreets and bring back the bison, before we hang it up, before we grow despondent because our society just is not going to recognize the value of agriculture in general nor our specialized services in particular, let me ask this question.

Do we have a marketing problem? Yes. We do.

In part, my answer to this builds upon the definition of services. Services as in the service economy. Services as in public service.

By definition, a service is not a service unless someone is being served. Anything else is sitting at a desk with a phone that doesn't ring.

What I mean is, someone must benefit from a specific set of activities or there is no service. That's because no value is being transferred from the person performing the service to the person being served.

Here's an instance of that. An insurance agent who has no customers writes policies for no one and is not performing any service. They are not likely to remain an insurance agent very long.

In a similar context, we help ensure the sustainability of agriculture in many regions. Who is our customer? And do they know we act on their behalf.

Clearly the producer is our customer and we are agents of change who enhance his or her operation. So when we show that noxious weed control is profitable, either through utilization or protection of land values, we perform direct service and transfer value. And they know we are there for them.

But in many cases, there is little or no direct payment for *the results of* our services. With the general public, they may benefit from our works without their knowledge.

For example, the public servant does a socially beneficial labor, draws a paycheck, has programs funded. Some benefit directly, but for the rest the value flows to them indirectly.

Here's how. Farmers save money when they apply new findings in crop research. The result: cheaper food for all of us. And it's something for which we all have paid. That's simple, you say.

Of course it is. But does the general public understand? Not very likely.

So I'd add another criterion. It is one that I think relevant to indirect values transferred in the service economy. It concerns this matter of ensuring that the benefits of our services remain sustainable.

I think that an indirect service is not valuable unless it is perceived by enough people to be important, beneficial, relevant, and valuable.

And that leads us to the importance of public involvement in noxious weed control.

The work we do is for the greater good. Yet I wonder if we get enough recognition to sustain our efforts.

Yes, it is very nice to get a pat on the back. But that's not what I mean. If what we do is critical to society, we need recognition to keep it going. So our ego needs are really

secondary to the larger problem of preserving agriculture. And I believe we are at a turning point not entirely of our own making. We can stem the spread of noxious weeds like leafy spurge through improved control on the farm, advancement of research, and strengthened regulation. Or we can lapse.

In Nebraska we have a rather unique group of folks who help ensure that this recognition occurs. That is the Nebraska Leafy Spurge Working Task Force, and the regional chapters spawned by the state organization.

These ranchers, farmers, researchers, regional, state and county officials, local residents, agribusiness representatives all actively advocate for better leafy spurge control and educate the public about noxious weeds. This grassroots organization has helped supply the political will to fuel a resurgent noxious weed effort.

They form a constituency for leafy spurge control, and can fulfill a political role when that is necessary in a society that indeed is political.

These folks have successfully lobbied for a strengthened state weed law.

They write letters to state and federal legislators to support increased funding for noxious weed control research.

They went to darn near every sales barn in the state with leafy spurge specimens to show producers what it looked like.

They have a weed mapping and tracking program.

They have stimulated interest in biological control and helped the various agencies put out insect releases.

They raised \$44,500 to pay for a weed physiologist position dedicated to leafy spurge at the University of Nebraska at Lincoln.

As individuals and a group they devoted countless hours to this cause. And there is not a single one of them who isn't quite busy in some other vocation. They have done many, many things. Tough, difficult, and challenging things.

Perhaps you have a group of folks in your region who perform a similar role. Perhaps you have an organized and inclusive group to whom you can provide direct service. For it is through their advocacy that a larger portion of society gains appreciation for your services. They can be the glue that holds the thing together, and sustains it. They give us depth, give us commitment and give us will.

There's a perfect example of this "people power" right across from our hotel. You all are familiar with Ross Perot and his withdrawal as an "alleged" presidential candidate just a few days ago. If you look outside you'll see a Ross Perot for President campaign office, signs in the windows, everything. And a great big "We're open" sign on the front door. The momentum carries this movement forward despite the loss of its leading light.

