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Biological Control of Leafy Spurge: An Emerging Success Story

G. L. ANDERSON[1], E. S. DELFOSSE[2], N. R. SPENCER[1],
C. W. PROSSER[1], and R. D. RICHARD[3]

[1]USDA, ARS, Northern Plains Agricultural Research Laboratory
1500 N. Central Ave., Sidney, Montana 59270, USA
[2]USDA, ARS, National Program Leader for Weed Science
The George Washington Carver Center, 5601 Sunnyside Avenue, Building 4,
Room 4-2238, Beltsville, Maryland 20705-5139, USA
[3]USDA, APHIS, Plant Protection and Quarantine
FSL, MSU, Bozeman, Montana 59717-0278, USA

Abstract

Leafy spurge (*Euphorbia esula L.)* is a deep-rooted, perennial weed with erect stems 40 to 80 cm tall. The weed reproduces by both vegetative buds and the production of large quantities of seeds. A native of Eurasia, leafy spurge was first reported in the state of Massachusetts in 1827. Leafy spurge now occurs abundantly on the northern Great Plains of the United States and the prairie provinces of Canada, where it often forms stands dense enough to displace native plants and restrict cattle grazing. Biological control of leafy spurge in the United States began in the 1960s with the introduction of *Hyles euphorbia*. Fifteen nonindigenous insect species have been approved for release in the United States for the control of leafy spurge. Different biological control agents affect the leafy spurge plant in different ways. Primary methods of attack include consumption of above-ground plant material, consumption of root material, and blocking seed production. *Aphthona sp.* flea beetles have produced the greatest impact on leafy spurge. *A. nigriscutis* and *A czwalinae/lacertosa* impact the plant by ovipositing eggs at the base of the plant. The resulting larvae feed on leafy spurge roots, increasing plant morbidity, reducing plant health and creating pathways for the introduction of plant pathogens. Data collection indicates that flea beetles can reduce leafy spurge stem densities by as much as 80%-90% over large areas. While leafy spurge continues to increase in the United States, techniques for control–while still evolving–continue to improve. Measuring the success of biological control has traditionally been approached from the perspective of agent/host interactions. Too often our perception of success or failure is predetermined by how we choose to view the problem. Multiple dimensions of success exist when one views the issue from a broader perspective. We must evaluate the success of weed control in terms of biological, ecological, scientific, social, economic, political and legal success. Evaluation of leafy spurge control in each of these thrust areas indicates that the program has been successful, at least in part. However, a great deal of work remains in several other problem areas. Successful leafy spurge control is on the horizon. How long it will take to be realized depends on our commitment to solving the problem and our willingness to work as a cohesive team in each of the major thrust areas.

Introduction

The use of biological agents to manage problem weed species is more than 100 years old (Gassmann 1996). The goal of biological control is to use diseases, parasites or predators to increase the mortality of the problem weed species, thus reducing the plant's ability to effectively compete with native vegetation (Krebs 1978). The success or failure of biological control programs has typically been evaluated from the perspective of the agent/host interaction. Perhaps the quintessential definition of biological control success was written by Lawton (1985). Lawton states, "The hallmark of successful biological control is a persistent, marked reduction in the pest population." Huffaker and Kennet (1969) outlined five principles that contribute to the success of biological control agents: "(1) general adaptation to the environment and the host, (2) high searching capacity, (3) high rate of increase relative to its host, (4) general mobility adequate for dispersal, and (5) minimal lag effects in responding to host changes in numbers". Given the above definition and the five principles for improving the effectiveness of biological control agents, the success of biological control programs is generally believed to be around 25-30% (Krebs 1978, Myers 1985). These low levels of success can generally be attributed to the fact that the principles of successful biological control can only be fully evaluated in the problem area, post-release. Myers (1985) stated that "Different agents may be successful in different environments, and successful control may only be achieved in certain environments." Therefore Myers (1985) hypothesizes that "we might think of success in terms of a lottery…. With every introduction comes the possibility of success."

