EVALUATION OF HERBICIDE COMBINATIONS FOR THE CONTROL OF JOHNSONGRASS (*SORGHUM HALEPENSE* (L.) PERS.)

By

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FOR THE CONTROL OF JOHNSONGRASS

(SORGHUM HALEPENSE (L.) PERS.)

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CHAPTER I

INTRODUCTION

Johnsongrass (*Sorghum halepense* (L.) Pers) is one of the most serious weed problems on highway rights-of-way in Oklahoma. Due to the tall, thick canopy formed by johnsongrass, it can seriously limit the motorist's vision and obscure road signs and guard rails. Since johnsongrass does produce an extensive amount of foliage, it can become a fire hazard, especially in times of drought. Most importantly, johnsongrass is a weed problem because it is a persistant and often successful competitor with desirable low-growing, sod-forming grasses.

One of the reasons for the persistance of johnsongrass is that it effectively propagates both vegetatively and by seeds. Satisfactory control of johnsongrass rhizomes has been achieved by the use of postemergence-applied herbicides applied in the late spring and early summer. However, there is frequently a reinfestation of the treated area by seedling johnsongrass.

One possible means of controlling the resultant seedling johnsongrass would be by the useage of preemergence herbicides. If the preemergence herbicide was applied at the same time as a tank mixture with the postemergence herbicide, it would result in a considerable savings in man-hours and equipment usage.

The objectives of this study are (1) to determine if the addition of a preemergence herbicide as a tank mixture would reduce the control of rhizomatous johnsongrass normally obtained by the postemergence herbicide, and (2) to evaluate the johnsongrass control obtained by the tank mixture (especially the preemergence herbicide) for the remainder of the growing season.

CHAPTER II

REVIEW OF LITERATURE

Johnsongrass

Johnsongrass (*Sorghum halepense* (L.) Pers) is a perennial, warm-season grass (15). It originated in the Mediterranean region and was introduced into the United States before 1830 (142). According to McWhorter (117) it has been known by over 40 common names and at least eight different Latin names. The name commonly used today was named after William Johnson, who introduced it into Alabama as a forage grass. During the Civil War it was spread throughout the southeastern United States by cavalry units which were feeding off the land. By 1895 it was a severe problem in Texas.

Today johnsongrass is no longer limited to the south. It is commonly found along roadsides in California (40). It has infested bottomland corn fields in Ohio (32) and has become a problem on roadsides and cultivated fields in Indiana (156). Alex et al. (5) discovered johnsongrass plants growing in Ontario, Canada and feared the possibility of a mutant allele for a winterhardy rhizome.

Johnsongrass is a world-wide problem as well. It has made several authors' lists of world's worst weeds (6, 79, 201). Johnsongrass has invaded soybean fields in some areas of southern Brazil (44). In Queenland, Australia, Monaghan (132) reported that a grain sorghum seed company had to move its base of operations due to pollen contaminations by severe infestations of johnsongrass. He futher stated that roadside johnsongrass in Australia harbored sugarcane mosaic virus and provided early season shelter for the sorghum midge. Both the virus and the insect caused severe yield losses in grain sorghum. Johnsongrass is also a major problem in orchards and irrigated fields in Israel (82).

Johnsongrass plants grow to heights of from one to three meters (133). McWhorter and Jordan (127) found the maximum height was reached by approximately the eighth week of growth. Johnsongrass leaves vary in length from 30 to 75 cm and in width from one to three cm (133). The leaves have a pronounced light-colored midrib (142). The inflorescence is panicled and is 15 to 50 cm long (15).

Johnsongrass is an intense competitor due to its aggresively spreading rhizomes (142). The rhizomes are white with red or purple areas and reach several feet (133). Rhizomes have two main functions, they serve as carbohydrate storage organs and as reproductive structures (7).

Johnsongrass seedlings produce rhizomes very quickly after emergence. McWhorter (118) detected a rhizome spur 18 days after emergence. Oyer et al. (135) noted several rhizomes had been produced 50 days after planting the seeds. Anderson et al. (7) found rhizome initiation four to five weeks after seedling emergence. Horowitz discovered rhizomes being produced less than two months after plant emergence from a seed or a rhizome bud (82).

McWhorter (118) found the rhizome growth rate to be relatively slow at first, but by the start of the bloom stage, the plants produced from 20 to 90 cm of rhizome per day. Oyer et al. (135) measured the highest growth rate of rhizomes from the boot stage of growth until the seeds were in the dough stage.

Horowitz (82) found no rhizomes at a depth greater than 40 cm in a clay soil. McWhorter (114) discovered more rhizomes at greater depths in clay loams than in sandy loams but attributed this to fractures in the clay which commonly occurred in that area. Normally he found a greater percentage of rhizomes only in the top 7.5 cm of plants grown in clay loam soils. No rhizomes were detected below 45 cm in an experiment in Newe Ya'ar, Israel (81). These investigators all concluded that johnsongrass rhizome production was greater and deeper in sandy soils than in clay soils.

The depth of the rhizome was verified to be an important factor in control by two investigators. Millhollon (131) controlled 81 percent of 15 cm long rhizomes when they were placed within a 7.5 cm layer of incorporated treflan (a,a,a-trifluro-2,6-dinitro-N,N-dipropyl-p-toluidine) at a rate of 3.4 kg/ha. This rate controlled 100 percent of the 2.5 cm long rhizomes. However, only 11 percent and 19 percent of the 7.5 and 15 cm long rhizomes were controlled respectively when planted below the layer. McWhorter (114) obtained 50 to 60 percent control measured over the entire soil profile using trifluralin at 0.84 kg/ha. However, no rhizomes were controlled below 8 cm.

McWhorter (118) concluded that johnsongrass plants originating from rhizomes grew more rapidly than johnsongrass plants originating from seed. He also found that more plants could emerge from rhizomes than from seed at greater depths (114). Burt and Wedderspoon (31) concluded that when johnsongrass plants produce a low amount of rhizomes the plant is more easily controlled. They found this occurred naturally in johnsongrass selections from cool climates. Ingle and Rogers (88) also suggested that rhizome production was relatively low in cool-climate selections of johnsongrass.

Stroller (179) indicated that low soil temperatures were the limiting factor in the northern range of johnsongrass in the United States. Since johnsongrass seeds survived winters better than rhizomes, and because in these areas there are no serious infestations of johnsongrass, he concluded that rhizomes must be of greater importance in the spread of johnsongrass. He found that johnsongrass rhizomes could not tolerate temperatures below -3° C in the laboratory and -9° C at a depth of 20 cm in the field. However, he discovered that the rhizomes could become acclimated to colder temperatures in the field. Alex et al. (5) reported that a snow cover could increase the cold tolerance of johnsongrass rhizomes. McWhorter (114) found that rhizomes could survive temperatures of 0° C for several days but could endure temperatures of -3 to -5° C for only one day. Hull (85) theorized that the lack of winter hardiness in johnsongrass rhizomes was due to the lack of storage of fructosans, which are stored by most cold-tolerant, temperate zone, perennial plants.

Since the lower rhizomes have a better chance of surviving a cold winter, apparently some selections of johnsongrass have adapted by accumulating more sugars in the deepest rhizomes before the onset of winter (81). McWhorter (112) detected both glucose and sucrose redistributions after the bloom stage.

Extremely high soil temperatures also had a detrimental effect on rhizomes. Temperatures of 50 to 60° C for one to three days completely killed all rhizome buds (114). Temperatures above 39° C have been shown to significantly lower the amount of sprouting of rhizome buds (80). The ideal temperature for maximum rhizome production ranged from 30° C (80) to 35° C (31) for warm-climate selections. The range of maximum rhizome growth for johnsongrass plants selected from cool climate was 25° C (31) to 27° C (88).

Advantages and disadvantages in the length of rhizomes have been reported. McWhorter (114) showed there was a greater percent of rhizome bud germination in short rhizomes (76 mm) than in long rhizomes (152 mm). However, McWhorter and Hartwig (126) found that shorter rhizomes are more prone to dehydration and cannot overcome greater depths of burial. Longer rhizomes were found to have fewer buds germinating, but as a result, a larger food supply was available to each bud that did germinate (114). The lower percentage of bud germination in longer rhizomes is due to dominance by the apical bud (22). Hull (85) found that the buds which had germinated suppressed the germination of adjacent buds.

Photosynthates were found to accumulate at the sites of growth, the germinating rhizome buds. Since only a few of the buds had germinated, a minimum of carbohydrates were translocated to the rhizomes. After seed production, the buds that were suppressed, the axillary buds, broke dormancy and formed secondary rhizomes. This new growth caused the downward translocation of assimilates into the rhizomes late in the growing season (86).

Johnsongrass also reproduces by means of seed. McWhorter (111) discovered the initiation of seed production in a johnsongrass shoot three to four weeks before the seed heads were visible.

Johnsongrass has been known to produce tmememdous amounts of seed.

Horowitz (82) observed one plant which produced 243 g of seed. This amounted to approximately 81,000 seeds. On the average, he found the johnsongrass plants to produce 84 g of seed per plant or 28,000 seeds.

Phillips and Chilton (141) calculated that the average amount of johnsongrass seeds in a heavily infested field in Louisiana was 1,657,195 seeds per acre to a depth of 2.5 inches. McWhorter (116) found a large variance in seed production capability between different selections of johnsongrass. One selection from Washington produced 352 seeds per panicle. Kelly and Bruns (98) counted weed seeds found in irrigation water where no weed control was practiced on the ditchbanks. They calculated that the irrigation water would have distributed an average of 40,000 seeds per hectare.

In a cultivated field, Stamper and Chilton (178) concluded that the number of viable seed from an infestation of johnsongrass decreased from 100 percent after eight months to 1.3 percent after 27 months. In an undisturbed soil, Roberts and Feast (154) disclosed that the number of viable seeds remaining after six years was ten times greater than in a cultivated soil.

After 2.5 years of a 50 year buried seed study, Egley and Chandler (58) noted 62 percent of the johnsongrass seed were still viable. They attributed this to the hard seed coat and suggested the apparent longevity of the johnsongrass seed may be responsible for it being a serious weed. Taylorson and McWhorter (186) likewise suggested that the relative longevity of johnsongrass seeds was due to the dormancy caused by the seed coat.

Many factors have been shown to influence johnsongrass and related weed seed germination. Keeley and Thullen (99) found that two-thirds of johnsongrass seeds would not germinate one month after harvest in October. However, 90 percent germinated the following March. According to the authors, this was an indication of dormancy in johnsongrass seeds.

Horowitz (80) concluded that johnsongrass seed germination required soil temperatures about 10° C higher than rhizome sprouting. Keeley and Thullen (99) discovered that the majority of johnsongrass seeds germinated when the soil temperature was 29° C or higher. However, some seeds had germinated at soil temperatures as low as 14° C.

Seedling johnsongrass that emerged as late as September was still able to produce rhizomes and seeds before the first frost in November (99). The genus Sorghum has been found to germinate well under simulated drought conditions (84), which may aid in late summer germination of johnsongrass seeds.

Toole et al. (188) have stated that all seeds must beet three conditions in order to germinate: there must be moisture, a suitable temperature range, and oxygen for respiration. In addition, many seeds have been shown to require other factors which may play an important role in dormancy. As was cited and described earlier, Taylorson and McWhorter (187) and Egley and Chandler (58) theorized that the breaking or removal of the seed coat was one necessary requirement for johnsongrass germination.

Wesson and Wareing (198) suggested that light was another possible ingredient for germination. They found that a 90 second long period of light increased germination by 60 percent. It was suggested that such a light source occurred during cultivation or other type of soil disturbance (197). From a different experiment, Wesson and Wareing (196) concluded that the seeds required a chilling requirement before breaking dormancy. After this requirement was met, the seeds germinated if not buried. If buried, the air around the seeds became concentrated (due to a lack of aeration) by an inhibitor, which was thought to be a product of the seed's metabolism. Eventually these seeds required light to break dormancy.

The quality of the light received by the seed has been verified as being an important factor in germination. Taylorson found that phytochrome conversions were responsible for seed germination (185). Toole et al. (188) discovered that red light (around 6550 A^{o}) changed the phytochrome from an inactive state to an active form. Far-red light (7350 A^{o}) resulted in the conversion back to the inactive form. Taylorson and Borthwick (186) concluded that weed seeds under a plant canopy often had a suppression of germination. This was because the canopy absorbed more light in the red region and the ratio of far-red/ red light reaching the seeds increased.

Taylorson (183, 184) found that pre-chilling and phytochrome conversion are both important in johnsongrass seed germination. Similarly, Duke and Williams (56) found that phytochrome distribution in the rhizomes decreased basipetally from the apex. This coincided with the findings of Hull (85) and Beasley (22), who both concluded that dominance in rhizome buds decreased logarithmically in a basipetal direction from the apex.

