FHWA/IN/JTRP-2000/17

Final Report

New Treatment Combinations for Vegetation Management Along Indiana Roadsides

D. James Morré

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16. Abstract

This report represents results from a project for research to develop and implement new treatment mixtures for control of problem brush, trees and other woody species, and herbicide-resistant weeds along Indiana roadsides. An environmentally safe mixture of trichlopyr (Garlon Herbicide) and ammonium nitrate for one application control of brush and for chemical pruning of trees was developed. Also developed were new, environmentally safe and effective mixtures of triclopyr, clopyralid ammonium nitrate, and a novel TR-III for brush control mixture and for possible use for the control of milkweed, Canada thistle, bindweed, ground cherry and other perennial, herbicide-resistant roadside weeds.

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INDOT Research

TECHNICAL *Summary*

Technology Transfer and Project Implementation Information

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New Treatment Combinations for Vegetation Management Along Indiana Roadsides

Introduction

This project was to develop and implement new treatment combinations for control of problem brush, trees, and biennial and perennial weed species along Indiana roadsides. Target species include wild carrot, common milkweed, trees, brush and brambles, vines, Canada thistle, Johnson grass, quackgrass, chicory, bull nettle, and bindweed. Focus was on the use of thiol reagent additives to enhance the herbicidal action of a trichlopyr-ammonium nitrate mixture to eventually lead to the eradication of all undesirable and introduced biennial and perennial roadside species without serious injury to bluegrass, fescue and most native prairie species including wild flowers and without potential hazard to the environment.

Findings

New treatment mixtures for control of problem brush, trees and other woody species, and herbicide-resistant weed were developed for use along Indiana roadsides. An environmentally safe mixture of trichlopyr (Garlon Herbicide) and ammonium nitrate give one application control of brush and chemical pruning of trees. New, environmentally safe and effective mixtures of triclopyr, clopyralid, ammonium nitrate and a novel TR-III enhances brush control, controls milkweed, Canada thistle, bindweed, ground cherry and other perennial, herbicide-resistant roadside weeds.

The program for chemical control of brush and weedy vegetation along roadsides is primarily to maintain sight distances. The mixture also provides for chemical pruning. Only the sprayed parts are killed. Unsprayed parts are unharmed. Spraying is delayed until fall to avoid environmental concerns from "brown-out."

The new additive enhances the effectiveness of roadside herbicides for control of difficult-to-kill, noxious, or unsightly weeds. The additive is a safe and biodegradable natural substance that is inexpensive and allows for less frequent spraying and reduces overall herbicide requirements by 50%.

Implementation

Implementation was based on a minimum of three years of field experience involving different weather conditions and different locations within the state to minimize unexpected environmental problems. Since the work was primarily with brush and perennial weeds, effects of regrowth was evaluated, normally over two growing seasons in each implementation trial. Thus, limited trials, as part of the implementation program, were initiated as soon as possible to gain useful field experience in advance of full implementation. Actual use conditions were duplicated as closely as possible using truck-mounted equipment and licensed State or commercial (contractual) applicators. Close liaison with State, INDOT District and industrial personnel was maintained throughout.

Implementable findings have already been reported in the form of a User Manual and Video to facilitate implementation. Also included were personal contacts INDOT Supervisors, Engineers, and Maintenance personnel, working directly with contractors and chemical company representatives and through special meetings and seminars. Especially valuable was a close working relationship with State and District INDOT personnel.

Cost savings, safety, and appearance will be the primary benefits. Even with full width mowing, brush and unsightly or noxious perennial weeds are recurring problems of roadside vegetation management. If these problem species could be eradicated, limited two-cycle mowing should be sufficient to maintain sight distances and a well-maintained appearance to Indiana roadsides.

According to Transportation Guides for Determination of Mowing Limits, safety overrides all other features affecting roadside maintenance. Sight distances must be maintained at intersections and on the insides of curves. Safety setbacks must be observed. Guard rails, bridge approaches, signs, and other traffic control devices must be kept open to view.

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Figure 12. Soybean plants treated with clopyralid ± cysteine. Plants were grown in the greenhouse and pictured 4 weeks after treatment with 0.005 lb/A of clopyralid alone on the left and 0.005 lb/A of clopyralid plus 0.05 lb/A cysteine on the right.

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1) IDENTIFICATION

a) Title: NEW TREATMENT COMBINATIONS FOR VEGETATION MANAGEMENT ALONG INDIANA ROADSIDES – PHASE II

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c) Principal Investigator: D. James Morré, Dow Distinguished Professor

d) Starting Date: July 1, 1995

2) INTRODUCTION

Vegetation management along roadsides is an important factor in terms of safety and recurring costs in highway maintenance. Excessive vegetation growth can obscure sight lines or even cover important road signs and warnings. Such areas are unsightly, harbor weeds noxious to agriculture and are proven more costly to maintain if only mechanical methods are used than when mechanical methods are supplemented by chemicals.

Surveys showed that major contributors to unsightly roadsides, reductions in site distance and weeds noxious to agriculture are the basis for most extra vegetative management costs beyond minimal two-cycle mowing. Involved are only a small number of herbicide-resistant perennial species that include wild carrot, common milkweed, Canada thistle, brush and brambles, chicory and Johnsongrass. Also important from a noxious weed standpoint are Canada thistle, bindweed and quackgrass.

This research and implementation proposal has its origins in the discovery under a prior JTRP project of a new series of thiol reagent (TR) additives which, at very low rates of application, enhance considerably the effectiveness of herbicides first indicated from laboratory studies. The TR additives were developed further in greenhouse studies and finally in the field. The additives were used effectively on brush to control trichlopyr-resistant ash and hard maple. The treatment also had promise for control of herbicide-resistant broad leaf weeds. Broad spectrum control of perennial weed species including milkweeds, wild carrot, field and hedge bindweed, bullnettle, Canada thistle, chicory and ground cherry was achieved.

A major accomplishment under the previous project was the development of a low cost combination of materials useful for control of woody vegetation along roadsides (brush control). The principal material was Garlon 4 (trichlopyr) at a basal rate of application of 2 pounds/100 gallon of total spray mixture. Combined with this are one or two low cost additives, both of which cost less than $1.00/100 gallons of spray mixture. The end result was an efficacious brush control treatment that gave complete control of all major roadside brush species in the state of Indiana and that can be used either for eradication or for chemical pruning.

With the loss of 2,4,5-T, there have been few, if any, low cost materials available in the Midwest for use in brush control programs along Indiana highways. Brush control is a major state maintenance operation particularly in the southern half of Indiana, both for safety and maintenance of sight distances. A derivative of 2,4,5-T, 2,4,5-TP or Silvex, was utilized in some brush control mixtures. However, this compound also was largely withdrawn from the market due to safety considerations.

The approach followed initially was to examine what herbicides were available with modes of action resembling that of 2,4,5-T but without the environmental hazards associated with that material. The strategy was then to determine what was missing from their activity pattern that caused them to be less effective than 2,4,5-T and, through the use of additives, to attempt to restore the missing parts of the activity pattern.

In the initial selection, the following herbicides were evaluated: trichlopyr (Garlon), picloram (Tordon), dicamba (Banvel), 2,4-D, clopyralid (Lontrel), and fluroxypur (Starane). These compounds were evaluated extensively in laboratory and greenhouse trials and in mechanism of action-based assays using both isolated membrane fractions and partially purified enzymes. Membranes and enzymes used were those that contained the portion of the response mechanisms affected generally by phenoxy herbicides of which 2,4-D and 2,4,5-T were representatives. Trichlopyr was selected for detailed study. It was found that the part of the activity given by 2,4,5-T and missing from the action of trichlopyr appeared to be related to an ability of 2,4,5-T to block the action of a cell-surface ATPase. A simple and inexpensive ATPase inhibitor was sought to combine with trichlopyr. Cobalt chloride was selected and found to be effective at low rates of application of one pound/100 gallons of total spray mixture. Cobalt chloride was especially effective because it penetrated the plant parts readily and was compatible in the spray mixture with trichlopyr.

The mechanism of action of cobalt chloride was investigated and was shown by mass spectroscopic experiments to be unrelated to the uptake of trichlopyr but was synergistic in its ability to enhance trichlopyr toxicity.

Cobalt chloride is relatively expensive, costing several dollars per pound and there was some concern about introducing large quantities of cobalt into the environment. Therefore, a less expensive and more environmentally favorable alternative to cobalt chloride was sought. In a series of trials comparing other salts, ammonium nitrate, available at low cost at any fertilizer or feed store, was found to be nearly as efficacious in enhancing the activity of trichlopyr as was cobalt chloride. Therefore in subsequent implementation trials, cobalt chloride was replaced by ammonium nitrate.

Implementation trials for brush control using the new mixture were initiated with Don Bickel of the Crawfordsville District. These trials were highly successful and all major roadside species examined were controlled by the mixture except for hard maple and ash. These latter two species were found to be resistant not only to trichlopyr alone but also to the combination of trichlopyr plus either cobalt chloride or ammonium nitrate.

The basis for a new series of additives, designated TR (for thiol reagent), was next investigated in the laboratory and greenhouse. The target molecule for the additive at the outer cell surface is apparently involved in the response to the trichlopyr (Garlon-4 herbicide). The new additives apparently work by modifying the interaction of trichlopyr with this target. A number of laboratory experiments were then designed and carried out to better define this interaction. The experiments used isolated surface membranes and direct chemical determinations of various response parameters. The laboratory and greenhouse tests also were used to define the optimum rates and ratios of herbicide and additive.

