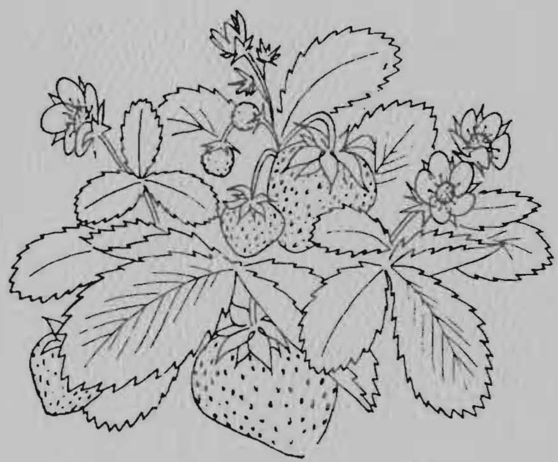
Weed Control in Annual Strawberries Grown with Plastic Mulch:
Efficacy, Phytotoxicity, And Soil Persistence Studies

By

Martha Farris and Jeffery S. Conn



Agricultural and Forestry Experiment Station
School of Agriculture and Land Resources Management
University of Alaska-Fairbanks
James V. Drew, Dean and Director

Bulletin 75 October 1987

Weed Control in Annual Strawberries Grown with Plastic Mulch:
Efficacy, Phytotoxicity, And Soil Persistence Studies

Martha Farris* and Jeffery S. Conn**

Introduction

Cool soil temperatures in Alaska are a limiting factor for many crops. Clear plastic mulch has been shown to increase soil temperatures, and use of this mulch has allowed the production of many warm season crops, such as corn, tomatoes, cucumbers, and squash, farther north than they could otherwise be grown (Hill et al. 1982; Dinkel 1966, 1973). Clear plastic mulch and row covers are used in interior Alaska to promote early growth and increase yields of strawberries. Two varieties of day-neutral, everbearing strawberries, 'Hecker' and 'Quinault', have demonstrated high yields when grown in this system as annuals; i.e., the crop is planted and harvested in one growing season.

When clear plastic is used as a mulch, the transmission of light through the plastic allows weeds to grow. Since hand weeding through the plastic is not economically feasible, some form of weed control is required. Seven herbicides are now cleared for use with strawberries: dinoseb, diphenamid, chloroxuron, napropamide, DCPA, simazine, and terbacil[1]. In the forty-eight contiguous states, these herbicides are generally applied to unmulched

[1]Trade names, respectively: Premerge® (Dow Chemical Co.), Enide® (Upjohn Co.), Tenoran® (Ciba Geigy Corp.), Devrinol® (Stauffer Chemical Co.), Dacthal® (Diamond Shamrock Corp.), Princep® (Ciba Geigy Corp.), Sinbar® (Dupont Co.).

***Agricultural Assistant, Agricultural and Forestry Experiment Station, University of Alaska-Fairbanks.**
****Research Agronomist, USDA-Agriculture Research Service, University of Alaska-Fairbanks.**

strawberry plants grown in matted rows or spaced beds in a perennial system. The chemicals are usually applied in the spring or fall when the strawberry plants are dormant but the weeds are beginning to grow (Putman and Hancock 1982, Ahrens 1982, Weller 1984, Albregts and Howard 1981). The effects of the herbicides when used with different planting methods are unknown. Two of the herbicides, diphenamid and napropamide, are root growth inhibitors and could potentially cause injury to newly planted actively growing plants. Simazine and terbacil have been known to cause injury to strawberries (Robinson 1965, Weller 1984). Since the technique of growing strawberries as annuals with clear plastic mulch and row covers is unique, an experiment was designed to determine the effects of the herbicides on the production of strawberries as annuals.

The differential tolerance of plants to herbicides is the basis of the selective action of these chemicals (Anderson 1983), and this selectivity may be increased by the use of materials that inactivate the herbicide in such localized areas as the immediate vicinity of crop roots. The recommendations developed previously for strawberry production at the Fairbanks Agricultural and Forestry Experimental Station include the application of an herbicide, followed by placement of the mulch and row cover immediately after the herbicide has dried. Plants are then planted through the mulch layer of plastic. Because herbicides may cause injury or reduce yields in strawberries, nontreated potting soil is used to fill around the transplants to avoid contact between the herbicide-treated soil and the roots of the plant. This potting soil or other amendment may act to reduce herbicide contact with the plant, thereby increasing selectivity. However, use of potting soil on a large scale during strawberry planting is expensive, time consuming, and difficult. Activated charcoal is the compound most widely used to inactivate herbicides and prevent injury to sensitive crops (Hance 1980). The charcoal absorbs the herbicide on and around the plant roots, thus preventing uptake of the herbicide by the plant (Kratky et al. 1970). Since the treatment of strawberry roots with charcoal may be less expensive, an experiment was conducted to compare the relative effectiveness of potting soil and charcoal in preventing injury to the strawberry transplant.

A final area of interest was the persistence in soil of the herbicides that could be used in the strawberry-plastic mulch systems. Herbicide-soil interactions are complex and are influenced by site and weather conditions so specific persistence rates vary with location and season (Hance 1980). Persistence is affected by concentration and rate of herbicide application, soil type, soil moisture, temperature, photodecomposition, and microbial decomposition (Klingman et al. 1972). Soil moisture and soil temperature directly influence microbial decomposition and chemical breakdown of herbicides; researchers consistently report greater persistence in cooler, drier northern regions (Hance 1980, Klingman et al. 1972, Smith 1982, Smith and Hayden 1976, Pritchard and Stobbe 1980). Herbicides are known to persist longer under Alaskan conditions than under more temperate conditions. When trifluralin was used in the Fairbanks and Delta areas, 25-51 percent of the amount applied in the spring remained in the soil at the end of the growing season, compared to 10-23 percent remaining in Saskatchewan soils (Conn and Knight 1984). Picloram, applied in Alaska, has also been shown to persist in quantities great enough to cause substantial plant damage (Burgoyne 1981). Herbicide residues in soil are measured by either physiochemical or biological tests (Hance 1980). Biological assays are advantageous because they measure the amount of herbicide in the soil that is capable of affecting plant growth, rather than total residues (Eberle and Gerber 1976).

Materials and Methods

All studies were carried out at the Agricultural and Forestry Experiment Station Fairbanks Research Farm. The soil was Tanana silt loam (nonacid pergelic cryaquept) with pH 7.0 and 4.1 percent organic matter. All field herbicide applications were made with a backpack plot sprayer using CO_2 as a propellent.