Leafy spurge is now believed to infest two million hectares throughout 35 states and all the Canadian provinces except Newfoundland (Quimby and Wendel 1997). Presently, nine of the 15 insects approved in the United States for leafy spurge field releases have established. Yet, the best estimates of leafy spurge population change indicate that infestations are doubling every ten years and in some cases every five years (Anderson *et al.* 1999). Based on Lawton's (1985) definition and the above information we conclude that biological efforts to control leafy spurge–over its current range–have not been successful. Notice how the context within which we apply Lawton's definition (control leafy spurge "over its current range" predetermined the answer to the question of success. Too often our perception of success or failure is predetermined by how we choose to view the problem. Certainly, as Lawton stated, "The hallmark of successful biological control is a persistent, marked reduction in the pest population" over a majority of the weed's range, but measures of success should not be limited to a biological evaluation of agent/host interactions. The evaluation of biological control success is both time and scale sensitive; it is not independent of the knowledge base and infrastructure supporting the program, and it is closely tied to the socioeconomic conditions existing across the region at any given time. Perhaps we are blurring the line between classical biological control and biological control programs; however, the two are codependent. The methodology we use to approach a problem is often as important to the success or failure of a program as the biological interaction.

This paper addresses one fundamental question: Has the leafy spurge biological control program in North America been successful? We take a brief look at the history of the problem and expand our understanding of success beyond that of agent/host interactions, based on a new protocol of success.

Historical Context

Leafy spurge (*Euphorbia esula* L.) is a deep-rooted perennial weed with erect stems 40 to 80 cm tall (Stevens 1963). The weed reproduces by both vegetative buds and the production of large quantities of seeds. A native of Eurasia, leafy spurge was first reported in the state of Massachusetts in 1827 (Noble *et al*. 1979). Several sources can be used to document the historical progression of leafy spurge from Massachusetts into the central United States and Canada (key sources include Dunn 1979, Britton 1921, Quimby and Wendel 1997, Selleck *et al*. 1962, Galitz 1980, and Bangsund and Leistritz 1991). Table 1 provides a short synopsis of the historical facts concerning leafy spurge and key biological control events. This information helps us to place the current situation facing weed

Table 1.
Historical progression of leafy spurge and key biological control events.

Year	Key Event
1827	Leafy spurge was first documented in Massachusetts.
1876	The plant was found in New York and identified as a "rare plant."
1881	Leafy spurge was found in Michigan.
1913	Leafy spurge was found in at least four states and Canadian provinces.
1921	Leafy spurge was first labeled as a "weed" in a *New York Herald* editorial.
1933	The plant is found in 19 states and several Canadian provinces.
1949-1950	Leafy spurge is found in all Canadian provinces except Newfoundland.
1940s and 1950s	New herbicides become available and managers begin to use them on a progressively larger scale.
1960s	Efforts to manage leafy spurge with biological control begin.
1964	The first leafy spurge biocontrol agent (*Hyles* hawk moth) is released.
1970	Leafy spurge occupies 26 states.
1979	The first leafy spurge symposium was held and participants begin to develop today's local, state and federal leafy spurge management programs.
1979	Leafy spurge occurs in 30 states.
1982	North Dakota reports 350,000 hectares infested with leafy spurge.
1985	The first *Aphthona* flea beetle (*A. flava*) was released.
1988	The USDA-Animal and Plant Health Inspection Service (APHIS) began their leafy spurge biological control program.
1989	*Aphthona nigriscutis* was approved and released.
1990	Researchers determine that leafy spurge infestations double in area every 10 years.
1991	Agricultural economists at North Dakota State University estimate direct and indirect economic impacts of leafy spurge at $144 million for North and South Dakota, Montana and Wyoming.
1993	*Aphthona lacertosa* is approved and released.
1994	Leafy spurge is estimated to infest 650,000 hectares in North and South Dakota, Montana and Wyoming.
1997	Natural Resources Conservation Service reports the presence of leafy spurge in 35 states; the heaviest populations occur in North and South Dakota, Montana, Minnesota, Nebraska, Colorado, Idaho and Wyoming.
1998	Estimates of over 2 million hectares of leafy spurge in the U.S.
1999	North Dakota estimates its leafy spurge infestation to be 450,000 hectares.

managers within a historical context. Consider that prior to the year 2000, leafy spurge had existed in North America for at least 173 years. It took almost 100 years before the plant was identified as a weed. Cultural controls and scorched earth practices were the primary methods for dealing with leafy spurge prior to the development of effective herbicides (late 1940s and early 1950s). Chemical control quickly became the tool of choice for treating leafy spurge infestations because it was relatively cheap and the effects were almost immediate. Chemical control efforts of the last 50 years certainly have affected the distribution and rate of leafy spurge spread; however, chemical costs have continued to rise and the process has proven to be ineffective in achieving sustained long-term control. Negative environmental impacts have also resulted from the use of non-selective chemicals.