In much the same way, people power can support our efforts. They can also help us in directing our effort, so that what we do in research, regulation, or marketing has direct value to them.

In your region such a group may not be called the Leafy Spurge Task Force. It may go by some other name, but serve a similar role. In any case, we must recognize them, for they recognize us.

So let us take a moment to recognize three individuals key to the success of the Nebraska Leafy Spurge Task Force. By doing so, before a group such as yourselves, we increase the honor paid to them as individuals. And just as important, we honor what they represent. For that is why the Nebraska Leafy Spurge Task Force honors these three people today.

First, let's recognize Sid Salzman. Sid has ranched in Brown County, Nebraska, for over 40 years. He first observed leafy spurge on his land in 1951. He helped found the Task Force and was its first president, from 1987 to 1989. He has been president of the Society of Range Management's Nebraska section, and has been active in livestock associations. More recently, he was elected Mayor of Ainsworth, Nebraska. Sid has been a true soldier of spurge. He's devoted many hours and much thought and energy organizing political and control efforts. All without compensation. Because of Sid's leadership, knowledge and effort, the state leafy spurge effort has attained credibility and success.

Next let us recognize Dennis Jilg. Dennis couldn't be here today, for as some of you know he ranches in Rock County, Nebraska, near Newport. With all this rain, the ranchers are a little behind putting up hay, so that's what he's busy doing now. Dennis has been a member of the Task Force since 1987. He was the group's second president, serving from 1989 to 1991. With the help of Dennis's leadership, the task force won honorable mention in state and national Take Pride In America award programs. He also was instrumental in raising the \$44,500 for the plant physiologist position at the university. We hope this research will yield fruitful knowledge for the long-term struggle. These funds were raised in six months from area, state and local organizations and agencies, including Natural Resource Districts and county weed programs. Dennis continues to provide leadership on this as chairman of the task force research committee.

Lastly, and for me a very special award, let us recognize the efforts of a representative of the agribusiness community. It's special for me because I work closely with this person and regard him as a personal friend. And that is John Kitchell of DowElanco. John's leadership, organizational help, time and energy have helped foster the Task Force. John has also been in a position to provide a great deal of information, through posters, photos, videos, and literature. DowElanco each year has supported the Task Force's annual meeting and weed tour. And all these things have helped the Task Force reach the farming community and the general public efficiently and effectively.

So let us recognize these people, with the understanding that what they do is valuable to us, and to the society we all serve.

Thank you.

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Mohair production

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Mohair is the long, lustrous, wavy hair produced by Angora goats. Their name is derived from Ankara, the province in Turkey where they have thrived for centuries. They were guarded against exportation until 1849 when seven does and two bucks were imported into the United States. Later more goats were imported from Turkey and South Africa. From this small beginning the United States has become the second largest producer of world mohair. The other two major producers are South Africa and Turkey.

The mohair industry is centered in Texas, but the goats are raised over wide areas of the United States. The goats adapt well to many conditions, but are particularly well suited to the arid conditions of the southwestern United States. The major mohair warehouses are located in central and southwestern Texas where 90% of the United States clip of mohair originates.

Angora goats, said to be the most efficient fiber-producing animals in the world, are usually sheared twice a year, before breeding and before kidding. The hair grows about 3/4 of an inch a month, and adult hair should be four to six inches long at shearing. An adult goat usually will produce seven to fifteen pounds of mohair a year. Kid hair will be finer and shorter and may yield three to five pounds a year. Mohair fiber diameter (micron) ranges from 20 to 40 microns.

Care should be given to keeping the hair clean and free from contaminants such as weeds, grass seeds, and urine. Badly contaminated hair and hair showing second cuts will be severely discounted by the buyers. Fleeces should be bagged separately and identified according to type, such as kid, yearling, young adult, buck, and stained with spring or fall clip and growers name properly identified on each bag usually a permanent type felt tip marker. Special problems, such as burrs, coarse, extra long or short, should also be listed on the bags. Mohair is bagged in six-foot burlap bags, with only one type of hair in a bag. The buyers slit the side of the bag when inspecting prior to buying, so it is in the sellers' interest to present a uniform product.

