# A MINIMUM-COST, ENVIRONMENTALLY SAFE PROGRAM OF HERBICIDE MAINTENANCE FOR INDIANA ROADSIDES

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The purpose of this study was to design a minimum-cost maintenance program for control of vegetation along Indiana roadsides. Mechanical and chemical methods were combined to maintain healthy turf at low cost. A 3-year (environmentally safe) spraying rotation in combination with mowing was recommended and implemented. It provides a maximum-benefit, low-cost maintenance program for the state with cost savings in excess of $200,000 annually.

•WITH the development of the Interstate System, the management of turfed roadsides is an increasingly important function of highway departments. Divided lanes, median strips, and broad rights-of-way are an integral part of the modern highway, and the management of turfed roadsides is no longer a minor consideration of roadside maintenance. Healthy roadside turf prevents soil erosion, protects adjacent cropland from invading weeds, and provides features of beauty, safety, and convenience.

Rights-of-way are designed for safety and convenience. They must be maintained if the safety and convenience features are to be preserved.

What happens when roadsides are not maintained in a turfed or semiturfed condition? Even with careful landscaping and restricted mowing, areas that are not maintained revert to native vegetation. Tall weeds and wild grass kill turf by shading, only to die back during the winter to leave patches of bare soil open to erosion (Figure 1). In as little as 1 year, tree seedlings and root sprouts may become established on unmaintained rights-of-way. After a number of years, these sprouts become brush and eventually trees. Brush obscures vision, adding a hazardous condition to an otherwise safe highway. If sight distances are reduced by vegetation below minimum specifications, the state is liable to litigation in the case of accidents. Trees immediately adjacent to a major highway present an obvious safety hazard. Such trees and brush must be removed at considerable expense and the turf reestablished to prevent additional erosion. The costs of tree and brush removal and reestablishment of turf exceed the costs of modest annual maintenance programs.

Turf stabilizes the soil and prevents erosion. Sediment from soil erosion is the major pollutant of Midwestern waterways; the problem would only increase in severity if roadside rights-of-way were not maintained.

Along the Interstate System and major state highways in Indiana and throughout most of the Midwest, the roadsides are already turfed, principally bluegrass, and mostly free of trees between the edge of the shoulder and the fence-line (Figure 2) except for steep banks and certain scenic areas. The soil is mostly of high fertility, and much of the roadside borders on cultivated agricultural land of high productivity. Of major concern in protecting both the established roadside turf and the adjacent cropland is the control of weeds and brush. The control methods must be effective, inexpensive, and not deleterious to either the environment or adjacent crops.

The program recommended and implemented for the State of Indiana involves combined herbicide and mowing treatments. Environmental and crop safety are ensured by use of nontoxic amine formulations of herbicides and late-fall and early-spring ap-

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Figure 1. Unsprayed section of I-69 near the Indiana-Michigan border. Tall weeds and grass have smothered out the turf leaving patches of bare soil subject to erosion. Photographed June 2, 1973.

Figure 2. Sprayed section of I-69 near the Indiana-Michigan border. This portion received the fall-spring 2,4-D application cycle in the 1972-73 season as described in Table 1. The roadside is essentially weed-free. Photographed June 2, 1973.

Figure 3. Unsprayed median of I-69 near the Indiana-Michigan border. Numerous weeds are seen in the foreground. Photographed June 2, 1973.

plications. Effectiveness and low cost are provided by a 3-year rotation in combination with reduced mowing.

## EFFECT OF FALL APPLICATION

Applications of herbicides in the fall prevent growth of weeds the following spring and summer and provide maximum safety to the environment. Implementation of results obtained under the Joint Highway Research Project at Purdue University (1) established the effectiveness of fall applications of herbicides to control problem weeds along roadsides (Figures 1-4). Applications are made from September 1 until the first killing frost (Table 1).

As the first killing frost approaches, hard-to-kill perennial weeds move all available materials into the underground parts of the plants. Herbicides applied at this time reach the underground plant parts through translocation activity when these parts are most susceptible to the killing action of the herbicide (1, 2). Dandelion, plantain, buckhorn, creeping charlie, milkweeds, Canadian thistle, dock, and other problem roadside perennials are among the weeds susceptible to fall applications of herbicides.

