

EVALUATION OF HERBICIDES FOR NO-TILL CORN ESTABLISHMENT

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Thesis submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

MASTER OF WEED SCIENCE

in

Plant Pathology, Physiology and Weed Science

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May, 1986

Blacksburg, Virginia

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(ABSTRACT)

Field experiments were conducted in 1984 and 1985 in Fluvanna and Montgomery Counties in Virginia, to evaluate HOE-0661 (glufosinate) [ammonium-(3-amino-3-carboxypropyl)-methylphosphinate], cyanazine (2-[[4-chloro-6-(ethylamino)-s-triazin-2-yl]amino]-2-methylpropionitrile), glyphosate [N-(phosphonomethyl)glycine] and paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) for the control of vegetation existing at the time of no-till corn establishment. These herbicides were applied alone or in combination with 2,4-D [(2,4-dichlorophenoxy)acetic acid] or dicamba (3,6-dichloro-2-methoxybenzoic acid) at three timings of application. Both locations were heavily infested with annual, biennial, and perennial broadleaf weeds, including horseweed (Conyza canadensis), buckhorn plantain (Plantago lanceolata), field bindweed (Convolvulus arvensis), curly dock (Rumex crispus) and wild mustard (Sinapis arvensis). All four non-selective herbicides provided good overall weed control. The addition of 2,4-D or dicamba generally improved the control of broadleaf weeds in all four experiments. Control of horseweed with paraquat was variable, but improved significantly when dicamba was applied in combination with paraquat. Glyphosate, cyanazine and HOE-0661 alone or in combination with 2,4-D or dicamba provided excellent horseweed control. Wild mustard control with glyphosate was

dependent on the weed size and growth stage of development. Control with paraquat, cyanazine and HOE-0661 was not affected by differences in wild mustard size or growth stage. Glyphosate and HOE-0661 provided acceptable field bindweed control alone, and all herbicides gave excellent field bindweed control when applied in combination with 2,4-D or dicamba. Cyanazine and HOE-0661 showed better control of shoot growth on the more difficult-to-control weeds than paraquat and glyphosate when applied alone. With the addition of either 2,4-D or dicamba, cyanazine and HOE-0661 provided better overall weed control, in most cases, than corresponding paraquat and glyphosate combinations. Timing of application and weed size did not significantly affect herbicide activity, even at later application timings when weeds were well established and exceeded 60 cm in height.

ACKNOWLEDGEMENTS

I sincerely thank Dr. Scott Hagood, my major professor and close friend, for the extra time and consideration he shared with me.

A special thanks also to the members of my committee, Drs. Dan Brann, Jeff Derr and David Orcutt. I also extend appreciation to Mr. Claude Kenley for help with field work and his friendship throughout the project. Mrs. Ruth Pennington donated invaluable time and secretarial skills in all phases of the project. The faculty, staff and fellow graduate students of PPWS provided encouragement and assistance with both my courses and research.

I would like to thank Mr. Hollis Black and Mr. Roger Black, of Blackgate Farms, for their time and support in allowing me to conduct research on their farm.

A very special thanks goes to my parents, Mr. and Mrs. Clifton W. Davis, who have provided endless support and encouragement, not only in this project but in every decision I have ever made.

My deepest thanks and appreciation go to my wife, Marian E. Davis, for her patience, encouragement, support and especially for her belief in my ability to complete this project.

I also thank my daughter, Trudy Lynn Davis, for being a daily reminder that there is a lot more to life than studying.

Finally, I want to thank God for my given talents and the desire to acquire new ones.

TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	ii
ACKNOWLEDGEMENTS	iv
LIST OF TABLES	vi
INTRODUCTION	1
LITERATURE REVIEW	4
MATERIALS AND METHODS	13
RESULTS AND DISCUSSION	17
CONCLUSIONS	51
LITERATURE CITED	52
VITA	60

LIST OF TABLES

	<u>Page</u>
Table 1. Timing of application (planting dates) for the four experiments	14
Table 2. Rates of application for herbicide treatments	16
Table 3. Weed species present in 1984 Fluvanna County, Va. experiment as percent of total sample dry weight from check plots and as frequency of occurrence in check plots	18
Table 4. Weed species present in 1984 Montgomery County, Va. experiment as percent of total sample dry weight from check plots and as frequency of occurrence in check plots	19
Table 5. Weed species present in 1985 Fluvanna County, Va. experiment as percent of total sample dry weight from check plots and as frequency of occurrence in check plots	20
Table 6. Weed species present in 1985 Montgomery County, Va. experiment as percent of total sample dry weight from check plots and as frequency of occurrence in check plots	21
Table 7. Effect of herbicide treatment and timing of application on overall weed control in Fluvanna County, Va., 1984	23
Table 8. Total weed dry weight, expressed as the percent of untreated at each timing, as affected by herbicide treatment in Fluvanna County, Va., 1984	25
Table 9. Effect of herbicide treatments and timing of application on overall weed control in Montgomery County, Va., 1984	26
Table 10. Total weed dry weight, expressed as the percent of untreated at each timing, as affected by herbicide treatment in Montgomery County, Va., 1984	28
Table 11. Effect of herbicide treatment and timing of application on overall weed control in Fluvanna County, Va., 1985	29
Table 12. Total weed dry weight, expressed as the percent of untreated at each timing, as affected by herbicide treatment in Fluvanna County, Va., 1985	31

	<u>Page</u>
Table 13. Effect of herbicide treatment and timing of application on overall weed control in Montgomery County, Va., 1985	32
Table 14. Total weed dry weight, expressed as the percent of untreated at each timing, as affected by herbicide treatment in Montgomery County, Va., 1985	34
Table 15. Effect of herbicide treatment and timing of application on horseweed control in Montgomery County, Va., 1984	36
Table 16. Effect of herbicide treatment and timing of application on horseweed control in Montgomery County, Va., 1985	37
Table 17. Effect of herbicide treatment and timing of application on field bindweed control in Fluvanna County, Va., 1984	39
Table 18. Effect of herbicide treatment and timing of application on curly dock control in Montgomery County, Va., 1984	40
Table 19. Effect of herbicide treatment and timing of application on prickly lettuce control in Montgomery County, Va., 1984	41
Table 20. Effect of herbicide treatment and timing of application on wild mustard control in Fluvanna County, Va., 1984	43
Table 21. Effect of herbicide treatment and timing of application on wild mustard control in Fluvanna County, Va., 1985	44
Table 22. Effect of herbicide treatment and timing of application on buckhorn plantain control in Montgomery County, Va., 1984	46
Table 23. Effect of herbicide treatment and timing of application on ragweed control in Fluvanna County, Va., 1984	48
Table 24. Effect of herbicide treatment and timing of application on ragweed control in Fluvanna County, Va., 1985	50

INTRODUCTION

No-till corn production has increased steadily over the past ten years as an alternative to conventionally tilled corn (64, 65). The success and benefits associated with no-till corn production have been the primary impetus for its adoption. Since its introduction, no-till corn has produced yields comparable to those achieved with conventional tillage while reducing soil erosion and operating costs (63, 69).

Associated with this increase in no-till corn acreage has been the development of annual, biennial, and perennial weed species that have not typically been associated with conventional tillage (52). The success or failure of no-till corn depends upon control of the vegetation existing at planting as well as residual control of weeds during the growing season. In conventional tillage, moldboard plowing provides a means for disrupting and destroying root systems of perennial weed species (52). In addition to the lack of weed suppression via tillage, the development of weed problems in no-till systems are due to the lack of effective control of many species with standard no-till herbicide treatments. Horseweed (*Conyza canadensis*) is a major weed problem that has developed in no-till production systems because paraquat affords variable control of this species (31, 35, 51, 75, 76, 77, 78). Other no-till problem weeds include hedge bindweed (*Convolvulus sepium* (71), field bindweed (*Convolvulus arvensis*) (17) and fall panicum (*Panicum dichotomiflorum*). Fall panicum is the most extensive annual weed problem in no-till corn in the mid-Atlantic states (9, 29, 42).

Currently, standard no-till herbicide programs involve the use of non-selective postemergence (POST) herbicides including paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) and glyphosate [N-(phosphonomethyl)-

glycine] to control weeds existing at planting. Preemergence (PRE) herbicides including atrazine [2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine], simazine [2-chloro-4,6-bis(ethylamino)-s-triazine], alachlor [2-chloro-2,6'-diethyl-N-(methoxymethyl)acetanilide] and metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methyl-ethyl)acetanilide] are tank-mixed with these non-selective herbicides to provide residual weed control.

Recent research has shown that HOE-0661, with the proposed common name of glufosinate [ammonium-(3-amino-3-carboxypropyl)-methylphosphinate], and cyanazine (2-[[4-chloro-6-(ethylamino)-s-triazin-2-yl]amino]-2-methylpropionitrile) also have the potential to provide effective control of certain grasses and broadleaf weed species when used as POST herbicide treatments at the time of no-till corn establishment (6, 22, 30, 31, 51, 67, 74, 76, 78). The primary objective of this research was to compare paraquat, glyphosate, HOE-0661 and cyanazine with respect to their ability to control vegetation existing at no-till corn establishment under Virginia conditions.

The compounds, 2,4-D [(2,4-dichlorophenoxy)acetic acid] and dicamba (3,6-dichloro-2-methoxybenzoic acid) are both broadleaf specific herbicides that are normally used on escape weeds as POST treatments in corn. The ability of these compounds in no-till corn establishment to increase the effectiveness and spectrum of control of non-selective herbicides has been evaluated in several studies (33, 37, 38, 49, 54, 66). The second objective of this research was to determine if the addition of 2,4-D or dicamba would enhance the activity of these non-selective herbicides.

