J. Range Manage.
51:614–620

Impact of leafy spurge on post-Conservation Reserve Program land

STEVEN A. HIRSCH AND JAY A. LEITCH

Hirsch is a former research assistant and Leitch is a professor, Department of Agricultural Economics, College of Agriculutre, North Dakota State University, P.O. Box 5636, Fargo, North Dakota 58105.

Abstract

Leafy spurge (*Euphorbia esula* L.), a noxious weed infests some of the 1.2 million hectares of Conservation Reserve Program (CRP) land in North Dakota. Once established a leafy spurge monoculture will reduce expected CRP benefits and impact returns to some post-CRP land uses. The study estimated statewide direct economic impacts of about $351,000 on post-CRP land maintained in vegetative cover, $1.118 million on post-CRP grazing land, and negligible (assumed $0) on post-CRP cropland, for a total of $1.469 million. Total annual direct and secondary economic impacts to North Dakota's economy were estimated to be $4.665 million, which would support about 57 jobs.

Key Words: CRP, economic impact, *Euphorbia esula*, grazing, North Dakota, noxious weed, vegetative cover

Resumen

La lechetrezna frondosa (titímalo, tártago, euphorbia esula L.), una yerba perniciosa, infecta una parte de los 1,2 millones de hectareas del terreno perteneciente al Programa de Preservación y Reserva (Conservation Reserve Program o CRP) de laDakota del Norte. Una vez establecida, una monocultura de Lechetrezna frondosa disminuirá los benificios anticipados del CRP, y repercutirá en su devolución al uso posterior previsto. El estudio pronosticó un impacto económico directo de aproximadamente $351,000 en las tierras mantenidas posteriormente con vegetación, $1.118 millones en las destinadas posteriormente al pasto, e insignificante (Ò conjeturar $0) en tierras sembradas posteriormente, sumándose a una cifra total de $1.469 millones. El impacto anual económico, tanto directo como secundario, a la economía de laDakota del Norte se calculó a $4.665 millones, fondos que sostendrían unos 57 empleos.

Leafy spurge (*Euphorbia esula* L.) is widely established in North Dakota, infesting about 300,000 ha in the state in 1990 (personal commun., Dean A. Bangsund, research associate, Dept. Agr. Econ., N.D. State Univ., Fargo, N.D. 1995). Leafy spurge can withstand all but the most intensive eradication attempts and spreads easily through grazing land, doubling the size of an infestation every 10 years when left uncontrolled (Leitch et al. 1994). The state's grazing lands are not the only lands impacted by the expansion of leafy spurge. Other untilled lands, such as road ditches, recreation areas, and wildlife areas, are also infested (Messersmith and Lym 1990). Rangeland experts, local weed control boards, and landowners have confirmed the presence of leafy spurge on Conservation Reserve Program (CRP) land (personal commun., Donald A. Kirby, professor, Dept. Anim. and Range Sci., N.D. State Univ., Fargo, N.D. 1995, and Russell J. Lorenz, soil scientist, Mandan, N.D., 1995).

The Impact of Leafy Spurge on CRP Land

The soil and water conservation benefits and the wildlife habitat values of the CRP are well-known, although not well-measured. In addition, the potential for lower crop surpluses, increased commodity prices, and income support made the CRP popular with farmers and agriculture policymakers (Council for Agricultural Science and Technology 1995). North Dakota accounts for about 1.2 million hectares of the almost 15 million hectares enrolled in the CRP nationwide. In spite of its benefits and popularity, the CRP had the unforeseen and unintended consequence of facilitating the spread of some noxious weeds, including leafy spurge. Leafy spurge is kept under control by regular tillage, but it spreads easily in untilled land such as CRP land. Once established, leafy spurge will displace desirable replanted grasses and convert CRP's diverse cover of vegetation to a leafy spurge monoculture.

As vegetative cover changes from more diverse (CRP) to less diverse (a monoculture of leafy spurge), increased soil erosion will result. A monoculture of leafy spurge also reduces wildlife habitat benefits of CRP land, affecting the kinds and numbers of animals the land can support (Wallace 1991).

Leafy spurge infestations also impact the returns to income generating land uses after the CRP contract expires. For example, if converted to grazing, leafy spurge infestations would limit grazing land carrying capacities, thereby reducing land values and limiting cattle production and incomes from grazing.