1983 Field Experiment

The effects of clear and black plastic mulches on weed control, and the phytoxicity and persistence of herbicides used with the clear mulch, were studied in 1983 using a completely randomized block statistical design. Each block consisted of the following treatments: chloroxuron = N'-[4-(4-chlorophenoxy) phenyl]-N, N-dimethylurea; dinoseb = 2-(1-methylpropyl)-4, 6-dinitrophenol; DCPA dimethyl tetrachloroterephthalate; diphenamid = N, N-dimethyl-α-phenyl benzeneacetamide; napropamide = N, N-diethyl-2-(1-naphthalenyloxy) propanamide, simazine = 6-chloro-N,N'-diethyl-1, 3, 5-triazine-2,4-diamine, terbacil = 5-chloro-3-(1-dimethylethyl)-6-methyl-2,4(1H, 3H)-pyrimidinedione, a black plastic treatment with no herbicide, and two clear plastic controls: one weeded by hand and one unweeded. Two strawberry varieties, 'Hecker' and 'Quinault', were used to determine the varietal response to weed control. Plots were 10 ft × 3 ft, separated by a 5 ft. space. There were four replicates laid out in eight rows. On May 18 the plots were fertilized with 69 lb/A nitrogen (as monoammonium phosphate and urea), 136 lb/A phosphate (as monoammonium phosphate), and 121 lb/A potassium (as potassium sulfate); they were then disked and harrowed. Two lines of Chapin twin wall drip irrigation hose were laid over each row and connected to the water source. The plots were sprayed on May 23 using the following rates for each herbicide: dinoseb (5 lb/A), diphenamid (6 lb/A), DCPA (8 lb/A), chloroxuron (4 lb/A), napropamide and simazine (2 lb/A), and terbacil (0.5 lb/A). All herbicides were applied at 30 psi (total spray volume 21.5 gal/A), except terbacil which was applied at 40 psi (total spray volume 25.6 gal/A). After spraying, all herbicides except dinoseb and chloroxuron were incorporated into the top 2 in of soil by raking. A composite sample of weed seeds obtained from screenings at the Plant Material Center in Palmer was applied to the plots with a Cyclone® hand seeder. A commercial mulch-laying machine was then used to lay three sheets of plastic over each row: one 5-ft wide sheet laid on the bottom (the soil mulch) and two 3-ft sheets placed even with each edge of the 5-ft sheet to form a plastic canopy. Soil, 6 in deep, was smoothed over each outer edge of the 3 ft layer, leaving the inside free to form the canopy. Black plastic was taped over the clear mulch layer for the black plastic treatment. Strawberries were planted in the plots on May 25 and 26. Prior to planting, both varieties had been placed in peat in a greenhouse for 2 weeks to leaf out.

Approximately thirty plants per plot were set at 1-ft spacings. A bulb cutter was used to puncture the plastic and remove soil in the root zone. Sterilized potting soil was placed around the strawberry roots to prevent contact between the plant roots and the herbicide-treated soil. The newly planted strawberries were then top-watered. Wire hoops were placed at 3-ft intervals in each row, and the plastic row covers were pulled up over the hoops and fastened with clothespins to form a tunnel over the plants. Plots were irrigated as needed, generally at 1-week intervals, throughout the summer. The row covers remained closed until July 2 and 3, when they were lowered to allow insect pollination of the first flowers. Plots were fertilized weekly with a liquid soluble fertilizer, 20-20-20 (ammonium nitrogen, urea, nitrate, phosphoric acid, and soluble potash), at 109 lb/A from July 2 until July 23. By mid-July the Quinault berries appeared to be smaller than normal and somewhat shriveled. Since the best fertilizer practice for this method of strawberry culture has not been determined (Dinkel 1981), and since in the previous years the experiment station has used a biseasonal application of liquid fertilizer, we decided to discontinue fertilization to avoid any possible adverse effects from excessive rates. Benomyl[2] (methyl 1- [butylcarbamoly]-2-benzimidazole carbamate), a fungicide appropriate for strawberries, was applied twice during the season at 1 lb/A to prevent *Botrytis* sp. Control plots were weeded by hand on June 22 and July 12, and the time required to weed the plots was recorded. Injury ratings were made weekly from the end of May to early July; dead

[2]Trade name: Benlate® (Dupont Co.).

and chlorotic plants were noted. Weed control was assessed on July 8 by measuring percent cover of each particular weed species in a randomly chosen 2.7-ft^2 quadrat in each plot. Strawberry yield was determined through accumulative harvests which began on July 21 and continued at 2- or 3-day intervals until August 16. Rain from mid-August until frost on September 2 prevented further harvest.

1984 Field Experiment

This experiment was repeated in 1984 on different land but in the same manner as in 1983 with the following exceptions. Because the holes cut through the plastic for the strawberry plants allowed weeds to grow, a handweeded black plastic control was included. The bottom layer of clear plastic was removed beneath the black plastic to prevent any possible insulating effects of two layers of plastic. Plots were fertilized, tilled, and harrowed on May 17. Herbicides were applied on May 21, plastic mulches and row covers were laid on May 22, and strawberries were planted on May 23 and 24. Tents were lowered on July 3 and 4. The same liquid soluble fertilizer used in 1983 was applied again in 1984 on August 1 and August 9. Benlate was sprayed at the same rate as in 1983 on July 18 and 25 and August 9. Direct injury was assessed on June 11 and July 12. Weed control, again assessed by measuring percent cover, was estimated on July 13. The control plots were kept free of weeds by hand weeding on June 28 and July 19, and the amount of time taken for weeding was noted. Harvesting in the plots began on July 31 and ended on August 24 because of frost.

Planting Method Study

An additional experiment was conducted to determine the effect of planting method on phytotoxicity of herbicides to strawberries. A completely randomized design was used. The treatments were three planting methods: use of sterilized potting soil to fill in around the roots and planting directly into the herbicide-treated soil with or without a charcoal dip. The seven herbicides (same rates and application parameters as in the efficacy-phytoxicity study) and the two strawberry varieties were tested. Plots were

1 ft by 1.6 ft and contained five plants 1 ft apart. Fertilizer, herbicides, and mulches were applied at the same time as in the main study. Plant roots were dipped into a 10 percent slurry of activated charcoal before planting (Kratky et al. 1970). Two people were timed as they planted to determine the length of time required to plant one plot when using the potting soil or the direct-planting method. Strawberries were planted for both studies at the same time. Mortality of strawberry plants was measured from mid-June until July 1.