Plants with a biennial growth habit are also controlled by fall applications of herbicides. Wild parsnip and wild carrot are examples of especially troublesome roadside weeds with biennial growth habits. Plants germinate in the spring and summer to overwinter as small plants with a whorl of leaves about grass height in mowed turf. The following spring, the plants produce a flowering stalk up to 5 ft high that is unsightly, obstructs vision, kills turf by shading, and produces abundant seed to ensure reinfestation. Herbicide applications in spring or summer are ineffective in killing the plants or even in preventing production of viable seed because the plants grow rapidly in early spring. They are frequently in full flower by May 15. Fall applications of herbicide give complete control of these weeds for up to 3 years (Figure 6), whereas spring applications of twice the amount of herbicide do not provide even single-season control.

Winter annuals are a third category of weeds controlled by fall applications of herbicides. Winter annuals germinate in the fall, enter a rosette stage in which they overwinter, and flower in early spring. Examples include henbit, shepherd's purse, yellow rocket, and most of the wild mustards. These plants are killed in the fall as they germinate through pre-emergence action of the herbicides.

The only category of plants that escapes a fall application of herbicide is the summer annuals such as pigweed, ragweed, lambsquarter, and velvet leaf. These plants are common weeds of croplands but seldom invade healthy turf. They are encountered only infrequently along Indiana's roadsides.

An important advantage of fall applications of herbicides is that of environmental safety. In the fall, desirable plants in cropland or gardens and shrubs and flowers in lawns, golf courses, or recreational areas and in roadside plantings and forests are dying, dead, or dormant. Trees and shrubs are losing their leaves and, unlike the plants to be controlled, escape the herbicide. Problems of drift onto soybean or tomato fields are eliminated because the growing season is over. By the following spring, soil residues are completely dissipated, especially with the biodegradable herbicides such as 2,4-D.

## AMINE FORM RECOMMENDED

Only nontoxic 2,4-D amine formulations of herbicide are recommended. The environmental safety of various roadside herbicides was evaluated in laboratory, greenhouse, and field investigations (1, 3, 4). The potential hazard of pure 2,4-D to fish or algae from terrestrial runoff water (concentrations of 0.1 ppm or less) or direct or accidental contamination (3 lb/acre applied directly to 6 in. of water) is nil. Studies with formulated materials, however, showed that 2,4-D ester derivatives are substantially more toxic than the parent acid; fish and phytoplankton kills result at the 3 lb/acre rate applied directly to water.

In June 1971, a recommendation was made to the Indiana State Highway Commission that only nontoxic amine and salt formulations of 2,4-D be used for roadside spraying and that use of toxic ester formulations be discontinued. The recommendation was

Figure 4. Sprayed median of I-69 near the Indiana-Michigan border. This portion received the fall-spring 2,4-D application cycle in the 1972-73 season as described in Table 1. The area is essentially weed-free. Photographed June 2, 1973.

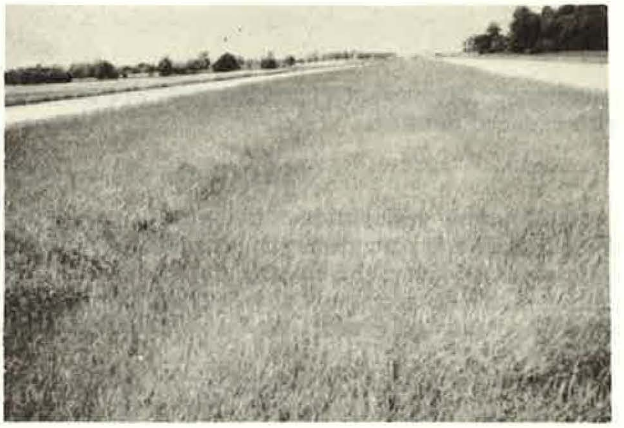


Table 1. Program of alternating fall and spring applications of herbicide implemented in the spraying-by-contract program for Indiana.