The degree to which established vegetation is controlled depends on the species, growth stage, and the height and density of vegetation at the time of herbicide application (29, 31, 32, 49). Kern (9) and Ritter (49) observed that cyanazine was most effective on annual grasses less than 8 cm in height and ineffective on annual grasses taller than 10 cm. Kapusta (29) also observed foxtail (Setaria spp.) and crabgrass (Digitaria spp.) were controlled more easily with paraquat if applied before the grasses reached 10 cm in height. Kapusta (31) found that paraquat only gave partial control of 90 to 120 cm horseweed. With the understanding that this variable can affect weed control, the third and final objective was to determine the effect of weed size and growth stage on response to herbicide treatments.

LITERATURE REVIEW

Paraquat

Reduced-tillage or no-till methods of crop production did not develop until the mid-1960's, when herbicides such as paraquat offered alternatives to mechanical weed control (21). The use of paraquat has become standard in no-till production for control of vegetation that exists at planting (9, 44, 46, 49). Paraquat is a non-selective, POST, contact herbicide that is used to kill annual grasses and broadleaf weeds and suppress perennial weed growth (2). The herbicidal activity of paraquat is dependent upon the paraquat cation. In the presence of light and oxygen the cation is broken down to form N-methyl isonicotinic acid and finally to methylamine as the ultimate product. In the process one-electron reductions occurs to form stable free radicals such as the peroxide. Peroxides and other free radicals then destroy plant membranes (26). Paraquat provides rapid desiccation of emerged green tissue whenever contact with plant occurs. This desiccation occurs in less than 48 hours in most situations (2). The use of a nonionic surfactant greatly enhances paraquat's effectiveness (2, 43). Paraquat is only active as a foliar spray and becomes completely inactivated upon contact with soil, due to rapid and complete adsorption to soil colloids, especially clay colloids (2).

Crop yields with reduced tillage production have shown to equal those of conventional tillage where paraquat provided satisfactory weed control at the time of crop establishment (63, 70). Recent studies have reported that control of some weeds treated with paraquat frequently diminished with time, thus leaving regrowth of injured weeds to compete with the crop (6, 78). Horseweed has developed into a major weed

problem in no-till production, due to the variable control with paraquat (6, 31, 35, 50, 75, 76, 78). Kapusta and Stricker (29) were able to achieve 100% control of horseweed, and observed this control to last through the entire growing season. Bellinder and Wilson (6) and Wilson et al. (78), however, found that horseweed recovery following paraquat application was extensive 40 days after treatment. Similarly, Ritter (50) observed the control of horseweed with paraquat decreased from 87% at 25 days after treatment to 38% by 50 days after treatment.

The lack of control of certain weed species with paraquat has led researchers to investigate alternative non-selective, POST herbicides for control of the vegetation that exists at no-till crop establishment. Glyphosate, HOE-0661 (glufosinate) and cyanazine are three promising alternative herbicides to paraquat that have demonstrated potential for this use.

Glyphosate

Glyphosate is a non-selective, broad-spectrum, POST herbicide that is readily translocated throughout the plant (1). Because of its translocation characteristics, it provides control of both annual and perennial grasses and broadleaf weeds. Glyphosate's site of activity is the inhibition of 5-enolpyruvyl-shikimate-3-phosphate (EPSP) synthase, the enzyme completing the second step in the shikimic acid pathway between shikimate and chlorismate (58). This activity ultimately inhibits the synthesis of the aromatic amino acids and numerous other secondary plant metabolites. Symptoms may not be apparent for the first ten days or more after application (1).

In the early 1970's, researchers studied the possibility of using glyphosate for controlling vegetation existing at the time of no-till

crop establishment (69, 79, 80). Peters and Dest (44, 46) showed that glyphosate gave complete control of both perennial sods and rye cover crops in sufficient time to prevent competition with the corn crop. In both situations, glyphosate at 1.12 kg/ha provided better grass control than paraquat at 0.56-1.12 kg/ha. Glyphosate is also important in the control of certain problem perennial weed species such as johnsongrass (Sorghum halepense), Canada thistle (Cirsium arvense) and field bindweed (1, 15).

Since these early studies, glyphosate and paraquat at 1.12 kg/ha and 0.56 kg/ha, respectively, have been evaluated extensively with respect to control of annual and perennial grasses and broadleaves in no-till cropping situations. In most situations, glyphosate provides equal or better control than paraquat (3, 9, 10, 29, 31, 37, 44, 46, 56, 66, 72, 80). Burnside and Wicks (9) found glyphosate and paraquat to be equally effective in controlling velvetleaf (Abutilon theophrasti) and large crabgrass (Digitaria sanguinalis), but found that glyphosate afforded superior control of fall panicum. Wilson (76) and Somody (56) compared glyphosate and paraquat for control of rye cover crops in no-till corn and observed excellent control with both herbicides.

Field studies using glyphosate on field bindweed have resulted in variable control (27, 47). Researchers in Nebraska obtained 90-100% control of field bindweed with glyphosate applied at 0.8 kg/ha; however, similar tests in Wyoming with glyphosate at 1.7 kg/ha resulted in only 13% control. DeGennaro and Weller's (17) studies suggested that the variable control of field bindweed observed may be due to the occurrence of different biotypes which differ in their susceptibility to glyphosate.

The efficacy of glyphosate in combination with atrazine, a residual herbicide, used in no-till cropping systems has also been variable (3, 7, 28, 45, 55). Selleck and Baird (55) and Brecke et al. (7) showed that the addition of atrazine to a glyphosate tank-mix reduced glyphosate control of winter cover crop cultivars, dandelion (Taraxacum officinales), quackgrass (Agropyron repens) and Canada thistle. Other field studies, however, (3, 28, 45) have shown no loss of glyphosate activity, when applied in a tank mix with atrazine for the control of either dandelion or quackgrass.

Glyphosate has recently been labeled for the control of many annual grass and broadleaf weeds less than 15 cm tall, in reduced tillage systems at the rate of 0.56 kg/ha. At this rate the addition of 0.5 to 1% by volume nonionic surfactant is needed to enhance glyphosate's activity (15).

Sandberg (53) found that glyphosate at 0.43 and 0.56 kg/ha provided excellent control of large crabgrass, barnyardgrass (Echinochloa crus-galli) and cocklebur (Xanthium pensylvanicum) in reduced tillage pre-plant tests when their heights were less than 10 cm. When weed heights exceeded 10 cm glyphosate at 0.43 and 0.56 kg/ha did not provide acceptable control.

HOE-0661 (Glufosinate)

HOE-0661, with the proposed common name glufosinate, is a non-selective, non-residual, POST, contact herbicide that controls a wide spectrum of annual and perennial weed species with minimal translocation (40). Kocher (34) reported that HOE-0661 specifically inhibited glutamine synthetase, the initial enzyme required for ammonium assimilation. HOE-0661 is highly active as a foliar spray and completely inactive

through the soil (48). The rate of plant symptom development in response to HOE-0661 has shown to be intermediate when compared to paraquat and glyphosate (6, 73).

In research conducted from 1980 to 1983, HOE-0661 provided control of annual grass and broadleaf weeds comparable or superior to that provided by paraquat and glyphosate (6, 11, 30, 31, 35, 50, 51, 73, 75, 76, 78). Wilson (73, 75, 78) and McCutchen and Hayes (35) found that HOE-0661 was comparable to glyphosate and superior to paraquat in control of horseweed, while Ritter (50) showed better control of horseweed with HOE-0661 than with either glyphosate or paraquat. HOE-0661 and glyphosate provided excellent control of 90-120 cm tall horseweed, while paraquat afforded only partial control of this species (31). Wilson et al. (78) also observed that HOE-0661 was superior to glyphosate and paraquat in control of hairy vetch (Vicia villosa), as a cover crop, and common ragweed (Ambrosia artemisiifolia). Bellinder and Wilson (6) found that HOE-0661 exhibited superior control of horseweed, common ragweed and Pennsylvania smartweed (Polygonum pensylvanicum) when compared to glyphosate. Control of common lambsquarters (Chenopodium album), large crabgrass and redroot pigweed (Amaranthus retroflexus) was better with glyphosate than with HOE-0661.

Control of weeds treated with HOE-0661 frequently diminished within 25-40 days after treatment (6, 35, 57, 74, 78). Stahlman (57) observed good initial control of fall panicum and field sandbur (Cenchrus paniculatus) with HOE-0661, but recovery was observed 25 days after treatment. Bellinder (6) and Wilson (74, 78) reported the control of horseweed treated with HOE-0661 diminished with time, while similar plots treated with glyphosate generally showed improved weed control

over the same time period. HOE-0661 has proven less efficacious than glyphosate or paraquat in controlling rye (Secale cereale L.) used as a cover crop for no-till corn (78).

Cyanazine

Cyanazine is readily absorbed by the foliage and also translocated from roots to shoots. Inhibition of photosynthesis, the proposed site of action, occurs when electron transport is interrupted on the reducing side of photosystem II (2). Cyanazine has primarily been used as an early preplant (EPP) or PRE selective residual herbicide for the control of annual grasses and broadleaf weeds in corn, sorghum and soybeans (4, 8, 13, 18, 19, 20, 59, 60, 61, 62, 68). Recent studies, however, have shown that cyanazine provides effective control of both grasses and broadleaves when used as a POST non-selective herbicide in reduced tillage situations (9, 14, 22, 23, 24, 25, 49, 50, 67, 77).

From 1981 to 1984, Stougaard (59, 60, 61, 62) conducted field studies on cyanazine applications in the fall and at three, two or one month before planting of no-till soybeans. All cyanazine treatments prevented vegetation from becoming established before planting and season-long weed control was achieved. At the time of the one-month application, giant foxtail, large crabgrass, horseweed, redroot pigweed, pennsylvania smartweed and prickly lettuce (Lactuca scariola) were already established. Stougaard's research showed that treatments including cyanazine gave excellent control of established stands of all species except for redroot pigweed and prickly lettuce.

