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Common Windgrass (Apera spica-venti L.) Control
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**COMMON WINDGRASS (*APERA SPICA-VENTI* L.)
CONTROL IN MICHIGAN WINTER WHEAT**

By

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ABSTRACT

COMMON WINDGRASS (*Apera spica-venti* L.) CONTROL IN MICHIGAN WINTER WHEAT

by

Andrew James Chomas

Field research was conducted in 1992 to 1995 to evaluate the effectiveness of postplant incorporated trifluralin for the control of common windgrass in Michigan winter wheat. Trifluralin significantly reduced common windgrass densities in 1992-1993. Trifluralin applied at 0.56 kg/ha reduced common windgrass density by 85% and increased wheat yields by 32%. Significant wheat injury and stand reduction occurred in response to trifluralin incorporation in 1995. Wheat injury increased as trifluralin rate increased. Effect of incorporation implement on wheat injury was Fuerst harrow > spike tooth drag > rotary hoe. When shallowly incorporated, no significant wheat injury was observed at any site from 1992 to 1995 from trifluralin incorporation at the 0.56 kg/ha rate, when wheat was planted at least 5 cm deep.

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REVIEW OF LITERATURE

INTRODUCTION

Common windgrass (*Apera spica-venti* L.) is an alien weed species that has become widely distributed in North America. It successfully infests and reproduces in winter grain culture. Common windgrass has been in Michigan (U.S.A.) nearly one century, and during the past fifteen years it has caused concern as a crop weed. In Michigan (U.S.A.), it has increasingly become an economic concern to farmers growing winter wheat. Common windgrass is not widely distributed in Michigan, with major infestations primarily in Huron and Sanilac Counties. Infestations have also been reported in Saginaw County. Currently, no weed control strategy, neither mechanical nor chemical, is available in Michigan that will provide consistent control of common windgrass in winter wheat.

COMMON WINDGRASS

Name. *Apera spica-venti* L. In the United States this species is called common windgrass. In Canada it is referred to as loose silky bentgrass (15). Common windgrass, at times, has been included within *Agrostis*, the bentgrass genus. It is readily distinguished by using the key outlined in McNeill (15). In Michigan it is often confused with another plant *Agrostis gigantea* (Redtop) (9).

Description. Common windgrass may be easily distinguished from the fall cereals that it infests by its long prominent, membranous ligule and very narrow leaves. It generally overwinters in the two to three leaf stage (1, 16, 30,). According to Warwick et al. (30), it is an annual ranging from 20 to 100 cm in height. Culms are tufted or solitary, erect, slender, and smooth. Leaf blades are pointed and flat ranging from 7 to 25 cm long, 3 to 10 mm wide. The leaves are green, hairless or minutely hairy, and usually scabrous. The leaf sheaths are smooth or rough near the apex and are green or purple in color. The ligule ranges from 3 to 12 mm long and is membranous. Panicles have numerous scattered spikelets which are laterally compressed, one flowered, often purplish, 2.5 to 3.0 mm long and disarticulating above the glumes. Panicles are 10 to 25 cm long and 3 to 5 cm wide. Glumes are unequal in length, membranous, and pointed at the apex. They are also scabrous on the keel in the upper half. The lower glume is narrowly lanceolate and one nerved. The upper glume is oblong-lanceolate and three nerved. The lemma is slightly shorter than the upper glume, lanceolate-oblong, chartaceous, and minutely hairy at the base. Lemmas are finely five-nerved, having a long subapical straight or flexous awn, that is 5 to 12 mm long. The palea is two nerved and as long as the lemma. The floral axis (rachilla) extends as a slender filament beyond the floret. Anthers are 1 to 2 mm long. Grain is tightly enveloped between the hardened lemma and palea (30).

Biology. Common windgrass typically reproduces as a winter annual with only one generation per year (1, 14, 27, 30). Wallgren et al. (27) concluded that *Apera spica-venti* had peak germination in the autumn, with little or no germination during the following spring after the seeds were "stored" outdoors in the soil.

Common windgrass has one seed per spikelet. Plants have been reported to produce up to 2000 seeds per plant from the numerous panicles (30). Seed viability may range from one to seven years, but seldom exceeds two years (34). Seeds exhibit relatively little dormancy when freshly harvested. It was found that of mature seeds collected in Britain, about 50% of the seeds could germinate at harvest (14). Wallgren and Avholm (27) in Sweden found that primary dormancy was broken two to three weeks after shedding when the seeds were stored under dry conditions. Studies conducted in Czechoslovakia found that seeds collected from various years and locations showed very different percentages of germination (30).

Seeds of common windgrass germinate mostly at or near the soil surface (0 to 1 cm depths) and only have minimal emergence from depths greater than 1 cm (30). Aamisepp and Avholm (1) reported that no germination occurred when the seeds were placed at depths greater than 2 cm. The highest germination was obtained when seeds were placed at the soil surface.

The seeds also require moist to wet conditions to germinate (14). Wallgren and Aamisepp (26) found that common windgrass emerged best at a soil moisture of field capacity. Common windgrass germinates at all temperatures between 5 and 30°C (26).