3) PROBLEM STATEMENT

In the 1970's a spraying program for control of broadleaf weeds was instituted using an environmentally safe amine formulation of 2,4-D. A reduction from 5-cycle to 3-cycle mowing resulted in a substantial cost savings estimated at between $500,000 and $750,000 annually.

A remaining problem with the use of 2,4-D amine or Banvel-2,4-D mixture in combination with reduced mowing was the invasion of roadsides by brush, bramble, briars and trees. A mixture was developed beginning in 1989 and implemented beginning in 1994 of trichlopyr and ammonium nitrate that gave low cost and broad spectrum control of brush and trees along roadsides. The treatment was useful for both eradication and chemical pruning. Only sprayed portions of trees were killed. Grass was not affected by the treatment.

With low-cost and effective roadside brush control a reality, attention was turned to the last remaining roadside vegetation management problem – problem perennial or biennial weeds. Much of the need for vegetation management beyond two cycle mowing is the result of just a few species that are either unsightly, tall enough to obstruct lines of sight or are noxious to agriculture. All have either a biennial or perennial growth habit, all have fleshy underground parts and all are relatively resistant to 2,4-D amine. Included in the list of target species were wild carrot, common milkweed, Canada thistle, Johnsongrass, chicory, bindweed and quackgrass.

Laboratory and greenhouse studies initiated in 1989 led eventually to the discovery of a novel series of thiol reagent "TR" additives that potentiated the action of the trichlopyr-ammonium nitrate combination sufficiently to suggest that their further development and implementation might result in the eventual eradication of most, if not all, problem perennial weeds and grasses without injury to desirable roadside species such as bluegrass, fescue and even annual wild flowers.

This project was to further develop and implement the TR series of additives with special emphasis on TR-III which may be among the most effective, least expensive and least difficult to implement from the standpoint of availability and environmental safety. The project activities would range from additional laboratory and greenhouse studies to trials with truck-mounted equipment. Patent protection was to be sought for the TR additive series and aspects of its eventual commercialization and availability for INDOT use were to be developed.

4) OBJECTIVES

This project was to develop and implement new treatment combinations for control of problem biennial and perennial weed species along Indiana roadsides. Target species include wild carrot, common milkweed, trees, brush and brambles, vines, Canada thistle, Johnsongrass, quackgrass, chicory, bull nettle, and bindweed. All are woody species or non-woody species that are biennials with fleshy roots or are perennials from rhizomes. Focus was to be on the use of thiol reagent additives to enhance the herbicidal action of a trichlopyr-ammonium nitrate mixture to eventually lead to the eradication of all undesirable and introduced biennial and perennial roadside species without serious injury to bluegrass, fescue and most native prairie species including wild flowers or potential hazard to the environment.

Specific objectives were as follows:

i) To determine the cost-effective herbicide and additive rates and ratios under field use conditions. Guidance in determining ratios would come from laboratory and greenhouse studies.

ii) To determine herbicide rates and ratios leading to eradication of problem species. These studies would require application in one year and subsequent evaluation of regrowth and/or reinfestation in one or more subsequent years depending on species. Also to be determined was the need for reapplication, possibilities of developing resistance to the mixtures and other aspect uniquely associated with a program of weed eradication.

iii) To evaluate different dates of application at several rates and ratios of application to optimize overall treatment effectiveness.

iv) To obtain patent protection, regulatory approval and commercialization of the TR additive sufficient to permit implementation and continue use in INDOT programs or roadside vegetation management.

v) To intensify laboratory studies to isolate, identify and clone the target for the TR additives. Presumably the additional basic information provided would permit further improvements in the treatment combinations.

vi) To explore the use of the TR additive series in combination with trichlopyr, ammonium nitrate and possibly other herbicides for control of perennial weedy grasses including Johnsongrass and quackgrass.

vii) To investigate the use of the TR additive combinations for specialized problems involving weeds growing from bulbs such as wild garlic and yellow nut sedge.

viii) To complete a series of environmental safety trials in progress to monitor possible adverse effects of continuous herbicide applications and to initiate new trials as implementation of new materials, or combinations of materials are anticipated. These environmental safety trials were critical. Some of these had been in place for several years, were under Indiana use conditions and were not being duplicated anywhere else. It seemed vital to the interest of chemical weed and brush control programs both in Indiana and nationwide that these trials be completed.

ix) To implement the various combinations involving TR additive series and to provide instructions for their use to INDOT personnel, cost-benefit information and follow-up in terms of treatment evaluation and indicated modifications as work progressed.

x) To monitor all aspects of environmental safety associated with the use of chemicals and chemical combinations along Indiana roadsides such as carry over, drift, unfavorable interactions, damage to non-target vegetation, injury to fish, aquatic organisms, wildlife and humans as well as any possible hazards to the applicator. The greatest limitation to evaluation of environmental safety is real data from actual use situations that gives new information upon which environmental decision can be based.

All research, including basic studies, was carried out in close consultation and cooperation with the Indiana Department of Transportation and with representatives of chemical manufacturers.

5) WORK PLAN

The work emphasized variations in the rates and ratios of herbicides and additives in the mixture of trichlopyr, ammonium sulfate and TR-III additive. The herbicide is the most expensive component of the mixture (ca. More than $50 per gallon). The rate of herbicide ultimately determines effectiveness together with the ratio of herbicide to TR-III additive. The optimum ratio changes with the rate of herbicide addition. Thus, small adjustments involving only fractions of a gallon per acre of herbicide or additive could result in cost savings of upwards of $5 per acre or more than $50,000 annually state-wide even with only partial implementation. Since there are three components of the mixture, it was necessary to vary each independently as two were held constant. Each species was checked as to optimum rate and ratio. Rate and ratio was then verified for different dates of application (early, mid season and late). All trials were under roadside conditions and in triplicate. This represented a major undertaking each year during the project.

The approach that was followed was structured so that work would proceed simultaneously on each of the several objectives each year. This was important as well to reduce the total time between initial testing and actual implementation.

1) Herbicides rates and ratios leading to eradication of problem species were determined in the greenhouse and test plots. The approach differed in that rate and

ratio determinations giving single season control, in that rates and ratios were included that exceeded those necessary for single season control to determine rates and ratios to eliminate regrowth and/or reinfestation in one or more subsequent years. Regrowth was retreated in succeeding years to determine effectiveness or need for reapplication and possibilities of resistance to the trichlopyr-TR-III mixtures. This objective required nearly the entire 5 years to complete due to the need for long-term follow-up.

2) Different dates of application were evaluated at several rates and ratios of application to optimize overall treatment effectiveness. Best guess rates and ratios were employed initially with fine tuning in subsequent years. Dates included early, mid season and late applications between March and November depending on species. These studies were restricted to roadside plots.

3) Laboratory studies focused on identification, isolation and cloning of the target protein of the TR additives. Environmental trials were continued. These placed emphasis on repeated annual applications of the same treatment at the same location to monitor possible adverse effect from repeated usage. Results were prepared for publication. Specialized applications were evaluated for certain troublesome species that originate from bulbs. Included in the category were wild garlic and yellow nut sedge. Both involved spring applications with evaluations the following fall and spring. Winter months were devoted to laboratory studies and greenhouse evaluations. New work was initiated to focus on attempting to understand how the TR additives offer selectivity for biennial or perennial species from fleshy roots or stems (e.g. rhizomes) and why other species which were perennials from stolons (bluegrass, fescue, goldenrod, aster, etc.) were unaffected. Implementation studies initiated in FY94 to evaluate the trichlopyr-ammonium nitrate mixture for brush control were continued. FY94 treatments were evaluated and additional implementation trials were initiated in succeeding years. Close liaison was maintained with Federal, State and District personnel. INDOT equipment and personnel was utilized for implementation activities.

4) FY96 was devoted to continued testing and evaluation of the trichlopyr-ammonium nitrate-TR-III mixture to further refine rates and ratios. Near final optimum rates and ratios were evaluated at different dates of application and weed eradication studies were continued. For the latter, FY95 treatments were evaluated with re-applications as indicated. Mode-of-action studies were continued as were greenhouse studies and environmental tests together with the evaluation of brush control implementation activities. Applications for Johnsongrass and quackgrass control in FY95 were evaluated and new treatments were established based on FY95 experience.

5) FY97 marked the beginning of the initial implementation of the trichlopyr-ammonium nitrate-TR-III mixture at the most promising rates, ratios and dates of application. FY96 plots were evaluated together with brush control implementation activities. Laboratory and environmental studies were continued .

6) FY98 was the first year possible for enlarged implementation activities including mixtures for control of Canada thistle. Test plots established in FY96 and

FY97 received final evaluation to determine rates and ratios necessary for problem weed eradication. This information was implemented initially for spot application, e.g. for control of Canada thistle or wild carrot. Materials were applied to extensive areas at several locations over the state during the entire spraying season but centered around optimum times of application determined from FY95-FY97 trials. Environmental studies were completed in FY98 but laboratory studies were continued.

7) In FY99, the final year of the study, we concentrated on a thorough evaluation of all test areas and trials and final modification of the basic herbicide to additive ratios and rates based on FY98 implementation trails. Additionally, extensive plot trials with Canada thistle and Johnsongrass were established throughout the state for evaluation in 2000. Focus was on state-wide implementation of the TR-III additive-containing mixtures, including commercialization and preparation of the final report.

8) A patent was filed and issued covering the TR series, cobalt chloride and ammonium nitrate additives. An initial supply of TR-III was arranged as well under an experimental use arrangement. A commercial supplier of TR-III was sought and finalized.

6) ANALYSIS OF DATA

<u>Brush Control Mixtures</u>

Implementation activities to evaluate the trichlopyr-ammonium nitrate-additive TR-III mixture were completed.