Besides prolific rhizome and seed production, several other reasons have been discovered for johnsongrass's competitiveness. Evetts and Burnside (60) found that johnsongrass possessed the fastest shoot growth rate of the nine weed species that they investigated. An analysis by

McWhorter and Jordan (128) disclosed that johnsongrass shoots also exhibited a fast growth rate when light levels were low. They concluded that johnsongrass would be competitive even if growing underneath a crop canopy. Johnsongrass was also more competitive with soybeans when there were seasons of less rainfall (125).

Williams and Ingber (200) demonstrated that johnsongrass was even competitive with itself to a certain extent. Crowded johnsongrass plants suffered reduced rhizome and seed production, delays in reproductive structure formation, and inhibition of tillering due to intraspecific competition as the population density increased from one to eight plants in a 20 cm, 4 liter pot.

Johnsongrass has been found to be allelopathic to other species. Wood (201) defined allelopathy as a biochemical interaction between plant species (usually inhibitory) resulting in the inhibition of seed germination, formation of abnormal seedlings, prevention or reduction of root elongation, and cellular disorganization in roots, among other adverse effects.

Friedman and Horowitz (63) moistened seeds by an undiluted extract from decayed johnsongrass rhizomes. They noted that the radicle length of the seedlings were significantly less than the untreated control. After repeating the experiment in soil, they discovered that the growth reduction was greater in light soils than in heavy soils. After further testing (83), they concluded that the reduction in growth was directly proportional to the concentration of decayed johnsongrass rhizomes in the soil. In addition, they detected a reduction in seedling germination and emergence in the treated soils. In support of their earlier work, they found greater activity in the light soils than in the heavy soils. They suggested this was due to greater absorption of the toxin produced by the decaying rhizomes. The increased absorption by the clay resulted in more inactivation than in the sandier soils.

In Oklahoma, Abdul Wahab (1) observed that johnsongrass frequently grew in almost pure stands and suggested than an inhibitor was involved besides the ability of johnsongrass to compete for light, minerals, and water. Using extracts from decayed johnsongrass rhizomes and shoots, he significantly reduced the percentage of seed germination in pigweed (Amaranthus retroflexus), japanese and downy brome (Bromus japonicus and Bromus tectorum), crabgrass (Digitaria sanguinalis), and green foxtail (Setaria viridis). Interestingly enough, the extract also reduced the percent germination of johnsongrass seeds. He verified the existence of three plant inhibitors in the extract: chlorogenic acid, p-coumaric acid, and p-hydroxybenzaldehyde. Of the species he tested, only the seeds of prairie threeawn (Aristida oligantha) were not affected by the rhizome and shoot extract.

Booth (27) observed four stages of succession in abandoned fields in Oklahoma and Kansas: (1) weed, (2) annual grass, (3) perennial bunchgrass, and (4) climax prairie. The annual grass stage was dominated by prairie threeawn. In central Oklahoma, Rice (150) noted the same stages of succession in the disturbed soils of abandoned fields. He noticed that, if johnsongrass was present when the field was being cultivated, it soon dominated the weed stage. He found the weed stage lasted around four years before being replaced by the annual grass stage. This stage lasted nine to thirteen years and was dominated by prairie threeawn. Rice (150) and Booth (27) both stated that it took 30 to 40 years or more to reach the climax vegetation.

Abdul-Wahab (1) theorized that johnsongrass dominated the weed stage of a disturbed soil because of its competitive nature and the allelopathic response from decayed rhizomes and plant tops. He further suggested that the resistance to these toxins by prairie threeawn explained why it dominated the second stage of succession.

Johnsongrass plants showed marked differences in morphology and physiology with differences in location (127). Apparently johnsongrass has developed ecotypes with respect to latitude in North America (30). Wedderspoon and Burt (194) observed that northern selections of johnsongrass flowered two weeks earlier than southern selections grown at the same location. Burt (30) also found that johnsongrass plants from more northern latitudes flowered earlier. He also observed lower plant heights, stem numbers, and leaf numbers in the northern plants. Wedderspoon and Burt (194) discovered the northern plants to possess lower shoot, root, and rhizome weights.

McWhorter and Jordan (127) detected differences in response to the herbicide dalapon (2,2-dichloropropionic acid) due to differences in ecotype. However, the herbicidal response was not necessarily correlated to latitudinal ecotypes. Hamilton and Tucker (69) also found differences in response to dalapon from different selections of johnsongrass. They concluded the difference was due to variations in absorption potential due to morphological differences and not because of the development of resistant strains.

Many researchers have conducted inquiries into mechanical and other non-chemical methods of johnsongrass control suitable for roadside operations. Sturkie (180) found that mowing reduced the rootstock development of established johnsongrass. As the cuttings became more frequent, the reduction was greater. Continuous cutting during the growing season also resulted in reduced top-growth the following season. McWhorter (118) discovered that seedling johnsongrass plants were killed if clipped by the thirteenth day after emergence. They were not killed if a rhizome spur had formed, which was usually around 20 days after emergence. Oyer (135) claimed that once a rhizome was formed, control could not be obtained by clipping or contact chemicals. McWhorter (121) found that the regrowth of clipped johnsongrass plants contained significantly higher levels of glucose and sucrose than did unclipped plants. He measured the regrowth of clipped plants from rhizomes and obtained rates of 4 cm/day. McWhorter (118) observed growth of johnsongrass rhizomes even under constant clipping of johnsongrass tops. Crafts (40) maintained that the main reason for mowing was to prevent seed head formation, but lateral branching still allowed some production.

Crafts (40) reported that burning to kill weed seeds obtained little control and created a greater hazard of smoke. He found that small areas of infestation by young johnsongrass plants could be controlled by the use of a mulch. The mulch needed to be two to four feet thick, depending on its looseness.

McWhorter (115) achieved control of four week old johnsongrass plants by flooding. After two weeks of submergence, 68 percent control was obtained. All plants were dead after eight weeks of flooding with five to ten cm of water. Budding rhizomes in flooded soil were completely controlled after 14 days and 95 percent kill was achieved in seven days.

Chandler (34) attempted to control johnsongrass by an electrical discharge system. The range in volts was from 1500 to 3000. Although some success was achieved with other weed species, no control of johnsongrass was reported.

Chemicals

Alachlor (2-chloro-2',6'-diethyl-N-(methorymethyl)acetanilide) (195) is classified as a chloroacetamide herbicide (97). Its solubility in water is 240 ppm at 24° C (97). The methods of application include preemergence, early postemergence, and preplant incorporated and recommended rates are 1.5 to 4 lbs per acre (195).

Hamm (70) reported that alachlor was developed as an improvement over previous acetamides which caused irritation of the skin and eyes. Alachlor also exhibited good activity on sandy as well as clayey soils. Alachlor was introduced commercially in 1969.

Wood (201) reported that the primary site of absorption was the shoot of the young seedling. A secondary site was the roots. Armstrong et al. (12) found that after absorption, the alachlor was translocated acropetally throughout the young seedling.

Akobundu et al. (4) found that alachlor caused a reduction in protein levels of chloroplasts of Japanese millet. Wood (201) described alachlor as being an inhibitor of protein synthesis in susceptible plants. Deal and Hess (46) found that alachlor inhibited cell division and cell enlargement in peas and oats at concentrations of 5×10^{-7} M.

Jaworski (92) also observed that alachlor inhibited protein synthesis. This occurred by the inhibition of GA_3-induced alpha-amylase production. He further suggested that there could be additional sites. He discovered that the alpha-halogen in alachlor could nucleophilically displace an amino group in enzymes that contained sulfhydryl groups. He concluded that since there were numerous such enzymes throughout the plant, there were multiple sites of inhibition.

Yu et al. (204) discovered that alachlor degraded rapidly in water and predicted no magnification would occur in the food chain. Wood (201) reported the soil persistence of alachlor was 6 to 10 weeks at normal use rates. Beestman and Deming (23) found the half-life to be 14 days. Leaching made no contributions to dissipation. They concluded that the greatest loss of alachlor from soils was by microbial decomposition. According to Skipper et al. (168), rainfall was an important factor in the dissipation of alachlor. Their experiment was conducted on a sandy loam soil while the investigation of Beestman and Deming took place on a silty clay soil.

Beestman and Deming (23) found that some losses occurred due to volatilization. These were mainly under windy conditions. Hargrove and Merckle (72) observed that more degradation of alachlor occurred under conditions of low humidity and high temperature. They maintained that this explained why poor weed control has been obtained under hot, dry conditions. In a two year experiment, Marriage (108) observed better control in the year in which there was greater rainfall during the first week after application.

Banks and Robinson (18) applied alachlor through standing and loose wheat straw. The plots were irrigated with 2.1 cm of water ten days after application. Fourteen days after application there were no differences in herbicide concentration to a depth of 15.2 cm between the mulched plots and the plots where the straw had been previously incorporated.

Incorporation of alachlor has been found to improve control. Slack and Hayes (169) improved control of yellow nutsedge (Cyperus esculentus) by 25 percent by incorporation at application. Roeth (155) obtained better control of johnsongrass seedlings from alachlor by incorporating to greater depths.

Soil texture has also been shown to be an important factor in johnsongrass seedling control by alachlor. Andrews et al. (9) reported 85-90 percent seedling johnsongrass control in sandy loam soils. This was opposed to 81 percent on clayey soils. Both experiments had alachlor applied at a rate of 2 lbs ai/acre. Andrews et al. (10) found that adequate seedling johnsongrass control was obtained on a clay loam soil at 3 to 4 lbs ai/acre. A two to 2.5 lbs ai/acre rate was used on the sandy loam soil.

In Kentucky, Bohn and Rieck (25) obtained 80 percent control of johnsongrass seedlings in soybeans with a 3.36 kg/ha rate. Using 2.0 lb/acre of alachlor, Crawford and Rogers (41) obtained 70 percent control of seedling johnsongrass in corn. The addition of atrazine at 2.5 lb/acre did not improve the control. Blevins and Rieck (24) found that the addition of alachlor at 3.36 kg/ha to asulam (methylsulfanilycarbamate) caused earlier activity by the asulam than when the asulam was used alone.

Atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine) (195) is a member of the symmetric triazine group of herbicides. Its water solubility is 33 ppm at 25^{o} C (97). The application rates commonly used are 2 to 4 lb/acre for selective weed control (195).

Ashton and Crafts (13) reported that atrazine is absorbed by the roots. It was rapidly translocated apoplastically to the shoots. They stated that atrazine strongly inhibited the Hill reaction of photosynthesis in susceptible plants.

Wood (201) reported that plants that were tolerant were able to detoxify the atrazine more quickly than susceptible plants. Ashton and Crafts (13) disclosed two means of detoxification. One involved hydroxylation at the two position of the azine ring. The other method was dealkylation of the side chains in the four and six positions.

Wood (201) found that atrazine was resistant to leaching because it was readily adsorbed by the soil. He noted the amount of leaching that occurred was dependent upon the soil type and the amount of rainfall, or irrigation. Ritter et al. (153) measured atrazine losses of 18 percent after a simulated 2.5 inch rain four days after application. They observed that the majority of loss of atrazine was due to runoff and the movement through the soil was only eight to ten inches per year.

Atrazine has been used quite frequently with other herbicides. Marriage (108) found that control of both yellow and green foxtail was more consistent when atrazine and alachlor were used together rather than either used alone. An atrazine (2.0 lb ai/acre) and alachlor (2.0 lb ai/acre) combination provided no better control of seedling johnsongrass than alachlor used alone (9). McMahon et al. (110) observed good to excellent control of most annual grasses with a combination of atrazine and metolachlor (3.0 lb ai/acre). However on seedling johnsongrass, Crawford and Rogers received no better control with a combination of atrazine and metolachlor than with metolachlor alone (41).

Metolachlor (2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl) acetamide is classified as a chloroacetamide herbicide. Its solubility in water is 530 ppm at 20^{o} C. Recommended application rates are 1.5 to 3.0 lb ai/acre (195).

Pillai et al. (145) found that, for grasses, the primary site of absorption was the shoots. Skipper et al. (168) likewise discovered that the predominant entry site was the shoots of grasses and broadleaves. Wood (201) reported that the shoot absorbed the metolachlor soon after germination and the plant dried before or soon after emergence. Pillai et al. (147) used activated charcoal to localize absorption specifically to either shoot, root, seed, or total seedling. They found that more metolachlor was absorbed by the shoot alone but the widest spectrum of control was obtained when the entire plant was allowed to absorb. Diner et al. (51) found that the main direction of translocation was toward the leaves no matter where the site of uptake was.