Common windgrass seeds germinates in the fall and over-winter in the two to three leaf stage (26, 30). Wallgren and Aamisepp (26) report that seedlings emerge and develop synchronously with winter wheat. However, the period from pollination to maturity is more compressed in common windgrass and seed is usually shed before winter wheat is harvested (14). In Michigan, through personal observations, the same life cycle seems to occur. In Ontario (Canada), most of the seed is shed in summer from the mature plants before wheat is harvested (35). Wallgren and Avholm (27) note that the ability of common windgrass to germinate and establish seedlings in the autumn, with little germination in the spring, is probably one of the reasons for its importance as a weed in winter cereals.

Habitat. Common windgrass is primarily a winter annual thriving on sandy loam soils (14). It also grows on coarse textured soils (13). Northam and Callihan (13) in England noted common windgrass growing on sandy soils and Aamisepp and Avholm (13) in southern Sweden found high numbers of windgrass on loams and sandy loams.

The common windgrass in Michigan, southern Ontario, and its extensive distribution in Europe suggest that a mesic temperate condition seems favorable for common windgrass (16).

Distribution. Common windgrass is found in Great Britain but is much more prevalent in central Europe (14, 27, 30). It is also found in central Asia, northwestern Africa, Turkey and Caucasus region, and northwestern Iran (16). McNeill (15) reported *Apera spica-venti* was first identified in Canada in 1979 at a few farms. McNeill (15) also stated that *Apera spica-venti* has been found to be an introduction in North America and was not common until recently. Common windgrass was first found on ship ballast and waste lands in the northeastern United States (15).

Some early reports by Beal (3) made reference of *Apera spica-venti* in areas "near Lansing," Michigan (9). It was subsequently reported by Gereau and Rabeler (9) that in July 1980 a specimen submitted for identification from the "thumb" of Michigan was found to be *Apera spica-venti*. Gereau and Rabeler (9) also reported that given the seriousness of the problem in some Canadian sites, the abundance of *Apera spica-venti* at the Sanilac County, Michigan, site may give cause for agricultural concern. Further reports of *Apera spica-venti* existence in Michigan include Saginaw County (21). Visual observations in these regions, and personal correspondence with farmers, confirms that common windgrass has become more common in Michigan during the 1980s.

Control. Early chemical control measures for *Apera spica-venti* involved using calcium cyanamide (1, 34). Aamisepp and Avholm (1) reported that along with calcium cyanamid, dichlobenil (2,6-dichlorobenzonitrile) was also used. At the time of publication neither was still marketed in Sweden (1).

Studies conducted in a field demonstration using trifluralin (2,6-dinitro-N,N-dipropyl-4-4(trifluoromethyl)benzenamine) at 0.4 kg/ha with fall rye provided 91% control of common windgrass (35). Trifluralin has a minor use label for preemergence control of *Apera spica-venti* in fall cereals in Ontario and was registered in 1987 (35). Currently no chemical control options exist for effective control of common windgrass in the United States.

Common windgrass can easily be controlled by cultivating the soil in late autumn after the seed germinates (30). The problem arises that common windgrass usually germinates about the same time as winter annual cereal crops. Warwick et al. (30) also refer to studies that involve various cultural practices such as summer fallowing, crop rotation, and tillage to eliminate weed populations. The studies concluded that common windgrass populations may be reduced through these various practices. However, when intensive cereal cropping over a long period of time was conducted, an increase in *Apera spica-venti* population was realized (30).

WHEAT

History. Wheat is an important food crop worldwide. It can be found in our everyday foods such as cookies, pastas, and bread. A brief history as summarized by Smith (23) is given.

Rather than attempting to determine an exact origin, botanists, archaeologists, and geneticists have identified an area of evolution, cultivation, and early movement of wheat. The earliest evidence places wheat production utilizing diploid and tetra species around 8000 BC in an area known as the Fertile Crescent now in present day Iran and Iraq.

Early farming in 8000 BC in the Far East gives indication that early plant selection was taking place. Gathering the wheat and bringing it to a common thrashing site may have been the start of identifying non shattering mutations. Other plant selection criteria, including seed size, hardness, and number of inflorences, may have led to development of wheat as a potential food crop.

Wheat was introduced into New England by the Pilgrims in 1620. Early government wheat promotions were developed. As the years went on, various wheat cultivars were introduced. In 1844, 30 cultivars of wheat were grown in one county alone in New York State. Many cultivars were reported growing in Ohio by 1858. Many new cultivars were brought in with the immigrants looking for a new beginning (23).

Soft White vs. Soft Red Wheat. Michigan produced 234,726 ha of wheat in 1994 (7). Of the wheat planted, 70 to 75% is of the soft white winter class (5). Soft white wheat is also grown in Ontario, New York, and the Pacific Northwest. The other main class of wheat grown in Michigan is a soft red winter wheat and is prominent in southern Michigan (5, 8). Marketing is probably the key factor in choosing which class to grow. Since most elevators only buy soft white, producers grow primarily soft white varieties.

