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Morphology, temperature tolerance, and control of two weedy sorghum selections in Michigan

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MORPHOLOGY, TEMPERATURE TOLERANCE, AND CONTROL OF TWO WEEDY SORGHUM SELECTIONS IN MICHIGAN

By

Dennis R. Cosgrove

A DISSERTATION

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ABSTRACT

MORPHOLOGY, TEMPERATURE TOLERANCE, AND CONTROL OF TWO WEEDY SORGHUM SELECTIONS IN MICHIGAN

By

Dennis R. Cosgrove

In order to characterize weedy sorghum populations in Michigan, an overwintering and a non-overwintering selection were compared with overwintering selections from Ontario, New York, Ohio, Tennessee, and Mississippi and non-overwintering selections from Ontario, Illinois, and a selection of Sorghum almum (Parodi) from Minnesota. Characteristics compared were morphology, dry weight production and allocation, the effects of temperature on seed germination, rhizome sprouting, and survival. The effect of cold temperatures on the degree of saturation of fatty acids in rhizome cell membranes of the two Michigan selections, the Tennessee selection, and S. almum was investigated to determine if this may play a part in differential cold tolerance. Control of the two Michigan

selections was also evaluated using selective and non-selective herbicides. Non-overwintering selections had larger seeds, wider leaves, thicker culms, fewer leaves, flowered earlier, were taller, and produced lower rhizome dry weights than overwintering selections. Germination of seeds of non-overwintering selections at low temperatures was greater than that of the overwintering selections but rhizome sprouting was lower. Rhizomes of overwintering selections tolerated lower temperatures than non-overwintering ones but there were no consistent differences in the degree of saturation of the membrane fatty acids. Control of the non-overwintering Michigan selection was greater with single early postemergence applications of quizalofop (2-[4-(6-chloro-2-quinoxalinyl)oxy]phenoxyl]propionic acid), fluazifop {(+)-2-[4-[(5-(trifluoromethyl)-2-pyridinyl)oxy]phenoxy]propanoic acid}, haloxyfop (2-[4-[[3-chloro-5-(triflouromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid), and sethoxydim {2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one} in soybeans [Glycine max (L.) Merr.] while few differences in control provided by the non-selective herbicides glyphosate (N-(phosphonomethyl)glycine), sulphosate (trimethylsulphonium carboxymethylaminomethyl phosphonate), and HOE-661 (ammonium-(3-amino-3-carboxypropyl)-methyl phosphinate) were observed. The results of this study suggest that two distinct sorghum species exist as weed problems in Michigan,

an overwintering ecotype of *Sorghum halepense* (L.) Pers. and a non-overwintering ecotype of *S. almum*.

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I would like to thank Dr. William Meggitt and the members of my guidance committee, Drs. Kells, Putnam, Penner, and Stephenson, for their suggestions and assistance during the course of this study. I would also like to recognize the technical assistance of Mark Benjamin and Mike Leen. Finally, I would like to thank Bernard Anderson and the students and staff at Andrews University in Berrien Springs, MI, Larry Brodbeck of Sunfield, MI, and Ray Christenson of Greenville, MI for the use of their cropland for the field experiments included here.

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INTRODUCTION

Johnsongrass [*Sorghum halepense* (L.) Pers.] has been a serious weed problem in the United States since its introduction in the early 1800's. Though typically associated with the warmer climates of the southern U.S., in recent years reports of Johnsongrass infestations in the northern regions of the U.S. have increased. Johnsongrass infestations have been known to exist in Michigan since the 1950's. At that time infestations were isolated in the extreme southwestern counties where it was assumed the relatively warm soil temperatures and heavy snow cover through the winter enabled rhizomes to survive. Recently, reports of Johnsongrass in more northern locations in Michigan have increased. Table 1 and Figure 1 show the results of a survey conducted in 1986. These results illustrate to what extent Johnsongrass infestations have increased in Michigan since the 1950's. These increasing reports raised questions as to whether Johnsongrass populations in Michigan represented an ecotype which had developed, or was developing, tolerance to the cooler temperatures in this region which would enable infestations

to increase and become a serious weed problem in the state. With this in mind, studies were undertaken with these objectives:

— to characterize Johnsongrass populations in Michigan in relation to populations from other parts of the U.S.

— to determine if physiological differences exist between these populations which would enable Michigan populations to better withstand cold temperatures.

— to evaluate existing control measures for Johnsongrass and determine if these practices are equally effective on populations in Michigan.

Table 1. Estimated acreage in Michigan infested with Johnsongrass by county.

County	Acreage Infested	County	Acreage Infested
1. Allegan	200	15. Jackson	200
2. Barry	300	16. Kalamazoo	?
3. Bay	2-3,000	17. Kent	100
4. Berrien	1,000	18. Lenawee	20
5. Branch	2,000	19. Livingston	?
6. Calhoun	2-5,000	20. Mason	?
7. Cass	1,000	21. Menominee	1,000
8. Clinton	100	22. Monroe	?
9. Eaton	600	23. Montcalm	300
10. Emmet	?	24. Ottawa	1,000
11. Genesee	100	25. Shiawassee	100
12. Hillsdale	2-5,000	26. St. Joseph	2,000
13. Ingham	200	27. VanBuren	200
14. Ionia	50	28. Washtenaw	200

Total estimated infested acreage: 16,000-23,000.

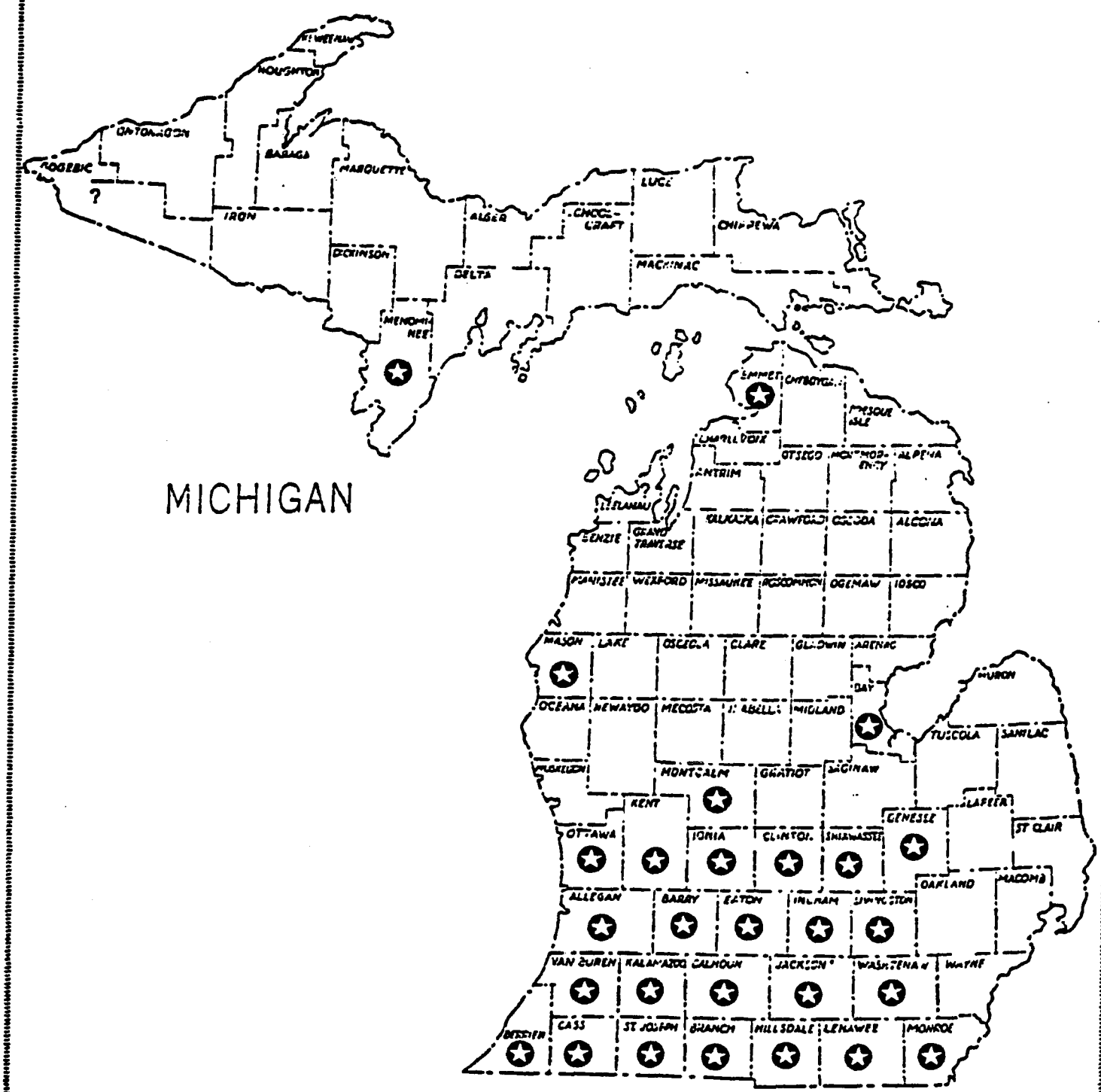

Figure 1. The distribution of Johnsongrass in Michigan.

CHAPTER ONE

LITERATURE REVIEW

Name

Sorghum halepense (L.) Pers., Johnsongrass

Description

Johnsongrass is described by Warwick and Black (66) as a perennial grass with fleshy rhizomes to 1 cm in diameter and 2 m in length, often rooting from the nodes, internodes partially covered with brown scale-like sheaths. Culms (flowering stems) erect, usually unbranched, 0.5-2.5 m tall, 0.5-2.0 cm in diameter, often with basal adventitious prop roots, nodes sometimes with fine hairs. Leaves cauline; leaf sheaths often with a waxy secretion at the base, veins prominent, surface hairless and ribbed, margins open, overlapping; ligules membranous with a hairy fringe, 2-5 mm long; auricles absent; blades rolled in bud, flat, bright green or sometimes with purple pigments, 20-60 cm long,

1.0-3.0 cm wide, mid-vein conspicuous, everywhere hairless, with scabrous (small rough) projections on the lower surface and margins. Inflorescence a large, erect panicle, at first compact, later spreading and open, pyrimidal, purplish, hairy, up to 50 cm long and 20 cm wide. Branches in numerous whorls, slender, the lower up to 15 cm long, usually without spikelets for 2-5 cm from the base. Spikelets in pairs or at the end of each branch in threes, usually disarticulating as a unit. Spikelet units with one sessile and either one or two pedicelled spikelets. Sessile spikelet, 4-6 mm long, 1.8-2.5 mm wide, dorsiventrally compressed; perfect, green, almost glabrous to appressed silky; glumes becoming leather-like at maturity; lower glume flat across the back, rounded on the margins against the upper glume, 7-11 veins, tip three toothed; upper glume slightly boat shaped, acute entire, 3-11 veins, margins rolled around the lemma; lemma hyaline, ciliate, 3-5 mm long, one to three veins, usually with a 1.0 to 1.6 cm long awn which generally develops after anthesis and is early deciduous as the seed ripens; palea hyaline, 3-4 mm long; two free lodicules about 0.5 mm long; three anthers 2.2-3.0 mm long; ovary apex glabrous; styles free to the base and yellow, pink, red, purple, or black. Pedicelled spikelet, pedicels densely ciliate, 1.5-4.0 mm long; male or sterile; glumes green-purplish, lanceolate 4-6 mm long, 1.5-2.0 mm

wide, lemma awnless, lemma and palea hyaline with 0-2 veins, shorter than the glumes. Grain remains enclosed by glumes 4.0-6.6 mm long, 2.0-2.6 mm wide, oblong-ovate, glumes reddish brown to shiny black, glossy, marked with fine lines on the surface.

Distribution

Johnsongrass occurs in all major agricultural areas of the world from latitude 55N to 45S (28). It was introduced into the United States in the 1830's (9) and now occurs in all but a dozen states (see Figure 1) (65). In Michigan, Johnsongrass has been reported in 27 counties (see Figure 2). Most infestations in Michigan occur in the southern half of the lower peninsula, however, Johnsongrass has been reported as far north as Menominee county in the southwestern upper peninsula.

Cytology and Taxonomy

Sorghum halepense belongs to the sorghum section of the genus Sorghum. Several treatments of the taxonomy of this section have been made. Snowden (60) divided the section in two subsections, Arundinaceae, consisting of diploid (2n=20) species, and Halepensia consisting of tetraploid (2n=40)

species. Snowden described 52 species in the section. DeWet and Huckaby (20) divided the section into a single species, Sorghum bicolor (L.) Moench, with two subspecies S. bicolor ssp. bicolor which contains the cultivated sorghums, companion weeds, and semiwild relatives, and S. bicolor ssp. halepense. This subspecies contains two morphologically distinct complexes, a Mediterranean and a tropical ecotype. The Mediterranean ecotype consists of small plants with narrow leaves and extends from Asia Minor to West Pakistan where it is replaced by a larger more robust tropical ecotype which extends to southern India. It is the smaller Mediterranean ecotype which is believed to have been introduced into the new world and is commonly referred to as Johnsongrass (52). DeWet and Huckaby (20) suggested the more robust tropical ecotype, sometimes referred to as S. miliaceum (59) may have resulted from an introgression with cultivated sorghum. Harlan and DeWet (25) divided the section into two species, S. halepense (L.) Pers. to include tetraploid (2n=40) taxa, and S. bicolor (L.) Moench to include diploid (2n=20) taxa. The most recent treatment by DeWet (19) recognizes three species in the section sorghum; two rhizomatous species, S. halepense and S. propinquum (Kunth) Hitchcock (2n=20) and S. bicolor (2n=20) which includes all annual wild, weedy, and cultivated taxa.

In Argentina an introgression of S. halepense with an unknown cultivated sorghum has been described as S. almum (Parodi) (23). S. almum resembles S. halepense in being rhizomatous and having 40 somatic chromosomes (18), however, it differs from S. halepense in having taller, thicker stems, broader leaves, and shorter rhizomes which curve upwards. S. almum also has larger caryopses and larger pedicles with the sessile spikelets attached to the pedicel. Simon (58) has prepared a key in which he distinguishes S. almum from S. halepense (Mediterranean ecotype) and S. miliaceum (tropical ecotype). S. halepense is distinguished from S. miliaceum through its wider leaf blades, as well as taller and thicker culms. S. almum is distinguished from these two through larger sessile spikelets, shiny black seed color, greater degree of branching in the panicle, as well as shorter, thicker rhizome internodes.

Seasonal Growth and Development

Johnsongrass plants arise from both seeds and rhizomes present in infested areas. Growth and development of plants from each is similar (29, 40, 53), however, Horowitz (29) showed seeds require 10C higher temperatures to germinate than was required for rhizome sprouting. This difference in temperature requirement results in rhizome germination prior

to seed germination in field situations. Plants arising from seed exhibit more rapid leaf production in early stages of growth (29, 40) therefore seedlings emerging after plants from rhizomes show equal aerial development soon after emergence.

Rhizome initiation occurs when the plants are in the 3-7 leaf stage (33, 35, 53). In a study by Horowitz (29), January and March seedings did not produce rhizomes for 7 and 3 months, respectively, while May, June, and September seedings produced rhizomes in 42, 59, and 42 days after planting. Plants from each of the different seeding times had varying amounts of top growth at the time of rhizome initiation thus Horowitz suggests rhizome initiation is not directly related to the age of the plant but that temperature may be the determining factor. Initial rhizome growth is slow but increases rapidly with the onset of flowering. Oyer et al. (53) reported rhizome production began at the seven leaf stage and reached its maximum between the boot and dough stages. McWhorter (40) reported a rapid increase in rhizome production after the start of blooming. Anderson et al. (4) found the greatest increase in rhizome production from the mature seed stage to the onset of winter dormancy while Horowitz (29) found no causal relationship between flowering and rhizome production. Early in the life cycle, vegetative growth exceeds rhizome

production, however after flowering, rhizome growth predominates. McWhorter (40) found that the rate of leaf growth decreased progressively after blooming. Oyer et al. (53) found vegetative growth reached a maximum when the plants were in the dough stage then gradually decreased until the end of the season.

Johnsongrass ecotypes vary in their ability to produce rhizomes. Production of rhizome nodes varied from a maximum of 229 in a study by McWhorter and Jordan (49) up to 5,200 in a study by Anderson et al. (4). Keeley and Thullen (35) investigating the influence of planting date on Johnsongrass growth reported 400 grams of rhizomes produced on plants sown in May with less rhizome production from earlier or later plantings. Lolas and Coble (38) reported rhizome production of 200-600 grams per plant depending on the length of the original rhizome section planted. Keeley and Thullen (35) found that rhizomes accounted for 13%, 25%, and 40% of the total fresh weight 6, 9, and 12 weeks after sowing for plants sown in April to August while roots accounted for 16%, 9%, and 6% and shoots 70%, 66%, and 54% of the total fresh weight. Horowitz (31) reported rhizome production of 40 meters and 450 grams per plant in a study conducted in Israel. In this study, rhizome weight was equal to 90% of the total subterranean weight. Oyer et al. (53) found the ratio of top growth to rhizomes to be

approximately 1.0 at the end of the growing season while Horowitz (31) reported this ratio to vary from 0.4 to 0.9 but was never greater than 1.0.