Fawcett et al. (20) compared PRE applications of paraquat or glyphosate, atrazine, and alachlor or metolachlor with EPP applications of cyanazine followed by metolachlor plus atrazine or cyanazine for

annual grass control in no-till corn. Fawcett et al. (19) also compared PRE applications of paraquat or glyphosate plus alachlor or metolachlor plus linuron [3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea] or metribuzin [4-amino-6-tert-butyl-3-(methylthio)-as-triazin-5 (4H)-one] with EPP applications of cyanazine for annual grass control in no-till soybeans. In both studies, the EPP cyanazine treatments provided equal or superior giant foxtail (Setaria faberi), green foxtail (Setaria viridis) and yellow foxtail (Setaria pumila) control than PRE combinations. Brenneman (8) observed similar annual grass control results when he compared EPP cyanazine with paraquat plus atrazine plus alachlor applied PRE in no-till corn production.

Cyanazine is presently labeled for reduced tillage use on weeds less than 10 cm tall (14). In field research conducted by Hagood (22), Ritter (49, 50, 51) and Webb (67) from 1982 to 1984, cyanazine provided control of giant foxtail, pennsylvania smartweed, horseweed, redroot pigweed and fall panicum that existed at planting. The level of control afforded by cyanazine in these studies was comparable or superior to paraquat or glyphosate where weed seedlings were small. An advantage associated with the use of cyanazine for control of vegetation existing at no-till corn establishment is the additional residual control of annual weed species provided by this herbicide (14).

Dicamba and 2,4-D Amine

Dicamba and 2,4-D amine are both broadleaf-specific herbicides that are normally used on escaped weeds as POST treatments in corn (12, 16). These compounds have also been evaluated as a way in which to increase the effectiveness of weed control in no-till corn establishment. Some researchers have shown the addition of either 2,4-D or dicamba to a

non-selective, postemergence herbicide has improved weed control over the non-selective herbicide when applied alone, while other researchers have not observed additional weed control from similar additions of 2,4-D or dicamba (9, 10, 22, 33, 36, 38, 39, 41, 45, 49, 54, 66).

In the mid 1970s, Webb (66) improved broadleaf weed control with the addition of 2,4-D to paraquat and glyphosate, while Byford (10) observed no improvement in overall broadleaf weed control with the addition of dicamba to glyphosate, over glyphosate alone or split paraquat applications. More recently Ritter (49) and Burnside (9) used 2,4-D plus cyanazine to effectively control velvetleaf, field bindweed and hedge bindweed and achieve corn yields that were equal to those obtained with the use of paraquat and glyphosate. Schultz (54) observed better hemp dogbane (Apocynum cannabinum) control with 2,4-D plus glyphosate than dicamba plus glyphosate. Noel (38) observed that dicamba plus glyphosate provided better control of wild buckwheat (Polygonum convolvulus) and field pennycress (Thlaspi arvense) than 2,4-D plus glyphosate. Further, dicamba in combination with glyphosate gave superior control of this species than dicamba plus paraquat. Moomaw (36) showed the addition of 2,4-D to paraquat did not improve lambsquarters, redroot pigweed, velvetleaf or pennsylvania smartweed control.

O'Donovan and O'Sullivan (39, 41) reported that amine formulations of 2,4-D reduced paraquat's effect on weed control in small grains, but 2,4-D ester formulations did not. These researchers also found that ester formulations of 2,4-D could be mixed with paraquat for broad spectrum weed control (41). Knake (33) added 2,4-D or dicamba to glyphosate and improved the control of alfalfa (Medicago sativa) but

found that the addition of dicamba slightly reduced glyphosate's effectiveness against tall fescue (Festuca arundinaceae), orchardgrass (Dactylis glomerata), smooth broomgrass (Bromus inermis) and Kentucky bluegrass (Poa pratensis).

MATERIALS AND METHODS

Four field studies were conducted; two in 1984 and two in 1985. Research was located in Fluvanna and Montgomery Counties in Virginia. All experiments had corn no-till planted into naturally-occurring weed infestations. Montgomery County studies were conducted on a Hayter sandy loam with 2.0% organic matter (O.M.) and 6.2 pH, and Fluvanna County studies on a Tatum silt loam with 1.0% O.M. and 6.1 pH. The Montgomery plantings were made in existing corn residue and Fluvanna plantings in soybean residue. To determine the effect of weed size on response to herbicides, three different planting dates were used. Planting dates began approximately the first of May and proceeded in two-week intervals (Table 1). At each planting date, the weed species present, height, and stage of growth were recorded.

Corn¹ was planted in 102-cm rows using a commercial no-till planter², with a population of 54,600 kernels/ha. Plots consisting of rows 3.6 m wide and 7.6 m long were established to receive herbicide treatments. Herbicides were applied to all four rows of each plot using a four-nozzle boom, spraying a 1.8 m swath. Herbicides were applied prior to emergence of the corn using CO₂-pressurized backpack equipment. Herbicides were delivered in water at a volume of 222 L/ha at 207 KPa using flat-fan spray tips.³ All treatments were replicated four times in a split-plot, randomized complete block experimental design in which planting date represented the main plot effect and herbicide treatments the sub-plot effect.

¹Pioneer 3369-A hybrid.

²John Deere and Co., Moline, IL.

³Teejet 8003 tips, Spraying Systems Co., Wheaton, IL 60287.

Table 1. Timing of application (planting dates) for the four experiments.

County ¹	Timing		
	Early	Middle (Mid)	Late
Fluvanna, 1984	May 2	May 16	May 30
Montgomery, 1984	May 1	May 15	May 28
Fluvanna, 1985	May 6	May 16	May 29
Montgomery, 1985	April 30	May 13	May 27

¹Average last freeze date in the spring for Fluvanna County is April 20, and April 30 for Montgomery County.

Thirteen herbicide treatments and an untreated control were evaluated. All herbicide treatments contained atrazine at 1.12 kg/ha plus 1/2% V/V of a nonionic surfactant.⁴ Four non-selective herbicides were used alone or in combination with either 2,4-D amine at 0.56 kg/ha or dicamba at 0.28 kg/ha. The non-selective herbicides included paraquat at 0.56 kg/ha, cyanazine at 2.24 kg/ha, glyphosate at 0.56 kg/ha, and HOE-0661 at 0.84 kg/ha. Rates of application for all herbicide treatments are presented in Table 2.

A visual evaluation was conducted 21 days after treatment to evaluate overall herbicide effectiveness, weed control by species, and the vigor of uncontrolled weeds by species. At this time, one square meter of each plot was randomly selected, and the weeds in this area harvested and separated by species. These samples were subsequently oven-dried at 57°C for 7 days and dry weights of individual weed species calculated to determine the effects of herbicide treatments and timings of application on weed biomass in each plot. In the fall, corn from one row from each of the Montgomery County plots was harvested, weighed, and grain yields calculated.

All evaluation parameters were subjected to analysis of variance for the split plot, randomized complete block design and differences between means were compared using Duncan's Multiple Range Test at the 5% level of significance.

⁴X-77, Chevron Chemical Co., San Francisco, CA 94119.

Table 2. Rates of application for herbicide treatments.

Treatment ¹	Rate of Application —— (kg/ha) ——
Control (no herbicide)	
Atrazine control	1.12
Paraquat	0.56
Paraquat + 2,4-D	0.56 + 0.56
Paraquat + dicamba	0.56 + 0.28
Cyanazine	2.24
Cyanazine + 2,4-D	2.24 + 0.56
Cyanazine + dicamba	2.24 + 0.28
Glyphosate	0.56
Glyphosate + 2,4-D	0.56 + 0.56
Glyphosate + dicamba	0.56 + 0.28
HOE-0661	0.84
HOE-0661 + 2,4-D	0.84 + 0.56
HOE-0661 + dicamba	0.84 + 0.28

¹All treatments excluding the control contained atrazine at 1.12 kg/ha plus a non-ionic surfactant (X-77) at 1/2% V/V.

RESULTS AND DISCUSSION

Analysis of variance for the split plot design and the F-test ($\alpha = 0.05$) were used to determine significance of the main effects of herbicide treatment and timing of application and of the herbicide treatment x timing of application interaction. Where a significant interaction was observed for a specific evaluation parameter, Duncan's new multiple range test was used to compare herbicide treatment means within each level of timing of application, and similarly to compare timing of application means within each level of herbicide treatment. Where the interaction was not significant, treatment means and mean separation techniques as described above were applied to herbicide treatments averaged over all application timings, and to application timings averaged over all herbicide treatments.

Overall Weed Control

The weed species present in weed harvests from control plots in 1984 Fluvanna County, 1984 Montgomery County, 1985 Fluvanna County, and 1985 Montgomery County experiments are contained in Tables 3, 4, 5, and 6, respectively. These tables contain data on the composition of weed infestations as percent of total biomass and as frequency of occurrence in the four control plots within each timing of application at each location.

Overall control of vegetation that existed at the time of no-till corn establishment was quantified via visual evaluations of overall weed control (Tables 7, 9, 11, 13) and via total weed biomass from weed harvests (Tables 8, 10, 12, 14). Results from both locations and in both years were consistent relative to the effects of herbicide

Table 3. Weed species present in 1984 Fluvanna County, Va. experiment as percent of total sample dry weight from check plots and as frequency of occurrence in check plots.