Soil Persistence Studies

Persistence of herbicides used with a clear plastic mulch was studied in conjunction with the 1983 field experiment. Soil was collected from the plots from August 27 to 31, 1983. A soil auger was used to collect ten (1 in. diameter) cores 6 in. deep. Untreated soil next to the experimental plots was collected for use in preparing the standard curves, relating herbicide concentration to growth reduction. Samples were held in a freezer at 0 degrees Fahrenheit until February 1984 when bioassay tests were conducted. Bioassay tests were carried out to determine persistence of all herbicides except dinoseb. Degradation rates of this herbicide are known to be rapid with 2 to 4 weeks average persistence of phytotoxicity (Beste 1983). Soils were air dried and screened with a 0.08 in sieve before testing.

Two types of bioassay were used: an oat (*Avena sativa* L. 'Perdeck') root bioassay for napropamide and diphenamid (Horowitz and Hulin 1971), and oat shoot bioassays for DCPA, chloroxuron, terbacil, and simazine (Singh and Campbell 1965, Eberle and Gerber 1976, Marriage 1975, and Marriage et al. 1977).

A dilution series was prepared for each herbicide to determine the effect of herbicide concentration on plant growth. The highest concentration used for each standard curve was the concentration of each herbicide solution initially applied in the field (determined by dividing the amount applied in the spring by the weight of an acre furrow slice). Six serial dilutions were made from this solution. Each dilution was stirred mechanically for 10 minutes and was inverted twenty-five times.

For the oat root bioassay, 2.8 oz of untreated soil were placed in a petri dish. The amount of herbicide solution needed to bring the soil to field capacity (0.88 fl. oz.) was pipetted onto the soil and covered with a filter paper. There were four replicates for each dilution. Five pregerminated oat seeds were placed across the center of the paper and the dishes were covered and sealed with parafilm. They were placed in a growth chamber at 77 degrees Fahrenheit without light. After 48 hours, dishes were removed and the length of the primary root was measured.

For the oat shoot test, .035 fl. oz. of a particular dilution was pipetted onto 1 lb of soil. The soil was placed in a jar on a rotary mixer for 10 minutes; the jar was then inverted and returned to the rotary mixer for another 10 minutes. For the shoot bioassays, 0.22 lb. of this soil were placed in plastic water-tight pots. The oat variety, 'Perdek', was used for DCPA, terbacil, and simazine bioassays, while cucumber (*Cucumis sativa* L. cv. 'Victory') was used for chloroxuron. Five oat seeds were placed in each water-tight pot which was watered to field capacity. Containers were placed in a greenhouse at 77-79 degrees Fahrenheit, under supplemental lighting for 16 hours per day. All treatments were randomized under the lights to minimize the effects of lighting variation. Pots were watered as needed. To ensure uniform stands, oats were thinned to three plants per container at a height of 2 in. and were grown for an additional 3 weeks. The plants were then clipped at soil level and fresh weights were determined. Samples were then dried in an oven at 176 degrees Fahrenheit for 36 hours, and dry weights were recorded.

Field samples were prepared in the same manner and at the same time as the standard series. Growth conditions and data collection procedures were the same for both the standard series and the field units.

Statistical Analysis

Statistical analysis was performed on Honeywell and Vax computers using SPSS software packages (Nie et al. 1975). Confidence intervals for the mean persistence of herbicides were calculated according to Neter and Wasserman's Equation 3.37 (1974).

Results

Phytotoxicity

Phytotoxicity was assessed by measuring both mortality (the number of strawberry plants per plot that died) and yields. Analysis of variance of the data in 1983 and 1984 indicated significant differences in strawberry mortality due to variety effects ($p = 0.018$ and 0.001 respectively). Mortality was significantly greater for Hecker than for Quinault plants both years (table 1). More than twice as many Hecker as Quinault plants died each year.

Treatment effects on mortality are shown in Table 2. Mortality was greatest in simazine plots; differences between the other treatments were not significant in either year.

Yields also showed significant responses to variety in 1983 and 1984 ($p = 0.031$ and 0.001 respectively). Quinault yields were greater than Hecker yields (table 3).

Treatment effects were significant in both years (table 4).

In 1983 the weeded control and DCPA plots produced the highest yields and were significantly greater than the simazine, dinoseb, terbacil, black plastic, and nonweeded clear plastic treatments. The other herbicide treatments were intermediate in yields: diphenamid plots produced greater yields than the black plastic treatment or the nonweeded control, and the other treatments did not differ significantly. In 1984 the highest yields were obtained with the diphenamid, terbacil, weeded clear plastic, and weeded black plastic treatments. The chloroxuron, napropamide, diphenamid, DCPA, dinoseb, terbacil, and weeded clear plastic plots did not differ significantly from each other and were intermediate in yields. The effects of the nonweeded clear plastic treatment did not differ significantly from those of the chloroxuron treatment. Simazine plots had the lowest yields both years. Strawberry yields were affected by mortality (coefficient of determination = .7176 and .4679 in 1983 and 1984, respectively), indicating that 71.76 percent and 46.79 percent of the variability in yields is attributable to mortality.

Table 1. Strawberry plant mortality by variety in 1983-84.

Variety	Mean Plants Killed/Plot 1983	1984
Quinault	2.7	2.2
Hecker	5.0	4.5

Table 2. Strawberry plant mortality by treatment in 1983-84.

Treatment	Mean Plants Killed/Treatment 1983	1984
Handweeded, Clear Plastic	0.7 a[1]	1.6 a
Handweeded, Black Plastic		2.7 a
DCPA, Clear Plastic	1.1 a	1.0 a
Diphenamid, Clear Plastic	1.3 a	1.2 a
Nonweeded, Clear Plastic	2.1 a	3.5 a
Nonweeded, Black Plastic	2.2 a	2.7 a
Napropamide, Clear Plastic	2.2 a	2.0 a
Chloroxuron, Clear Plastic	2.2 a	2.5 a
Terbacil, Clear Plastic	2.3 a	2.8 a
Dinoseb, Clear Plastic	2.8 a	3.2 a
Simazine, Clear Plastic	21.0 b	14.1 b

[1]Letters in a column indicate significant differences at p= .05 based on Duncan's Multiple Range Test (DMRT).

Table 3. Strawberry yield by variety in 1983-84.

Variety	Yield/Plot (oz) 1983	1984
Quinault	76.82	78.50
Hecker	67.11	51.59

Table 4. Strawberry yield by treatment in 1983-84.