Pillai and Davis (143) showed that metolachlor did not effectively inhibit photosynthesis and stimulated respiration. Metolachlor inhibited root elongation, seed germination, seedling growth, and cell division. Deal and Hess (46) discovered that metolachlor inhibited cell division and cell enlargement at concentrations of 5×10^{-5} M. Diner et al. (52) showed that lipid synthesis was reduced by 25 percent at concentrations of 10^{-4} M. The production of phosphatidyl choline was almost totally interrupted.

Pillai et al. (144) found that the germination of several species of seeds were inhibited at 10^{-3} M. At lower concentrations root growth was diminished. They proposed that the major cause of phytotoxicity by metolachlor was membrane damage. After further research, Phillai et al. (145) suggested that the permeability of the membranes may have been altered by lethal doses of metolachlor to susceptible plants. This reduced the ability of the plant to retain leucine and consequently caused a reduction in protein synthesis. Ebert (57) proposed that the membranes affected were those at growing points. The membrane's decline was caused by the lack of sugars being transported to the growing points. He concluded that the cause of the shortage of sugars was that the metolachlor blocked either the synthesis or activity of enzymes that broke down starch to sugars.

Skipper et al. (168) found that metolachlor had a longer period of phytoactivity than alachlor. He measured half-lives in the soil of two to three weeks. Obrigawitch et al. (134) obtained good control of yellow nutsedge with rates from 2.24 to 4.48 kg/ha. They anticipated season-long control with metolachlor.

McGahen and Tiedge (109) found that metolachlor was degraded by the fungus _Chaetomium globosum_. They counted eight degradation products, most of which were produced by the removal on an R group from nitrogen or the dehydrogenation of an ethyl substituent.

McMahon et al. (110) found that control suffered when rain or irrigation was delayed until after the weeds had emerged. Lewis et al. (105) also discovered that metolachlor performed better in a year of normal rainfall than in a year of drought.

Hayes and Slack (74) found that incorporation increased control of yellow nutsedge, especially in a year of low rainfall. With heavy rainfall, Lewis et al. (105) noticed a slight decrease in control of incorporated metolachlor compared to surface applied metolachlor after four weeks.

Blevins and Rieck (24) obtained good control of johnsongrass with a tank mixture of asulam at 3.36 kg/ha and metolachlor at 3.36 kg/ha. Tank mixtures of metolachlor, naptalam, and dinoseb were more effective in controlling sicklepod than dinoseb and naptalam used alone (50). Mixtures of 1.5 + 2.0 + 1.0 lbs ai/acre, respectively, obtained 95 to 99 percent control.

Crawford and Rogers (41) obtained 80 percent of control of johnson-grass seedlings with metolachlor applied to the surface at 2 lb/acre. The addition of atrazine resulted in no improvement in control. Bohn and Rieck (25) found that metolachlor at 2.24 kg/ha provided 80 percent seedling johnsongrass control after eight weeks.

Dill and Dumford (49) obtained effective control of crabgrass and goosegrass at rates as low as 1.5 lbs ai/acre. Even though it did not rain for 17 days after application, Buering (29) achieved 80 percent or greater control of goosegrass with metolachlor applied to the surface at a rate of 1.75 lbs ai/acre. Davis et al. (143) received 96-100 percent control of crabgrass, goosegrass, and green foxtail 90 days after application of metolachlor 8E at 3.0 lbs ai/acre.

Metribuzin (4-amino-6-tert-butyl-3-(methylthio)-as-triazin-5(4H)-one) is an assymmetrical triazine. Its water solubility is 1220 ppm at 20^{o} C. Application rates range from 0.5 to 4.0 lbs ai/acre (195).

Wood (201) reported that the absorption sites, translocation, and mode of action for metribuzin were very similar to the symmetrical triazines. More specifically, Pallett and Dodge (136) discovered that metribuzin inhibited the flow of electrons in the electron transport system of chloroplasts of Pisum sativum.

Wax (192) found that control of several weed species by metribuzin was improved significantly by rainfall within ten days. In the absence of rainfall, control was increased by a greater depth of incorporation from 0 to 7.6 cm.

Kempson-Jones and Hance (101) predicted that there would be a few problems from the leaching of metribuzin. They based their prediction on the fact that degradation occurred to depths of 60 cm.

Sharom and Stephenson (167) observed that on a loam soil, the half-life of metribuzin was about three months. Based on first-order kinetics, Hayzak and Zimdahl (87) calculated that the half-life of metribuzin in a sandy loam soil was 329 days at 5^{o} C. Their estimates dropped to 44 and 16 days at 20 and 35^{o} C, respectively. Under greenhouse conditions, Savage (162) measured half-lives of 17 to 28 days as the temperature ranged from 30 to 20^{o} C. All three groups of investigators concluded that the persistence of metribuzin was primarily affected by microbial degradation.

McWhorter and Anderson (122) found that metribuzin was more effective when applied in a sequence of preemergence applications. They recorded 90 percent control of cocklebur and increased yields of soybeans.

Johnson (94) effectively controlled goosegrass and crabgrass with 1.1 kg/ha treatments of metribuzin. In addition, he observed no injury to bermudagrass or centipedegrass but severe injury to St. Augustinegrass.

Talbert and Frans (182) obtained control of seedling johnsongrass with metribuzin at 1 lb ai/acre on a silt loam soil.

Oryzalin (3,5-dinitro-N^4, N^4-dipropylaniline) (75) is a member of the dinitroaniline group of herbicides. Its water solubility is 2.6 ppm at 25^{o} C. Its vapor pressure is $<1.4 \times 10^{-6}$ mm Hg at 25^{o} C (193). According to Kearney and Kaufman (97), oryzalin was developed to be used as a surface-applied herbicide for soybeans.

Parka and Soper (137) claimed that the primary site of absorption of oryzalin was by the shoot for monocots and the hypocotyl for dicots. Wood (195) noted that tap roots are much less than lateral roots.

Kearney and Kaufman (97) reported that the interference with cell division is the primary mode of action. Secondarily, oryzalin limited photosynthesis and respiration to a certain extent. Bartels and Hilton (20) observed that oryzalin caused the enlargement of vacuoles in cells of actively growing plant parts. They suggested this secondary mode of active was due to the alteration of the membrane by the herbicide binding to it.

The main effect of oryzalin noticed by Bartels and Hilton was the adverse influence on mitosis. They found there was a disappearance of microtubules, which are important in cell division. They concluded that oryzalin blocked the synthesis of the microtubule subunits and consequently reduced the number of microtubules.

Gingerlich and Zimdahl (64) calculated the half-life of oryzalin using first order kinetics and obtained values of 1.4 months at 30° C and 4.35 months at 15° C. Golab and Amundson (65) measured a half-life in the field of two months under aerobic conditions. Jacques and Harvey (91) used a bioassay to determine that the activity of oryzalin was nearly undetectable after 48 days.

The persistance of oryzalin has been shown to be detrimentally affected by several different factors including: leaching, decomposition, and volatility losses. Helling (75) reported that, although not a common characteristic to most dinitroanilines, oryzalin leached short distances, especially when the soil was wet at application.

Parochetti and Dec (139) applied oryzalin to dry-soil, thin-layer plates at a rate of 1 kg/ha. Following seven days of exposure to the sun, they measured a reduction of 26.6 percent. They determined the loss to be caused by photodecomposition.

Kennedy and Talbert (102) measured the losses sustained by several dinitroaniline herbicides after delayed incorporations of up to seven days. After seven days, oryzalin suffered a 19 percent reduction from the original concentration. The investigators assumed that the losses were due to photodecomposition but had no direct evidence.

Golab and Amundson (65) observed that many of the products of photodegradation were benzimidazoles. They theorized that the mechanism involved cyclization of a nitro group with a neighboring ethyl group.

Golab et al. (66) discovered that most of the products of microbial degradation were indistinguishable from the products of photodecomposition. They observed that 36 months after the application only 1 percent of the oryzalin was recovered. The remainder had dissipated or was recovered in the soil as one of many degradation products.

Jacques and Harvey (90) proposed that the major factors of dinitroaniline movement in soils were mass flow, diffusion through water and vapor diffusion. Since oryzalin is nonvolatile (193), Jacques and Harvey assumed vapor diffusion to be nil. They concluded that water would be required for movement of oryzalin in soils.

Jacques and Harvey (89) found that the diffusion of oryzalin increased as the soil water content increased. This opposed the trend of the other dinitroaniniline herbicides tested. They further discovered that oryzalin was the most mobile when the soil was saturated with water. They concluded that the herbicidal activity of oryzalin was reduced under dry conditions. Kennedy and Talbert (102) concluded that when applied to the surface, adequate rainfall was required to insure incorporation.

Lynn et al. (106) sprayed oryzalin (1.5 lb/acre) over the top of wheat at the jointing stage. They observed no damage to the wheat and season-long control of many annual grasses in soybeans in a double-crop system.

Banks and Robinson (18) applied oryzalin at rates from 0.56 to 2.24 kg/ha over a standing straw mulch and nonmulched area. Less weed control was obtained in the mulched areas.

Maftoun and Abssiri (107) discovered a correlation between phosphorus levels in the soil and activity of oryzalin in chickpeas. They found greater phytotoxicity by oryzalin when 100 ppm P was added than when 0 or 50 ppm P was added.

Dancy and Coble (42) found that oryzalin caused some damage to forage bermudagrass when applied at the rate of 3.59 kg/ha.

MAA (methanearsonic acid) is classified as an organic arsencial herbicide. It is commonly marketed as two formulations: either the monosodium salt, MSMA (Monosodium methanearsonate), or the disodium salt, DSMA (disodium methanearsonate) (195).

Since the arsenicals are applied to the foliage, it was assumed that absorption occurred through the leaves. Duble et al. (54) discovered that DSMA was readily absorbed through the roots in a nutrient solution by Coastal bermudagrass. In a soil, there was still some uptake by the roots but it was very minimal. Sckerl and Frans (163) also found uptake to occur through johnsongrass roots in a nutrient solution. They detected no uptake from roots in the soil, however.

McWhorter (119) found no indications that DSMA was translocated in johnsongrass. He did not find any increase in arsenic content of treated rhizomes versus untreated rhizomes. Anderson (6) classified MSMA and DSMA as contact herbicides but noted that there was some translocation to rhizomes. Duble et al. (54) developed radioautographs of bermudagrass that had been foliar-treated with DSMA. They found that while most of the DSMA translocated very little, 25 percent of what had translocated had moved to the rhizomes and roots after five days. Seventy-six percent of the DSMA remained at the site of application.

In contrast, other investigators have observed extensive amounts of translocation of DSMA and MSMA. Domir et al. (53) documented both apoplastic and symplastic movement of MSMA in wheat. Arsenic from the labeled MSMA was detected in all plant parts two weeks after application. Sckerl and Frans (163) found that DSMA was translocated in the xylem and the phloem in johnsongrass. They discovered that apoplastic movement was faster and that uptake and translocation throughout the plant occurred after four hours. Halveka and Merckle (73) measured arsenic levels in rhizomes and regrowth of treated johnsongrass stands. They found significantly greater accumulations in these plants. They concluded that the DSMA had translocated from the treated foliage to the rhizomes. After regrowth the DSMA was again translocated to the shoots. Rumburg et al. (158) observed translocation of DSMA to occur in crabgrass. They further discovered that the translocation was greater at 85° F than at 60° F.

Ashton and Crafts (13) reported that arsenic was amphoteric. They found that the trivalent form was much more phototoxic to plants. They considered herbicides containing trivalent arsenic to be contact herbicides because they killed so rapidly. They found that pentavalent forms of arsenic possessed lower contact toxicity. This allowed herbicides of this class, such as DSMA and MSMA, to be translocated before killing the plant. They considered this to be a necessity for the control of storage organs of perennial weeds.

Since arsenic is chemically similar to phosphorus, Ashton and Crafts (13) suggested that one of its modes of action was substitution for phosphates in energy transformations in the plant. They discovered arsenate to be an uncoupler of phosphorylation.

Sckerl and Frans (163) investigated the nature of selectivity of MSMA. They found that johnsongrass, a susceptible plant, formed a complex with histidine. They concluded that such a complex may block a biosynthetic pathway.

Sachs and Michael (160) observed that plants which were resistant to MSMA absorbed an amount equal to susceptible plants. They suggested that in tolerant plants, MSMA did not form a complex with amino acids. They also found that the major site of herbicide activity of MSMA was the regions of meristematic tissue. Phillai et al. (146) discovered that MSMA blocked leucine uptake and inhibited protein synthesis.

Ashton and Crafts (13) reasoned that any arsenical that was applied to the soil or plant would eventually leave a residue of arsenic after decomposition. Johnson and Hiltbold (95) determined that no serious accumulations of arsenic occurred after four years of repeated applications of MSMA and DSMA at rates of 8.95 kg/ha per year. They predicted no accumulation would occur at normal use rates due to erosion, crop removal, and leaching.