Common Name	Scientific Name	Timing			Totals
		Early	Mid	Late	
		————— %, Frequency —————			— % —
Buckhorn plantain	<u>Plantago lanceolata</u>	17,1/4	22,4/4	40,4/4	30
Field bindweed	<u>Convolvulus arvensis</u>	24,3/4	31,4/4	14,2/4	20
Wild mustard	<u>Sinapis arvensis</u>	4,2/4	26,1/4	6,1/4	11
Field pepperweed	<u>Lepidium campestre</u>	0,0/4	0,0/4	20,3/4	11
Common chickweed	<u>Stellaria media</u>	32,3/4	4,1/4	0,0/4	8
Wild carrot	<u>Daucus carota</u>	12,2/4	0,0/4	5,1/4	6
Horseweed	<u>Conyza canadensis</u>	0,0/4	3,2/4	8,3/4	5
Common ragweed	<u>Ambrosia artemisiifolia</u>	0,0/4	6,2/4	3,2/4	3
Common lambsquarters	<u>Chenopodium album</u>	1,1/4	3,1/4	0,0/4	< 1
Yellow woodsorrel	<u>Oxalis stricta</u>	7,2/4	4,2/4	1,1/4	< 3
Other		3	1	3	< 3

Table 4. Weed species present in 1984 Montgomery County, Va. experiment as percent of total sample dry weight from check plots and as frequency of occurrence in check plots.

Common Name	Scientific Name	Timing			Totals
		Early	Mid	Late	
		— % , Frequency —			— % —
Buckhorn plantain	<u>Plantago lanceolata</u>	9,2/4	27,1/4	48,3/4	45
Curly dock	<u>Rumex crispus</u>	14,1/4	0,0/4	27,4/4	18
Whiteheath aster	<u>Aster pilosus</u>	0,0/4	0,0/4	14,2/4	8
Common ragweed	<u>Ambrosia artemisiifolia</u>	3,4/4	15,4/4	6,3/4	7
Yellow rocket	<u>Barbarea vulgaris</u>	46,3/4	1,1/4	0,0/4	8
Horseweed	<u>Conyza candensis</u>	3,1/4	8,3/4	4,1/4	4
Dairy fleabane	<u>Erigeron philadelphicus</u>	0,0/4	23,2/4	0,0/4	2.5
Wild mustard	<u>Sinapis arvensis</u>	0,0/4	18,1/4	0,0/4	2
Henbit	<u>Lamium amplexicaule</u>	10,2/4	0,0/4	0,0/4	1
Purslane speedwell	<u>Veronica peregrina</u>	10,3/4	1,1/4	0,0/4	1.5
Others		5	7	1	3

Table 5. Weed species present in 1985 Fluvanna County, Va. experiment as percent of total sample dry weight from check plots and as frequency of occurrence in check plots.

Common Name	Scientific Name	Timing			Totals
		Early	Mid	Late	
		— % , Frequency —			— % —
Common ragweed	<u>Ambrosia artemisiifolia</u>	8,3/4	54,4/4	51,3/4	39
Giant foxtail	<u>Setaria faberii</u>	40,4/4	24,3/4	4,1/4	20
Buckhorn plantain	<u>Plantago lanceolata</u>	19,1/4	1,1/4	27,1/4	18
Horseweed	<u>Conyza canadensis</u>	5,2/4	20,3/4	17,4/4	14
Wild mustard	<u>Sinapis arvensis</u>	27,2/4	0,0/4	0,0/4	8
Others		1	1	1	1

Table 6. Weed species present in 1985 Montgomery County, Va. experiment as percent of total sample dry weight from check plots and as frequency of occurrence in check plots.

Common Name	Scientific Name	Timing			Totals
		Early	Mid	Late	
		————— %, Frequency —————			— % —
Prickly lettuce	<u>Lactuca scariola</u>	55,3/4	52,2/4	59,2/4	57
Common ragweed	<u>Ambrosia artemisiifolia</u>	17,4/4	19,4/4	15,4/4	16
Common lambsquarter	<u>Chenopodium album</u>	9,3/4	20,4/4	13,4/4	14
Whiteheath aster	<u>Aster pilosus</u>	9,1/4	4,1/4	5,2/4	6
Horseweed	<u>Conyza canadensis</u>	0,0/4	4,1/4	7,2/4	5
Curly dock	<u>Rumex crispus</u>	8,2/4	0,0/4	0,0/4	1
Others		2	1	1	1

treatments and timings of application. Several general observations regarding these results can be made as follows: First, timing of application (weed size) did not have a significant effect on overall weed control. Second, the effectiveness of the four non-selective herbicides was of the general order: HOE-0661 > cyanazine > paraquat > glyphosate. Finally, the addition of either 2,4-D or dicamba generally improved overall weed control.

In the 1984 Fluvanna County experiment, the weed infestation was moderate and consisted primarily of buckhorn plantain and field bindweed, perennial, broadleaf species and of wild mustard, a winter annual (Table 3). The soil moisture conditions were dry at the early application timing, very dry for the mid application timing, and moist for the late application timing. Visual observations of overall weed control (Table 7) show that, in the early timing, all non-selective herbicides provided only poor to fair weed control, where control afforded by the paraquat treatment alone was significantly worse than that provided by glyphosate treatment alone. The addition of 2,4-D or dicamba generally resulted in improved overall weed control relative to application of non-selective herbicides alone in this timing, and gave significant increases in overall weed control in the paraquat plus 2,4-D and HOE-0661 plus dicamba treatments. The mid timing results were similar to those observed in the early timing except that control with glyphosate combinations tended to decrease slightly and no additional control was observed when dicamba was tank-mixed with HOE-0661 relative to the HOE-0661 treatments applied alone. Both the addition of 2,4-D and dicamba to cyanazine resulted in increased overall weed control relative to cyanazine applied alone in the mid timing. Overall control with

Table 7. Effect of herbicide treatment and timing of application on overall weed control in Fluvanna County, Va., 1984.

Treatment ¹	Timing ¹		
	Early	Mid	Late
	(% Control)		
Control	0.0 D (a)	0.0 D (a)	0.0 D (a)
Atrazine control	35.0 D (b)	58.0 C (ab)	65.0 C (a)
Paraquat	58.0 C (b)	65.0 C (ab)	80.0 ABC (a)
Paraquat + 2,4-D	80.0 B (a)	80.0 ABC (a)	83.0 AB (a)
Paraquat + dicamba	58.0 C (b)	73.0 BC (ab)	85.0 AB (a)
Cyanazine	68.0 BC (a)	70.0 BC (a)	75.0 BC (a)
Cyanazine + 2,4-D	83.0 AB (a)	90.0 A (a)	95.0 A (a)
Cyanazine + dicamba	88.0 AB (a)	90.0 A (a)	80.0 ABC (a)
Glyphosate	78.0 B (a)	73.0 ABC (a)	73.0 BC (a)
Glyphosate + 2,4-D	85.0 AB (a)	70.0 BC (a)	85.0 AB (a)
Glyphosate + dicamba	88.0 AB (a)	70.0 BC (a)	83.0 AB (a)
HOE-0661	73.0 BC (ab)	80.0 ABC (a)	60.0 C (b)
HOE-0661 + 2,4-D	88.0 AB (a)	85.0 AB (a)	80.0 AB (a)
HOE-0661 + dicamba	98.0 A (a)	80.0 ABC (b)	88.0 AB (ab)

¹Treatment means within a column followed by the same upper case letter and timing means within a row followed by the same lower case letter do not differ significantly at $\alpha = 0.05$ as determined by Duncan's multiple range test.

paraquat improved significantly over the early timing by the late planting, while control with HOE-0661 decreased significantly. The addition of dicamba and 2,4-D resulted in some degree of increase in overall weed control with all treatments, where significant increases were observed for the cyanazine plus 2,4-D and the HOE-0661 plus 2,4-D or dicamba treatments.

Total dry weight measurements from the 1984 Fluvanna County experiment (Table 8) were similar to those in visual evaluations. All herbicide treatments caused weed biomass to be reduced significantly relative to the control treatment. Within herbicide treatments, weed biomass values varied in a manner consistent with control values from visual observations, and showed slight increases in weed biomass in paraquat and paraquat plus dicamba treatments in the early timing, and a significant increase in weed biomass in the HOE-0661 treatment relative to other herbicide treatments in the late timing.

A heavy infestation was observed in 1984 Montgomery County experiments (Table 4) with the major weeds being buckhorn plantain and curly dock, both perennials, along with common ragweed and horseweed. Since analysis of variance showed no significant interactions between herbicide treatments and timing of applications, means and mean separation values are provided only for overall treatment and timing means (Table 9).

No significant effect of timing of application (weed size) was observed in this experiment. Significant differences among herbicide treatments were observed. HOE-0661 gave significantly better overall weed control than the other three non-selective herbicides when applied alone, with glyphosate providing the least control. All 2,4-D and

Table 8. Total weed dry weight, expressed as 100- percent of untreated at each timing as affected by herbicide treatment in Fluvanna County, Va., 1984.

Treatment ¹	Timing ¹		
	Early	Mid	Late
	(% Control)		
Control	0.0 C (a)	0.0 C (a)	0.0 C (a)
Atrazine control	52.0 B (b)	64.0 B (b)	80.0 AB (a)
Paraquat	74.0 AB (b)	86.0 A (a)	95.0 A (a)
Paraquat + 2,4-D	93.0 A (a)	100.0 A (a)	100.0 A (a)
Paraquat + dicamba	75.0 AB (b)	91.0 A (a)	100.0 A (a)
Cyanazine	86.0 A (a)	84.0 A (a)	95.0 A (a)
Cyanazine + 2,4-D	92.0 A (a)	99.0 A (a)	100.0 A (a)
Cyanazine + dicamba	100.0 A (a)	100.0 A (a)	100.0 A (a)
Glyphosate	82.0 A (a)	83.0 A (a)	99.0 A (a)
Glyphosate + 2,4-D	88.0 A (a)	91.0 A (a)	100.0 A (a)
Glyphosate + dicamba	94.0 A (a)	74.0 AB (b)	95.0 A (a)
HOE-0661	92.0 A (a)	96.0 A (a)	70.0 B (b)
HOE-0661 + 2,4-D	96.0 A (a)	98.0 A (a)	100.0 A (a)
HOE-0661 + dicamba	100.0 A (a)	90.0 A (a)	100.0 A (a)

¹Treatment means within a column followed by the same upper case letter and timing means within a row followed by the same lower case letter do not differ significantly at $\alpha = 0.05$ as determined by Duncan's multiple range test.