McWhorter (40) reported the emergence of seed stalks at 27 days after emergence with 80-90% of the total seed stalk growth occurring one week preceding early bloom. Early bloom occurred approximately 46 days after emergence after which plants were in continuous bloom throughout the season. Keeley and Thullen (35) also reported the onset of flowering at 6-7 weeks after emergence with viable seed collected 2 weeks after flowering. In a study investigating the effects of varying photoperiods on Johnsongrass flowering, Knight and Bennett (36) observed flowering at 8, 10.5, 12, 14, and 16 hour photoperiods but seedhead formation was reduced at photoperiods greater than 12 hours. The highest seed yields were obtained at 10.5 and 12 hour photoperiods. Burt and Wedderspoon (11) studying three Johnsongrass populations from Maryland and Louisiana, found flowering was inhibited in all three populations at a 16 hour photoperiod. In a study by Keeley and Thullen (35) investigating the influence of planting date on Johnsongrass development, no such dependence on daylength for flowering was established. Peak flowering for plants sown in May occurred when day lengths were 14 to 14.5 hours while peak flowering from plants sown in August occurred when daylengths were 11 to 12 hours.

Total seasonal production of seed is high. Keeley and Thullen (35) observed seed yields of up to 20,000 seeds per plant while Horowitz (31) found 28,000 seeds per plant produced in a study investigating the spread of Johnsongrass plants.

Vegetative production is effected by both temperature and photoperiod. Ingle and Rogers (34), using a Johnsongrass selection from Indiana, found shoot dry weights increased with temperature up to 32C when grown under 16 hour photoperiods, however under 12 hour photoperiods, 27C was the optimum temperature for shoot growth. Burt and Wedderspoon (11) found no significant differences in shoot weight for three Johnsongrass selections grown under 8, 12, and 16 hour photoperiods, however, total fresh weight was higher for all selections when grown at 35C than at 25C or 30C. McWhorter and Jordan (50) studying the effects of temperature and light intensity on Johnsongrass growth found maximum dry weight production at 32C and 19 klux, however, maximum production of individual plant parts varied with temperature and light intensity.

Factors Affecting Rhizome Production and Sprouting

Many factors may effect the production and sprouting of Johnsongrass rhizomes during the growing season, among them

soil temperature, soil type, soil moisture, depth and length of the primary rhizome, temperature, and photoperiod. Several studies have been conducted to investigate the effect of temperature on rhizome bud sprouting. Hull (33) reported 13.5% sprouting at 15C, 81.5% at 22.5C, and 91.5% at 30C. Horowitz (29) investigated bud sprouting at several temperatures from 10C to 39C and obtained maximum sprouting at 28C. Thus, Johnsongrass rhizomes have a relatively high temperature requirement for sprouting. Soil type has a significant effect on depth of rhizome production. Rhizome production has been shown to decrease with depth. Horowitz (30) reported 60%, 30%, and 10% of the total subterranean weight found in the 0-15 cm, 15-30 cm, and 30-45 cm soil layer, respectively. In a second study, Horowitz (31) reported 80% of the rhizome dry weight in the upper 20 cm of the soil and that rhizomes did not penetrate deeper than 40 cm. McWhorter (45) found 80% of the rhizomes in the top 7.5 cm layer of a clay soil while 80% of the rhizomes occurred in the upper 12.5 cm of a sandy loam soil. Total rhizome production was 4.94 kg/m^3 in a clay soil compared to 12.29 kg/m^3 in a loam.

Soil temperature also has a profound effect on the viability of rhizome buds. Johnsongrass exhibits very little cold hardiness. In a study by McWhorter (45), rhizomes exposed to temperatures of -3C or lower for more

than 4 hours did not survive. Hull (33) also found rhizomes did not survive exposure to temperatures of -3.5C or less. Hull states that Johnsongrass rhizomes are starch storing organs while perennial organs of most temperate grasses contain fructosans as the major storage carbohydrate and that this may be the basis for the lack of cold hardiness in Johnsongrass rhizomes, however, other studies have shown sucrose to be the major storage carbohydrate in Johnsongrass rhizomes (9, 41). Stoller (61) investigating the differential cold tolerance of Johnsongrass and quackgrass rhizomes found quackgrass rhizomes tolerated temperatures as low as -17C while Johnsongrass rhizomes were killed below -9C. Stoller reported a higher proportion of unsaturated fatty acids in quackgrass rhizomes and suggested this difference may contribute to the cold tolerance of quackgrass. He did not, however, find a significant difference in the polar lipids important in membrane structure.

Higher temperatures and desiccation in dry soil also may result in decreased rhizome viability. McWhorter (45) reported exposure to temperatures of 50-60C killed rhizomes within 1 to 3 days. Drying for 6 days to 22% of initial weight prevents sprouting of rhizome buds (29). Anderson et al. (4) also found a reduction in germination when rhizomes were dried below 40% moisture and complete absence of germination below 20%.

Growing temperature and photoperiod also affect rhizome production. Burt and Wedderspoon (11) found rhizome fresh weight increased as growing temperature increased from 20C to 35C for a selection from Mississippi. This selection also produced a greater dry weight of rhizomes when grown under a 12 to 16 hour photoperiod than an 8 hour photoperiod. McWhorter and Jordan (50) investigating the effects of light intensity and temperature on Johnsongrass growth, found rhizome development increased with increasing light intensity from 9 to 19 klux and was maximum at 32C and minimum at 40C.

Rhizome bud dormancy and inhibition of axillary bud sprouting through apical dominance are both means which could increase the colonizing ability and persistence of a Johnsongrass infestation through delaying sprouting until favorable conditions exist. These traits also ensure a reserve supply of rhizomes in the event some buds are lost due to adverse environmental conditions or herbicide applications (52). Hull (33) detected no natural dormancy in single node rhizome sections harvested at any time of the year. Horowitz (30) reported similar results in a separate study. Anderson et al. (4) refer to a winter dormancy stage, however, Monaghan (52) suggests this may be low temperature suppression of bud sprouting. Beasley (8) demonstrated apical dominance in Johnsongrass rhizomes.

When rhizome apexes were removed, shoot extension from the axillary buds increased from the proximal to the distal end of the rhizome. With an intact shoot apex, axillary bud growth is significantly less. Hull (33) obtained similar results using 3 and 6 node rhizome pieces. Germination of the axillary bud closest to the apex was increased when the apical bud was removed. McWhorter (45) found germination of rhizome buds increased as rhizomes were cut into smaller pieces. Anderson's results also indicated more shoots were produced from segmented than intact rhizome pieces (4). Length of the primary rhizome also affects early vigor and seasonal plant growth. Beasley (8) found greater shoot extension after 5 to 20 days of growth in a mist chamber from larger single node segments. Plant height, number of leaves, number of tillers, and fresh weights of shoots and secondary rhizomes increased significantly as the length of rhizome pieces increased from 2.5 cm to 10 cm to 25 cm. Longer rhizomes pieces also produced secondary rhizomes sooner than shorter rhizome pieces.

Seed Germination and Dormancy

Seed dormancy and shattering are characteristics which influence both the invasiveness and longevity of a weed infestation. Johnsongrass produces a large number of seeds

and exhibits varying degrees of shattering depending on ecotype. McWhorter (43) found 1% to 73% seed shattering in a study investigating the growth and development of 55 different Johnsongrass ecotypes. Johnsongrass seed is dormant when first mature. This dormancy is in part due to the presence of tannin compounds in the seed coat which reduce permeability (9). This dormancy is overcome after storing 4-5 months at room temperature (52). Taylorson and Brown (64) found an increase in germination from 7% to 29% with an after ripening period of 14 days. Taylorson and McWhorter (63) examined the effects of temperature, light, and KNO_3 on the germination of 44 ecotypes. They found that dormancy varied among ecotypes. Highest germination was obtained after pre-chilling at 10C for 20 days, with alternating temperatures of 24/40C, continuous light, and the addition of 0.2% KNO_3. Exposure to far red light during or at the end of the chilling treatment inhibits germination. This inhibition can be partially overcome by exposure to red light indicating phytochrome involvement in the germination process of Johnsongrass (62). Seed longevity is also important in the persistence of a weed infestation. Egley and Chandler (22) found 50% viability of Johnsongrass seed after burial for 2.5 years at depths of 8, 24, and 38 cm.

McWhorter (45) found emergence of Johnsongrass seed decreased with increasing depth of burial and was lower in a clay soil than a fine sandy loam. Holm et al. (28) reported most seedlings arise from seed in the upper 7 cm of soil but can arise from seeds at depths of up to 15 cm.

Morphological Variation of Johnsongrass Ecotypes

A number of studies have been conducted to investigate morphological variation among Johnsongrass ecotypes. Beadle and Costin (7) describe an ecotype as a genotypical variant of a species which arises as a response to a particular habitat. Burt and Wedderspoon (11) suggest the term selection is more appropriate in many of these studies as ecotype is restricted to a variation which has been shown to be adaptive to a particular ecosystem. It is feasible, however, that ecotypes of Johnsongrass have developed as a response to northward migration. In 1926, Johnsongrass was seldom reported to overwinter north of 38°N latitude. In 1971, overwintering was reported at 40°N latitude (11). Presently, winterhardy ecotypes have been reported as far north as 43°N latitude in Ontario and New York state (66).

Burt (10), working with 12 different Johnsongrass selections from 4 different regions of the U.S., found selections from more southern latitudes flowered later than

northern selections. Wedderspoon and Burt (67) found similar results in a study involving a northern selection from Maryland and a southern selection from Mississippi. The southern selection flowered later and yielded significantly greater root, rhizome, and total fresh weight. In addition, the northern selection exhibited the most susceptibility to the herbicide dalapon. In a second study involving the effects of temperature and dark period on these same selections, Burt and Wedderspoon (11) found that at 20C all selections grew equally, however, at 35C the southern selection produced more total fresh weight. Rhizome production and the total stem number were also greater for the southern selection at 35C. In a study comparing the morphology of 6 different Johnsongrass selections, McWhorter and Jordan (49) found variations in several characteristics including the number of primary and secondary culms, plant height, and rhizome number. In an earlier study involving morphological variation of 55 different Johnsongrass selections as well as 3 selections of S. almum, McWhorter (43) found differences in length and width of leaf blades, plant height, culm density, and floret production. S. almum produced taller plants although culm density and lateral growth were less than that of Johnsongrass. In a separate study involving the susceptibility of these selections to the herbicide dalapon,

McWhorter (42) found wide variation in responses. Hamilton and Tucker (24) also found differences in susceptibility to dalapon among five selections from Arizona. Ingle and Rogers (34) reported rhizomes obtained from a Michigan selection produced greater growth at low temperatures than a selection from Indiana. Warwick and Black (66) in a study comparing overwintering selections from Ontario, Ohio, and New York and non-overwintering selections from Ontario found non-overwintering selections were taller, had wider culms and leaves, larger seeds and inflorescence, greater rates of germination, larger seedlings, and greater rates of seedling growth. Chernicky and Slife (12) compared an Illinois selection of sorghum to a selection of Johnsongrass from Tennessee and found the Illinois selection to be taller with wider leaf blades than Johnsongrass. The Tennessee selection also produced more rhizomes per plant. They determined that the Illinois sorghum strain more closely resembled S. almum than Johnsongrass.

Johnsongrass Control

Johnsongrass is a highly competitive species and control is essential for successful crop production. Ahmed et al. (3) found yield reductions of up to 36% in sugarcane heavily infested with Johnsongrass while Williams and Hayes

(68) reported soybean yield reductions of up to 88% in heavily infested fields. In addition to competitive ability, several studies have demonstrated the presence of allelopathic compounds in Johnsongrass leaves and rhizomes. Lolas and Coble (39) found soybean seedling dry weights were decreased as percent rhizomes in the soil increased. Soybean dry weights were also decreased when plants were watered using rhizome extracts. Horowitz and Friedman (32) reported similar inhibition of barley seedlings. Abdul-Wahab and Rice (1) reported that decaying Johnsongrass leaves or rhizomes in the soil inhibited the germination and development of several weed species studied. Chlorogenic acid, p-coumaric acid, and p-hydroxybenzaldehyde were the main plant inhibitors present in leaf and rhizome extracts.

Several strategies have been investigated for the control of Johnsongrass in both crop and non-crop situations. In non-crop areas, repeated mowings or tillage may be used to prevent seed production and reduce rhizome growth as well as regrowth of shoots (9, 46). McWhorter (46) found a 99% reduction in rhizome production when a heavily infested area was tilled six times at 2 week intervals. Repeated tillage brings rhizome pieces to the soil surface where they are exposed to desiccation during the summer as well as freezing temperatures through the winter months. Hauser and Thompson (26) obtained 88%

Johnsongrass control in a non-crop area using the herbicide dalapon (2,2-dichloropropionic acid) at 5.6 kg/ha applied as a split application of 2.8 kg/ha each. A single application of 5.6 kg/ha did not provide adequate control. Dalapon rates of 8.4 kg/ha or greater applied as either a single or sequential application provided greater than 90% Johnsongrass control. More recently the non-selective herbicide glyphosate (N-(phosphonomethyl)glycine) has been used extensively for Johnsongrass control in non-crop areas. Baird and Upchurch (5) reported on four separate studies in which they obtained greater than 90% control with the isopropylamine salt of glyphosate at rates of 1.12 kg/ha or more. Parochetti et al. (55) reported significantly greater control when glyphosate was applied when Johnsongrass was in the boot to head stage rather than when 45 to 60 cm in height. When applied at the earlier growth stage, control was 90% or greater at glyphosate rates of 1.12 kg/ha or more, however, control diminished as the season progressed and at 8 to 11 weeks after treatment control was less than 70% for all treatments. When applied at the boot to head stage most treatments provided greater than 90% control at 9 weeks after treatment. Although the above options provide adequate Johnsongrass control they necessitate removal of the land from crop production for a season which represents a potential loss of income for the grower. Control options

which allow the land to remain in production are therefore more attractive to the grower and many such options do exist.

Both herbicidal treatments and tillage as well as combinations of these practices have been used to control Johnsongrass in corn and soybeans. McWhorter and Hartwig (48) obtained 90% Johnsongrass control following 10 discings prior to planting soybeans. Dalapon applied as a preplant incorporated treatment at 4.4 kg/ha provided 70% control when application was proceeded by two discings for field preparation and followed by one discing for incorporation. When treatment was followed by 5 discings, control was increased to 86%. Crawford and Rogers (15) applied glyphosate at a rate of 1.68 kg/ha to Johnsongrass 2 to 4 feet tall 7, 14, and 28 days prior to field preparation and soybean planting and obtained control of 86%, 80%, and 81%, respectively, one month after planting. Dalapon at 5.6 kg/ha provided only 65% control. Connell and Derting (14) investigated the use of glyphosate at rates of 0.56 to 5.6 kg/ha as a preplant application in soybeans using three different tillage systems. Glyphosate rates of 1.12 kg/ha and above provided acceptable control of both seedling and rhizome Johnsongrass 25 days after treatment, however, control diminished as the season progressed due to reinfestation by new Johnsongrass seedlings. Season long

control was increased with addition of post-directed treatments, however, soybean stand reduction occurred. McWhorter (44) also reported significant soybean injury when applying glyphosate as either an overhead or direct application at rates of 0.56 to 2.24 kg/ha. Dale (16) employed the rope wick applicator as a method of selectively applying glyphosate for Johnsongrass control in emerged soybeans. Glyphosate applied twice at 0.1 kg/ha each time provided 92% control at crop maturity with no visible crop injury compared to 51% control when glyphosate was applied as a preplant broadcast spray at 2.2 kg/ha. Preplant applications of glyphosate at the proper stage of growth often necessitate delays in soybean planting which may cause yield loss. Preplant treatments of glyphosate are more difficult in the northern range of Johnsongrass infestations due to the cooler temperatures which prevent plants from reaching the proper stage for glyphosate applications until well past the optimum planting date for both corn and soybeans. Herbicide treatments which provide selective control of Johnsongrass in the growing crop are therefore attractive options to growers.

Several selective herbicides are available for Johnsongrass control in soybeans. Parochetti (54) compared trifluralin (2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl) benzenamine), nitralin (4-(methylsulfonyl)-2,6-dinitro-n,n-

dipropylanaline), and vernolate (S-propyl dipropylthiocarbamothioate) applied as preplant incorporated treatments at rates of 1.12, 1.12, and 3.36 kg/ha, respectively, with dalapon applied as a preplow application at 5.7 kg/ha. Dalapon provided 75% control compared to 44% for the preplant incorporated treatments. When a preplow application of dalapon was followed by a preplant incorporated treatment, control was increased to 85%. The greatest control was obtained from a preplow application of dalapon followed by trifluralin preplant incorporated. This treatment provided 89% Johnsongrass control. McWhorter (47) investigated several dinitroanaline herbicides for the efficacy in controlling Johnsongrass in soybeans. Trifluralin at the normal use rate of 1.1 kg/ha did not provide acceptable control. At twice this rate control was 88% or more in 4 of the 6 experiments reported.

Recently, several postemergence herbicides have been introduced which provide excellent control of Johnsongrass in soybeans as well as many other broadleaf crops. Among these are fluazifop {(+)-2-[4-[(5-(trifluoromethyl)-2-pyridinyl)oxy]phenoxy]propanoic acid}, sethoxydim {2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one}, quizalofop (2-[4-(6-chloro-2-quinoxalinyl)oxy]phenoxyl]propionic acid), and haloxyfop (2-[4-[[3-chloro-5-(triflouromethyl)-2-pyridinyl]oxy]phenoxy]propanoic

acid). Banks and Tripp (6) applied sethoxydim and fluazifop to 30-40 cm tall Johnsongrass 26 days after planting soybeans at rates of 0.3 and 0.6 kg/ha. All treatments provided 100% control, both 32 and 110 days after treatment with the exception of sethoxydim applied at 0.3 kg/ha. Control with this treatment was 83 and 92%, 32 and 110 days after treatment, respectively. Control with sethoxydim was increased by a second application of 0.3 kg/ha 28 days later. Abernathy et al. (2) obtained greater control of rhizome Johnsongrass 14 months after treatment from fluazifop than sethoxydim. Rates used were not stated. Colby et al. (13) found sequential applications of fluazifop at 0.28 kg/ha controlled regrowth from rhizomes and substantially reduced regrowth the year following treatment. Duray and Kapusta (21) compared several postemergence grass herbicides for Johnsongrass control in soybeans. Quizalofop, sethoxydim, and fluazifop provided excellent Johnsongrass control when applied to Johnsongrass 37 to 62 cm in height. Control decreased at fluazifop rates of .15 kg/ha and sethoxydim rates of 0.22 kg/ha, however, a second application at these rates improved control. Langemeier and Witt (37) compared control of 30 to 50 cm tall Johnsongrass obtained from fluazifop, haloxyfop, and sethoxydim at rates of 0.2, 0.1, and 0.2 kg/ha, respectively, at two sites in Kentucky. Control 8 weeks after treatment was 87, 91, and

73% for fluazifop, haloxyfop, and sethoxydim, respectively, when averaged over both sites and both years of the study. Patterson et al. (56) reported excellent control of many perennial grasses including Johnsongrass using haloxyfop at rates of 0.07 to 0.2 kg/ha. Meninato (51) obtained greater than 90% control of 37 to 62 cm tall Johnsongrass haloxyfop rates of 0.2 to 0.28 kg/ha. Ready and Wilkerson (57) found no significant difference in control of a selection of Johnsongrass from California compared to that of a selection from North Carolina using fluazifop.

