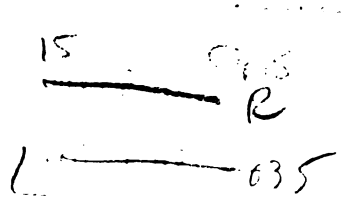
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YELLOW NUTSEDGE (*CYPERUS ESCULENTUS* L.) CONTROL WITH BENTAZON (3-ISOPROPYL-1*H*-2,1,3-BENZOTHIADIAZIN-(4)-3*H*-ONE 2,2-DIOXIDE) AND GLYPHOSATE (*N*-(PHOSPHONOMETHYL)CLYGINE)

By

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ABSTRACT

YELLOW NUTSEDGE (CYPERUS ESCULENTUS L.) CONTROL WITH BENTAZON (3-ISOPROPYL-1H-2,1,3-BENZOTHIADIAZIN-4-(3H)-ONE 2,2-DIOXIDE) AND GLYPHOSATE (N-(PHOSPHONOMETHYL)GLYCINE)

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Postemergence application of bentazon (3-isopropyl-1H-2,1,3-benzothiadiazine-4-(3H)-one 2,2-dioxide) to yellow nutsedge (Cyperus esculentus L.) grown in the greenhouse provided greatest control when applied at rate 2.2 kg/ha to 7.6 cm tall plant and resulted in death of parent tuber. A single 2.2 kg/ha application was more effective than a single 1.1 kg/ha application. Bentazon was less effective on taller plants, control was less than 50% with single application of 2.2 kg/ha application to plants 30.5 cm tall or taller. Split applications of bentazon enhanced control, a time lapse between split applications of 5 days provided greater control than 10 or 20 days if the initial application was 1.1 kg/ha and the plants were 30.5 cm tall or less. Under field conditions, split applications of bentazon also provided greater control than a single application when applied to plants 5 to 7.6 and 10 to 15.2 cm tall. A time lapse between first and second applications from 10 to 20 days did not effect yellow nutsedge control. Applications of bentazon to 20 or 30.5 cm tall yellow nutsedge did not provide control

and resulted in soybean (Clycine max L.) yield loss.

Single postemergence applications of glyphosate (N-(phosphonomethyl) glycine) controlled shoots of 7.6 cm tall yellow nutsedge plants but not taller plants, and the parent tubers still lived.

Further greenhouse and growth chamber studies indicated that a higher light intensity (48.4 klux) increased the activity of glyphosate. In contrast, bentazon caused more injury to yellow nutsedge under low light intensity (16.1 klux). Bentazon and glyphosate were more effective under high soil moisture (field capacity) than under low soil moisture conditions. Bentazon caused more injury to 7.6 cm tall plants at 15 C than 35 C. When the plants were 30.5 cm tall bentazon caused greatest injury at 25 C. Glyphosate controlled 7.6 cm tall plants at 15, 25, and 35 C. But when the plants were 30.5 cm tall, glyphosate controlled only plants grown at 25 and 35 C.

Additives to increase bentazon and glyphosate activity were evaluated in the greenhouse. Ammonium phosphate, ammonium chloride, ammonium sulfate, and ammonium thiocyanate in combination with bentazon significantly increased bentazon injury to yellow nutsedge plants. Ethephon (2-chloroethylphosphonic acid), 2,4-D (2,4-dichlorophenoxy)acetic acid), urea and ammonium salts in combination with glyphosate also increased yellow nutsedge injury primarily by reducing the stand density.

In laboratory studies more ^{14}C-bentazon was absorbed and translocated by 7.6 cm tall plants than those 15.2 cm tall. ^{14}C-bentazon moved acropetally and basipetally and translocated down into tubers of 7.6 and 15.2 cm tall plants. Split applications of bentazon and addition of ammonium sulfate increased ^{14}C-bentazon absorption and translocation in 15.2 cm tall plants. Yellow nutsedge grown in EPTC (S-ethyl-dipropyl

thiocarbamate) treated sand culture and in low soil moisture conditions absorbed less ^{14}C-bentazon.

More ^{14}C-glyphosate was absorbed by 15.2 cm tall than 7.6 cm tall plants. However, translocation was greater in 7.6 cm tall plants than 15.2 cm tall plants 5 days after treatment. No ^{14}C-glyphosate was translocated to tubers. Ethephon and ammonium sulfate increased ^{14}C-glyphosate absorption and translocation by 15.2 cm tall plants but only ethephon increased basipetal movement of ^{14}C-glyphosate to the tubers. Less ^{14}C-glyphosate was absorbed by plants grown under low light intensity than by plants grown under high light intensity.

Most of the ^{14}C found in the treated leaf, other leaves, roots, rhizomes and parent tubers was parent bentazon. The metabolism in various plant parts was similar with up to nine ^{14}C-metabolites separated. The percent of ^{14}C remaining as parent or non-metabolized bentazon did not differ in 7.6, 15.2 cm tall plants, or 15.2 cm tall plants treated with ammonium sulfate.

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INTRODUCTION

Most preemergence herbicides used for yellow nutsedge (Cyperus esculentus L.) control killed only the sprouting buds but not the tubers (101,113,119). Tubers contain several buds in various stages of dormancy. It is difficult to kill all the buds on a tuber with a single herbicide application (113). When ever the herbicide concentration in soil decreased to less than optimum for yellow nutsedge control, the plants resumed growth.

Bentazon (3-isopropyl-1H-2,1,3-benzothiadiazin-(4)3H-one 2,2-dioxide), a selective postemergence herbicide for broadleaf weed control in corn (Zea mays L.) (62), soybean (Glycine max L.) (56,66,71,101,114), rice (Oryza sativa L.) (3), navy bean (Phaseolus vulgaris L.) (3) and Kentucky bluegrass (Poa pratensis L.) (3,50,63) has shown potential for yellow nutsedge control (101,102,103).

Glyphosate (N-(phosphonomethyl)glycine), a non selective postemergence herbicide for annual, perennial, grass and broadleaf weed control (7), has also been reported to control yellow nutsedge (20,101).

The purpose of this research was to determine: (1) the optimum stage of yellow nutsedge growth, bentazon and glyphosate rate, and time lapse between split applications of bentazon for yellow nutsedge control; (2) the effect of bentazon and glyphosate on tuber viability and bentazon on soybean yield were also considered; (3) the influence of light intensity, soil moisture, and temperature on yellow nutsedge control with

with bentazon and glyphosate; (4) potential of additives to increase the activity of bentazon and glyphosate on yellow nutsedge; (5) the influence of stage of plant growth, split applications of herbicide, additives and environmental conditions on absorption and translocation of ^{14}C-bentazon and ^{14}C-glyphosate on yellow nutsedge; and (6) the nature of bentazon metabolism in yellow nutsedge.

CHAPTER 1

LITERATURE REVIEW

Biology of Yellow Nutsedge

Taxonomy

Yellow nutsedge (Cyperus esculentus L.), a perennial herb, has been classified in the family Cyperaceae (24). Culms (rachis) are triangular, stem like, erect above ground, and terminated by an inflorescence (126). Leaves are three ranked, pale green 4 to 6 mm wide with a prominent mid-vein about as long as or longer than the culm. The inflorescence is subtended by unequal leaf like bracts varying from 5 to 25 cm long (49). Spikelets are golden brown, 0.5 to 3 cm long and 1.5 to 3 mm wide, and pinnately arranged along an elongate axis (126). There are three stamens and three cleft styles in each flower (49). The achenes are yellowish brown, three angled, and 1.2 and 1.5 mm long. They are covered by a thin ablong, obtuse-shaped scale (126). The root system is fibrous (25). Rhizomes are covered by cladophylls at nodes and long internodes (51). Tubers are 1 to 2 cm long (25).

Anatomy and Morphology

Wills (126) reported that leaves grow out from the bulb in an in-folded triangular fascicle. Fascicle development on the bulb begins at the outer-most leaf, progresses inward, and terminates with a seed-bearing

rachis (126). The upper leaf surface is composed of large epidermal cells covered by waxy cutin and no stomata. The lower leaf surface is composed of smaller epidermal cells and cover less cutin than the upper leaf surface (126). The vascular bundles are surrounded by chlorenchymatous cells (126) similar to those of purple nutsedge (C. rotundus L.) (124). Black et al. (17) categorized purple nutsedge as a C_4 plant, yellow nutsedge may also be categorized a C_4 plant (126). There are vacuolated cells which are supported by a fiber bundle above and below vascular bundle cells (126).

Rhizomes develop from parent tuber or basal bulbs (51). Cross sections of rhizome reveal an epidermis, a cortex, and an endodermis surrounding a vascular cylinder. The vascular cylinder have the xylem outside the phloem. There is an apical meristem at the rhizome apex covered by sharply pointed scale-leaves (cladophylls) (126).

Tuber formation occurs at the rhizome apex in the meristematic region. The internodes cease to elongate and the leaf primodia remain dormant during tuber maturity (51). The vascular bundles in tubers are the same as in rhizomes and are continuous from the rhizome through the tubers to buds and roots (16).

The basal bulb is formed from the rhizomes apex in the meristematic region the same as tubers except the leaf primodia do not become dormant and subsequent shoots elongation occurred (51).

Roots can be formed from the endodermis of tubers, bulbs, or rhizomes. Cross-sections of roots reveal xylem vessels surrounded by phloem vessels. The vascular cylinder is surrounded by a pericycle which is surrounded by endodermal cells. The endodermis is surrounded by cortex and epidermis (126).

Propagation and Tuber Dormancy

Yellow nutsedge is propagated by both seeds and tubers (12,13,54, 112). A simple seedling develops into a stand of plants that can produce a yield of 90,000 seeds with germination of 51% (47). However, under field conditions yellow nutsedge seeds germinate only 1 to 32% (12). Seeds germinate in the zone very close to the soil surface and do not germinate at 3.3 cm or deeper (12).

Tubers are the principal way yellow nutsedge spreads in agricultural land (13). One tuber may produce 1900 plants and 6,900 tubers in 1.6 square meter in one year (112). Most tubers were found in the zone up to 15 cm below soil surface (112) and most of them sprouted from this zone (26,98). However, they can sprout from as much as 30 cm below the soil surface (112). The percent of sprouting depends on soil type with low sprouting percentages found in compacted soil (26).

In Illinois (98), under field conditions, tubers remained viable for a period of up to 22 months, however, Bell et al. (13) reported the percent of sprouting was still high after 3 years of storage at room temperatures or under refrigeration. Yellow nutsedge tubers are sensitive to cold temperature (97,110) and little sprouting occurs when buried in the field at 2.5 and 5.1 cm depth (98). Tuber dormancy occurs during the late summer and early fall. Sprouting was highest during the winter and spring (109).

Growth Development

Tubers are the source of shoots, rhizomes, root and basal bulbs (51, 96). During sprouting, over 60% of the tuber dry weight, carbohydrate, oil, starch and protein were consumed (96). If sprouting is disturbed

or arrested new buds can sprout (111) but then less than 10% of the constituents were utilized during subsequent sprouting (96).

There are five to seven buds formed, per tuber, one per node. The oldest bud is the largest and located at the basipetal end of the tuber. The smallest bud is the youngest and located at the apical end of the tuber. Buds break dormancy in acropetal order starting with the oldest bud (16).

One or more rhizomes are formed from the newly sprouting bud. Each rhizome develops a basal bulb (51,96). The length of rhizome between the tuber and basal bulb may be several meters or shorter and it appears that the basal bulb develops from the tuber without a rhizome (51). Basal bulbs are the basic site of leaf shoot and subterranean growth (51). The apical growth of basal bulbs produces the leafly plant and inflorescence. The new rhizomes also develop from the basal bulb and may develop into new tubers or secondary basal bulbs. If the plant forms secondary and tertiary basal bulbs, it will become a complex system (51).

Growth of yellow nutsedge was tremendously effected by the photoperiod, and increased photoperiod from 14 to 24 hrs., increased vegetative growth. New photosynthic leaves differentiate every 4.5 to 5 days, and exhibited sigmoid pattern of growth for 24 to 40 days (51). The rate of basal bulb formation from rhizome tips was maximum at 16 hours (51) and the rate of tuber formation maximum at a 8 to 12 hour photoperiod (37, 51). Delayed tuber formation occurred under the longest photoperiod (37, 51). Flowering occurred with a 12 to 14 hour photoperiod. Active vegetative growth was competitive with tuberization and flowering was competitive with both shoot formation and tuberization (51).

Not only long photoperiods, but high levels of nitrogen in the soil,

and gibberellic acid also inhibit tuberization (14,15,37). High temperatures and low level of nitrogen favored tuberization (37). Shoot formation was promoted and carbohydrate level in plants decreased when soil nitrogen levels were high, photoperiod long and temperatures high (37). Triiodobenzoic or naphthylphthalanic acid also accelerated transformation of rhizomes to shoots (14).

Distribution and Ecotypes

Yellow nutsedge is distributed from the equator to Alaska and even found in eastern and southern Africa (49). It can grow in all soil types, including black peat soil, and grows well at a pH of 5 to 7 (49). Generally, it is found in poorly drained soils (49,117). However, it is very susceptible to low light intensity or shading (49,61).

There are different ecotypes of yellow nutsedge with different morphological characteristics such as tuber size and leaf size in different parts of the United States (21,70).

Hauser (42) suggested that variable susceptibility of yellow nutsedge to atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)-S-triazine) and 2,4-D ((2,4-dichlorophenoxy)acetic acid) in different geographical areas may be explained by the presence of different yellow nutsedge varieties. Recently Casta and Appleby (27) categorized yellow nutsedge into two different varieties, C. esculentus L. var. esculentus and C. esculentus var. leptostachyus. Var. esculentus was less susceptible to preplant application of atrazine and metribuzin (4-amino-6-tert-butyl-3-(methylthio)-as-triazine-5(4H)one) but more susceptible to postemergence 2,4-D than leptostachyus (27,133). Yip and Sweet (132) described the characteristic of these two varieties. Var. esculentus has short spikelets

(0.5-1 cm) and produces small sized but many tubers and secondary shoots are produced 1-2 cm away from the primary shoot, whereas va. leptostachyus has a long spikelet (1.5-3.5 cm), produced fewer, but large sized tubers and secondary shoots are produced 5-14 cm away from the primary shoot.

Stoller and Weber (100) reported that yellow nutsedge "I" the Illinois ecotype and yellow nutsedge "G" the Georgia ecotype contain very different amounts of starch and lipids after exposure to 2 C for 6 weeks. Yellow nutsedge "I" had a higher ratio of unsaturated to saturated fatty acids, higher triglycerides and polar lipids than yellow nutsedge "G". Starch and lipid contents increased significantly in yellow nutsedge "I" but did not change in yellow nutsedge "G".

Agricultural Importance of Yellow Nutsedge

Yellow nutsedge has been ranked as one of the most serious weed problems in the United States (51,117). The areas infested by this weed have increased in the past decide (13,49,67). Using herbicides for annual weed control and reduced tillage may have increased yellow nutsedge infestation in crop land (42).

Yellow nutsedge not only reduces yields and increases crop production cost, but reduces crop quality as well (13). The rhizomes of yellow nutsedge grow into and through potato (Solanum tuburosum L.) tubers causing them to be graded as culls. Clumps of yellow nutsedge went through lima beans (Phaseolus linensis L.) and caused viners to break down (13). Tubers of yellow nutsedge could be mixed with shell beans (13). In cotton (Gossypium hirsutum L.) fields, yellow nutsedge also delayed cotton maturity (60).

Holm et al. (49) reported that yellow nutsedge is a weed on all continents. It is a serious weed of sugar cane in Hawaii, Peru, South Agrica, and Swaziland; of corn in Angola, South Africa, Tanzania, and United States; of cotton in Mozambique, Rhodesia, and United States; of soybeans in Canada, South Africa, and United States; of potatoes in Canada, South Africa, and United States; and of vegetable in Mozambique and United States.

Yellow Nutsedge Control with Herbicides

Herbicides have played an important role in yellow nutsedge control but a combination of herbicides and tillage is often needed for maximum yellow nutsedge control (121). All herbicides discussed below are currently used for yellow nutsedge control.

Alachlor (2-chloro-2,6-diethyl-N-(methoxymethyl)acetanilide) is a selective herbicide that can be used for yellow nutsedge control in corns (Zea mays L.) (62), soybeans (Glycine max (L.) Merr.) (4,84,119), and cottons (57,58,59). Preplanting incorporation of alachlor provided greater control than preemergence applications when rainfall was limited (4,5).

Metolachlor (2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acetamide) is chemically similar to alachlor and can also be used to control yellow nutsedge in corn (30,48), soybeans (30), peanuts (Arachis hypogaea L.) and potatoes (48). Metolachlor provided more effective (29) and longer season (48) control of yellow nutsedge than alachlor because it was more persistent in the soil than other acetanilide herbicides (29).