A) Ammonium nitrate mixture
200 gallons of water
6 lb ammonium nitrate
5 gallons Garlon 3A (triclopyr)
2 quarts surfactant

Applied at a rate of 25 gal/A. If ash and maple were dominant species, 0.5 additive TR-III (mixture B) should be added.

B) Ammonium nitrate mixture plus additive TR-III
200 gallons of water
6 lb ammonium nitrate
5 gallons Garlon 3A (triclopyr)
2 quarts surfactant
0.5 lb additive TR0III (cysteine)

Mixture B is recommended especially where hard maple and ash are dominant species.

Application Date: Last week of August (No earlier to avoid "brown out" and drift onto sensitive crops) until leaves begin to turn in fall.

Foliage application: Good coverage is important.

Tanks mixtures are stable for several days.

Sprayed foliage will be killed in about one month and if the foliage is killed there is little or no regrowth the following season.

Purchase ammonium nitrate (fertilizer) at Co-Op or garden store.

TR-III is available from In Vitro Vegetal, S.A., Attn. Dr. Guy Auderset, 59 Chemin des Mésanges, CH 1225 Chene-Bourg, Geneva, Switzerland. The material is shipped in 1 lb (50 g) containers each costing about $90.00 including shipping. Because the substance is generally recognized as safe, EPA approval is not required for its use.

Brush Control

A low-cost, effective and environmentally safe program of chemical control of brush along roadsides. Only the sprayed parts are killed; the unsprayed parts of the tree are unharmed. Chemical pruning of woody plants to maintain sight distances along roadsides. Only fall application to avoid "brown out" is recommended.

In general, both the mixture of triclopyr with ammonium nitrate and the mixture with ammonium nitrate and additive TR-III have performed well. For most species the sprayed foliage is killed completely within one month of application. For those plants or plant parts where the foliage was killed, there was no subsequent regrowth the following season. The mixture could be used either to kill brush by overspraying to stop encroachment or to chemically prune to improve sight distance on road segments lined by larger trees and brush. The unsprayed portions of larger trees especially seem not to be adversely affected by the treatment, yet the sprayed branches and limbs die and fall away.

The species controlled by the mixture are summarized in Table 1. Very sensitive species include briars (raspberry and blackberry), mulberry, walnut, sumac, sassafras, box elder, buckeye, cottonwood, wild grape and poison ivy. Sensitive species include red bud, elm, honey locust, hackberry, black locust, willow, sycamore, osage orange, multiflora rose, alternate-leaved dogwood and white oak. Black cherry, hard maple and honeysuckle were intermediate. Resistant species included green briar, bittersweet, juniper and ash. There was no injury to grass.

Table 1. Species controlled by brush control mixture.

Very Sensitive	Sensitive	Intermediate	Resistant
Briars (Blackberry, Raspberry)	Red Bud	Hard Maple	Juniper
Mulberry	Elm	Black Cherry	Ash
Walnut	Honey Locust	Honeysuckle	Green Briar
Sumac	Black Locust		Bittersweet
Sassafras	Hackberry		
Box Elder	Willow		
Buckeye	White Oak		
Cottonwood	Sycamore		
Wild Grape	Osage Orange		
Poison Ivy	Multiflora Rose		
	Alternate-leaved Dogwood		

The brush control mixture has been one of the most successful of the various vegetation management practices developed for post implementation. Use of the recommended mixture has already achieved the desired brush control along Indiana roadsides. Especially if applied late in the season, "brown out" is not obvious with these mixtures and defoliation and kill gradually blends into normal fall foliage changes. The treatment is equally useful for chemical trimming with trees, foliage and branches actually sprayed are killed but the unsprayed portions of the trees remain alive and unharmed.

HERBICIDE MIXTURE FOR NOXIOUS AND PERSISTENT WEEDS

Control of Persistent Weeds

Development of a new additive enhances the control by herbicides of difficult to control noxious and unsightly roadside weeds. Allows for less frequent spraying and reduces overall herbicide requirements by 50%.

Control of 2, 4-D resistant species and brush.
Control of seed heads in smooth brome.
Combine late summer application of herbicide with a spring application of retardants to reduce or eliminate mechanical mowing.

Table 2. Herbicide mixture for control of persistent weeds.

250 gallons of water
15 lb ammonium nitrate fertilizer
10 gallons Garlon 3A

¾ lb TR-III additive
0.5 gallons X-77 wetting agent

Apply at a rate of 25 gal/A
Spray late July to end of September

Field and implementation trials were carried out beginning in 1995. Summer rate and date studies were carried out with the TR additive plus Garlon 4. Approximately 600 test plots were established. The mixture was tested at 6 rates of application given in Table 3 at the different dates indicated. Species (application dates in parentheses) investigated with at least three dates of application are as follows: Canada thistle (5/31/95, 6/15/95, 6/28/95, 7/8/95, 7/12/95, 7/17/95, 7/18/95, 7/19/95, 7/25/95, 8/10/95, 8/14/95, 8/25/95); Wild carrot (5/31/95, 6/29/95, 7/8/95, 7/13/95, 7/14/95, 7/17/95, 7/18/95, 7/19/95, 7/25/95, 7/26/95, 8/8/95, 8/10/95, 8/21/95, 8/23/95); Common milkweed (6/19/95, 6/28/95, 7/12/95, 7/17/95, 7/18/95, 7/19/95, 7/26/95, 8/3/95, 8/10/95, 8/17/95, 8/28/95); Chicory (6/19/95, 6/29/95, 7/8/95, 7/17/95, 7/18/95, 7/19/95, 8/5/95, 8/10/95, 8/21/95); Horse nettle (8/5/95, 8/17/95, 8/28/95); Wild parsnip (6/15/95, 9/19/95, 9/26/95); Knotweed (5/31/95, 7/8/95, 7/10/95); Wild sweet potato (6/19/95, 7/3/95, 7/5/95); Smooth brome (6/19/95, 7/3/95, 7/5/95); Bindweed (6/29/95, 7/12/95,7/25/95); Cattails (7/5/95, 9/11/95, 9/15/95); Yellow nutsedge (8/15/95, 9/6/95, 9/11/95); Kudzu (8/8/95, 8/31/95, 9/8/95); Crown vetch (8/25/95, 9/4/95, 9/8/95).

Table 3. Persistent species controlled.

Wild Carrot
Wild Parsnip
Common Milkweed
Climbing Milkweed
Field Bindweed
Hedge Bindweed
Wild Sweet Potato
Chicory
Dogbane
Bull Nettle
Poison Ivy
Wild Grape
Blackberry
Horsetails (Equisetum)
White Clover
Trumpet Vine
Plus the common 2,4-D susceptible lawn weeds:
- Dandelion
- Common Plantain
- Buckhorn Plantain
- Clovers and most other legumes

The rate and date studies were to optimize application rates over a wide range of application dates and stages of plant growth ranging from early growth, through flowering and late post-flower stages as well as the growth after mowing.

TR-III is available from In Vitro Vegetal, S.A., Attn. Dr. Guy Auderset, 59 Chemin des Mésanges, CH 1225 Chene-Bourg, Geneva, Switzerland. The material is shipped in 1 lb (500 g) containers each costing about $90.00 including shipping. Because the substance is generally recognized as safe, EPA approval is not required for its use.

Table 4. Rate and date studies using a near optimum ratio (for most roadside vegetation) of 1 lb triclopyr (Garlon 4 or Garlon 3A) to 0.025 lb cysteine per acre.

Rate	Triclopyr (lb/A)	Cysteine (lb/A)	Ammonium nitrate (lb/A)
A	1	0.025	0.5
B	2	0.050	1.0
C	3	0.075	1.5
D	4	0.100	2.0
E	5	0.150	2.5
F	6	0.200	3.0

X-77 surfactant was present at 0.025% of the spray mixture.

Evaluations were compiled in 1996. Evaluations by predominant species are as follows:

Wild carrot (*Daucus carota*)

There was no problem with virtual eradication of wild carrot at any stage of application throughout the entire growing season.

Chicory *(Cichorium intybus)*

Early control of chicory was achieved with 80-90% control the following season with the C or D rate of application (3 to 4 lb/A triclopyr + 0.075 to 0.1 lb/A cysteine + the ammonium nitrate and surfactant). However with fall rosettes or with regrowth after mowing, control was much better even down to the B rate of application (2 lb/A triclopyr + 0.05 lb/A cysteine, etc.). All of the applications beginning in August and continuing through October gave effective control at reasonable rates of application.

Common milkweed (*Asclepias syriaca*)

Milkweed was treated on the following dates and stages: 6/19/95 (prebloom), 6/28/95 (late prebloom), 7/12/95 (early bloom), 7/17/95, 7/18/95 (full bloom) 7/26/95 (post bloom), 8/10/95 (mature full pod), 8/17/95 (mature full pod), and 8/28/95 (late pod).

Mowed regrowth was sprayed on 8/3/95 and the plots were mowed on 9/15/95. Plant counts were taken at the time of spraying and approximately one year later.

Overall, the control of milkweed by spraying in 1995 was 75% independent of stage for treatments C-F based on 1996 evaluations. The regrowth was short and mostly below the mow line. Plants in treated plots were 1-2 ft tall whereas in the check plots the plants were 4-5 ft tall. The experiment where regrowth was treated gave no obvious control.

Table 5. Control of milkweed in 1995.

Milkweed	Check	A	B	C	D	E	F
Plants/plot	7.4	4.6	3.8	1.8*	1.9*	1.9*	1.4*

*All 1996 regrowth was short and below the mow line and did not flower. Selected milkweed areas were resprayed in 1996.