Treatment	Yield/Treatment (oz) 1983	1984
Simazine, Clear Plastic	14.08 a[1]	22.11a
Nonweeded, Black Plastic	57.55 b	30.04 a
Nonweeded, Clear Plastic	63.49 bc	42.73 b
Dinoseb, Clear Plastic	68.20 bcd	70.19 c
Terbacil, Clear Plastic	78.20 bcd	80.73 cd
Napropamide, Clear Plastic	80.17 bcde	76.66 c
Chloroxuron, Clear Plastic	84.43 cde	60.54 bc
Diphenamid, Clear Plastic	87.31 de	78.21 cd
Handweeded, Clear Plastic	92.85 e	82.56 cd
DCPA, Clear Plastic	93.43 e	69.14 c
Handweeded, Black Plastic		100.94 d

[1]Letters in a column indicate significant differences at p = .05 based on DMRT.

1983 Weed Control Efficacy

Efficacy of weed control was measured by percent cover of the various weed species. The five most predominant species measured were: common lambsquarters (*Chenopodium album* L.), pineappleweed (*Matricaria matricarioides* [Less.] Porter), sheperdspurse (*Capsella bursa-pastoris* [L.] Medik.), marsh yellowcress (*Rorippa islandica* [Oeder] Borbas), and grasses (a mixture of several unidentified grass species).

In 1983, analysis of variance indicated significant differences between treatments in weed control for each of these species except common lambsquarters. Interaction between treatments and blocks prevented analysis of the treatment effects on sheperdspurse. Mean percent cover data for the various weed control treatments are shown in Tables 10 through 14. All of the herbicides except DCPA significantly reduced the cover of pineappleweed below that of the nonweeded clear plastic control, and simazine controlled pineappleweed more effectively than the other herbicide treatments (table 5).

Simazine was also the most effective weed control treatment for marsh yellowcress (table 6). Terbacil, black plastic, chloroxuron, and dinoseb were intermediate in controlling this species, while the percent cover of this weed in the DCPA, diphenamid, and napropamide plots did not differ from the nonweeded control.

Black plastic, diphenamid, simazine, napropamide, and chloroxuron all reduced grass cover below that of the clear plastic nonweeded control (table 7). DCPA, terbacil, and dinoseb did not significantly decrease these grasses.

Table 8 shows the percent cover for common lambsquarters. The simazine, DCPA, diphenamid, and dinoseb plots had the lowest percent

Table 5. Pineappleweed control by weed control treatment in 1983.

Treatment	Mean Cover/Plot (%)
Handweeded, Clear Plastic	0.0 a[1]
Simazine, Clear Plastic	0.1 a
Chloroxuron, Clear Plastic	2.6 ab
Nonweeded, Black Plastic	2.9 ab
Dinoseb, Clear Plastic	3.6 ab
Terbacil, Clear Plastic	5.2 ab
Diphenamid, Clear Plastic	8.1 b
Napropamide, Clear Plastic	9.1 b
Nonweeded, Clear Plastic	19.2 c
DCPA, Clear Plastic	36.4 d

[1]Letters indicate significant differences at p = .05 on DMRT.

Table 6. Marsh yellowcress control by weed control treatment in 1983.

Treatment	Mean Cover/Plot (%)
Handweeded, Clear Plastic	0.0 a[1]
Simazine, Clear Plastic	0.0 a
Nonweeded, Black Plastic	0.2 ab
Terbacil, Clear Plastic	1.2 ab
Chloroxuron, Clear Plastic	1.8 ab
Dinoseb, Clear Plastic	4.8 ab
Diphenamid, Clear Plastic	7.6 bc
Nonweeded, Clear Plastic	13.2 cd
DCPA, Clear Plastic	16.8 d
Napropamide, Clear Plastic	16.9 d

[1]Letters indicate significant differences at $p = .05$ based on DMRT.

Table 7. Unindentified grass control by weed control treatment in 1983.

Treatment	Mean Cover/Plot (%)
Handweeded, Clear Plastic	0.0 a[1]
Nonweeded, Black Plastic	0.0 a
Diphenamid, Clear Plastic	0.5 ab
Simazine, Clear Plastic	1.0 ab
Napropamide, Clear Plastic	1.0 ab
Chloroxuron, Clear Plastic	2.8 ab
DCPA, Clear Plastic	5.3 abc
Terbacil, Clear Plastic	7.6 bc
Dinoseb, Clear Plastic	8.5 bc
Nonweeded, Clear Plastic	13.2 c

[1]Letters indicate significant differences at $p = .05$ based on DMRT.

Table 8. Common lambsquarters control by weed control treatment in 1983.

Treatment	Mean Cover/Plot (%)
Handweeded, Clear Plastic	0.0
Simazine, Clear Plastic	0.0
DCPA, Clear Plastic	1.6
Diphenamid, Clear Plastic	2.5
Dinoseb, Clear Plastic	7.0
Nonweeded, Black Plastic	11.4
Chloroxuron, Clear Plastic	11.7
Terbacil, Clear Plastic	13.0
Napropamide, Clear Plastic	13.6
Nonweeded, Clear Plastic	26.2

cover of this weed, although the differences were not statistically significant ($p = .09$).

Simazine, terbacil, chloroxuron, and dinoseb plots had less sheperdspurse than did the diphenamid, napropamide, and DCPA plots, although block-treatment interaction prevented mean separations (table 9).

The average percent control for each of these five weed species is presented in Table 10. Diphenamid, DCPA, and simazine provided greater than 75 percent control of common lambsquarters. Chloroxuron, dinoseb, and simazine effectively controlled pineappleweeded (greater than 75 percent control). The mustards, marsh yellowcress and shepherdpurse, were controlled (75 percent) by simazine, chloroxuron, and terbacil. Diphenamid, chloroxuron, and napropamide provided more than 75 percent control of grasses.

Table 9. Shepherdspurse control by weed control treatment in 1983.

Treatment	Mean Cover/Plot (%)
Handweeded, Clear Plastic	0.0
Simazine, Clear Plastic	0.0
Terbacil, Clear Plastic	2.1
Chloroxuron, Clear Plastic	3.4
Dinoseb, Clear Plastic	5.0
Nonweeded, Black Plastic	5.5
Diphenamid, Clear Plastic	10.7
Nonweeded, Clear Plastic	16.8
Napropamide, Clear Plastic	24.9
DCPA, Clear Plastic	38.6

Table 10. Percent control of weed species by treatment in 1983.