EPTC (S-ethyl diprophylthiocarbamate) one of the oldest herbicides, is also used for yellow nutsedge control in corn (13), cotton (43), and soybeans (119). Occasionally EPTC causes corn injury, however, a protectant or antidote, R-25788 (N,N-diallyl-2,2-dichloroacetamide) has been used in combination with EPTC. EPTC plus antidote provided yellow nutsedge control and less corn injury than EPTC alone (62,121).

Butylate (S-ethyl diisobutylthiocarbamate) is from the same chemical group as EPTC but appeared less effective than EPTC for yellow nutsedge control. It shows less corn injury than EPTC (43,62,84).

Vernolate (S-propyl dipropylthiocarbamate) is one of the most effective herbicides for yellow nutsedge control in soybean (121) and peanuts (41). Pebulate (S-propyl butylethylthiocarbamate) also provided yellow nutsedge control in peanuts (40).

All preemergence or preplant incorporated herbicides described above control yellow nutsedge for only 6 to 8 weeks. They did not inhibit sprouting of yellow nutsedge but inhibited shoot elongation (5,29,59). Yellow nutsedge grew normally when lesser amounts of herbicide remained in soil (59).

Bromacil (5-bromo-3-sec-butyl-6-methyluracil) and terbacil (3-tert-butyl-5-chloro-6-methyluracil) have been used for yellow nutsedge control in non-crop areas. These two herbicides did not kill yellow nutsedge tubers, but killed new shoots from sprouting tubers. The herbicides remain in the soil a long period of time and eventually yellow nutsedge tubers were killed as food reserves were exhausted (59).

Atrazine, a selective herbicide in corn, has been reported to control yellow nutsedge when preplant incorporated (84), however, the control was only fair and erratic (121). Atrazine plus phytobland oil used as a

postemergence and split application provided excellent yellow nutsedge control (62). Another triazine, prometryne (2,4-bis (isopropylamino)-6-(methylthio)-s-triazine) was reported helpful in controlling yellow nutsedge in corn (121).

Cyperquat (1-methyl-4-phenylpyridinium) has been used as postemergence application for yellow nutsedge control in Kentucky bluegrass (Poa pratensis L.) (10,50,63) and soybean (56).

Pefluidone (1,1,1-trifluoro-N-(2-methyl-4-(phenylsulfonyl)phenyl) methane-sulfonamide) effectively controlled yellow nutsedge either as preplant incorporated, preemergence or postemergence treatment (38,121). Perfluidone showed selectively in cotton (31) and Kentucky bluegrass (50, 63) but in soybean occasional injury occurred.

Behavior of Bentazon in Plant and Soil

Bentazon (3-isopropyl-1H-2,1,3-benzothiadiazin-(4)3H-one 2,2-dioxide) is a selective postemergence herbicide used to control broadleaf weeds and yellow nutsedge in soybean (55,66,71,101,114), corn (62), rice (Oryza sativa L.), dry beans (Phaseolus vulgaris L.), peanuts (3), and turf-grass (3,50,63).

Andersen, et al. (2) reported that bentazon controlled wild mustard (Brassica kaber (DC) L.C.), common ragweed (Ambosia artemisiifolia L.), velvet leaf (Abutilon theophrasti Medic), Pennsylvania smartweed (Polygonum pensylvanicum L.), common cocklebur (Xanthium pensylvanicum Wallr.), wild common sunflower (Helianthus annuus L.) and pigweed (Amaranthus sp.). Recently, Oliver, et al. (82) reported that bentazon controlled many species of morning glory (Ipomoea spp.) and was often

enhanced by using split applications (46,56,62,63,66,103). Bentazon gives excellent control of young yellow nutsedge plants (101,103). Moreover, the parent tubers have been reported to be killed by the bentazon treatment (101,103). However, Stoller et al. (102) reported that in corn fields, pre and postemergence combinations of preemergence alachlor or EPTC and postemergence treatments with bentazon did not reduce the number of yellow nutsedge tubers after 1 year but after a 2 year period of combination applications, the number of tubers were significantly reduced.

The activity of bentazon is dependent on environmental conditions (78,104). Bentazon activity on pigweed was greater under high humidity than low humidity (78). The efficiency of bentazon under high humidity was greater at 10 C than 20 or 30 C (78). Rainfall within 24 hours after application reduced pigweed (78) and velvet leaf (35) control.

Wills (127) reported that bentazon was more toxic to common cocklebur grown in wet soil at field capacity than in the dry soil near the wilting point. The translocation of ^{14}C-bentazon was more rapid in common cocklebur grown in wet soil, under high temperature (35 C), or under high relative humidity (96%).

Several surfactants such as the acetylenic surfactants were effective in enhancing the phytotoxicity of bentazon (135). Addition of emulsifiable linseed oil and petroleum oil to the spray solution increased the activity of bentazon on pigweed control. The emulsifiable linseed oil and petroleum oil minimized the effect of low humidity and simulated rainfall (78). However, the water-soluble linseed oil formulation was more effective than emulsifiable linseed oil in increasing bentazon activity (79). Water-soluble linseed oil enhanced absorption and translocation of ^{14}C-bentazon in redroot pigweed more than did emulsifiable linseed oil, petroleum, or surfactants (80).

Mahoney and Penner (68,69) studied the translocation and metabolism of ^{14}C-bentazon in soybean and navy bean (Phaseolus vulgaris L.) and compared it to cocklebur and black nightshade (Solanum nigrum L.). ^{14}C-bentazon moved throughout the treated leaf of cocklebur, but little acropetal movement occurred in the trifoliate leaves of navy bean (69). The rate of ^{14}C-bentazon metabolism was more rapid in soybean and navy bean than in cocklebur and black nightshade (68,69).

The mechanism of bentazon selectivity in rice and susceptible Cyperus serotinus Rottb. were studied by Mine et al. (73). The absorption and translocation of ^{14}C-bentazon was not different between rice and C. serotinus. However, ^{14}C-bentazon was metabolized more rapidly in rice than in C. serotinus 24 hours after treatment. Seven days after herbicide application only 5% of parent ^{14}C-bentazon remained in rice but 50-75% of parent ^{14}C-bentazon remained in C. serotinus. The major metabolite in rice was 6-(3-isopropyl-2,1,3-benzothiadiazin-4-one-2,2-dioxide)-O-β-glucopyranoside.

Bentazon is a herbicide selective in soybean but not all soybean varieties are resistent to bentazon (120). ^{14}C-bentazon translocation was greater in the susceptible soybean cultivar than the resistant one (127). Hayes and Wax (44) reported that more ^{14}C-bentazon was absorbed in the sensitive cultivar "PI 229.342" (Nookishirohana) than by the tolerant cultivar "Clark 63". The tolerant "Clark 63" metabolized ^{14}C-bentazon faster than "PI 229.342".

Retzlaff and Hamm (87) reported that CO_2 assimilation in wheat (Triticum eastivum L.) resistant to bentazon was inhibited after the plant received bentazon. However, CO_2 assimilation was increased and became normal again after a period of time. The rate of CO_2 assimilation

increase in wheat plants correlated with the rate of ^{14}C-bentazon metabolism. ^{14}C-bentazon was metabolized to 6 and 8-hydroxybentazon.

Mine and Matsunaka (74) reported that bentazon inhibited the Hill reaction in isolate chloroplast of spinach (Spinacia aleracea L.) and Cyperus serotinus Rottb. However, Boger et al. (19) isolate chlorophasts from algea Bumilleriopsis filiformis and observed that bentazon inhibited photosystems II but not photosystem I.

Potter and Wergin (85) observed that light was the essential factor for necrosis development in bentazon treated cocklebur leaves. The higher the illuminance the faster necrosis developed. The length of time required to stop photosynthesis and develop necrosis was about 7 hours after photosynthesis was stopped. This evidence supported the hypothesis that photo-induced toxic by-products resulted from stopping photosynthesis (6).

Klepper (64) proposed that the nitrite is a secondary phytotoxic agent responsible for initial injury and final death of the plant after herbicide treatment. Bentazon was shown to block light-dependent nitrite reduction and caused nitrite accumulation in green leaf of winter wheat (Triticum aestivum L.) "Centurk" (65).

The mobility and adsorption of bentazon in soil has been studied by Abernathy and Wax (1). Bentazon was anionic in neutral solution and was not adsorbed by soil or by the cation exchange resin, carboxy methyl cellulose (CMC). But bentazon was adsorbed by charcoal and by the anion exchange resin, diethylaminoethyl cellulose (DEAE). It moved with the water front on soil thin layer chromatography plates and also moved through the soil columns.

Behavior of Glyphosate in Plant and Soil

Glyphosate (N-(phosphonomethyl)glycine), is a translocated nonselective postemergence herbicide for grass and broadleaf weed control (7). The perennial weeds which can be controlled by glyphosate are Johnson grass (Sorghum halepens L. Pers.), Bermuda grass (Cynodon dactylon L. Pers.), paragrass (Brachiaria mutica Forssk. stapf.), quackgrass (Agropyron repens L.), purple nutsedge (Cyperus rotundus L.) (7), field bindweed (Convolvulus purpurea L.), hedge bindweed (C. sepium L.), and tall morning glory (Ipomoea purpurea L. Roth) (89). Glyphosate also has potential for yellow nutsedge control (20,101).

Glyphosate can be used prior to planting corn, soybeans, and cereal crops (7) and for turfgrass, Kentucky bluegrass, and alfalfa (Medicago sativa L.) establishment (76,77). In deciduous fruit trees, applications must be careful to prevent spray drift to other areas except the basal trunk (86). Glyphosate applied in a recirculating sprayer provided effective control of Johnson grass with little soybean injury and greatly increasing soybean yields (72).

Adding a cationic surfactant to a glyphosate spray solution enhanced the phytotoxicity more than nonionic surfactants for common milkweed (Asclepias syriaca L.) and hemp dogbane (Apocynum cannabinum L.) control (130).

The activity of glyphosate on purple nutsedge increased when applied at 100 percent relative humidity on plants grown at 25 C rather than 35 C (125). More ^{14}C-glyphosate was absorbed and translocated in Bermuda grass at 32 than 22 C and at 100% RH than at 40% RH, this appeared related to greater control (53).

Fernadez and Bayer (36) proposed that translocation of glyphosate appeared to follow the typical source-sink relationship after they observed ^{14}C-glyphosate translocation in Bermuda grass.

In purple nutsedge, ^{14}C-glyphosate moved through the mature tuber to the newly forming tubers at rhizome tips. Tubers were killed when glyphosate was applied to young plants. There is no evidence for ^{14}C-glyphosate metabolism in purple nutsedge (134).

In quackgrass, ^{14}C-glyphosate was rapidly absorbed and translocated from the treated leaf to the rhizomes and untreated shoot (95). ^{14}C-accumulation was greatest in the nodes near the rhizome tip and least in the nodes near the mother shoot with greater numbers of buds killed near the rhizome tip due to large accumulation of glyphosate in this part of quackgrass rhizome (28).

Glyphosate may break bud dormancy. Parker (83) reported that sub-lethal doses of glyphosate affected apical dorminance of the perennial weeds , Agropyron repens L., Cyperus rotundus L. and Convovulus arvensis L. Increased number of shoots were formed by 30 cm tall yellow nutsedge plants after treated with glyphosate (20,105). Field bindweed, hedge bindweed, and tall morning glory showed a characteristic response of bud proliferation and shoot proliferation to sub-lethal rates of glyphosate (89). Low concentrations of glyphosate have also been reported to stimulate basal bud development of sorghum (Sorghum bicolor L.) at normal and above normal temperatures (8).

Richard et al. (88) examined the effect of glyphosate on electron transport in pea chloroplast by monitoring oxygen uptake in the present of paraquat or methyl viologen. No inhibition was observed at concentrations of 10^{-2} to 10^{-7} M. In soybean leaf cells, glyphosate affected

photosynthesis or respiration less than protein or RNA synthesis (23,115).

Jaworski (52) reported that glyphosate inhibits the shikimic or aromatic amino acid biosynthesis pathway. The growth inhibition of duckweed (Lemma gibba) caused by glyphosate can be alleviated by the addition of L-phenyl alanine. Glyphosate may inhibit or repress chorismate mutase and, or prephenate dehydratase. However, Brecke and Duke (23) studying bean discs and isolated cells, indicated that glyphosate inhibited ^{14}C-uracil incorporation into RNA within 3 hours of glyphosate application. Glyphosate directly inhibited ion transport 1 hour after treatment while membrane integrity and the level of ATP were not affected.

The ultrastructural effects of glyphosate on Lemma gibba L. was reported by Hoagland and Paul (45). Chloroplast, mitochondria, and cell walls were progressively damaged with increased herbicide exposure time, but microtubules, spherosomes, rough endoplasmic reticulum, golgibodies or microbodies were not significantly changed.

Sprankle et al. (93,94) indicated that glyphosate was inactivated in soil by adsorption to clay and organic matter through the phosphonic acid moiety and ^{14}C-glyphosate was biodegraded in soil to $^{14}CO_2$ by co-microorganism. However, glyphosate has shown activity in coarse-textured soil when applied at high rates to the soil surface (22,91).

The Influence of Ammonium Salts on Herbicide Phytotoxicity

Ammonium sulfamate, ammonium sulfate, and ammonium thiocyanate have been classified as a herbicide (6) when used at high rates. However, low rates of ammonium salts have been used to increase herbicide phytotoxicity. Ammonium thiocyanate has been reported to increase the

activity of DNOC (4,6-dinitro-o-cresol) (6), endothal(7-oxabicyclo (2.2.1) heptane-2,3-dicarboxylic acid) (6), picloram (4-amino-3,5,6-trichloro-picolinic acid) (128), and glyphosate (18,108).

Ammonium salts could affect herbicide absorption and translocation in plants. Ammonium thiocyanate increased amitrol translocation in quackgrass (34). Ammonium sulfate also increased picloram absorption by guava (Psidium cattleianum Sabine) and dwarf bean (Phaseolus vulgarlis L.((128). The basis for the affect may be the increase in the permeability as reported for tritiated water through citrus leaf cuticular membranes (90).

Ammonium ion may act at the same or different site of action as the herbicides but cause more injury to the plant than the herbicides alone (81). Ammonium ions prevented phosphorylation and increased the rate of electron flow from plastoquinone to photosystem I (39) and may interact with herbicides that inhibit electron flow. Ammonium ions also suppressed both nitrate and nitrite reductase levels in plant leaves (123) and may enhance nitrite accumulation. When applied in combination with herbicides they may cause more nitrite accumulation in leaves than herbicides alone.

The Influence of Ethephon (2-chloroethylphosphonic acid) on Herbicide Phytotoxicity

Ethephon has been reported to increase phytotoxicity of dicamba (2,6-dichloro-o-anisic acid) (9) and 2,4,5-T (2,4,5-trichlorophenoxy) acetic acid) (75). Binning et al. (9) proposed that ethelene released from ethephon may alter source-sink relationship in plant and increase basipetal movement of herbicides. However, Morey et al. (75) reported that ethephon caused a reduction of xylem tissue formation and increased the activity of 2,4,5-T.

CHAPTER 2

YELLOW NUTSEDGE (*CYPERUS ESCULENTUS*) CONTROL WITH BENTAZON AND GLYPHOSATE

Abstract

The influence of stage of growth and herbicide rate on yellow nutsedge (*Cyperus esculentus* L.) control with bentazon (3-isopropyl-1*H*-2,1,3-benzothiadiazin-(4)3*H*-one 2,2-dioxide) and glyphosate (*N*-(phosphonomethyl)glycine) were evaluated in greenhouse studies. Yellow nutsedge tubers collected in Michigan were sprouted at 21 C and transplanted into soil for the various herbicide treatments in the greenhouse. Bentazon provided greatest control when the plants were 7.6 cm tall. A single 2.2 kg/ha application was more effective than a single 1.1 kg/ha application. Bentazon was less effective on taller plants, control was less than 50% with a single 2.2 kg/ha application to plants 30.5 cm tall or taller. Split applications of bentazon enhanced control, a time lapse between applications of 5 days provided greater control than 10 or 20 days if the initial application was 1.1 kg/ha and the plants were 30.5 cm tall or less. A single 2.2 kg/ha glyphosate application controlled yellow nutsedge 7.6 cm tall, was less effective on plants 15.2 cm tall and provided no control of taller plants. None of the glyphosate treatments resulted in death of the tubers. Under field conditions bentazon provided greater control when split applications were applied to plants

5 to 7.6 and 10 to 15.2 cm tall than a single application. Extending the time lapse between first and second applications from 10 to 20 days did not affect yellow nutsedge control. Delay of bentazon application until the yellow nutsedge was 20 to 30.5 cm tall failed as a control and resulted in significant soybean (Glycine max (L.) Merr.) yield loss in 1975.

Introduction

Yellow nutsedge is one of the most serious weed problems in the United States (6,18). It is widely distributed and an increasing problem in most corn (Zea mays L.) and soybean producing areas (8,17). It is estimated that one million hectares are infested in the North Central and Northeastern United States and that it is still spreading (5). A previous report indicated that increased control of annual weeds with herbicides and decreased tillage may have contributed to the increased infestation of cropland by yellow nutsedge (2). Both seed and tubers are produced but propagation by tubers is the most important means of dissemination in cultivated crops (2).