Whorled milkweed (*Asclepias verticillata*)

Whorled milkweeds were treated on 7/17/95. Based on 1996 regrowth, control was 60-65% at rates A-C and 100% at rates D-F.

Kudzu

Kudzu was treated on 3 dates 8/8/95, 8/31/95 and 9/8/95. Final evaluations were on 8/8/96, one year later. The lowest rate of application was 0.25 lb/A triclopyr (Garlon 4) + 0.006 lb/A cysteine + 0.125 lb/A ammonium nitrate. The highest rate of application was 6 lb/A triclopyr, 0.15 lb/A cysteine and 3 lb/A ammonium nitrate. The mixture gave complete control of kudzu in all plots at all rates. If the kudzu was largely over-sprayed, it was controlled and did not regrow. If only a small portion was treated, many plants so treated did recover. Complete or nearly complete coverage was necessary to ensure eradication.

Yellow nutsedge (*Cyperus esculentus*)

Yellow nutsedge was treated on 8/15/95 with 3 lb/A triclopyr + 0.05 lb/A cysteine + 1 lb/A ammonium nitrate. Control was 90% based on regrowth.

Treatments were continued on 9/16/95, 9/30/95, 10/10/95 and 11/1/95 in which the triclopyr was reduced to 2 lb/A. No reductions in regrowth were observed in any of the treatments.

Indications from 1996 are that mowing just prior to spraying enhances treatment effectiveness and that 2 lb/A triclopyr may not be sufficient.

Nimblewell (*Muhlenbergia schreberii*)

Nimblewell was treated on 8/15/95 and 8/23/95 with 3 lb/A triclopyr + 0.05 lb/A of either cysteine or dithiothreitol + 1 lb/A ammonium nitrate. Control based on regrowth was > 90%.

Smooth brome/Quackgrass

Smooth brome was treated on 6/19/95 and 7/5/95.

On 6/19/95 > 50% control based on regrowth was obtained with the D rate and 85% at the E and F rate of application based on regrowth. There was no obvious control with the 7/15/95 date of application based on regrowth although the treatment has given consistent suppression of seed heads.

One quackgrass trial was applied 7/3/95. It appeared, as in 1994, that there was significant control at high application rates. This needs to be repeated in a large experiment.

Cattails, sedges and rushes

Treatments were applied on 7/5/95, 9/11/95 and 9/15/95. Cattails showed no response even at the highest rates of application. Control of a wet land rush was indicated at the D rate and above.

Bull nettle (Horse nettle) (*Solanum carolinense*)

Horse nettle was treated 8/17/95 and 8/28/95 (mid-fruiting stage, fruit still green). > 90% control based on regrowth was achieved at all rates.

Bull nettle regrowth was treated on 8/5/95. Plants were 3”-6” high and in early bloom. No control was observed.

Dogbane (*Apocynum cannabinum*)

Mature plants of dogbane were treated in early pod stage on 8/5/95 and 8/21/95. Control was 75% at the lowest application rate (treatment A) and complete at treatment rates D through F. Control was 50% with treatment A, 75% at treatment rate B and 100% at treatment rates D through F.

Bindweed

Both field (*Convolvulus arvensis*) in 1994, and hedge (*Convolvulus sepium*) in 1995, bindweed were treated successfully. Application dates in 1995 were 6/29/95 (early bloom), essentially 100% control with treatments D-F; 7/12/95, 71% control with treatments A-F and 7/26/95, 60% control with treatments C and D and 85% control with treatments E and F based on regrowth in 1996.

Wild sweet potato (*Ipomea pandurata*)

Treatments were on 6/19/95, 8/14/95 and 8/21/95. Control was about 75% with treatments C-F (E and F on 8/21/95) based on regrowth in 1996.

Wild parsnip (*Pastinaca sativa*)

Wild parsnip was treated early on 6/15/95 (full flower) and late 9/19/95 (fall rosettes). Based on 1996 regrowth, all treatments (A-F) were 100% effective.

Canada thistle (*Cirsium arvense*)

Dates of application in 1995 were 5/31/95 (12-15" tall), 6/15 (early bloom), 6/28 (full bloom), 7/8 (late bloom), 7/12 (late bloom), 7/17 (late bloom), 7/18 (late bloom), 7/19 (late bloom), 7/25 (regrowth after mowing, 2-3" high), 8/10 (regrowth after mowing), 8/14 (late seed, upper 6" of plants dead), 8/25 (regrowth after mowing, repeat mowing on 9/3), 10/25 (regrowth after mowing, two locations).

Of the 14 applications, control was achieved only in the earliest treatments. Based on regrowth, 60% control was achieved with treatment E and 75% control with treatment F with 5/31/95 application. In the experiment of 6/15 additional treatments of G (8 lb triclopyr + 0.2 lb cysteine), H (10 lb triclopyr + 0.3 lb cysteine) and I (12 lb triclopyr and 0.4 lb cysteine) were included (plus ammonium nitrate and X-77). Control was 50-60% with treatments D and E and 80% with treatments F-I. Treatment on 6/28, 7/8, 7/12 and 7/17 resulted in about 50% control based on regrowth with treatments E and F. At all dates thereafter, there was no control obvious at any of the treatment rates in 1996 evaluations including sprayed regrowth.

The ratio of cysteine to triclopyr was varied from 0.05 lb: 2 lb, 0.1 lb: 2 lb and 0.2 lb: 2 lb (1x, 2x and 4x cysteine). Based on regrowth, the 1x rate of cysteine still appeared to be the best.

Knotweed (*Polygonum spp*) and Curled dock (*Rumex crispus*)

Curled dock was treated on 6/15/95 with no regrowth at any rate. Knotweed was treated on 7/8/95 and 7/10/95 with control at the C-F rates.

Poison ivy, Wild grape

Poison ivy and wild grape were treated on 6/19/95 with good control at the C-F rates. Poison ivy was killed at all rates.

Crown vetch, Birdsfoot trefoil, White clover

White clover was treated on 7/11/95, crown vetch on 8/25/95 and 9/4/95 and birdsfoot trefoil on 8/8/95. All were controlled at the C rate of application.

For most troublesome species of broadleaf weeds, except Canada thistle, the C rate of application of 3 lb/A triclopyr, 0.075 lb/A cysteine and 1.5 lb/A ammonium nitrate provided eradication (plus 0.025% X-77). Application dates from mid July to the end of August were best with the first week in August being about optimum.

If the weed population contains a lot of vines (bindweed, wild sweet potato), then the D rate of application should be used consisting of 4 lb/A triclopyr plus 0.1 lb/A cysteine and 2 lb/A ammonium nitrate. The D rate would be preferable as well for general roadside vegetation management although for some species (wild carrot, wild parsnip, common milkweed and legumes) this rate is not required.

Table 6. Summary of control by species.

Species	A	B	C	D	E	F	Dates
Wild carrot	X	X	X	X	X	X	5/31 - 10/04
Chicory			X	X	X	X	8/05 - 10/19
Common milkweed				X	X	X	6/19 - 10/19
Kudzu	X	X	X	X	X	X	8/08 - 9/08
Bullnettle	X	X	X	X	X	X	8/17 - 8/28
Dogbane				X	X	X	8/05 - 8/21
Bindweed					X	X	6/29 - 7/26
Wild sweet potato					X	X	6/19 - 8/21
Wild parsnip	X	X	X	X	X	X	6/15 - 9/19
Canada thistle						X	5/31 - 6/15
Whorled milkweed				X	X	X	7/17

Spot Treatments for Canada Thistle

Clopyralid plus additive

Greater than 90% control in one season

Mix 100 gallons and apply at a rate of 20 gal/acre

2.6 pints Transline = 1/3 gallon = 1.0 lb clopyralid per 100 gallons plus 2.5 gallons of a wetting agent such as Sidekick, Citrus Plus or X-77, plus 5 lb ammonium nitrate fertilizer and 0.5 lb (8 oz) of TR-III (cysteine) additive.

This is for a spot treatment only and the amount of mixture can be reduced by dividing everything by half for a 50 gallon starting mixture or by whatever fraction is convenient.

ENVIRONMENTAL SAFETY

All aspects of environmental safety of the TR-III additive alone and in combination with triclopyr and clopyralid were evaluated. There were no problems with carryover, drift, damage to non-target vegetation or injury to fish from either the additive or its combination with trichlopyr. The additive is generally recognized as safe and can be used as if it were a fertilizer. No potential hazards to the applicator were noted. Precautions should be the same as working with fertilizer. Skin and eye contact should be avoided with the concentrate due to the possibility of mild irritation. The substance is not toxic to humans or to wildlife.

Environmental trials of growth retardants turnover were completed. Three primary growth regulators/herbicides, mefluidide, chlorsulfuron and sulfometuron, alone and in combinations with and without surfactant or 2,4-dichlorophenoxyacetic acid (2,4-D), were applied annually at 8 to 10 times the cost-effective rates of application to roadside stands of mixed tall fescue (*Festuca arundinacea* Schreb.) and native bluegrass (*Poa pratensis* L.). The plots were not mowed. Applications were during the first week of May prior to elongation of culms bearing seed heads. With all of the materials and at all rates of applications, the grass had recovered fully by the end of the growing season (August). Even in the final year of the trial, all plots still supported strong stands of perennial grasses. The results show that the growth retardant mefluidide alone or in combination with the sulfonylurea herbicides, chlorsulfuron or sulfometuron, can be applied to established turf at cost-effective rates on an annual basis without permanent damage to turf or detrimental carryover of materials.