Selective control of Johnsongrass in corn has proven more difficult. Preplant incorporated applications of thiocarbamate herbicides such as EPTC (S-ethyl dipropyl carbamothioate), or butylate (S-ethyl bis(2-methylpropyl) carbamothioate) have been effective in controlling seedling Johnsongrass, however, rhizome Johnsongrass is only suppressed. Hicks and Fletchall (27) reported EPTC applied at rates of 3.36 kg/ha prevented the emergence of seedlings and severely retarded the growth and elongation of shoots arising from rhizomes. Significant reductions in Johnsongrass plants were observed at three weeks after application, however, later evaluations showed inadequate season long control. Roeth (58) reported 81% Johnsongrass control 4 weeks after planting after applications of 4.5 kg/ha butylate for two consecutive years. Control at

harvest was reduced to 57%. EPTC applied in a similar manner at 3.4 kg/ha provided 91% control at 4 weeks after application but only 57% at harvest. Dale and Chandler (17) reported that corn could be grown successfully on land infested with Johnsongrass when rotated with other crops such as cotton [Gossypium hirsutum (L.)] which provided an opportunity for employment of more effective control measures. Currently the most effective and long lasting control measures for Johnsongrass in field crops consist of combinations of tillage, crop rotations, and the use of selective pre and postemergence herbicides as well as selective placement and spot treatment with non-selective herbicides such as glyphosate.

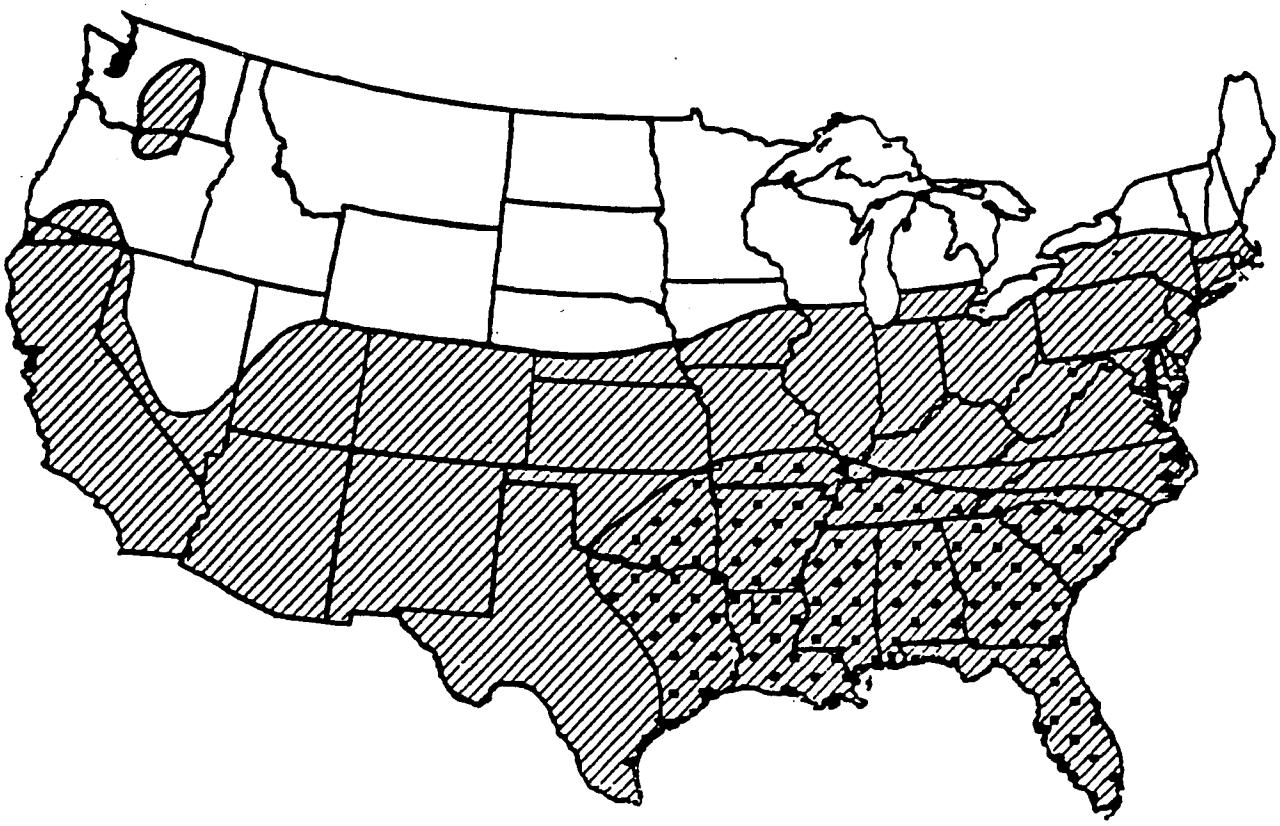

Figure 1. The distribution of Johnsongrass in the United States. Dots indicate area of greatest economic importance.

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CHAPTER TWO

CHARACTERIZATION OF MORPHOLOGICAL VARIATION OF WEEDY JOHNSONGRASS [SORGHUM HALEPENSE (L.) PERS.] POPULATIONS IN MICHIGAN

ABSTRACT

In recent years, reports of Johnsongrass [Sorghum halepense (L.) Pers.] infestations in Michigan have increased. This increasing occurrence of Johnsongrass may be the result of development of ecotypes which are more tolerant of the cool soil temperatures characteristic of northern climates.

In order to characterize Johnsongrass populations in Michigan, morphology and dry matter production of overwintering and non-overwintering Michigan populations were compared with that of overwintering populations from Ontario, New York, Ohio, Tennessee, and Mississippi and non-overwintering populations from Ontario and Illinois as well as a population of S. almum (Parodi) from Minnesota. Distinct differences existed between S. almum and selections

of S. halepense with S. almum having larger seeds, faster emergence, taller plants, wider leaves, greater culm circumference, fewer leaves/culm, and fewer days to flowering. S. almum also exhibited greater crown, shoot, and total dry weight while rhizome weight was greater for S. halepense. In all cases the non-overwintering Michigan selections were similar to S. almum while those of the overwintering selections were similar to S. halepense. These results suggest two distinct sorghum species exist as weed problems in Michigan, an overwintering ecotype of S. halepense and a non-overwintering ecotype of S. almum.

INTRODUCTION

Johnsongrass [Sorghum halepense (L.) Pers.] is classified in the sorghum section of the genus Sorghum. Snowden (13) divided the section in two subsections; Arundinaceae, consisting of diploid (2n=20) species and Halepensia, consisting of tetraploid (2n=40) species. Snowden described 52 species in this section. DeWet and Huckaby (5) divided the section into a single species, S. bicolor (L.) Moench, with two subspecies, S. bicolor ssp. bicolor which contains the cultivated sorghums, companion weeds, and semi-wild relatives, and S. bicolor ssp. halepense which contains two morphologically distinct complexes, a Mediterranean and a tropical ecotype. The Mediterranean ecotype consists of small plants with narrow leaves and extends from Asia Minor to West Pakistan where it is replaced by a larger and more robust tropical ecotype which extends to southern India. It is the smaller Mediterranean ecotype which is believed to have been introduced into the new world and is commonly referred to as Johnsongrass (10). In Argentina, an introgression of S. halepense with an unknown cultivated sorghum has been described as S. almum (11). S. almum

resembles S. halepense in being rhizomatous and having 40 somatic chromosomes (4), however, it differs in having taller, thicker stems, broader leaves, and shorter rhizomes. Simon (12) has prepared a key in which he distinguishes S. almum from the tropical and Mediterranean ecotypes of S. halepense as having larger sessile spikelets, greater degree of branching in the panicle, as well as shorter and thicker rhizomes.

Considerable morphological variation exists among Johnsongrass populations from different locations. These variations may arise as a result of hybridization with other sorghum species (6, 7), or as an adaptation to a particular habitat. Burt and Wedderspoon (2) suggest the term selection to be applicable to populations showing variation as a result of hybridization while the term ecotype is more appropriate when describing populations exhibiting morphological differences in response to a particular ecosystem. In 1926, Johnsongrass was seldom reported to overwinter north of 38°N latitude. In 1971, overwintering ecotypes were reported at 40°N latitude (2). Presently, winterhardy ecotypes have been reported as far north as 43°N latitude in Ontario and New York state (14). It is feasible, therefore, that ecotypes of Johnsongrass may have developed as a result of the northward migration of this species. Burt (1), working with 12 different Johnsongrass populations from 4

different regions of the U.S., found selections from more southern latitudes flowered later than northern populations. Wedderspoon and Burt (16) found similar results in a study involving a northern population from Maryland and a southern population from Mississippi. The southern population flowered later and yielded significantly greater root, rhizome, and total fresh weight. In a second study involving the effects of temperature and dark period on these same populations, Burt and Wedderspoon (2) found that at 20C all selections grew equally, however, at 35C the southern selection produced more total fresh weight. Rhizome production and total stem number were also greater for the southern selection at 35C. Ingle and Rogers (8) reported rhizomes obtained from a Michigan population produced greater growth at low temperatures than a population from Indiana. Warwick and Black (14) compared populations which overwinter in Ontario, Ohio, and New York with non-overwintering populations from Ontario. They found that the non-overwintering population were taller, had wider culms and leaves, larger seeds and inflorescence, greater germination, larger seedlings, and greater rates of seedling growth. Warwick et al. (15) suggest the non-overwintering populations from Ontario may represent an introgressed form of S. halepense with a cultivated sorghum. While this population possesses the larger, more robust growth traits

of S. almum and the tropical ecotype of S. halepense, the sessile spikelet size and seed color are similar to S. almum as described by Simon (12). Chernicky and Slife (3) compared a sorghum population from Illinois to a population of Johnsongrass from Tennessee. They found the Illinois population to be taller with wider leaf blades than Johnsongrass. The Illinois population produced more seeds per panicle and fewer rhizomes than Johnsongrass. They determined that the Illinois population more closely resembled S. almum than S. halepense.

Although not a serious problem in the past, reports of Johnsongrass as a weed problem in Michigan have been increasing. The objective of the present study was to compare morphological characteristics of weedy sorghum populations in Michigan with those of populations from other locations in the eastern U.S., and determine if the Michigan populations possess distinct morphological characteristics, and if these characteristics are a result of hybridization, ecotypical adaptation, or a separate introduction of the species into the area. Morphological characteristics of two populations of Johnsongrass in Michigan were determined. These characteristics were compared with those of overwintering populations from New York, Ohio, Tennessee, Mississippi, and Canada and non-overwintering populations

from Illinois and Canada as well as a selection of S. almum from Minnesota.

MATERIALS AND METHODS

Ten Johnsongrass selections were obtained from different locations in the eastern U.S. and Canada. Overwintering selections were obtained from Ohio, New York, Mississippi, Tennessee, Brant County, Ontario, and Berrien County, Michigan. Non-overwintering selections were obtained from Illinois, Essex County, Ontario, and Eaton County, Michigan. A selection of S. almum from Minnesota was also included for comparative purposes. Seeds of each selection were planted in individual peat pots and placed in a greenhouse maintained at 25C ± 5C with a 16 hour photoperiod. After two weeks (May 15, 1984 and May 16, 1985), pots were thinned to one plant per pot and placed in bushel baskets filled with greenhouse potting soil (1:1:1 soil, sand, peat) and placed outdoors in an area bordered by greenhouses in East Lansing, MI. Plants were watered daily and fertilized once a week with 100 ml of a solution containing 640 ppm N, P_2O_5, and K_2O. Baskets were arranged in a randomized complete block design with 10 replications of each selection, one basket/1.5 m^2. Growth parameters measured are shown in Table 1.

Plants were harvested 22 weeks after sowing. Characters 8-14 were determined just prior to harvest. Characters 16-18 were determined immediately after harvest prior to dry weight determinations. Dry weights were obtained by drying the plant material for 48 hours at 140C. Characters 1-3 and 19 were determined following dry weight determinations. Data from 1984 and 1985 were combined and analyzed using analysis of variance techniques and means separated using Duncans Multiple Range Test.

Table 1. Growth parameters measured.

I. Seed and seedling characteristics:
1. Weight of 25 seeds (g)
2. Seed length (mm)
3. Seed width (mm)
4. Days to emergence (days)
5. Height 1 week after emergence (cm)
6. Height 2 weeks after emergence (cm)
7. Height 4 weeks after emergence (cm)

II. Morphological characteristics (vegetative):
8. Leaf width — fourth leaf, main culm (cm)
9. Leaf length — fourth leaf, main culm (cm)
10. Leaf number — main culm (no)
11. Branch number — main culm (no)
12. Node number — main culm (no)
13. Stem circumference — fifth internode, main culm (cm)
14. Number of tillers (no)
15. Plant height at flowering (cm)

III. Morphological characteristics (reproductive):
16. Seedhead length (cm)
17. Number of whorls/seedhead — main culm (no)
18. Number of branches/whorl — main culm (no)
19. Number of seeds/plant (no)
20. Number of days from sowing to flowering (days)

IV. Dry weights:
21. Total weights (g)
22. Rhizome weights (g)
23. Seed weights (g)
24. Root weights (g)
25. Crown weights (g)
26. Shoot weights (g)
27. Reproductive weights (g)
28. Vegetative weights (g)
29. Above ground weights (g)
30. Below ground weights (g)

V. Dry weight allocation:
31. Dry weight to rhizomes (%)
32. Dry weight to seed (%)
33. Dry weight to roots (%)
34. Dry weight to crown (%)
35. Dry weight to shoot (%)
36. Dry weight to vegetative tissue (%)
37. Dry weight to reproductive tissue (%)
38. Dry weight to above ground tissue (%)
39. Dry weight to below ground tissue (%)

RESULTS AND DISCUSSION

Seed and Seedling Characteristics

Distinct differences existed in seed size, weight, germination, and seedling growth between overwintering and non-overwintering selections in this study (Table 2). Seeds of non-overwintering selections were both larger and heavier than those of overwintering selections. In addition, these seeds exhibited faster germination and seedlings from these seeds were taller than overwintering selections. These results are in agreement with those of Warwick and Black (14) reporting on morphological studies comparing overwintering and non-overwintering populations from Canada. One of each of these populations is included in the present study with similar results. Chernicky and Slife (3) comparing an Illinois sorghum selection to a selection of S. halepense from Tennessee determined the Illinois selection more closely resembled S. almum than S. halepense. It is, therefore, of interest to compare the two Michigan selections in this study with both S. almum and S. halepense using the S. halepense selection from Tennessee for

comparative purposes. In the case of seed weight, the overwintering selection from Berrien County, Michigan had a weight of 0.14 g/25 seeds compared with 0.27 g for the non-overwintering selection from Eaton County, Michigan. Comparing these weights with those of S. almum and a selection of S. halepense from Tennessee, it is apparent that the non-overwintering type compares most favorably with that of S. almum (0.21 g) while the overwintering type is more similar to the S. halepense (0.16 g) although seed weight of the non-overwintering Michigan selection was significantly greater than that of S. almum. Similar results are observed upon comparison of seed length and width, germination, and seedling size. These results are in agreement with Simon (12) and McWhorter (9) who state that the sessile (fertile) spikelets of S. almum are larger than those of S. halepense.

Morphological Characteristics (Vegetative)

Of the eight vegetative morphological characteristics measured, significant differences between overwintering and non-overwintering selections were observed in leaf width, leaf number, stem circumference, and plant height at flowering while there were no differences in leaf length, node number, number of branches, or number of tillers (Table

3). Non-overwintering selections had wider leaves, fewer leaves, thicker stems, and taller plants than overwintering selections. There was very little variation between selections within these two types. These results are in agreement with those of Warwick and Black (14) who found non-overwintering selections from Canada to possess similar characteristics as the non-overwintering populations in this study. Similar results were observed upon comparison of the two Michigan selections with S. almum and S. halepense. Although plants of S. almum were significantly taller than the non-overwintering Michigan selection, in all cases the overwintering Michigan selection more closely resembled S. halepense while the non-overwintering selection resembled S. almum.

Morphological Characteristics (Reproductive)

Previous studies (3, 9, 14) have reported differences in inflorescence length, whorls/inflorescence, branches/whorl, and seeds/plant between Johnsongrass selections, however in the current study, no consistent differences were observed in these characteristics (Table 4). Consistent differences were observed only in days to flowering. Non-overwintering selections flowered approximately 1 week later than overwintering selections.