Material: 2,4-D amine form concentrate containing at least 4 pounds of acid equivalent per gallon. Ester formulations of 2,4-D are not used due to possible environmental hazards.

Rate: Material is mixed at the rate of 2 gallons of 2,4-D concentrate to 100 gallons of water. The mixture is applied at the rate of 40 gallons per acre.

Schedule of application:

Fall: September 1 to first killing frost.

Spring: March 15 to April 30.

Table 2. Control of perennial weed species by fall applications of 2,4-D.

| | Plants/100 ft² | |
|---|---|---|
| Weed Species | Control | 2,4-D |
| Dandelion | 588 | 71 |
| Plantain | 155 | 3 |
| Wild parsnip | 211 | 0 |
| Curled dock | 19 | 0 |

Note: The 2,4-D was applied (2.7 lb/acre) using conventional truck-mounted equipment by a contractual herbicide applicator on October 4, 1971; evaluations were December 4, 1971.

Figure 5. Portion of US-421 north of Lafayette, Indiana, in White County. The right side of the road received a single fall application of experimental formulation M-3766 (3 parts picloram and 1 part 2,4-D) at a rate of 2 lb active ingredient per acre. The left side of the road was unsprayed. Photographed in the spring following application.

Figure 6. Wild parsnip plots on July 25, 1972, approximately 2 years after treatment with a mixture of ¾ lb per acre of picloram plus ¼ lb per acre of 2,4-D. The unsprayed area on the left shows numerous plants of wild parsnip 4 to 5 ft high that have matured and produced seed. The treated area on the right is free of weeds.

accepted and, beginning in the fall of 1971, use of 2,4-D has been restricted to amine formulations.

## 3-YEAR SPRAYING PLAN

A 3-year spraying rotation minimizes costs and maximizes effectiveness. In 1971, approximately 1,500 linear miles of highway received a fall application of 2,4-D between September 15 and October 15 under the spraying program by contract. Evaluations of test plots throughout the state showed the treatment to be extremely effective, with weed control 2 months after treatment ranging from 85 percent to over 95 percent (Table 2). The fall application was followed by a second application in early spring (Table 1). The spring application was to control seedlings and new growth that escaped the fall application. It, too, was effective and environmentally safe. The spring application was scheduled early enough to avoid crops and at a time when most trees and shrubs were still in a dormant or near-dormant condition. The combined spring and fall applications were sufficiently effective to eliminate all midsummer chemical treatments (Figures 1-4). This was advantageous from an environmental standpoint because the midsummer treatments were those most likely to cause injury to nontarget vegetation. The direct cost saving to the state from the Herbicide Treatment Program by Contract alone was an estimated $60,000 annually. This figure is based on the difference in cost between the standard 3 applications of herbicide in spring and midsummer used prior to 1971 and the 3-year rotation implemented in 1971. Not included are benefits from increased weed control, safety, or reduced mowing costs.

The concept of a 3-year rotation stemmed from data summarized in Figure 7. These data are from the 1971 spraying program 1 year after spraying. The lower curve represents roads that had been sprayed in previous years and contained mostly resistant species. The upper curve represents roads that had not been sprayed recently and contained mostly species susceptible to 2,4-D.

A pattern of weed control emerged as follows: The optimum weed density for maximum effectiveness was about 150,000 weeds per acre. With this weed density, control approached 90 percent on roads not previously sprayed. As the weed density decreased or increased from this value, effectiveness of weed control decreased. With roads having 25,000 weeds per acre or less, treatment effectiveness ranged from 0 to 30 percent. These roads were not "weedy" to begin with, contained mostly species resistant to 2,4-D, and should never have been sprayed in a contract program.

Based on these data and results from experimental plots, a 3-year spraying rotation was established for the entire state. The roads were divided into 3 groups of about 4,000 linear miles (24,000 acres) each. Group A was the Interstate System. Groups B and C were composed of roads of the state highway system. Roads of group A received a fall-spring 2,4-D cycle in 1972-73 (Figures 2 and 4). Roads of group B received a fall-spring cycle in 1973-74, and roads of group C will receive a fall-spring cycle in 1974-75. In the fall of 1975, the cycle will be repeated beginning with roads in group A. The program is computerized to reduce administrative costs. Marion Bugh, Landscape Supervisor of the Indiana Highway Commission, and his staff did an excellent job in setting up the contracts so that each year approximately one-third of the state is sprayed, with maximum efficiency for both the state and the individual contractors.