The relatively high cost of chemicals to provide long-term leafy spurge control, coupled with the public's growing concern that chemicals are harmful to the environment, may force re-evaluation of chemical control practices. Without chemical control, however, leafy spurge will spread in many areas (Bangsund and

Financial support was provided by the Animal and Plant Health Inspection Service through the Cooperative State Research Service of the U.S. Department of Agriculture and the North Dakota Agricultural Experiment Station, Fargo, N.D.
Manuscript accepted 5 Feb. 1997.

Leistritz 1991). Concern over leafy spurge is further heightened because biological controls are still being developed and cultural practices, such as tillage of high erodible lands, will not be appropriate for some CRP land when the program ends.

The purpose of this study was (1) to assess the role of CRP in the expansion of leafy spurge and (2) to estimate the potential economic impact of leafy spurge on alternative uses for CRP land in North Dakota after the program ends.

Leafy Spurge Control

Leafy spurge, a perennial native to Europe and Asia, was first observed in New England in 1827 and in North Dakota in 1909 (Lym et al. 1993). In the years since leafy spurge was first sighted in North Dakota, it has spread to each of the state's 53 counties. LaMoure County in southeastern North Dakota is an example of the spread of leafy spurge. The county reported 6 ha of leafy spurge in 1937 and about 2,800 ha in 1994 (Wallace 1991).

Leafy spurge control is a long-term management problem (Lym et al. 1993). The most common forms of control are chemical applications and tillage practices, however, biological controls are gaining support. The use of herbicides to control and limit the spread of leafy spurge is the most widely used control practice (Alley and Messersmith 1985). Herbicides have been only partially effective, and costs of treatment usually outweigh the benefits of control if infestations are widespread in range- or pastureland (Bangsund et al. 1996). Present and future concerns over groundwater quality may lead to regulations that restrict the use of many herbicides now used to control leafy spurge (Fox et al. 1991).

Insects used for biological control of leafy spurge have been the focus of ongoing research. Four species of *Apthona* L. flea beetles have been studied in greenhouse trials and were introduced to the field in 1986 (Lym et al. 1993). Adult flea beetles lay eggs at the base of the stem. The larvae feed on roots.

Leafy spurge is not grazed by cattle, although sheep and goats will graze young plants of leafy spurge (Derscheid et al. 1985). Sheep grazing continuously on leafy spurge will slow its spread and stop seed production. Grazing with Angora goats reduces leafy spurge cover while grasses, forbs, and shrubs in the grazed area are generally unaffected or increased (Hanson 1994).

Cultural controls, such as mowing and cultivation, are used to control leafy spurge on cultivated land and in pasture. By making the plant regenerate its top growth, both practices reduce its underground nutrient reserves (Derscheid et al. 1985).

No-till cultivation minimizes soil erosion on erodible land, but does not completely destroy leafy spurge roots buried deeper in the soil. Deep tillage (e.g., using a moldboard plow) can effectively destroy the leafy spurge root system; but increased soil erosion may result from deep plowing erodible land. This raises issues over the effectiveness of cultivation to control leafy spurge in highly erodible cropland previously enrolled in CRP. Even though no-till cultural practices are not as effective as moldboard plowing for leafy spurge control, the Natural Resources Conservation Service (NRCS) may require no-till cultivation on certain uses of post-CRP land (U.S. General Accounting Office 1995). At the same time, the use of the moldboard plow is discouraged in NRCS conservation plans for highly erodible cropland.

Potential Economic Impact of Leafy Spurge on Post-CRP Lands

To estimate the economic impact of leafy spurge, possible alternative uses for land enrolled in CRP were identified. Alternative uses for post-CRP land include

- maintain post-CRP land in vegetative cover similar to the current CRP,
- convert post-CRP to grazing land, or
- return post-CRP land to cropland.

Direct economic impacts of leafy spurge on alternative post-CRP land uses were estimated. Direct impacts included the values of lost forage and foregone production in the grazing industry, reduced wildlife-associated recreation activity, and reduced soil and water conservation benefits. The direct impacts were applied to an input-output model to estimate secondary economic effects of leafy spurge on other sectors of the state's economy.