Dry Weights

Of the dry weights measured, there existed significant differences between overwintering and non-overwintering selections in all characters except total weight and root weight (Table 5). Non-overwintering selections exhibited lower rhizome, reproductive, and below ground weights and higher seed, crown, shoot (above ground vegetative), vegetative, and above ground weights. While considerable variation existed between individual selections, in most cases the weights of the overwintering Michigan selection most closely resembled S. halepense while weights of the non-overwintering Michigan selection resembled S. almum. Of particular interest are differences in rhizome and seed weight between these selections. Rhizome weights for the overwintering Michigan selection and S. halepense from Tennessee were 59 and 67 g, respectively, compared with 8 and 11 g for the non-overwintering Michigan selection and S. almum. While seed weights were significantly higher for non-overwintering selections overall, this weight was lower for the non-overwintering Michigan selection than S. almum. This difference resulted in significantly different reproductive weights for these two selections. Above ground weights were also effected by this difference although this could also be attributed, in part, to the highly variable

shoot weights observed in this study. Significantly lower root weights were observed in the overwintering Michigan selection and S. halepense from Tennessee. This resulted in significantly lower below ground weights for the overwintering Michigan selection relative to S. halepense. Although there was no difference in total weight between the overwintering and non-overwintering selections, S. almum did produce significantly greater dry weight than either the Michigan selection or the S. halepense selection from Tennessee.

Dry Weight Allocation

There were significant differences in dry weight allocation between overwintering and non-overwintering selections in all cases except percent dry weight allocated to crown tissue and to root tissue (Table 6). As with rhizome dry weight, the amount of dry matter allocated to rhizomes by the overwintering Michigan selection was similar to S. halepense while that of the non-overwintering selection was similar to S. almum. The same was true for the amount of dry matter allocated to reproductive and vegetative structures as well as above and below ground growth. Although seed weights of the non-overwintering Michigan selection was lower than that of S. almum the

amount of dry matter allocated to seed production was similar between these two selections.

The results of this study indicate distinct differences in morphology as well as dry weight production and allocation between overwintering and non-overwintering sorghum selections. Comparison of the overwintering Michigan selection with S. halepense from Tennessee as well as from Mississippi demonstrates the similarity between these selections for many of the parameters measured, however, differences among these selections as well as other overwintering selections suggest that the overwintering Michigan type represents a distinct ecotype of S. halepense. Similar comparison between the non-overwintering Michigan selection and S. almum demonstrate the similarities between these selections, however, differences do exist in height, seed weight, and total dry weight which suggest the non-overwintering Michigan type represents a distinct ecotype of S. almum. Warwick et al. (15) reached similar conclusions on comparison of overwintering and non-overwintering sorghum selections from Ontario, Canada. Two of these selections have been included in this study and as with the two Michigan selections, in most cases the overwintering Canadian selection most closely resembles S. halepense while the non-overwintering selections most closely resembles S. almum. Based on the results of this

study it is apparent that, as in Ontario, two distinct sorghum selections exist as weed problems in Michigan. Based on personal observations, it seems likely that the majority of infestations in the northern counties in Michigan, such as Ingham, Montcalm, and Eaton consist of the non-overwintering S. almum, whereas infestations in the southern tiers of counties consist of the overwintering S. halepense. Whether this is due to adaptation of these species to particular areas or separate introduction of these species to these areas and the practical implications concerning control measures for these two species is the subject of the two subsequent chapters.

Table 2. Seed weight and size, days to emergence, and height 7, 14, and 28 days after emergence for 10 sorghum selections[a].

Selection	Wt. of 25 Seeds	Seed Length	Seed Width	Days to Emergence	Plant Height		
					7 Days	14 Days	28 Days
	(g)	(mm)	(mm)	(days)		(cm)	
Overwintering							
Michigan	0.14cd	4.3de	1.8b	10.0b	14b	18c	31b
Ontario	0.14cd	4.2def	1.8b	13.0a	7b	13d	30b
New York	0.17c	4.8ab	2.0b	10.0b	15b	18c	36b
Ohio	0.13d	4.2ef	1.6c	10.0b	15b	18c	42a
Tennessee	0.16c	4.3def	1.9b	11.0b	17b	19c	35b
Mississippi	0.16c	4.1f	1.8b	6.0e	21a	31a	35b
Non-Overwintering							
Michigan	0.27a	4.8a	2.1a	6.0e	22a	32a	42a
Ontario	0.20b	4.5abc	1.9b	9.0cd	21a	25b	44a
Illinois	0.17c	4.6abc	1.9b	8.0d	23a	29ab	45a
S. almum	0.21b	4.5abc	2.1a	6.0e	21a	34a	43a
Type Means							
Overwintering	0.15b	4.3b	1.8b	10.0a	15b	20b	35b
Non-overwintering	0.21a	4.6a	2.0a	7.2b	22a	30a	43a

[a]Means within a column followed by the same letter are not significantly different at the 0.5% level as determined by Duncans Multiple Range Test.

Table 3. Leaf width, leaf length, stem circumference, plant height, number of leaves, branches, nodes, and tillers of 10 sorghum selections[a].

Selection	Leaf Width	Leaf Length	Number of Leaves	Number of Branches	Number of Nodes	Number of Tillers	Stem Circumference	Height at Flowering
	(cm)	(cm)	(no)	(no)	(no)	(no)	(cm)	(m)
Overwintering								
Michigan	3.6c	62a	19ab	3.2ab	5.2ab	15c	3.1cd	2.1c
Ontario	3.7c	59a	19ab	4.1a	5.3ab	16bc	3.3bc	2.0c
New York	3.5c	54a	15cde	3.2ab	5.5ab	19abc	3.0cd	2.1c
Ohio	3.5c	61a	21a	3.2ab	5.2ab	19abc	2.9d	2.1c
Tennessee	3.2c	55a	17bc	3.2ab	4.9bc	20ab	3.0cd	2.0c
Mississippi	3.4c	56a	17bc	3.1ab	6.0a	18bc	3.1cd	2.1c
Non-Overwintering								
Michigan	4.5ab	55a	13e	3.9a	5.3ab	20ab	3.8a	2.4a
Ontario	4.2b	55a	13de	3.0a	4.3c	20ab	3.6ab	2.4a
Illinois	4.9a	57a	15bcde	2.3b	5.2ab	19ab	3.6ab	2.3ab
S. almum	4.7ab	58a	13e	3.2ab	5.6ab	22a	3.6ab	2.3b
Type Means								
Overwintering	3.5b	58a	18a	3.3a	5.3a	18a	3.1b	2.1b
Non-Overwintering	4.6a	56a	13b	3.1a	5.1a	21a	3.6a	2.4a

[a]Means within a column followed by the same letter are not significantly different at the 0.05% as determined by Duncans Multiple Range Test.

Table 4. Seedhead length, number of whorls per seedhead, number of branches per whorl, number of seeds per plant, and number of days to flowering for 10 sorghum selections[a].

Selection	Seedhead Length	Whorls Per Seedhead	Branches Per Whorl	Seeds Per Plant	Days to Flower
	(cm)	(no)	(no)	(x100)	(no)
Overwintering					
Michigan	31ab	9.6ab	4.5ab	157ab	75bc
Ontario	31ab	9.4ab	3.4c	114cd	78ab
New York	33ab	9.7ab	4.5ab	94d	78ab
Ohio	30ab	10.2ab	3.9bc	120cd	76bc
Tennessee	31ab	10.1ab	4.0bc	123c	78ab
Mississippi	33ab	10.8a	3.8bc	124c	80a
Non-Overwintering					
Michigan	30ab	9.9ab	4.2bc	92d	71d
Ontario	34a	8.9b	4.1bc	114cd	72d
Illinois	28b	9.2ab	4.0bc	181a	71d
S. almum	31ab	9.1b	5.3a	139bc	72d
Type Means					
Overwintering	31a	10.0a	4.0a	122a	77a
Non-overwintering	31a	9.3a	4.4a	132a	71b

[a]Means within a column followed by the same letter are not significantly different at the 0.05% level as determined by Duncans Multiple Range Test.

Table 5. Rhizome, seed, root, crown, shoot, reproductive, vegetative, above ground, below ground, and total dry weights of 10 sorghum selections[a].

Selection	Total Weight	Rhizome Weight	Seed Weight	Root Weight	Crown Weight	Shoot Weight	Reproductive Weight	Vegetative Weight	Above Ground Weight	Below Ground Weight
	(gm)	(gm)	(gm)	(gm)	(gm)	(gm)	(gm)	(gm)	(gm)	(gm)
Overwintering										
Michigan	435bc	59ab	87bc	74d	56e	136cd	144a	290d	301bcd	134cd
Ontario	425c	63ab	63de	76d	68bcd	123de	126ab	298cd	286cde	139bc
New York	467abc	53b	62de	124a	84a	129cd	116bc	350ab	289cde	139bc
Ohio	435bc	57ab	56e	99bc	75abc	129cd	114bc	321bcd	277de	157ab
Tennessee	437bc	67a	79c	108abc	62de	105e	146a	291d	261e	176a
Mississippi	468ab	57ab	75cd	112ab	58de	132cd	133ab	335abc	298bcd	170a
Non-Overwintering										
Michigan	432bc	8c	97b	90cd	75abc	140bcd	106c	326abc	333b	99e
Ontario	436bc	9c	91bc	107abc	80ab	149abc	100c	336abc	320bc	116de
Illinois	475ab	8c	119a	98bc	72abc	159ab	127ab	347ab	367a	107e
S. almum	489a	11c	117a	97bc	72abc	168a	128ab	361a	380a	108e
Type Mean										
Overwintering	444a	59a	70b	99a	67b	126b	130a	314b	285b	159a
Non-Overwintering	458a	9b	106a	98a	75a	154a	115b	342a	350a	107b

[a]Means within a column followed by the same letter are not significantly different at the 0.05% level as determined by Duncans Multiple Range Test.

Table 6. Dry weight allocation to rhizomes, seeds, roots, crowns, reproductive, vegetative, above ground, and below ground tissue of 10 sorghum selections[a].

Selection	Rhizome	Seed	Root	Crown	Shoot	Reproductive	Vegetative	Above Ground	Below Ground
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Overwintering									
Michigan	13.7ab	19cd	17f	14cd	34b	33a	66d	62d	31c
Ontario	14.9a	15ef	17ef	16abc	35ab	30ab	70cd	67bc	32bc
New York	11.5b	13f	26a	18ab	30cd	24cd	75ab	61d	38a
Ohio	13.2ab	13f	23abcd	17ab	34bc	26bcd	73abc	63cd	36ab
Tennessee	15.4a	18cde	25ab	14cd	27d	33a	66d	59d	40a
Mississippi	12.5ab	16def	23abcd	12d	34bc	28bc	71bc	63cd	36ab
Non-Overwintering									
Michigan	1.9c	22ab	21bcde	17ab	37ab	24d	75a	76a	23d
Ontario	2.0c	21bc	24abc	18a	33bc	23d	76a	73a	26d
Illinois	1.8c	25a	20cdef	15bc	36ab	27bcd	73abc	77a	22d
S. almum	2.2c	24a	20def	14cd	34bc	26bcd	73abc	77a	22d
Type Mean									
Overwintering	13.5a	15b	22a	15a	32b	29a	70b	64b	35a
Non-Overwintering	2.0b	23a	21a	16a	36a	25b	74a	76a	23b

[a]Means within a column followed by the same letter are not significantly different at the 0.05% level as determined by Duncans Multiple Range Test.

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CHAPTER THREE

EFFECTS OF TEMPERATURES ON THE SEED GERMINATION, VIABILITY, AND SPROUTING OF RHIZOMES AND FATTY ACID CONTENT OF SEVERAL SORGHUM SELECTIONS

ABSTRACT

In recent years, reports of Johnsongrass [Sorghum halepense (L.) Pers.] as a weed problem in Michigan have increased. This apparent spread may, in part, be due to the development of ecotypes tolerant to cold temperatures. Experiments were conducted to determine the effects of cold temperature on rhizome sprouting, seed germination, and rhizome viability of overwintering and non-overwintering selections from Michigan as well as overwintering selections from Ontario, New York, Ohio, Tennessee, and Mississippi and non-overwintering selections from Ontario and Illinois as well as a selection of S. almum (Parodi) from Minnesota. With the exception of S. almum, non-overwintering selections exhibited less rhizome sprouting at lower temperatures than overwintering selections but seed germination was greater.

Rhizome sprouting of S. almum was similar to that of the overwintering selections at all temperatures. Overwintering of rhizomes was investigated at two locations in Michigan, a northern location in Montcalm County and a southern location in Berrien County. Rhizome survival overwinter was poor for all selections at the northern location, however, at the southern location overwintering types showed superior cold tolerance. Exposure to temperatures of -4C or -7C in growth chambers killed rhizomes of both Michigan selections as well as the selection from Tennessee and S. almum. Exposure to 5C had no effect on rhizome survival. Exposure to 0C decreased viability of the non-overwintering Michigan selection and S. almum after 3 days but had no effect of the overwintering Michigan selection or the S. halepense from Tennessee. No consistent differences were observed in cell membrane fatty acid saturation between overwintering and non-overwintering selections to account for the differences in cold temperature tolerance.

INTRODUCTION

Since the introduction of Johnsongrass into the southeastern U.S. in the 1800's (9), it has gradually spread to more northern latitudes. In 1926, Johnsongrass was seldom reported to overwinter north of 38°N latitude. In 1971, overwintering was reported at 40°N latitude (2). Present winterhardy ecotypes have been reported as far north as 43°N latitude in Ontario and New York state (16). Several studies have been conducted to determine possible differences in morphology and growth patterns of Johnsongrass selections from northern and southern locations. Burt (1), working with 12 different selections from 4 different regions of the U.S., found selections from more southern latitudes flowered later than those from more northern latitudes. Wedderspoon and Burt (17) found similar results in a study involving a northern selection from Maryland and a southern selection from Mississippi. The southern selection flowered later and yielded significantly greater root, rhizome, and total fresh weight. In a second study involving the effects of temperature and dark period on these same selections, Burt and Wedderspoon (2) found

that at 20C all selections grew equally, however, at 35C the southern selection produced more total fresh weight. Rhizome production and total stem number were also greater for the southern selection at 35C. Ingle and Rogers (7) reported that a selection of Johnsongrass from Michigan had an optimum growth temperature of 21C compared to 27C for a selection from Mississippi. Warwick and Black (16) compared overwintering Johnsongrass selections from Ontario, New York, and Ohio with non-overwintering selections from Ontario and found differences in several morphological characteristics including plant height, leaf and culm width, and seed size. Chernicky and Slife (3) compared an Illinois selection of sorghum with Johnsongrass from Tennessee and found the Illinois selection to be taller with wider leaf blades. The Tennessee selection also produced more rhizomes per plant.

The results of these studies as well as studies by this author indicate the development of geographical ecotypes of Johnsongrass as a result of the northward migration of the species. Earlier flowering and greater rates of growth at lower temperatures are obvious advantages for species growing in more northern locations, however, it would seem necessary for other adaptations to occur in order to insure survival of the species at the cooler temperatures common to the north central region of the U.S. Among these

adaptations would be greater tolerance of rhizomes to cold temperatures which would increase the ability of the rhizomes to overwinter and the ability for rhizomes to sprout and seeds to germinate at lower temperatures. Due to the relatively recent introduction of Johnsongrass into the northern regions of the U.S., few studies have investigated the possible presence of these adaptations in northern ecotypes. Johnsongrass rhizomes have been shown to have a high temperature requirement for optimum sprouting. Hull (6) reported 13.5%, 81.5%, and 91.5% germination at 15C, 22.5C, and 30C, respectively. Horowitz (5) obtained maximum bud sprouting at 28C. Burt and Wedderspoon (2) investigated shoot emergence of three Johnsongrass selections from Maryland and Mississippi at 35C, 25C, and 20C and found no differences in emergence rate among selections at any of the three temperatures. Taylorson and McWhorter (15) found seed germination differed among 44 different Johnsongrass ecotypes. Johnsongrass rhizomes have shown very little tolerance to freezing temperatures. In a study by McWhorter (10), rhizomes exposed to temperatures of -3C or less for more than 4 hours did not survive. Hull (6) also found rhizomes did not survive exposure to temperatures of -3.5C or less. Chernicky and Slife (3) compared the overwintering capacity of an Illinois sorghum strain to that of a Johnsongrass selection from Tennessee and found that 90% of

the rhizomes from the Tennessee selection survived the winter while only 5% of those from the Illinois strain survived. They attributed this difference to greater soil penetration by the rhizomes from the Tennessee strain which enabled them to escape exposure to lethal soil temperatures. Stoller (14) in a rhizome burial study found quackgrass rhizomes tolerated temperatures as low as -17C while Johnsongrass rhizomes were killed at temperatures below -9C. He found a higher proportion of unsaturated fatty acids in quackgrass rhizomes and suggested this may contribute to the cold tolerance of quackgrass. He did not, however, find a significant difference in the polar lipids which are important in cell membranes.

Michigan is currently on the northern edge of the range of Johnsongrass in the U.S., however, reports of Johnsongrass as a weed problem in Michigan fields have been increasing. Previous studies have demonstrated morphological similarities between overwintering sorghum selections from Michigan, Ontario, New York, and Ohio and S. halepense selections from Mississippi and Tennessee while non-overwintering selections appeared closer in morphology to S. almum. The objective of the current study was to determine if similarities also exist in optimum temperature for rhizome sprouting, seed germination, and rhizome cold tolerance of these selections. Fatty acids changes in the

cell membrane phospholipids of rhizomes after exposure to low temperature were also investigated to determine if this may be a factor in differential cold tolerance of these selections.