Bucks should be sheared at least three weeks before breeding and should be well fed and vigorous. A buck should be able to service 30 to 40 does on range conditions, as many as 50 does in confinement, but it is poor management to depend on a single buck. Bucks should be chosen for body conformation, fine hair, and open-faced bucks not

blinded by hair are preferred. Bucks should be left with the does for six weeks. Angora goats are seasonally estrus and usually start cycling in September, so the normal breeding season is from late September into December. The gestation period for goats is usually 150 days, but it can vary several days each way, the first kids can be expected 156 days after turning in the buck. Kids are usually dropped from late February through April or early May. Twins are common in mature does, with a much lower percentage being triplets.

Angora goats are animals with high nutrient requirements and they will give nutritional advantage to fiber growth at the expense of other demands. Meeting the nutritional needs of the goats should be the producers main concern. Range forage of browse and forbs, protein supplements, grain and crop residues, and cereal crop pastures can all be used to supply the nutrients needed for growth and reproduction. Poor nutrition is the leading cause of abortion and poor mothering, with young or lighter-weight goats most subject to abortion. Stress from disease, moving long distances, or cold wet weather also causes abortions. Does should be in good condition and gaining weight at breeding time. Young does should weigh at least 55 pounds and mature does at least 75 pounds sheared weight at breeding. During pregnancy and lactation does need almost 1/2 pound of crude protein daily. Supplement feeding must be started as soon as the goats begin to lose weight and condition. The rewards of improved nutrition are more and better kids and heavier fleeces.

Goats should be given adequate nutrition before and after shearing. Angora goats must be able to take shelter from cold rains and chilling winds. The animals are very sensitive to wet and cold and great death loss can occur if shelter has not been provided. They should have shelter available for four to six weeks after shearing.

Large herds are usually kidded on the range, while many small herds use a more intensive confinement system to handle the goats. For open kidding, small pastures with shelter, centrally located watering and supplement feeding area, and a bedding area, are required. This arrangement reduces the number of kids which get separated from the does. It is wise to minimize disturbance of the does and kids for several weeks, to prevent does from abandoning the kids. Be sure to check the pastures for kids that may have been left behind when the goats are moved. Predators are always a threat to kids and fencing should be made to keep them out.

A more intensive kidding system makes use of buildings, small individual stalls, heat lamps, and feeder space. With this system kidding can be done earlier in the year, however, such a system is much more labor intensive and more expensive, but a larger kid crop can be realized if the facility is well managed. Before kidding the does should be kept outdoors except in cold or wet weather or at night, this will help keep the bedding clean and dry. As the does kid they should be moved into the stalls and the navel of the kids treated with 7% iodine and they should be helped to suck. Antitoxin C & D should be given. Cold kids will not try to suck and a heat lamp may be needed, they will usually suck by themselves when they are warm. Angora kids are very sensitive to the cold and will die within a short time if they are left chilled. Goats are born with a low glucose level and their energy is soon used up; there are products on the market to compensate for this loss. Severely chilled kids can be immersed in warm water to speed up the restoration of body temperature and thoroughly dried.

Does and kids can be moved to group pens or holding areas after the kids are well established. Pairs should have some form of identification, either paint or ear tags, before they are moved. Twins and triplets should not be coupled with singles since the stronger does will often rob from the usually smaller multiple birth kids. Likewise, the groups should contain kids of similar age.

Internal and external parasites are a major health problem with goats. Lice can be controlled by spraying after shearing. Coccidiosis is a threat to all goats, especially kids, and any kid not growing properly is probably infected. A good health program worked out with the veterinarian is a producer's best defense against disease and parasites.