Spring vs. Winter Wheat. Most farmers in Michigan plant winter wheat. One reason is yield potential. Winter wheat generally yields 30% more than spring wheat (4). Other reasons include weed control and disease management. Hard winter wheat is predominately grown in the southern Great Plains of the United States (6). Hard red spring wheat is mostly grown in and around North and South Dakota (6). Distribution of winter wheat varieties are throughout the northeast United States and the Pacific Northwest (6).

Wheat Production. Wheat production in North America has doubled since 1950 (6). However, total hectarage over the past 35 years has remained constant and the increased production is attributed to changes in yield rather than changes in hectarage (6). Average wheat yields have doubled between 1949 and 1976, with average wheat yields in North America rising from 1010 to 2020 kg/ha, respectively (6). Wheat hectarage in the United States peaked prior to World War II and has not significantly grown since (6). Donald (6) gives several reasons: government programs, devoting less productive land to wheat, and economic considerations.

In 1985, Michigan averaged over 4000 kg/ha and was the highest average in the United States along with being the highest recorded state average for Michigan (4). In the past years, wheat hectarage in Michigan has trended down since the 1960s (8). Wheat yield reached a plateau in the 1980s and early 1990s and has been averaging about 3360 kg/ha (8). Michigan's loss in hectarage, from 445,000 ha in 1960 to 234,726 ha in 1995, was compensated by higher yields to maintain a constant production level (8). Michigan has the potential to produce wheat. However, varying hectarage and quality provides for an unstable wheat supply (8). Currently campaigns to increase productivity of wheat in Michigan have been developed and are being implemented. Increased attention to weed control is one facet of the program to revitalize Michigan's wheat producing capability.

Tillage

Tillage management systems for wheat production in the United Sates varies by region. The factors involved in deciding what tillage practice to include or whether tillage at all is necessary depend on several factors. Some factors include amount of residue present, weeds, soil tilth, and previous crop. Erosion control, water and wind, also play an important role in deciding what tillage to use (12).

Michigan wheat producers plant wheat by a variety of methods. The most common are minimum tillage, no-tillage, and aerial seeding (28). Generally, Michigan wheat is planted in rotation with dry beans, soybeans, and sugar beets (29). Planting wheat after dry beans is advantageous because dry beans are generally harvested during September; whereas, soybeans are predominantly harvested in October. Planting after these crops requires different tillage. Sugar beets for instance may have more "ruts" from the heavy harvesting equipment along with compaction. Tillage allows producers to relieve compaction, remove weeds and provide an adequate seed-bed for the wheat. Minimum tillage is growing in popularity (29). Minimum tillage practices allows producers to leave more residue on the soil surface for wind and water erosion (12).

Aerial and broadcast seeding is another planting option. This planting system is estimated to include 15 to 20% of Michigan's hectarage (28). It is fast and convenient but caution is advised, due to non-uniform seeding rates and depths (28). It is very advantageous during periods of extended rainfall when field conditions may become too wet for field operations.

Tillage equipment varies from producer to producer. Some use disks, field cultivators, and harrows. The most common may be a one pass system with a field cultivator. This varies greatly depending on previous crop.

Pest Management

Insects. A host of insect pests inflict damage on wheat (4). The predominant insects that invade wheat are Hessian fly (*Mayetiola destructor* (Say)), armyworm (*Pseudaletia unipuncta* (Haworth)), cereal leaf beetle (*Oulema melanopus* (Linnaeus)), English grain aphid (*Sitobion avenae* (Fabricius)), bird-cherry aphid (*Rhopalosiphum padi* (Linneaus)) corn leaf aphid (*Rhopalosiphum maidis* (Fitch), and greenbugs (*Schizaphis graminum* (Rondani)) (11). Although important, most insect problems can be controlled below economic impact through cultural and biological means (4). The Hessian fly is potentially the most serious insect pest of wheat in Michigan (4). Cultural control is the best control measure for the Hessian fly (4). Planting according to the "fly-free" date virtually eliminates risks of infestation (11). Tables of the fly free dates for Michigan and various location have been calculated (11).

Diseases. Good farming practices such as crop rotation, seed treatment, and the use of resistant varieties are vital in avoiding most disease problems (5). Total yield losses from disease are estimated to range from 10 to 70% in individual fields (29). On a statewide basis, disease losses are estimated around 25%. Yield losses due to diseases are difficult to estimate (29). One may have combinations of pests and yield losses may be attributed to other factors such as fertility, rainfall, and weeds.

Weeds. Information is available on weed distribution, severity, and introduction (6). However, scientific studies on the impact of specific weeds at various densities on wheat yields are not abundant (6). Weeds are a problem in winter wheat on numerous fields in Michigan. However, it may be best to control weeds in other crop rotations, especially perennial weeds (13). A number of choices may exist for weed control in other crops such as corn or soybean (13).