MATERIALS AND METHODS

Rhizomes and seeds used in the following experiments were obtained from Johnsongrass selections grown in East Lansing, Michigan during the summer of 1984 and 1985. Seeds of non-overwintering Johnsongrass selections from Ontario, Illinois, and Eaton County, Michigan and overwintering selections from Ontario, New York, Tennessee, Mississippi, Ohio, and Berrien County, Michigan as well as a selection of S. almum from Minnesota were planted in individual peat pots and placed in a greenhouse maintained at 25 ± 5C with a 16 hour photoperiod. After 2 weeks (May 15, 1984 and May 16, 1985) pots were thinned to one plant per pot and placed in bushel baskets filled with greenhouse potting soil (1:1:1 soil, sand, peat) and placed outdoors in an area bordered by greenhouses in East Lansing, MI. Plants were watered daily and fertilized once a week with 100 ml of a solution containing 640 ppm N, P_2O_5, and K_2O. Baskets were arranged in a randomized complete block design with ten replications. Plants were harvested 22 weeks after planting and seeds and rhizomes collected from each plant and either used immediately or placed in polyethylene bags and stored at 5C

until used. Representative rhizome samples were obtained by first selecting uniform plants of each selection. Rhizomes from these plants were then combined and uniform three node rhizome sections selected for each study. Seeds were obtained in a similar manner with several hundred seeds of each uniform plant from each selection combined. Seed samples were then drawn from this composite sample.

Rhizome Sprouting vs. Temperature

The optimum rhizome germination temperature for each selection was determined by placing 3-three node rhizome segments 2.5 cm deep in 0.5 L plastic pots containing greenhouse potting soil (1:1:1 soil, sand, peat). The pots were then placed in growth chambers maintained at 15C, 25C, or 30C for 2 weeks. At the end of the 2 week period, rhizomes were removed and percent sprouting determined for each selection. The experimental design was a split plot with three replications, 3-three node segments per replication. The experiment was done in each of two successive years. Means reported are averages of two experiments.

Seed Germination vs. Temperature

The optimum seed germination temperature for each selection was determined by placing ten seeds of each selection in a 60 by 15 mm petri dish containing 5.5 cm Whatman No. 1 filter paper and 2 ml distilled water. The dishes were then sealed and placed in total darkness in growth chambers maintained at 15C, 20C, 25C, 30C, or 35C for 2 weeks. At the end of the 2 week period, plates were removed and percent germination determined for each selection. Prior to the onset of the experiment, seeds were stored for 4 months at room temperature to allow ample time for after ripening. Experimental design was a split plot with ten replications. The experiment was done in each of two successive years. Means reported are averages of two experiments.

Rhizome Burial Study

Uniform 3-node rhizome pieces of each selection were placed in nylon mesh bags and buried 10 cm or 20 cm deep in a sandy loam soil in Montcalm County, Michigan (northern location) or a sandy clay loam soil in Berrien County, Michigan (southern location) in mid November. The rhizomes were allowed to remain in the soil through the winter and

excavated in early May of the following year. Rhizomes which exhibited obvious signs of decay were discarded. The remaining rhizomes were planted 2.5 cm deep in 0.5 L plastic pots containing greenhouse potting soil (1:1:1 soil, sand, peat) and placed in a growth chamber maintained at 30C for 2 weeks at which time rhizomes were removed and percent sprouting determined. Selections from Illinois and New York were not included in this study. As there were no differences in survival between the two depths means, reported are averages of five replications, 2 rhizome pieces/replication. The experiment was done in each of two successive years. Means reported are averages of two experiments.

Rhizome Temperature Tolerance

Cold temperature tolerance of a non-overwintering selection from Eaton County, Michigan and overwintering selections from Tennessee and Berrien County, Michigan as well as a selection of S. almum from Minnesota was determined by placing 3-three node rhizome segments of each selection 2.5 cm deep in 20.5 cm by 12.5 cm by 6.0 cm styrofoam pots containing slightly moistened greenhouse potting soil (1:1:1 soil, sand, peat). The pots were then placed in growth chambers maintained at -7, -4, 0, or 5C for

24, 48, 72, or 96 hours. At the end of the various exposure times, pots were removed from the growth chambers and the soil slowly warmed to room temperature. Rhizomes were removed and planted 2.5 cm deep in 0.5 L plastic pots containing sterilized field soil. These pots were then placed in a greenhouse maintained at 30C ± 5C for 2 weeks at which time rhizomes were removed and percent sprouting determined for each selection. The experimental design was a three factor factorial with three replications, 3-three node segments constituting one replication. The experiment was done in each of two successive years. Means reported are averages of two experiments.

Cell Membrane Lipid Composition vs. Temperature

The effects of cold temperature exposure on fatty acid composition of cell membranes phospholipids of rhizomes from a non-overwintering selection from Eaton County, Michigan and overwintering selections from Tennessee and Berrien County, Michigan as well as a selection of S. almum from Minnesota was determined. Three 3-node rhizome segments were placed 2.5 cm deep in 20.5 cm by 12.5 cm by 6.0 cm styrofoam pots containing slightly moistened greenhouse potting soil (1:1:1 soil, sand, peat). The pots were then placed in growth chambers maintained at 0C or 5C for 96

hours. At the end the exposure time pots were removed from the growth chamber and the soil was allowed to slowly warm to room temperature and the rhizomes removed. The three rhizome segments from each replication were cut into approximately 1 cm pieces and a single 20 g sample removed for analysis. In addition to the rhizomes exposed to the various temperatures, a sample of fresh rhizomes not exposed to low temperature was also obtained. Each treatment was replicated three times with three segments per replication. The experiment was repeated. Rhizomes used in the first experiment were obtained as previously described. Rhizomes for the second experiment were obtained from plants grown in a greenhouse maintained at 30C with a 12 hour photoperiod. With this exception and that of planting date all other growth parameters were similar. No morphological differences were observed between plants grown in the greenhouse and those grown outdoors and this distinction has been ignored throughout.

Following temperature treatment rhizome fatty acid content was determined according to a slightly modified procedure described by Rivera and Penner (12). Plasmalemma membranes were obtained by homogenizing 20 g rhizome samples in a Virtis grinder for 90 seconds in 30 ml of an ice-cold medium consisting of 0.26 M sucrose, 3 mM EDTA, 50 mM Tricine (N-Tris (hydroxy-methyl) methyl glycine), and 1%

(w/v) BSA (Bovine Serum Albumin) (fatty acid free) (pH 7.8). The homogenate was strained through four layers of cheesecloth and centrifuged at 13,000 x g for 15 minutes at 2C. The supernatant containing plasmalemma was further centrifuged at 80,000 x g for 30 minutes. The resulting pellet was then resuspended in 2 ml 20% (w/w) sucrose containing 1 mM $MgSO_4$ and 1 mM Tris-Mes (2-N-morpholino-ethane sulphonic acid) (pH 7.8). The suspension was layered onto a discontinuous sucrose gradient consisting of 28 ml of 45% (w/w) sucrose and 8 ml of 34% (w/w) sucrose. The sucrose solutions each contained 1 mM $MgSO_4$ and 1 mM Tris-Mes (pH 7.8). The gradient tubes were centrifuged for 2 hours at 95,000 x g in a swinging bucket rotor. The plasmalemma were obtained from the 34% to 45% interface, diluted in deionized water, and pelleted at 80,000 x g for 10 minutes. The plasmalemma samples were held at -15C for further analysis.

The frozen membrane samples were lyphilized and the lipids extracted according to a modified procedure by Folch et al. (4). Ten ml of chloroform/methanol (2:1) was added to the lyphilized tissue and the samples were shaken in a water bath at 33C for 30 minutes. The extract was filtered (Whatman No. 4) into a second tube, and the residue re-extracted once with 5 ml chloroform/methanol by shaking in a water bath for 15 minutes. The filtered extracts were

obtained and washed with 0.2 vols of 0.9% NaCl solution in a tube stirrer for 30 seconds. After the mixture settled, the upper phase was discarded and the lower phase washed twice with 0.2 vols of $CHCl_3$-MeOH-H_2O (3:48:37 by volume) containing 0.9% NaCl. The lower phase containing the lipids was taken to dryness under N_2 at 33C and the residue dissolved in 50 µl $CHCl_3$. The lipids were then applied to TLC plates (20 x 20) precoated with 0.25 mm silica gel 60 F254. The phospholipids were separated from the remaining lipids in Me_2CO-MeCOOH-H_2O (100:2:1) by volume and the phospholipid band selected on the basis of published Rf values (13) was scraped from the plates, extracted with 2 ml chloroform/methanol followed by 1 ml MeOH and the resultant solution taken to dryness under N_2 at 33C. Fatty acid methyl esters were prepared according to a modified procedure of Metcalfe et al. (11). 0.5 N methanolic KOH (1 ml) was added to the dried sample followed by boiling for 5 minutes. After the tubes had cooled, 1 ml of 14% BF3-MeOH was added and the sample boiled for an additional 2 minutes. One drop of saturated NaCl solution was then added and the methyl esters extracted 3 times with 1 ml hexane each. The extracts were combined, dried under N_2, and the residue taken up in 50 µl acetone for GLC analysis. Fatty acid composition was determined by FID using a 1.83 m by 2 mm glass column packed with 12% stabilized DEGS on anakrom ABS

and operated at 190C with N_2 as the carrier gas. Peak identification and quantification was performed by comparison with authentic fatty acid methyl ester standards. Data was analyzed as a split plot and means separated using Duncans Multiple Range Test. Means reported are averages of two experiments.

RESULTS AND DISCUSSION

Effect of Temperature on Rhizome Sprouting

The results of this study demonstrate a significant difference in sprouting ability of rhizomes from overwintering and non-overwintering selections. At 15C all overwintering selections except those from New York and Ohio exhibited significantly greater rhizome sprouting than all non-overwintering selections except S. almum (Table 1). Percent sprouting of rhizomes of S. almum was significantly greater than all other non-overwintering selections and similar to that of the overwintering selections. Average rhizome sprouting of the overwintering selections at this temperature was 63% compared with 39% for the non-overwintering selections. At 25C all overwintering selections showed greater rhizome sprouting than the non-overwintering selections with the exception of S. almum. Average rhizome sprouting at this temperature was 87% for overwintering selections, 45% for non-overwintering selections. At 30C there was no significant difference in rhizome sprouting between any of the selections. Average

sprouting was 84% for the overwintering selections, 81% for non-overwintering selections. The overwintering and non-overwintering selections from Michigan showed these same trends with the overwintering selection exhibiting significantly greater sprouting at both 15C and 25C and no difference at 30C. Sprouting at 15C, 25C, and 30C was 66%, 91%, and 83%, respectively, for the overwintering selections compared with 8%, 33%, and 83% for the non-overwintering selection.

Due to the morphological similarity of the overwintering Michigan selection to selections of S. halepense from Mississippi and Tennessee and the similarity of the non-overwintering Michigan selection to S. almum, it is of interest to compare the sprouting ability of rhizomes from these selections. Sprouting of the overwintering Michigan selection was similar to the two selections of S. halepense at all three temperatures while that of the non-overwintering Michigan selection was less at 15C and 25C. These results support previous morphological studies which suggested the overwintering Michigan selection represented an ecotype of S. halepense while the non-overwintering selection represented an ecotype of S. almum, however, comparison of the sprouting ability of rhizomes of the two Michigan selections with that of S. almum does not. Contrary to expectations, the non-overwintering Michigan

selection exhibits significantly less sprouting at 15C and 25C than S. almum while the overwintering selection is similar to S. almum at all three temperatures. It appears that if the two Michigan selections do represent selections of S. halepense and S. almum, respectively, they are distinctly different ecotypes.

The results of the previous morphological study demonstrated the greatly reduced capacity of the non-overwintering selections to produce rhizomes. The results of the current study suggest that rhizomes produced by these selections are less vigorous and require much higher soil temperatures for sprouting. In Michigan, this would result in sprouting of these rhizomes much later in the growing season when the competitive ability, particularly, with early planted crops such as corn would be reduced relative to the earlier emerging, more vigorous overwintering selections.

Effect of Temperature on Seed Germination

Although differences in germination between individual selections existed, in general, non-overwintering selections exhibited significantly greater germination than the overwintering selections at the lower temperatures of 15C and 20C (Table 2). Percent germination at 15C and 20C was

45% and 64% for the non-overwintering selections compared to 31% and 45% for the overwintering selections. At temperatures above 20C there was no significant differences in germination between overwintering and non-overwintering selections. The exception to this generalization as with rhizome sprouting was S. almum. S. almum exhibited greater germination than both the overwintering and non-overwintering selections at all temperatures except 20C. Germination of seeds of the overwintering and non-overwintering Michigan selections was similar at temperatures of 20C, 25C, and 30C, however, at the lowest temperature (15C) and the highest temperature (35C) germination was greatest for the non-overwintering selection. Germination of seed from the non-overwintering selection was 60% and 77% at 15C and 35C compared with 32% and 53% for the overwintering selections.

As with rhizome sprouting, it is of interest to compare seed germination of the two Michigan selections with that of the S. halepense selections from Mississippi and Tennessee and S. almum. Germination of the overwintering Michigan selection and the S. halepense selection from Mississippi is similar at all temperatures except 20C whereas the non-overwintering selection exhibited greater germination at all temperatures except 25C and 30C (Table 2). Germination of both the overwintering and non-overwintering Michigan

selections is similar to the Tennessee selection of S. halepense at all temperatures except 25°C and 35°C. This is due to the greater germination rate of the Tennessee selection relative to the Mississippi selection which results in fewer differences between this selection and the non-overwintering Michigan selection. Both Michigan selections exhibit significantly less seed germination than the selection of S. almum at all temperatures above 20C. At 20C germination percentage is similar for all three selections whereas at 15C germination of the overwintering Michigan selection is less than both S. almum and the non-overwintering Michigan selection.

The results of this study demonstrate a higher germination rate for seeds of non-overwintering selections at lower temperatures. Given the poor survival rate of rhizomes of these selections and the fact that these rhizomes show decreased sprouting at lower temperatures relative to the overwintering selections, it would be advantageous for seeds of these non-overwintering selections to germinate at lower temperatures than their overwintering counterparts in order to establish plants and be competitive early in the season. The ability of seeds of these selections to germinate at lower temperatures may also represent an adaptation to more northern climates as in most cases non-overwintering selections originate in more

northern locations than overwintering selections. Germination of seeds of the overwintering Michigan selection was similar in most cases to that of the S. halepense selections from Tennessee and Mississippi while seeds of both Michigan selections was less than that of S. almum. It appears from this data as in the previous experiments that if the non-overwintering Michigan selection does represent a selection of S. almum, it as well as the other non-overwintering selections in this study are distinct ecotypes.

Effect of Cold Temperature on Rhizome Viability

The results of this study illustrate the effects of extreme cold temperatures of rhizome viability. Exposure of rhizomes to temperatures of -4C and -7C for 24 hours or more was sufficient to kill rhizomes of all four selections, whereas exposure of rhizomes to 5C for up to 4 days had no effect of rhizome viability of any selection (Table 3). Exposure to 0C had little effect on viability of rhizomes of the overwintering selections from Michigan and Tennessee but significantly reduced viability of the non-overwintering Michigan selection and S. almum (Figure 1, Table 3). Percent sprouting following four day exposure to 0C for the overwintering selections from Michigan and Tennessee was 77.8% and 72.2%, respectively, compared to 24.5% and 44.5%

for the non-overwintering Michigan selection and S. almum. These results illustrate the increased susceptibility of the non-overwintering selections to cold temperatures. This increased susceptibility would naturally reduce the potential of these selections to reproduce from rhizomes in areas where soil temperatures are 0°C or below for extended periods of time, whereas the more temperature tolerant overwintering selections may be able to tolerate these winter temperatures and reproduce from both seeds and rhizomes the following spring.

Overwintering Ability of Eight Sorghum Selections

Table 4 demonstrates the overwintering abilities of eight sorghum selections at two locations in Michigan. At the southern Michigan location (Berrien County) distinct differences existed in overwintering abilities between overwintering and non-overwintering selections. The overwintering selections exhibited an average percent survival of 47.0% with no significant differences among selections while the non-overwintering selections exhibited a survival rate of only 5.0% overall. At the northern location (Montcalm County) there was no differences in overwintering ability among any selections with all selections exhibiting poor survival. It is of particular

interest to note the results of this experiment concerning the two Michigan selections. At the southern location the southern selection showed increased rhizome survival relative to the northern selection. At the northern location the survival rate was poor for both the northern and southern selection.

Records of soil temperatures for the winter of 1985/86 at depths of 10 and 20 cm are shown in Figures 2 and 3. These records demonstrate the differences in soil temperature at the two locations during the winter months. At the southern location temperatures at the 20 cm depth did not fall below 0C the entire winter while temperatures at the 10 cm depth remained at 0C to 1C throughout the winter. Although in the previous experiment, significant survival of rhizomes of the non-overwintering selections was shown following 4-day exposure to 0C, it is apparent from the results of this experiment that these same rhizomes cannot tolerate exposure to this temperature for prolonged periods of time while the rhizomes of overwintering selections do possess this ability. Soil temperatures at the northern locations were less than 0°C for most of the winter with lows of -5C at the 20 cm depth and as low as -10C at the 10 cm depth. As seen in the previous experiment, these low temperatures, for even a short period of time, are

sufficient to cause death of rhizomes of both overwintering and non-overwintering selections.

It is apparent from the results of this and the preceding experiment that the degree of rhizome survival of Johnsongrass selections is greatly influenced by soil temperature and that very little overwintering of these rhizomes will occur in areas where winter soil temperatures fall below 0C for extended periods of time. Although the overwintering Michigan selection exhibited some greater temperature tolerance than the S. halepense selection from Tennessee in the previous experiment, this adaptation, if it exists, has very little impact on the overwintering ability of this selection relative to those from other, more southern locations. More likely, rather than any adaptation to lower temperatures it is the higher soil temperatures in the southern part of Michigan which are allowing rhizomes of this selection to overwinter. If this selection is occurring at more northern latitudes in Michigan, it is likely that reproduction is taking place via seed rather than rhizomes whereas reproduction of the non-overwintering selection is occurring exclusively by seed regardless of the location infestations are occurring.