We anticipate that by the fall of 1975 roads in group A will have weed densities in the range of 75,000 to 150,000 weeds per acre so that the cycle will be repeated. One year after spraying, the weed density is about 15,000 weeds per acre. To spray these roads then would be a waste of time and money. Two years after spraying, we forecast the weed density to be 30,000 to 50,000 weeds per acre. At best, we could expect 50 percent control to reduce the population back to 15,000 weeds per acre. By 3 years, when the weed population has again reached the level of 75,000 to 150,000 weeds per acre, the roads will be resprayed.

## OTHER HERBICIDE MIXTURES

Some experimental herbicide mixtures give a weed-free turf for 3 years following a single fall application. What about 2,4-D-resistant weed species? Will they eventually

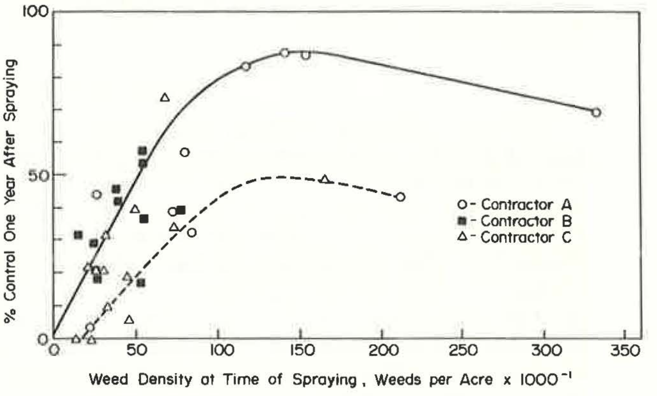



**Figure 7.** Relationship between weed density in thousands of plants per acre and percent total weed kill for the fall-spring 2,4-D application cycle described in Table 1. The upper solid curve is for roads previously unsprayed, which contained mostly 2,4-D susceptible species. The lower dotted curve is for roads that had been sprayed within the past 2 years and contained mostly 2,4-D resistant species. Each point represents data from a different highway within a single district. The different symbols show results from the commercial applicators involved in the 1971-72 spraying program. Evaluations were in late August, September, and early October 1972, 1 year following the fall application.

**Figure 8.** Appearance of test plots in a 3-year evaluation prior to spraying in early August 1970. Wild carrot was especially abundant and unsightly.

**Figure 9.** Same test area as shown in Figure 1 photographed in July 1972, approximately 2 years after spraying with varying rates of the picloram-2, 4-D combination herbicide. Even though the area was recently mowed, growth of wild carrot, buckhorn plantain, and other weeds was evident in the control plot in the foreground. The treated plots remained free of weeds.

increase to the point that 2,4-D spraying becomes ineffective? We do not have answers to these questions but are exploring new and more potent herbicide mixtures for use along Indiana roadsides if and when they are needed. By using more potent herbicides, we have maintained turf in a nearly weed-free condition for at least 3 years following a single fall application (Figures 8-10) with no injury to grass or trees. Therefore, only 1 application every 3 years is required. Even the spring application is eliminated, an additional cost-saving feature.

One of these herbicide mixtures, currently under intensive investigation, consists of a combination of 3 parts of picloram (trade name Tordon) and 1 part of 2,4-D, plus an agent to control drift. The picloram-2,4-D combination is a potent herbicide for control of a wide range of broad-leaved herbaceous and woody roadside vegetation. Difficult-to-control perennial species such as common milkweed and Canadian thistle are especially susceptible to picloram. A significant portion of the picloram necessary for control of these species is replaced by the less-expensive phenoxy herbicides such as 2,4-D without reducing the overall effectiveness of the treatment (1, 2).