Table 9. Effect of herbicide treatment and timing of application on overall weed control in Montgomery County, Va., 1984.

Treatment ¹	Timing ¹			Mean
	Early	Mid	Late	
(% Control)				
Control	0.0	0.0	0.0	0.0 G
Atrazine control	50.0	54.0	59.0	54.0 F
Paraquat	85.0	85.0	76.0	82.0 CD
Paraquat + 2,4-D	87.5	87.0	92.5	89.0 ABC
Paraquat + dicamba	87.5	92.0	91.5	90.3 ABC
Cyanazine	71.0	93.0	89.0	84.5 BCD
Cyanazine + 2,4-D	88.0	95.0	92.0	91.0 AB
Cyanazine + dicamba	86.0	90.0	92.5	89.5 ABC
Glyphosate	77.5	77.5	76.0	77.0 E
Glyphosate + 2,4-D	86.0	91.0	84.0	87.0 ABC
Glyphosate + dicamba	79.0	84.0	77.5	80.0 DE
HOE-0661	95.5	94.0	94.0	94.0 A
HOE-0661 + 2,4-D	96.5	96.0	94.0	95.0 A
HOE-0661 + dicamba	95.0	91.0	95.5	94.0 A
Mean (Timings) ¹	77.5 A	80.6 A	79.6 A	

¹Treatment means and timing means followed by the same letter do not differ significantly at $\alpha = 0.05$ as determined by Duncan's multiple range test.

dicamba combinations improved overall weed control slightly, but a significant increase in overall weed control was observed only in the glyphosate plus 2,4-D treatment. All HOE-0661 treatments resulted in excellent weed control in all timings of application.

Total dry weight measurements from the 1984 Montgomery County experiment (Table 10) were similar to those observed in evaluations of overall weed control relative to herbicide treatments. Although herbicide treatments did not significantly affect dry weight yields of weeds, HOE-0661 treatments tended to produce lower sample yields, while glyphosate treatments resulted in higher yields. A significant difference was observed for weed biomass yields for the timing of herbicide applications with the largest weights in the later timing.

The 1985 Fluvanna County study had the lightest weed infestation of the four experiments, where common ragweed, giant foxtail, buckhorn plantain, and horseweed comprised the infestation (Table 5). Wild mustard was a major component of the infestation only in the early planting date. Glyphosate provided significantly lower levels of overall weed control than the other non-selective herbicides at the early timing (Table 11). This result can be attributed to the lack of control of wild mustard with glyphosate treatments in the early application timing (Table 21) discussed below. In the later two planting dates, overall weed control was good to excellent, with little or no advantage in overall weed control observed from 2,4-D or dicamba tank mix combinations relative to application of non-selective herbicides alone. No significant effects of timing of application on overall weed control were observed in this experiment except in the glyphosate and glyphosate plus dicamba treatments, where the lack of wild mustard

Table 10. Total dry weight, expressed as 100- percent of untreated at each timing, as affected by herbicide treatment in Montgomery County, Va., 1984.

Treatment ¹	Timing ¹			Mean
	Early	Mid	Late	
(% Control)				
Control ²	0.0	0.0	0.0	0.0 C
Atrazine control	92.0	41.0	39.0	57.0 B
Paraquat	100.0	70.0	69.0	80.0 AB
Paraquat + 2,4-D	99.0	84.0	85.0	89.0 A
Paraquat + dicamba	100.0	64.0	69.0	78.0 AB
Cyanazine	100.0	75.0	94.0	89.0 A
Cyanazine + 2,4-D	98.0	99.0	53.0	83.0 AB
Cyanazine + dicamba	100.0	44.0	60.0	68.0 AB
Glyphosate	97.0	84.0	42.0	74.0 AB
Glyphosate + 2,4-D	100.0	86.0	45.0	77.0 AB
Glyphosate + dicamba	100.0	79.0	54.0	78.0 AB
HOE-0661	100.0	100.0	70.0	90.0 AB
HOE-0661 + 2,4-D	100.0	96.0	98.0	91.0 A
HOE-0661 + dicamba	100.0	98.0	82.0	93.0 A
Means (timing) ²	92.0 A	73.0 B	60.0 C	

¹Treatment means and timing means followed by the same letter do not differ significantly at $\alpha = 0.05$ as determined by Duncan's multiple range test.

²Total weed dry weights for untreated plots were 542.0, 534.0 and 1988.0 for the early, mid and late timings, respectively.

Table 11. Effect of herbicide treatment and timing of application on overall weed control in Fluvanna County, Va., 1985.

Treatment ¹	Timing ¹		
	Early	Mid	Late
(% Control)			
Control	0.0 E (a)	0.0 D (a)	0.0 C (a)
Atrazine control	32.5 D (b)	57.5 C (a)	60.0 B (a)
Paraquat	95.0 AB (a)	98.8 A (a)	92.5 A (a)
Paraquat + 2,4-D	97.5 A (a)	96.3 AB (a)	98.8 A (a)
Paraquat + dicamba	98.8 A (a)	95.0 AB (a)	98.8 A (a)
Cyanazine	96.3 AB (a)	91.3 AB (a)	97.5 A (a)
Cyanazine + 2,4-D	95.0 AB (a)	95.0 AB (a)	100.0 A (a)
Cyanazine + dicamba	95.0 AB (a)	85.0 B (a)	98.8 A (a)
Glyphosate	62.5 C (b)	90.0 AB (a)	95.0 A (a)
Glyphosate + 2,4-D	83.8 B (a)	85.0 B (a)	95.0 A (a)
Glyphosate + dicamba	70.0 BC (b)	88.8 AB (a)	97.5 A (a)
HOE-0661	97.5 A (a)	98.8 A (a)	100.0 A (a)
HOE-0661 + 2,4-D	91.3 AB (a)	95.0 AB (a)	100.0 A (a)
HOE-0661 + dicamba	96.3 AB (a)	96.3 AB (a)	100.0 A (a)

¹Treatment means within a column followed by the same upper case letter and timing means within a row followed by the same lower case letter do not differ significantly at $\alpha = 0.05$ as determined by Duncan's multiple range test.

control discussed above resulted in significantly lower levels of control than in the mid and late timings.

Total dry weight measurements from the 1985 Fluvanna County experiment (Table 12) reflect the low overall weed pressure observed in this experiment relative to the 1984 Fluvanna County experiment and the Montgomery County experiments. In the early application timing, all herbicide treatments reduced weed biomass values relative to those observed in the control and atrazine control treatments. Glyphosate treatments in the early application timing resulted in large harvests of weeds in the sample area, while no weeds were harvested from paraquat, cyanazine, or HOE-0661 treatments. This result is reflected in the relatively low overall control values observed for these treatments in visual evaluations. No appreciable weed harvest was made from the sample area in either the mid or late application timings except for paraquat plus 2,4-D and glyphosate plus 2,4-D in the mid timing.

The heaviest overall weed infestation occurred in the 1985 Montgomery County experiment (Table 13), where prickly lettuce, common ragweed, horseweed, common lambsquarters, and other annual species provided the majority of the weed infestation (Table 6). HOE-0661 and cyanazine provided good to excellent overall weed control in all three timings when applied alone, and slight, but insignificant, increases in overall weed control were observed when 2,4-D or dicamba were applied in combination with these herbicides. Paraquat and paraquat tank mixes also provided good to excellent control at all three timings except for paraquat alone in the late timing where only 77.5% of the weeds were controlled. Again, the addition of 2,4-D and dicamba to the tank mix improved overall, but generally not significantly. Glyphosate and

Table 12. Total weed dry weight, expressed as 100- percent of untreated at each timing, as affected by herbicide treatment in Fluvanna County, Va., 1985.

Treatment ¹	Timing ¹		
	Early	Mid	Late
	(% Control)		
Control	0.0 B (a)	0.0 C (a)	0.0 B (a)
Atrazine control	29.0 B (b)	73.0 A (a)	87.0 A (a)
Paraquat	100.0 A (a)	100.0 A (a)	100.0 A (a)
Paraquat + 2,4-D	100.0 A (a)	69.0 AB (a)	100.0 A (a)
Paraquat + dicamba	100.0 A (a)	100.0 A (a)	100.0 A (a)
Cyanazine	100.0 A (a)	100.0 A (a)	100.0 A (a)
Cyanazine + 2,4-D	100.0 A (a)	100.0 A (a)	100.0 A (a)
Cyanazine + dicamba	100.0 A (a)	96.0 A (a)	100.0 A (a)
Glyphosate	83.0 A (a)	100.0 A (a)	100.0 A (a)
Glyphosate + 2,4-D	88.0 A (a)	58.0 B (b)	100.0 A (a)
Glyphosate + dicamba	83.0 A (a)	100.0 A (a)	100.0 A (a)
HOE-0661	100.0 A (a)	100.0 A (a)	100.0 A (a)
HOE-0661 + 2,4-D	100.0 A (a)	100.0 A (a)	100.0 A (a)
HOE-0661 + dicamba	100.0 A (a)	100.0 A (a)	100.0 A (a)

¹Treatment means within a column followed by the same upper case letter and timing means within a row followed by the same lower case letter do not differ significantly at $\alpha = 0.05$ as determined by Duncan's multiple range test.

Table 13. Effect of herbicide treatment and timing of application on overall weed control in Montgomery County, Va., 1985.