Further information concerning Angora goat production can be obtained from the following sources:

Mohair Council of America
P.O. Box 5337
San Angelo, TX 76902
915-655-3161

Ranch Magazine
P.O. Box 2678
San Angelo, TX 76902
915-655-4434

E. (Kika) de la Garza Institute for Goat Research
Langston University
P.O. Box 730
Langston, OK 73050
504-466-3836

Texas A & M University System
7887 North Highway 87
San Angelo, TX 76901
915-653-4576

Angora Goats the Northern Way
Susan Black Drummond
Stony Lonesome Farm
1451 Sisson Road
Freeport, MI 49325

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Cashmere production in the United States

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Cashmere fiber is the fine underdown produced by cashmere goats. Cashmere is a type, not a breed of goat. Any breed of goats, except angora, can carry the gene for the soft underdown known as cashmere. Any goat producing this down in sufficient quantities is called a cashmere goat. There is no such thing as a "pure-bred" cashmere goat. The goats produce a fleece consisting of the very fine, crimped down and the coarse straight guard hairs. A goat that does not display both types of fiber should be avoided. These fibers must be separated, either by combing the down out or by a commercial dehairer after shearing. The separated guard hairs are used in rugs or for hair canvas to be used in the construction of tailored garments. The longest, finest down is used in knitted garments and the other down in woven fabrics.

Garments made of cashmere are prized for the unique feel of the fiber. It is very soft, very warm and very long wearing. Cashmere feels much softer to the skin than wool, and while it is not as strong as wool, cashmere outwears wool. Cashmere has long been known as the fiber of kings, and the demand has always exceeded supply.

The majority of the world supply of cashmere has come from Iran, Outer Mongolia, India, and China. In recent years these countries have been in such political disarray that the cashmere supplies have been disrupted and manufacturers are looking for more stable supplies. New Zealand and Australia have been producing cashmere for about 15 years. The first Australian sale of cashmere fiber was in December of 1980. However, feral (wild) goats were captured and the breeding process started several years earlier.

It is interesting to note that both in Australia and the United States, many of the leaders of the industry are women. Women seem to have a natural affinity for the goats, both in size and temperament.

Cashmere herds can be developed in several ways, depending upon the grower's situation, no one way is superior to another. Prospective herd members can be selected from either dairy goat or meat goat sources. Since cashmere down growth begins about the longest day of the year and stops on about the shortest day, selection should take place during the later part of this time. Shortly after the down growth stops it will be naturally shed if it is not combed or sheared. When determining if a goat has the down, the guard hair should be parted to search for the down underneath. If the goat carries the gene for

down it can, over time be developed into saleable amounts. A very tightly crimped down is most desirable, the crimp is called the character or style of the fiber. The diameter of the fiber must be under 19 microns to be considered cashmere. The usual range is 16 to 19 microns, however selected goats may have fiber as fine as 14 microns. A yield of at least 30% down in a fleece is desirable, but that is a goal and not the average by any means. Buyers pay on the down weight or weight of dehaired fiber, not the weight of the entire fleece.

Goats come in many colors and combinations of colors, but solid colored goats are preferred. The cashmere down is either white, brown, or gray solid colored goats. The less desirable down from mixed colored goats is either classed as white with color or mixed color.

Some growers have imported goats from Australia or New Zealand, where much of this selection process has been in progress for some years. These goats, as a herd, or used as breeding stock to improve the selected native goats, will produce greater returns more quickly than will native stock. It must be noted that there are many very good goats among the native stock. Their fiber diameter is apt to be smaller, but the length and yield of fiber is much less. The aim would be to keep the finer diameter and increase the length and yield through selective breeding. Dramatic results in fiber are shown in crosses of imported bucks and native does, these crosses are called F1 or bred-on crosses. It must be remembered that crosses with angora goats produce a fiber with very limited uses, the fiber is called cashgora. Cashgora does not have the characteristics of either cashmere or mohair. Angora goats do not produce angora, rabbits produce angora, and angora goats produce mohair. Mohair by itself is a beautiful fiber of an entirely different type: long, coarse, and wavy, and should be kept strictly separate. Mohair diameters run from 20 to 40 microns. Great care should be taken to avoid any angora infusion into a cashmere herd, it will greatly increase the yield of fiber, but the fiber combination (cashgora) is very undesirable.