If the field contains weeds at planting time, they must be removed with either tillage or a burndown herbicide (22). Paraquat, 1,1'-dimethyl-4,4'-bipyidinium ion, and glyphosate, N-(phophonomehtyl)glycine are two common burndown herbicides. If a herbicide is necessary, the majority is spring applied postemergence in Michigan winter wheat. Most weed problems affecting winter wheat production in Michigan are winter annuals, with some annuals occurring in the spring (22). The most critical step for good weed control in wheat is proper planting procedure (13). Wheat is extremely competitive with weeds. A healthy, vigorous wheat stand is the single most important component of a weed control strategy in this crop (13). When weeds are present, producers may encounter slower harvesting due to weeds in the wheat (4).

Competition between wheat and weeds for light, water, and nutrients may all be factors in final yield determination (6). The economic analysis of weed control in wheat has not been studied as a routine part of applied research (6). Determining if weed control is necessary becomes a judgment rather than a scientific decision. If weeds are present, at what point do you need to treat? These are all questions that need to be addressed. On-going research may answer these questions in the future.

Trifluralin

History. Ashford et al. (2, 32) reported trifluralin (2,6-dinitro-N,N-dipropyl-4-4(trifluoromethyl)benzenamine) for the first time as a herbicide in 1960. Eli Lilly and Company was responsible for both discovery and development of trifluralin (2). Trifluralin was registered mainly as a preplant incorporated (PPI) treatment for use in broadleaf crops for control of annual broadleaf and annual grass weeds in the first ten years following registration (2). Ashford et al. (2) reports that trifluralin's main use was in cotton (*Gossypium hirsutum* L.) and soybeans (*Glycine max* (L.) Merr.) in the United States; while in Canada, its primary use has been for weed control in rapeseed (Brassica sp.). In 1976, trifluralin was registered in Canada for green foxtail (*Setaria viridis* (L.)) control in wheat by Eli Lilly and Company (2). In the United States, trifluralin was registered for wheat as a shallow incorporation postplant (PoPI) treatment for green foxtail (*Setaria viridis* (L.)) in 1981 (2). The predominant use of this registration has been on the northern Great Plains devoted to a significant hectarage of spring wheat (2).

Chemical Characteristics. Trifluralin is a member of the 2,6-dinitroaniline herbicide family (2). Two other common herbicides in this family are ethafluralin [N-ethyl-n-(2-methyl-2-propenyl)-2)-2,6-dinitro-4-(trifluoromethyl)benznamine] and pendimenthalin [N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine] (2). Trifluralin is an orange crystalline solid with a melting point of 48.5 to 49.0°C (32).

Physiological and Biochemical Behavior. There is no significant translocation of trifluralin in crops grown in soil treated with trifluralin (20). Trifluralin affects physiological growth processes associated with the inhibition of lateral or secondary root development (17). The roots grown in soil containing trifluralin exhibit a residue in the region of contact with the herbicide, but its known degradation products are not translocated into the leaves, seeds, or fruit of a variety of plants (20).

Mechanism of Action. Trifluralin binds to tubulin, the major microtuble protein. The herbicide-tubulin complex inhibits polymerization of microtubule at the growing end of the tubule but has no effect on depolymerization of the tubule on the other end leading to a loss of microtubule (25). The spindle apparatus becomes absent, preventing the alignment and separation of chromosomes during mitosis and the cell plate does not form. Cell wall formation is also a function of the microtubule (31). Trifluralin causes cortical microtubule loss which may prevent cells from either dividing or elongating. Vaughn et al. (25) conclude that because cortical microtubule are involved in cell shape, cells cannot elongate but rather expand in a square shape rather than a rectangular. The result is swollen or club-shape root tip.

Behavior in Soil. Trifluralin readily adsorbs to soil colloids and thus is not subject to leaching (10, 32, 33). Trifluralin has a low water solubility, high energy bonding, and it readily binds to soil colloids during the adsorption process (32).

Trifluralin loss is subject to four processes: microbial attack, chemical alteration, volatilization, and photodecomposition.

Microbial degradation. Microorganisms contribute to degradation and disappearance of trifluralin in the soil (19, 31). Microbial degradation occurs more rapidly in flooded anaerobic than in moist soils (31).

Chemical alteration. Degradation under aerobic soil conditions consists primarily of N-dealkylation, hydrolytic cleavage of the dipropylamine group to produce the phenolic derivative, and oxidation of an N-propyl group followed by cyclization to produce the benzimidazole derivative (31). Under anaerobic conditions, the initial detoxication reactions are nitro reduction and N-dealkylation. However, non-biological degradation rates appear to be insignificant (31).

Volatilization. Volatility is an important factor with trifluralin; it was found that high soil temperature and moisture enhance such losses (19). Spencer and Cliath (24) reported that when 14 kg/ha was incorporated into 10 cm of soil, the loss rate during the first 24 hours was only 0.0517 kg/ha per day. Surface application rates of 1 to 10 kg/ ha to a wet soil resulted in loss rates up to 4.0 kg/ha per day. Application to dry soil surface resulted in essentially no volatilization. Volatilization of trifluralin occurs much more rapidly when applied to the soil surface than when incorporated into the soil (24). Persistence of trifluralin is increased by incorporation as compared to surface application and will provide an increase in consistency of herbicidal performance (18).