Treatment ¹	Timing ¹		
	Early	Mid	Late
(% Control)			
Control	0.0 D (a)	0.0 D (a)	0.0 E (a)
Atrazine control	64.0 C (a)	25.0 C (b)	52.5 D (a)
Paraquat	90.0 AB (a)	95.0 A (a)	77.5 C (b)
Paraquat + 2,4-D	91.3 AB (a)	96.3 A (a)	85.0 BC (a)
Paraquat + dicamba	97.5 A (a)	92.5 A (a)	87.5 ABC (a)
Cyanazine	92.5 AB (a)	86.3 AB (a)	92.5 AB (a)
Cyanazine + 2,4-D	96.3 A (a)	96.3 A (a)	98.8 A (a)
Cyanazine + dicamba	93.8 AB (a)	90.0 A (a)	95.0 AB (a)
Glyphosate	82.5 B (a)	86.3 AB (a)	82.5 BC (a)
Glyphosate + 2,4-D	82.5 B (a)	90.0 A (a)	92.5 AB (a)
Glyphosate + dicamba	86.3 AB (a)	75.0 B (b)	78.8 C (ab)
HOE-0661	95.0 A (a)	97.5 A (a)	92.5 AB (a)
HOE-0661 + 2,4-D	97.5 A (a)	96.3 A (a)	95.0 A (a)
HOE-0661 + dicamba	93.8 AB (a)	97.5 A (a)	98.8 A (a)

¹Treatment means within a column followed by the same upper case letter and timing means within a row followed by the same lower case letter do not differ significantly at $\alpha = 0.05$ as determined by Duncan's multiple range test.

glyphosate plus 2,4-D combinations gave overall weed control which ranged from 82.5% to 92.5% control over all three timings. Weed control with the glyphosate plus dicamba treatment decreased significantly from the early planting (86.3%) to the mid planting (75.0%), then increased slightly in the late planting (78.8%).

Total dry weight measurements from the 1985 Montgomery County experiment (Table 14) demonstrate results similar to those observed from visual evaluations. In the early timing little or no weed growth was present in samples from plots containing herbicide treatments. Plots treated with glyphosate plus dicamba in the mid timing produced significantly more biomass than the other herbicide treatments. This result is confirmed by results discussed above with reference to overall visual evaluations. Similar comparisons can be made with paraquat plus 2,4-D treatments in the late timing, where paraquat plus dicamba gave significantly lower weed dry weight values relative to paraquat plus 2,4-D.

Individual Weed Studies

In addition to overall evaluations of weed control, the control of individual weed species was evaluated. Discussed below are results of these evaluations for individual weed species which represented significant proportions of the weed infestation at a given location and which are agronomically important weeds in no-till corn establishment.

Horseweed. Control of horseweed with paraquat was variable in these experiments, with results similar to those which have been reported by other researchers (6, 50, 78). Horseweed control with paraquat and paraquat plus 2,4-D treatments in the 1984 Montgomery County test (Table 15) was 70% in the early application timing. In the same timing, cyanazine provided only 30% control of this species. All other

Table 14. Total weed dry weights, expressed as 100- percent of untreated at each timing, as affected by herbicide treatment in Montgomery County, Va., 1985.

Treatment ¹	Timing ¹		
	Early	Mid	Late
	————— (% Control) —————		
Control ²	0.0 B (a)	0.0 C (a)	236.0 C (b)
Atrazine control	87.0 A (a)	76.0 AB (a)	89.0 AB (a)
Paraquat	100.0 A (a)	100.0 A (a)	81.0 AB (a)
Paraquat + 2,4-D	100.0 A (a)	95.0 A (a)	74.0 BC (b)
Paraquat + dicamba	100.0 A (a)	100.0 A (a)	94.0 A (a)
Cyanazine	100.0 A (a)	99.0 A (a)	92.0 AB (a)
Cyanazine + 2,4-D	100.0 A (a)	95.0 A (a)	99.0 A (a)
Cyanazine + dicamba	100.0 A (a)	90.0 A (a)	86.0 AB (a)
Glyphosate	99.0 A (a)	97.0 A (a)	94.0 A (a)
Glyphosate + 2,4-D	100.0 A (a)	100.0 A (a)	98.0 A (a)
Glyphosate + dicamba	100.0 A (a)	21.0 BC (b)	92.0 AB (a)
HOE-0661	100.0 A (a)	100.0 A (a)	96.0 A (a)
HOE-0661 + 2,4-D	100.0 A (a)	100.0 A (a)	99.0 A (a)
HOE-0661 + dicamba	100.0 A (a)	96.0 A (a)	100.0 A (a)

¹Treatment means within a column followed by the same upper case letter and timing means within a row followed by the same lower case letter do not differ significantly at $\alpha = 0.05$ as determined by Duncan's multiple range test.

²Total weed dry weights for untreated plots were 79.0, 102.0 and 236.0 for early, mid and late timings, respectively.

cyanazine treatments and all HOE-0661 treatments gave 100% horseweed control in all three timings. Glyphosate also gave 99%-100% control in all timings and in all combinations except for early and mid timing with glyphosate alone where control was 87% and 89%, respectively.

In the 1985 Montgomery County experiment (Table 16), paraquat provided 95% and 96% horseweed control, respectively, in the early and mid application timings, where horseweed was 5-17 and 10-35 cm tall, respectively, but provided only 85% control in the late planting where horseweed was 35-75 cm tall. Similar results were observed with the paraquat plus 2,4-D tank mix. All other non-selective herbicide treatments provided good to excellent horseweed control, where HOE-0661 provided 98% or greater control in all herbicide treatments and timings of application. Timing of application in this experiment was only observed to be a significant factor within the paraquat treatments, as described above, and in the mid treatments with cyanazine and glyphosate plus dicamba.

These results indicate that excellent horseweed control may be obtained with HOE-0661, glyphosate and cyanazine alone, or in a tank mix with either 2,4-D or dicamba. Paraquat plus dicamba also provides excellent horseweed control while paraquat and paraquat plus 2,4-D treatments provide only variable horseweed control.

Field bindweed Field bindweed, a deep-rooted perennial, was present only in the 1984 Fluvanna County experiment. No significant effect of timing of herbicide application on control of this species was observed (Table 17). Glyphosate provided 97%, 86% and 92% control of field bindweed when applied alone, in the early, mid and late plantings,

Table 15. Effect of herbicide treatment and timing of application on horseweed control in Montgomery County, Va., 1984.

Treatment ¹	Timing ¹		
	Early	Mid	Late
	(% Control)		
Control	0.0 D (a)	0.0 D (a)	0.0 C (a)
Atrazine control	3.0 D (c)	42.0 C (b)	74.0 B (a)
Paraquat	70.0 B (a)	76.0 B (a)	75.0 B (a)
Paraquat + 2,4-D	63.0 B (b)	86.0 AB (ab)	100.0 A (a)
Paraquat + dicamba	100.0 A (a)	95.0 A (a)	100.0 A (a)
Cyanazine	30.0 C (b)	100.0 A (a)	100.0 A (a)
Cyanazine + 2,4-D	100.0 A (a)	100.0 A (a)	100.0 A (a)
Cyanazine + dicamba	100.0 A (a)	100.0 A (a)	100.0 A (a)
Glyphosate	87.0 AB (a)	89.0 AB (a)	100.0 A (a)
Glyphosate + 2,4-D	100.0 A (a)	100.0 A (a)	100.0 A (a)
Glyphosate + dicamba	100.0 A (a)	100.0 A (a)	99.0 A (a)
HOE-0661	100.0 A (a)	100.0 A (a)	100.0 A (a)
HOE-0661 + 2,4-D	100.0 A (a)	100.0 A (a)	100.0 A (a)
HOE-0661 + dicamba	100.0 A (a)	100.0 A (a)	100.0 A (a)

¹Treatment means within a column followed by the same upper case letter and timing means within a row followed by the same lower case letter do not differ significantly at $\alpha = 0.05$ as determined by Duncan's multiple range test.

Table 16. Effect of herbicide treatment and timing of application on horseweed control in Montgomery County, Va., 1985.

Treatment ¹	Timing ¹		
	Early	Mid	Late
	(% Control)		
Control	0.0 C (a)	0.0 D (a)	0.0 D (a)
Atrazine control	15.0 B (b)	10.0 C (b)	30.0 C (a)
Paraquat	95.0 A (a)	96.0 AB (a)	85.0 B (b)
Paraquat + 2,4-D	98.0 A (a)	93.0 AB (a)	82.0 B (b)
Paraquat + dicamba	99.0 A (a)	93.0 AB (a)	97.0 A (a)
Cyanazine	98.0 A (a)	89.0 B (b)	98.0 A (a)
Cyanazine + 2,4-D	100.0 A (a)	99.0 A (a)	100.0 A (a)
Cyanazine + dicamba	100.0 A (a)	99.0 A (a)	100.0 A (a)
Glyphosate	94.0 A (a)	90.0 AB (a)	100.0 A (a)
Glyphosate + 2,4-D	93.0 A (a)	98.0 A (a)	100.0 A (a)
Glyphosate + dicamba	98.0 A (ab)	89.0 B (b)	100.0 A (a)
HOE-0661	100.0 A (a)	98.0 A (a)	100.0 A (a)
HOE-0661 + 2,4-D	100.0 A (a)	100.0 A (a)	100.0 A (a)
HOE-0661 + dicamba	100.0 A (a)	100.0 A (a)	100.0 A (a)

¹Treatment means within a column followed by the same upper case letter and timing means within a row followed by the same lower case letter do not differ significantly at $\alpha = 0.05$ as determined by Duncan's multiple range test.

respectively. Field bindweed at these three timings was 15-20, 20-38, and 30-55 cm in length. HOE-0661 also provided acceptable control in the early and mid plantings, 93% and 91%, respectively, but provided only 74% in the late timings. The addition of either 2,4-D or dicamba to the four non-selective herbicides generally increased the control of field bindweed in all three timings if not significantly.

Curly dock. Curly dock control (Table 18) in the 1984 Montgomery County experiment was not significantly affected by timing of herbicide application, although control tended to decrease at the late application timing. Growth stages of this species were vegetative, early bloom, pod and late bloom - seed formation at the early, mid and late timings, respectively. The HOE-0661 treatments provided the best overall curly dock control, with control values of 93%-96%, while other treatments gave 69% to 90% control of this species.