The spanish meat goats from Texas and the Southwest are a source of breeding stock that produces big meaty goats. Of the dairy breeds, Toggenburg, Saanen, and Nubian are being used with good results. Pygmy and Fainting goats are being used by some growers. Good-sized goats with wide, thick, meaty bodies will bring more income when goats are sold for meat or culled. Large bodies can also produce more hair if they also have dense hair follicles.

Goats are browsing animals and can be pastured with sheep and cattle, since each species prefers different plants. Goats prefer brush, tree leaves, and rough plants. They are being used extensively for pasture improvement and in reforestation areas. Ranchers in the high plains are finding them useful in controlling leafy spurge. Goats will also destroy multiflora rose, red cedar, and many other problem weeds and brush. When growing plants are not available the goats will need to have supplemental feeding of hay and perhaps grain. Does need extra feed prior to breeding. Pregnant does need good feed in order for the fetus to develop hair follicles. To assure big healthy kids, nursing does need good feed.

Goats have special fencing needs both to keep them in and to keep predators out. Fences should be four feet in height. Five wire electric fences constructed with three hot

wires and two grounded wires work well. Existing fences can be used with the addition of a 12 inch outrigger electric wire, located about 12 inches above the ground. Goats like to go under or through obstacles. Other types of fencing are also used. If woven wire is used, care must be taken that the mesh size is large enough that the goat can withdraw its head without the horns catching in the mesh or small enough that they cannot get their heads through the mesh. The larger size mesh allows the kids to escape so it may not prove satisfactory. Horns caught in the fence or the crotch of a tree become life threatening, not only from predators, but from other goats. While goats are not aggressive toward humans, they are not always kind to other goats who cannot defend themselves and can do serious or lethal damage with their horns in very short time.

While it may seem desirable to dehorn the animals, a goat raiser will soon discover that horns are very useful, they are the only handles these animals have. A goat without horns is hard to control and most shearing stands depend on horns when securing the goat for shearing. Care should be taken not to damage a young goats horns by rough handling. A frightened or startled goat is apt to jump or flail around and handlers should always use caution or prevent injury from the horns. Eye injury is the greatest concern. For safety, both for the handler and other animals, the sharp point of the goat's horn may be clipped off using a bolt cutter or similar device.

Health problems of goats are similar to those of sheep. They are subject to both internal and external parasites and pneumonia. Their hooves may need to be trimmed, depending on the walking conditions, rocky ground usually takes care of the problem. A good health care program that includes vaccination for most diseases can be established between a grower and a veterinarian.

Goats are hardy animals and kidding problems are nothing any experienced livestock person would find unusual. The umbilical cord should be treated with 7% iodine to prevent infection. (C and D) antitoxin should be given immediately after birth. The gestation period for goats is usually 150 days, but may vary a day or two on either side. With proper management it is possible to get three kid crops in two years. Twins are common in older does and triplets are not uncommon. Does may be bred to kid when a year old if they have made sufficient growth before breeding. Male kids should be removed from the herd at four months of age, since they usually reach sexual maturity at this age. Accidental breeding can take place if they are not removed.

For those interested in securing more information about starting a cashmere goat operation the following references should prove helpful.

Cashmere Producers of America (CaPrA)
1-800-FOR-GOAT

Concerning Cashmere (bimonthly publication from CaPrA)
1-800-FOR-GOAT

American Cashmere Growers Marketing Coop (ACGMC)
Cashmere America
95 Ute
Kiowa, CO 80117
303-621-2874

Ranch Magazine
P.O. Box 2678
San Angelo, TX 76902
915-655-4434

Cashmirror Magazine
P.O. Box 639
Toledo, WA 98591
206-864-4200

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Cashmere – the new American challenge - 1991

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Cashmere, we love to just touch the sensual, ultra soft fabric, even if we can't afford to own it. Sweater prices start at \$200 and up, blazers at \$1,000 and up. As early as the 15th century cashmere was known as the fiber for kings. The demand has always exceeded the supply.