With the objective of testing the possibility of a 3-year spraying rotation in which 1 herbicide treatment would keep the roadsides free of weeds for the entire 3-year period, plots were established in the falls of 1970, 1971, 1972, and 1973 to evaluate the lasting effectiveness of combination treatments and in 1972 and 1973 to evaluate environmental safety. Triplicate plots were sprayed at rates of ½, 1, 1½, and 2 lb/acre (up to 6 lb/acre in the environmental tests) in mid-August to early October. All species were 90 to 100 percent controlled the first season by applications at rates of 1 lb/acre or greater (Tables 3 and 4). Evaluations 1 and 2 years later indicated lasting control for most species except a few summer annuals such as nodding spurge that germinate from seed in early summer and are not especially objectionable. For all practical purposes, the sprayed plots were still weed-free (Figures 9 and 10) at the 2 lb/acre rate 3 years after spraying for the experiment begun in 1970.

In the 1972 study, the environmental safety of picloram was evaluated. Based on extensive laboratory, greenhouse, and field testing (1, 2, 3, 4), a 3:1 ratio of picloram plus 2,4-D was selected for initial evaluation under roadside conditions at a rate of 1 lb/acre of total herbicide (¾ lb picloram plus ¼ lb 2,4-D amine). The application, in early October, used truck-mounted equipment supplied by Chemitrol, Indianapolis. The formulation, designated M-3766, was provided by Dow Chemical Company, Midland, Michigan, according to our specifications. It contained 1½ lb active ingredient picloram plus ½ lb active ingredient 2,4-D per gallon as the triisopropanolamine salts. Applications were at rates of ½, 1, 2, and 6 lb active ingredient per acre. Endrift, a commercially available drift-reducing agent manufactured by Nalco Chemical Company, was included at the rate of 1 quart per 100 gallons of spray in all applications. Drift tests showed a 40 to 50 percent reduction in the amount of herbicide reaching nontarget areas using this material. Included in the test were roadside plantings, ornamental plantings, hardwood forest, conifers, a flowing stream, and cropland. Species composition was determined and soil and water samples were collected prior to and after spraying. At 1 lb/acre, M-3766 gave 90+ percent control of all weed species (Table 4; Figure 5).

Using a sensitive biological assay procedure developed under this project, testing of water samples collected from the stream running through one of the test sites revealed no detectable herbicide entering the water from drift at the time of spraying. Tests of soil samples showed that the herbicide remained on the target area except for 1 situation at the 6 lb/acre rate where the sprayed roadside was higher than the adjacent field and where the drainage ditch channeled soil and water from approximately 1 mile of road directly into 1 spot of the field. Here, herbicide entered the field and caused slight injury to soybeans. Examination of roadside plantings, native vegetation, and fruit trees in an orchard adjacent to the sprayed roadside revealed no damage to species not oversprayed directly.

A similar test, although not as extensive, was established in the spring of 1973, with M-3766 applied at a rate of 2 lb/acre. In this test, basswood trees adjacent to the sprayed roadside were killed. Other tree species showed only minor injury symptoms, including those in which root systems were directly oversprayed, and all survived. In

**Table 3. Effectiveness of fall application of picloram plus 2,4-D mixtures on control of roadside weeds in the season following application.**

| Weed Species | Control | Rate of Application of Total Herbicide Mixture | | | |
|---|---|---|---|---|---|
| | | ½ lb/acre | 1 lb/acre | 1½ lb/acre | 2 lb/acre |
| Wild carrot | 16 | 2 | 0 | 0 | 0 |
| Buckhorn plantain | 119 | 1 | 0 | 0 | 0 |
| Rough cinquefoil | 6 | 0 | 0 | 0 | 0 |
| Common milkweed | 3 | 0 | 0 | 0 | 0 |
| Wild parsnip | 1 | 0 | 0 | 0 | 0 |
| Broadleaf plantain | 8 | 0 | 0 | 0 | 0 |
| Whorled milkweed | 3 | 0 | 0 | 0 | 0 |
| Black medic | 12 | 0 | 0 | 0 | 0 |
| White clover | 10 | 0 | 0 | 0 | 0 |
| Yellow woodsorrel | 5 | 0 | 0 | 0 | 0 |
| Nodding spurge | 29 | 9 | 15 | 9 | 9 |
| Composite family (goldenrod, asters, etc.) | 6 | 0 | 0 | 0 | 0 |