Prickly lettuce. In the 1985 Montgomery County experiment, control of prickly lettuce (Table 19) with glyphosate was dependent on the timing of application due to increases in weed size over time. Prickly lettuce was 10-35 cm, 20-60 cm, and 30-150 cm tall at early, mid and late timings, respectively. Control with glyphosate was 100% on 10-35 cm prickly lettuce at the early timing, and 69% on 30-150 cm tall prickly lettuce at the late timing. The other three non-selective herbicides, when applied alone, provided excellent control in all timings. The only significant response to addition of 2,4-D or dicamba was observed in the glyphosate treatment, where control increased to 100% relative to 69% observed in response to treatment with glyphosate alone.

Table 17. Effect of herbicide treatment and timing of application on field bindweed control in Fluvanna County, Va., 1984.

Treatment ¹	Timing ¹		
	Early	Mid	Late
	(% Control)		
Control	0.0 E (a)	0.0 D (a)	0.0 C (a)
Atrazine control	25.0 D (c)	55.0 C (b)	86.0 AB (a)
Paraquat	76.0 BC (a)	70.0 B (a)	87.0 AB (a)
Paraquat + 2,4-D	92.0 ABC (a)	97.0 A (a)	98.0 A (a)
Paraquat + dicamba	94.0 AB (a)	97.0 A (a)	97.0 A (a)
Cyanazine	82.0 B (a)	78.0 B (a)	85.0 AB (a)
Cyanazine + 2,4-D	94.0 AB (a)	98.0 A (a)	100.0 A (a)
Cyanazine + dicamba	98.0 AB (a)	96.0 A (a)	84.0 AB (a)
Glyphosate	97.0 AB (a)	86.0 AB (a)	92.0 AB (a)
Glyphosate + 2,4-D	96.0 AB (a)	98.0 A (a)	96.0 AB (a)
Glyphosate + dicamba	99.0 A (a)	98.0 A (a)	100.0 A (a)
HOE-0661	93.0 ABC (a)	91.0 A (a)	74.0 B (b)
HOE-0661 + 2,4-D	96.0 AB (a)	97.0 A (a)	97.0 A (a)
HOE-0661 + dicamba	99.0 A (a)	98.0 A (a)	98.0 A (a)

¹Treatment means within a column followed by the same upper case letter and timing means within a row followed by the same lower case letter do not differ significantly at $\alpha = 0.05$ as determined by Duncan's multiple range test.

Table 18. Effect of herbicide treatment and timing of application on curly dock control in Montgomery County, Va., 1984.

Treatment ¹	Timing ¹			Mean
	Early	Mid	Late	
(% Control)				
Control	0.0	0.0	0.0	0.0 F
Atrazine control	65.0	70.0	68.0	68.0 E
Paraquat	80.0	96.0	95.0	90.0 ABC
Paraquat + 2,4-D	74.0	88.0	76.0	79.0 BCD
Paraquat + dicamba	78.0	96.0	79.0	84.0 ABCD
Cyanazine	84.0	90.0	69.0	81.0 ABCD
Cyanazine + 2,4-D	96.0	81.0	72.0	83.0 ABCD
Cyanazine + dicamba	82.0	88.0	64.0	78.0 CDE
Glyphosate	83.0	79.0	55.0	72.0 D
Glyphosate + 2,4-D	96.0	86.0	66.0	82.0 ABCD
Glyphosate + dicamba	86.0	78.0	45.0	69.0 DE
HOE-0661	94.0	94.0	92.0	93.0 AB
HOE-0661 + 2,4-D	99.0	94.0	91.0	95.0 A
HOE-0661 + dicamba	100.0	98.0	90.0	96.0 A
Mean (Timings) ¹	79.7 A	81.0 A	68.7 A	

¹Treatment means and timing means followed by the same letter do not differ significantly at $\alpha = 0.05$ as determined by Duncan's multiple range test.

Table 19. Effect of herbicide treatment and timing of application on prickly lettuce control in Montgomery County, Va., 1985.

Treatment ¹	Timing ¹		
	Early	Mid	Late
	(% Control)		
Control	0.0 B (a)	0.0 C (a)	0.0 D (a)
Atrazine control	100.0 A (a)	45.0 B (b)	45.0 C (b)
Paraquat	100.0 A (a)	100.0 A (a)	92.0 A (a)
Paraquat + 2,4-D	100.0 A (a)	100.0 A (a)	90.0 A (a)
Paraquat + dicamba	100.0 A (a)	100.0 A (a)	96.0 A (a)
Cyanazine	100.0 A (a)	95.0 A (a)	92.0 A (a)
Cyanazine + 2,4-D	100.0 A (a)	100.0 A (a)	100.0 A (a)
Cyanazine + dicamba	100.0 A (a)	100.0 A (a)	95.0 A (a)
Glyphosate	100.0 A (a)	95.0 A (a)	69.0 B (b)
Glyphosate + 2,4-D	99.0 A (a)	99.0 A (a)	100.0 A (a)
Glyphosate + dicamba	100.0 A (a)	98.0 A (a)	100.0 A (a)
HOE-0661	100.0 A (a)	100.0 A (a)	90.0 A (a)
HOE-0661 + 2,4-D	100.0 A (a)	100.0 A (a)	100.0 A (a)
HOE-0661 + dicamba	98.0 A (a)	100.0 A (a)	100.0 A (a)

¹Treatment means within a column followed by the same upper case letter and timing means within a row followed by the same lower case letter do not differ significantly at $\alpha = 0.05$ as determined by Duncan's multiple range test.

Wild mustard. Wild mustard control was similar when compared in the two Fluvanna County experiments with respect to effects of herbicide treatments, but differences with respect to timing of application were observed. In the 1984 Fluvanna County Experiment (Table 20), all herbicide treatments gave good to excellent control in early application timings. As stated, the soil moisture conditions at the mid planting date were very dry in this experiment. Possibly due to reduced plant vigor associated with these soil conditions, wild mustard control generally decreased in the mid planting relative to the early timing. Significant reductions in wild mustard control were observed for all glyphosate treatments and for the HOE-0661 treatment applied alone in the mid application timing relative to the early application timing. By the late application timing, soil moisture conditions had improved, along with a general increase in control values for this species. In the late application timing, all paraquat and cyanazine treatments gave 100% control of wild mustard. At this timing, the glyphosate treatment only provided 65% control of this species. The addition of dicamba to glyphosate and HOE-0661 resulted in significant increases in wild mustard control relative to applications of glyphosate and HOE-0661 alone in the late application timing. Similar results were observed in the 1985 Fluvanna County experiment (Table 21) where paraquat, cyanazine and HOE-0661 treatments provided good to excellent control over all three timings. Wild mustard control was variable with glyphosate treatments, however, where only poor to fair control of this species was observed in early and mid application timings.

Table 20. Effect of herbicide treatment and timing of application on wild mustard control in Fluvanna County, Va., 1984.

Treatment ¹	Timing ¹		
	Early	Mid	Late
	(% Control)		
Control	0.0 B (a)	0.0 D (b)	0.0 C (a)
Atrazine control	100.0 A (a)	23.0 D (b)	85.0 AB (a)
Paraquat	100.0 A (a)	100.0 A (a)	100.0 A (a)
Paraquat + 2,4-D	96.0 A (a)	80.0 A (a)	100.0 A (a)
Paraquat + dicamba	100.0 A (a)	100.0 A (a)	100.0 A (a)
Cyanazine	100.0 A (a)	97.0 A (a)	100.0 A (a)
Cyanazine + 2,4-D	100.0 A (a)	85.0 A (a)	100.0 A (a)
Cyanazine + dicamba	100.0 A (a)	95.0 A (a)	100.0 A (a)
Glyphosate	100.0 A (a)	51.0 BC (b)	65.0 B (b)
Glyphosate + 2,4-D	90.0 A (a)	56.0 BC (b)	83.0 AB (a)
Glyphosate + dicamba	100.0 A (a)	32.0 C (b)	87.0 A (a)
HOE-0661	100.0 A (a)	68.0 AB (b)	75.0 B (b)
HOE-0661 + 2,4-D	100.0 A (a)	98.0 A (a)	73.0 B (b)
HOE-0661 + dicamba	100.0 A (a)	92.0 A (a)	100.0 A (a)

¹Treatment means within a column followed by the same upper case letter and timing means within a row followed by the same lower case letter do not differ significantly at $\alpha = 0.05$ as determined by Duncan's multiple range test.

Table 21. Effect of herbicide treatment and timing of application on wild mustard control in Fluvanna County, Va., 1985.

Treatment ¹	Timing ¹		
	Early	Mid	Late
	(% Control)		
Control	0.0 C (a)	0.0 D (a)	0.0 B (a)
Atrazine control	20.0 C (c)	42.0 C (b)	100.0 A (a)
Paraquat	92.0 A (a)	98.0 A (a)	100.0 A (a)
Paraquat + 2,4-D	95.0 A (a)	98.0 A (a)	100.0 A (a)
Paraquat + dicamba	98.0 A (a)	96.0 A (a)	100.0 A (a)
Cyanazine	92.0 A (a)	97.0 A (a)	100.0 A (a)
Cyanazine + 2,4-D	94.0 A (a)	95.0 A (a)	100.0 A (a)
Cyanazine + dicamba	92.0 A (a)	85.0 AB (a)	95.0 A (a)
Glyphosate	40.0 B (b)	43.0 C (b)	100.0 A (a)
Glyphosate + 2,4-D	82.0 A (ab)	65.0 B (b)	100.0 A (a)
Glyphosate + dicamba	42.0 B (b)	88.0 A (a)	92.0 A (a)
HOE-0661	92.0 A (a)	95.0 A (a)	100.0 A (a)
HOE-0661 + 2,4-D	84.0 A (a)	80.0 AB (a)	100.0 A (a)
HOE-0661 + dicamba	90.0 A (a)	89.0 A (a)	100.0 A (a)

¹Treatment means within a column followed by the same upper case letter and timing means within a row followed by the same lower case letter do not differ significantly at $\alpha = 0.05$ as determined by Duncan's multiple range test.