Effect of Cold Temperature on Fatty Acid Composition of Cell Membrane Phospholipids

The previous two studies demonstrated the decreased cold tolerance of the non-overwintering Michigan selection relative to that of the overwintering selection. The objective of the following study was to determine if any differences existed in the fatty acid composition of phospholipids from cell membranes of rhizomes from these selections which may account for this differential temperature susceptibility. For comparative purposes, a selection of S. halepense from Tennessee and a selection of S. almum from minnesota were also included.

Previous studies have suggested that the degree of saturation of the fatty acids in cell membranes play a role in cold temperature tolerance in that those plants with a higher percentage of unsaturated fatty acids are better able to withstand cold temperatures (8). Table 5 shows the individual fatty acid content and the unsaturated to saturated (U:S) ratio for fatty acids of cell membrane phospholipids for the four selections following 4 day exposure to 0C or 5C wherein a higher number indicates a greater degree of unsaturation. Exposure of rhizomes to 0C for 4 days resulted in a significant increase in the U:S ratio for the overwintering Michigan selection but had no

effect on any of the other three selections. This increase resulted in a significantly higher U:S ratio for the overwintering Michigan selection relative to the non-overwintering selection. This increase is due mainly to a shift in the amounts of palmitic (16:0) and linoleic acids (18:2) in the membrane phospholipids of the overwintering selection. Prior to temperature treatment palmitic acid accounts for 48% of the total fatty acids while linoleic acid accounts for 25%. Following 4 day exposure to 0°C the percentages changed to 37% for each. These results suggest that the degree of unsaturation may be in part responsible for the greater cold tolerance of this selection demonstrated in the previous experiments, however, in these experiments S. almum exhibited a greater susceptibility to cold temperatures than either the overwintering Michigan selection or the Tennessee selection but there is no difference in the U:S ratio demonstrated by any of these three selections while this ratio is significantly greater for S. almum than the non-overwintering Michigan selection which exhibited similar cold tolerance. It is difficult, therefore, to base the differential cold tolerance of these four selections solely upon differences in the degree of saturation of the fatty acids in the membrane phospholipids.

It is apparent from these studies that the rhizomes of the non-overwintering selections are less vigorous and less

tolerant to cold temperatures than the overwintering selections, while seeds of these selections possess an ability to germinate at lower soil temperatures than the overwintering selections. This would indicate that Johnsongrass infestations in which rhizome reproduction is a major factor would be limited to areas where soil temperatures do not fall below 0C for extended periods of time. If infestations of these overwintering selections occur in areas where soil temperatures fall below freezing for long periods, it is likely that reproduction is occurring by seed rather than rhizomes and control measures could therefore be similar to those used for annual grasses rather than those used to control perennial species. In Michigan, Johnsongrass infestations in the southern most counties produce abundant rhizomes which due to the relatively warm soil temperatures overwinter well but cannot tolerate the cooler soil temperatures in more northern locations, while infestations in more northern counties produce few rhizomes which are highly susceptible to low soil temperatures. Based on the results of this study, it does not appear that the spread of either of these selections by seed is limited by climate but rather that individual infestations have most likely resulted from separate introduction of one of these two selections into an area.

In the previous study, it was seen that the southern selection was morphologically similar to S. halepense while the northern selection appeared similar to S. almum. These similarities, particularly between the northern selection and S. almum, were not as apparent in rhizome sprouting and seed germination although cold temperature tolerance was similar. It appears that if the northern selection is indeed S. almum it represents a distinctly different ecotype than the one used for comparative purposes in this study while the overwintering selection appears quite similar in morphology, rhizome sprouting ability, seed germination, and temperature tolerance to the selections of S. halepense and most likely represents an ecotype of this species.

Table 1. Effect of temperature on rhizome sprouting of 10 sorghum selections[a].

Selection	Temperature (°C) 15	25	30
	Sprouting (%)		
Overwintering			
Michigan	66bcde	91ab	83abc
Ontario	66bcde	91ab	83abc
New York	33fgh	83abc	75abcd
Ohio	75abcd	75abcd	75abcd
Tennessee	83abc	91ab	91ab
Mississippi	58cdef	91ab	100a
Non-Overwintering			
Michigan	8h	33fgh	83abc
Illinois	50defg	33fgh	83abc
Ontario	25gh	41efg	83abc
S. almum	75abcd	75abcd	75abcd
Type Mean			
Overwintering	63a	87a	84a
Non-overwintering	39b	45b	81a

[a]Means followed by the same letter are not significantly different at the 0.05% level as determined by Duncans Multiple Range Test.

Table 2. Effect of temperature of seed germination of 10 sorghum selections[a].

Selection	Temperature (°C) 15	20	25	30	35
	Germination (%)				
Overwintering					
Michigan	32pq	52jklm	50klmn	76b-g	53jklmn
Ontario	18qr	38nop	43mnop	60hijkl	51jklmn
New York	31pq	62f-l	58h-m	72c-i	71c-i
Ohio	8r	20qr	30pq	48lmno	52jklm
Tennessee	61g-l	58h-m	73b-h	80abcd	78abcde
Mississippi	35op	38nop	60h-l	63e-l	55j-n
Non-overwintering					
Michigan	60h-l	65e-k	48l-o	78a-e	77b-f
Illinois	35op	76b-g	48l-o	66d-j	57i-m
Ontario	43mnop	52jklmn	53jklmn	63lmno	61g-l
S. almum	72c-i	63e-l	82abc	87ab	92a
Type Mean					
Overwintering	31g	45f	52ef	66cd	60de
Non-overwintering	45f	64cd	58ef	74cd	72cd

[a]Means followed by the same letter are not significantly different at the 0.05% level as determined by Duncans Multiple Range Test.

Table 3. Effect of cold temperature on rhizome survival of 4 sorghum selections[a].

Temperature	Duration	Selection			
		Michigan[b] (OV)	Michigan[c] (NOV)	Tennessee	S. almum
		Sprouting			
(°C)	(days)	(%)			
5	1	83abcd	91ab	100ab	89abc
	2	89abc	74bcde	94ab	100ab
	3	94ab	74bcde	94ab	89abc
	4	94ab	100a	94ab	100ab
0	1	89abc	100ab	72bcde	100ab
	2	83abcd	74bcde	88abc	61cdef
	3	88abc	58def	72bcde	38fg
	4	77bcd	24g	72bcde	44fg
-4	1	0h	0h	0h	0h
	2	0h	0h	0h	0h
	3	0h	0h	0h	0h
	4	0h	0h	0h	0h
-7	1	0h	0h	0h	0h
	2	0h	0h	0h	0h
	3	0h	0h	0h	0h
	4	0h	0h	0h	0h

[a]Means followed by the same letter are not significantly different at the 0.05% level as determined by Duncans Multiple Range Test.

[b]OV = Overwintering.

[c]NOV = Non-overwintering.

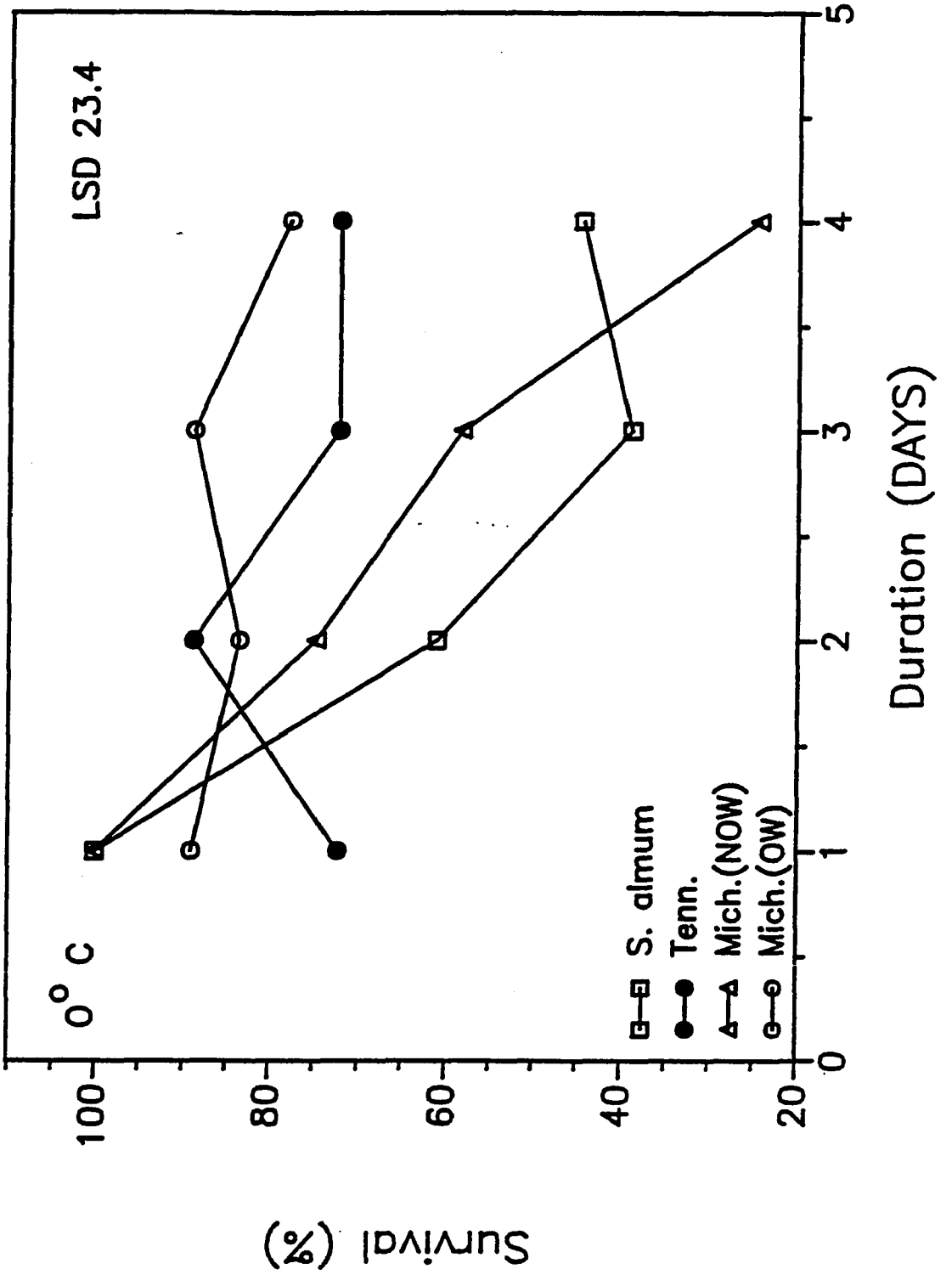

Figure 1. Percent rhizome survival following exposure to 0C for 1, 2, 3, or 4 days.

Table 4. Overwintering ability of 8 sorghum selections at 2 locations in Michigan[a].

Selection	Location[b]	
	Northern	Southern
	Survival (%)	
Overwintering		
Michigan	20.0bc	50.0a
Ontario	5.0c	40.0ab
Ohio	0.0c	40.0ab
Tennessee	10.0c	55.0a
Mississippi	0.0c	50.0a
Non-Overwintering		
Michigan	0.0c	0.0c
Ontario	0.0c	10.0c
S. almum	0.0c	5.0c
Type Mean		
Overwintering	7.0b	47.0a
Non-overwintering	0.0b	5.0b

[a]Means followed by the same letter are not significantly different at the 0.05% level as determined by Duncans Multiple Range Test.

[b]Northern = Montcalm County, Michigan. Southern = Berrien County, Michigan.

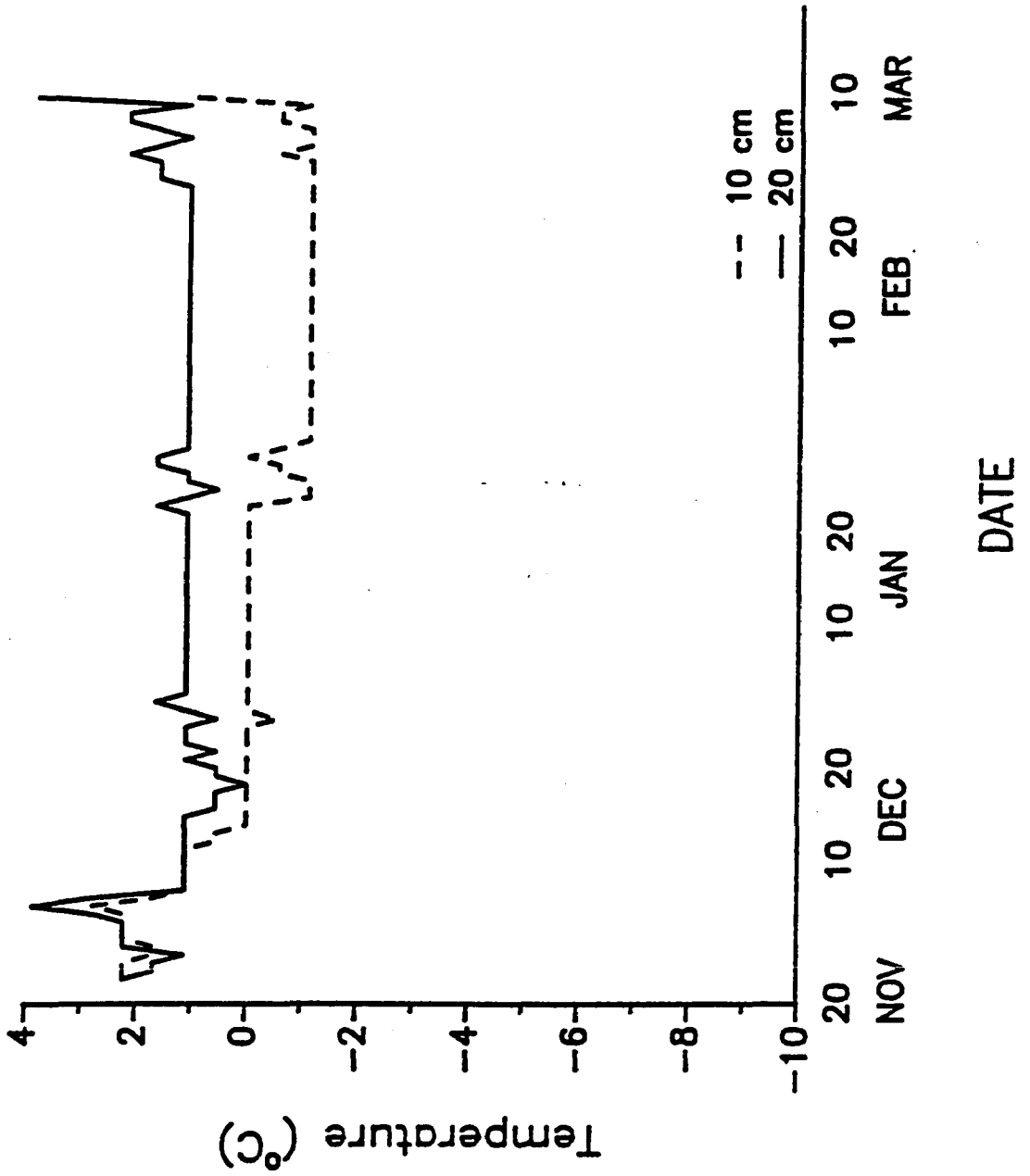

Figure 2. Soil Temperature — Southern Location.

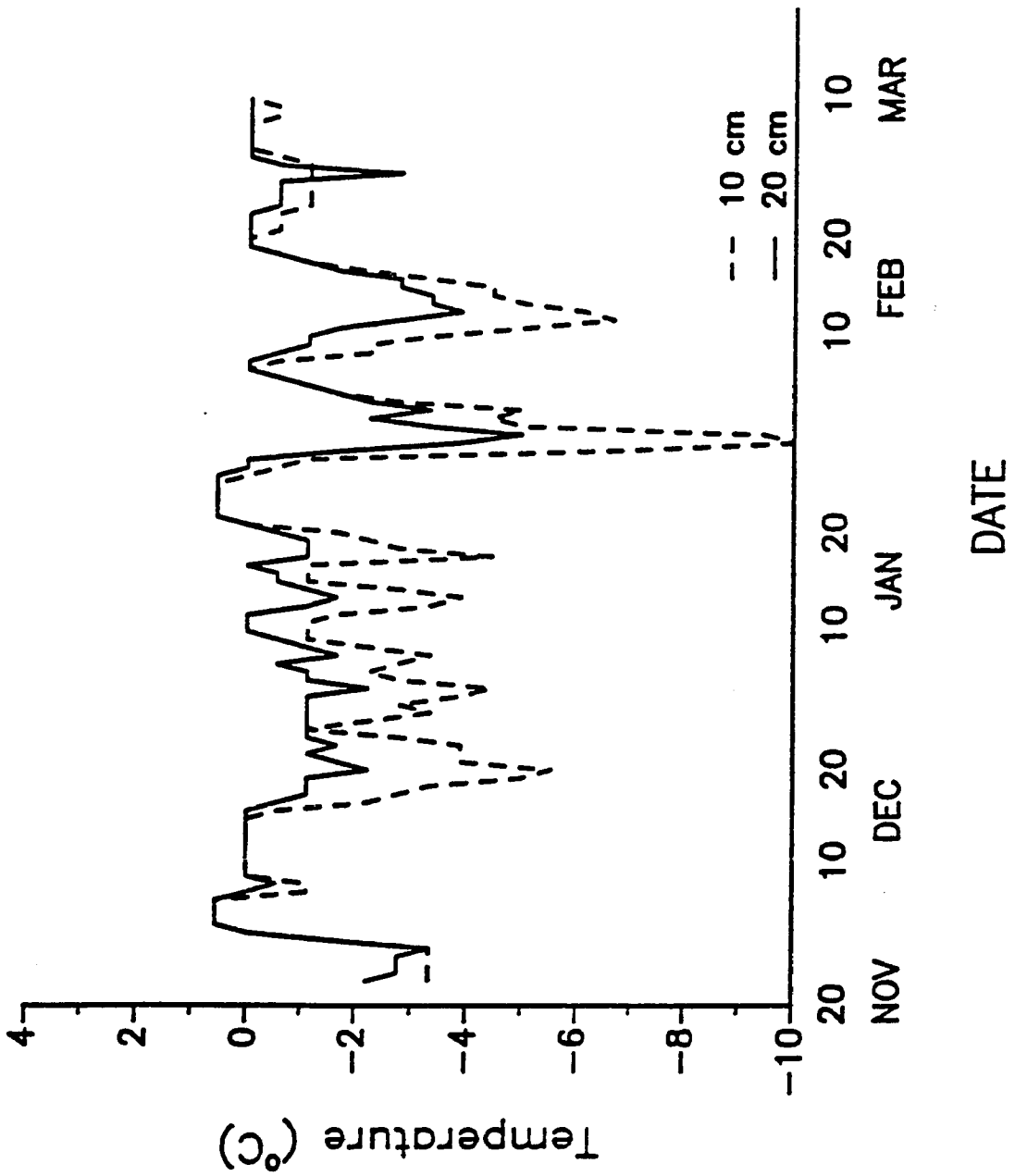

Figure 3. Soil Temperature — Northern Location.