7) CONCLUSIONS

Summary of Implementation of Basic Laboratory Findings and Resultant Cost Savings and Environmental Benefits

A unique feature of the program has been the discovery of new and novel basic research findings that have led to improved practices of roadside vegetation management of benefit to the environment.

Laboratory Findings	Implementation Activity	Benefit
Plants move herbicides into difficult-to-kill under-ground parts mainly in the fall of the year.	Environmentally safe fall-spring spraying rotation to control roadside weeds and to reduce mowing (below).	Eliminated damage to crops combined with reduced mowing (below).
Grass, when mowed just before seedhead emergence, does not require further mowing to	Program of reduced mowing in conjunction with chemical control of weeds (above).	Reduced mowing and reduced use of fossil fuel. Annual present day cost savings of $1,000,000.

maintain roadside sight distances.		
Different plant growth retardants have different modes of action.	More effective and less-expensive combinations of two plant growth retardants with different modes-of-action.	Effective chemical mowing that was cost- competitive with two-cycle mowing.
Additives based on mode-of-action studies enhance herbicide activity.	A low-cost, effective and environmentally-safe program of chemical control of brush along roadsides. Only the sprayed parts are killed; the unsprayed parts of the tree are unharmed.	Chemical pruning of woody plants to maintain sight distances along roadsides. Fall application to avoid "brown out".
A target protein at the plant cell surface responds to the phenoxy-type herbicides.	Development of a new additive to enhance the control by herbicides of difficult-to-control, noxious and unsightly roadside weeds.	Allows for less frequent spraying and reduces overall herbicide requirements by 50%.

8) RECOMMENDATIONS

Implementation was based on a minimum of 3 years of field experience involving different weather conditions and different locations within the state to minimize unexpected environmental problems. Since the work was primarily with brush and perennial weeds, effects of regrowth was evaluated, normally over two growing seasons in each implementation trial. Thus, limited trials, as part of the implementation program, were initiated as soon as possible to gain useful field experience in advance of full implementation. Actual use conditions were duplicated as closely as possible using truck-mounted equipment and licensed State or commercial (contractual) applicators. Close liaison with State, District and industrial personnel was maintained throughout.

Implementable findings have already been reported in the form of a User Manual and Video to facilitate implementation. Also included were personal contacts with Department of Transportation Supervisors, Engineers and Maintenance personnel, working directly with contractors and chemical company representatives and through special meetings and seminars. Especially valuable was a close working relationship with State and District INDOT personnel.

Thus far, implementation of findings has been restricted to the Division of Operations Support, INDOT. However, it is expected that findings may be applicable to roadside maintenance programs throughout the Midwestern and Eastern United States.

- A program of environmentally safe and cost-effective chemical weed control in combination with reduced mechanical mowing to eliminate herbicide damage to crops, to reduce fossil fuel use and reduce roadside maintenance costs. Annual present day cost savings of $1,000,000.

- Program for chemical control of brush and weedy vegetation along roadsides to maintain sight distances. The mixture provides for chemical pruning. Only the sprayed parts are killed. Unsprayed parts are unharmed. Spraying is delayed until fall to avoid esthetic concerns from “brown out”.

- A new additive to enhance effectiveness of roadside herbicides for control of difficult-to-kill, noxious or unsightly weeds. The additive is a safe and biodegradable natural substance that is inexpensive and allows for less frequent spraying and reduces overall herbicide requirements by 50%.

9) IMPLEMENTATION SUGGESTIONS

Factors favoring implementation are cost savings, safety and appearance. Greatest cost savings will come from reduced mowing. However, even with full width mowing, brush and unsightly or noxious perennial weeds require special attention. If these problem species could be eradicated, limited 2-cycle mowing should be sufficient to maintain sight distances and a well-maintained appearance to Indiana roadsides.

According to Transportation Guides for Determination of Mowing Limits, safety overrides all other features affecting roadside maintenance. Sight distances must be maintained at intersections and on the insides of curves. Safety setbacks must be observed. Guard rails, bridge approaches, signs, and other traffic control devices must be kept open to view.

Mechanical mowing is presently the most expensive feature of roadside maintenance in Indiana. About 45,000 acres are mowed in the contract program with an additional 55,000 acres in force account mowing by State crews. With current cost estimates of $16 per acre per cycle for limited width contract mowing and up to $30 to $35 per acre per cycle for force account mowing, costs are estimated to be between $2,000,000 and $3,000,000 annually with additional costs as more full-width mowing is added to the program. The present Indiana recommendations are one cycle of 3 in full-width so that slightly more than 50% of the mowing costs are in support of full-width mowing for control of brush. The major justification for full-width mowing in Indiana is for control of weeds and brush. The availability of a good program of chemical brush and weed control would virtually eliminate the need for full-width mowing at every mowing cycle or reduce or eliminate the need for full-width mowing overall. Full implementation of the herbicide mixture proposed for development under this project is expected to reduce state-wide mowing costs by more than 50%.

Benefits. Cost savings, safety and appearance are the primary benefits of the program. Even with full-width mowing, brush and unsightly or noxious weeds are continuing problems of roadside management. They tend to reduce sight distances at intersections and on the insides of curves and obscure guard rails, bridge approaches, signs and other traffic control devices.

Brush is one of the major offenders in obstructing vision. Within two years, black locust, willow or elm will become established even with new construction. In non-prairie areas, where woody vegetation is natural to the environment and continually invades, one must be prepared to make periodic repeat applications even with the most effective mixtures. Tree seedlings or root sprouts grow up into trees which represent solid objects and present even more serious safety hazards. Trees too near to traffic lanes must be removed normally at considerable expense if mechanical means are used and the trees have been allowed to become large. Mechanical removal of established trees and of trees and brush growing in areas inaccessible to mowing is a very expensive alternative to application of brush-controlling chemicals.

There is general agreement that removal of trees and brush as well as the subsequent control of sprouts is a major economic factor in the total cost of vegetation management along roadsides. When left uncontrolled, woody vegetation quickly reduces sight distance, increases the possibility of collision with wildlife, pedestrians or other objects, chokes out grasses and other ground cover species that contribute to erosion control, stops up drainage facilities, may produce shady spots that contribute to build-up of ice and snow in winter, and necessitate an expensive reclearing project.

Brush and small trees will kill turf by shading and competition which leaves patches of bare soil open to erosion. Trees close to the pavement represent a traffic hazard and must be removed. The turf must then be re-established to prevent further erosion. Even full-width mowing is not the answer. Trees and brush small enough to be mowed will not be killed by mowing but will continue to re-sprout year after year. The size of their root systems will increase until a sapling several feet high and more than an inch in diameter will be produced in a single growing season with some species. Roadsides already heavily infested with trees and brush too large to mow, are especially prevalent in scenic areas or areas where the terrain prevents full cycle mowing (steep banks, cuts and fills, for example). These areas require frequent trimming or pruning to prevent further encroachment and to maintain sight distances.

Chemical brush control would be used primarily in three different situations: 1) To prevent encroachment (for example, of black locust) on Interstate and 4-lane roads, 2) At bridges where brush is always a problem and 3) Insides of curves in wooded areas when brush begins to restrict sight distances. The primary use is as a spot application.

With chemicals, the primary advantage is that trees and brush small enough to be oversprayed are killed, roots as well as the stems, so that no further treatment is necessary.

Woody plants are easier to kill when small, which reduces the total expenditure. Woody plants killed when small are not large enough to be unsightly when killed. Early treatment removes the woody plants and allows desired vegetation cover to become established sooner.

In areas where brush and trees have still not become established to the point of requiring mechanical removal, the present approach to the prevention of further encroachment by woody species is full-width mechanical mowing. The State of Indiana is presently mowing full width at least once per growing season and some districts are considering full-width mowing at every mowing cycle largely because of the brush problem. The practices will more than double current mowing expenses based on limited width 3-cycle mowing.

Mechanical mowing is presently the most expensive feature of roadside maintenance in Indiana. About 45,000 acres are mowed in the contract program with an additional 55,000 acres in force account mowing by State crews. With current cost estimates of $16 per acre per cycle for limited width contract mowing and up to $30 to $35 per acre per cycle for force account mowing, costs are estimated to be between $2,000,000 and $3,000,000 annually with additional costs as more full-width mowing is added to the program. The present Indiana recommendations are one cycle of 3 in full-width so that slightly more than 50% of the mowing costs are in support of full-width mowing for control of brush. The availability of a good program of chemical brush and weed control would virtually eliminate the need for full-width mowing at every mowing cycle or reduce or eliminate the need for full-width mowing overall. Through careful prioritization of what areas and what trees and brush in those areas would be treated, spraying costs will be kept at the minimum required to reduce or eliminate the requirements for full-width mechanical mowing.

In the State of Indiana, about 45,000 acres of roadside are mowed in the contract program with an additional 55,000 acres in force account mowing by State Crews. Current cost estimates are about $16 to $20 per acre for limited width mowing and up to $30 per acre for full-width mowing.

Work previously implemented resulted in reductions from 5-cycle mowing to 3-cycle mowing due to improved weed control and more effective timing of mowing operations. Taking an average mowing cost of $10 per acre per cycle, cost savings of 100,000 acres x $20/acre= $2,000,000 annually were realized.

At present, the major justification for full-width mowing is for control of brush and problems weeds. Especially on Interstates and divided highways, slightly more than 50% of the mowing costs are in support of full-width mowing. The availability of an improved program of chemical brush and weed control will greatly reduce or even eliminate the need for full-width mowing at every mowing cycle with additional cost savings of $10 to $15 per acre. If applied only to the contract program, additional cost savings of between $500,000 and $750,000 per year in reduced mowing cost are projected as a result of a return to limited width mowing.