Photodecomposition. Photodecomposition is another factor of decomposition of trifluralin. Most literature reports that trifluralin on the soil surface is subject to photo decomposition (32) and can be avoided by mechanical incorporation (2).

Weeds Controlled by Trifluralin. Weeds controlled by trifluralin are predominately grasses and some broadleafs. Some common grasses in Michigan controlled by trifluralin are barnyard grass (*Echinochloa crus-gali*), crabgrass (*Digitaria* sp.), fall panicum (*Panicum dicholomiflorum*), and foxtails (*Setaria* sp.). Broadleafs in Michigan include common lambsquarter (*Chenopodium album*) and redroot pigweed (*Amaranthus retroflexus*) (22). Zilkey and Capell (35) in Canada reported effective control of common windgrass with trifluralin.

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Chapter 2

COMMON WINDGRASS [*Apera spica-venti* L.] CONTROL IN MICHIGAN WINTER WHEAT

ABSTRACT

Common windgrass is found in Central Europe predominantly, but is also found in the northeastern and northwestern United States. It is an increasing weed problem in Michigan winter wheat (*Triticum aestivum* L.) production. Field research was conducted in 1992 to 1995 to evaluate the effectiveness of postplant incorporated trifluralin for control of common windgrass in Michigan winter wheat. Trifluralin significantly reduced common windgrass densities in the 1992-1993 growing season. Trifluralin applied at 0.56 kg/ha reduced common windgrass density by 85% and increased wheat yields by 32%. Studies conducted in 1994-1995 in Huron County provided 85% or greater control in small plot research and 70% or greater control in production-scale research. In 1993-1995, studies were conducted to evaluate rotary hoe, spike tooth drag, and Fuerst harrow as incorporation implements for trifluralin. In the absence of common windgrass in 1993-1994, wheat density and yield were unaffected by trifluralin application. In Saginaw County in 1994-1995, incorporation implement had no effect on initial wheat density. However, in a spring 1995 evaluation, injury was observed. At Huron County significant wheat injury and stand reduction occurred in response to trifluralin incorporation. Wheat injury increased as trifluralin rate increased. Effect of incorporation implement on wheat injury was Fuerst harrow > spike tooth drag > rotary hoe. When shallowly incorporated, no significant wheat injury was observed at any site 1992 to 1995 from trifluralin

incorporation at the 0.56 kg/ha rate, when wheat was planted at least 5 cm deep. Data suggest injury from postplant incorporated trifluralin is related to planting depth, with increased injury associated with shallower seed placement.

Nomenclature: Trifluralin, 2-6-dinitro-N,N-dipropyl-4-(trifluoromethyl)benzenamine; common windgrass, *Apera spica-venti* L.; wheat, *Triticum aestivum* L. **Additional index words:** APESV

INTRODUCTION

Common windgrass *(Apera spica-venti* L.) is an invading weed to North America from Europe (10, 13, 19). In Europe it is recognized as a major weed problem in winter cereals (10). McNeill (10) reported infestations of common windgrass in the United States around the latter half of the 19th century on ballast and waste places in the northeastern United States. Early reports from Beal (3) give reference of common windgrass "near Lansing," in Ingham County, Michigan (6). Gereau and Rabeler (6) also reported sightings in Kent and Sanilac Counties. Common windgrass was also found in Saginaw County (16). Gereau and Rabeler (6) stated that the abundance of *Apera spica-venti* at the Sanilac County site may give cause for agricultural concern. Common windgrass is predominantly a problem when a winter cereal such as winter wheat is grown. Common windgrass may be easily dispersed by wind and farm machinery (19).

Common windgrass is an annual plant (1, 9, 18, 19). Individual plants have been found to produce up to 2000 seeds per plant (19). Seed viability ranges from one to seven years, but often it will not exceed two years (20). Seeds of common windgrass germinate mostly at or near the soil surface (19). Common windgrass requires wet conditions for germination (1, 9, 18). Seeds from common windgrass germinate in the fall and seedlings overwinter in the two to three leaf stage (18, 19).

Control measures have been limited for common windgrass. European growers have used triazines and urea derivatives for control (20). Michigan currently has no effective chemical control options in wheat. Mechanical control through tillage is effective in the fall (19). However, common windgrass germinates simultaneously with winter wheat (9, 18, 19). Chemical control in Canada using trifluralin (2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl)benzenamine) in fall rye has shown success in controlling common windgrass (21). Others have tested trifluralin use in wheat (4, 8, 11, 12, 14) investigating the feasibility of using trifluralin for weed control in wheat.

Trifluralin as a control measure for common windgrass in winter wheat in Michigan offers a possible option.

Studies were conducted in Michigan from 1992 to 1995 to 1) evaluate the effectiveness of trifluralin for common windgrass control, 2) evaluate incorporation methods for trifluralin in winter wheat, and 3) validate small plot research in production-scale research sites.