Table 5. Effect of cold temperature on fatty acid composition of rhizome phospholipids in 4 sorghum selections[a].

Biotype	Fatty Acid Composition					
	16:0	18:0	18:1	18:2	18:3	U:S Ratio[b]
				No Treatment		
Michigan (OV)[c]	49ab	6.3a	15ab	25bc	4.4b	0.80bcd
Michigan (NOV)[d]	52a	7.8a	15a	19c	4.0b	0.65d
Tennessee	38cd	9.8a	13abc	36a	6.3b	1.18a
S. almum	42bcd	6.7a	12abc	35a	5.0b	1.08abc
				5°C		
Michigan (OV)	47abc	5.7a	11bc	32ab	4.4b	0.91abcd
Michigan (NOV)	45abcd	9.6a	16a	25bc	4.1b	0.85bcd
Tennessee	42bcd	6.2a	10cd	35a	6.3b	1.06abcd
S. almum	52a	4.8a	10cd	27abc	3.6b	0.74cd
				0°C		
Michigan (OV)	38d	8.4a	12abc	38a	3.8b	1.20a
Michigan (NOV)	49ab	9.4a	15a	21bc	3.0b	0.69d
Tennessee	42bcd	6.1a	7d	29abc	16.1a	1.10abc
S. almum	39cd	7.6a	10cd	38a	5.7b	1.14ab

[a]Means within a column followed by the same letter are not significantly different at the 0.05% level as determined by Duncans Multiple Range Test.

[b]U:S = Unsaturated:saturated fatty acid ratio.

[c]OV = Overwintering.

[d]NOV = Non-overwintering.

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CHAPTER FOUR

CONTROL OF TWO WEEDY SORGHUM SELECTIONS IN MICHIGAN WITH SELECTIVE AND NON-SELECTIVE HERBICIDES

ABSTRACT

Johnsongrass [Sorghum halepense (L.) Pers.] is a relatively new weed problem in the state of Michigan and very little attempt has been made to determine if control measures effective elsewhere are equally effective in Michigan. In addition, previous experiments have suggested the existence of two sorghum species present as weed problems in Michigan, an overwintering type similar to S. halepense and a non-overwintering type similar to Sorghum almum (Parodi) and it was unknown if these two species respond similarly to these herbicide treatments. Test plots were established at two locations in Michigan in the spring of 1984 and 1985 to evaluate the efficacy of four selective postemergence herbicides for control of these two selections in soybeans [Glycine max (L.) Merr.]. The infestation at the northern location (Eaton County, Michigan) consisted of

the non-overwintering type while the infestation at the southern location (Berrien County, Michigan) consisted of the overwintering type. Herbicides applied was fluazifop {(+)-2-[4-[(5-(trifluoromethyl)-2-pyridinyl)oxy]phenoxy]propanoic acid}, haloxyfop (2-[4-[[3-chloro-5-(triflouromethyl)-2-pyridinyl]oxy]phenoxy] propanoic acid), quizalofop (2-[4-(6-chloro-2-quinoxalinyl)oxy]phenoxyl]propionic acid), and sethoxydim {2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one} at rates of 0.12 and 0.25 kg/ha in 1984 and 0.06, 0.12, and 0.25 kg/ha in 1985. Treatments were applied early postemergence when plants were 30 cm high or late postemergence when plants were 45 cm high or as a split application with one half the rate applied early postemergence and one half the rate applied late postemergence. Control was greatest for treatments applied late postemergence or as a split application. Treatments applied as a single early postemergence application provided greater control of the northern than the southern type. Control of regrowth in the year following treatment was also greater at the northern than southern location. Plots were also established to evaluate three non-selective herbicides for control of these same selections. Plots were established at two locations in Michigan, a northern location in Montcalm County, Michigan and a southern location in Berrien County, Michigan. Herbicides applied

were glyphosate (N-(phosphonomethyl) glycine), sulphosate (trimethylsulphonium carboxymethylaminomethyl phosphonate), and HOE-661 (ammonium-(3-amino-3-carboxypropyl)-methyl phosphinate) at rates of 0.84 and 1.68 kg/ha in a carrier volume of 140 or 280 l/ha when plants were 45 to 60 cm in height or at the boot to head stage. Treatments applied at the boot to head stage provided greater control than those applied earlier. Where differences existed, treatments applied in the lower carrier volume provided greater control than those applied in the higher carrier volume. Very little difference was observed among individual herbicides or between the two locations.

INTRODUCTION

Johnsongrass is a highly competitive species and its control in infested areas is essential for successful crop production, however, its prolific rhizome and seed production make effective control difficult. The use of non-selective herbicides such as glyphosate has proven effective in non-crop areas or as an application to emerged Johnsongrass prior to planting (1, 5, 10). The recently introduced postemergence grass herbicides have provided excellent Johnsongrass control in soybeans (2, 4, 6, 8), among these are fluazifop, sethoxydim, quizalofop, and haloxyfop. Selective control of Johnsongrass in corn [*Zea mays* (L.)] has proven more difficult. Preplant incorporated applications of thiocarbamate herbicides such as EPTC (*S*-ethyl dipropyl carbamothioate) or butylate (*S*-ethyl bis(2-methylpropyl)carbamothioate) have proven effective in controlling seedling Johnsongrass, however, they do not provide consistent season long control of plants emerging from rhizomes (7, 11). Currently the most effective and long lasting control measures for Johnsongrass in field crops consist of combinations of tillage, crop rotation, and

the use of selective postemergence and preplant applications or selective placement of non-selective herbicides.

The results of recent studies have indicated the existence of overwintering and non-overwintering ecotypes of Johnsongrass in Michigan, Ohio, New York, Illinois, and Ontario, Canada (3, 12). The non-overwintering ecotypes have wider leaf blades, thicker culms, and produce significantly less rhizomes than the overwintering types. These studies have suggested the non-overwintering ecotypes more closely resemble the less perennial S. almum than S. halepense. Due to the reduced rhizome production and the lower capacity of these rhizomes to survive the winter it is possible that control practices for these non-overwintering ecotypes may differ dramatically from those required to control the more vigorous overwintering ecotypes. In addition, studies by McWhorter (9) have indicated a wide variation in response of Johnsongrass ecotypes to the herbicide dalapon (2,2-dichloropropionic acid). It is possible that these overwintering and non-overwintering Johnsongrass ecotypes may demonstrate differential responses to herbicide treatments as well.

The objectives of the current study were to investigate the response of an overwintering and non-overwintering ecotype of Johnsongrass in Michigan to applications of several selective and non-selective herbicides in the field.

MATERIALS AND METHODS

Johnsongrass Control in Soybeans

Field experiments were established in spring of 1984 and 1985 to investigate control of overwintering and non-overwintering populations of Johnsongrass in Michigan with several selective postemergence herbicides. Plots were established in Eaton County, Michigan (non-overwintering population) and Berrien County, Michigan (overwintering population). Herbicides investigated were quizalofop, fluazifop, haloxyfop, and sethoxydim at rates of 0.12 and 0.25 kg/ha in 1984 and 0.06, 0.12, and 0.25 kg/ha in 1985 applied as a single application when Johnsongrass was 30 cm in height (early postemergence), or 45 cm in height (late postemergence), or as a split application with ½ the rate applied early postemergence and ½ the rate applied late postemergence. All treatments included 2.34 L/ha crop oil concentrate. Treatments were applied with a tractor mounted sprayer in a spray volume of 280 L/ha at a pressure of 345 kPa using Tee-Jet 730308 flat fan nozzles. Soil texture was a clay loam at Eaton County with 4.0% organic matter and a

pH of 6.0 and a sandy clay loam with 3.0% organic matter and a pH of 7.2 at Berrien County. Soybeans were planted in 76 cm rows at each location. Soybean varieties were Corsoy 79 at Eaton County and Pioneer 2480 at Berrien County. Planting date in 1984 was June 6 at both locations. In 1985, planting date was May 25 in Berrien County and May 28 in Eaton County. Plot evaluations were made 14 and 28 days after treatment at each location in 1984 and 14, 28, and 42 days after treatment at each location in 1985. Percent control was evaluated relative to an untreated control plot. Ratings were also taken in July of the year following treatment at each location to evaluate residual weed control. Plot size was 3.0 meters by 12.2 meters. The experimental design was a randomized complete block with three replications.

Johnsongrass Control with Non-Selective Herbicides

Field plots were established in spring of 1984 and 1985 to investigate control of overwintering and non-overwintering populations of Johnsongrass in Michigan with several non-selective postemergence herbicides. Plots were established in Montcalm County, Michigan (non-overwintering population) and Berrien County, Michigan (overwintering population). Herbicides investigated were glyphosate,

sulphosate, and HOE-661 applied at 0.84 and 1.68 kg/ha in a carrier volume of 140 and 280 L/ha when Johnsongrass was 45 to 60 cm in height or in the boot to head stage. Treatments were applied with a tractor mounted sprayer at a pressure of 345 kPa. Soil texture was a loamy sand with 1.5% organic matter and a pH of 6.0 at the Montcalm County site and a sandy clay loam with 3.0% organic matter and a pH of 7.2 at the Berrien County site. Plot evaluations were made 21 and 42 days after treatment. Ratings were also taken in July of the year following treatment to evaluate residual weed control. Plot size was 3.0 meters by 9.14 meters. The experimental design was a split-split plot with three replications.

RESULTS AND DISCUSSION

Johnsongrass Control with Selective Postemergence Herbicides

The results of postemergence herbicide treatments for Johnsongrass control in 1984 are shown in Table 1. At 14 days after treatment, control was approximately 90% with nearly all treatments except sethoxydim at 0.12 kg/ha which exhibited only 65% control of the northern selection. Control of the northern selection was similar at 28 days after treatment, however, treatments applied as a single early postemergence treatment provided reduced control of the southern selection. Results in 1985 were similar (Table 2). Control of the two selections was similar at 14 days after treatment with all treatments providing good control with the exception of sethoxydim which provided poor control at the 0.12 kg/ha rate and only fair control at the higher rate. At 28 and 42 days after treatment, as in 1984, control of the southern selection was reduced when treatments were applied as a single, early postemergence application. With the exception of sethoxydim, there were

few differences among individual herbicides or rates. Rates of fluazifop butyl, quizalofop, and haloxyfop as low as 0.06 kg/ha provided control of the northern selection regardless of the time of application and of the southern selection when applied as a late postemergence treatment.

Since Johnsongrass is a perennial plant it is of particular interest to evaluate the degree to which a herbicide treatment reduces regrowth in the year following application. Treatments applied as split applications or as single late postemergence application in 1984 provided control of Johnsongrass regrowth at both locations in 1985 (Table 3). Treatments applied as a single early post-emergence application provided poor control of regrowth when applied at 0.12 kg/ha at the northern location and at both rates at the southern location with significantly less control of the southern than the northern selection in most cases. Treatments applied in 1985 provided regrowth control of the northern selection in 1986 at all rates and treatment times. Control of regrowth of the southern selection was also provided by treatments applied as a split application or as a single late postemergence treatment, however, treatments applied as single early postemergence treatment provided significantly less control in many cases. In nearly all cases, control of regrowth in 1986 was

significantly better for the northern than southern selection.

The results of this study provide additional evidence of two distinct sorghum selections in Michigan. With the exception of sethoxydim all treatments provided control of the northern selection, however, early postemergence treatments failed to control the southern selection. Regrowth of the southern selection in the year following treatment was also significantly greater for the southern vs. the northern selection. Although this difference could arise from a differential physiological tolerance to these herbicides, it is more likely that the extensive rhizome system produced by the southern selection causes control to be more difficult than the northern selection which produces few rhizomes as is the case with these herbicides when attempting to control an annual grass such as giant foxtail (Setaria faberi Herrm.) vs. a perennial such as quackgrass [Agropyron repens (L.) Beauv.]. It is therefore important for growers to determine which of these two selections are present prior to choosing a control strategy as timing of applications appears to be more critical for the southern, rhizomatous selection than the northern selection.

Johnsongrass Control with Non-Selective Herbicides

Tables 4 and 5 show the effects of growth stage and carrier volume on Johnsongrass control provided by three non-selective herbicides as evaluated 21 days after treatment in 1984 and 1985, respectively. At this early rating date there were essentially no differences among treatments and values shown are averaged over growth stage and carrier volume, respectively. All treatments providing 90% or greater control which indicates that all treatments performed equally well in providing initial control of above ground vegetation. Tables 6 and 7 show results of ratings made 42 days after treatment in 1984 and 1985. As significant interactions existed, individual treatment means are presented. Both growth stage and carrier volume had a significant effect on control in 1984. In general, treatments applied at the lower carrier volume at the boot to head stage provided the greatest control. Treatments applied at the earlier stage provided good initial control, however, seeds continue to germinate well into the season and reinfestation occurs. At the southern location reinfestation also occurs from previously dormant rhizome buds which were not killed by these herbicide treatments at the early application time. Application of these same herbicides at the boot to head stage results in greater

translocation to and control of these rhizomes. Control was poor when treatments were applied at the early growth stage in the higher carrier volume. Decreasing the carrier volume resulted in an increase in control with all treatments at the southern location. Decreasing carrier volume increased control provided by the high rates of all herbicides at the northern location but control provided by the herbicides at the lower rates was not effected. There were few consistent differences in control between the two locations with the exception that treatments applied at the boot to head stage in the higher carrier volume provided significantly greater control of the northern selection.

Control in 1985 was generally greater, with fewer differences among treatments. Plants grew much more rapidly in 1985 and the difference in time between the early and late application time was short. In addition, plant growth was more variable with many plants entering the early boot stage at the early application time. This resulted in fewer differences in control between the two application times and in some cases resulted in greater control for treatments applied at the early growth stage. There were essentially no differences in control between the two growth stages or between the two locations in 1985.

Tables 8 and 9 show control of Johnsongrass regrowth in 1985 and 1986, one year following treatment. Control was

80% or greater in both years for all treatments except HOE-661 which provided less control than all other treatments when applied to the northern selection in the boot to head stage at the lower rate and higher carrier volume. There were few other consistent differences. Although some treatments provided excellent control in 1984, overall control was only fair. Control of regrowth in the year following treatment, however, was good with most treatments. Many treatments, while not providing excellent control, inhibited growth to such an extent that seed and rhizome production was reduced or prevented by preventing plants from reaching a stage of growth where rhizome and seed production begin. It is possible that the depletion of seed and rhizome reserves in the soil, without replenishment during the growing season may result in greater control in the year following treatment than was evident in the year of treatment. In 1985, control was good with most treatments and as a result control of regrowth the following year was excellent as well.

These results, particularly those of 1984, tend to support the suggestion that two distinct sorghum species exist as weed problems in Michigan. At the early application time the southern selection showed a greater response to a change in carrier volume than the northern. Control was also greater at the northern location when

treatments were applied at the boot to head stage in the higher carrier volume. This was due primarily to the poor control of the southern selection obtained with these treatments. These results suggest that the interaction between growth stage and carrier volume is more important with the southern than the northern selection and, as stated previously, it is important for growers with these weed problems to recognize these differences when planning their control programs.

Table 1. Johnsongrass control in soybeans 1984 at 2 locations in Michigan with selective postemergence herbicides[a].

		Location[b]			
		North	South	North	South
		14 DAT[c]		28 DAT	
Herbicide	Rate	Control			
	(kg/ha)	(%)			
Early Postemergence					
Fluazifop	0.12	97ab	87bc	92b-f	60k
	0.25	100a	83c	93a-e	67j
Sethoxydim	0.12	65d	93a-c	53l	58kl
	0.25	97ab	83c	85f-h	81h
Haloxyfop	0.12	98a	93a-c	88d-g	90d-f
	0.25	98a	93a-c	93a-e	73i
Quizalifop	0.12	93a-c	90a-c	90c-f	75i
	0.25	98a	93a-c	88d-g	81h
Early Postemergence + Late Postemergence					
Fluazifop	0.12 + 0.12	97ab	97ab	97a-c	90c-f
Sethoxydim	0.12 + 0.12	87bc	87bc	88e-g	87e-h
Haloxyfop	0.12 + 0.12	97ab	90a-c	97a-c	90c-f
Quizalifop	0.12 + 0.12	93a-c	97ab	93a-e	97a-c
Late Postemergence					
Fluazifop	0.12	100a	98a	100a	98ab
	0.25	100a	100a	100a	100a
Sethoxydim	0.12	100a	93a-c	100a	93a-c
	0.25	100a	100a	100a	100a
Haloxyfop	0.12	100a	97ab	100a	97a-c
	0.25	100a	95ab	100a	95a-d
Quizalifop	0.12	100a	100a	100a	100a
	0.25	100a	98a	100a	98ab
Check		0m	0m	0m	0m

[a]Means within a rating date followed by the same letter are not significantly different at the 0.05% level as determined by Duncans Multiple Range Test.