Most herbicides contributing to yellow nutsedge control kill only the sprouting buds and not the tubers (13,16,20). Tubers contain several buds with various stages of dormancy. It is difficult to kill all the buds on a tuber (14). Bentazon, a selective postemergence herbicide and glyphosate, a non-selective postemergence herbicide have both shown potential for yellow nutsedge control (3,4,7,13,19).

The objectives of this investigation were to determine the optimum stage of yellow nutsedge growth, bentazon and glyphosate rate, and time lapse between split applications of bentazon for yellow nutsedge control.

The effect of bentazon and glyphosate on tuber viability and of bentazon on soybean yield were also examined.

Materials and Methods

For the greenhouse experiments, yellow nutsedge tubers were collected at East Lansing, Michigan, washed with tap water and placed in petri dishes to sprout in a controlled environment chamber at 21 C. Sprouted tubers with the same shoot length were transplanted into a greenhouse soil mix, one per 946-ml cup. The plants were grown in the greenhouse at 25 $\pm$ 3 C with supplemental fluorescent lighting, the plants at 7.6 (3 to 4 leaf stage), 15.2 (5 to 6 leaf stage), 30.5 (8 to 9 leaf stage) and 61.0 (12 to 15 leaf stage) cm tall were selected for herbicide application. Bentazon at 1.1 and 2.1 kg/ha with 0.25% alkyl-aryl-polyglycol ether surfactant[1] at 346 L/ha was applied in single and split applications. The time lapse for split applications was 5, 10, and 20 days. Single applications of glyphosate were applied at the same rates used for bentazon and at the same stage of growth. Treatments were replicated four times in a randomized complete block design. Fourty days after the last bentazon application and 30 days after the glyphosate application the plants were rated for control, number of shoots per plant in each cup, plant height was mreasured, and dry wt determined by harvesting all leaves above the soil surface. The cups containing the roots were placed out-of-doors for a winter cold treatment. The number of shoots that

[1]This surfactant is known commercially as Citowett, a product of BASF Wyandotte Corp.

sprouted in the spring were recorded.

Field experiments to study the effect of bentazon on yellow nutsedge control in soybeans were conducted in 1975 and 1976 at the Crop Science Research Farm, Michigan State University, East Lansing, Michigan on sandy clay loam soil with 2.5% organic matter. Treatments were replicated four times in a randomized complete block design. Plot size was 5.0 m by 20 m with four rows in 1.25 m row widths. Bentazon was applied as postemergence single and split applications at 1.1 and 2.2 kg/ha with 0.25% of the same surfactant as used in the greenhouse experiments at 215 L/ha. The time lapse between split applications was 10 and 20 days. Yellow nutsedge plants were 5.0 to 7.6, 10.0 to 15.2 and 20 to 30.5 cm tall, and soybean plants averaged 20.0, 40.0 and 50.0 cm tall, respectively, at the time of bentazon application. Weed control ratings were recorded 20 days after the last herbicide treatment. Two rows of soybeans 10.0 m long in the middle of the plot were harvested for grain yield. The density of new yellow nutsedge shoots in each plot was determined the next spring by using 0.25 m^2 quadrat for five random samplings in each plot.

Yellow nutsedge in weed-free plots was controlled by hoeing. The grasses in bentazon-treated plots were also controlled by hoeing in 1975 and preplant incorporated trifluralin at 1.1 kg/ha in 1976.

The data presented in the tables are the means of two experiments and the field data which is presented for the individual years.

Results and Discussion

Single applications of bentazon at 2.2 kg/ha controlled yellow nutsedge in the greenhouse when the plants were 7.6 cm tall, including

killing the tubers (Table 1). Death of yellow nutsedge tubers following bentazon application has been reported by Stoller et al. (13). A single application of 2.2 kg/ha of bentazon to yellow nutsedge at 15.2 cm provided only 65% control and reduced the number of shoots, plant height, dry wt, and the number of shoots after regrowth (Table 1). Bentazon failed to control yellow nutsedge plants 30.5 and 61.0 cm tall. Regrowth the following spring increased as the height of plants increased. Application of 2.2 kg/ha bentazon to yellow nutsedge 61.0 cm tall increased the regrowth the following spring perhaps by stimulating tuber production (Table 1). In the greenhouse the 1.1 kg/ha rate of bentazon was ineffective in controlling yellow nutsedge.

Split applications of bentazon at the rate of 1.1 kg/ha gave complete control of plants 7.6 cm tall with no regrowth evident in spring (Table 2). The most effective time lapse between the first and second bentazon application was 5 or 10 days. Split applications of bentazon provided yellow nutsedge control of plants 30.5 cm tall (Table 2). The 2.2 kg/ha rate in a single application provided only 36% control (Table 1). Since yellow nutsedge leaves are erect, single applications of bentazon may not cover all leaf surfaces and leaves that received less bentazon can grow as normal. The bentazon translocated from yellow nutsedge leaves that received herbicide from a single application may not adequately kill other leaves (13).

If the initial bentazon application rate was 1.1 kg/ha and followed with 1.1 and 2.2 kg/ha, the 5-day time lapse between bentazon applications gave complete control of yellow nutsedge 15.2 cm tall (Table 2). Split applications with a 10-day time lapse showed good yellow nutsedge control if the second application rate was 2.2 kg/ha; however, the tubers

were not killed. Initial application of bentazon at 2.2 kg/ha followed with 1.1 and 2.2 kg/ha 5, 10, or 20 days later killed the yellow nutsedge foliage (Table 3). The 5-day time lapse between the split treatments was again the most effective time for bentazon for killing the tubers.

Split applications of bentazon did not increase the control of plants 61.0 cm tall as all treatments failed (Tables 2 and 3). Single or split applications of bentazon at 1.1 and 2.2 kg/ha did not kill the tubers when applied to plants 30.5 or 61.0 cm tall. The older yellow nutsedge plants have more leaves than the younger plants and spray solutions may not have been adequate to cover the whole plant. The leaves of older yellow nutsedge plants may also have thickner cuticles than younger plants allowing less penetration of the herbicide.

Data from 1975 and 1976 showed that split applications of bentazon 10 or 20 days apart were more effective for control than single application (Table 4). Plants in the field may be more susceptible to bentazon as the 1.1 kg/ha rate provided over 50% control of plants 7.6 cm tall. The control ratings indicated that only for the 20.0 to 30.5 cm tall plants the low rate of bentazon was more effective with a 10-day time lapse between applications than a 20-day lapse. Bentazon did not reduce the regrowth of yellow nutsedge shoots, although greenhouse experiments showed that parent tubers could be killed at these rates. These data can be explained by tuber dormancy, as tubers germinated at different times depending on their depth in the soil. A greater portion of the tubers in shallow soil germinated than those deep in the soil (12). The shoots of late germinating tubers would not have received bentazon and can produce tubers again in that season. Repeat applications of bentazon for two or three seasons may meet the requirements of yellow nutsedge control

programs.

Soybean yields were not reduced with split applications of 1.1 and 2.2 kg/ha of bentazon applied at the initiation of the first trifoliolate leaves. Reduction of soybean yields occurred when bentazon was applied to 20.0-30.5 cm tall yellow nutsedge (Table 4). Yield reduction may have been the effect of yellow nutsedge and not the effect of bentazon because bentazon failed to control yellow nutsedge when it was taller than 10.0-15.2 cm.

Glyphosate applied at the rate of 2.2 kg/ha to yellow nutsedge plants 7.6 cm tall gave 87% control (Table 5). The number of shoots per cup, plant height and dry wt were reduced, although control of yellow nutsedge was not complete nor were the tubers killed (13). Glyphosate at 2.2 kg/ha provided 68% control of plants 15.2 cm tall primarily by reducing plant height and plant dry weight. Glyphosate failed to control plants 30.5 cm tall or taller.

Parker (10) reported that sub-lethal doses of glyphosate affected apical dorminance of the perennial weeds, quackgrass (Agropyron repens L.), purple nutsedge (Cyperus rotundus L.), and tall morning glory (Convovulus arvensis L.). Glyphosate at 1.1 kg/ha applied to yellow nutsedge 30.5 cm tall stimulated tubers to sprout and develop new shoots (Table 5). This agreed with the results of Boldt and Sweet (3).

Glyphosate has been shown to effectively control numerous perennial weeds (1). The pattern of translocation indicates that it moves readily in the phloem (11). This in contrast to bentazon which appears to move primarily in the apoplast (9).

It appears paradoxical that the bentazon treatment results in death of the tubers but the glyphosate treatment at the 2.2 kg/ha rate did not.

Literature Cited

1. Baird, D.D., R.P. Upchurch, W.B. Homesley, and J.E. Branz. 1971. Introduction of new broad spectrum postemergence herbicide class with utility for herbaceous perennial weed control. Proc. North Centr. Weed Contr. Conf. 26:64-68.

2. Bell, R.S., W.H. Lachman, E.M. Rahn, and R.D. Sweet. 1962. Life and history studies as related to weed control in the northeast. 1. Nutgrass. Univ. of Rhode Island Agr. Exp. Sta. Bull. 364, 33 pp.

3. Boldt, P.F. and R.D. Sweet. 1974. Glyphosate studies on yellow nutsedge. Proc. Northeast Weed Sci. Soc. 28:197-204.

4. Hendrick, L.W., M.A. Veenstra, and R.E. Ascheman. 1973. Canada thistle and yellow nutsedge control with split application of bentazon. Proc. North Centr. Weed Contr. Conf. 28:64.

5. Holm, L.G., D.L. Plucknett, J.V. Pancho, and J.P. Herberger. 1977. The World's Worst Weeds. The University Press of Hawaii. Honolulu, 609 pp.

6. Jansen, L.L. 1971. Morphology and photoperiodic responses of yellow nutsedge. Weed Sci. 19:210-219.

7. Ladlie, J.S., W.F. Meggitt, and R.C. Bond. 1973. Preplant incorporated, preemergence and postemergence application on yellow nutsedge in soybean. Res. Rpt. North Centr. Weed Contr. Conf. 31: 112-113.

8. Lewis, W.M. and A.D. Worsham. 1970. The ten worst weeds of field crops. Nutsedge. Crops and Soils 22:14-16.

9. Mahoney, M.D. and D. Penner. 1975. Bentazon translocation and metabolism in soybean and navy bean. Weed Sci. 23:265-271.

10. Parker, C. 1976. Effects on the dormancy of plant organs (in Herbicides, Physiology, Biochemistry, Ecology, Edited by L.J. Audus). Vol. I. Academic Press, London 608 pp.

11. Sprankle, P., W.F. Meggitt, and D. Penner. 1975. Absorption, action, translocation of glyphosate. Weed Sci. 23:235-240.

12. Stoller, E.W. and L.M. Wax. 1973. Yellow nutsedge shoot emergence and tuber longevity. Weed Sci. 21:76-81.

13. Stoller, E.W., L.M. Wax, and R.L. Matthiesen. 1975. Response of yellow nutsedge and soybeans to bentazon, glyphosate and perfluidone. Weed Sci. 23:215-221.

14. Stoller, E.W. 1975. Growth, development and physiology of yellow nutsedge. Proc. North Centr. Weed Contr. Conf. 30:124-125.

15. Suwanketnikom, R. and D. Penner. 1975. Yellow nutsedge control with bentazon and glyphosate. Proc. North Centr. Weed Contr. Conf. 30:115.

16. Tumbleson, M.E. and T. Kommedahl. 1962. Factors affecting dormancy in tubers of Cyperus esculentus. Bot. Gaz. 123:186-189.

17. U.S. Department of Agriculture Research Service. 1970. Selected weeds of the United States Agr. Handbook 266, 463 pp.

18. U.S. Department of Agriculture, Agricultural Research Service, Federal Extension Service and Economic Research Service. 1968. Extend and cost of weed control with herbicides and an evaluation of important weeds, 1965. ARS 34-102. 85 pp.

19. Wax, L.M. 1975. Control of yellow nutsedge in field crops. Proc. North Centr. Weed Contr. Conf. 30:125-128.

20. Wax, L.M., E.W. Stoller, F.W. Slife and R.N. Andersen. 1972. Yellow nutsedge control in soybeans. Weed Sci. 20:194-201.

Table 1. Influence of plant height and rate of bentazon application on yellow nutsedge grown in the greenhouse 40 days after application.

Plant ht (cm)	Bentazon rate (kg/ha)	Control (%)	Density (shoots/pot)	Plant ht (cm/plant)	Dry wt (gm/system)	Regrowth in spring (shoots/pot)
7.6	0	0 a[a]	5.0 b	44.1 de	2.9 cde	4.2 c
	1.1	2 a	6.5 bc	39.6 de	1.8 bc	1.5 b
	2.2	100 d	0.0 a	0.0 a	0.2 a	0.0 a
15.2	0	0 a	5.2 b	49.6 de	3.3 de	4.9 c
	1.1	2 a	4.7 b	38.0 de	1.8 bc	1.8 b
	2.2	65 b	1.1 a	22.7 b	0.6 ab	1.2 b
30.5	0	0 a	10.8 d	50.7 de	3.9 e	8.0 cd
	1.1	6 a	10.1 d	37.5 cd	2.3 cd	4.5 c
	2.2	36 b	4.4 b	24.0 bc	0.9 ab	5.0 c
61.0	0	0 a	10.5 d	55.2 e	7.5 g	13.6 d
	1.1	2 a	9.1 d	51.7 de	6.3 fg	13.0 d
	2.2	7 a	8.6 cd	51.6 de	5.5 f	26.6 e

[a]Means within columns with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 2. Split postemergence application of bentazon to yellow nutsedge grown in the greenhouse with an initial application rate of 1.1 kg/ha and second application rate of 1.1 or 2.2 kg/ha.

Plant ht (cm)	Bentazon rate (kg/ha)	Time of split (days)	Control after 40 days (%)	Density (shoots/pot)	Plant ht (cm/plant)	Dry wt (gm/system)	Regrowth in spring (shoots/pot)
7.6	0		0 a[a]	5.0 c	44.1 d	2.93 c	4.2 a
	1.1		2 a	6.5 d	39.6 c	1.80 cb	1.5 b
	1.1+1.1	5	100 c	0.0 a	0.0 a	0.06 a	0.0 a
	1.1+2.2	5	100 c	0.0 a	0.0 a	0.04 a	0.0 a
	1.1+1.1	10	100 c	0.0 a	0.0 a	0.34 a	0.0 a
	1.1+2.2	10	100 c	0.0 a	0.0 a	0.03 a	0.0 a
	1.1+1.1	20	58 b	2.0 b	26.8 b	0.56 a	1.0 b
	1.1+2.2	20	70 b	1.4 ab	11.9 a	0.47 a	5.4 c
15.2	0		0 a	5.6 c	49.6 d	3.30 d	4.9 c
	1.1		2 a	4.8 b	38.0 cd	1.82 c	1.8 b
	1.1+1.1	5	100 c	0.0 a	0.0 a	0.09 a	0.0 a
	1.1+2.2	5	100 c	0.0 a	0.0 a	0.09 a	0.0 a
	1.1+1.1	10	80 bc	0.9 a	10.0 ab	0.19 a	2.5 b
	1.1+2.2	10	100 c	0.0 a	0.0 a	0.12 a	2.8 b
	1.1+1.1	20	18 a	3.6 b	33.6 c	1.51 bc	2.6 b
	1.1+2.2	20	60 b	1.9 a	16.1 b	0.84 ab	2.5 b
30.5	0		0 a	10.8 e	50.8 d	3.93 e	8.0 a
	1.1		6 ab	10.1 de	37.5 c	2.35 d	4.5 a
	1.1+1.1	5	100 d	0.0 a	0.0 a	0.36 a	3.0 a
	1.1+2.2	5	100 d	0.0 a	0.0 a	0.36 a	4.0 a
	1.1+1.1	10	35 c	4.8 b	24.2 b	0.91 ab	6.0 a
	1.1+2.2	10	90 d	1.1 a	5.1 a	0.60 a	10.0 a
	1.1+1.1	20	12 ab	8.2 cd	32.2 c	1.50 c	4.0 a
	1.1+2.2	20	16 b	7.1 c	30.8 bc	1.33 bc	5.0 a
61.0	0		0 a	10.5 a	55.2 a	7.49 b	13.6 a
	1.1		2 a	9.1 a	51.8 a	6.30 ab	13.0 a
	1.1+1.1	5	0 a	8.4 a	50.5 a	5.50 ab	17.5 a
	1.1+2.2	5	6 a	7.6 a	45.5 a	5.03 ab	11.0 a
	1.1+1.1	10	5 a	9.4 a	50.5 a	5.71 ab	9.5 a
	1.1+2.2	10	6 a	8.5 a	48.4 a	4.45 a	12.5 a
	1.1+1.1	20	2 a	10.4 a	50.8 a	5.75 ab	8.0 a
	1.1+2.2	20	0 a	6.5 a	51.9 a	5.77 ab	15.5 a

[a]Means within columns for a given plant height with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 3. Split postemergence application of bentazon to yellow nutsedge grown in the greenhouse with an initial application rate of 2.2 kg/ha and second application rate of 1.1 or 2.2 kg/ha.