Hiltbold et al. (77) found that no arsenic had leached below the plow layer in either a loamy sand or a silt loam. They found that MSMA before decomposition was more mobile than the arsenic. The MSMA leached the fastest through the loamy sand. Dickens and Hiltbold (48) determined that the pH of the soil had no effect on the leaching rate of DSMA.

Von Endt et al. (191) determined that crop removal of arsenic was governed by soil pH, similar to the uptake of phosphorus. An increase in soil pH reduced the availability to the plants because of the formation of insoluble calcium arsenates. Johnson and Hiltbold (95) discovered that all of the crops they tested showed higher levels of uptake of arsenic when MSMA was the source rather than DSMA or monammonium methanearsonate.

Von Endt et al. (191) detected more adsorption of arsenates by clayey soils than by sandy soils. Johnson and Hiltbold (95) found that 90 percent of the soil arsenic was found in the clay fraction. Dickens and Hiltbold (48) observed that the clay minerals kaolinite and limonite adsorbed more DSMA than vermiculite and montmorillonite.

Von Endt et al. (191) observed that no $^{14}CO_2$ was produced in a steam-sterilized soil to which ^{14}C-labeled MSMA had been applied. They concluded that microbial decomposition was an important factor in the fate of arsenicals. They reasoned that any microbial metabolism of MSMA would produce inorganic arsenic because of the single carbon atom in MSMA. Domir et al. (53) and Duble et al. (54) found that the carbon-arsenic bond was not broken.

In Oregon, concern was expressed over the possibility of a reduction in ammonification and nitrification due to inhibition of the microbial activity by high levels of arsenic in the soil. Bollen et al. (26) concluded that this happened only where concentrated MSMA was accidently spilled, and even in that small area, the effects were temporary.

Some researchers found MSMA to be more effective than DSMA. Hamilton (68) reported better control of johnsongrass in Arizona at different dates of application and on several different selections of johnsongrass. In Texas, Rea (149) reported better control of johnsongrass in non-crop areas by MSMA than by DSMA. Smith (170) reported consistently better control of woolyleaf bursage by MSMA than by DSMA. He noticed that the effect was greater as more time elapsed.

The number of applications of DSMA or MSMA required to control johnsongrass varied with many factors. McWhorter (119) found that seven applications of DSMA at 2 lb/acre were needed at Stoneville, Mississippi. Hamilton (68) noted differences in the selections across Arizona. The susceptible strains required five or six applications of MSMA or DSMA while the tolerant strains required nine or ten applications. Each treatment of arsenicals was at a 2 lb ai/acre rate. Millhollon (130) obtained 95 percent control of johnsongrass in ditchbanks in Louisiana with two applications of MSMA at 4 + 4 and 4 + 2.5 lb/acre.

Sckerl et al. (164) obtained complete rhizomatous control of johnsongrass with four applications of DSMA and MSMA at 3 lbs/acre along Arkansas highways. One application the following season, at a rate of 3 lb/acre, controlled 95 percent of the seedling johnsongrass. Along Mississippi highways, Snuggs (171) noted that severe infestations of johnsongrass were reduced to occasional spot spraying by the third season. Initially, three applications of MSMA at 3 lb/acre was applied at intervals of six weeks. The second season required two treatments at the same rate. Rea (149) found that three applications of MSMA at 3 lb/acre was required to reach a minimum of 90 percent control.

Many other factors were found to influence johnsongrass control by arsenicals. McWhorter (119) discovered that DSMA was more toxic to johnsongrass in periods of dry weather. He further showed that, for use in cropped areas, no improvement in johnsongrass control was obtained by using a carrier rate higher than 20 gallons/acre.

Rea (148) showed that the best control of johnsongrass by MSMA or DSMA was obtained by applications at the boot stage of growth. Hamilton (68) claimed that the best control resulted when applications were made in the fall or spring.

McWhorter (113) proved that changes in the level of nitrogen fertility had little effect on the effectiveness of DSMA on johnsongrass. He also noted that control by MSMA was not different between johnsongrass ecotypes, while Hamilton (68) found some differences in control among selections in Arizona.

Several authors reported that bermudagrass replaced johnsongrass in non-crop areas after control by arsenicals. Sckerl et al. (164) found no damage to bermudagrass during the removal of johnsongrass by arsenicals. Snuggs (171) noticed that where MSMA was used to control johnsongrass, areas of bahiagrass also yielded to bermudagrass. Millhollon (129) found that MSMA was the only chemical treatment for johnsongrass that resulted in the establishment of bermudagrass on ditchbanks. Other treatments resulted in domination by brambles or broadleaf weeds. These species were less deisrable because they did not control erosion.

MSMA and DSMA have been used in combination with many other herbicides. Bounds (28) obtained better control of johnsongrass with the addition of diuron or bromacil to MSMA. He claimed that synergistic factors might have improved the control. He noticed no damage to bermudagrass.

Hernandez (76) applied one application of MSMA at 10 lb/acre to johnsongrass in southeastern Texas in July. He noted good control but regrowth had occurred by September. He achieved 98 percent johnsongrass control in September by a single application in April of 8 lbs of bromacil + 5 lbs of DSMA + 9 lbs pf 2,4-D per acre.

Kliefeld (103) applied trifluralin at 1200 g/ha in cotton. He reduced from four to two the number of applications of MSMA necessary to control johnsongrass. Millhollon (129) observed good residual control of johnsongrass seedling by the addition of fenac or bromacil to the first application of MSMA.

Baker (16) applied a tank mixture of MSMA and fluometuron to control annual weeds. He observed significantly lower control by the addition of fluometuron.

Glyphosate (N-(phosphonomethyl)glycine) is a nonselective, postemergence herbicide. Its solubility in water is 1.2 percent at 25° C. The formulation used is the isopropylamine salt of glyphosate (195).

Wyrill and Burnside (203) observed that glyphosate was absorbed more quickly and in greater amounts by plants which had less epicuticular wax and less cuticle. Sprankle et al. (173) found that glyphosate was easily absorbed and translocated to both the shoots and rhizomes of quackgrass. Following absorption, glyphosate was translocated by all the weeds and crops that they tested.

Claus and Behrens (37) found that the rhizome buds nearest the tip were most effectively killed. They related this to the translocation pattern, which showed that the greatest accumulation of glyphosate was at the rhizome tips.

Fernandez and Bayer (61) postulated that the translocation of glyphosate was a source-sink relationship. Kells and Rieck (100) supported this with their work. They found the major accumulations of glyphosate were in areas of active growth.

Rioux et al. (152) determined that the stage of growth was an important factor in basipetal translocation of glyphosate. They detected downward movement at the three and four-leaf stage but not at the two-leaf stage in quackgrass. Kells and Rieck (100) found that translocation of glyphosate was 192 percent greater in full light than in darkness.

Richard et al. (151) reported that glyphosate had little effect on either electron transport or phosphorylation in isolated chloroplasts. Sprankle et al. (173) also found little evidence of inhibition of photosnythesis or respiration.

Campbell et al. (33) found that glyphosate affected the membrane permeability in chloroplasts. This led to altered osmotic potentials and consequently senescence. Shaner (166) reported a reduction in transpiration by plants treated with glyphosate. He assumed that it was simply an early indication of death since lethal doses were used.

At sublethal rates, Coupland and Caseley (39) discovered that glyphosate caused increased tillering and a reduction in the silica content of the leaves of quackgrass. They hoped the discovery might lead to better palatability for livestock.

Most researchers have found the mode of action of glyphosate to be related to the aromatic amino acid biosynthetic pathway. Jaworski (93) was the first to suggest this mechanism. He further stated that glyphosate possibly accomplished this by the inhibition of an enzyme.

Ekanayake et al. (59) found that glyphosate blocked the pathway leading to phenylalanine resulting in an increase in tyrosine. Hoagland et al. (78) found a decrease in both tyrosine and phenylalanine. They attributed the reductions to a glyphosate-induced increase in the activity of phenylalanine ammonia-layase (PAL). Duke et al. (55) discovered that glyphosate required light to stimulate PAL activity.

Haderlie et al. (67) reversed the effect of glyphosate by adding phenylalanine, tyrosine, and tryptophan to glyphosate-treated carrot and tobacco cells. The effect only occurred if the combination of aromatic amino acids was added by eight days after the glyphosate application.

Glyphosate was found to be rapidly inactivated by the soil. Sprankle et al. (174) discovered that adsorption occurred less than one hour after the glyphosate was applied. They found that most of the adsorption occurred in the clay fraction and organic matter. Kaolinite accounted for more adsorption than illite or bentonite.

Sprankle et al. (175) found that glyphosate adsorption was greater at a lower pH. They also found that phosphorus and glyphosate competed for adsorption sites. They deduced that the phosphorus group in glyphosate was responsible for the adsorption.

Sprankle et al. (175) found that plants absorbed glyphosate through the roots. The roots were unable to compete with the soil, however. Absorption by roots only occurred in a nutrient solution and in washed quartz sand.

After its adsorption by soil, Torstensson and Aamisepp (189) found that glyphosate was detoxified by microbial activity. They reported that the major source of inactivation of glyphosate in soils was due to microbial degradation. Rueppel et al. (157) also maintained that degradation of glyphosate was by microbial action; was not prone to photodecomposition; and was resistant to losses from runoff.

Many investigations have noted the effects of the environment on glyphosate. At a low relative humidity, Jordan (96) observed that glyphosate was more toxic to bermudagrass when applied at 32° C than at 22° C. McWhorter and Azlin (123) found that, all other factors the same, johnsongrass was more susceptible as the temperature increased from 24° C to 35° C. Davis et al. (45) discovered that glyphosate treatment at 4° C protected alfalfa from injury but not quackgrass.

McWhorter and Azlin (123) concluded that better control of johnsongrass was obtained by glyphosate at 100 percent relative humidity as opposed to 45 percent. Jordan (96) found that bermudagrass was more susceptible to glyphosate at 100 percent relative humidity than at 40 percent. Chase and Appleby (35) concluded that glyphosate was more effective on purple nutsedge at 90 percent than at 50 percent relative humidity.

Ahmadi et al. (2) observed that glyphosate was less effective in controlling barnyardgrass when the moisture level in the silty clay loam soil was below field capacity. Whitwell and Santelmann (199) discovered that bermudagrass under moisture stress did not respond well to glyphosate treatments. Chase and Appleby (35) measured twice as much translocated glyphosate at -2 bars than at -11 bars of soil water potential. McWhorter and Azlin (123) reported that, other factors apart, glyphosate exhibited better control of johnsongrass at 20 percent than at 12 percent soil moisture (w/w).

Upchurch and Baird (190) observed that, regardless of the temperature, glyphosate controlled johnsongrass better at 2000 foot-candles of light than at 500 foot-candles.

Banks et al. (17) found that the best control of field bindweed by glyphosate was obtained by applications at the blooming stage of growth. Earlier applications were not as effective. Ahmadi et al. (2) increased barnyardgrass absorption of glyphosate by 25 percent by applications to plant heights of 15 cm rather than 5 cm.

Hanson and Rieck (71) obtained better johnsongrass control with glyphosate from August applications as opposed to June. They claimed greater rhizome kill also. Parochetti et al. (140) compared applications of glyphosate to 50 cm tall johnsongrass plants and johnsongrass plants in the late boot stage. There was less regrowth from the boot stage application treatments.

Several investigators conducted inquires into the best carrier rates for glyphosate application. Sandberg et al. (161) discovered that 130 l/ha produced the lowest amount of runoff from the leaves of morningglory. Using a dye they detected that 1/2 to 3/4 of the spray ran off the leaf surface at 375 to 750 l/ha. Stahlman and Phillips (176) sprayed grain sorghum with glyphosate at 0.84 kg/ha in distilled water. They killed every test plant with carrier rates varying from 93 to 374 l/ha. They discovered that an increase in the calcium comtent of the water did not produce the same results. When the calcium content was 0.01 M, the only carrier rate that still provided adequate control was the lowest, 93 lg/ha. Sandberg et al. (161) also obtained reduced control with increased calcium concentration of the water. Baird and Upchurch (14) found that the lower spray volumes of 10 to 30 gpa resulted in more activity from glyphosate. They also discovered that rainfall eight hours or less after application lowered control. A shower that occurred four hours or less drastically reduced control.

Glyphosate has been used extensively on johnsongrass in cultivated and non-crop situations. Derting et al. (47) reported better johnsongrass control from September applications. The following spring, the johnsongrass was reduced by 80 to 90 percent. McWhorter (120) obtained excellent control of rhizomatous johnsongrass with applications of glyphosate at 1 to 2 lb/acre in soybeans. The soybean losses were 65 to 75 percent, however.

Klosterboer (104) applied glyphosate on johnsongrass in citrus. Ninety-five percent control was obtained at a rate of 3.0 lb/acre. Andrews et al. (8) evaluated glyphosate for control of johnsongrass on railroad rights-of-way. A 3.0 lb/acre rate provided 90 percent control.