MATERIAL AND METHODS

General Experimental Procedures. Sites were planted with wheat using common seeding, fertility, and tillage practices consistent with Michigan State University Extension Bulletin E-2188. Studies were established in tilled fields. Tillage consisted of disking, field cultivation, or a combination of the two depending on the previous grown crop. Cultivars grown were all winter wheats. Planting dates, depths, and wheat cultivars are presented for each study in Tables 1 and 2.

A tractor mounted compressed air sprayer was used to apply all herbicide treatments and was calibrated to deliver 206 L/ha at a pressure of 207 k/Pa using Teejet[1] 8003 flat fan nozzles on research sites. On the production-scale research sites, application equipment varied with cooperator. All treatments were applied postplant incorporated (PoPI). Incorporation implements were set at a depth of 2.5 cm. Incorporation was effected immediately after trifluralin application. Detailed application information for the research studies are presented in Table 1.

Data were subjected to analysis of variance, Fisher's Protected LSD at the 5% level for the small plot research and production-scale research. Common windgrass control and injury were evaluated on a scale with zero representing no visible injury and 100 representing complete plant death.

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[1]Spraying Systems Co., North Avenue, Wheaton, IL 60188.

1992-1993 Study. A field study was established in Huron County, Michigan in 1992. The soil was a Riverdale-Pipestone complex (Loamy, mixed, mesic Aquic Arenic Hapludalf). The study was designed as a split-plot with four replications. The main plot factor was incorporation method. Incorporation methods were none or rotary hoe. The sub-plot factor was herbicide. Five rates of trifluralin were used: 0, 0.28, 0.56, 0.84, and 1.12 kg/ha. The plot size was 3 m wide and 9 m long. Evaluations of wheat injury, common windgrass control, and common windgrass densities were taken. Wheat was harvested and yields determined.

1993-1994 and 1994-1995 Studies. In the 1993-1994 growing season a field study was conducted in Saginaw County, Michigan. The soil was a Wixom sand (sandy over loamy, mixed, mesic Alfic Haplaquod) with 2.2% organic matter and a pH of 6.9. Field studies were conducted in 1994-1995 in Huron and Saginaw Counties. The soil was a Guelph-londo (fine-loamy, mixed, mesic Glossoboric Hapludalf with 2.2% organic matter and a pH of 7.6 at the Huron County location. At the Saginaw location in 1994-1995, the soil was a Wixom sand (sandy over loamy, mixed, mesic Alfic Haplaquods) with 2.5% organic matter and a pH of 6.6.

All three experiments were designed as split-plots with four replications, except the Saginaw County location in the 1993-1994 establishment year, which had three replications. The plot sizes were 4.8 m wide and 9 m long. The main plot factor was incorporation method. Incorporation methods were none, rotary hoe, spike tooth drag, and Fuerst harrow[2]. The subplot factor was herbicide. Five rates of trifluralin were used: 0, 0.28, 0.56, 0.84, and 1.12 kg/ha.

Evaluations of wheat injury, and common windgrass control were taken. Wheat was harvested and yields determined

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[2]The Fuerst FLEXIBLE TINE Harrow®, Fuerst Brothers, Gibson City, IL, 60936-0427

Production-Scale Research Sites 1994-1995. Three on-farm production-scale research sites were established, each 4 ha in size. Each site represents one of the incorporation implements and are identified as sites A, B, and C (Table 2). Incorporation implements evaluated were a rotary hoe, spike tooth drag, and Fuerst harrow. Fields were divided into strips or tracts of land throughout the 4 ha. The strips alternated between treated and untreated areas. Incorporation was performed by the respective incorporation implement to the entire 4 ha immediately following application.

Wheat density data at all three sites were collected approximately four weeks after planting in the fall of the establishment year, 1994, and May 5, 1995. Common windgrass densities were determined May 5, 1995 on all three sites. On May 25, 1995 common windgrass densities were determined on sites B and C. Site A was discontinued, due to the absence of windgrass and no observed wheat injury. Data was collected at 10 random locations within each treated and untreated strip. The area of collection was concentrated in the first 50 m of each strip. Each 4 ha production-scale research site had at least three treated and untreated areas. Site B was harvested and yield determined July 19, 1995.

RESULTS AND DISCUSSION

1992-1993. No significant differences between rotary hoe and no rotary hoe were observed; therefore, data were averaged over incorporation method (Table 3). No visual wheat injury was observed at this site from any treatment. Common windgrass densities were significantly reduced at all rates of trifluralin when compared to the untreated plots. Trifluralin applied at 0.56 kg/ha reduced common windgrass densities by 85% and increased wheat yields by 32%. Significant yield increases were observed at trifluralin rates of 0.56 kg/ha or higher. Zilkey et al. (21) reported 18 to 100%

control of common windgrass using trifluralin postplant incorporated at rates of 0.4 and 0.6 kg/ha in rye.

1993-1994. In the absence of common windgrass, wheat density (data not reported) and yield were unaffected by trifluralin rate or incorporation method (Table 4).

1994-1995. Data from the Saginaw County site indicated that incorporation method did not affect initial wheat density (Table 5). However, in a spring 1995 visual wheat evaluation, injury was observed. Significant wheat injury was observed from the spike tooth drag and the Fuerst harrow incorporation implements at trifluralin rates of 0.84 kg/ha or higher.