Assumptions

To estimate the economic impact of leafy spurge on CRP land in North Dakota now and in the future, in the absence of actual data, assumptions were made about (1) the portion of land allocated to each alternative post-CRP land use and (2) the number of leafy spurge infested hectares on each alternative land use. For the economic impact analysis, an assumption was made that *1/3 of the 1.2 million ha of CRP land, about 400,000 ha, will be allocated to each alternative use when the program ends.* The analysis also assumes *the leafy spurge infestation rate in CRP land after 10 years of the program is about 4.2%*, the current infestation rate in North Dakota's grazing land, or about 16,800 infested ha on each alternative use (personal commun., Dean A. Bangsund, research associate, Dept. Agr. Econ., N.D. State Univ., Fargo, N.D. 1985). In this study, *all infested hectares are assumed to be a leafy spurge monoculture.*

Results are sensitive to these assumptions. However, readers can easily modify the first 2 assumptions to align with their perceptions of some of the unknown values. The assumption regarding a leafy spurge monoculture is necessary to avoid introducing a very complex infestation-level function. See Bangsund et al. (1996) for more on this issue.

Economic Impact of Maintaining Vegetative Cover

The impacts of leafy spurge on post-CRP land maintained in vegetative cover result from the difficulty to control or eradicate leafy spurge and from the plant's ability to choke out replanted grasses and other vegetation. Reduced plant diversity on infested post-CRP land will lower its value as wildlife habitat as well as its water and soil conservation benefits.

Impacts on wildlife-associated recreation

Because of the similarity of land in CRP to wildland, an impact function for estimating the relationship between leafy spurge infestations and the wildlife habitat value of North Dakota's wildlands (Wallace 1991) was used to describe the relationship between leafy spurge and the habitat value of post-CRP land

remaining in vegetative cover (Fig. 1). Wildland is land not classified as urban or built-up industrial, forest, range, cropland, or recreation areas.

The estimated impact of reduced wildlife habitat value from leafy spurge infestations on CRP land was used to estimate the economic impact of leafy spurge on wildlife-associated recreation in North Dakota. Direct economic impacts from changes in wildlife-associated recreation activity are the result of changes in expenediture that impact suppliers of recreational goods and services.

Wallace (1991) expressed the reduction in expenditures (R) from weed infestations as

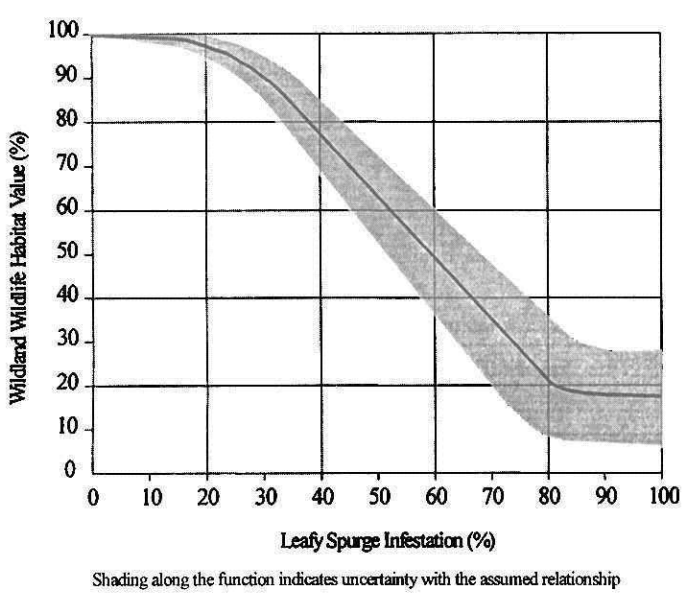
$$R = (E * C)(H * W)(S) \quad (1)$$

where

- R = the change in wildlife-associated expenditures due to leafy spurge infestations in post-CRP land maintained as vegetative cover,
- E = the total statewide annual wildlife-associated recreation expenditures,
- C = a species/land use coefficient,
- H = the percentage reduction in wildlife habitat value from infested wildland,
- W = percentage of post-CRP land maintained as vegetative cover that is infested with leafy spurge, and
- S = percentage of expenditures lost to the state's economy.

Statewide hunting expenditures (E) were about $220 million in 1990. The estimated reduction in wildlife habitat value (H) caused by an infestation was 80% due to the assumed leafy spurge monoculture on infested post-CRP land uses (see Figure 1). The leafy spurge infestation rate (W) for wildland, the percentage of total wildland infested, is 4.2% (about 16,800 infested ha of 400,000 ha of post-CRP maintained as vegetative cover).