The introduction of biological control in the mid-1960s provided another tool for the control of leafy spurge. In the 1960s, the concept of biological control for leafy spurge was in its infancy. Demonstrations were made during symposiums where *Hyles euphorbiae* "leafy spurge hawk moth larvae" were released into glass containers containing healthy leafy spurge. By the end of the presentation the hawk moth caterpillars had devoured the leafy spurge stems and leaves. This type of showmanship excited the leafy spurge control community and the search for additional leafy spurge biological control agents was expanded. Unfortunately for *Hyles*, like so many "prototypes" before it, the species was not destined to become the workhorse of the biological control program. Disease problems prevented *Hyles* from developing population levels substantial enough to impact leafy spurge populations. But the potential demonstrated by the hawk moth energized the search for other biological control agents. Table 2 lists the 15 leafy spurge biological control agents currently approved in the United States for field release on leafy spurge. Presently, nine of the 15 insects have established; however, control of leafy spurge on a local level within specific habitats has been achieved primarily by *Aphthona nigriscutis*, *A. czwalinae* and *A. lacertosa*. The other six biological control agents that have established in the United States and Canada have enjoyed less success than these three *Aphthona* species, however, background populations are present over large areas dominated by leafy spurge. What role these "lesser" control agents will play as leafy spurge population levels decrease remains to be seen, but as the ratio of leafy spurge stems to biological control agent decreases we might expect a much more significant contribution.

So, what is the state of the ecosystem weed managers have to contend with today? Leafy spurge is well established (greater than two million hectares in the United States). It displaces most native vegetation, including threatened and endangered species. The deep roots of the plant, along with its ability to reproduce and spread both by vegetative buds and seeds, enable the population to double in size every ten years or less (Anderson *et al*. 1999). Chemical control has not produced sustained long-term control, and inappropriate chemical use has caused negative impacts to other components of the environment. Cultural control methods such as sheep and goat grazing are not widely accepted as viable control alternatives. Conversely, the acceptance of biological control has increased. Nowierski (1985) attributed the increased acceptance and use of biological control to reduced economic and ecological costs during a period of depressed agronomic income and heightened environmental awareness. The *Aphthona* flea beetles have demonstrated the greatest amount of success in controlling leafy spurge populations within specific habitats; however, determining the number of hectares the flea beetles have controlled is

Table 2.
Leafy Spurge Biological Control Agents.

Species and Authority	**Order: Family**	**Date Approved**
Hyles euphorbia (L.)	Lepidoptera: Sphingidae	1964
Chamaesphecia empiformis (Esp.)	Lepidoptera: Sesiidae	1975
Chamaesphecia tenthrediniformis(Den. Sch.)	Lepidoptera: Sesiidae	1975
Oberea erythrocephala (Schrank)	Coleoptera: Cerambycidae	1980
Spurgia esulae Gange	Diptera: Cecidomyiidae	1985
Aphthona flava Guill.	Coleoptera: Chrysomelidae	1985
Aphthona cyparissiae (Koch)	Coleoptera: Chrysomelidae	1986
Aphthona czwalinae (Weise)	Coleoptera: Chrysomelidae	1987
Aphthona nigriscutis Foundras	Coleoptera: Chrysomelidae	1989
Dasineura sp. nr. *capsulae* Kieffer	Diptera: Cecidomyiidae	1991
Aphthona abdominalis (Duftschmid)	Coleoptera: Chrysomelidae	1993
Aphthona lacertosa (Rosenhauer)	Coleoptera: Chrysomelidae	1993
Chamaesphecia hungarica (Tomala)	Lepidoptera: Sesiidae	1993
Chamaesphecia crassicornis Bartel	Lepidoptera: Sesiidae	1996
Spurgia capitigena (Bremi)	Diptera: Cecidomyiidae	1998

more elusive than estimating the amount of leafy spurge in North America. While the overall rate of leafy spurge establishment is still likely greater than the rate of control, the populations of biological control agents are also increasing rapidly. It is very difficult to find leafy spurge stands in western North Dakota that do not have a resident population of *Aphthona* flea beetles. This leads scientists to believe that control rates will quickly approach and even surpass the rate of leafy spurge establishment as these small resident populations expand to critical density levels and link with other areas where larger populations have substantially reduced leafy spurge stem densities.