Fisher (62) reported the use of glyphosate for spot spraying along Virginia highways. He used a 1 percent solution and sprayed to runoff. He recorded 95 percent kill of johnsongrass. McWhorter and Barrentine (124) also evaluated glyphosate for spot spraying johnsongrass. They found the best results were at 6 g per liter.

Many herbicides have been used with glyphosate in an attempt to provide residual control. Aitken (3) achieved successful control of crabgrass in pecans using combinations of glyphosate with simazine or oryzalin. Chykaliuk et al. (36) obtained only 5 percent regrowth of woolyleaf bursage using a combination of glyphosate and dicamba. Rushing and Peeper (159) employed a combination of glyphosate and oryzalin for weed control in no tillage plots. They achieved only 4 percent ground cover at a 1 + 1 lb/acre rate.

Connell and Jeffrey (38) used combinations of glyphosate with metolachlor or oryzalin in soybeans for johnsongrass control. The combination with metolachlor gave the better seedling johnsongrass control for a longer period of time. Oryzalin showed fair residual control.

Banks and Santelmann (19) applied glyphosate as a tank mix with chlorflurenol. There was no enhancement or reduction in control of johnsongrass by glyphosate.

Suwunnamek and Parker (181) used glyphosate with several herbicides to attempt to control Cyperus rotundus. They noted antagonistic responses from diuron, atrazine, and terbacil. Selleck (165) noted reductions in control of glyphosate in mixtures with diuron, terbacil, bromacil, and simazine. Glyphosate reduced the effectiveness of bormacil on dandelions.

Andrews et al. (8) reported that glyphosate was more effective alone for johnsongrass control than when tank mixed with bromacil, prometone, diuron, or simazine. Worsham (202) discovered that glyphosate was less effective on johnsongrass when combined with paraquat or atrazine. Baur and Bovey (21) noted that the addition of either tebuthiuron or endothall to glyphosate resulted in antagonism or no additional response. Parochetti and Bell (138) noted an average of 20 percent reduction in phytotoxicity of glyphosate by the tank mixture of a residual herbicide.

Stahlman and Phillips (177) tested mixtures of glyphosate with seven herbicides and two inert ingredients of herbicide formulations. They observed that all of the herbicides tested were antagonistic to glyphosate to a certain extent. But the inert ingredients alone caused as much reduction in glyphosate activity as an equivalent amount of clay.

Appleby and Somabhi (11) found an antagonism existed with simazine or atrazine for glyphosate. They concluded that the problem was with ingredients in the wettable powder. They concluded that the antagonism was due to physical binding which took place within the spray solution. They proposed that the binding could increase after application on the surface of the tested leaves. They discovered that the antagonism was greatest at the lowest rate of glyphosate. They indicated that the antagonism was overcome by the use of an increased rate of glyphosate.

CHAPTER III

METHODS AND MATERIALS

Field experiments were conducted on roadsides at two locations in Oklahoma in the summer of 1980. The first site was along the north side of US 60 at the intersection with US 77. The plot site was one mile north of Tonkawa in north central Oklahoma. The second site was located on the south shoulder of Interstate Highway 40 at the intersection with State Highway 27, and was immediately outside the city limits of Okemah in east central Oklahoma. Hereafter the sites will be referred to as the Tonkawa and Okemah sites, respectively. Both plot sites had been infested with johnsongrass (Sorghum halepense (L.) Pers) for several years. The soil types and additional soil data for both sites are shown in Table XXXIX in the Appendix.

The experimental design and arrangement were the same at both plots. A randomized block design was used with a split plot arrangement. The main plots were composed of postemergence herbicides and a check which contained the sub-plot treatments but no postemergence herbicides and a check which contained the sub-plot treatments but no postemergence herbicides. The sub-plots were comprised of preemergence herbicides and a check. The check contained a main plot treatment but no preemergence herbicide. Thus for each replication there was a main plot by sub-plot treatment which was a check for both main plot and subplot, and had no herbicide applied to it.

The individual plots were 1.52 by 3.05 m in size. There were three replications and each replication was 3.05 by 45.72 m in size. At both sites, the replications were arranged parallel to the highway in an east-west orientation. The herbicides and the rates used are shown in Table I. The rates for the preemergence herbicides are slightly higher than normal use rates. This was to offset expected losses due to photodecomposition and interception.

All herbicide treatments were applied by means of a hand held sprayer using carbon dioxide as a propellant. The carrier rate for the glyphosate treatments was 187.0 l/ha. The carrier rate for the MSMA, DSMA, and check treatments was 374.0 l/ha. The difference in carrier rates was due to compliance with label recommendations and normally used carrier rates by the Oklahoma Highway Department.

The herbicides for each paired treatment was mixed at the plot site and applied to the plot as a tank mixture less than thirty minutes after mixture. For each combination the preemergence herbicide was mixed first and then the postemergence herbicide was added to the mixture.

Before application in the field, each combination of herbicides was pretested in the laboratory for compatability. The herbicides were mixed together in the same ratio that they would be used in the field, with the postemergence herbicide added after the preemergence herbicide.

The treatments were applied on June 18 at Okemah and June 19 at Tonkawa. At both sites the johnsongrass was at the boot stage of growth. There was a 100% infestation of johnsongrass. Two additional retreatments were applied later to each organic arsenical treatment. The rates for the retreatments were the same as the original application, with the only difference being the deletion of the preemergence herbicides.

TABLE I

POSTEMERGENCE AND PREEMERGENCE HERBICIDES AND APPLICATION RATES USED AT BOTH SITES FOR JOHNSONGRASS CONTROL

Common Names	Chemical Names	Application Rates kg ai/ha
Main Plots Postemergence Herbicides		
DSMA	disodium methanearsonate	4.0
MSMA	monosodium methanearsonate	3.4
Glyphosate	N(phosphonomethyl)glycine	1.3, 2.1 (a.e.)
Sub-plots Preemergence Herbicides		
Alachlor	2-chloro-2', 6'-diethyl-N-(methoxymethyl)acetanilide	5.0
Metribuzin	4-amino-6-tert-butyl-3-(methylthio)-as-triazin-5(4H)-one	5.0
Oryzalin	3, 5-dinitroN^4, N^4-dipropylsulfanilamide	6.0
Metolachlor	2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acetamide	4.6
Metolachlor + Atrazine	2-chloro-4-ethylamino-6-isopropylamino-s-triazine	8.3

The dates for the retreatments with DSMA and MSMA were July 10 and 29 at Okemah and July 11 and 31 at Tonkawa. Environmental conditions for the initial treatments and retreatments for each site are shown on Table XXX in the Appendix.

Visual observations and ratings of johnsongrass control were made on a scale of 1 to 10, where 1 is no weed control and 10 is complete weed control. Evaluations were made on July 8 and 23, August 15, September 10, and October 1 at the Okemah site and on July 7 and 30, September 10, and October 2 at the Tonkawa site.

Due to the difficulty in distinguishing whether the johnsongrass originated from rhizomes or seeds, no attempt was made to evaluate the types of johnsongrass control separately. Any attempt to uproot the plants to discover their origin would not only have destroyd that plant for the remainder of the experiment, but may have punctured the herbicide seal. This would have given other developing plants an avenue through which to emerge.

Amounts of rainfall and dates of precipitation (important factors in canopy penetration) were obtained from nearby weather stations. The data from the Blackwell and the Okemah stations were used to represent rainfall at the Tonkawa and Okemah sites, respectively. Results are shown in Table XXXI in the Appendix.

CHAPTER IV

RESULTS AND DISCUSSION

Preliminary tests in the laboratory for compatability resulted in no precipitate formation with any combination of postemergence and preemergence herbicides. In the field, however, one of the first mixtures, metribuzin with glyphosate, resulted in the formation of a thick, gummy precipitate. It was soon discovered that the order of mixing had been reversed from the sequence in the preliminary tests. After switching the mixing back to preemergence herbicide first, there was no precipitate formed and no further problems with compatability. This it appears the order of mixture is an important factor in the compatability of tank mixtures of herbicides.

Ratings for each site on each date of evaluation are shown in Appendix Tables XXXII and XXXIII for each main plot by sub-plot treatment condition as averaged across the replications. Due to the fact that visual ratings only were collected, no comparisons were made between different sites or between different dates at the same site. For each date, an analysis of variance table was constructed to test the three variables: main treatment (postemergence herbicides), sub-treatment (preemergence herbicides), and main treatment x sub-treatment interaction.

In an effort to try to locate the sources of differences, a Duncan's Multiple Range test was performed on the means of all main plot treatments as averaged across the sub-plots and the replications. A Duncan's Multiple Range test was also used to search for differences among the means of the sub-plot treatments as averaged across the main plots and replications. On some dates, the sub-plot means were also compared by an additional Duncan's test in which the values for the main-plot check (no postemergence herbicide) was deleted. This was done in an attempt to better describe the control obtained in general by a preemergence herbicide when combined with the postemergence herbicides. In this way a more representative analysis of each sub-treatment could be achieved that would not be masked by the consistently low rating of the main plot check.

In addition to the above analyses, an interaction graph was constructed for any date in which a relatively low observed significance level appeared in the variable row for the main plot x sub-plot interaction.

Okemah Experiment

The ratings from the first two observation dates were very useful in discovering which preemergence herbicides were perhaps going to be antagonistic to the postemergence herbicides. On July 8 and July 23, highly significant differences were found among the main plot treatments and sub-plot treatments as shown by the analysis of variance in Tables II and III, respectively.

The differences among the sub-plot treatment means for July 8 and 23 are shown in Tables IV and V. The means shown are averaged across all postemergence herbicides and replications. Consequently they are indicators of how much each premergence herbicide improved or lowered

TABLE II

ANALYSIS OF VARIANCE OF JOHNSONGRASS CONTROL RATINGS FOR THE OKEMAH SITE ON 8 JULY, 1980

Source	Degrees of Freedom	Mean Square	F	Observed Significance Level
Replication	2	0.08	0.13	.8812
Main Plots	4	145.74	240.67	.0001
Error a	8	0.61		
Sub-plots	5	10.82	18.23	.0001
Main x Sub	20	0.98	1.65	.0772
Error b	50	0.59		
Corrected Total	89			

TABLE III

ANALYSIS OF VARIANCE OF JOHNSONGRASS CONTROL RATINGS FOR THE OKEMAH SITE ON 23 JULY, 1980

Source	Degrees of Freedom	Mean Square	F	Observed Significance Level
Replication	2	0.84	0.50	.6225
Main Plots	4	196.63	117.20	.0001
Error a	8	1.68		
Sub-plots	5	5.62	12.64	.0001
Main x Sub	20	0.77	1.73	.0601
Error b	50	0.44		
Corrected Total	89			

TABLE IV

DUNCAN'S MULTIPLE RANGE TEST OF THE SUB-PLOT TREATMENT MEANS OF THE JOHNSONGRASS CONTROL RATINGS FOR THE OKEMAH SITE ON 8 JULY, 1980

Treatment	Mean*		
Check	6.8	A	
		A	
Metolachlor	6.6	A	
		A	
Oryzalin	6.4	A	B
			B
Alachlor	5.9		B
Metolachlor + Atrazine	5.1	C	
		C	
Metribuzin	4.7	C	

Degrees of freedom = 50
Mean square = 0.593

*Means followed by a common letter are not significantly different at an alpha level of .05.

TABLE V

DUNCAN'S MULTIPLE RANGE TEST OF THE SUB-PLOT TREATMENT MEANS OF THE JOHNSONGRASS CONTROL RATINGS FOR THE OKEMAH SITE ON 23 JULY, 1980

Treatment	Mean*		
Check	7.8	A	
		A	
Metolachlor	7.5	A	B
		A	B
Alachlor	7.3	A	B
			B
Oryzalin	7.2		B
Metolachlor + Atrazine	6.6	C	
		C	
Metribuzin	6.1	C	

Degrees of freedom = 50
Mean square = 0.444

*Means followed by a common letter are not significantly different at an alpha level of .05.

the control obtained by the postemergence herbicide collectively. The check represented the postemergence herbicides used alone. The herbicide listed is the preemergence herbicide that was tank-mixed with the postemergence herbicide. The metolachlor treatment at 4.6 kg/ha was the only preemergence herbicide that did not significantly lower the control of the postemergence herbicides as compared to the check for both dates. The combination of metolachlor and atrazine at 8.3 kg/ha and metribuzin at 5.0 kg/ha significantly lowered the control as compared to the check. They also rated significantly lower than any other preemergence herbicide for both dates.

The Southern Weed Science Society Research Report (172) considered 90 - 100% weed control as excellent, 80 - 90% weed control as good. Using this criteria, the control obtained by the postemergence herbicides collectively when used by themselves (check) or tank mixed with metolachlor was excellent through July 23 as shown on Table VI. This Table was constructed similarly to Table V except that the main treatment check has been deleted. The control obtained by tank mixtures with either alachlor at 5.0 kg/ha or oryzalin at 6.0 kg/ha was good.