The species/land use coefficient, developed by Leitch (1978) and Wallace (1991), represents the relative importance of different land uses in supporting wildlife populations. The species/land use coefficient for all CRP lands is 0.24, which means 24% of North Dakota's wildlife populations are produced and maintained on CRP land. If 1/3 of CRP lands remains in vegetative cover after contracts expire, the species/land use coefficient (C) would be about 8%, assuming a linear relationship and no change in overall wildlife populations. Multiplying the reduction in post-CRP's wildlife habitat value, (H * W), by wildlife-associated expenditures attributable to wildland, (E * C), gives an estimate of the reduction in wildlife-associated expenditures from leafy spurge infesting post-CRP vegetative cover.



Shading along the function indicates uncertainty with the assumed relationship

Fig. 1. Estimates of reduced wildland habitat value caused by various leafy spurge infestation rates. Source: Leistritz et al. (1993).

If wildlife-associated recreation opportunities within the state decrease, some expenditures previously used for wildlife-associated recreation would be reallocated to other in-state activities; but some may be spent in other states, representing a loss to the economy. The wildlife-expenditure coefficient (S) is the percentage of spending lost to the state's economy because of reduced wildlife-associated recreation opportunities. For North Dakota, the expenditure coefficient value is 0.42, which means 42% of North Dakota recreationists would pursue their recreation activities in other states if they were not available in North Dakota. Combining these factors into the equation, the direct economic impact of reduced wildlife-associated recreation due to leafy spurge infestations on post-CRP vegetative cover was estimated to be about $283,000 (Table 1).

Impacts on soil and water conservation

An infestation will change the composition of vegetation on CRP, which may reduce the soil and water conservation benefits. No research or case study data describing a functional relationship between leafy spurge and water runoff and soil erosion exist, so an assumption was made by others (Leistritz et al. 1993) to quantify the overall effect. A leafy spurge monoculture would conservatively reduce the soil and water conservation benefits of post-CRP vegetative cover by 25% (Leistritz et al. 1993).

Direct economic impacts from changes in post-CRP soil and water conservation benefits are the changes in defensive expenditures to mitigate damages from water runoff and soil erosion. An increase in the amount of water treatment, for example, represents the cost of decreased water quality. Based on a USDA study by Ribaudo (1989), the annual erosion control benefits of CRP land were estimated to be $14.50 per hectare in the Northern Plains region in 1990 (Leistritz et al. 1993). Applying the assumed 25% reduction in CRP erosion control benefits due to leafy spurge infestations to the $14.50 ha^{-1} value gives an estimate of $3.63 per ha^{-1} reduction in soil and water conservation benefits. Multiplying the $3.63 ha^{-1} reduction in benefits by 16,800 ha (4.2% of 400,000 ha) of leafy spurge-infested post-CRP resulted in about $68,000 in annual damages when adjusted to 1994 dollars (Table 1).

Total direct impacts of leafy spurge on post-CRP land remaining in vegetative cover are the sum of (1) the reduced wildlife-associated recreation expenditures ($283,000) and (2) the lost soil and water conservation benefits ($68,000). The total direct impacts of leafy spurge infestations on post-CRP land in vegetative cover are about $351,000 annually (Table 1). The impacts were about $21.15 ha^{-1} infested or about $0.88 ha^{-1} if averaged across the 400,000 ha of post-CRP vegetative cover.

Table 1. Annual direct economic impacts of leafy spurge on post-CRP land in North Dakota.

Business sector	Post-CRP Land Use			Totals
	Grazing	Permanent Cover		
		Wildlife associated benefits	Soil & water conservation benefits	
	(dollars)			
Ag. livestock	64,000	0	0	64,000
Ag. crops	371,000	0	19,000	390,000
Transportaion	26,000	0	0	26,000
Communication, public utilities	17,000	0	0	17,000
Retail trade	176,000	0	0	176,000
Finance, insurance, real estate	42,000	0	0	42,000
Business, personal service	16,000	0	0	16,000
Households*	406,000	0	0	406,000
Government	0	0	48,000	48,000
Electrical generation	0	0	1,000	1,000
Recreation, tourism	0	283,000	0	283,000
Totals	1,118,000	283,000	68,000	1,469,000

*The direct impact to Households is the value of AUMs of forage lost by ranchers and loandowners, $385,000, plus the impact on Households due to reduced livestock production, $21,000.