Based on the above information we conclude that biological control agents have not yet successfully controlled leafy spurge, based on a narrow concept of "success" (Lawton 1985). But control has been established in many local areas, such as hillsides, warm and more open plant communities, and areas where the soils are not too wet or too sandy. Furthermore, the success that has occurred is relatively recent. The first Aphthona species of the leafy spurge biological control program (Aphthona flava) was cleared for release just 15 years ago. The most recent and potentially most effective agent (Aphthona lacertosa) was cleared for release in 1993. The success that leafy spurge biological control has enjoyed is actually amazing when one considers the large area infested and the huge disparity in time (158 years vs. 15 years) between the introduction of leafy spurge and the introduction of effective biological control agents. While it is premature to label the biological control program a success, current evidence gives us every reason to believe that successful control of leafy spurge in the broad sense is only a matter of time.

Multiple dimensions of success

Biological Success

What is success? To most ranchers, farmers and weed control specialists, success is getting rid of leafy spurge or at least having less spurge this year than last. Biological control agents help control leafy spurge in different ways. Primary methods of attack include consumption of above-ground plant material, consumption of root material, and blocking seed production. *Aphthona sp.* flea beetles have produced the greatest impact on leafy spurge. *A. nigriscutis* and *A czwalinae/lacertosa* impact the plant by ovipositing eggs at the base of the plant. The resulting larvae feed on leafy spurge roots, increasing plant morbidity, reducing plant health and creating pathways for the introduction of plant pathogens. Data collection indicates that flea beetles can reduce leafy spurge stem densities by as much as 80-90% over large parts of the landscape. We could label this type of success as "botanical or biological success." *Biological success is reducing the density of the problem species to the point that it is a manageable part of the landscape.* Remember, however, our perspective determines our views of success or failure. We cannot simply associate a reduction in the amount of leafy spurge as a success without considering the impact of the pest and the associated treatment(s) on the ecosystem as a whole.

Ecological Success

Ecological success is a bit more difficult to define. Ideally, the biological control program will impact only the target pest and the indigenous plants will reestablish much as they were prior to the weed's introduction. Unfortunately, most weed infestations and their associated treatments alter some aspect of the ecosystem. An analogy is the use of surgery, chemotherapy, and radiation to treat a cancerous tumor. The tumor is the immediate threat. Left untreated, it will cause irreparable damage or even kill the host organism. The treatments themselves are usually invasive, causing permanent damage to surrounding tissues and organs and sometimes even contribute to the organism's death. How do you define success or failure under these circumstances? It is not as simple as destroying the tumor or eliminating the infestation. For most patients or ecologists it is the quality of the life they lead or the health of the entire system that is important. Determining what constitutes a quality life or a healthy ecosystem is dependent on the individual or individuals evaluating the circumstances. Therefore, we can conclude that the course of action taken by an individual or group will be based on personal reflection and a qualitative assessment of short-term risks verses long-term gains.

While an ecosystem is not a cognitive organism, the individuals who use and manage these systems are. The decisions they make concerning the use of biological control or other integrated pest management (IPM) strategies are dependent on their perspective, values and aspirations toward the system they are dealing with. From the rancher's perspective, success is the removal of the pest and a subsequent increase in more desirable plant species. Ranch operators are typically not as concerned with the composition of the ecosystem as they are with the quality and quantity of forage available to the operation. Environmental groups are concerned with protecting the quality (health) of the system and its composition (biological diversity). Most federal and state land managers are required to manage the land to maintain or improve productivity and quality and allow for multiple land uses. These differing perspectives often lead to disagreements, protests and lawsuits (such as against Paterson's curse/salvation Jane, *Echium plantagineum*, in Australia; Cullen and Delfosse 1985, Delfosse 1985, 1990, Delfosse and Cullen 1985) as each group positions itself to insure that its ideologies prevail or that its views are at least considered.

The management guidelines individuals and agencies use on a relatively healthy ecosystem often work together to produce a better system. Unfortunately, as a system deteriorates (e.g., when the condition of a patient worsens or a weed-infestation becomes more pervasive) there comes a point when the rules designed to protect the system (or the individual) can actually interfere with system maintenance and recovery. So it is within this quagmire of emotion, qualitative assessments and conflicting policies that we define exactly what we mean by ecological success. *Ecological success is stopping or reversing the progression of an invading pest through the use of biological control agents and other IPM tools that have no direct detrimental effect on the system, or whose negative impacts to the ecosystem are outweighed by the overall benefit of their use.* Notice that this definition does not deal with returning the system to some preconceived notion of health and it ignores issues such as maximizing biodiversity or preserving threatened and endangered species. These are important issues that must be addressed, but are probably more appropriately dealt with in the context of post-control rehabilitation.