Although not significant at an alpha level of .05, the analysis of variance table for July 23 indicates there may have been differences due to the interaction of main plot treatment x sub-plot treatment. The interaction graph in Figure 1 tends to indicate the control by glyphosate at both rates was adversely affected to a greater degree by the addition of a tank-mixed preemergence herbicide than either of the arsenicals. Most of this difference was probably due to the fact that this date of evaluation was after the first application of arsenicals which was done without a preemergence herbicide. However, it did appear

TABLE VI

DUNCAN'S MULTIPLE RANGE TEST OF THE SUB-PLOT TREATMENT MEANS OF THE JOHNSONGRASS CONTROL RATINGS FOR THE OKEMAH SITE ON 23 JULY, 1980*

Treatment	Mean**		
Check	9.4	A	
		A	
Metolachlor	9.1	A	B
		A	B
Alachlor	8.8	A	B
			B
Oryzalin	8.7		B
Metolachlor + Atrazine	7.9	C	
		C	
Metribuzin	7.3	C	

Degrees of freedom = 40
Mean square = 0.533

*The main plot treatment check was deleted from the computations.

**Means followed by a common letter are not significantly different at an alpha level of .05.

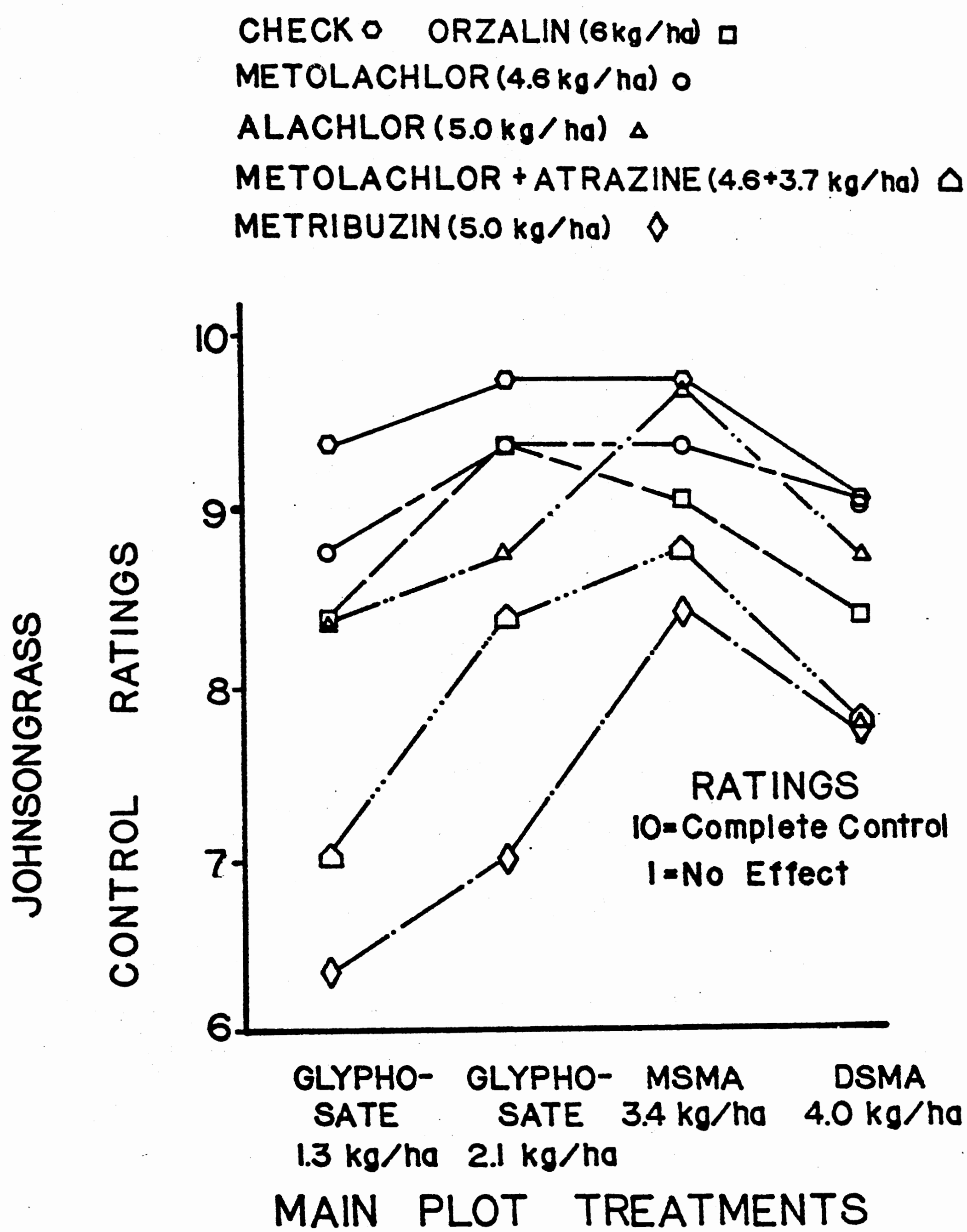

Figure 1. Interaction of Main Plots by Sub-Plots for the Okemah Site on July 23, 1980

that the glyphosate x metribuzin interaction was more detrimental than any interaction of any other combination.

As shown in Table VII, it appeared that after one application of each postemergence herbicide, the control by the glyphosate at 2.1 kg/ha was significantly higher than any other treatment. Except for the check, DSMA at 4.0 kg/ha exhibited the lowest control. Glyphosate at 1.3 kg/ha and MSMA at 3.4 kg/ha were between these and showed no differences between each other.

By July 23, which was after the first retreatment of arsenicals, there were no differences between MSMA, glyphosate at 2.1 kg/ha, and DSMA. The control by the MSMA treatment was excellent, while the control for the glyphosate treatment at 2.1 kg/ha and the DSMA treatment was good. The Duncan's test is shown in Table VIII.

The analysis for August 16, two weeks after the last application of organic arsenicals is shown in Table IX. Highly significant differences were noted among the main plot treatments, sub-plot treatments, and main plot x sub-plot interactions.

The differences between the means among the main plot treatments are shown in Table X. MSMA at 3.4 kg/ha per application and DSMA at 4.0 kg/ha per application showed no difference from each other. Both achieved excellent control and were significantly higher than both rates of glyphosate. Still both rates of glyphosate displayed good control. At this time the main plot checks also started to show some control and were no longer receiving an almost automatic minimum rating as they had earlier. Although the ratings for the check were inconsequential compared to the other treatments, they were perhaps indicative of the drought which was increasing in severity at that time.

TABLE VII

DUNCAN'S MULTIPLE RANGE TEST OF THE MAIN PLOT TREATMENT MEANS OF THE JOHNSONGRASS CONTROL RATINGS FOR THE OKEMAH SITE ON 8 JULY, 1980

Treatment	Mean*	
Glyphosate @ 2.1 kg/ha	8.2	A
Glyphosate @ 1.3 kg/ha	7.2	B
		B
MSMA	7.1	B
DSMA	6.1	C
Check	1.0	D

Degrees of freedom = 8
Mean square = 0.606

*Means followed by a common letter are not significantly different at an alpha level of .05.

TABLE VIII

DUNCAN'S MULTIPLE RANGE TEST OF THE MAIN PLOT TREATMENT MEANS OF THE JOHNSONGRASS CONTROL RATINGS FOR THE OKEMAH SITE ON 23 JULY, 1980

Treatment	Mean*		
MSMA	9.1	A	
		A	
Glyphosate @ 2.1 kg/ha	8.7	A	B
		A	B
DSMA	8.4	A	B
			B
Glyphosate @ 1.3 kg/ha	8.0		B
Check	1.2	C	

Degrees of freedom = 8
Mean square = 1.678

*Means followed by a common letter are not significantly different at an alpha level of .05.

TABLE IX

ANALYSIS OF VARIANCE OF JOHNSONGRASS CONTROL RATINGS FOR THE OKEMAH SITE ON 16 AUGUST, 1980

Source	Degrees of Freedom	Mean Square	F	Observed Significance Level
Replication	2	0.48	0.62	.5615
Main Plots	4	177.09	230.16	.0001
Error a	8	0.77		
Sub-plots	5	4.68	14.44	.0001
Main x Sub	20	1.43	4.42	.0001
Error b	50	0.32		
Corrected Total	89			

TABLE X

DUNCAN'S MULTIPLE RANGE TEST OF THE MAIN PLOT TREATMENT MEANS OF THE JOHNSONGRASS CONTROL RATINGS FOR THE OKEMAH SITE ON 16 AUGUST, 1980

Treatment	Mean*	
MSMA	9.9	A
		A
DSMA	9.7	A
Glyphosate @ 2.1 kg/ha	8.7	B
		B
Glyphosate @ 1.3 kg/ha	8.6	B
Check	2.3	C

Degrees of freedom = 8
Mean square = 0.769

*Means followed by a common letter are not significantly different at an alpha level of .05.

The early antagonism toward the postemergence herbicides was not in evidence on August 16 as shown in Table XI. This is due in most part to the retreatment of the MSMA and DSMA treatments which increased control in those plots. As a result, this increased the average of each sub-plot treatment. There were no differences between the check and any of the other sub-plot treatments except for the metribuzin. As shown in Table XII, control by these plots were all excellent except for the metribuzin which showed only fair control. This is due mainly to the initial interaction of the metribuzin with the postemergence herbicides, especially the glyphosate. As shown by the interaction graph in Figure 2, the antagonism of metribuzin toward glyphosate was the primary cause of the differences depicted in the interaction row in the analysis of variance table.

What appeared to be seedling regrowth started to appear just after the evaluation on August 16. The last two evaluation dates, September 10 and October 1, were utilized as assessments of this seedling re-growth. This was done even though there was not complete control ob-tained on all plots prior to this date. Consequently the values for these two dates were not strictly indicative of seedling control because of the aforementioned reasons in Chapter III.

As shown in Table XIII, there were significant differences in the variable rows for main plot and sub-plot treatments for the September 10 evaluation. The Duncan's Test (Table XIV) for the main plots on September 10 showed the main difference to be between the check plot and the other treatments. There were no differences in control between the MSMA, DSMA, and glyphosate at 2.1 kg/ha. As expected the postemergence treatments had no apparent influence on the seedling regrowth.

TABLE XI

DUNCAN'S MULTIPLE RANGE TEST OF THE SUB-PLOT TREATMENT MEANS OF THE JOHNSONGRASS CONTROL RATINGS FOR THE OKEMAH SITE ON 16 AUGUST, 1980

Treatment	Mean*	
Metolachlor	8.2	A
		A
Oryzalin	8.2	A
		A
Alachlor	8.1	A
		A
Check	8.0	A
		A
Metolachlor + Atrazine	7.9	A
Metribuzin	6.7	B

Degrees of freedom = 50
Mean square = 0.324

*Means followed by a common letter are not significantly different at an alpha level of .05.

TABLE XII

DUNCAN'S MULTIPLE RANGE TEST OF THE SUB-PLOT TREATMENT MEANS OF THE JOHNSONGRASS CONTROL RATINGS FOR THE OKEMAH SITE ON 16 AUGUST, 1980*

Treatment	Mean**	
Metolachlor	9.7	A
Oryzalin	9.7	A
Alachlor	9.5	A
Check	9.4	A
Metolachlor + Atrazine	9.2	A
Metribuzin	7.8	B

Degrees of freedom = 40
Mean square = 0.406

*The main plot treatment check was deleted from the computations.