Economic Impact of Grazing Post-CRP Land

Because leafy spurge spreads easily in untilled land, post-CRP land used for grazing domestic livestock can facilitate the expansion of leafy spurge in North Dakota. Because cattle avoid grazing leafy spurge, direct economic impacts of leafy spurge infestations affect North Dakota's grazing industry, specifically ranchers, landowners, businessess supplying livestock production inputs, and communities that rely on ranching as an economic base. Direct impacts are the sum of (1) the value of lost forage resulting from reduced grazing land output and (2) foregone sales of livestock production inputs associated with herd reductions. Reduced carrying capacity also lowers grazing land values, especially in the absence of alternative uses.

Value of lost forage

To estimate the value of lost grazing on land once in CRP, the amount of forage lost due to a leafy spurge infestation must be estimated.

The value of forage, which was $18.33 AUM^{-1} in 1994, was estimated using average grazing land rental rates ($/ha) and carrying capacities (AUMs/ha) for grazing land in each North Dakota county. Following the method of Thompson (Leitch et al. 1994), the value of forage was used to estimate the potential reduction in stock growers' net incomes resulting from reduced forage output in infested post-CRP used for grazing land. We assumed neither demand nor supply of forage or livestock were affected by these changes.

Carrying capacity reduction model

A carrying capacity reduction model (CCRM) developed by Thompson (Leitch et al. 1994) was used to estimate the amount of lost forage from leafy spurge infestations. Leafy spurge reduces carrying capacity in 2 ways: (1) forage production is reduced due to competition from leafy spurge and (2) additional useful forage is lost because cattle partially or totally avoid infested sites. The CCRM estimates the potential carrying capacity (AUMs/ha) for leafy spurge infested grazingland and is approximated by the function:

$$RCC = CC * [1 - (1.25 * PI/100)] \quad (2)$$

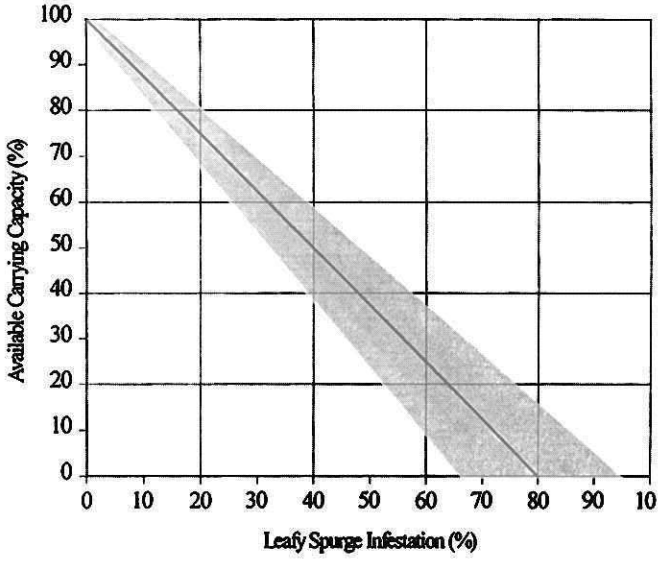
where

RCC = reduced carrying capacity (AUMs/ha),
CC = normal carrying capacity (AUMs/ha), and
PI = percent of infestation in post-CRP land used as grazing.

A leafy spurge infestation covering 80% or more of a pasture would reduce its forage output to 0 from a range management standpoint (Fig. 2).

Economic impact of reduced grazing

The 400,000 ha of post-CRP grazing land would produce about 478,000 AUMs of forage based on an estimate of average carrying capacity (1.21 AUMs ha^{-1}) for North Dakota. If the percent of leafy spurge infestation was 4.2% (about 16,800 of 400,000 grazing ha),



Shading along the function indicates uncertainty with the assumed relationship

Fig. 2. Reduced carrying capacity for cattle associated with various levels of leafy spurge infestation. Source: Leistritz et al. (1993).

Table 2. Combined (direct plus secondary) economic impacts of leafy spurge on post-CRP land in North Dakota.