Scientific Success

Another area of success that is often only realized in academia is scientific success. The initiation of a biological control program is often fraught with uncertainty. Successful establishment of an agent in one area does not always translate into success elsewhere. *Scientific success is the knowledge gained by scientific investigation that improves our understanding of the biological control agent(s), the agent(s) impact on the host plant and what effects the introduction of the agent or changes in the weed population will have on the associated ecosystem.* Scientific success helps managers improve the potential of achieving effective control; however scientific success can be achieved independent of biological, ecological, economic, social, political and legal success. Using the North American leafy spurge program as an example of an emerging success story, the program does have several areas where our knowledge base has been expanded. Information concerning the additive or synergistic effects of plant pathogens, alternative grazing programs and limited chemical use with biological control agents helps us to understand how weed control programs can be enhanced by the interaction of multiple control tools (biologically-based IPM). Other research helps us understand the complex ecological interactions (ecological barriers) that can influence the establishment or effectiveness of control agents and other IPM tools on leafy spurge. The fact that several issues remain unanswered, especially in the areas of complex ecological and socioeconomic decision-making, indicates that there is still much to learn, however the scientific progress made to date is certainly a success upon which others will continue to build.

Economic Success

Economic success seems more straightforward than the other concepts we have looked at, but what is economic success? To the rancher it is one of three things: (1) saving on treatment costs and obtaining the same or better degree of weed control; (2) improving the quality and/or quantity of a marketable commodity; and (3) improving land quality and sustainability (economic value and ecological health). Economic success at the federal, state or local level includes increased revenue from sales and/or taxes, reduced expenditures for weed control and increased consumer satisfaction and utilization of the land for outdoor activities. In general, we can say that *economic success is less cash* *expended for the same or better weed control and/or an increase in the amount of cash returned for every dollar spent on weed control at the local, state, and federal levels.* It is generally economic impacts that drive most weed control programs. Unfortunately, the time lag between a weed becoming an ecological problem and its emergence as an economic problem is often decades. This allows the weed to become firmly established, which usually translates into a greater expenditure of resources to achieve control. Perhaps the best alternate definition of economic success is never letting a weed problem reach the level where it has economic impact. Viewing the leafy spurge control program with respect to economic success is much the same as evaluating it with respect to the ecological success. Control has been established in many local areas, but the infestation of leafy spurge continues to grow. Exactly how much land is being improved by biological control and other IPM technologies is unknown. Therefore, it is difficult to claim that the program has been an economic success, but it has been successful in many local areas. As biological control agents continue to become an integral part of an IPM strategy the cost of control (or at least the rate of increased dollars spent to manage the weed) should become less. Furthermore, as biological control agents continue to have greater impact, the revenue gained from increased production and utilization will increase.

Political Success

Political success can only be achieved when scientists, community leaders, land managers and special interest groups gain enough support to convince public representatives that it is in the best interest of the state and the country to increase the resources needed to impact the problem. Therefore, *political success is effective communication of the problem to important customers and stakeholders, such as federal and state representatives who ultimately enact legislation designed to develop and improve weed management efforts.* A major step toward achieving political success was enacted in 1999 with the issuance of the Executive Order # 13112 on Invasive Species. The order establishes an advisory council, mandates agency participation and begins the development of a *National Invasive Species Management Plan*. The heightened visibility given to weeds by the Executive Order has definitely been positive, but the success of the initiative depends on the ability of Congress and the administration to directly impact invasive weeds by allocating the resources needed to adequately address the problem.

Social Success

Social success is fairly straightforward. Here we must consider two groups. The land manager is the one directly fighting weed infestations. The tools chosen to address a particular weed problem are often based on previous experience. The adoption of a new approach to the problem is often overlooked or is dismissed without much thought. Biological control and biologically-based IPM must be demonstrated, and the land manager's faith in its ability to outperform existing tools increased, before the majority will use the approach. Sell *et al.* (1999) conducted a survey in the four-state region of North Dakota, South Dakota, Montana, and Wyoming. They concluded that the most frequent impediment for using biological control is the view that the agents take too long to work and the perspective that access to biological agents is limited. The same group of respondents indicated that environmental, financial, and educational constraints were the primary reason for not using biologically-based IPM control strategies. Therefore, one component of social success is improving the acceptance of biological control and other IPM strategies by land managers and increasing their willingness to actively lobby for additional resources to address their weed problem.