Plant ht (cm)	Bentazon rate (kg/ha)	Time of split (days)	Control after 40 days (%)	Density (shoots/pot)	Plant ht (cm/plant)	Dry wt (gm/system)	Regrowth in spring (shoots/pot)
15.2	0		0 a	7.6 b	51.4 c	3.17 c	4.6 c
	2.2		65 b	1.1 a	22.8 b	0.58 b	1.2 b
	2.2+1.1	5	100 c	0.0 a	0.0 a	0.15 ab	0.0 a
	2.2+2.2	5	100 c	0.0 a	0.0 a	0.13 ab	0.0 a
	2.2+1.1	10	100 c	0.0 a	0.0 a	0.11 ab	1.9 b
	2.2+2.2	10	100 c	0.0 a	0.0 a	0.24 ab	0.0 a
	2.2+1.1	20	100 c	0.0 a	0.0 a	0.10 ab	1.2 b
	2.2+2.2	20	100 c	0.0 a	0.0 a	0.04 a	0.0 a
30.5	0		0 a	10.6 c	44.0 d	3.94 b	12.0 a
	2.2		34 b	4.4 b	24.0 c	0.81 a	5.0 a
	2.2+1.1	5	96 c	0.1 a	3.0 a	0.36 a	10.0 a
	2.2+2.2	5	100 c	0.0 a	1.0 a	0.38 a	4.0 a
	2.2+1.1	10	85 c	1.5 a	11.1 ab	0.36 a	3.0 a
	2.2+2.2	20	86 c	0.9 a	6.0 a	0.40 a	6.0 a
	2.2+1.1	20	46 b	4.1 b	16.9 bc	0.59 a	4.0 a
	2.2+2.2	20	40 b	4.6 b	18.6 bc	0.64 a	4.0 a
61.0	0		0 a	8.9 a	52.4 a	7.02 b	18.2 a
	2.2		8 a	8.6 a	51.4 a	5.52 ab	26.6 a
	2.2+1.1	5	10 a	10.0 a	42.9 a	4.07 a	20.0 a
	2.2+2.2	5	10 a	10.0 a	46.4 a	4.68 a	16.0 a
	2.2+1.1	10	10 a	9.4 a	52.8 a	4.57 a	13.5 a
	2.2+2.2	10	18 a	8.4 a	44.5 a	4.30 a	12.5 a
	2.2+1.1	20	11 a	9.8 a	51.8 a	5.65 ab	12.3 a
	2.2+2.2	20	10 a	8.9 a	55.8 a	5.07 a	4.5 a

[a]Means within columns for a given plant height with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 4. Influence of plant height, rate and split application of bentazon on yellow nutsedge control and soybean yield in the field in 1975 and 1976.

Plant ht (cm)	Bentazon rate (kg/ha)	Time of split (days)	Control 1975	Control 1975	Regrowth[a] (shoots/ 25 cm^2)	Soybean[a] yield (kg/ha)
Control	0		0 a[b]	0 a	27.9 a	3577 a
Control weed free	0		100 i	100 g	15.2 a	6024 def
5.0-7.6	1.1		62 def	57 cd	18.4 a	6385 ef
	1.1+1.1	10	80 fghi	82 efg	7.1 a	6426 ef
	1.1+1.1	20	90 ghi	92 gh	11.4 a	7002 f
	2.2		67 efg	65 de	19.2 a	5632 de
	2.2+1.1	10	95 hi	97 g	12.2 a	5991 def
	2.2+1.1	20	95 hi	92 gh	13.9 a	6490 ef
10.0-15.2	1.1		45 cde	52 bcd	32.6 a	5071 cd
	1.1+1.1	10	100 i	100 g	20.2 a	6426 ef
	1.1+1.1	20	97 i	95 fg	18.6 a	6428 ef
	2.2		75 fghi	72 def	25.2 a	6080 def
	2.2+1.1	10	100 i	97 g	20.5 a	6655 ef
	2.2+1.1	20	98 i	95 fg	12.4 a	6338 ef
20.0-30.5	1.1		5 ab	10 a	23.9 a	4587 abc
	1.1+1.1	10	70 efgh	72 def	17.3 a	5978 def
	1.1+1.1	20	37 cd	40 bc	10.8 a	4318 abc
	2.2		25 bc	32 b	21.9 a	4257 abc
	2.2+1.1	10	62 def	67 de	12.9 a	4624 bc
	2.2+1.1	20	56 def	55 cd	23.9 a	3896 ab

[a]Results in 1975.

[b]Means within columns with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 5. Influence of plant height and rate of glyphosate application on yellow nutsedge grown in the greenhouse 30 days after application.

Plant ht (cm)	Glyphosate rate (kg/ha)	Control (%)	Density (shoots/pot)	Plant ht (cm/plant)	Dry wt (gm/system)
7.6	0	0 a[a]	6.4 de	48.0 c	2.75 de
	1.1	34 d	6.9 e	28.1 b	0.73 abc
	2.2	87 f	1.1 a	14.4 a	0.09 a
15.2	0	0 a	6.1 de	44.6 c	2.35 d
	1.1	20 bc	3.9 bcd	29.3 b	0.67 abc
	2.2	69 e	1.6 ab	12.3 a	0.16 ab
30.5	0	0 a	6.7 e	55.0 c	3.78 ef
	1.1	5 a	9.6 f	31.4 b	1.90 cd
	2.2	29 cd	3.0 abc	29.7 b	1.49 bcd
61.0	0	0 a	5.4 cde	52.7 c	5.66 h
	1.1	0 a	4.0 dcd	52.5 c	5.37 gh
	2.2	11 ab	4.5 cde	48.9 c	4.16 fg

[a]Means within columns with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

CHAPTER 3

INFLUENCE OF THE ENVIRONMENT ON YELLOW NUTSEDGE (CYPERUS ESCULENTUS) CONTROL WITH BENTAZON AND GLYPHOSATE

Abstract

The influence of light intensity, soil moisture, and temperature on yellow nutsedge (Cyperus esculentus L.) control with bentazon (3-isopropyl-1H-2,1,3-benzothiadiazin-(4)3H-one 2,2-dioxide) and glyphosate (N-(phosphonomethyl)glycine) was evaluated in greenhouse and growth chamber studies. Yellow nutsedge tubers collected in East Lansing, Michigan were sprouted at 21 C and then transplanted into soil for the herbicide treatments under various environmental conditions. The higher light intensity (48.4 klux) increased the activity of glyphosate at 1.1 and 2.2 kg/ha. In contrast, bentazon at 2.2 kg/ha caused more injury to yellow nutsedge under the low light intensity (16.1 klux) than under a higher light intensity. Bentazon and glyphosate were more effective under high soil moisture (field capacity) than under low soil moisture conditions. Injury to yellow nutsedge plants 7.6 cm tall increased as the temperature decreased from 35 C to 15 C. If the plants were 30.5 cm tall, greatest injury with bentazon was obtained at 25 C. Glyphosate at 2.2 kg/ha controlled yellow nutsedge 7.6 cm tall grown at 15, 25, and 35 C. But when the plants were 30.5 cm tall at time of treatment, glyphosate at 2.2 kg/ha provided control only of plants grown at 25 and 35 C.

Bentazon was more effective than glyphosate in killing yellow nutsedge tubers.

Introduction

Bentazon, a selective postemergence herbicide for corn (Zea mays L.) and soybean, (Glycine max (L.) Merr.) has shown potential for yellow nutsedge control (1,5,6,11). Occasionally the control has been erratic (12). Temperature, humidity, simulated rainfall, and oil additives have been reported (7) to influence bentazon activity on redroot pigweed (Amaranthus retroflexus L.).

Glyphosate, a non-selective postemergence herbicide has also been reported to control yellow nutsedge (3,9). The activity of glyphosate on purple nutsedge (Cyperus rotundus L.) increased when applied at 100 percent relative humidity and to plants grown at 25 C rather than 35 C (13). Thus, glyphosate activity may also be affected by environmental factors.

The purpose of this research was to determine the influence of light intensity, soil moisture, and temperature on yellow nutsedge control with bentazon and glyphosate.

Materials and Methods

Yellow nutsedge tubers collected in East Lansing, Michigan, were placed in petri dishes to sprout in a controlled environment chamber at 21 C. After tubers had sprouted, plants selected for uniformity of shoot length were transplanted to 946-ml cups containing a greenhouse soil mix.

Three tubers with shoots were planted per cup for the light intensity and soil moisture studies and four tubers per cup for the temperature study. For the light intensity study, the yellow nutsedge plants were placed in the greenhouse and shaded to receive 16.1 klux and 48.4 klux of light intensity at full daylight and the temperature maintained at 25 $\pm$ 3 C during the months of March and May. The higher light intensity (48.4 klux) treatment received supplementary fluorescent lighting. The herbicide treatments were applied when the plants were 15.2 cm tall. The experiments were a randomized complete block with a two-way factorial design and replicated four times. The cups of plants were randomized within blocks every 2 or 3 days.

In the soil moisture experiment, the transplanted yellow nutsedge was grown in the greenhouse at 25 $\pm$ 3 C with supplemental fluorescent lighting. For high soil moisture treatments the plants received 200 ml of water per 946-ml cup daily, whereas those grown under low soil moisture received only 20 ml per cup when they began to wilt. The herbicide treatments were applied when the plants were 15.2 cm tall. The experiments were randomized complete block with a two-way factorial arrangement and replicated four times. The cups of plants were randomized within blocks every 2 or 3 days.

For the temperature experiment, the yellow nutsedge plants were grown in growth chambers with subirrigation. The temperature treatments were held constant at 15, 25, and 35 C during day and night. Fluorescent and incandescent lighting provided 12.9 klux for the 14-hr day length. Plants 7.6 and 30.5 cm tall received the herbicide treatments. The experiments were a completely randomized design with a two-way factorial arrangement and replicated three times.

In all experiments bentazon and glyphosate were applied postemergence at the rate of 1.1 and 2.2 kg/ha at 346 L/ha. Bentazon was applied with 0.25% of an alkyl-aryl-polyglycol ether[1] surfactant. For all experiments, the plants were returned to the original temperature, light intensity, and soil moisture after herbicide application. Thirty days after herbicides were applied, visual injury to yellow nutsedge was rated, plant height was measured, and the plants were harvested for dry weight and determination of tuber viability.

All experiments were repeated and all data presented are the means of two experiments with three or four replications each.

Results and Discussion

Bentazon at 2.2 kg/ha was more active on yellow nutsedge grown under 16.1 klux than under 48.4 klux (Table 1). The effect was evident for plant density, height, and percent of parent tubers which rotted at the 2.2 kg/ha rate but not at the 1.1 ka/ha rate. Plants grown under high light intensity may have thicker cuticles than plants grown under low light intensity (4) and thus absorb less bentazon. Light quality or amount of ultraviolet light may also affect cuticle development (4).

In contrast to bentazon, glyphosate was more active on yellow nutsedge grown under 48.4 klux than 16.1 klux at both 1.1 and 2.2 kg/ha rates (Table 1). The effect was most evident on plant height. The glyphosate formulation contained isopropyl amine salt (15) which may increase

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[1]This surfactant is known commercially as Citowett, a product of BASF Wyandotte Corp.

absorption and decrease the barrier presented by the cuticle of plants grown under high light intensity. Light may also be necessary for the manifestation of the phytotoxic action of glyphosate similar to that observed for the triazine herbicides (8).

Under higher soil moisture conditions bentazon at 1.1 kg/ha provided adequate control of yellow nutsedge by reducing stand density, plant height, and number of viable tubers (Table 2). Increasing the application rate to 2.2 kg/ha did not increase the visual injury rating above the 1.1 kg/ha rate under high soil moisture conditions. Under low soil moisture conditions neither rate provided adequate yellow nutsedge control. Bentazon has also been shown to be more toxic to common cocklebur (Xanthium pensylvanicum Wallr.) grown in wet soil at field capacity than in the dry soil near the wilting point (14). The translocation of ^{14}C-bentazon was rapid in common cocklebur grown in wet soil (14). Greater activity of glyphosate on yellow nutsedge was also apparent under high soil moisture conditions (Table 2). Under water stress the cuticle may be less hydrated, reducing absorption of polar materials (2).

Bentazon, especially at 2.2 kg/ha, showed greater phytotoxicity to yellow nutsedge 7.6 cm tall as temperature decreased from 35 to 15 C (Table 3). This was evident for all parameters measured. Yellow nutsedge showed optimum growth at 25 C (Table 3). High temperatures may encourage thickner cuticle formation and ecrease permeability. Lower temperatures may prolong drying time, promoting foliar absorption. Low temperature (10 C) and high humidity also increased redroot pigweed control with bentazon (7). If the yellow nutsedge was 30.5 cm tall when treated with bentazon at 2.2 kg/ha, greater visual injury was obtained

at 25 C (Table 3).

Temperature had little effect on injury to yellow nutsedge 7.6 cm tall by 2.2 kg/ha of glyphosate (Table 4). At this rate glyphosate was highly effective at all three temperatures, 15, 25, and 35 C. However, if the yellow nutsedge plants were 30.5 cm tall, glyphosate was more injurious at 25 and 35 C than at 15 C (Table 4).

Yellow nutsedge injury due to bentazon was greatest at low light intensity, high soil moisture, at 15 C for 7.6 cm tall plants and at 25 C for 30.5 cm tall plants. Glyphosate activity was greatest at the high light intensity, high soil moisture, and 25 and 35 C when plants were 30 cm tall. Plants 7.6 cm tall were controlled about equally well with glyphosate in the temperature range of 15 to 35 C.

Literature Cited

1. Andersen, R.N., W.E. Lueschen, D.D. Warnes, and W.W. Nelson. 1974. Controlling broadleaf weeds in soybeans with bentazon in Minnesota. Weed Sci. 22:136-142.

2. Ashton, F.M. and A.S. Crafts. 1973. Mode of action of herbicides. John Wiley and Sons, Inc. 504 pp.

3. Boldt, P.F. and R.D. Sweet. 1974. Glyphosate studies on yellow nutsedge. Proc. Northeast. Weed Sci. Soc. 28:197-204.

4. Davis, D.G. 1978. Cuticle development on Citrus mitis leaves as a function of light quality and intensity. Weed Sci. Soc. of Amer. Abstr. No. 171.

5. Kapusta, G. and J.A. Tweedy. 1973. Yellow nutsedge control in soybean. Res. Rpt. North Centr. Weed Contr. Conf. 30:108 and 110-111.

6. Ladlie, J.S., W.F. Meggitt, and R.C. Bond. 1973. Preplant incorporated, preemergence and postemergence application on yellow nutsedge in soybeans. Res. Rpt. North Centr. Weed Contr. Conf. 30: 112-113.

7. Nalewaja, J.D., J. Pudelko, and K.A. Adamczewski. 1975. Influence of climate and additives on bentazon. Weed Sci. 23:504-507.

8. Shimabukuro, R.H., V.J. Masteller, and W.C. Walsh. 1976. Atrazine injury: relationship to metabolism, substrate level, and secondary factors. Weed Sci. 24:336-340.

9. Stoller, E.W., L.M. Wax, and R.L. Matthiesen. 1975. Response of yellow nutsedge and soybeans to bentazon, glyphosate and perfluidone. Weed Sci. 23:215-221.

10. Suwanketnikom, R. and D. Penner. 1976. Environmental influence on yellow nutsedge control with bentazon and glyphosate. Proc. North Centr. Weed Contr. Conf. 31:141.

11. Tweedy, J.A., G. Kapusta, and O. Kale. 1972. The effect of several herbicides on nutsedge control in soybeans. Proc. North Centr. Weed Contr. Conf. 27:28-29.

12. Wax, L.M. 1975. Control of yellow nutsedge in field crops. Proc. North Centr. Weed Contr. Conf. 30:125-128.

13. Wills, G.D. 1974. Effect of temperature, relative humidity, soil moisture and surfactant on the toxicity of glyphosate to cotton and purple nutsedge. Weed Sci. Soc. of Amer. Abstr. No. 275.

14. Wills, G.D. 1976. Translocation of bentazon in soybean and common cocklebur. Weed Sci. 24:536-540.

15. Weed Science Society of America. 1974. Herbicide Handbook. Champaign, IL. 430 pp.

Table 1. The effect of light intensity on bentazon and glyphosate activity on yellow nutsedge 15.2 cm tall measured 30 days following treatment.