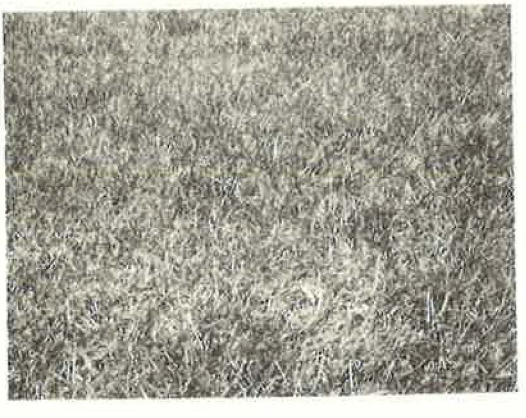
Note: Treatments (3 parts picloram, 1 part 2,4-D) were applied in mid-August 1970 and counts were taken October 7, 1971. Data are given in plants per 100 ft$^2$.

**Table 4. Effectiveness of fall application of picloram plus 2,4-D mixture on control of roadside weeds.**

| Weed Species | Control | Rate of Application | | |
|---|---|---|---|---|
| | | ½ lb/acre | 1 lb/acre | 2 lb/acre |
| Plantain | 19,575 | 0 | 0 | 0 |
| Dandelion | 8,260 | 435 | 210 | 0 |
| Wild carrot | 6,520 | 0 | 0 | 0 |
| Clovers | 3,480 | 0 | 0 | 0 |
| Curled dock | 960 | 0 | 0 | 0 |
| Common thistle | 1,300 | 135 | 95 | 0 |
| Other composites | 4,350 | 0 | 0 | 0 |
| Other weeds | 6,000 | 450 | 0 | 0 |

Note: Treatments (3 parts picloram plus 1 part 2,4-D) were applied in early October 1972 with commercial truck-mounted equipment and counts were taken in May 1973. Data are given in plants per acre.

**Figure 10. Close-up view of the treated area from tests described in Figures 8 and 9 photographed in July 1973, approximately 3 years after spraying. The plots remained free of weeds for a minimum of 3 years following the single application of herbicide.**



spite of heavy rains, soil movement of no more than 3 ft was experienced. However, picloram will not be recommended for use in spring or summer applications for general roadside weed control because of possible crop injury.

Picloram, which has a mode of action similar to that of 2,4-D (5), has proved nontoxic in pure form (3, 4). Laboratory tests of the formulated material are nearing completion and show no injury to fish or algae that might result from normal use practices.

A third herbicide combination involving dicamba (Banvel) plus 2,4-D also looks promising in preliminary tests to control 2,4-D-resistant species. This material is not as effective as the picloram plus 2,4-D combination but is expected to provide an even greater margin of environmental safety.

## BENEFIT FROM REDUCED MOWING COSTS

Effective programs of herbicide treatment reduce the number of required roadside mowings. With the weed control provided by the 3-year rotation (with either 2,4-D amine alone or with the more potent mixtures), 3-cycle mowing (once in late spring, once in midsummer, and once in late summer or early fall) is sufficient. The reduction in the number of mowing cycles (from 4 or 5 to 3) produces an additional $100,000 annual cost saving to the program (based on figures provided by Marion Bugh).

Further reductions in mowing cycles (less than 3) may not be feasible. One-cycle mowing, or even 2-cycle mowing, if scheduled early, leaves too much growth in the fall for effective applications of herbicides. If scheduled later, the tall grass that is mowed and not raked smothers the underlying sod. Large bare spots subject to erosion are the result. It may prove more advantageous to not mow at all than to mow only once or twice.

## CONCLUSION

In summary, rights-of-way are designed for safety and convenience. They should be kept as corridors of open turfed areas to provide the features of safety, beauty, and convenience for which they were intended. To maintain a healthy turf, maintenance of these areas by mechanical and chemical methods must continue. Our findings show new ways of providing such maintenance at low cost to the state and minimum danger to the environment.

## ACKNOWLEDGMENT

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