**Means followed by a common letter are not significantly different at an alpha level of .05.

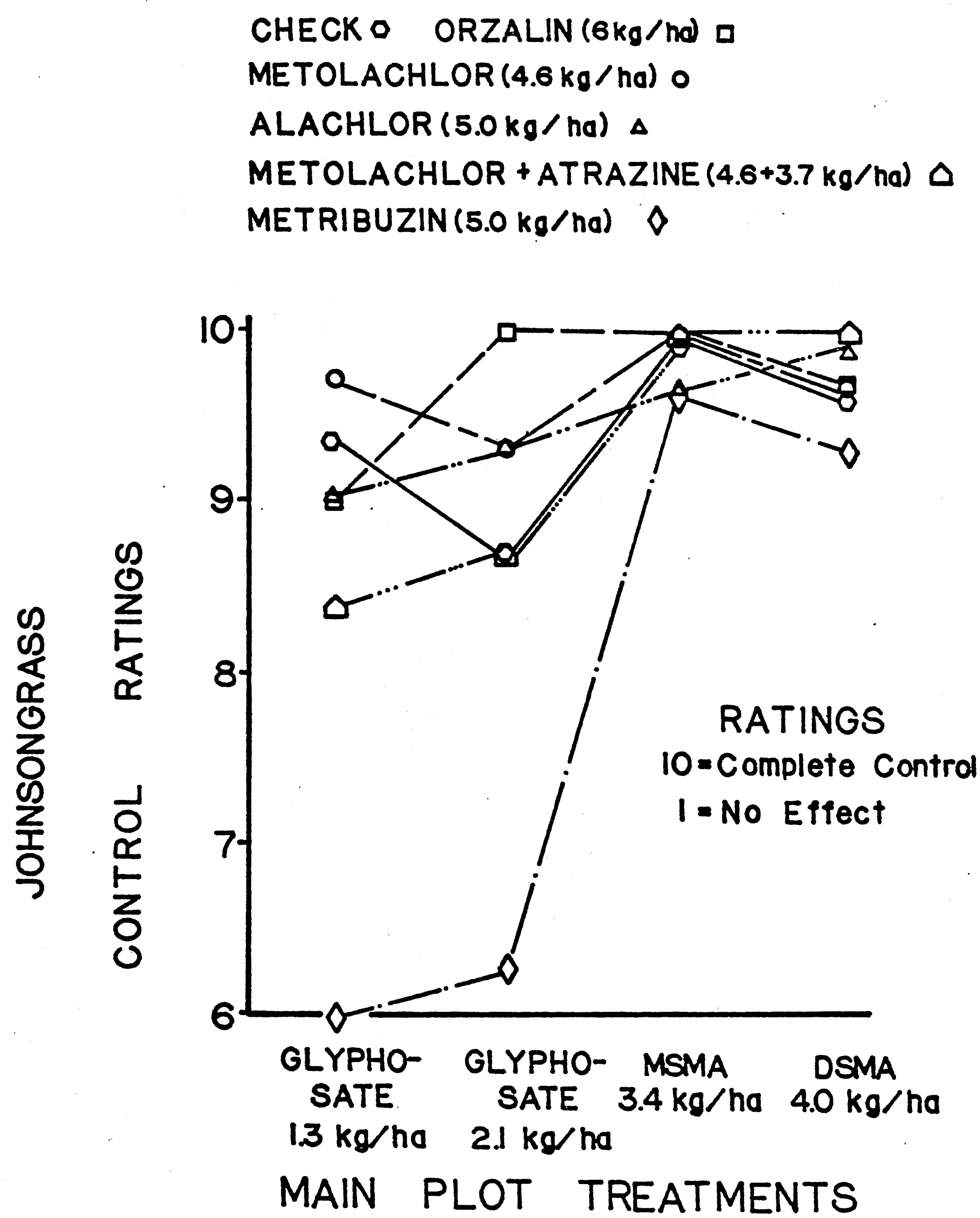

Figure 2. Interaction of Main Plots by Sub-Plots for the Okemah Site on August 16, 1980

TABLE XIII

ANALYSIS OF VARIANCE OF JOHNSONGRASS CONTROL RATINGS FOR THE OKEMAH SITE ON 10 SEPTEMBER, 1980

Source	Degrees of Freedom	Mean Square	F	Observed Significance Level
Replication	2	2.18	0.69	.5271
Main Plots	4	162.63	51.86	.0001
Error a	8	3.14		
Sub-plots	5	4.44	7.77	.0001
Main x Sub	20	0.85	1.50	.1250
Error b	50	0.57		
Corrected Total	89			

TABLE XIV

DUNCAN'S MULTIPLE RANGE TEST OF THE MAIN PLOT TREATMENT MEANS OF THE JOHNSONGRASS CONTROL RATINGS FOR THE OKEMAH SITE ON 10 SEPTEMBER, 1980

Treatment	Mean*		
MSMA	8.8	A	
		A	
DSMA	8.1	A	B
		A	B
Glyphosate @ 2.1 kg/ha	7.5	A	B
			B
Glyphosate @ 1.3 kg/ha	7.2		B
Check	1.3	C	

Degrees of freedom = 8
Mean square = 3.136

*Means followed by a common letter are not significantly different at an alpha level of .05

The preemergence herbicide treatments had only slight effect as shown in Table XV. There were no statistical differences in control between the treatments of oryzalin at 6.0 kg/ha, metolachlor at 4.6 kg/ha, metolachlor + atrazine at 8.3 kg/ha, and alachlor at 5.0 kg/ha as illustrated in Table XVI. Of these treatments only the oryzalin displayed significantly better control than was observed in the check. Only the oryzalin and metolachlor showed good control for this evaluation date.

The interaction of postemergence herbicide x preemergence herbicide resulted in no differences in control at an alpha level of .10. This was true for both September 10 and October 1 evaluations as shown by the analysis of variance in Tables XIII and XVII.

By October 1 the differences in control were highly significant and significant for the main plot and sub-plot treatments, respectively. In the main plots this difference was due mainly to the check as shown in Table XVIII. The differences in the sub-plot treatment means were due for the most part to the initial poor control in the metribuzin treatments (Table XIX). There were no differences among the other treatments including the check. They all had a control rating of poor. Using the check as a reference, there was no reduction in the amount of seedling regrowth by any of the preemergence herbicides by the final date of observation.

Tonkawa Experiment

The initial evaluation on July 7, two weeks after the treatments were applied, showed significant differences among the treatment means in the variable rows of main plot, sub-plot, and main plot x sub-plot interaction (Table XX). Although there were significant differences

TABLE XV

DUNCAN'S MULTIPLE RANGE TEST OF THE SUB-PLOT TREATMENT MEANS OF THE JOHNSONGRASS CONTROL RATINGS FOR THE OKEMAH SITE ON 10 SEPTEMBER, 1980

Treatment	Mean*		
Oryzalin	7.1	A	
		A	
Metolachlor	6.9	A	B
		A	B
Metolachlor + Atrazine	6.8	A	B
		A	B
Alachlor	6.7	A	B
			B
Check	6.4		B
Metribuzin	5.6	C	

Degrees of freedom = 50
Mean square = 0.571

*Means followed by a common letter are not significantly different at an alpha level of .05.

TABLE XVI

DUNCAN'S MULTIPLE RANGE TEST OF THE SUB-PLOT TREATMENT MEANS OF THE JOHNSONGRASS CONTROL RATINGS FOR THE OKEMAH SITE ON 10 SEPTEMBER, 1980*

Treatment	Mean**		
Oryzalin	8.6	A	
		A	
Metolachlor	8.3	A	B
		A	B
Metolachlor + Atrazine	8.2	A	B
		A	B
Alachlor	8.0	A	B
			B
Check	7.7		B
Metribuzin	6.7	C	

Degrees of freedom = 40
Mean square = 0.714

*The main plot treatment check was deleted from the computations.

**Means followed by a common letter are not significantly different at an alpha level of .05.

TABLE XVII

ANALYSIS OF VARIANCE OF JOHNSONGRASS CONTROL RATINGS FOR THE OKEMAH SITES ON 1 OCTOBER, 1980

Source	Degrees of Freedom	Mean Square	F	Observed Significance Level
Replication	2	2.18	0.72	.5149
Main Plots	4	130.43	20.72	.0003
Error a	8	6.29		
Sub-plots	5	2.18	3.21	.0136
Main x Sub	20	1.03	1.52	.1174
Error b	50	0.68		
Corrected Total	89			

TABLE XVIII

DUNCAN'S MULTPILE RANGE TEST OF THE MAIN PLOT TREATMENT MEANS OF THE JOHNSONGRASS CONTROL RATINGS FOR THE OKEMAH SITE ON 1 OCTOBER, 1980

Treatment	Mean*		
MSMA	8.8	A	
		A	
DSMA	8.3	A	B
		A	B
Glyphosate @ 2.1 kg/ha	7.1	A	B
			B
Glyphosate @ 1.3 kg/ha	6.4		B
Check	2.0	C	

Degrees of freedom = 8
Mean square = 6.294

*Means followed by a common letter are not significantly different at an alpha level of .05.

TABLE XIX

DUNCAN'S MULTIPLE RANGE TEST OF THE SUB-PLOT TREATMENT MEANS OF THE JOHNSONGRASS CONTROL RATINGS FOR THE OKEMAH SITE ON 1 OCTOBER, 1980*

Treatment	Mean**		
Oryzalin	8.1	A	
		A	
Metolachlor	7.9	A	
		A	
Alachlor	7.8	A	
		A	
Metolachlor + Atrazine	7.7	A	
		A	
Check	7.5	A	B
			B
Metribuzin	6.8		B

Degrees of freedom = 40
Mean square = 0.847

*The main plot treatment check was deleted from the computations.

**Means followed by a common letter are not significantly different at al alpha level of .05.

TABLE XX

ANALYSIS OF VARIANCE OF JOHNSONGRASS CONTROL RATINGS FOR THE TONKAWA SITE ON 7 JULY, 1980

Source	Degrees of Freedom	Mean Square	F	Observed Significance Level
Replication	2	5.83	2.76	.1224
Main Plots	4	96.01	45.48	.0001
Error a	8	2.11		
Sub-plots	5	3.65	9.38	.0001
Main x Sub	20	1.49	3.83	.0001
Error b	50	0.39		
Corrected Total	89			

among the main plot treatment means, the best rated mean, DSMA at 4.0 kg/ha, only received a rating of poor weed control (Table XXI). The control that was obtained in the treatment plots was erratic and spotty. It suggested that rain may have washed part of the chemical off the leaf surface after application. The plots were finished in mid-afternoon and a 1 inch rain was recorded that evening (Appendix, Table XXXI). Also, the plots were saturated, as water was standing in most parts of the plots at the time of application. This was due to 3.66 inches and 0.37 inches of rain two days and one day, respectively, before the day of application. The plots were in a relatively flat area at the base of a rather steep slope leading up to the highway. The johnsongrass plants may have been under a stress condition due to the standing water. For whatever reasons, the postemergence materials did not control the johnsongrass as well as would be normally expected.

The lack of control by the postemergence herbicides seemed to enhance the antagonism by the preemergence herbicides. This seemed to agree with the findings of several researchers who discovered that antagonism was reduced when the postemergence herbicide rate was increased. In this case, when the postemergence herbicide was decreased by rainfall, the antagonism increased as shown in Table XXII.

The analysis of variance for the evaluations of July 30 are shown in Table XXIII. There were highly significant differences among the means of the main-plot treatments and among the means of the sub-plot treatments. The means of the main plot treatments of MSMA and DSMA were significantly higher than the other treatments and showed no difference between each other (Table XXIV). The control by both was rated fair. Since they were retreated, the arsenicals were better able to recover

TABLE XXI

DUNCAN'S MULTIPLE RANGE TEST OF THE MAIN PLOT TREATMENT MEANS OF THE JOHNSONGRASS CONTROL RATINGS FOR THE TONKAWA SITE ON 7 JULY, 1980

Treatment	Mean*		
DSMA	7.0	A	
		A	
MSMA	6.8	A	
		A	
Glyphosate @ 2.1 kg/ha	6.0	A	B
			B
Glyphosate @ 1.3 kg/ha	5.1		B
Check	1.3	C	

Degrees of freedom = 8
Mean square = 2.111

*Means followed by a common letter are not significantly different at an alpha level of .05.

TABLE XXII

DUNCAN'S MULTIPLE RANGE TEST OF THE SUB-PLOT TREATMENT MEANS OF THE JOHNSONGRASS CONTROL RATINGS FOR THE TONKAWA SITE ON 7 JULY, 1980

Treatment	Mean*		
Check	6.1	A	
Metolachlor	5.3		B
			B
Metribuzin	5.1	C	B
		C	B
Oryzalin	5.1	C	B
		C	B
Alachlor	5.0	C	B
		C	
Metolachlor + Atrazine	4.7	C	

Degrees of freedom = 50
Mean square = 0.389

*Means followed by a common letter are not significantly different at an alpha level of .05.

TABLE XXIII

ANALYSIS OF VARIANCE OF JOHNSONGRASS CONTROL RATINGS FOR THE TONKAWA SITE ON 30 JULY, 1980

Source	Degrees of Freedom	Mean Square	F	Observed Significance Level
Replication	2	0.34	0.49	.6309
Main Plots	4	136.49	193.45	.0001
Error a	8	0.71		
Sub-plots	5	3.22	5.08	.0008
Main x Sub	20	0.83	1.31	.2176
Error b	50	0.63		
Corrected Total	89			

TABLE XXIV

DUNCAN'S MULTIPLE RANGE TEST OF THE MAIN PLOT TREATMENT MEANS OF THE JOHNSONGRASS CONTROL RATINGS FOR THE TONKAWA SITE ON 30 JULY, 1980

Treatment	Mean*		
MSMA	7.7	A	
		A	
DSMA	7.5	A	
Glyphosate @ 2.1 kg/ha	6.6		B
Glyphosate @ 1.3 kg/ha	5.4	C	
Check	1.0		D

Degrees of freedom = 8
Mean square = 0.706

*Means followed by a common letter are not significantly different at an alpha level of .05.

from the possible rain-hindered initial application.