Business sector	Post-CRP Land Use			
	Grazing	Permanent Cover		Totals
		Wildlife associated benefits	Soil & water conservation benefits	
	(dollars)			
Ag. livestock	154,000	22,000	1,000	177,000
Ag. crops	449,000	54,000	21,000	524,000
Nonmetal mining	6,000	1,000	0	7,000
Construction	83,000	15,000	2,000	100,000
Transportation	38,000	4,000	0	42,000
Communication, public utilities	117,000	25,000	2,000	144,000
Ag. processing, misc. manufacturing	126,000	143,000	3,000	272,000
Retail trade	931,000	121,000	16,000	1,068,000
Finance, insurance, real estate	205,000	30,000	3,000	238,000
Business, personal service	79,000	16,000	1,000	96,000
Households	80,000	13,000	1,000	94,000
Government	1,222,000	191,000	19,000	1,423,000
Coal Mining	107,000	20,000	50,000	177,000
Electrical generation	0	0	0	0
Petroleum exploration, extraction	0	0	0	0
Petroleum refining	0	0	0	0
Recreation, tourism	0	283,000	0	283,000
Total	3,597,000	938,000	120,000	4,655,000
Secondary FTE Jobs	43	10	4	57

the reduction in forage output would be over 21,000 AUMs.

Direct impacts of leafy spurge on land once in CRP, but converted to grazing land, include foregone income from reduced grazing capacity and reduced livestock production expenditures. The value of lost grazing capacity was estimated by multiplying the value of lost grazing ($18.33 AUM^{-1}) by the number of AUMs of lost forage (21,000 AUMs). The result, about $385,000, represented the direct economic impact of leafy spurge on ranchers and landowners from lost grazing capacity on the 1/3 of post-CRP land assumed to be used as grazing land. The amount of forage lost to leafy spurge infestations in post-CRP grazing land would support a herd of 2,100 cows, requiring about $733,000 in annual production expenditures.

Potential total direct impacts can be summed from (1) the value of forage lost by ranchers and landowners ($385,000) and (2) decreased livestock production and outlays (a lost opportunity) associated with lost grazing capacity ($733,000). The estimated potential direct impacts of leafy spurge infestations in post-CRP grazing land were about $1.118 million (Table 1). The impacts were about $66.55 ha^{-1} infested or about $2.80 ha^{-1} if averaged across the 400,000 ha of post-CRP land assumed to become grazing land.

Returning Land Once in CRP to Cropland

Leafy spurge in cultivated land occurs most frequently where infested land has been recently broken for crop production. Roots scattered by cultivation produce new plants in addition to those established by seeds. However, leafy spurge can be suppressed with a combination of "low-till" farming practices and chemical applications (personal commun., Russell J. Lorenz, soil scientist, Mandan, N.D., 1995). Although 1 or 2 growing seasons may require more intensive pesticide applications, no additional ongoing chemical costs for leafy spurge control were assumed. Therefore, the economic impact of leafy spurge infestation on post-CRP land returned to cropland is negligible compared to the other alternative land uses.

Combined Impacts of Leafy Spurge Infestations

The majority of the impacts (direct plus secondary) of reduced wildlife-associated expenditures affected the *recreation and tourism, household, manufacturing,* and *retail* sectors of the state's economy. The impacts of reduced soil and water conservation mainly affected the *government, agricultural crops,* and *household* sectors of the economy. The impacts were estimated using the North Dakota Input-Output Model, a closed model with respect to households (Coon et al. 1990). Total combined impacts for post-CRP vegetative cover were just over $1 million annually. The reduction in business activity could have supported about 14 full-time equivalent (FTE) jobs in the state's economy (Table 2).

The impacts of reduced grazing capacity on the state's economy affected the *household, retail,* and *agricultural crops* sectors. The potential direct plus secondary impacts for post-CRP grazing land is about $3.6 million annually. The reduction in business activity would support about 43 FTE jobs in the state's economy (Table 2).

Conclusions

Leafy spurge is present on CRP land in North Dakota. Considering the potential of leafy spurge to spread in untilled lands like CRP, individual producers and the state's economy face potential adverse economic impacts if the problem is not adequately addressed before or when CRP contracts expire.