At the Huron County site, significant wheat injury and stand reduction occurred in response to trifluralin incorporation (Table 6). Injury increased as trifluralin rate increased. Trifluralin affects root development (15, 11) and as trifluralin rate increased, root injury increased. Trifluralin caused the wheat injury by contact with root system of the wheat. Generally, the effect of incorporation implement on wheat injury was as follows: Fuerst harrow > spike tooth drag > rotary hoe.

A factor that may contribute to increased wheat injury is seed planting depth in relation to trifluralin placement. The Saginaw County site was planted at 5 cm. The Huron County site was planted at 3.8 cm. Trifluralin placed at higher concentrations near the root development zone of the wheat may be the primary cause for the injury. Although a 2.5 cm incorporation depth was intended, deeper placement may have occurred. In visual observations, soil disturbance from the incorporation implement was as follows: Fuerst harrow > spike tooth drag > rotary hoe, which corresponds with the injury ratings on the wheat. Initial injury may not have occurred at the Saginaw County site due to a deeper planting depth. Injury occurred after overwintering on plots with 0.84 kg/ha or higher of trifluralin.

Downward movement of trifluralin in the soil profile is limited by its low water solubility (5). However, trifluralin does have the potential to move in the soil profile

(5, 7). Golab et al. (7) reported that 76 to 95% of the trifluralin remained in the 7.5 cm zone of incorporation and that 91 to 99% of the trifluralin remained in the 0 to 15 cm zone. Trifluralin rate, incorporation depth, seed placement, soil type, and environmental conditions play an integral role in the risk of wheat injury. Data suggest that deeper incorporation of trifluralin is related to the increased wheat injury. Shallower planted wheat may have increased risk of injury, dependant on type of incorporation implement used and rate of trifluralin.

In Saginaw County, common windgrass densities were not taken. Infestations of common windgrass became so severe that accurate counts could not be taken. Yields are not reported due to variability caused by the severe common windgrass infestation. However, in a visual assessment, trifluralin significantly controlled common windgrass when compared to the untreated areas (Table 5).

Trifluralin at rates of 0.56 kg/ha or higher provided 75% or greater control of common windgrass when visually assessed two weeks before harvest in Huron County (Table 6). Common windgrass densities were reduced by 85% or more by the same trifluralin rate. No significant yield increases were observed.

Production-Scale Research 1994-1995. Trifluralin applied at 0.56 kg/ha reduced common windgrass density 70 to 100% when incorporated with a spike tooth drag (Site B) or Fuerst harrow (Site C)(Table 7). Site A (rotary hoe) was not evaluated due to insufficient common windgrass populations. Yield was determined at Site B however, no significant yield increases were observed. Yields were not determined for Sites A and C.

Significant wheat density reduction was observed at site C (Fuerst harrow) which was planted at 3.8 cm. Sites A (rotary hoe) and Site B (spike tooth drag) had no observable injury. These data are consistent with plot research where less injury was observed when wheat was planted at the 5 cm depth as compared to shallower planting.

Trifluralin applied at 0.56 kg/ha reduced common windgrass densities by 85% or more at the plot research sites and 70% or more at the production-scale research sites (Tables 6 and 7), respectively. Zilkey et al. (21) reported, in a field demonstration experiment with fall rye, trifluralin at 0.4 kg/ha provided 91% control of common windgrass.

Similar herbicide rates have been established for control of green foxtail (*Setaria viridis* L.) in spring wheat using trifluralin postplant incorporated. Ashford et al. (2) recommends a rate of trifluralin postplant incorporated of 0.56 to 0.84 kg/ha in Saskatoon, Canada. The actual rate within this range depends on soil type and organic matter content.

CONCLUSIONS

Trifluralin effectively reduced common windgrass densities. When shallowly incorporated, no significant wheat injury was observed at any site in 1992 to 1995 from trifluralin at the 0.56 kg/ha rate, provided the wheat was planted at the 5 cm depth. Production-scale research provided consistent results when compared to the small plot research. Planting depth and incorporation method affected wheat injury from trifluralin. These are critical factors in avoiding wheat injury from trifluralin.

To provide the best results, a protective band of untreated soil must be maintained between the wheat seed and the surface band of soil treated with trifluralin. Postplant incorporation of trifluralin requires that the wheat be seeded at least 5.0 cm deep, after which trifluralin is shallowly incorporated in soil above the seed.

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Table 1. Herbicide application information for control of common windgrass.

	1992-93	1993-94	1994-95	
	Huron Co.	Saginaw Co.	Huron Co.	Saginaw Co.
Application Date	10/02/92	9/28/93	9/20/94	9/20/94
Time of Application	10:00 a.m.	4:30 p.m.	10:30 a.m.	4:15 p.m.
Temperature (C)	20	11	29	26
Relative Humidity (%)	58	80	45	37
Soil Temperature (C at 5 cm)	13	15	22	18
Date Planted	9/30/92	9/25/93	9/19/94	9/19/94
Planting Depth	5 cm	5 cm	3.8 cm	5 cm
Cultivar	'Harus'	'Chelsea'	'Harus'	'Chelsea'

Table 2. Production-scale research application information for control of common windgrass, 1994-1995.