	Weed Species[1]				
Treatment	LQ	PW	SP	MY	UG
	(%)				
Diphenamid	87	59	38	43	95
Chloroxuron	51	83	76	84	76
Terbacil	57	99	86	90	91
Simazine	100	99	100	100	91
Napropamide	57	53	-35[2]	19	91
DCPA	92	-63[2]	-89[2]	-13[2]	59
Dinoseb	72	77	66	65	37

[1]LQ = common lambsquarters, PW = pineappleweed, SP = shepherdspurse, MY = marsh yellowcress, UG = unindentified grasses.
[2]Negative values indicate treatments with a higher percentage of cover than the control plots.

1984 Weed Control Efficacy

The five weed species that dominated the plots in 1983 did so again in 1984. Analysis of variance indicated significant treatment effects for pineappleweed, shepherdspurse, and the grasses. Treatment differences are shown in Table 15 through 20. Interaction between blocks and treatments prevented analysis of treatment differences for common lambsquarters and marsh yellowcress.

The simazine, dinoseb, terbacil, napropamide, and chloroxuron treatments reduced pineappleweed significantly (table 11).

Percent cover of shepherdspurse was reduced by simazine, dinoseb, and terbacil. The other treatments did not differ significantly from the control (table 12).

Table 11. Pineappleweed control by weed control treatment in 1984.

Treatment	Mean Cover/Plot (%)
Handweeded, Clear Plastic	0.0 a[1]
Simazine, Clear Plastic	0.1 a
Dinoseb, Clear Plastic	0.6 ab
Terbacil, Clear Plastic	1.7 ab
Nonweeded, Black Plastic	1.8 ab
Napropamide, Clear Plastic	2.8 abc
Chloroxuron, Clear Plastic	3.0 bc
Diphenamid, Clear Plastic	3.6 cd
DCPA, Clear Plastic	5.7 cd
Nonweeded, Clear Plastic	7.3 d

[1]Letters indicate significant differences at p = .05 on DMRT.

Table 12. Shepherdspurse control by weed control treatment in 1984.

Treatment	Mean Cover/Plot (%)
Handweeded, Clear Plastic	0.0 a[1]
Simazine, Clear Plastic	0.2 a
Dinoseb, Clear Plastic	0.8 ab
Terbacil, Clear Plastic	1.1 abc
Nonweeded, Black Plastic	3.5 abc
Diphenamid, Clear Plastic	3.6 bcd
Chloroxuron, Clear Plastic	4.8 cd
Napropamide, Clear Plastic	7.1 cd
Nonweeded, Clear Plastic	7.1 cd
DCPA, Clear Plastic	8.1 d

[1]Letters indicate significant differences at p = .05 based on DMRT.

All herbicide treatments except DCPA and dinoseb significantly reduced cover of the grasses (table 13).

Common lambsquarters coverage is shown in Table 14. Simazine controlled this weed more than the other treatments, although the block-treatment interaction prevented further analysis.

Coverage of marsh yellowcress is shown in Table 15. Simazine, terbacil, and dinoseb controlled this weed completely.

Percent weed control for 1984 is shown in Table 16. Simazine, dinoseb, DCPA, napropamide, and terbacil all controlled common lambsquarters effectively (greater than 75 percent). Terbacil, simazine, and dinoseb controlled pineappleweed and shepherdspurse above the 75 percent level. Marsh yellowcress was controlled by dinoseb, terbacil, and simazine. Diphenamid, terbacil, simazine, and napropamide were effective in reducing grass cover (above 75 percent).

Table 13. Grass control by weed control treatment in 1984.

Treatment	Mean Cover/Plot (%)
Handweeded, Clear Plastic	0.0 a[1]
Simazine, Clear Plastic	0.0 a
Nonweeded, Black Plastic	0.6 a
Napropamide, Clear Plastic	0.8 a
Diphenamid, Clear Plastic	1.2 a
Terbacil, Clear Plastic	3.5 a
Chloroxuron, Clear Plastic	3.7 a
DCPA, Clear Plastic	9.6 ab
Dinoseb, Clear Plastic	8.0 ab
Nonweeded, Clear Plastic	15.0 b

[1]Letters indicate significant differences at p = .05 based on DMRT.

Table 14. Common lambsquarters control by weed control treatment in 1984.

Treatment	Mean Cover/Plot (%)
Handweeded, Clear Plastic	0.0
Simazine, Clear Plastic	0.2
Napropamide, Clear Plastic	6.0
Dinoseb, Clear Plastic	7.7
Terbacil, Clear Plastic	9.7
DCPA, Clear Plastic	10.6
Diphenamid, Clear Plastic	15.5
Chloroxuron, Clear Plastic	29.8
Nonweeded, Clear Plastic	71.9

Table 15. Marsh yellowcress control by weed control treatment in 1984.

Treatment	Mean Cover/Plot (%)
Handweeded, Clear Plastic	0.0
Simazine, Clear Plastic	0.0
Terbacil, Clear Plastic	0.0
Dinoseb, Clear Plastic	0.0
Diphenamid, Clear Plastic	1.1
Chloroxuron, Clear Plastic	1.7
DCPA, Clear Plastic	2.7
Napropamide, Clear Plastic	3.0
Nonweeded, Clear Plastic	3.9

Table 16. Percent control of weed species by weed control treatment in 1984.

	Weed Species[1]				
Treatment	LQ	PW	SP	MY	UG
	(%)				
Diphenamid	73	51	49	74	92
Chloroxuron	53	59	32	58	75
Terbacil	79	76	84	100	77
Simazine	99	98	96	100	100
Napropamide	87	61	0	26	94
DCPA	80	25	-14[2]	34	47
Dinoseb	83	91	88	100	37

[1]LQ = common lambsquarters, PW = pineappleweed, SP = shepherdspurse, MY = marsh yellowcress, UG = unindentified grasses.
[2]Negative values indicate treatments with a higher percentage of cover than the control plots.

1983-84 Weed Control Comparison

Herbicides showed similar trends in weed control in 1983 and 1984. Simazine, diphenamid, DCPA, and dinoseb controlled common lambsquarters effectively (greater than 70 percent). Simazine and dinoseb controlled pineappleweed in both years. More than 75 percent control of the mustards, shepherdspurse and marsh yellowcress were achieved by simazine and terbacil. Diphenamid, chloroxuron, simazine, and napropamide provided more than 75 percent control of grass cover in both years.

In 1983 and 1984, handweeding the clear plastic control plots required an average of 15 minutes per plot. In 1984, handweeding the black plastic control plots required an average of 1.5 minutes.

Planting Method Experiment

Analysis of variance of the planting method study revealed variety, herbicide treatment and planting method effects on strawberry mortality (table 17).