[b]North = Eaton County, Michigan. South = Berrien County, Michigan.

[c]DAT = Days after treatment.

Table 2. Johnsongrass control in soybeans in 1985 at 2 locations in Michigan with selective postemergence herbicides[a].

Treatment	Rate	Location[b]					
		North	South	North	South	North	South
		14 DAT[c]		28 DAT		42 DAT	
		Control					
	(kg/ha)	(%)					
Early Postemergence							
Fluazifop	0.06	100a	86a-g	92a-f	67j-m	92a-d	67i-l
	0.12	97a-c	91a-g	92a-f	77d-l	92a-d	75c-j
	0.25	100a	93a-e	100a	83a-j	100a	83a-i
Haloxyfop	0.06	88a-h	87a-g	90a-g	63k-m	90a-e	67i-l
	0.12	97a-c	90a-g	95a-d	75e-l	95ab	73d-k
	0.25	100a	89a-g	100a	83a-j	100a	75c-j
Quizalifop	0.06	95a-d	86a-g	95a-d	74f-l	95ab	68i-l
	0.12	100a	90a-g	100a	77d-l	100a	70g-l
	0.25	100a	91a-g	95a-d	79b-l	95ab	73b-k
Sethoxydim	0.12	63i	63i	57mn	47n	57k-m	43mn
	0.25	78g	79f-g	75f-l	67j-m	75d-j	68i-l
Early Postemergence + Late Postemergence							
Fluazifop	0.06 + 0.06	100a	92a-g	100a	100a	100a	100a
	0.12 + 0.12	100a	94a-d	100a	94a-d	100a	100a
Haloxyfop	0.06 + 0.06	97a-c	95a-d	100a	94a-d	100a	100a
	0.12 + 0.12	100a	96a-c	100a	98ab	100a	100a
Quizalifop	0.06 + 0.06	100a	91a-g	100a	94a-d	100a	100a
	0.12 + 0.12	100a	95a-d	100a	90a-g	100a	100a
Sethoxydim	0.06 + 0.06	87a-g	62i	85a-i	66j-m	85a-i	67i-l
	0.12 + 0.12	93a-e	85b-g	88a-g	79c-l	88a-f	87a-g
	0.12 + 0.12	92a-g	95a-d	93a-e	92a-f	93a-c	93a-c

Table 2 (Continued).

Treatment	Rate	Location[b] North	Location[b] South	North	South	North	South
		14 DAT[c]		28 DAT		42 DAT	
	(kg/ha)	Control (%)					
Late Postemergence							
Fluazifop	0.06	93a-e	100a	93a-e	98ab	93a-c	95ab
	0.12	100a	100a	100a	100a	100a	98ab
	0.25	100a	100a	100a	98ab	100a	100a
Haloxyfop	0.06	100a	98ab	92a-f	94a-d	92a-d	90a-e
	0.12	100a	96a-c	95a-d	96a-c	95ab	95ab
	0.25	100a	98ab	93a-e	100a	93a-c	100a
Quizalifop	0.06	92a-g	97a-c	95a-d	97a-c	95ab	100a
	0.12	97a-c	98ab	95a-d	94a-d	95ab	98ab
	0.25	100a	100a	100a	100a	100a	98ab
Sethoxydim	0.06	85b-g	47j	80b-k	70i-m	80b-j	37n
	0.12	95a-d	83c-g	90a-g	62l-n	90a-e	53lm
	0.25	82d-g	100a	73g-m	87a-i	73e-k	68i-l

[a]Means within a rating date followed by the same letter are not significantly different at the 0.05% level as determined by Duncans Multiple Range Test.

[b]North = Eaton County, Michigan. South = Berrien County, Michigan.

[c]DAT = Days after treatment.

Table 3. Control of Johnsongrass regrowth in soybeans at two locations in Michigan one year after treatment with selective postemergence herbicides[a].

		Year Rated			
		1985		1986	
		Location[b]			
		North	South	North	South
Herbicide	Rate (kg/ha)	Control (%)			
Early Postemergence					
Fluazifop	0.06			100a	85c-g
	0.12	67ghi	63hij	98a	84d-g
	0.25	80def	60ijk	100a	86c-g
Haloxyfop	0.06			100a	77g-i
	0.12	75efg	56jk	97ab	80f-h
	0.25	86cd	60ijk	95a-c	87b-g
Quizalifop	0.06			93a-d	83efg
	0.12	80def	60ijk	100a	83d-g
	0.25	80def	73fgh	100a	82efg
Sethoxydim	0.12	52k	60ijk	93a-d	70i-k
	0.25	60ijk	73fgh	100a	81f-h
Early Postemergence + Late Postemergence					
Fluazifop	0.06 + 0.06			98a	93a-d
	0.12 + 0.12	88bcd	85cde	100a	95a-c
Haloxyfop	0.06 + 0.06			90a-f	90a-f
	0.12 + 0.12	85cde	87bcd	98a	90a-f
Quizalifop	0.06 + 0.06			100a	92a-e
	0.12 + 0.12	94abc	88bcd	100a	85c-g
Sethoxydim	0.06 + 0.06			100a	87b-f
	0.12 + 0.12	82def	82def	97ab	95abc
Late Postemergence					
Fluazifop	0.06			98a	87b-g
	0.12	93abc	50k	97ab	85c-g
	0.25	97ab	68ghi	100a	80fgh
Haloxyfop	0.06			100a	70ijk
	0.12	97ab	80def	93a-d	80fgh
	0.25	99a	73fgh	97ab	85c-g
Quizalifop	0.06			97ab	95abc
	0.12	90a-d	73fgh	100a	85c-g
	0.25	94abc	67ghi	98a	85c-g
Sethoxydim	0.06			100a	65jk
	0.12	67ghi	75efg	100a	62k
	0.25	86cd	53jk	98a	65jk

[a]Means within a rating date followed by the same letter are not significantly different at the 0.05% level as determined by Duncans Multiple Range Test.

[b]North = Eaton County, Michigan. South = Berrien County, Michigan.

Table 4. Effects of carrier volume and stage of growth at time of application on Johnsongrass control 21 days after treatment with non-selective herbicides in 1984[a].

		Selection[b]							
		Northern		Southern		Northern		Southern	
		Stage of Growth				Carrier Volume			
Herbicide	Rate	45-60	Boot to Head	45-60	Boot to Head	140	280	140	280
	(kg/ha)	(cm)		(cm)		(L/ha)			
		Johnsongrass Control							
		(%)							
Glyphosate	0.84	100a	95abc	97ab	97ab	95ab	100a	99ab	95ab
	1.68	100a	97ab	93bc	99a	100a	97ab	96ab	97ab
Sulphosate	0.84	100a	98ab	95abc	99a	99ab	99ab	97ab	97ab
	1.68	100a	100a	93bc	100a	100a	100a	98ab	95ab
HOE-661	0.84	93bc	91c	97ab	95abc	89c	95ab	94b	97ab
	1.68	100a	96ab	97ab	95abc	97ab	99ab	96ab	96ab

[a]Means within carrier volume and growth stage followed by the same letter are not significantly different at the 0.05% level as determined by Duncans Multiple Range Test.

[b]Northern = Montcalm County, Michigan. Southern = Berrien County, Michigan.

Table 5. Effects of carrier volume and stage of growth at time of application on Johnsongrass control 21 days after treatment with non-selective herbicides in 1985[a].

		Selection[b]							
		Northern		Southern		Northern		Southern	
		Stage of Growth				Carrier Volume			
Herbicide	Rate	45-60	Boot to Head	45-60	Boot to Head	140	280	140	280
	(kg/ha)	(cm)		(cm)		(L/ha)			
		Johnsongrass Control							
		(%)							
Glyphosate	0.84	99ab	91efg	95abcde	94bcdef	94bcde	96abc	95abc	94bcde
	1.68	100a	93cdefg	98abc	97abcd	97ab	96abc	97ab	97ab
Sulphosate	0.84	100a	95abcde	95abcde	92defg	97ab	97ab	92cde	95abcd
	1.68	100a	98abc	99ab	98abc	98ab	100a	97ab	100a
HOE-661	0.84	96abcde	88g	96abcde	89fg	94bcde	90de	96abc	89a
	1.68	99ab	94bcdef	94bcdef	97abc	97ab	96abc	95abcd	97abc

[a]Means within carrier volume and growth stage followed by the same letter are not significantly different at the 0.05% level as determined by Duncans Multiple Range Test.

[b]Northern = Montcalm County, Michigan. Southern = Berrien County, Michigan.

Table 6. Effects of carrier volume and stage of growth at time of application on Johnsongrass control 42 days after treatment with non-selective herbicides in 1984[a].

		Selection[b]			
		Northern		Southern	
Carrier Volume		Stage of Growth			
Herbicide	Rate	45-60	Boot to Head	45-60	Boot to Head
	(kg/ha)	(cm)		(cm)	
140 (L/ha)		Johnsongrass Control (%)			
Glyphosate	0.84	75fg	85a	78defg	87abcd
	1.68	87abcd	97a	77ef	87abcd
Sulphosate	0.84	80cdef	92ab	83abcdef	80cdef
	1.68	78defg	95a	77ef	82bcdef
HOE-661	0.84	35k	85abcde	77ef	82bcdef
	1.68	85abcde	88abcd	70ghi	80cdef
280 (L/ha)					
Glyphosate	0.84	73fgh	78defg	50j	78defg
	1.68	50j	98a	68hi	82bcdef
Sulphosate	0.84	75fg	93ab	70ghi	78defg
	1.68	60ij	92ab	68hi	80cdef
HOE-661	0.84	27k	70ghi	60ij	75fg
	1.68	58ij	92abc	60j	75fg

[a]Means within carrier volume and growth stage followed by the same letter are not significantly different at the 0.05% level as determined by Duncans Multiple Range Test.

[b]Northern=Montcalm County, Michigan. Southern=Berrien County, Michigan.

Table 7. Effects of carrier volume and stage of growth at time of application on Johnsongrass control 42 days after treatment with non-selective herbicides in 1985[a].

		Selection[b]			
		Northern		Southern	
Carrier Volume		Stage of Growth			
Herbicide	Rate	45-60	Boot to Head	45-60	Boot to Head
	(kg/ha)	(cm)		(cm)	
140 (L/ha)		Johnsongrass Control (%)			
Glyphosate	0.84	90abcd	83cdef	97abc	83bcdef
	1.68	90abcd	78ef	93ab	83cdef
Sulphosate	0.84	93ab	88abcd	86abcde	82cdef
	1.68	95a	90abcd	87abcde	83bcdef
HOE-661	0.84	81cdef	63g	88abcd	73f
	1.68	92abc	73f	90abcd	80def
280 (L/ha)					
Glyphosate	0.84	93ab	87abcde	89abcd	78ef
	1.68	97a	87abcde	89abcd	83cdef
Sulphosate	0.84	93ab	90abcd	88abcde	80def
	1.68	92abc	90abcd	90abcd	82cdef
HOE-661	0.84	87abcde	77f	89abcd	87abcde
	1.68	90abcd	83cdef	83cdef	90abcd

[a]Means within carrier volume and growth stage followed by the same letter are not significantly different at the 0.05% level as determined by Duncans Multiple Range Test.

[b]Northern=Montcalm County, Michigan. Southern=Berrien County, Michigan.

Table 8. Effects of carrier volume and stage of growth at time of application on control of Johnsongrass regrowth one year after treatment with non-selective herbicides in 1985[a].

		Selection[b]			
		Northern		Southern	
Carrier Volume		Stage of Growth			
Herbicide	Rate (kg/ha)	45-60 (cm)	Boot to Head	45-60 (cm)	Boot to Head
140 (L/ha)		Johnsongrass Control (%)			
Glyphosate	0.84	97abc	95abcde	84cdef	88abcdef
	1.68	100a	88abcdef	87abcdef	91abcdef
Sulphosate	0.84	98a	88abcdef	87abcdef	93abcde
	1.68	98a	78f	84cdef	91bcdef
HOE-661	0.84	92abcde	100a	85bcdef	92abcde
	1.68	95abcd	97abc	82ef	95abcd
280 (L/ha)					
Glyphosate	0.84	95abcde	85bcdefg	83defg	78g
	1.68	100a	83defg	90abcdefg	85bcdefg
Sulphosate	0.84	93abcdef	85bcdefg	97abc	91abcdefg
	1.68	97abcd	85bcdefg	91abcdefg	90abcdefg
HOE-661	0.84	100a	80fg	93abcdef	86abcdefg
	1.68	100a	95abcde	90abcdefg	93abcde

[a]Means within carrier volume and growth stage followed by the same letter are not significantly different at the 0.05% level as determined by Duncans Multiple Range Test.

[b]Northern=Montcalm County, Michigan. Southern=Berrien County, Michigan.

Table 9. Effects of carrier volume and stage of growth at time of application on control of Johnsongrass regrowth one year after treatment with non-selective herbicides in 1986[a].

		Selection[b]			
		Northern		Southern	
Carrier Volume		Stage of Growth			
Herbicide	Rate (kg/ha)	45-60 (cm)	Boot to Head	45-60 (cm)	Boot to Head
140 (L/ha)		Johnsongrass Control (%)			
Glyphosate	0.84	97ab	93abc	93abc	98ab
	1.68	100a	93abc	95ab	97abc
Sulphosate	0.84	100a	92abc	92abc	100a
	1.68	92abc	100a	83cde	98ab
HOE-661	0.84	73e	100a	83cde	98ab
	1.68	92abc	95abc	95abc	93abc
280 (L/ha)					
Glyphosate	0.84	100a	97abc	78de	95abc
	1.68	93abc	98ab	87abcd	100a
Sulphosate	0.84	100a	92abc	92abc	90abcd
	1.68	100a	97abc	100a	95abc
HOE-661	0.84	97abc	100a	83cde	95abc
	1.68	97abc	100a	85bcde	97abc

[a]Means within carrier volume and growth stage followed by the same letter are not significantly different at the 0.05% level as determined by Duncans Multiple Range Test.

[b]Northern=Montcalm County, Michigan. Southern=Berrien County, Michigan.

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CHAPTER FIVE

SUMMARY AND CONCLUSIONS

The morphology and dry matter production of two weedy sorghum selections from Michigan were compared with that of selections from several other locations in the U.S. and Canada. The selection from Berrien County, Michigan was similar to selections included in this study which produced rhizome able to overwinter in the areas they were originally obtained from, whereas the selection from Eaton County, Michigan was similar to selections which produced rhizomes unable to overwinter in the areas they were originally obtained from. Leaf width, leaf number, stem circumference, plant height, and rhizome dry weight of the overwintering types were similar to S. halepense whereas the non-overwintering types were similar to S. almum.

There were distinct differences in the response of the two Michigan selections to temperature. Rhizomes of the Berrien County type showed superior tolerance to cold temperatures relative to that of the Eaton County type. In outdoor overwintering studies, the rhizomes of the Eaton

County type showed very little ability to survive at either of two locations whereas those of the Berrien County type were able to tolerate winter temperatures at the more southern location. Exposure to 0C for 4 days in growth chambers significantly reduced rhizome survival of the Eaton County selection but did not effect that of the Berrien County selection. The Michigan selections did not appear to possess greater cold tolerance than selections from more southern locations. The degree of saturation of cell membrane phospholipids was examined to determine if this could play a part in the differential cold tolerance exhibited by the different types. There was no consistent correlation between the degree of fatty acid saturation and cold temperature tolerance. Rhizomes of the non-overwintering types showed greater ability to sprout at lower temperatures, however, seed germination was less.

Efficacy of several herbicides was examined for control of the two Michigan selections. Control provided by a single early postemergence application of the selective postemergence herbicides fluazifop, haloxyfop, quizalofop, and sethoxydim was greater at the northern location where infestations consisted mainly of the non-overwintering type than at the southern location where infestations consisted mainly of the overwintering type. There was no difference in control provided by these treatments between the two

locations when treatments were applied as a split application or as a single late postemergence application. Control of regrowth in the year following treatment was greater at the northern than the southern location. Control of these two selections provided by the non-selective herbicides glyphosate, sulphosate, and HOE-661 was also examined. Control provided by these treatments was greater when applied in a carrier volume of 140 than 280 l/ha. Control was greater when treatments were applied at the boot to head stage than when plants were 45 to 60 cm in height.

This study was conducted to investigate the apparent increase in the number of acres infested with Johnsongrass in the state of Michigan and to determine if this spread is a result of the adaptation of ecotypes of Johnsongrass to cooler temperatures. It does not appear from the results of this study, that the ecotypes of Johnsongrass present in Michigan exhibit any adaptation to cooler temperatures and that much of the apparent spreading of Johnsongrass in the state can be attributed to misidentification of S. almum as Johnsongrass. Based on the results presented here the spreading of Johnsongrass by rhizomes in Michigan is limited to areas of the state where soil temperatures remain above freezing throughout the winter. In areas where soil temperatures are below freezing for extended periods, infestations reported to be Johnsongrass are most likely S.

almum. Spreading of both species by seed, however, must be considered as both S. halepense and S. almum produce tremendous amounts of viable seed each year and movement of seed by equipment, animals, and in rivers and streams seems to be a major reason infestations of both these weed problems have increased in the state. It is important, therefore, that growers first obtain early, positive identification of these weed species and take quick, aggressive action to control infestations before they become major weed problems.