By July 30, there was still a significant difference between the sub-plot check and the other sub-plot treatments due to possible antagonism (Table XXV). The postemergence herbicides applied alone (sub-plot check) controlled johnsongrass at a rating of fair. As shown by the interaction graph in Appendix Table XXXIII, the control by DSMA, MSMA and glyphosate at 2.1 kg/ha x the sub-plot check was rated 8.3 or good for each interaction treatment.

What appeared to be seedling regrowth was first observed in the September 10 ratings. The seedlings were distributed relatively uniformly across the sub-plot treatments as shown by the analysis of variance in Table XXVI.

By the last date of evaluation, October 2, significant differences were observed only in the variable row of main plot treatments as shown in Table XXVII. As demonstrated in Table XXVIII, the major difference was due to the check. The MSMA treatments were rated fair but were significantly higher than only the glyphosate at 1.3 kg/ha.

There were no significant differences in mean johnsongrass control due to the sub-plot treatments. All were rated as having provided poor control of seedling johnsongrass.

While no statistical comparisons were made between sites, it was observed that more seedling regrowth of johnsongrass occurred at the Tonkawa site than at the Okemah site. This might be explained by the fact that, in a summer that was very hot (the average daily maximum temperature for both sites was in excess of 100° F for July and August), the Tonkawa site received more rainfall after the initial application.

TABLE XXV

DUNCAN'S MULTIPLE RANGE TEST OF THE SUB-PLOT TREATMENT MEANS OF THE JOHNSONGRASS CONTROL RATINGS FOR THE TONKAWA SITE ON 30 JULY, 1980*

Treatment	Mean**		
Check	7.8	A	
Metolachlor	6.8		B
			B
Oryzalin	6.8		B
			B
Metolachlor + Atrazine	6.8		B
			B
Alachlor	6.5		B
			B
Metribuzin	6.1		B

Degrees of freedom = 40
Mean square = 0.792

*The main plot treatment check was deleted from the computations.

**Means followed by a common letter are not significantly different at an alpha level of .05.

TABLE XXVI

ANALYSIS OF VARIANCE OF JOHNSONGRASS CONTROL RATINGS FOR THE TONKAWA SITE ON 10 SEPTEMBER, 1980

Source	Degrees of Freedom	Mean Square	F	Observed Significance Level
Replication	2	3.70	4.34	.0529
Main Plots	4	111.19	130.39	.0001
Error a	8	0.85		
Sub-plots	5	2.00	1.22	.3123
Main x Sub	20	1.66	1.02	.4622
Error b	50	1.64		
Corrected Total	89			

TABLE XXVII

ANALYSIS OF VARIANCE OF JOHNSONGRASS CONTROL RATINGS FOR THE TONKAWA SITE ON 2 OCTOBER, 1980

Source	Degrees of Freedom	Mean Square	F	Observed Significance Level
Replication	2	15.48	2.24	.1688
Main Plots	4	108.02	15.64	.0008
Error a	8	6.91		
Sub-plots	5	1.96	1.56	.1896
Main x Sub	20	0.60	0.48	.9634
Error b	50	1.26		
Corrected Total	89			

TABLE XXVIII

DUNCAN'S MULTIPLE RANGE TEST OF THE MAIN PLOT TREATMENT MEANS OF THE JOHNSONGRASS CONTROL RATINGS FOR THE TONKAWA SITE ON 2 OCTOBER, 1980

Treatment	Mean*		
MSMA	7.3	A	
		A	
DSMA	6.6	A	B
		A	B
Glyphosate @ 2.1 kg/ha	5.4	A	B
			B
Glyphosate @ 1.3 kg/ha	5.2		B
Check	1.0	C	

Degrees of freedom = 8
Mean square = 6.908

*Means followed by a common letter are not significantly different at an alpha level of .05

CHAPTER V

SUMMARY AND CONCLUSIONS

For the most part, the postemergence herbicides successfully controlled rhizomatous johnsongrass when used alone. However, when a preemergence herbicide was applied simultaneously as a tank mixture, there was always a reduction in control. In the majority of cases, the reduction was significantly lower. Occassionally, the reduction was drastic and the impact lingered for the entire growing season.

Although there was often a significant reduction in control by the addition of a preemergence herbicide, it was frequently not below a control rating of good. If there had been some seedling control by the preemergence herbicide, then a slight or even moderate reduction in control might have been tolerable.

This would be especially true in the case of the organic arsenical treatments. These treatments were able to recover from the initial antagonism simply because of the reapplications.

At either site, there was no evidence of seedling johnsongrass control by a preemergence herbicide as compared to the sub-plot treatment check. For both sites, there appeared to be sufficient rainfall (Appendix, Table XXXI) to wash the preemergence herbicide from the vegetation to the soil. Also the rain occurred soon enough after the initial application to minimize the time the herbicide spent on the leaf surface. Consequently, this should have resulted in a minimal amount of both photodegradation by the sun and absorption by the existing johnsongrass canopy. There also should have been adequate rainfall perhaps to enable the herbicide to infiltrate the soil.

Of the preemergence herbicides which resulted in tolerable reductions in control by the postemergence herbicides, none of them provided the late season control that had been desired. Possibly the existing johnsongrass canopy disrupted the distribution pattern sufficiently to prevent the formation of a continuous herbicide seal on the soil surface. Another possibility was that the duration of the growing season was too lengthy a period of time to expect constant control considering the half-lives of the preemergence herbicides.

Considering the objectives outlined in Chapter I, three preemergence herbicides did not lower the control by the postemergence herbicides below a tolerable level or a control rating of good. Of these three (alachlor, metolachlor, and oryzalin), none controlled seedling johnsongrass through the end of September at either site.

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APPENDIX

TABLE XXIX

SOIL TEST RESULTS FOR BOTH EXPERIMENTAL SITES

Analysis	Units	Okemah	Tonkawa
pH	-	6.9	7.3
Organic Matter	%	1.4	1.0
Cation Exchange Capacity	mel/100 g	10.0	11.1
Sand	%	60	41
Silt	%	23	38
Clay	%	17	21
Texture	-	Sandy Loam	Loam

TABLE XXX

WIND AND TEMPERATURE CONDITIONS FOR BOTH EXPERIMENTAL SITES ON EACH APPLICATION DATE

	Okemah	Tonkawa
First Application Date	6-18	6-19
Wind Speed	2-3 mph	5 mph
Wind Direction	Variable	E.S.E.
Air Temperature	90°F	90°F
Second Application Date (MSMA & DSMA only)	7-10	7-11
Wind Speed	5-7 mph	8-10 mph
Wind Direction	S.S.E.	S.S.W.
Air Temperature	95°F	95°F
Third Application Date (MSMA & DSMA only)	7-29	7-31
Wind Speed	3-5 mph	10-12 mph
Wind Direction	S.S.W.	S.W.
Air Temperature	100°F	100°F
Seasonal Air Temperatures (average maximum and minimum)		
June maximum	90.6	92.6
June minimum	69.5	68.0
July maximum	102.1	103.5
July minimum	73.4	72.6
August maximum	100.2	100.2
August minimum	73.3	72.7

TABLE XXXI

RAINFALL AMOUNTS FOR THE EXPERIMENTAL SITES FOR THE MONTHS OF JUNE, JULY, AND AUGUST (IN INCHES)

	June		July		August	
Day	Okemah	Tonkawa	Okemah	Tonkawa	Okemah	Tonkawa
1						T
2						
3						
4						T
5		.02				.20
6						
7						T
8						
9		.04				
10						
11						
12						T
13						
14						
15						.40
16						
17	.23	3.66				T
18	.27	.37		T		.41
19	1.03	1.00			.61	.12
20	2.06	.24				T
21						
22		.25	T	T		T
23						.11
24						
25						
26						
27				.01		
28		T		T		
29						.14
30		T				T
31						T

*In the month of May, 4.83 inches and 3.67 inches were recorded at Okemah and Tonkawa, respectively.

TABLE XXXII

JOHNSONGRASS CONTROL RATING MEANS FOR EACH EVALUATION DATE AND MAIN PLOT BY SUB-PLOT TREATMENT FOR THE OKEMAH SITE*

Treatment**		Evaluation Dates				
Main	Sub	7-8	7-23	8-15	9-10	10-1
1	1	6.33	7.00	8.33	7.00	6.33
1	2	7.67	8.67	9.67	7.67	7.00
1	3	7.33	8.33	9.00	7.67	7.00
1	4	5.67	6.33	6.00	5.67	5.00
1	5	7.67	8.33	9.00	8.00	7.00
1	6	8.33	9.33	9.33	7.00	6.00
2	1	7.00	8.33	8.67	8.00	7.00
2	2	9.00	9.33	9.33	8.33	7.33
2	3	8.00	8.67	9.33	7.00	7.33
2	4	6.67	7.00	6.33	5.67	5.67
2	5	9.33	9.33	10.00	8.67	8.00
2	6	9.33	9.67	8.67	7.33	7.33
3	1	5.67	8.67	10.00	8.67	8.33
3	2	7.67	9.33	10.00	9.00	8.33
3	3	7.33	9.67	9.67	9.00	9.00
3	4	6.00	8.33	9.67	8.67	9.33
3	5	7.67	9.00	10.00	9.00	9.00
3	6	8.00	9.67	10.00	8.67	8.67
4	1	5.33	7.67	10.00	9.00	9.33
4	2	7.67	9.00	9.67	8.33	9.00
4	3	5.67	8.67	10.00	8.33	8.00
4	4	4.33	7.67	9.33	6.67	7.00
4	5	6.33	8.33	9.67	8.67	8.33
4	6	7.33	9.00	9.67	7.67	8.00
5	1	1.00	1.33	2.33	1.33	2.00
5	2	1.00	1.00	2.33	1.33	2.00
5	3	1.00	1.33	2.33	1.33	2.00
5	4	1.00	1.33	2.33	1.33	2.00
5	5	1.00	1.00	2.33	1.33	2.00
5	6	1.00	1.33	2.33	1.33	2.00

*The means shown are averaged across three replications.

**Main Treatments: 1-Glyphosate @ 1.3 kg/ha, 2-Glyphosate @ 2.1 kg/ha, 3-MSMA, 4-DSMA, 5-Check
Sub-plot Treatments: 1-Metholachlor + Atrazine, 2-Metolachlor, 3-Alachlor, 4-Metribuzin, 5-Oryzalin, 6-Check

TABLE XXXIII

JOHNSONGRASS CONTROL RATING MEANS FOR EACH EVALUATION DATE AND MAIN PLOT BY SUB-PLOT TREATMENT FOR THE TONKAWA SITE*

Treatment**		Evaluation Dates			
Main	Sub	7-8	7-30	9-10	10-2
1	1	4.67	6.00	2.67	4.33
1	2	5.67	6.00	6.00	6.00
1	3	4.67	4.67	3.00	4.67
1	4	5.33	4.33	3.33	4.33
1	5	4.00	5.00	3.67	5.67
1	6	6.00	6.33	4.33	6.00
2	1	5.00	6.33	3.00	5.00
2	2	6.00	6.00	4.67	5.67
2	3	5.67	6.67	6.00	6.00
2	4	6.33	6.00	4.33	4.00
2	5	5.00	6.33	4.67	5.67
2	6	8.00	8.33	5.33	6.00
3	1	6.00	7.00	7.00	7.33
3	2	6.33	8.00	7.33	7.33
3	3	6.67	8.00	7.33	7.67
3	4	6.33	7.00	7.67	7.00
3	5	7.67	8.00	8.00	7.33
3	6	7.67	8.33	7.00	7.33
4	1	6.67	7.67	6.67	6.67
4	2	7.67	7.67	7.00	7.00
4	3	6.67	6.67	6.00	6.33
4	4	5.67	7.00	6.67	6.00
4	5	7.33	8.00	6.67	7.00
4	6	8.00	8.33	5.67	6.33
5	1	1.00	1.00	1.00	1.00
5	2	1.00	1.00	1.00	1.00
5	3	1.33	1.00	1.00	1.00
5	4	2.00	1.00	1.00	1.00
5	5	1.67	1.00	1.00	1.00
5	6	1.00	1.00	1.00	1.00

*The means shown are averaged across three replications.

**Main Treatments: 1-Glyphosate @ 1.3 kg/ha, 2-Glyphosate @ 2.1 kg/ha, 3-MSMA, 4-DSMA, 5-Check
Sub-plot Treatments: 1-Metolachlor + Atrazine, 2-Metolachlor, 3-Alachlor, 4-Metribuzin, 5-Oryzalin, 6-Check

2

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