Herbicides	Rate (kg/ha)	Visual injury rating[a] 16.1 klux	Visual injury rating[a] 48.4 klux	Density (shoots/cup) 16.1 klux	Density (shoots/cup) 48.4 klux	Plant ht (cm/plant) 16.1 klux	Plant ht (cm/plant) 48.4 klux	Dry wt (gm/plant system) 16.1 klux	Dry wt (gm/plant system) 48.4 klux	Parent tubers that rotted (%) 16.1 klux	Parent tubers that rotted (%) 48.4 klux
Bentazon	0	0.0 a[b]	0.0 a	6.0 d	6.2 d	40.6 e	32.4 d	1.6 c	1.7 c	0 a	0 a
	1.1	3.7 b	3.6 b	3.1 bc	5.0 cd	21.6 c	18.1 c	0.4 ab	0.9 b	37 b	23 b
	2.2	9.4 d	6.1 c	0.4 a	2.7 b	2.5 a	10.9 b	0.3 a	0.7 ab	100 d	70 c
Glyphosate	0	0.0 a	0.0 a	4.5 ab	8.0 b	40.8 d	33.7 c	1.5 c	2.5 d	0 a	0 a
	1.1	3.0 b	6.5 d	6.5 b	6.7 b	27.7 b	9.5 a	1.0 bc	0.2 a	3 ab	13 bc
	2.2	5.0 c	9.0 e	4.5 ab	2.1 a	23.0 b	4.5 a	0.7 ab	0.2 a	20 c	3 ab

[a]Control ratings were on a 0 to 10 scale; 0 = no injury, 10 = death.

[b]Means within a given herbicide for a givem parameter with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 2. The effect of soil moisture on bentazon and glyphosate activity on yellow nutsedge 15.2 cm tall measured 30 days following treatment.

Treatment	Rate (kg/ha)	Visual injury rating[a]		Density (shoots/cup)		Plant ht (cm/plant)		Dry wt (gm/plant system)		Parent tubers that rotted (%)	
		low moisture	high moisture	low moisture	high moisture	low moisture	high moisture	low moisture	high moisture	low moisture	high moisture
Bentazon	0	0.0 a[b]	0.0 a	7.0 c	11.2 d	19.2 b	41.4 c	1.1 b	3.8 c	0 a	0 a
	1.1	2.4 b	8.7 d	6.0 bc	1.2 a	16.9 b	4.2 a	0.9 ab	0.6 a	50 b	100 d
	2.2	4.5 c	9.2 d	4.7 b	1.0 a	15.2 b	5.5 a	0.9 ab	0.6 a	73 c	100 d
Glyphosate	0	0.0 a	0.0 a	7.8 ab	9.7 bc	18.0 a	41.1 c	1.4 a	3.9 c	0 a	0 a
	1.1	1.5 b	2.0 b	6.4 a	11.1 c	14.5 a	31.8 b	1.1 a	2.4 b	0 a	0 a
	2.2	1.6 b	4.0 c	7.9 ab	6.8 a	17.6 a	20.7 a	1.2 a	1.7 ab	13 a	0 a

[a]Control ratings were on a 0 to 10 scale, 0 = injury, 10 = death.

[b]Means within a given herbicide for a given parameter with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 3. The effect of temperature on bentazon activity on yellow nutsedge 7.6 and 30.5 cm tall measured 30 days following treatment.

Plant ht (cm)	Bentazon rate (kg/ha)	Visual injury rating[a]			Stand density (shoots/cup)			Plant ht (cm/plant)			Dry wt (gm/plant system)			Parent tuber that rotted (%)		
		15 C	25 C	35 C	15 C	25 C	35 C	15 C	25 C	35 C	15 C	25 C	35 C	15 C	25 C	35 C
7.6	0	0.0 a[b]	0.0 a	0.0 a	4.8 d	9.7 g	8.2 f	28.5 cd	43.7 f	35.0 de	1.0 c	4.6 g	3.2 f	0 a	0 a	0 a
	1.1	6.8 de	4.3 b	2.3 b	1.2 b	6.2 b	6.7 e	11.5 b	38.7 ef	34.3 cde	0.4 a	2.2 e	2.2 e	62 d	42 c	32 b
	2.2	8.8 f	7.3 e	6.5 d	0.5 a	2.5 c	5.0 d	3.0 a	26.7 c	34.7 cde	0.4 a	0.7 b	1.7 d	88 f	88 f	75 e
30.5	0	0.0 a	0.0 a	0.0 a	4.2 b	10.2 e	8.2 d	35.7 bcd	46.5 d	40.8 cd	1.4 b	4.8 e	3.1 d	0 a	0 a	0 a
	1.1	1.5 b	1.3 b	3.8 d	4.0 b	8.2 d	5.3 c	25.3 ab	33.2 bc	30.7 bc	0.8 a	1.8 c	1.8 c	25 b	38 c	63 e
	2.2	2.8 c	7.5 f	6.2 e	4.7 bc	2.0 a	4.5 bc	25.83ab	14.5 a	28.8 bc	1.1 b	0.7 a	1.3 b	50 d	80 f	75 f

[a]Control ratings were on a 0 to 10 scale, 0 = no injury, 10 = death.

[b]Means within each plant height and a given parameter with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 3. The effect of temperature on bentazon activity on yellow nutsedge 7.6 and 30.5 cm tall measured 30 days following treatment.

Plant ht (cm)	Bentazon rate (kg/ha)	Visual injury rating[a]			Stand density (shoots/cup)			Plant ht (cm/plant)			Dry wt (gm/plant system)			Parent tuber that rotted (%)		
		15 C	25 C	35 C	15 C	25 C	35 C	15 C	25 C	35 C	15 C	25 C	35 C	15 C	25 C	35 C
7.6	0	0.0 a[b]	0.0 a	0.0 a	4.8 d	9.7 g	8.2 f	28.5 cd	43.7 f	35.0 de	1.0 c	4.6 g	3.2 f	0 a	0 a	0 a
	1.1	6.8 de	4.3 b	2.3 b	1.2 b	6.2 b	6.7 e	11.5 b	38.7 ef	34.3 cde	0.4 a	2.2 e	2.2 e	62 d	42 c	32 b
	2.2	8.8 f	7.3 e	6.5 d	0.5 a	2.5 c	5.0 d	3.0 a	26.7 c	34.7 cde	0.4 a	0.7 b	1.7 d	88 f	88 f	75 e
30.5	0	0.0 a	0.0 a	0.0 a	4.2 b	10.2 e	8.2 d	35.7 bcd	46.5 d	40.8 cd	1.4 b	4.8 e	3.1 d	0 a	0 a	0 a
	1.1	1.5 b	1.3 b	3.8 d	4.0 b	8.2 d	5.3 c	25.3 ab	33.2 bc	30.7 bc	0.8 a	1.8 c	1.8 c	25 b	38 c	63 e
	2.2	2.8 c	7.5 f	6.2 e	4.7 bc	2.0 a	4.5 bc	25.83ab	14.5 a	28.8 bc	1.1 b	0.7 a	1.3 b	50 d	80 f	75 f

[a]Control ratings were on a 0 to 10 scale, 0 = no injury, 10 = death.

[b]Means within each plant height and a given parameter with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 4. The effect of temperature on glyphosate activity on yellow nutsedge 7.6 and 30.5 cm tall measured 30 days following treatment.

Plant ht (cm)	Glyphosate rate (kg/ha)	Visual injury rating[a]			Stand density (shoots/cup)			Plant ht (cm/plant)			Dry wt (gm/plant system)			Parent tubers that rotted (%)		
		15 C	25 C	35 C	15 C	25 C	35 C	15 C	25 C	35 C	15 C	25 C	35 C	15 C	25 C	35 C
7.6	0	0.0 a[b]	0.0 a	0.0 a	4.3 c	9.0 d	8.5 d	27.5 c	43.1 e	38.3 d	0.7 d	4.5 e	3.9 f	0 a	0 a	0 a
	1.1	4.5 b	4.3 b	4.5 b	3.3 b	8.7 d	11.3 e	7.3 b	8.2 b	28.5 c	0.2 ab	0.5 cd	0.4 bc	5 a	5 a	18 b
	2.2	9.8 d	9.3 c	9.5 cd	0.3 a	0.0 a	0.7 a	1.0 a	0.0 a	0.3 a	0.2 ab	0.2 ab	0.1 a	0 a	5 a	18 b
30.5	0	0.0 a	0.0 a	0.0 a	4.3 c	8.2 e	8.0 e	32.3 d	50.0 e	44.2 e	1.1 a	4.0 g	3.4 f	0 a	0 a	0 a
	1.1	0.0 a	3.7 ab	2.0 ab	4.7 c	5.5 d	15.8 f	31.0 d	23.8 bc	28.7 cd	1.5 c	2.2 e	2.0 e	5 ab	13 bc	13 bc
	2.2	0.0 a	7.5 b	6.5 b	4.5 c	3.3 b	2.2 a	26.9 cd	11.5 a	18.5 b	1.3 ab	1.8 d	1.4 bc	8 bc	30 c	8 bc

[a]Control ratings were on a 0 to 10 scale, 0 = no injury, 10 = death.

[b]Means within each plant height and a given parameter with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

CHAPTER 4

ADDITIVES TO INCREASE BENTAZON AND GLYPHOSATE ACTIVITY ON YELLOW NUTSEDGE (*CYPERUS ESCULENTUS*)

Abstract

2,4-D ((2,4-dichlorophenoxy)acetic acid), ethephon (2-chloroethylphosphonic acid), urea, and numerous ammonium salts were evaluated for increasing the postemergence activity of low rates of bentazon (3-isopropyl-1*H*-2,1,3-benzothiadiazin-(4)3*H*-one 2,2-dioxide) and glyphosate (*N*-(phosphonomethyl)glycine on yellow nutsedge (*Cyperus esculentus* L.). Yellow nutsedge tubers collected at East Lansing, Michigan, were sprouted at 21 C and transplanted into soil in the greenhouse. Bentazon and glyphosate were applied at 1.1 kg/ha, alone and in combination with 2,4-D or ethephon at 1.1 or 2.2 kg/ha or with urea or ammonium salts at 4.5 and 9 kg/ha, when the plants were 15 cm tall. After 30 days, the plants were rated for visual herbicide injury, the shoots per cup counted, and plant height and dry weight measured. Ammonium phosphate, ammonium chloride, ammonium sulfate, and ammonium thiocyanate in combination with bentazon significantly increased the injury ratings, reduced the stand density, plant height, and dry weight of shoots when compared to bentazon alone. All additives evaluated increased glyphosate activity as indicated by increased yellow nutsedge injury rating primarily by reducing the stand density compared to glyphosate alone. Varying the pH of the

spray solution from 3 to 11 did not affect bentazon or glyphosate activity.

Introduction

Phytobland oils and organic surfactants have often been used as spray additives for postemergence herbicide applications. However, inorganic salts can also be used as additives to increase herbicide activity. Amitrol-T, the combination of amitrol (3-amino-s-triazole) and ammonium thiocyanate has become a commercial product (13). Ammonium sulfate has been reported to increase the activity of picloram (4-amino-3,5,6-trichloropicolinic acid) (15), endothal (7-oxabicyclo(2.2.1)heptane-2,3-dicarboxylic acid) and DNOC (4,6-dinitro-o-cresol) (1).

Less than optimum yellow nutsedge control with bentazon and glyphosate occurs if the plants are too tall, over 15 cm, or under low soil moisture conditions (11,12). Suwunnamek and Parker (10) reported increased purple nutsedge (Cyperus rotundus L.) control with glyphosate upon addition of ammonium sulfate to the spray solution. Butyl acid phosphate and ammonium sulfate have been reported to increase glyphosate efficacy for quackgrass (Agropyron repens (L.) Beauv.) control (3).

The objective of this research was to evaluate potential additives to increase the activity of bentazon and glyphosate on yellow nutsedge.

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The objective of this research was to evaluate potential additives to increase the activity of bentazon and glyphosate on yellow nutsedge.

Materials and Methods

Yellow nutsedge tubers collected in East Lansing, Michigan, were washed with water and placed in petri dishes to sprout in a controlled environment chamber at 21 C. After sprouting, tubers with similar shoot length were transplanted, one per cup, to 946-ml cups containing greenhouse soil. The plants were grown to 15 cm in height in the greenhouse at 25 $\pm$ 2 C with supplemental fluorescent lighting. Bentazon and glyphosate were applied at 1.1 kg/ha at 346 L/ha. An alkyl-aryl-polyglycol ether[1] surfactant at 0.25% v/v was applied applied with the bentazon. Glyphosate was applied as the formulated isopropylamine salt. 2,4-D and ethephon were applied at 1.1 and 2.2 kg/ha. All ammonium salts were applied at 4.5 and 9 kg/ha. After the ammonium salts were mixed with bentazon and glyphosate, the solution pH was measured. To determine the effect of pH on the spray solution, the pH of 1.1 kg/ha bentazon and glyphosate solutions were adjusted with HCl and KOH. Thirty days after treatment the plants were rated for visual injury, the stand density in the cup determined, plant height and dry weight determined.

All data presented are the means of two experiments with three replications per experiment.

Results and Discussion

2,4-D at 1.1 and 2.2 kg/ha failed to increase the activity of bentazon applied to yellow nutsedge 15 cm tall (Table 1). Ethephon at

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[1]This surfactant is known commercially as Citowett, a product of BASF Wyandotte Corp.

1.1 kg/ha applied in combination with bentazon at 1.1 kg/ha resulted in greater stunting than either treatment alone (Table 1). Urea and ammonium acetate at 4.5 and 9 kg/ha had little or no effect on bentazon activity (Tables 1 and 2). In contrast, ammonium chloride, ammonium phosphate, ammonium sulfate, and ammonium thiocyanate at 4.5 and 9 kg/ha markedly increased bentazon phytotoxicity to yellow nutsedge (Table 2).

A single application of bentazon at 1.1 kg/ha did not provide adequate control of yellow nutsedge 15.0 cm tall in the greenhouse as previously reported field results (11). But in combination with ammonium salts, bentazon activity was greatly enhanced. The visual injury rating increased whereas the number of shoots per cup, plant height, and dry weight of shoots per cup decreased.

Nash (8) has proposed three possible site of pesticide interactions: (a) altered penetration at the site of absorption, (b) one pesticide affecting a primary metabolic pathway and the other secondary pathway, and (c) both pesticides affecting the same metabolic pathway and possibly ammonium salts could affect bentazon absorption, translocation, or act at a different or the same site of action as bentazon. Wilson and Nishimoto (16) reported that ammonium chloride, ammonium nitrate, ammonium phosphate, and ammonium sulfate increased absorption of ^{14}C-picloram by guava (Psidium cattleianum Sabine) leaves and indicated that the ammonium ion was primarily responsible for the enhancement effect.

Monovalent cations increase the permeability of tritiated water by citrus leaf cuticular membranes (9). The permeability increased in the order $Li^+ < Na^+ < K^+ < Rb^+ = NH_4^+$ (9). Thus ammonium salts may act on the cuticular membrane of yellow nutsedge and allow greater penetration of bentazon into the leaves.

It has also been reported (15) that ammonium sulfate reduces the pH of picloram spray solution from pH 10 to 7.4, picloram activity and absorption was increased by guava (15). As shown in Table 2, the pH of the spray solution was influenced by the ammonium salts. Adjusting the pH of the spray solution in pH unit increments from pH 3 to 11 showed no effect on bentazon activity (Table 3). Thus the effect of the additives evaluated was not mediated through changes in pH of the spray solution.

Ammonium ions and bentazon may act at different sites of action, but caused greater injury to yellow nutsedge than either one alone. Good and Izawa (6) reported that ammonium ions and methyl amine prevented phosphorylation and increased the rate of electron flow from plastoquinone to photosystem I. However, Boger et al. (4) observed that bentazon inhibited electron flow at photosystem II.

It is also possible that ammonium ion and bentazon may act at the same site of action and cause more injury than either one alone. Weissman (14) reported that ammonium ions received from the roots of soybean and sunflower suppressed both nitrate and nitrite reductase in the leaves of these plants. Bentazon has been reported (7) to block nitrite reduction and cause nitrite accumulation in wheat leaves. Thus, ammonium salts in combination with bentazon may cause more nitrite accumulation in yellow nutsedge leaf than either one alone, although the phytotoxicity of the nitrite is equivocal.

Ethephon at 1.1 and 2.2 kg/ha in combination with 1.1 kg/ha of glyphosate increased visual injury to yellow nutsedge compared to glyphosate alone (Table 4). The effect appeared to be primarily in reducing stand density. Ethylene released from ethephon can alter metabolic

source-sink relationship (2). The translocation of glyphosate follows typical source-sink relationship (5). The greater activity of the combination could result from increased glyphosate translocated to the basal bulb, roots, rhizomes and parent tuber resulting in reduced stand density of yellow nutsedge.

Urea or 2,4-D combinations with glyphosate, reduced stand density (Table 4). Urea and 2,4-D have also been shown to increase glyphosate activity on purple nutsedge (10).