In this, as in the main study, significantly fewer Hecker plants than Quinault plants survived. Mortality in simazine plots was significantly greater than in plots of the other herbicide treatments, which did not differ significantly from each other (table 18).

When planting methods were compared, strawberry mortality was significantly higher in plots planted directly; activated charcoal was as effective as potting soil in reducing mortality (table 19).

In 1984, during planting, two people were timed, as they filled around the plant roots with potting soil and again with the herbicide-treated soil with or without the carbon dip. In both cases, use of potting soil required twice as much time as use of herbicide-treated soil (3 vs. 1.5 minutes/plot and 2 vs. 1 minute/plot).

Table 17. Mortality by variety, planting method study.

Variety	Mean No. Plants Killed/Plot
Quinault	1.0
Hecker	1.4

Table 18. Strawberry plant mortality by treatment, planting method study.

Treatment	Mean No. Plants Killed/Plot
Diphenamid	0.4 a[1]
Chloroxuron	0.6 a
Terbacil	0.6 a
Dinoseb	0.7 a
Napropamide	1.0 a
DCPA	1.0 a
Simazine	4.0 b

[1]Letters indicate significant differences at $p = .05$ based on DMRT.

Table 19. Strawberry plant mortality by planting method.

Planting Method	Mean No. Plants Killed/Plot
Activated Charcoal Dip	1.0 a[1]
Potting Soil Filler	1.0 a
Direct Planting	1.6 b

[1]Letters indicate significant differences at $p = .05$ based on DMRT.

Soil Persistence

Scatter plots and regression analysis suggested a linear relationship between herbicide concentration and oat shoot dry weight accumulation for terbacil and simazine (coefficient of determination = 0.90 and 0.86 respectively) and between herbicide concentration in soil solution and oat root length for diphenamid and napropamide (coefficient of determination = 0.65 and 0.76 respectively). The equations for the herbicide standard curves were: simazine concentration = .561 + (-2.531 dry weight); terbacil concentration = .135 + (-.573 dry weight); diphenamid concentration = .296 + (-.137 root length); napropamide concentration = .199 + (-.045 root length). These equations were used to calculate mean concentrations and confidence intervals of herbicides applied in the field (table 20). Scatter plots of the data from the oat shoot bioassay tests did not indicate a linear relationship between concentration of herbicide applied to soil and shoot dry weight for chloroxuron or DCPA. Thus, persistence in the soil could not be calculated for these two herbicides. Napropamide and diphenamid were the least persistent herbicides. In some plots no herbicide remained in the soil at the end of the summer, while in other plots substantial amounts were found.

The percentage of each herbicide remaining in the soil at the end of the season is shown in Table 21. More than 50 percent of terbacil and simazine persisted through the field season.

Table 20. Mean Concentrations and confidence intervals (p = .05) for estimated herbicide residues in soil 15 weeks after application.

	Mean Concentration (lb/A)			
Block	Simazine	Terbacil	Napropamide	Diphenamid
1	1.208	.292	.050	.540
	1.780	.411	0	.203
2	1.684	.124	.713	0
	1.428	.224	.088	0
3	1.361	.277	.113	2.383
	1.581	.306	.413	2.049
4	1.613	.388	0	1.979
	1.446	.405	.063	.203

Table 21. Percent herbicide remaining after 15 weeks 1983.

Herbicide	Mean Herbicide Remaining (%)[1]
Simazine	75 ∓ 25
Terbacil	60 ∓ 22
Diphenamid	15 ∓ 40
Napropamide	9 ∓ 34

[1]Means plus or minus p = .05 confidence interval.

Discussion and Conclusions

Phytotoxicity

In 1983 and 1984 Hecker strawberry plants exhibited higher mortality than Quinault plants. Simazine was the only treatment to significantly influence mortality of both varieties in both years. Research in the contiguous states has also shown injury of strawberry plants from simazine treatments (Clay 1978, Robinson 1965, Andersen 1968). Mortality in the other herbicide treatments did not differ significantly from that in the controls, and there were no variety-treatment interactions. Since mortality occurs even in handweeded plots, it is clear that both varieties exhibit a certain degree of mortality, probably due to transplant shock, and the variety Hecker is more susceptible than the variety Quinault.

Quinault yields were significantly greater than Hecker yields in both years. In 1983 and 1984, simazine plots had significantly lower yields, which is not surprising since half or more of the plants died each year. None of the other herbicide treatments were significantly superior for yields in either year. This lack of significant differences between the other herbicide treatments is probably due to variations in yield caused by differences in yearly weather patterns and by yearly differences in the amount and kinds of weed seeds in the plots.

Although yields from the plots that were treated with black plastic and were handweeded were high in 1984, little research has been done in Alaska on the use of black plastic for weed control. Whether the effects of black plastic mulch on soil temperatures in Alaska differ from those in warmer climates is unknown. Caution should be used in comparing yields from the herbicide-treated plots to black or clear plastic weeded plots. Weeds that survived the herbicide treatment were allowed to grow, and many were able to grow in the space cut through the plastic for the strawberry plant. Some of these weeds, particularly common lambsquarters, grew quite large, shading many of the strawberry plants in a plot. It is likely that yields from the herbicide-treated plots would have been greater had the few large weeds that were growing through the plastic in those plots been removed.

Weed Control

It is difficult to compare 1983 and 1984 weed control results for each weed species since the different amounts of weed seeds may have been present and/or introduced into the plots each year. However, certain trends are evident: DCPA was ineffective in controlling pineappleweed both years, and DCPA and napropamide did not control marsh yellowcress in 1983. Generally, plant species that were effectively controlled by an herbicide (above 70 percent) one year were also controlled the next year (control of common lambsquarters and pineappleweed by terbacil in 1983 is an exception). Those not controlled (less than 40 percent) one year were not controlled the next. Common lambsquarters was controlled consistently by diphenamid, DCPA, and dinoseb. Pineappleweed was controlled both years by dinoseb, and both years DCPA was ineffective. The mustards, shepherdspurse and marsh yellowcress, were controlled each year by terbacil but not by napropamide and DCPA. The grasses were consistently controlled by diphenamid, chloroxuron, and napropamide. Simazine provided excellent and consistent control of all weeds and, unfortunately, of strawberry plants too.

Although there was general agreement between the manufacturers' lists of weeds controlled and the response of those weeds to the herbicide under Alaskan conditions, the following exceptions were noted. DCPA, which is labelled for control of annual grasses, gave less than 70 percent control both years.