10) IMPLEMENTATION PLAN

An overall implementation plan for the project was developed. The plan, prepared together with Bobby McCullough, Department of Civil Engineering, follows:

Background

For approximately 15 years, JTRP has sponsored research in vegetation control (chemical mowing, weed and brush control), performed under the direction of Dr. D. James Morré. The research has produced good results when implemented. At a recent close-out meeting for the New Treatment Combinations Study (SPR-2026) concerns were raised regarding implementation of the results from this and other vegetation control studies. INDOT has received a good rate of return, but not what could be realized if the sub-districts took more initiative. The prevailing cause appears to be that sub-district managers have relied heavily on mowing and are apprehensive about changing operations to chemical control. Since sub-districts have quite a bit of independence and influence over what gets implemented change has been slow. They also are not well informed regarding the various options available for chemical control. A new approach is needed to help change this mindset within the Department.

Proposed Activities

Dr. Morré has indicated that in past years there has been a positive move away from three cycle mowing and some acceptance of chemical control. This was primarily the result of influence an operations engineer in central office that held regular meetings with district people to explain the advantages of implementing positive changes. Unfortunately the pattern of influence has changed and currently sub-districts continue to mow excessively when they could benefit from effective brush and weed control. Since it is unlikely more money will be made available to spray, an effort needs to be made to demonstrate that using mowing dollars for spraying may be cost effective. The following describes a suggested program to accomplish cost effective changes in the vegetation control by lobbying sub-districts and conducting field demonstration trials.

The first step will be to host informational sessions to convince sub-districts to try spraying over mechanical mowing. A couple of key sub-districts will be solicited to implement the chemical mowing program for a year in lieu of mechanical mowing, check actual results and determine the potential of transferring results statewide via executive staff support.

Dr. Morré will direct the spraying program. Informational sessions will be held at three locations, in the northern, central and southern areas of the state. These sessions will be held in March 2001 by inviting key district and central operations personnel to informal working lunches during which information will be presented and feedback solicited. At these sessions, Dr. Morré will explain the various options that are available for vegetation control and then encourage sub-district participation. The Vegetation CD-ROM will also be distributed at this time.

During the 2001 growing season sub-district operations will be monitored and results recorded. A report to the executive staff would be generated and a presentation made to gather consensus and support.

Schedule and Budget

This project's main focus is explaining and marketing a comprehensive vegetation control program. It has the potential to save INDOT a considerable amount of money. A minimum amount of personnel time is required. Sub-district activities will be documented for one growing season, so this will determine the project duration. The meetings will be held in March and April and the growing season runs through October, so the duration is expected to be 12 months (several months for review and interaction by sub-districts is included).

The time requested is 12 months and the budget will be $7,500.

Additionally, it is anticipated that participating sub-districts may require minor equipment upgrades or rentals that may incur additional expense that cannot be accurately predicted at this time.

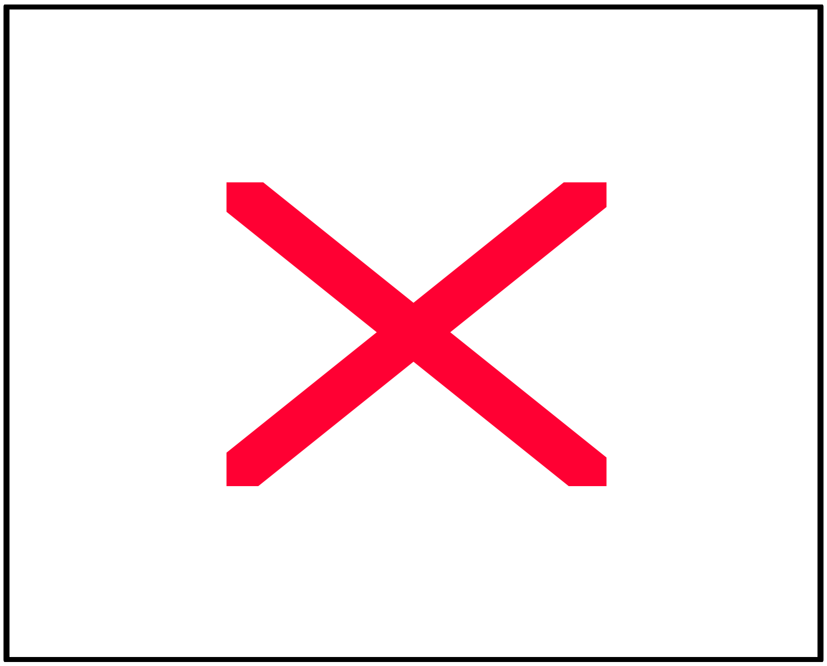

Figure 1. Brush along SR 25N treated with a mixture of 5 gallons Garlon 3A, 6 lb ammonium nitrate and 0.5 gallons X-77 wetting agent in 250 gallons of water at a rate of 25 gal/A on September 10, 1997. Photographed August 4, 1998.

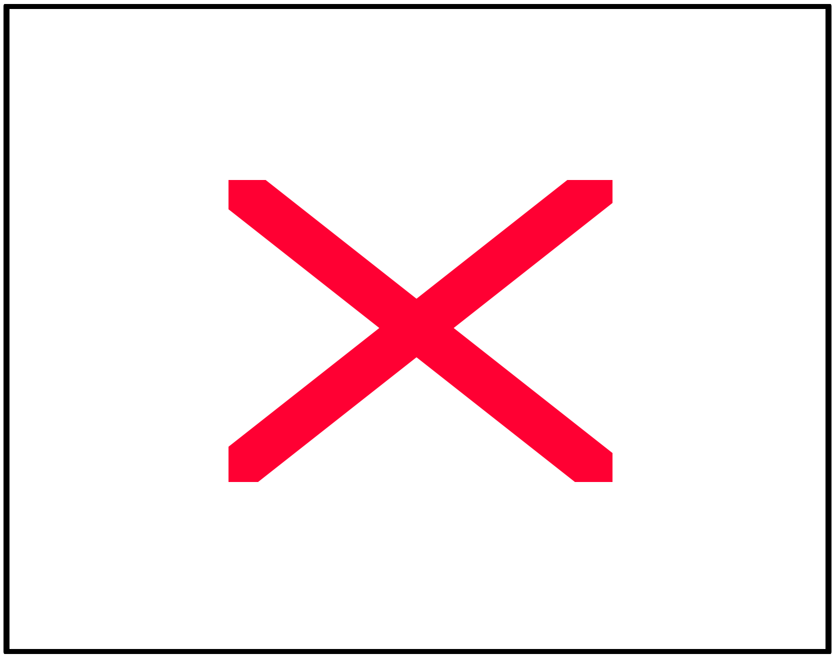

Figure 2. Chemical pruning of brush along SR 47 in Parke County. Applied in late August 1997 to avoid “brown out”. Applied was a mixture of 5 gallons Garlon 3A, 6 lb/A ammonium nitrate and 0.5 gallons X-77 wetting agent in 250 gal water at a rate of 25 gal/A. Photographed July 12, 1998.

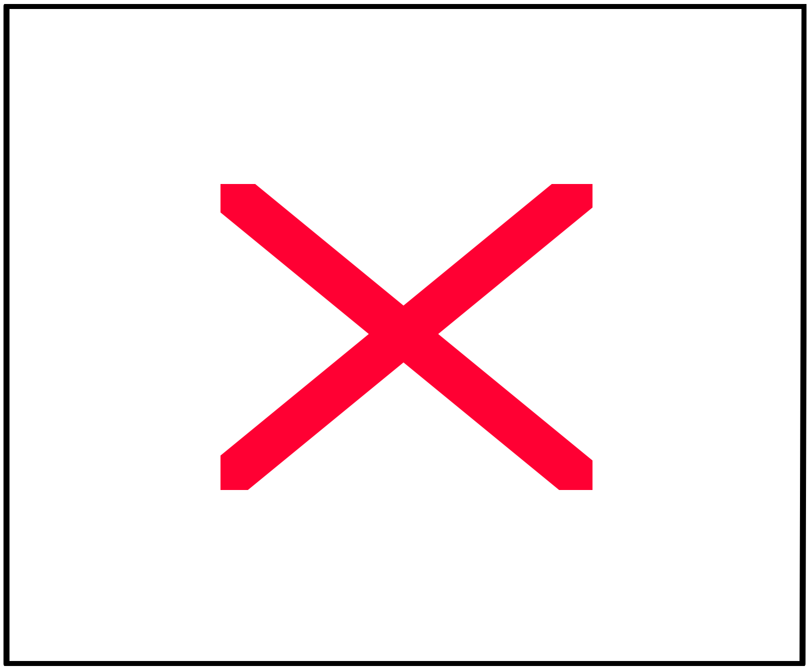

Figure 3. Control of brush along SR 25N with a mixture of 5 gallons Garlon 3A, 6 lb ammonium nitrate and 0.5 gallons X-77 wetting agent in 250 gallons of water applied at a rate of 25 gal/A on September 10, 1997 to avoid “brown out”. Photographed August 4, 1998.