Glyphosate activity was enhanced with all of the ammonium salts evaluated (Table 5). However, the high rate of ammonium thiocyanate, 9 kg/ha, did not increase the activity of glyphosate (Table 5). Glyphosate has a very different chemical structure, and possibly mode of action from bentazon. The effect of ammonium salts on glyphosate activity may or may not act at the same site of bentazon activity. Suwunnamek and Parker (10) concluded that ammonium sulfate may have effected glyphosate activity inside the plant, but not at the site of uptake. Since ammonium sulfate applied 1 day after glyphosate was applied, ammonium sulfate still increased glyphosate activity on purple nutsedge (10).

Adjusting the pH of the spray solution in 1 pH unit increments from pH 3 to 11 had no effect on glyphosate activity (Table 6).

In summary, all ammonium salts evaluated, except for ammonium acetate, increased the activity of bentazon for yellow nutsedge. This was evident both in reduced stand density and plant size. All additives evaluated increased the activity of glyphosate for yellow nutsedge. This effect was primarily in reducing stand density.

Literature Cited

1. Ashton, F.M. and A.S. Crafts. 1973. Mode of action of herbicides. John Wiley and Sons, Inc. 504 pp.

2. Binning, L.K., D. Penner, and W.F. Meggitt. 1971. The effect of 2-chloroethyl phosphonic acid on dicamba translocation in wild garlic. Weed Sci. 19:73-75.

3. Blair, A.M. 1975. The addition of ammonium salts or a phosphate ester to herbicides to control Agropyron repens. Weed Res. 15:101-105.

4. Boger, P., B. Beese, and R. Miller. 1977. Long-term effects of herbicides on the photosynthesic apparatus: an investigation on bentazon inhibition. Weed Res. 17:61-67.

5. Fernandez, C.H. and D.E. Bayer. 1977. Penetration, translocation and toxicity of glyphosate in Bermuda grass (Cynodon dactylon). Weed Sci. 25:396-400.

6. Good, N.E. and S. Izawa. 1973. Uncoupling and energy transfer inhibition in phosphorylation. (In Current Topics in Bioenergetics, Edited by D.R. Sanadi.) Vol. 1. Academic Press, New York. 292 pp.

7. Klepper, L.A. 1975. Inhibition of nitrite reduction by photosynthesic inhibitor. Weed Sci. 23:188-190.

8. Nash, R.G. 1968. Synergistic phytotoxicities of herbicide-insecticide combination in soil. Weed Sci. 16:74-77.

9. Schonherr, J. 1976. Water permeability of isolate cuticular membrane: the effect of pH and cation on diffusion, hydrodynamic permeability and size of polar pores in the cutin matrix. Panta 128:113-126.

10. Suwunnamek, U. and C. Parker. 1975. Control of Cyperus rotundus with glyphosate: the influence of ammonium sulfate and other additives. Weed Res. 15:13-19.

11. Suwanketnikom, R. and D. Penner. 1975. Yellow nutsedge control with bentazon and glyphosate. Proc. North Centr. Weed Contr. Conf. 30:115.

12. Suwanketnikom, R. and D. Penner. 1976. Environmental influence on yellow nutsedge control with bentazon and glyphosate. Proc. North Centr. Weed Contr. Conf. 31:141.

13. Weed Science Society of America. 1974. Herbicide Handbook. Champaign, IL 430 pp.

14. Weissman, G.S. 1972. Influence of ammonium and nitrate nutrition on enzymatic activity in soybean and sunflower. Plant Physiol. 49: 138-141.

15. Wilson, B.J. and R.K. Nishimoto. 1975. Ammonium sulfate enhancement of picloram activity and absorption. Weed Sci. 23:289-296.

16. Wilson, B.J. and R.K. Nishimoto. 1975. Ammonium sulfate enhancement of picloram absorption by detached leaves. Weed Sci. 23:297-301.

14. Weissman, G.S. 1972. Influence of ammonium and nitrate nutrition on enzymatic activity in soybean and sunflower. Plant Physiol. 49: 138-141.

15. Wilson, B.J. and R.K. Nishimoto. 1975. Ammonium sulfate enhancement of picloram activity and absorption. Weed Sci. 23:289-296.

16. Wilson, B.J. and R.K. Nishimoto. 1975. Ammonium sulfate enhancement of picloram absorption by detached leaves. Weed Sci. 23:297-301.

Table 1. Control of yellow nutsedge 15 cm tall with postemergence application of bentazon plus 2,4-D, ethephon, or urea.

Additive	Rate (kg/ha)	Bentazon rate (kg/ha)	Visual injury rating after 30 days[a]	Density (shoots/cup)	Plant ht (cm/plant)	Dry wt (gm/plant system)
2,4-D	0	0	0.0 a[b]	9.5 b	41.8 c	2.92 b
	0	1.1	0.5 a	7.3 ab	40.7 bc	1.48 a
	1.1	0	0.0 a	7.0 ab	36.0 abc	1.47 a
	2.2	0	0.2 a	6.0 a	31.3 a	1.05 a
	1.1	1.1	0.2 a	6.2 ab	32.5 ab	1.22 a
	2.2	1.1	0.3 a	7.7 ab	33.7 abc	1.37 a
Ethephon	0	0	0.0 a	9.5 b	41.8 bc	2.32 b
	0	1.1	0.5 a	7.3 ab	40.7 bc	1.48 a
	1.1	0	0.0 a	8.2 ab	46.7 c	2.56 b
	2.2	0	0.3 a	6.0 a	36.5 ab	1.45 a
	1.1	1.1	0.7 a	5.2 a	32.5 a	0.74 a
	2.2	1.1	1.2 a	5.5 a	31.5 a	0.82 a
Urea	0	0	0.0 a	9.5 b	41.8 ab	2.32 d
	0	1.1	0.5 a	7.3 ab	40.6 ab	1.48 bc
	4.5	0	0.0 a	6.8 ab	43.3 b	1.84 cd
	9.0	0	0.0 a	7.5 ab	42.5 b	1.54 c
	4.5	1.1	2.2 a	4.3 a	28.5 a	0.55 a
	9.0	1.1	2.2 a	5.5 a	28.0 a	0.82 ab

[a]Ratings were on a 0 to 10 scale, 0 = no injury, 10 = death.

[b]Means within columns for a given additive with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 2. Control of yellow nutsedge 15 cm tall with postemergence application of bentazon plus various ammonium salts.

Ammonium salts	Rate (kg/ha)	Bentazon rate (kg/ha)	pH of spray solution	Visual injury rating after 30 days[a]	Density (shoots/cup)	Plant ht (cm/plant)	Dry wt (gm/plant system)
Ammonium acetate	0	0		0.0 a[b]	9.5 a	42.2 a	2.32 c
	0	1.1	5.1	0.5 a	7.3 a	40.7 a	1.48 ab
	4.5	0	7.1	0.0 a	6.5 a	44.3 a	1.77 bc
	9.0	0	6.7	0.0 a	6.7 a	45.2 a	1.97 bc
	4.5	1.1	7.0	0.2 a	6.0 a	35.3 a	0.94 a
	9.0	1.1	7.2	2.0 a	6.0 a	34.3 a	1.20 ab
Ammonium chloride	0	0		0.0 a	9.5 b	41.8 b	2.32 b
	0	1.1	5.1	0.5 a	7.3 b	40.7 b	1.48 b
	4.5	0	5.9	0.0 a	7.2 b	44.3 b	1.80 b
	9.0	0	5.6	0.0 a	8.5 b	45.3 b	2.09 b
	4.5	1.1	4.8	7.0 b	2.0 a	9.8 a	0.31 a
	9.0	1.1	5.1	9.0 c	1.8 a	5.7 a	0.21 a
Ammonium phosphate	0	0		0.0 a	9.5 c	41.8 b	2.32 c
	0	1.1	5.1	0.5 a	7.3 bc	40.7 b	1.48 b
	4.5	0	5.0	0.0 a	7.8 bc	46.7 b	2.18 c
	9.0	0	4.9	0.0 a	6.3 b	46.7 b	1.74 bc
	4.5	1.1	5.0	5.3 b	2.5 a	16.3 a	0.41 a
	9.0	1.1	5.0	5.8 b	2.5 a	15.0 a	0.37 a
Ammonium sulfate	0	0		0.0 a	9.5 c	41.8 cd	2.32 c
	0	1.1	5.1	0.5 a	7.3 c	40.7 c	1.48 b
	4.5	0	5.7	0.0 a	7.5 c	48.8 d	2.48 c
	9.0	0	5.8	0.0 a	8.8 c	49.3 d	2.61 c
	4.5	1.1	5.1	2.8 b	4.0 b	20.8 d	0.46 a
	9.0	1.1	5.0	9.7 c	0.5 a	1.3 a	0.17 a
Ammonium thiocyanate	0	0		0.0 a	9.5 c	41.8 b	2.32 c
	0	1.1	5.1	0.5 a	7.3 b	40.7 b	1.48 b
	4.5	0	6.2	0.0 a	6.8 b	47.5 b	2.12 bc
	9.0	0	5.9	0.0 a	7.3 bc	39.5 a	2.00 bc
	4.5	1.1	5.0	8.5 b	0.7 a	5.0 a	0.22 a
	9.0	1.1	4.9	9.5 b	0.5 a	1.5 a	0.20 a

[a]Ratings were on a 0 to 10 scale, 0 = no injury, 10 = death.

[b]Means within columns for a given ammonium salt with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 3. The effect of pH on control of yellow nutsedge 15 cm tall with bentazon.

Bentazon rate (kg/ha)	pH of solution	Visual injury rating after 30 days[a]	Density (shoots/cup)	Plant ht (cm/plant)	Dry wt (gm/plant system)
0		0.0 a[b]	5.5 a	38.3 a	2.38 c
1.1	no adjust (5.1)	0.0 a	3.8 a	28.6 a	0.63 ab
1.1	3	3.3 a	3.7 a	21.0 a	0.63 ab
1.1	4	1.7 a	3.7 a	23.8 a	0.47 a
1.1	5	0.0 a	4.2 a	28.2 a	0.60 ab
1.1	6	1.7 a	2.8 a	23.3 a	0.66 ab
1.1	7	0.0 a	3.8 a	27.7 a	0.50 ab
1.1	8	0.0 a	2.7 a	29.2 a	0.62 ab
1.1	9	1.7 a	2.0 a	23.2 a	0.44 a
1.1	10	0.0 a	5.3 a	30.0 a	1.13 b
1.1	11	3.3 a	3.3 a	23.0 a	0.56 ab

[a]Ratings were on a 0 to 10 scale, 0 = no injury, 10 = death.

[b]Means within columns with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 3. The effect of pH on control of yellow nutsedge 15 cm tall with bentazon.

Bentazon rate (kg/ha)	pH of solution	Visual injury rating after 30 days[a]	Density (shoots/cup)	Plant ht (cm/plant)	Dry wt (gm/plant system)
0		0.0 a[b]	5.5 a	38.3 a	2.38 c
1.1	no adjust (5.1)	0.0 a	3.8 a	28.6 a	0.63 ab
1.1	3	3.3 a	3.7 a	21.0 a	0.63 ab
1.1	4	1.7 a	3.7 a	23.8 a	0.47 a
1.1	5	0.0 a	4.2 a	28.2 a	0.60 ab
1.1	6	1.7 a	2.8 a	23.3 a	0.66 ab
1.1	7	0.0 a	3.8 a	27.7 a	0.50 ab
1.1	8	0.0 a	2.7 a	29.2 a	0.62 ab
1.1	9	1.7 a	2.0 a	23.2 a	0.44 a
1.1	10	0.0 a	5.3 a	30.0 a	1.13 b
1.1	11	3.3 a	3.3 a	23.0 a	0.56 ab

[a]Ratings were on a 0 to 10 scale, 0 = no injury, 10 = death.

[b]Means within columns with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 4. Control of yellow nutsedge 15 cm tall with postemergence application of glyphosate plus 2,4-D, ethephon, or urea.

Additive	Rate (kg/ha)	Glyphosate rate (kg/ha)	Visual injury rating after 30 days[a]	Density (shoots/cup)	Plant ht (cm/plant)	Dry wt (gm/plant system)
2,4-D	0	0	0.0 a[b]	8.5 bc	43.5 c	2.02 d
	0	1.1	3.2 bc	9.8 c	20.2 a	0.65 ab
	1.1	0	0.3 ab	6.2 b	29.3 b	1.09 c
	2.2	0	0.5 ab	6.0 b	27.2 b	0.92 bc
	1.1	1.1	4.2 c	3.3 a	19.2 a	0.48 a
	2.2	1.1	4.2 c	3.2 a	19.6 a	0.65 ab
Ethephon	0	0	0.0 a	8.5 b	43.6 b	2.02 b
	0	1.1	3.2 b	9.8 b	20.2 a	0.65 a
	1.1	0	0.0 a	8.7 b	41.0 b	2.13 b
	2.2	0	0.0 a	10.0 b	40.8 b	1.75 b
	1.1	1.1	7.3 c	2.2 a	19.4 a	0.45 a
	2.2	1.1	8.5 c	2.5 a	17.2 a	0.50 a
Urea	0	0	0.0 a	8.5 b	43.8 b	2.02 b
	0	1.1	3.2 b	9.8 b	20.2 a	0.65 a
	4.5	0	0.0 a	10.5 b	43.8 b	2.05 b
	9.0	0	0.0 a	8.9 b	44.5 b	2.09 b
	4.5	1.1	5.8 c	2.3 a	19.3 a	0.58 a
	9.0	1.1	8.3 d	1.8 a	18.0 a	0.43 a

[a]Ratings were on a 0 to 10 scale, 0 = no injury, 10 = death.

[b]Means within columns for a given additive with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 4. Control of yellow nutsedge 15 cm tall with postemergence application of glyphosate plus 2,4-D, ethephon, or urea.

Additive	Rate (kg/ha)	Glyphosate rate (kg/ha)	Visual injury rating after 30 days[a]	Density (shoots/cup)	Plant ht (cm/plant)	Dry wt (gm/plant system)
2,4-D	0	0	0.0 a[b]	8.5 bc	43.5 c	2.02 d
	0	1.1	3.2 bc	9.8 c	20.2 a	0.65 ab
	1.1	0	0.3 ab	6.2 b	29.3 b	1.09 c
	2.2	0	0.5 ab	6.0 b	27.2 b	0.92 bc
	1.1	1.1	4.2 c	3.3 a	19.2 a	0.48 a
	2.2	1.1	4.2 c	3.2 a	19.6 a	0.65 ab
Ethephon	0	0	0.0 a	8.5 b	43.6 b	2.02 b
	0	1.1	3.2 b	9.8 b	20.2 a	0.65 a
	1.1	0	0.0 a	8.7 b	41.0 b	2.13 b
	2.2	0	0.0 a	10.0 b	40.8 b	1.75 b
	1.1	1.1	7.3 c	2.2 a	19.4 a	0.45 a
	2.2	1.1	8.5 c	2.5 a	17.2 a	0.50 a
Urea	0	0	0.0 a	8.5 b	43.8 b	2.02 b
	0	1.1	3.2 b	9.8 b	20.2 a	0.65 a
	4.5	0	0.0 a	10.5 b	43.8 b	2.05 b
	9.0	0	0.0 a	8.9 b	44.5 b	2.09 b
	4.5	1.1	5.8 c	2.3 a	19.3 a	0.58 a
	9.0	1.1	8.3 d	1.8 a	18.0 a	0.43 a

[a]Ratings were on a 0 to 10 scale, 0 = no injury, 10 = death.

[b]Means within columns for a given additive with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 5. Control of yellow nutsedge 15 cm tall with postemergence application of glyphosate plus various ammonium salts.