Dinoseb, labelled for use against crucifers, provided less than 70 percent control in 1983 of shepherdspurse and marsh yellowcress. Terbacil gave good control (above 70 percent) of common lambsquarters in 1984 but not in 1983. Napropamide, which is listed for control of common lambsquarters and pineappleweed, did not control the former effectively in 1983 or the latter either year.

Planting Method

The planting method study indicated that activated charcoal was as effective as potting soil in reducing injury. Because the plots in this study were small (17.72 in by 35.43 in) with only 11.81 in between the plots, it is possible that some of the herbicides could have leached across the interstitial areas into adjacent plots. In spite of this potential problem, the experiment showed that any of the herbicides studied will increase mortality when the herbicide is in direct contact with the roots of the plant.

Commercial productions generally use machines for planting and the use of potting soil as a filler is awkward and time consuming. Sterilization of the potting soil for a large commercial operation would be expensive. Planting time was doubled in the planting method study when potting soil was used. Activated charcoal, however, can be added to the water that the strawberry plants are placed in while awaiting transplanting. Other studies have found activated charcoal to be effective in reducing injury from simazine, applied at 1, 1.5, 2 and 4 lb/A to newly transplanted strawberries and to runner plants (Kratky et al. 1970, Rath and O'Callaghan 1972). Robinson (1965) also found reduced injury of strawberry plants from simazine applied at 1 lb/A. In those experiments simazine was sprayed over the foliage of newly planted strawberries; it was not incorporated mechanically into the soil. In this experiment, activated charcoal and potting soil were more effective in reducing mortality in simazine plots than direct planting, but neither method gave adequate protection from simazine; mortality in simazine treated plots with potting soil, was 72 percent in 1983 and 48 percent in 1984. It is possible that the mechanical incorporation of simazine into the root zone of the strawberries increased the opportunity for uptake and translocation and greater injury. Beste (1983) reports that simazine has little foliar activity and must be absorbed by roots for activation. At reduced rates, and without incorporation, simazine might still give good weed control and reduced injury. For commercial operations that plant the strawberries before the plastic mulch is applied, simazine sprayed over the plants without incorporation might provide good weed control without the phytotoxic effects seen in this study. Future studies should examine this method of simazine use.

Handweeding of strawberries through the clear plastic mulch is impractical on a large scale. Because weeds in the black plastic treatment plots are restricted to the areas where the plastic is cut for strawberry plants to grow, less time (one tenth) was needed to weed the same size plot with black plastic. However, recommendations for selections of weed control treatments depend on site factors, including: specific weeds, soil types, site canopy, and other factors. Although the weeded black plastic treatment produced high yields in 1984, caution should be used before this treatment is chosen. The warmer temperatures in June of 1984 may have allowed early growth of the plants that would not be possible with cooler temperatures. Voth and Bringhurst (1959) noted that clear plastic mulch

allowed greater growth of strawberries in the spring which resulted in earlier yields but not greater yields. It is possible that cooler temperatures early in the season could delay berry production in black plastic treatments because the net soil temperature increase would not be enough to allow the early growth. Shading is another factor that could affect soil temperature. The site used in this experiment was an open field without any shading. It is possible that black plastic mulch in a shaded area would have a cooling effect on the soil resulting in decreased plant growth. Further work should be done using black plastic for weed control. Certainly this material should be studied for more than one season to determine the effects on soil temperature and berry production in different climatic patterns.

Soil Persistence

The percent of napropamide remaining after 15 weeks ranged from 0 to 43 percent (mean = 9 percent) of the original 2.0 lb/A applied. Beste (1983) reported the half life of napropamide to be 8 to 12 weeks at soil temperatures of 70 to 90 degrees Fahrenheit. Romanowski and Borowy (1979) found napropamide to persist in Indiana in quantities great enough to cause 48 percent growth reduction of wheat after 349 days when applied at 2.0 lb/A and 68 percent growth reduction after 349 days when applied at 4.0 lb/A. The persistence reported here is within the range reported by Beste and less than that reported by Romanowski and Borowy.

Diphenamid was found to persist at levels from 0 to 65 percent (mean = 15 percent) of the original 6 lb/A. Beste (1983) reported diphenamid to persist for 3 to 6 months under "warm, moist soil conditions." Research in Kentucky (Jones et al. 1964) showed diphenamid to persist at "phytotoxic levels" in the root zone (1 to 6 in) for 10-11 months after application when applied at 3.0 to 7.0 lb/A. The tests in Kentucky were conducted at two locations, both with similar soil types and climatic conditions. Results were variable: levels ranged from .39 to .58 ppm at one location and from .10 to .45 ppm at the other location. Estimated persistence of diphenamid in interior Alaska is less than that found by Jones et al.

From 38 to 82 percent (mean = 60 percent) of the 0.5 lb/A of terbacil applied in the spring in this study was estimated to remain in the soil 15 weeks later. General estimates of the half life of terbacil are from 5 to 6 months at 4.0 lb/A (Beste 1983). Wolf and Martin (1974) studied the decomposition of radioactive terbacil to radioactive carbon dioxide and found 25.5 percent of the labelled herbicide in the soil after 600 days. Marriage et al. (1977) studied accumulation of terbacil residues in peach orchard soil in Ontario by both analytic and bioassay methods. They reported residual levels of terbacil that were phytotoxic to oats after three years; average half life at 4.0 lb/A was 5-7 months. The residues estimated in this study are similar to those of Marriage et al. and Beste.

Simazine was the most persistent herbicide used. From 59 to 100 percent (mean = 75 percent) of the original 2.0 lb/A remained after 15 weeks. Other studies of simazine persistence show conflicting results. Allott (1969) reported 80 percent of simazine applied at 2.0 lb/A in the spring in Ireland remained in the top 0-2 in of soil after 11 weeks in 1966. In 1967, 22.5 weeks were required for the same level of degradation. He attributed the difference in levels of persistence to be due to greater rainfall in 1966. Horowitz (1969) found no loss of activity in simazine-treated soil in Israel during the first 1-5 months after application. Both biological and chemical methods of residue determination were used. In England, Holly and Roberts (1963) found considerable variation in the time required for the disappearance of simazine. At one site 5 weeks were required for 50 percent reduction in the origianal lb/A, while at another site 13 weeks were required. The estimated residues of simazine from 1983 in interior Alaska are greater than those estimated by Holly and Roberts, but are similar to those of Horowitz and Allott.