Glyphosate in the previous study, when applied alone, gave 100%, 51% and 65% wild mustard control in early, mid, and late timing of applications, respectively (Table 20). In 1985 (Table 21), glyphosate's control of this species was 40%, 43%, and 100% for these three timings, almost the reverse of the 1984 results for this species. The differences between results of the two studies were probably due to weed size and growth stage at timing of applications. Wild mustard growth stages in 1984 were early bloom, full flowering-early silique formation and early seed formation at early, mid and late timing of application, respectively. In 1985, growth stages were late bloom - early silique formation, seed formation, and late seed formation - senescence at early, mid and late timings, respectively. The 1984 mid timing is similar to 1985's early timing in both weed size and stage of growth, and control values at these timings are similar, 51% and 40%, respectively. The 1984 late timing and the 1985 mid timing are similar again in terms of weed size and development where control values are 65% and 43% control, respectively. Wild mustard was completely controlled by glyphosate at the early timing in 1984 and at late timing in 1985. In the early 1984 timing, wild mustard was in a vegetative stage of growth and actively growing; thus, glyphosate was probably readily translocated, resulting in improved control, while in the late 1985 timing wild mustard was already in the late seed formation to early senescence stage, and by 21 days after treatment, most of the plants had completed their life cycle.

Buckhorn plantain. Buckhorn plantain was a major component of the infestation weed in 1984 at both experimental locations (Tables 4 and 6). The Montgomery study (Table 22) showed that the timing of herbicide applications resulted in significant differences in buckhorn plantain

Table 22. Effect of herbicide treatment and timing of applications on buckhorn plantain control in Montgomery County, Va., 1984.

Treatment ¹	Timing ¹			Mean ¹
	Early	Mid	Late	
(% Control)				
Control	0.0	0.0	0.0	0.0
Atrazine	47.0	68.0	100.0	74.0 E
Paraquat	76.0	82.0	82.0	81.0 DE
Paraquat + 2,4-D	76.0	78.0	100.0	85.0 CDE
Paraquat + dicamba	60.0	91.0	100.0	84.0 DE
Cyanazine	100.0	100.0	100.0	100.0 A
Cyanazine + 2,4-D	100.0	100.0	100.0	100.0 A
Cyanazine + dicamba	85.0	100.0	100.0	97.0 ABC
Glyphosate	69.0 B	95.0 A	100.0 A	90.0 ABCD
Glyphosate + 2,4-D	96.0	100.0	100.0	99.0 AB
Glyphosate + dicamba	70.0	88.0	100.0	86.0 BCDE
HOE-0661	96.0	98.0	100.0	98.0 ABC
HOE-0661 + 2,4-D	90.0	100.0	100.0	98.0 ABC
HOE-0661 + dicamba	90.0	99.0	100.0	97.0 ABC
Mean (Timings) ¹	73.3 B	85.5 AB	91.6 A	

¹Treatment means and timing means within a column followed by the same letter do not differ significantly at $\alpha = 0.05$ as determined by Duncan's multiple range test.

control between early and late timings. This difference in control is primarily due to the lack of control with paraquat and glyphosate treatments in the early timing. Buckhorn plantain sizes in the Montgomery experiment were 12-20, 16-20, and 19-26 cm tall at early, mid, and late application timings, respectively. At the Fluvanna location, buckhorn plantain sizes were 10-15, 20-25, and 20-38 cm tall at early, mid and late timings, respectively. Cyanazine and HOE-0661 treatments provided excellent plantain control, as did the glyphosate plus 2,4-D treatment. The three paraquat treatments afforded the least control, 85% or less, followed by the glyphosate plus dicamba treatment. The addition of 2,4-D was generally, but not significantly, more effective than dicamba in controlling plantain with all four non-selective herbicides.

Control of buckhorn plantain was similar to that obtained in the Montgomery County study, especially with respect to treatment effects (Table 23). Paraquat, again, provided fair to good control in the early timing, while glyphosate, cyanazine and HOE-0661 gave excellent control of this species. The mid timing of application in the 1984 Fluvanna experiment again appeared to be affected by the very dry soil moisture conditions, where control levels decreased slightly relative to the early timing in most treatments, and decreased significantly in the cyanazine and glyphosate treatments when applied alone. These results also indicate that 2,4-D was generally more effective than dicamba as an addition to the non-selective herbicide at the mid application timing. By the late planting date, soil moisture conditions had improved and plantain was effectively controlled with all herbicide treatments.

Table 23. Effect of herbicide treatment and timing of application on buckhorn plantain control in Fluvanna County, Va., 1984.

Treatment ¹	Timing ¹		
	Early	Mid	Late
	(% Control)		
Control	0.0 C (a)	0.0 E (a)	0.0 B (a)
Atrazine control	70.0 B (b)	28.0 D (c)	90.0 A (a)
Paraquat	80.0 AB (ab)	62.0 BC (b)	98.0 A (a)
Paraquat + 2,4-D	81.0 AB (a)	89.0 AB (a)	87.0 A (a)
Paraquat + dicamba	57.0 B (b)	60.0 BC (b)	97.0 A (a)
Cyanazine	96.0 A (ab)	78.0 BC (b)	99.0 A (a)
Cyanazine + 2,4-D	98.0 A (a)	98.0 A (a)	100.0 A (a)
Cyanazine + dicamba	99.0 A (a)	90.0 AB (a)	100.0 A (a)
Glyphosate	91.0 A (a)	68.0 BC (b)	88.0 A (ab)
Glyphosate + 2,4-D	98.0 A (a)	79.0 ABC (a)	98.0 A (a)
Glyphosate + dicamba	98.0 A (a)	67.0 BC (b)	93.0 A (a)
HOE-0661	100.0 A (a)	91.0 AB (a)	84.0 A (a)
HOE-0661 + 2,4-D	100.0 A (a)	98.0 A (a)	98.0 A (a)
HOE-0661 + dicamba	100.0 A (a)	79.0 ABC (a)	98.0 A (a)

¹Treatment means within a column followed by the same upper case letter and timing means within a row followed by the same lower case letter do not differ significantly at $\alpha = 0.05$ as determined by Duncan's multiple range test.

Common ragweed. Common ragweed was present in all four experiments, with the heaviest and most uniform pressure in the 1985 Fluvanna County study (Table 3). The data from this study (Table 24) are representation of data from the other three experiments, and show that all the herbicide treatments provided excellent common ragweed control regardless of application timing and weed size which ranged from 1-12, 1-20, and 1-30 cm at early, mid and late application timings, respectively.

Table 24. Effect of herbicide treatment and timing of application on common ragweed control in Fluvanna County, Va., 1985.

Treatment ¹	Timing ¹		
	Early	Mid	Late
	(% Control)		
Control	0.0 B (a)	0.0 C (a)	0.0 B (c)
Atrazine control	100.0 A (a)	54.0 B (b)	93.0 A (a)
Paraquat	100.0 A (a)	100.0 A (a)	100.0 A (a)
Paraquat + 2,4-D	100.0 A (a)	100.0 A (a)	100.0 A (a)
Paraquat + dicamba	100.0 A (a)	100.0 A (a)	100.0 A (a)
Cyanazine	100.0 A (a)	100.0 A (a)	100.0 A (a)
Cyanazine + 2,4-D	100.0 A (a)	100.0 A (a)	100.0 A (a)
Cyanazine + dicamba	100.0 A (a)	100.0 A (a)	100.0 A (a)
Glyphosate	100.0 A (a)	100.0 A (a)	100.0 A (a)
Glyphosate + 2,4-D	100.0 A (a)	100.0 A (a)	100.0 A (a)
Glyphosate + dicamba	100.0 A (a)	100.0 A (a)	100.0 A (a)
HOE-0661	100.0 A (a)	100.0 A (a)	100.0 A (a)
HOE-0661 + 2,4-D	100.0 A (a)	100.0 A (a)	100.0 A (a)
HOE-0661 + dicamba	100.0 A (a)	100.0 A (a)	100.0 A (a)

¹Treatment means within a column followed by the same upper case letter and timing means within a row followed by the same lower case letter do not differ significantly at $\alpha = 0.05$ as determined by Duncan's multiple range test.

CONCLUSIONS

The results of these studies indicate that HOE-0661 at 0.84 kg/ha, cyanazine at 2.24 kg/ha, and glyphosate at 0.56 kg/ha compare favorably with paraquat at 0.56 kg/ha for control of vegetation existing at no-till corn establishment when applied alone or in combination with 2,4-D or dicamba. Applied alone, HOE-0661, cyanazine, and glyphosate provided superior control of horseweed and buckhorn plantain than paraquat. Wild mustard control with glyphosate was dependent upon weed size and growth stage while HOE-0661, cyanazine and paraquat provided excellent control of this species at any application timing. Control of field bindweed was acceptable with glyphosate and HOE-0661 alone, but where 2,4-D or dicamba was added to any of the four herbicides, field bindweed control was excellent.

Overall weed control effectiveness of the four herbicides was shown to be: HOE-0661 > cyanazine > paraquat > glyphosate under the conditions of these experiments. With the addition of either 2,4-D or dicamba to these non-selective herbicides, overall broadleaf weed control can be enhanced in some instances. The addition of 2,4-D generally improved the control of buckhorn plantain and curly dock while the addition of dicamba improved horseweed and wild mustard control. Together, these data indicate several good alternatives exist for a variety of weed species existing at no-till corn planting, and that control of these species can be accomplished across a range of weed sizes and growth stages.

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