Ammonium salts	Rate (kg/ha)	Glyphosate rate (kg/ha)	pH of spray solution	Visual injury rating after 30 days[a]	Density (shoots/cup)	Plant ht (cm/plant)	Dry wt (gm/plant system
Ammonium acetate	0	0		0.0 a[b]	8.5 b	43.6 b	2.02 b
	0	1.1	5.1	3.2 b	9.8 b	20.2 a	0.65 a
	4.5	0	5.4	0.0 a	8.8 b	46.7 b	2.32 b
	9.0	0	5.5	0.0 a	7.8 b	43.0 b	2.05 b
	4.5	1.1	5.3	4.0 b	4.0 a	19.0 a	0.48 a
	9.0	1.1	5.3	4.8 b	4.3 a	20.0 a	0.57 a
Ammonium chloride	0	0		0.0 a	8.5 c	43.6 b	2.02 b
	0	1.1	5.1	3.2 b	9.8 c	20.2 a	0.65 a
	4.5	0	5.9	0.0 a	7.3 bc	43.3 b	2.08 b
	9.0	0	5.6	0.0 a	7.3 bc	41.0 b	1.66 b
	4.5	1.1	4.8	5.8 c	3.7 a	20.7 a	0.60 a
	9.0	1.1	4.9	7.2 c	4.0 ab	19.7 a	0.57 a
Ammonium phosphate	0	0		0.0 a	8.5 b	43.6 b	2.02 b
	0	1.1	5.1	3.2 b	9.8 b	20.2 a	0.65 a
	4.5	0	5.0	0.0 a	7.7 b	42.5 b	2.13 b
	9.0	0	4.9	0.0 a	8.0 b	44.7 b	1.86 b
	4.5	1.1	5.0	8.7 c	2.3 a	19.0 a	0.40 a
	9.0	1.1	5.0	7.7 c	2.3 a	19.0 a	0.50 a
Ammonium sulfate	0	0		0.0 a	8.5 bc	43.6 c	2.02 c
	0	1.1	5.1	3.2 b	9.8 c	20.2 a	0.65 a
	4.5	0	5.7	1.5 ab	6.8 b	45.7 c	1.95 c
	9.0	0	5.8	0.0 a	7.3 bc	36.0 b	1.42 b
	4.5	1.1	4.6	8.3 c	2.7 a	17.3 a	0.50 a
	9.0	1.1	4.5	8.8 c	2.7 a	17.0 a	0.40 a
Ammonium thiocyanate	0	0		0.0 a	8.5 c	43.6 c	2.02 c
	0	1.1	5.1	3.2 b	9.8 d	20.2 a	0.65 a
	4.5	0	6.2	0.0 a	7.0 b	36.0 b	1.19 b
	9.0	0	5.9	0.0 a	5.7 a	34.3 b	1.07 b
	4.5	1.1	4.6	2.2 ab	5.5 a	20.0 a	0.55 a
	9.0	1.1	4.6	3.3 b	9.7 d	20.0 a	0.54 a

[a]Ratings were on a 0 to 10 scale, 0 = no injury, 10 = death.

[b]Means within columns for a given ammonium salt with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 6. The effect of pH on control of yellow nutsedge 15 cm tall with glyphosate.

Bentazon rate (kg/ha)	pH of solution	Visual injury rating after 30 days[a]	Density (shoots/cup)	Plant ht (cm/plant)	Dry wt (gm/plant system)
0		0.0 a[b]	7.7 a	41.5 c	2.87 c
1.1	not adjusted (5.1)	2.0 b	8.8 a	19.5 ab	0.62 ab
1.1	3	2.7 b	8.0 a	18.5 a	0.37 a
1.1	4	2.5 b	7.0 a	18.0 a	0.38 a
1.1	5	2.5 b	8.0 a	18.8 a	0.32 a
1.1	6	2.0 b	7.3 a	19.5 ab	0.44 a
1.1	7	2.0 b	9.0 a	18.8 a	0.59 ab
1.1	8	2.0 b	7.8 a	19.3 a	0.34 a
1.1	9	3.2 b	6.0 a	18.8 a	0.37 a
1.1	10	1.7 b	10.2 a	23.5 b	0.79 b
1.1	11	2.0 b	9.8 a	21.0 ab	0.77 b

[a]Ratings were on a 0 to 10 scale, 0 = no injury, 10 = death.

[b]Means within columns with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

CHAPTER 5

INFLUENCE OF STAGE OF GROWTH, ENVIRONMENTAL FACTORS AND ADDITIVES ON ^{14}C-BENTAZON AND ^{14}C-GLYPHOSATE ABSORPTION AND TRANSLOCATION BY YELLOW NUTSEDGE (*CYPERUS ESCULENTUS*)

Abstract

Absorption and translocation of ^{14}C-bentazon (3-isopropyl-1*H*-2,1,3-benzothiadiazin-(4)3*H*-one 2,2-dioxide) and ^{14}C-glyphosate (*N*-(phosphonomethyl)glycine) in yellow nutsedge (*Cyperus esculentus* L.) was studied in the greenhouse and laboratory with tubers collected in Michigan, grown in quartz sand, subirrigated with Hoagland's solution, and treated with ^{14}C-bentazon and ^{14}C-glyphosate applied to the second oldest leaf when the plants were 7.6 and 15.2 cm tall. Greater ^{14}C-bentazon absorption and translocation was observed with plants 7.6 cm tall than 15.2 cm. Absorption and translocation increased during the time period 4 to 24 hour after ^{14}C-bentazon application. ^{14}C-bentazon moved both acropetally and basipetally and translocated into parent tubers of plants 7.6 and 15.2 cm tall. Split applications of bentazon and addition of ammonium sulfate at 9 kg/ha to the spray solution increased absorption of ^{14}C-bentazon and translocation from the treated leaf to other leaves of plants 15.2 cm tall. Yellow nutsedge grown in EPTC (*S*-ethyl dipropylthiocarbamate) treated sand culture and in low soil moisture conditions absorbed less ^{14}C-bentazon 24 hour after treatment than plants grown in

normal soil conditions. Yellow nutsedge plants 15.2 cm tall absorbed more ^{14}C-glyphosate than plants 7.6 cm tall. However, translocation was more extensive in plants 7.6 cm tall than those 15.2 cm tall, 1 and 5 days after treatment. No ^{14}C-glyphosate was translocated to the tubers of yellow nutsedge if applied alone. Ammonium sulfate at 9 kg/ha in combination with ^{14}C-glyphosate rapidly increased absorption and basipetal movement of ^{14}C-glyphosate in plants 15.2 cm tall 4 to 24 hours after treatment. Ethephon (2-chloroethylphosphonic acid) at 2.2 kg/ha in combination with ^{14}C-glyphosate increased absorption and basipetal movement of ^{14}C-glyphosate from the treated leaf to roots, rhizomes, and parent tubers of yellow nutsedge plants 15.2 cm tall within 1 and 5 days after treatment. Yellow nutsedge grown under low light intensity absorbed less ^{14}C-glyphosate than plants grown under high light intensity.

Introduction

Bentazon is a selective postemergence herbicide used for weed control in corn and soybean (1,5,6,7). It is particularly effective for yellow nutsedge control. Glyphosate is a nonselective postemergence herbicide that has been used for purple nutsedge (Cyperus rotundus L.) (24) and yellow nutsedge control (4,12).

The activity of bentazon and glyphosate on yellow nutsedge is influenced by many factors, including stage of plant growth, split application of herbicide, rate of herbicide, additives, and environmental conditions (13,14,15).

^{14}C-bentazon is translocated both acropetally and basipetally in soybean with the translocation increasing to 5 days after treatment (7).

Susceptible soybean translocated more bentazon than the tolerant cultivars (22). The translocation of ^{14}C-bentazon has been related to the susceptibility of weed species to bentazon (9).

Glyphosate has been shown to translocate from treated leaf to untreated shoot and developing tillers of yellow nutsedge (11). In purple nutsedge, the translocation of ^{14}C-glyphosate was greatest in young plants (24).

The objective of this study was to determine the influence of stage of plant growth, split application of herbicide, additives and environmental conditions on absorption and translocation of ^{14}C-bentazon and ^{14}C-glyphosate on yellow nutsedge.

Materials and Methods

Yellow nutsedge tubers collected at East Lansing, Michigan, were germinated in controlled environmental chambers at 21 C. Tubers with similar size shoots were selected and planted 2 cm deep in quartz sand in 294-ml cups. These were subirrigated with a modified Hoagland's No. 1 solution adjusted to pH 6.5.

For the dry soil treatment, 10 ml of Hoagland's solution were subirrigated when plants started to wilt. EPTC at 0.56 kg/ha was applied as preplant incorporated treatment to sand before planting the yellow nutsedge tubers for the EPTC combination with bentazon. The plants were maintained under greenhouse conditions at 25 $\pm$ 3 C with supplemental fluorescent lighting to obtain a 14 hour day and 30.2 klux. To determine the influence of low light intensity on glyphosate absorption and translocation, the plants were exposed to 16.1 klux of light. Plants were

allowed to grow to 7.6 or 15.2 cm in height and then treated with the postemergence ^{14}C-herbicide. Ammonium sulfate at 9 kg/ha and ethephon at 2.2 kg/ha were applied as spray additives just prior to the application of the ^{14}C-herbicides. For the split application of bentazon, 1.1 kg/ha of bentazon was applied to yellow nutsedge plants 15.2 cm tall 5 days before the ^{14}C-bentazon was applied. The ^{14}C-bentazon, labelled in the 10 position, had a specific activity of 13.7 µCi/mmole and was purified to 98%. The methyl labelled ^{14}C-glyphosate had a specific activity of 1 µCi/mmole and was purified to 97%. It was then converted from the acid to the isopropyl amine salt and applied with 0.8% nonionic polyethoxylated tallow amine surfactant (MON 0818).

The second oldest leaf of a plant from each treatment was selected for the ^{14}C-herbicide application. Each leaf received a 5 µl drop containing 0.08 µCi of ^{14}C-bentazon and 0.05 µCi of ^{14}C-glyphosate. The drop of ^{14}C-herbicide was placed in the middle of the leaf between two lanolin bars perpendicular to the length of the leaf. The plants were harvested 4 or 24 hours, or 5 or 10 days after ^{14}C-herbicide application, depending on treatment.

The plants were harvested by washing the sand from the roots, rhizomes, and tubers with three successive water rinses. Plants were dissected into above-treated area, below-treated area, other leaves, roots and rhizomes, and parent tuber and then freeze-dried. The treated spot on the treated leaf was discarded since the herbicide in this area was not considered to be translocated. For the translocation study, plants were radioautographed to determine the pattern of distribution. Plant parts were combusted by the Schoeniger combustion method of Wang and Willis (18) to quantitatively determine translocation. The ^{14}C was then

radioassayed by liquid scintillation radioassay. All data presented are the means of two experiments with two replications each.

Results and Discussion

More ^{14}C-bentazon was absorbed by leaves of yellow nutsedge 7.6 cm tall than 15.2 cm (Table 1). The thinner cuticular wax covering of the leaves of the younger yellow nutsedge plants allowed greater penetration of the ^{14}C-bentazon into the leaves. This may explain the greater susceptibility of the younger yellow nutsedge to bentazon previously reported (13). The amount and percent of ^{14}C-bentazon absorbed by yellow nutsedge 7.6 cm tall increased from 4 to 24 hour after treatment.

^{14}C-bentazon moved both acropetally and basipetally (Table 2 and Figures 1 and 2). ^{14}C-bentazon was translocated to roots and rhizomes within 4 hours and to the parent tuber within 24 hours. The greatest translocation of ^{14}C-bentazon was observed when plants were harvested 5 days after herbicide application (Figure 1). The translocation of ^{14}C-bentazon to the parent tuber of relatively small plants, 7.6 cm tall may explain the previously reported (13) effectiveness of bentazon in killing tubers.

Ammonium sulfate increased the total percentage of ^{14}C-bentazon absorbed by plants 15.2 tall both 4 hours and 24 hours after treatment (Table 1). This is consistent with the increased bentazon activity observed when bentazon was combined with ammonium sulfate (15). Wilson and Nishimoto (19) reported that ammonium sulfate increased picloram activity and absorption by guava (Psidium cattleianum Sabine) and 'Bountiful' dwarf bean (Phaseolus vulgaris L.). They concluded that

the ammonium ion was responsible for the enhancement (20). Monovalent cations like ammonium ion increased penetration of tritiated water through citrus leaf cuticles (10). Similarly, it may increase ^{14}C-bentazon absorption by cuticular penetration but not via stomatal penetration as stomata are absent on the adaxial leaf surface of yellow nutsedge (21).

Four hours after application of ^{14}C-bentazon in combination with ammonium sulfate, more ^{14}C-bentazon was found in the leaf area below the treated area but less was found in roots and rhizomes (Table 2). However, ammonium sulfate did not increase ^{14}C-bentazon translocation to the parent tuber 1 and 5 days after treatment (Table 2, Figure 2). ^{14}C-bentazon movement is primary acropetal (7) and ammonium sulfate may not be able to change this translocation pattern in yellow nutsedge.

Split applications of bentazon simulated by applying bentazon 5 days peior to application of ^{14}C-bentazon increased ^{14}C-bentazon absorption by plants 15.2 cm tall (Table 1). These results are consistent with the increased bentazon activity observed when split applications of bentazon in other greenhouse studies (13). It appears that bentazon action involves increasing permeability of the leaves to polar materials. The split applications of bentazon increased ^{14}C-bentazon accumulation in the leaf area above the treated spot 4 and 24 hours after treatment (Table 2). However, 5 days after ^{14}C-bentazon application, the ^{14}C had moved throughout the plant (Figure 2) consistent with greater reported efficacy of the split treatments (13).

EPTC has been reported to reduce leaf surface wax of navy bean and increase the transpiration rate (23). However, preplant incorporation of a low rate of EPTC, 0.56 kg/ha, did not increase bentazon absorption by leaves (Table 1).

Yellow nutsedge, 15.2 cm tall, grown under a dry soil regime absorbed less ^{14}C-bentazon than plants grown in higher soil moisture regimes (Table 1) indicating that the reported loss of yellow nutsedge control under dry conditions (14) may be related to insufficient absorption of bentazon. Under water stress the leaf cuticle may be less hydrated and result in decreased absorption of polar materials (2).

^{14}C-bentazon translocation in yellow nutsedge grown under dry soil conditions was less extensive compared to plants grown under higher soil moisture conditions, perhaps a reflection of decreased absorption (Table 2, Figure 2).

Glyphosate absorption by yellow nutsedge 7.6 cm tall did not increase from 4 to 24 hours after the ^{14}C-glyphosate application, indicating rapid initial absorption (Table 3). The yellow nutsedge 15.2 cm tall absorbed more ^{14}C-glyphosate than the plants 7.6 cm tall.

^{14}C-glyphosate was translocated rapidly both basipetally and acropetally throughout yellow nutsedge plants 7.6 cm tall. However, even after 5 days no ^{14}C was translocated to the parent tuber (Figure 3). ^{14}C-glyphosate may be metabolized to non-toxic compounds or conjugated to other plant compounds before it can translocate into the tuber. This lack of translocation may explain why tubers of treated plants fail to rot as do tubers of bentazon treated plants. This is in contrast to purple nutsedge where ^{14}C-glyphosate was translocated into tubers (24). ^{14}C-glyphosate translocation was more extensive in the plants 7.6 cm tall than in the plants 15.2 cm tall (Figures 3 and 4), explaining the greater activity in yellow nutsedge 7.6 cm tall previously reported (13). Similar observations have been made for control of purple nutsedge with glyphosate (24).

Ammonium sulfate increased absorption of ^{14}C-glyphosate by yellow nutsedge 15.2 cm tall both 4 and 24 hours after treatment compared with ^{14}C-glyphosate alone (Table 3). Ammonium sulfate may alter cuticular membrane permeability allowing more ^{14}C-glyphosate to be absorbed. Ammonium sulfate has similarly been found to increase absorption of picloram by guava and dwarf bean (19).

The combination with ammonium sulfate also resulted in a large increase in the amount of ^{14}C-glyphosate found throughout the foliage (Table 4, Figure 4). This may have been a reflection of the increase in ^{14}C-glyphosate absorption shown in Table 3. Suwunnamek and Parker (16) concluded that ammonium sulfate had an effect on glyphosate action inside the purple nutsedge plant but not at the site of absorption, as ammonium sulfate applied 1 day after glyphosate still enhanced glyphosate activity on purple nutsedge.

Ethephon significantly increased ^{14}C-glyphosate absorption by yellow nutsedge 15.2 cm tall harvested 24 hours after treatment (Table 3). Ethephon has been reported (8) to reduce xylem tissue formation and increase the activity of 2,4,5-T ((2,4,5-trichlorophenoxy)acetic acid) on honey misquite (Prosopis glandulosa Torr.) control.

The ethephon treatment also increased the accumulation of ^{14}C-glyphosate in the leaves above the treated area but had little effect on the distribution in the remainder of the plant 4 to 24 hours after treatment (Table 4). However, by 5 days after treatment basipetal translocation of ^{14}C was enhanced (Figure 4). Binning et al. (3) proposed that ethylene release from ethephon can alter the metabolic source-sink relationship, as they found greater translocation of a dicamba (3,6-dichloro-o-anisic acid) in wild garlic when ethephon was applied 7 days before

the dicamba.

The influence of ammonium sulfate and ethephon on ^{14}C-glyphosate absorption and translocation by yellow nutsedge in this study are consistent with increased glyphosate activity by these combinations on yellow nutsedge control previously reported (15).

Under high light intensity the plants absorbed a higher percent of the ^{14}C-glyphosate applied than under low light intensity (Table 3). If uptake were an active process more energy would be available under the high light regime.

Growing the yellow nutsedge plants under low light intensity reduced basipetal transport of the ^{14}C (Table 4). Since glyphosate is translocated together with photoassimilate in the phloem, a decrease in photoassimilate accumulation and transport due to low light intensity should also result in decreased basipetal glyphosate movement.

Literature Cited

1. Andersen, R.N., W.E. Lueschen, D.D. Warnes, and W.W. Nelson. 1974. Controlling broadleaf weeds in soybeans with bentazon in Minnesota. Weed Sci. 22:136-142.