The Himalayan regions China, Outer Mongolia, India, Afghanistan, and Iran have been the traditional sources of cashmere. Since 1985 these countries have been in such political disarray, that the supply of cashmere has been disrupted. To further deplete the supply available to processors, in the 1970's China started to dehair its own fiber and produce garments, mainly sweaters for export. The world processors need an efficient and reliable source of high quality cashmere fiber.

Cashmere is not a breed, but a type of goat. A percentage of all breeds of goats will carry the gene to produce the fine under down called cashmere, these goats through selective breeding can be the basis for a cashmere-producing herd. These goats can be any combination of cross-bred goats, including the dairy breeds, and as long as they produce a marketable cashmere fiber, they are cashmere goats. The only goats that should not be crossed are angoras, they produce cashgora which is not a commercially salable fiber.

Serious western cashmere production began with the identification of cashmere fiber in the 'feral' or wild goats herds of outback Australia. These were offspring of goats brought by the first settlers in the 1780's, many of which had escaped into the wild. In 1978 a serious breeding effort was undertaken and the Australian industry has grown. Both the Australian and the New Zealand cashmere industries have used animal husbandry techniques unknown to the traditional cashmere producing countries, and have made very dramatic progress in improved production and quality.

It is interesting to note that both in Australia and the United States, the cashmere industry has been promoted to a great extent by women. Part of this is due to the size of the animals, but it also seems that women and goats relate well. Two women, Bronwyn Schuetze and Jill Darrah, from Longmont, Colorado imported the first three Australian cashmere goats in late 1987. Judith Richardson of Silver Creek, Washington imported 10

goats in June of 1988. Many more goats were imported from Australia and New Zealand over the next two years to become the nucleus of the American cashmere industry.

There are four major cashmere processors in the world, of these Amicale Industries and Forte' Cashmere Company are American and both strongly support a growing American cashmere industry.

The fleece of the cashmere goat is made up of two very distinct fiber groups, 1) the fine underdown known as cashmere and 2) the coarse outer hair known as guard hair. The cashmere dehairer separates these two fiber groups and offers them for sale. (Forte' Cashmere Company)

The full definition of cashmere accepted by Forte' Cashmere is: Cashmere – the fine down undercoat fibers produced by a cashmere goat. This fiber has a mean diameter of 10.0 microns or less and the co-efficient of variation around the mean shall not exceed 24%. There cannot be more than 3% of fibers (by weight) over 30 microns. The fiber is not medullated.

Goats have special fencing needs, both to keep them in and predators out. The recommended fencing consists of five strands of barbed wire, three hot and two grounded. If woven wire is used, it must either have mesh too small for the goats head or it must be large enough for them to get their heads and horns back out. This larger size will not keep the kids in. Horns caught in a fence or even a crotch of a tree are real problems. They are at risk not only of starvation or predators but other goats are apt to attack and kill them. We have never had a goat that showed any aggression toward us, but they are not kind to their own.

Health problems in goats are similar to those of sheep. They are subject to internal and external parasites and pneumonia. Their hooves may need to be trimmed, depending on the walking conditions, rocky ground pretty much takes care of that problem.

Goats are hardy animals and kidding problems are nothing any experienced livestock person would find unusual. Umbilical cords should be treated with iodine to prevent infection. With proper management it is possible to get three kid crops in two years.

Goats are very useful in all types of brush control. They can be pastured with cattle and sheep as they each have different grazing habits. Goats prefer browse. Goats are very useful in controlling leafy spurge, red cedars, and all sorts of undesirable brush and weeds.

Guard dogs or donkeys can be used to discourage predators.

We, at Airy Knoll Farms, did not know any of the above information when we became involved with goats. We had reached retirement age when we sold the last of our dairy herd in the whole herd buyout program. We knew we had been very hard on our pastures in the last months of the buyout, and we wanted to repair the damage done by too heavy grazing. We also had paved lots, loafing sheds, calf barns, and feeding facilities that had housed 1000 head of cattle. We wanted to use our facilities and improve the pastures. Our first 100 angora goats came the day before the last of the cattle left. Life has never been the same.