The second group of people that must be considered are those not directly connected to the land. Few individuals in our towns and cities realize the impact noxious weeds have on their lives. The reality is that public lands are our lands even though states and the federal government act as managers. It is in the best interest of every citizen to ensure that his or her lands are being maintained properly. As any facility manager will tell you, it is more cost-effective to constantly maintain and upgrade a facility than to wait and have to fix everything at once. To date, public land managers allocate far too little resources to fighting weeds (maintenance). The primary problem is that limited budgets are stretched too thin to adequately address the myriad of problems facing our public lands. Other important issues directly impacting individuals working outside the agricultural community are land values and production returns. A reduced amount of revenue results when weeds invade private and public lands and the value of the land and agricultural income decrease. Revenue also decreases as the money spent on alternate uses decreases. The estimated annual economic impact of leafy spurge in the four-state region of North Dakota, South Dakota, Montana and Wyoming is estimated to be $130 million (Leitch *et al.* 1994). This is a substantial amount of money that impacts one of the most economically depressed regions in the United States. The cost to the public is fewer public services and resources. Therefore, the second component of social success is educating the public concerning the problem, their responsibility to the land and the direct impact inadequate management has on their income. Combining the above components, we can define *social success as increased awareness of the problem, acceptance of individual responsibility in dealing with the issue, improved understanding of biologically-based IPM and how the different tools are used, and the need for proactive lobbying to acquire the resources needed to address the issue.* Social issues have not been adequately addressed in the past. A major part of the USDA, ARS, Area Wide Program–*The Ecological Area-wide Management of Leafy Spurge* (*TEAM Leafy Spurge*)–is to increase public awareness, demonstrate effective integrated control techniques, and to work directly with ranchers and land managers in implementing current control methodologies. The effectiveness of *TEAM Leafy Spurge* will be evaluated, in part, by the program's success in changing perceptions on how to deal with the problem and increasing the public's awareness of how the weed impacts on their lives and their community. From the perspective of the Northern Great Plains leafy spurge program, social success has not been achieved and additional resources must be committed to gaining public support and educating land managers.

Legal Success

Legal success is the enactment of laws that prevent the introduction of invasive species, mandate effective control programs and assess substantial penalties for failure to comply with existing laws. Many states have enacted laws designed to limit the spread and mandate the treatment of leafy spurge populations, but most lack the teeth to ensure compliance. In this instance, state and federal programs have not achieved the legal success needed to support the leafy spurge control program.

Conclusions

Leafy spurge has been in the United States for a long time and it will never go away. The best we can hope to do is reduce its impact below ecologically and economically significant levels. There is no one tool adequate to deal with the massive infestation currently existing in the United States and Canada; however we believe that biologically-based IPM stands the best chance of achieving the desired control level. Has biological control or biologically-based IPM been successful in controlling leafy spurge? The answer depends upon your perspective. Scientifically and politically, the program has made significant progress and we believe each can be considered a success, even though a great deal of additional work is still needed. At the national scale, several problem areas cannot yet be labeled as a success but success has occurred within certain habitat types and across many locations. These are the biological, ecological, and economic problem areas. Additional work is needed to educate land managers and the public concerning the best methods of treating the problem, the need for proactively augmenting and managing their biological control agents and additional time to allow the biological control populations to expand and coalesce across regions. Two problem areas where the leafy spurge control program has been relatively ineffective are the social and legal components of the program. A greater emphasis must be placed on public and land manager education, as well as enacting laws that provide significant incentives for public compliance.

The northern Great Plains leafy spurge program has contributed a great deal to our understanding of the weed and how it will be controlled in the future. It is important that we acknowledge the contribution of all individuals who have spent their careers, and in some cases their lives, putting in place the control infrastructure we have today. The momentum toward effective management of leafy spurge is rapidly increased because of their efforts. Successful leafy spurge control is on the horizon, especially using the wider concept of success. The amount of time it will take to be realized depends on our commitment to solving the problem and our willingness to work as a cohesive team.

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