The bioassay tests in this experiment gave variable results for all four herbicides. Confidence intervals for each herbicide were large. For example, within block estimates of the herbicide remaining after 15 weeks in 1983 ranged from 0 to 0.7 lb/A for napropamide and 0 to 2.4 lb/A for diphenamid. While this study may not be able to estimate the precise amount of herbicide remaining in the soil, the estimates are within the general range of other research conducted in temperate climates.

Research has consistently shown greater herbicide persistence in cooler, drier northern regions (Hance 1980, Klingman et al. 1972, Smith 1982). Low soil moisture and cool soil temperatures are two factors that inhibit herbicide degradation. However, annual cultivation of strawberries requires irrigation, which provides adequate soil moisture, and plastic mulch, which increases soil temperatures and promotes degradation of herbicide residues. These cultivation techniques may effect herbicide persistence, and may account for decreased persistence of napropamide and diphenamid. Future

research should examine, by both biological and chemical means, the persistence of herbicides in interior Alaska in order to ensure their safe and legal use.

References

Ahrens, J.F. 1982. Herbicides for newly planted strawberries. *Proc. Northeast. Weed Sci. Soc. 34*:259.

Albregts, E.E., and C.M. Howard. 1981. Weed control in strawberry nursery. *Proc. Fla. State Hortic. Soc. 94*:132-133.

Allott, D.J. 1969. Persistence of simazine applied annually in the prolonged absence of soil cultivation. *Weed Res.* 9:279-287.

Andersen, A.H. 1968. Inactivation of simazine and linuron in the soil by charcoal. *Weed Res. 8*:58-69.

Anderson, W.P. 1983. *Weed Science: Principles*. USA: West Publishing.

Beste, C.E., ed. 1983. *Herbicide Handbook*. Champaign, Illinois: Weed Science Society of America.

Burgoyne, W.E. 1981. The persistence of the herbicides 2,4-D and picloram in Alaskan soils north of latitude 60. *Agroborealis 13*:44-48.

Clay, D.V. 1978. Residues of simazine in soil following repeated applications to fruit, ornamental and forestry crops. *Exp. Hortic. 30*:45-55.

Conn, J.S., and C.W. Knight. 1984. An evaluation of herbicides for broadleaf-weed control in rapeseed. Agric. Exp. Stn. Bul. 62. University of Alaska-Fairbanks.

Dinkel, D.H. 1966. Polyethylene mulches for sweet corn in northern latitudes. *Proc. Am. Soc. Hortic. Sci. 89*:497-503.

Dinkel, D.H. 1973. Pumpkins, polyethylene and photoperiod. *Agroborealis 5*:16-17.

Dinkel, D.H. 1980. Growing everbearing strawberries as annuals in Alaska. Agric. Exp. Stn. Circ. 35., University of Alaska-Fairbanks.

Eberle, D.O., and H.R. Gerber. 1976. Comparative studies of instrumental and bioassay methods for the analysis of herbicide residues. *Arch. Environ. Cont. and Toxic. 4*:101-118.

Hance, R.J. ed. 1980. *Interactions between Herbicides and the Soil*. London: Academic Press Inc.

Hill, D., L. Hankin, and G. Stephens. 1982. Mulches, their effect on fruit set, timing and yields of vegetables. Conn. Agric. Exp. Stn. Bull. 805, New Haven.

Holly, K., and H.A. Roberts. 1963. Persistence of phytotoxic residues of triazine herbicides in the soil. *Weed Res. 3*:1-10.

Horowitz, M. 1969. Evaluation of herbicide persistence in soil. *Weed Res.* 9:314-321.

Horowitz, M., and N. Hulin. 1971. A rapid bioassay for diphenamid and its application in soil studies. *Weed Res. 11*:143-149.

Jones, G.E. H.D. Dubey, and J.F. Freeman. 1964. Persistence of diphenamid in tobacco field soils. *Weeds 12*:313-315.

Klingman, G.C. F.M. Ashton, and L.J. Noordhoff. 1972 *Weed Science: Principles and Practices*. 2nd Edition. New York: John Wiley and Sons.

Kratky, B.A., D.L. Coffey, G.F. Warren. 1970. Activated carbon root dips on transplanted strawberries. 18:577-580.

Marriage, P.B. 1975. Detection of triazine and urea herbicide residues by various characteristics of oat seedlings in bioassays. *Weed Res. 15*:291-298.

Marriage, P.B., S.U. Khan, and W.J. Saidak. 1977. Persistence and movement of terbacil in peach orchard soil after repeated annual applications. *Weed Res. 17*:219-225.

Neter, J., and W. Wasserman. 1974. *Applied Linear Statistical Models: Regression, Analysis of Variance and Experimental Designs*. R.D. Irwin, Illinois.

Nie, N.H., C.H. Hull, J.G. Jenkins, K. Steinbrenner, D.H. Bent. 1975. *Statistical Package for the Social Sciences*, 2nd ed. New York: McGraw-Hill Co.

Prichard, M.K., and E.H. Stobbe. 1980. Persistence and phytotoxicity of dinitroaniline herbicides in Manitoba soils. *Can. J. Plant Sci. 60*:5-11.

Putman, A.R., and J.F. Hancock. 1982 Influence of napropamide on strawberry growth and fruit yield. *Hort. Sci. 17*:650-651.

Rath, N., and T.F. O'Callaghan. 1972. The use of charcoal dips for protection against simazine damage in freshly planted strawberries. *Proc. 11th Brit. Weed Control Conf. 11*:368-373.

Robinson, D.W. 1965. The use of adsorbents and simazine on newly planted strawberries. *Weed Res.* 5:43-51.

Romanowski, R.R., and A. Borowy. 1979. Soil persistence of napropamide. *Weed Sci. 27*:151-153.

Singh, R.K.N., and R.W. Campbell. 1965. Herbicides in bluegrass. *Weeds 13*:170-171.

Smith, A.E. 1982. Herbicides and the soil environment in Canada. *Can. J. Soil Sci.* *62*:433-460.

Smith, A.E., and B.J. Hayden. 1976. Field persistence studies with eight herbicides commonly used in Saskatchewan. *Can. J. Plant Sci.* *56*:769-771.

Voth, V., and R.S. Bringhurst. 1959. Polyethylene over strawberries. *Cal. Agric.* *13*:5,14.

Weller, S.C., 1984. Evaluation of postplant applications of terbacil and napropamide to strawberry plants. Agric. Exp. Stn. Purdue Univ. J. Paper 9771.

Wolf, D.C., and J.P. Martin. 1974. Microbial degradation of 2-carbon-14 bromacil and terbacil. *Soil Sci. Soc. Am. Proc.* *38*:921-925.b.