We looked at those goats with all their horns and decided we hadn't lived with horns on our dairy cattle and they had to go. That was before we learned that those are the only handles those little animals have. The horns stayed and we use them daily. We didn't know then that if it won't hold diesel fuel it won't goats – a very profound saying.

Next we read about Successful Farming's Adapt 2 and five members of our family attend. We thought maybe mushrooms would be a good idea for our milking barn, or maybe something else would catch our fancy. Retirement is supposed to be fun, so we were just going with the flow. The conference was interesting and we learned a lot, but we didn't settle on anything.

In 1988 we read about a cashmere goat conference to be held at Longmont, Colorado. We had goats and it sounded interesting. We learned a lot, we couldn't cross our angora goats, but we could buy Texas meat goats and get started. We came home with a three month old, \$400 1/2 blood or F1 buck and we were on our way, all we needed were some does. Several weeks before, two family members had delivered mohair to the warehouse in Texas, and attended a sale where they saw thousands of meat goats. At the time they couldn't imagine anyone wanting those goats. Now we had a need for some of those goats, so it was back to Texas.

Many Texas ranchers at that time were not aware of cashmere, in fact they really didn't like goats that showed it. We had contacted a rancher who would let us go through some of his does and select for cashmere. We came home with 54 does and 3 big Spanish bucks that showed down. The does cost \$75 and the bucks \$125. In 1989 we sheared and sold our first 57 fleeces, for an average of \$2.76. We got enough to pay for the shearing and the UPS charges. We were members of CaPRa – Cashmere Producers of America, and we had marketed our first product.

At the conference we had been told it probably would take 10 to 15 years to develop a good herd from native stock, the quicker way was to import genetically superior animals. Since we were 65, we were not too sure that this would still be fun by the time we were 80, so we decided to buy some imported goats. We ordered 10 head, a black blue-eyed buck and 9 does bred to unrelated bucks. We ordered 3 each of white, brown and black does. Our goats cost \$3000 each, (a large part of the cost is for the 90 days quarantine and transportation costs) and we had to pick them up on the west coast. We had been told we wouldn't get rich on these goats and we were out to prove that.

Also in 1989 we returned to Texas to select goats from a black herd. We brought home 43 big meaty goats at a cost of \$50 per head. Shortly after that the rancher changed his ad to read "black Spanish goats with cashmere."

In 1990 we sheared and marketed 197 fleeces, at an average price of \$4.18. Our import head had grown to 39 head. Of the imports we had lost a set of triplets at birth and an older kid from pneumonia.

In 1991 we took goats to the first Cashmere Show and Sale at the Western National Livestock Show at Denver. We showed the Reserve Champion Six-tooth doe, a third place milk-tooth doe and a fourth place milk-tooth buck. In the show for sale we had the Champion Doe, the Champion Buck and the buck made Grand Champion. We also had a Texas meat goat that made it into the sale and brought \$400.

We entered 8 fleeces in the first American Cashmere Marketing Coop Contest and had third place adult male and second place male kid.

We sheared and sold 360 fleeces for an average of \$3.01, many of these fleeces were kid fleeces. Our import herd had grown to 66 head. We were selling a few breeding animals. Our Texas Spanish goat herd had grown to over 500 head, over 400 of which were F1 crosses. We hope to develop a demand for goats for control of leafy spurge, red cedars, and buck brush. Until that time cull goats will be sold for meat, we will sell several hundred this fall. Until we improve our cashmere production, the sale of meat goats will be necessary for a profitable bottom line.

To save stress and anxiety we use baby monitors (people baby monitors) in the buildings. At first we used them only at kidding time but we still leave several out year round now to keep us in touch with what is happening. They only have two channels so in busy times several monitors are reporting in to the same unit, we don't always know just where the problem is but it isn't hard to locate it. This makes for a noisy house but it is something we just ignore when the noises are normal. We have found these little units will carry the distance of a city block. We wouldn't be without them.

Our angora herd numbers about 400 animals now and we have 65 Rambouillet ewes.

Retirement isn't exactly what I expected, but it is never dull. We welcome visitors anytime, we are not far off I-80 in central Nebraska.