	Site A[a]	Site B[a]	Site C[a]
Approximate Experiment Area	4	4	4
Planting Date	10/4/94	9/18/94	9/19/94
Planting Depth	3.8 cm	5 cm	3.8 cm
Incorporation Implement	Rotary Hoe	Spike Tooth	Fuerst Harrow
Trifluralin Rate	0.56 kg/ha	0.56 kg/ha	0.56 kg/ha
Cultivar	'Harus'	'Chelsea'	'Harus'

[a]Huron County, Michigan

Table 3. Effect of trifluralin on common windgrass control and wheat yield, 1992-1993.[1]

	Common Windgrass		Wheat
Trifluralin rate	Control	Density	Yield
kg/ha	%	pl/m^2	100 kg/ha
0	0	238	16
0.28	33	119	20
0.56	58	37	23
0.84	65	32	24
1.12	74	27	24
$LSD_{0.05}$	16	48	5

[1]Averaged over incorporation method (rotary hoe, no rotary hoe).

Table 4. Wheat yield as affected by trifluralin rate and incorporation method, 1993-1994.

Trifluralin rate	None	Rotary hoe	Spike tooth	Fuerst harrow
kg/ha	------------------------------------ (100 kg/ha) ---------------------------			
0	31	25	29	27
0.28	28	30	34	31
0.56	33	28	34	34
0.84	24	27	33	33
1.12	34	27	34	30
$LSD_{0.05}$[a]		NS		
$LSD_{0.05}$[b]		NS		

[a]Incorporation Method within Rate
[b]Rate within Incorporation Method

Table 5. Effect of trifluralin rate and incorporation method on common windgrass and wheat in Saginaw County, 1994-1995.

		Common Windgrass	Wheat	
Incorporation Implement	Trifluralin rate	Control	Injury	Density
	kg/ha	%	%	pl/m of row
None	0	0	0	47
	0.28	29	0	39
	0.56	43	0	44
	0.84	46	3	43
	1.12	68	5	41
Rotary Hoe	0	0	1	38
	0.28	53	0	39
	0.56	38	0	36
	0.84	45	0	39
	1.12	63	0	37
Spike Tooth Drag	0	0	0	44
	0.28	38	1	39
	0.56	26	0	37
	0.84	26	19	40
	1.12	41	24	39
Fuerst Harrow	0	0	0	38
	0.28	30	3	41
	0.56	58	6	40
	0.84	47	18	38
	1.12	55	9	40
$LSD_{0.05}$[a]		NS	NS	NS
$LSD_{0.05}$[b]		12	9	NS

[a]Incorporation Method within Rate
[b]Rate within Incorporation Method

Table 6. Effect of trifluralin rate and incorporation method on common windgrass and wheat in Huron County, 1994-1995.

Incorporation Implement	Trifluralin rate	Common Windgrass Control	Common Windgrass Density	Wheat Injury	Wheat Density	Wheat Yield
	kg/ha	%	pl/m^2	%	pl/m of row	100 kg/ha
None	0	0	41	0	47	37
	0.28	94	4	0	43	40
	0.56	95	3	0	50	36
	0.84	91	0	0	47	38
	1.12	95	6	0	48	33
Rotary Hoe	0	0	62	0	48	34
	0.28	74	8	0	46	36
	0.56	88	6	3	48	38
	0.84	98	4	7	46	38
	1.12	90	3	19	43	35
Spike Tooth Drag	0	0	41	10	44	34
	0.28	66	6	11	37	34
	0.56	75	6	19	39	36
	0.84	80	0	24	36	37
	1.12	88	4	20	32	32
Fuerst Harrow	0	0	40	0	43	36
	0.28	56	16	13	44	34
	0.56	80	3	21	37	37
	0.84	100	0	28	31	38
	1.12	88	3	39	36	36
$LSD_{0.05}$[a]		NS	NS	6	6	NS
$LSD_{0.05}$[b]		10	15	7	4	NS

[a]Incorporation Method within Rate
[b]Rate within Incorporation Method

Table 7. Effect of trifluralin at 0.56 kg/ha on common windgrass control and wheat in field-scale research sites, 1994-1995.

	Common windgrass density			Wheat stand density			Wheat yield	
Implement	Untreated		Treated	Untreated		Treated	Untreated	Treated
	---------------- pl/m^2 ----------------			------------ pl/m of row -----			------------ kg/ha -----------	
Rotary Hoe[a]	6		0	57		61	—	—
Spike Tooth Drag[b]	56	*	16	49		51	2625	3009
Fuerst Harrow[c]	21	*	0	49	*	46	—	—

*Untreated and treated plots were significantly different at the 0.05 level.

[a]Site A, Huron County, Michigan
[b]Site B, Huron County, Michigan
[c]Site C, Huron County, Michigan