The potential economic impact estimate was based on previous

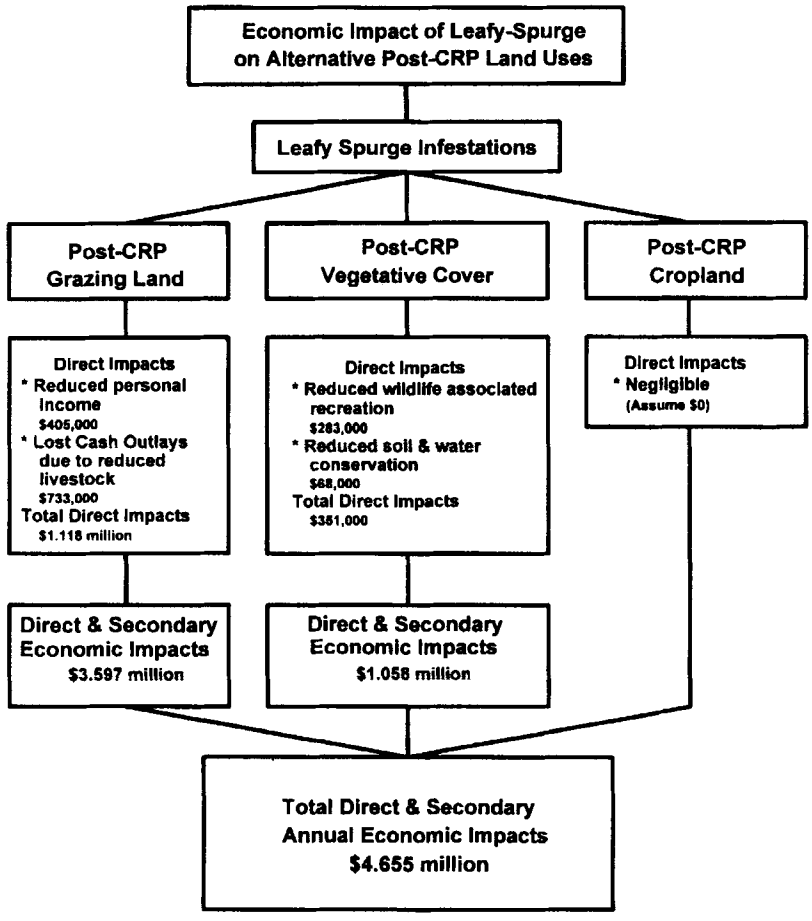


Fig. 3. Economic impact of leafy spurge on alternative post-CRP land uses.

grazing and wildland studies. Results indicate leafy spurge has the largest direct impact on livestock producers, but infestations would also impact other groups like water users, hunters, and outdoor recreationists. The direct economic impacts, about $1.469 million annually, result in secondary impacts to other sectors of North Dakota's economy. Direct plus secondary impacts of leafy spurge infestations on alternative post-CRP land uses total about $4.655 million annually, could support 57 FTE jobs in the state's economy (Fig. 3).

The results of this analysis are sensitive to the following conditions:

- A leafy spurge monoculture exists on infested post-CRP grazing land and on land maintained in vegetative cover.
- All land once in CRP, but used as grazing land, is grazed at full potential; and none is idle.
- The biophysical relationships used in this study are plausible approximations of actual conditions.
- Values used for the species/land coefficient, the wildlife expenditure coefficient, and in the cattle budget are appropriate for broad policy analysis.

This study is sensitive to its assumptions, models, and parameter values. If others are used, the results will be somewhat different, but the policy implications should hold.

Implications

Implications for both policymakers and scientists can be drawn from this estimate of the economic impacts of leafy spurge on land formerly in CRP. First, policymakers should consider the negative consequences of programs similar to the CRP and develop and enforce provisions to deal with them. If CRP land facilitates the spread of leafy spurge, the benefits of the program have been overstated. Second, economists depend heavily on inputs from others to accurately assess impacts. Scientists and policymakers alerted to the information shortcomings in the impact estimation process may be encouraged to refine the components of the economic impact models. Additional information that would help refine the impact estimate includes:

- more precise inventories of leafy spurge infestations,
- a better model of the biophysical relationships between leafy spurge infestations and soil erosion caused by surface water runoff, and
- a better model of the biophysical relationships between leafy spurge and wildlife habitat functions.

This additional knowledge would sharpen the statewide economic impact estimate and may allow for estimates at sub-state levels.