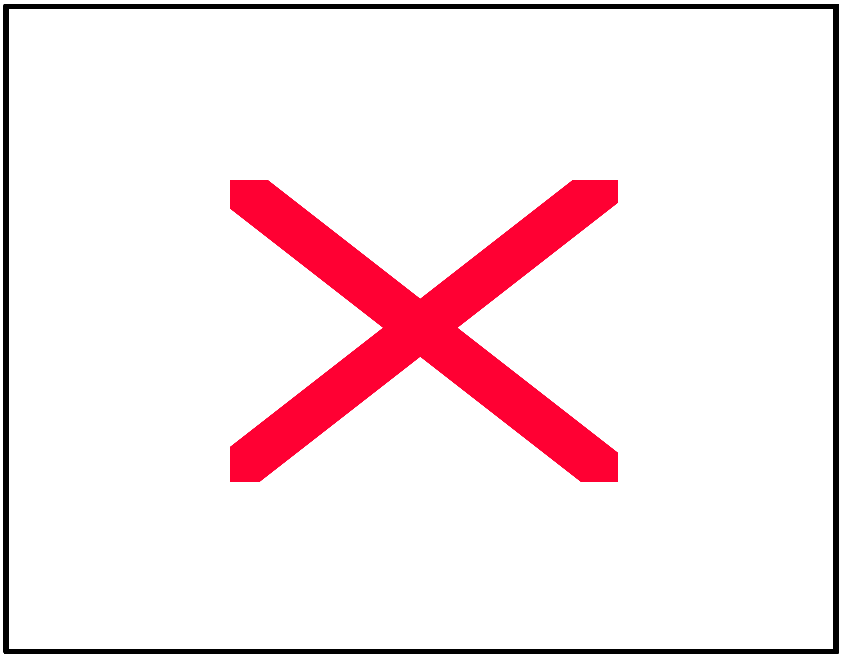

Figure 4. Control of willow in a ditch with 3 lb/A Garlon 4 plus 1.5 lb/A ammonium nitrate on September 29, 1997 (Expt. 97-94). Photographed July 15, 1998.

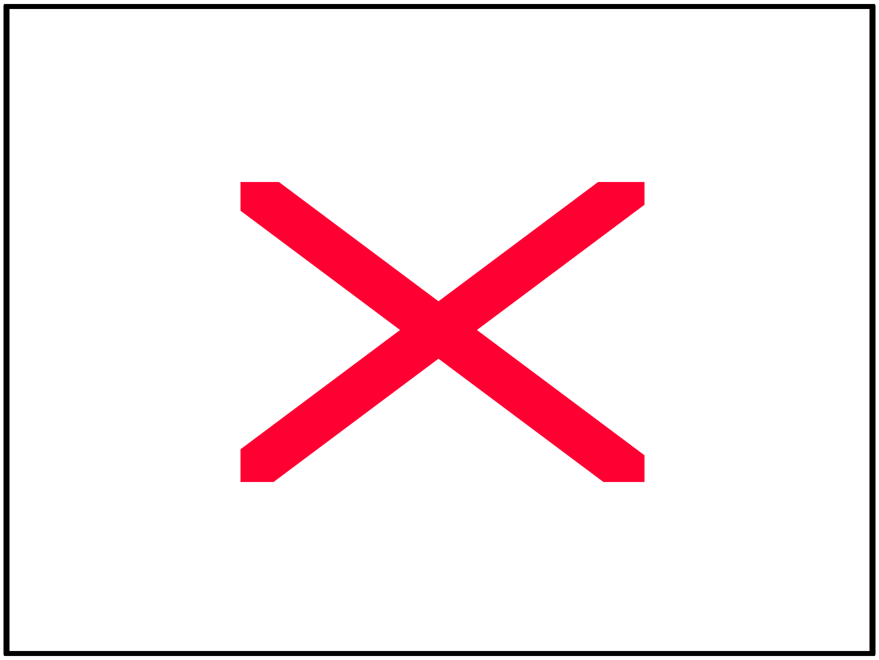

Figure 5. Smooth brome after formation of seed heads (back). Seed heads were prevented (foreground) by treatment with 3 lb/A Garlon 4 plus 1 lb/A ammonium nitrate plus 0.05 lb/A additive TR-3.

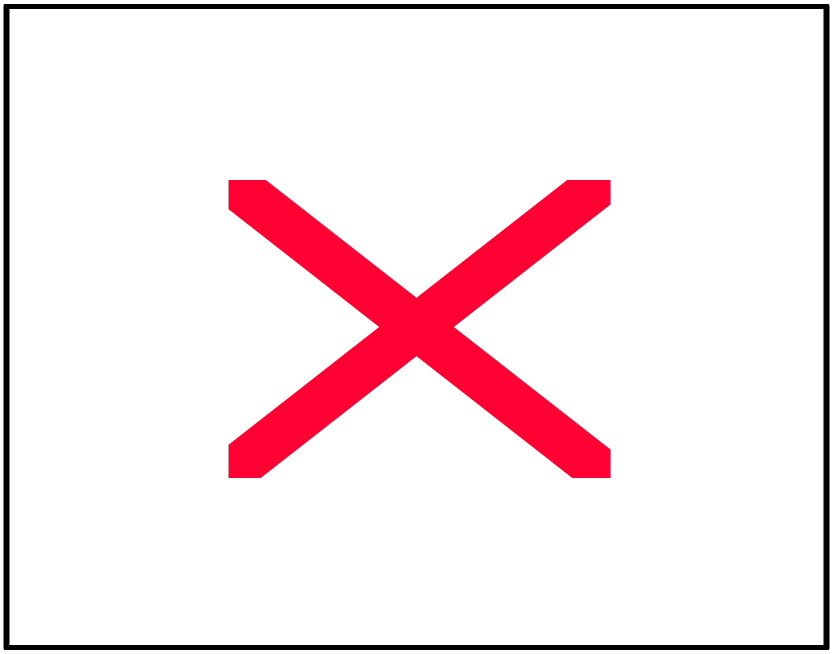

Figure 6. Milkweed (Expt. 95-82). Area treated with 3 lb/A Garlon 4 plus 1.5 lb/A ammonium nitrate plus 0.3 lb/A additive TR-III on August 28, 1995 is in the foreground. Surviving milkweed were mostly short (1-1.5 ft tall) and did not flower or fruit. Untreated area is in the background. Photographed Jul 22, 1996.

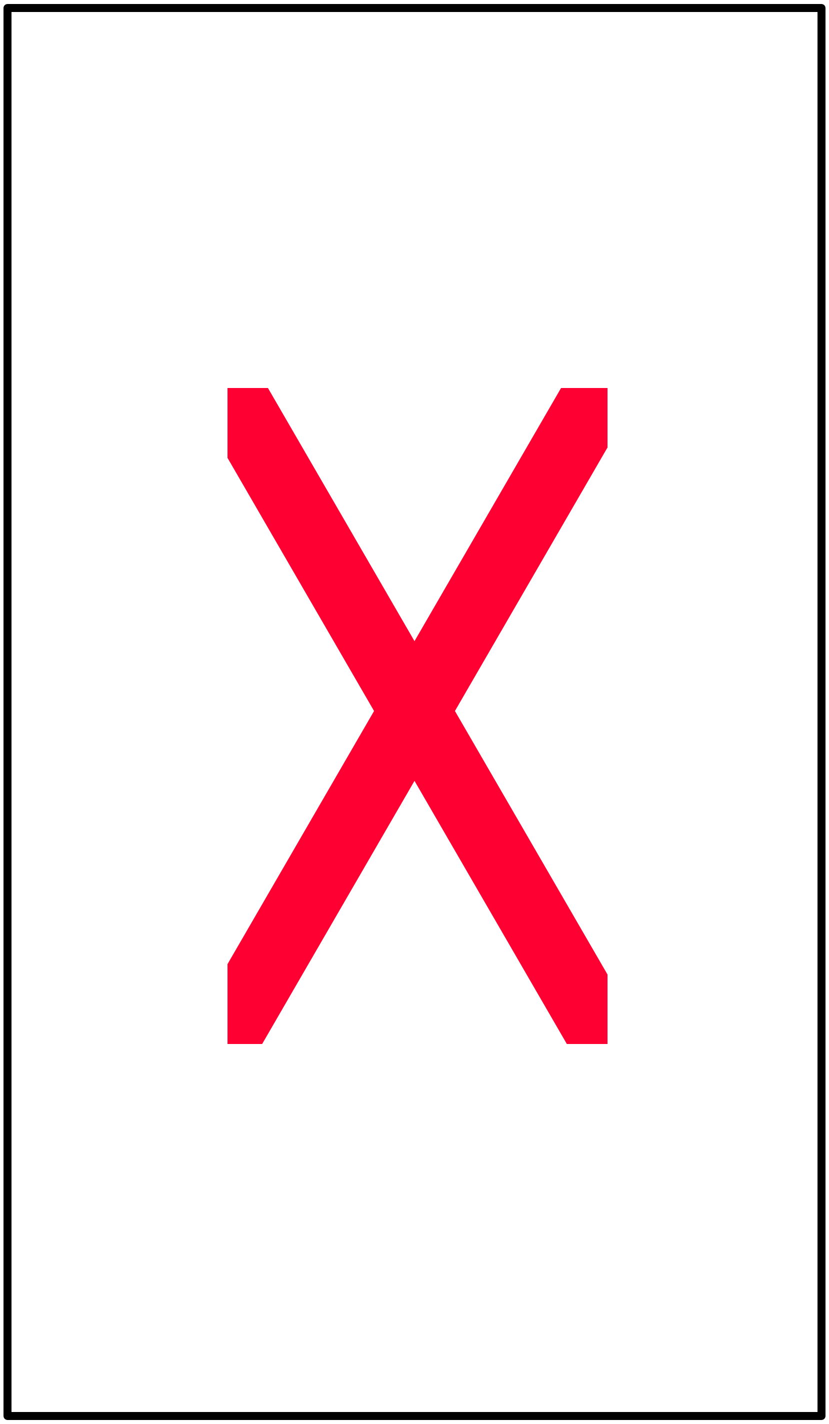

Figure 7. Field bindweed (Expt. 96-118). Upper - Control plot. Lower - Plot treated with 3 lb/A Garlon 4 plus 1 lb/A ammonium nitrate plus 0.05 lb/A TR-III additive on October 18, 1996. Photographed July 16, 1997.

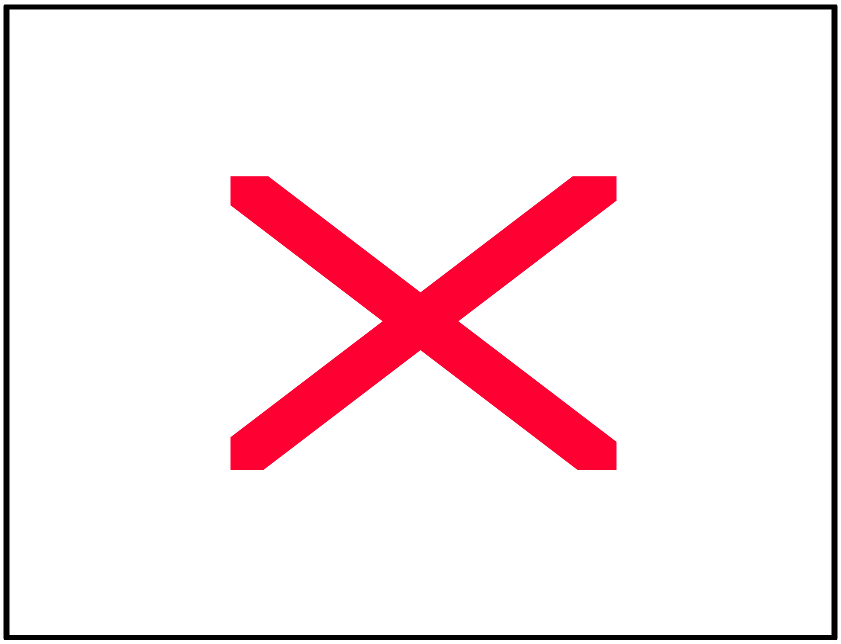

Figure 8. Canadian thistle invading roadside from adjacent corn field. Plants are in late flower. Photographed July 28, 1998.

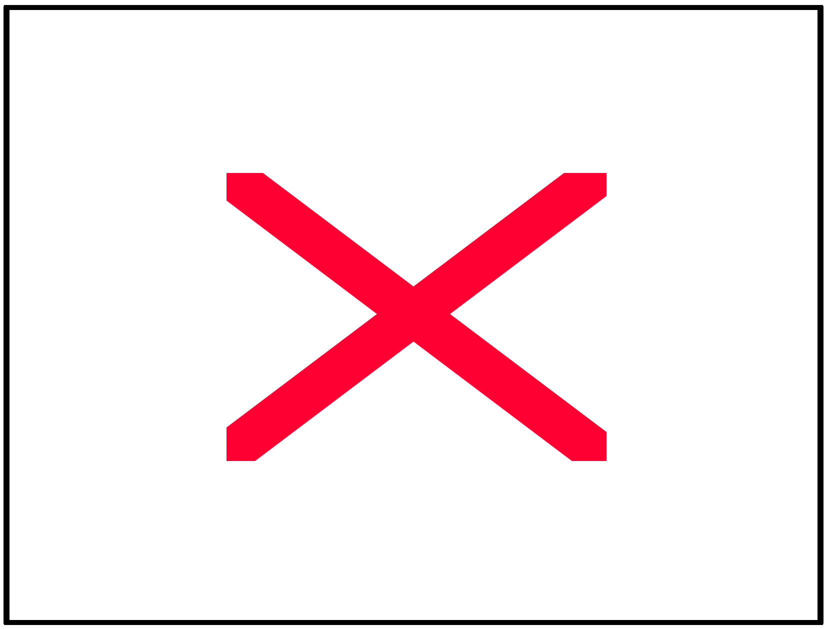

Figure 9. Canadian thistle regrowth. Photographed September 26, 1997 (Expt. 97-84).

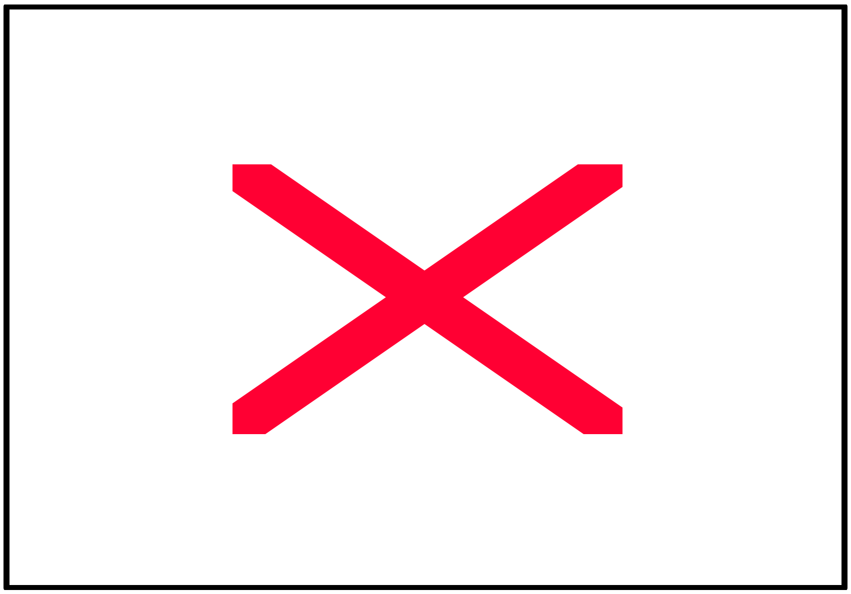

Figure 10. Soybean plants in the greenhouse. 0.005 lb/A clopyralid (two pots on left) and 0.005 lb/A clopyralid plus 0.05 lb/A cysteine (two pots on right. Photographed one week after spraying.

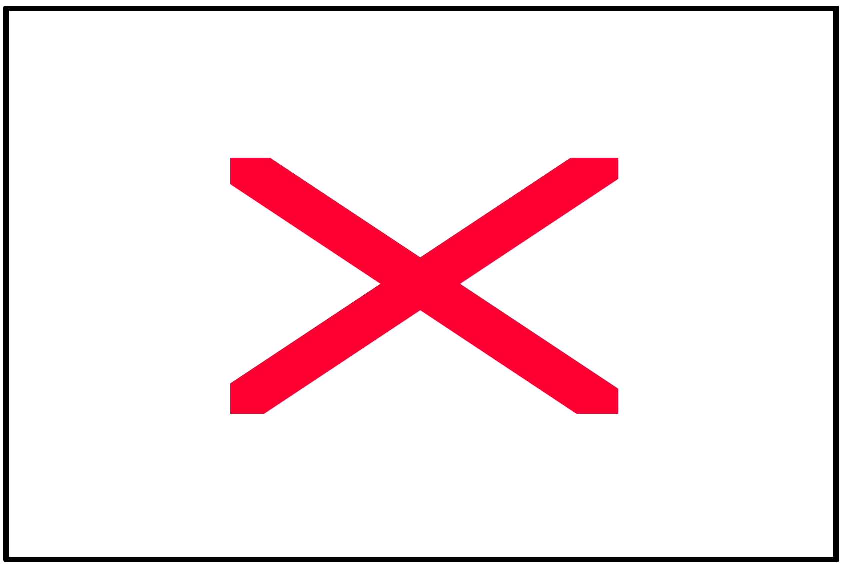

Figure 11. Soybean plants in the greenhouse treated with 0.001 lb/A clopyralid (two pots on left) or 0.001 lb/A clopyralid plus 0.05 lb/A cysteine (two pots on right). Photographed one week after spraying.

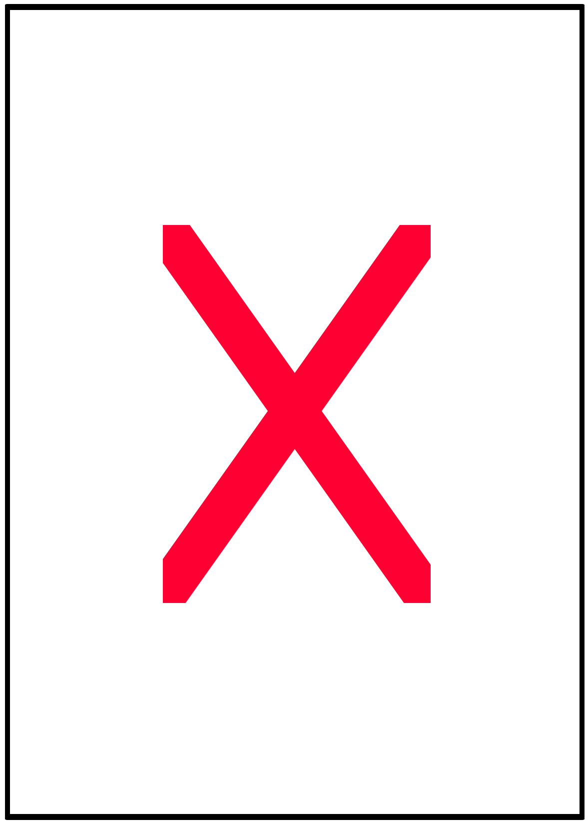

Figure 12. Soybean plants treated with clopyralid ± cysteine. Plants were grown in the greenhouse and pictured 4 weeks after treatment with 0.005 lb/A of clopyralid alone on the left and 0.005 lb/A of clopyralid plus 0.05 lb/A cysteine on the right.