The potential overstatement or understatement of economic impacts is of concern because:

- Actual ha for each alternative post-CRP land use are unknown (e.g., how many hectares of CRP will be returned to cropland or converted to grazing land after the program ends).
- The study assumes post-CRP grazing lands are grazed at full capacity. If used at less than full capacity, impacts to the grazing industry would be overstated.
- Leafy spurge may provide some conservation benefits on lands maintained as vegetative cover, which, if not accounted for in the analysis, would overstate adverse impacts.

Nevertheless, considering the past and potential future expansion rates of leafy spurge in North Dakota, continued attention to the threat from invasive, noxious weeds is warranted.

Literature Cited

Alley, Harold P. and Calvin G. Messersmith. 1985. Chemical control of leafy spurge, p. 57–64. *In:* A.K. Watson (ed.), Leafy Spurge. Weed Sci. Soc. of Amer., Champaign, Ill.

Bangsund, Dean A. and F. Larry Leistritz. 1991. Economic impact of leafy spurge in Montana, South Dakota, and Wyoming. Agr. Econ. Rep. 275. Agr. Exp. Sta., N.D. State Univ., Fargo, N.D.

Bangsund, Dean A., Jay A. Leitch, and F. Larry Leistritz. 1996. Economics of herbicide control of leafy spurge (*Euphoriba esula* L.). J. of Agr. and Resource Econ. 21(2):381–395.

Council for Agricultural Science and Technology. 1995. The Conservation Reserve: A survey of research and interest groups. Spec. Pub. No. 119. CAST, Ames, Iowa.

Coon, Randal C., Theresa K. Golz, and Jay A. Leitch. 1990. Expanding the North Dakota Input-Output Model to include recreation and tourism. Agr. Econ. Rep. 225. Agr. Exp. Sta., N.D. State Univ., Fargo, N.D.

Derscheid, Lyle A., Leon J. Wrage, and W.E. Arnold. 1985. Cultural control of leafy spurge, p. 57–64. *In:* A.K. Watson (ed.), Leafy spurge. Weed Sci. Soc. of Amer., Champaign, Ill.

Fox, Dean, Don Kirby, Rodney G. Lym, Joel Caton, and Kelly Krabenhoft. 1991. Chemical composition of leafy spurge and alfalfa. N.D. Farm Res. 48(6):7–9.

Hanson, Thomas P. 1994. Leafy spurge control, using angora goats. M.S. thesis, N.D. State Univ., Fargo, N.D.

Leistritz, F.L., Dean A. Bangsund, Nancy M. Wallace, and Jay A. Leitch. 1993. Economic impact of leafy spurge on grazing land and wildland in North Dakota. Great Plains Res. 3(1):21–37.

Leitch, Jay A. 1978. A Model to estimate the changes in sportsmen expenditures due to land use changes in a five county area of North Dakota. Agr. Econ. Paper 78003. Dept. Agr. Econ., N.D. State Univ., Fargo, N.D.

Leitch, Jay A., F. Larry Leistritz, and Dean A. Bangsund. 1994. Economic effect of leafy spurge in the upper Great Plains: methods, models, and results. Agr. Econ. Rep. 316. Agr. Exp. Sta., N.D. State Univ., Fargo, N.D.

Lym, Rodney G., Calvin G. Messersmith, and Richard Zollinger. 1993. Leafy spurge, identification and control. Ext. Ser. Rep. W-765 (Rev.). N.D. State Univ., Fargo, N.D.

Messersmith, Calvin G. and Rodney G. Lym. 1990. Leafy spurge control: 10 years of research enhancement. N.D. Farm Res. 47(6):3–6.

Ribaudo, Marc O. 1989. Water quality benefits from the Conservation Reserve Program. Agr. Econ. Rep. 606, Resources and Technology Div., Econ. Res. Ser. U.S. Dept. Agr., Washington, D.C.

U.S. General Accounting Office. 1995. Conservation Reserve Program: Alternatives are available for managing environmentally sensitive cropland. GAO/RECD-95-42, Rep. to the Committee on Agr., Nutr. and Forest., U.S. Senate, Washington, D.C.

Wallace, Nancy. 1991. Economic impact of leafy spurge on North Dakota wildland. M.S. thesis, N.D. State Univ., Fargo, N.D.