2. Ashton, F.M. and A.S. Crafts. 1973. Mode of action of herbicides. John Wiley and Sons, Inc. 504 pp.

3. Binning, L.K., D. Penner, and W.F. Meggitt. 1971. The effect of 2-chloroethyl phosphonic acid on dicamba translocation in wild garlic. Weed Sci. 19:73-75.

4. Boldt, P.F. and R.D. Sweet. 1974. Glyphosate studies on yellow nutsedge. Proc. Northeast. Weed Sci. Soc. 28:197-204.

5. Kapusta, G. and J.A. Tweedy. 1973. Yellow nutsedge control in soybean. Res. Rpt. North Centr. Weed Contr. Conf. 30:108 and 110-111.

6. Ladlie, J.S., W.F. Meggitt, and R.C. Bond. 1973. Preplant incorportated, preemergence and postemergence application on yellow nutsedge in soybeans. Res. Rpt. North Centr. Weed Contr. Conf. 30:112-113.

7. Mahoney, M.D. and D. Penner. 1975. Bentazon translocation and metabolism in soybean and navy bean. Weed Sci. 23:265-271.

8. Morey, P.R., R.E. Sosebee, and B.E. Dahl. 1976. Histological effects of ethephon and 2,4,5-T on misquite. Weed Sci. 24:292-297.

9. Nalewaja, J.D. and K.A. Adamczewski. 1977. Uptake and translocation of bentazon with additives. Weed Sci. 25:309-315.

10. Schonherr, J. 1976. Water permeability of siolate cuticular membranes: the effect of pH and cation on diffusion, hydrodynamic permeability and size of polar pores in the cutin wax matrix. Panta 128:113-126.

11. Sprankle, P., W.F. Meggitt, and D. Penner. 1975. Absorption, action and translocation of glyphosate. Weed Sci. 23:235-240.

12. Stoller, E.W., L.M. Wax, and R.L. Matthiesen. 1975. Response of yellow nutsedge and soybeans to bentazon, glyphosate and perfluidone. Weed Sci. 23:215-221.

13. Suwanketnikom, R., D. Penner, and W.F. Meggitt. 1978. Yellow nutsedge control with bentazon and glyphosate. Weed Sci. (Submitted).

14. Suwanketnikom, R. and D. Penner. 1978. Environmental influence on yellow nutsedge control with bentazon and glyphosate. Weed Sci. (Submitted).

15. Suwanketnikom, R. and D. Penner. 1978. Additives to increase bentazon and glyphosate activity on yellow nutsedge. Weed Sci. (Submitted).

16. Suwunnamek, U. and C. Parker. 1975. Control of Cyperus rotundus with glyphosate: the influence of ammonium sulfate and other additives. Weed Res. 15:13-19.

17. Tweedy, J.A., G. Kapusta, and O. Kale. 1972. The effect of several herbicides on nutsedge control in soybeans. Proc. North Centr. Weed Contr. Conf. 27:28-29.

18. Wang, C.H. and D.L. Willis. 1965. Radiotracer methodology in biological science. Prentice-Hall Inc., Englewood Cliffs, NJ. 363 pp.

19. Wilson, B.J. and R.K. Nishimoto. 1975. Ammonium sulfate enhancement of picloram activity and absorption. Weed Sci. 23:289-296.

20. Wilson, B.J. and R.K. Nishimoto. 1975. Ammonium sulfate enhancement of picloram absorption by detached leaves. Weed Sci. 23:297-301.

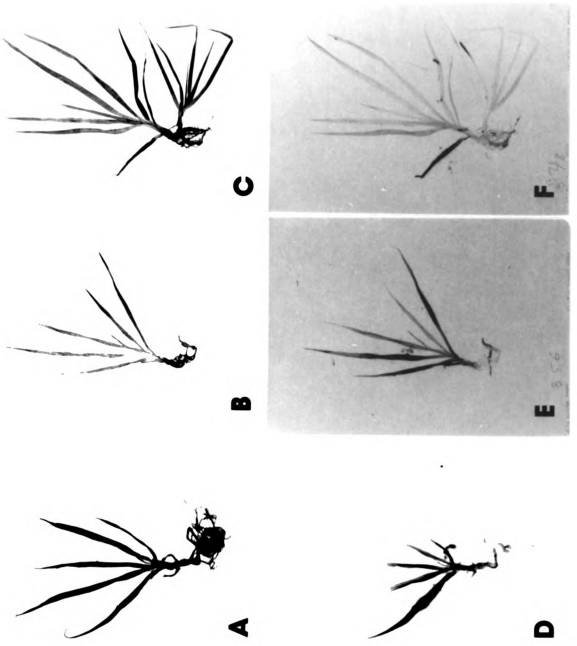
21. Wills, G.D. 1975. Taxonomy, morphology, anatomy, and composition of yellow nutsedge. Proc. North Centr. Weed Contr. Conf. 30:121-124.

22. Wills, G.D. 1976. Translocation of bentazon in soybeans and common cocklebur. Weed Sci. 24:536-540.

23. Wyse, D.L., W.F. Meggitt, and D. Penner. 1976. The interaction of atrazine and EPTC on navy bean. Weed Sci. 24:4-10.

24. Zandstra, B.H. and R.K. Nishimoto. 1977. Movement and activity of glyphosate in purple nutsedge. Weed Sci. 24:268-274.

Figure 1. Translocation of ^{14}C-bentazon in yellow nutsedge 7.6 cm tall. Plants harvested (A) 1 day, (B) 5 days, and (C) 10 days after foliar application. Treated plants above (A-C) and corresponding radioautographs below (D-F).


A
B
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E
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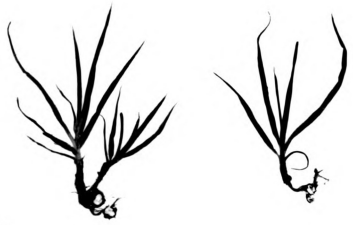
Figure 2. Translocation of ^{14}C-bentazon in yellow nutsedge 15.2 cm tall harvested 5 days after foliar application. Treated plants above, (A) ^{14}C-bentazon applied alone, (B) ^{14}C-bentazon applied in combination with ammonium sulfate, (C) split applications^{14}C-bentazon applied 5 days after application of 1.1 kg/ha of bentazon, and (D) ^{14}C-bentazon applied when plants were grown in low soil moisture conditions. Corresponding radioautograph below (E-H).

A
B
C
D
E
F
G
H

Figure 3. Translocation of ^{14}C-glyphosate in yellow nutsedge 7.6 cm tall Treated plants above harvested (A) 1 day and (B) 5 days after foliar application. Corresponding radioautographs below (C-D).


A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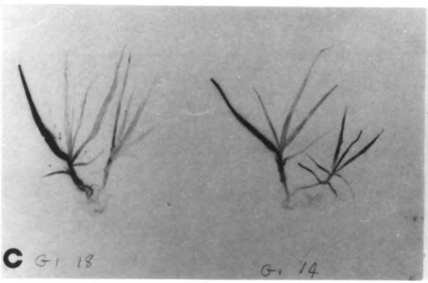
C
G1 18
G1 14


G1 48
D

Figure 4. Translocation of ^{14}C-glyphosate in yellow nutsedge plants 15.2 cm tall receiving ^{14}C-glyphosate applied (A) alone, (B) in combination with ethephon, and (C) in combination with ammonium sulfate 1 day after foliar application. Corresponding radioautographs are (D-E). Plants receiving ^{14}C-glyphosate applied (G) alone, (H) in combination with ethephon, and (I) in combination with ammonium sulfate 5 days after foliar application. Corresponding radioautographs are (J-L).

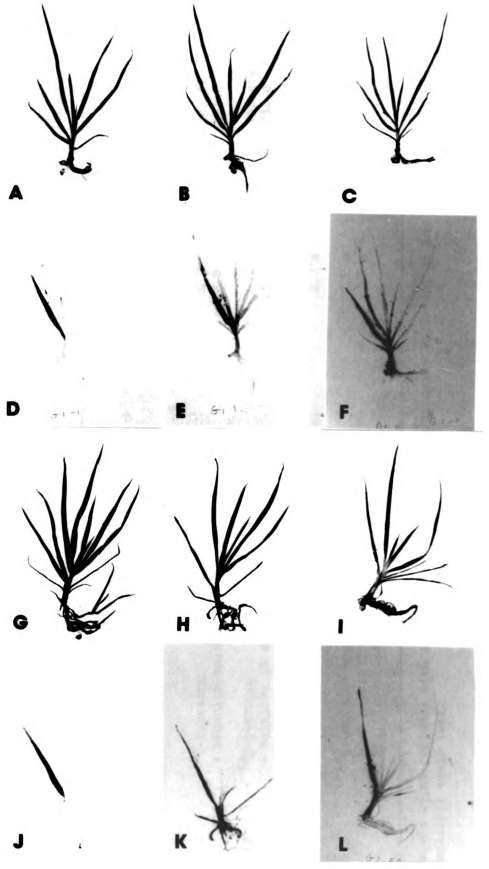
A
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Table 1. The affect of time, stage of plant growth, additives and soil moisture on foliar absorption of ^{14}C-bentazon by yellow nutsedge.

Plant ht (cm)	Treatment	Time of harvesting after herbicide application (h)	Absorption of C^{14} bentazon applied (%)	Amount of ^{14}C absorbed (dpm/mg)
7.6	^{14}C-bentazon	4	6.1 b[a]	782 d
		24	15.1 f	1524 e
15.2	^{14}C-bentazon	4	3.3 a	77 ab
		24	6.2 b	165 abc
15.2	^{14}C-bentazon + ammonium sulfate	4	9.3 c	261 bc
		24	13.5 e	291 c
15.2	^{14}C-bentazon + bentazon (5 day before)	4	6.9 b	161 abc
		24	11.3 d	732 d
15.2	^{14}C-bentazon + EPTC (preplant incorporated)	4	1.9 a	94 ab
		24	2.7 a	105 ab
15.2	^{14}C-bentazon applied when plants grew in dry soil condition	4	2.5 a	60 a
		24	2.5 a	82 ab

[a]Means within columns with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 2. The effect of time, stage of plant growth, additives and soil moisture condition on ^{14}C-bentazon translocation in yellow nutsedge expressed as percentage of total translocated and amount of ^{14}C-bentazon per plant dry weight.

Time of harvesting (h)	Plant ht (cm)	Treatment	Above treated area		Below treated area		Other leaves		Roots and rhizomes		Parent tuber	
			(%)	(dpm/mg)	(%)	(dpm/mg)	(%)	(dpm/mg)	(%)	(dpm/mg)	(%)	(dpm/mg)
4	7.6	^{14}C-bentazon	25.5 d-h[a]	893 f	28.5 e-i	1227 g	24.8 dg	92 bc	20.6 cde	83 bc	0.0 a	0 a
	15.2	^{14}C-bentazon	24.7 d-g	159 bcd	18.0 cd	40 b	32.2 fi	10 b	25.1 dh	22 b	0.0 a	0 a
	15.2	^{14}C-bentazon + ammonium sulfate	25.8 d-h	269 cd	37.8 i	483 e	28.3 fi	19 b	7.6 ab	13 b	0.0 a	0 a
	15.2	^{14}C-bentazon + bentazon (5 days before)	47.7 j	290 d	7.6 ab	101 bc	14.4 bc	8 b	30.3 f-i	82 bc	0.0 a	0 a
	15.2	^{14}C-bentazon + EPTC (preplant incorporated)	26.8 d-i	92 bc	29.5 e-i	136 bcd	8.9 ab	4 b	34.1 ghi	52 b	0.0 a	0 a
	15.2	^{14}C-bentazon applied when plants grew in dry soil condition	24.3 def	82 bc	34.5 hi	81 bc	20.4 cde	27 b	20.8 cde	13 b	0.0 a	0 a
24	7.6	^{14}C-bentazon	31.5 efg	315 e	7.2 ab	872 d	41.5 ghi	252 c	10.3 ab	84 ab	9.5 ab	59 ab
	15.2	^{14}C-bentazon	22.0 b-f	229 abc	13.7 abc	194 abc	40.8 ij	35 ab	10.2 ab	27 ab	3.3 a	8 ab
	15.2	^{14}C-bentazon + ammonium sulfate	28.9 d-g	397 c	20.6 b-e	381 c	36.3 fgh	43 ab	12.2 abc	40 ab	1.9 a	12 ab
	15.2	^{14}C-bentazon + bentazon (5 days before)	49.8 hij	990 d	17.4 a-e	1039 d	13.8 abc	38 ab	12.1 abc	90 ab	6.8 ab	38 ab
	15.2	^{14}C-bentazon + EPTC (preplant incorporated)	16.5 a-e	147 ab	12.2 abc	141 ab	61.4 j	23 ab	7.9 ab	5 a	2.1 a	0 a
	15.2	^{14}C-bentazon applied when plants grew in dry soil condition	21.6 b-f	99 ab	15.2 a-d	104 ab	29.9 d-g	15 ab	25.7 cf	15 ab	7.6 ab	13 a

[a]Means within the same time of harvesting and the same parameter with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 3. The effect of time, stage of plant growth, additives, and light intensity condition on foliar absorption of ^{14}C-glyphosate by yellow nutsedge.

Plant ht (cm)	Treatment	Time of harvesting after herbicide application (h)	Absorption of ^{14}C-glyphosate applied (%)	Amount of ^{14}C absorbed (dpm/mg)
7.6	^{14}C-glyphosate	4	11.8 bc[a]	58 ab
		24	12.8 c	84 bc
15.2	^{14}C-glyphosate	4	17.8 d	43 a
		24	20.3 e	56 ab
15.2	^{14}C-glyphosate + ammonium sulfate	4	25.1 f	121 d
		24	38.9 h	301 e
15.2	^{14}C-glyphosate + ethephon	4	18.9 de	56 ab
		24	35.6 g	94 cd
15.2	^{14}C-glyphosate applied when plant grew in low light intensity condition	4	9.3 a	47 a
		24	10.4 ab	52 ab

[a]Means within columns with similar letter are not significantly different at the 5% level by Duncan's multiple range test.

Table 4. The effect of time, stage of plant growth, additives and light intensity condition on ^{14}C-glyphosate translocation in yellow nutsedge expressed as percentage of total translocated and amount of ^{14}C-glyphosate per plant dry weight.

Time of harvesting (h)	Plant ht (cm)	Treatment	Above treated area		Below treated area		Other leaves		Roots and rhizomes		Parent tuber	
			(%)	(dpm/mg)	(%)	(dpm/mg)	(%)	(dpm/mg)	(%)	(dpm/mg)	(%)	(dpm/mg)
4	7.6	^{14}C-glyphosate	23.6 e[a]	98 fg	11.4 bc	30 bc	47.2 h	23 abc	15.3 bc	9 ab	0.0 a	0 a
	15.2	^{14}C-glyphosate	17.3 cd	28 bc	29.1 ef	76 ef	22.9 de	4 ab	30.7 fg	19 abc	0.0 a	0 a
	15.2	^{14}C-glyphosate + ammonium sulfate	24.2 e	181 h	14.8 bc	105 g	45.0 h	42 cd	16.0 c	36 cd	0.0 a	0 a
	15.2	^{14}C-glyphosate + ethephon	48.7 h	96 fg	28.6 ef	58 de	13.6 bc	5 ab	9.0 b	9 ab	0.0 a	0 a
	15.2	^{14}C-glyphosate in low light intensity condition	23.1 de	71 e	24.5 ef	30 bc	36.3 g	19 abc	16.1 c	22 abc	0.0 a	0 a
24	7.6	^{14}C-glyphosate	27.1 d-g	137 g	14.4 b	59 def	26.5 d-g	15 a-d	32.0 gh	39 a-e	0.0 a	0 a
	15.2	^{14}C-glyphosate	29.3 efg	84 f	14.6 b	54 c-f	23.6 c-f	8 ab	32.6 gh	20 a-e	0.0 a	0 a
	15.2	^{14}C-glyphosate + ammonium sulfate	26.1 d-g	305 i	27.5 efg	545 j	26.5 d-g	25 a-e	19.9 bcd	49 b-f	0.0 a	0 a
	15.2	^{14}C-glyphosate + ethephon	52.8 i	202 h	6.6 a	44 a-f	25.6 c-g	14 abc	14.9 b	24 a-e	0.0 a	0 a
	15.2	^{14}C-glyphosate in low light intensity condition	30.2 fg	63 ef	18.6 bc	53 c-f	27.9 h	22 a-e	13.4 b	23 a-e	0.0 a	0 a

[a]Means within the same time of harvesting and the same parameter with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

CHAPTER 6

METABOLISM OF ^{14}C-BENTAZON BY YELLOW NUTSEDGE (*CYPERUS ESCULENTUS*)

Abstract

^{14}C-bentazon (3-isopropyl-1*H*-2,1,3-benzothiadiazin-(4)3*H*-one 2,2-dioxide) metabolism in yellow nutsedge (*Cyperus esculentus* L.) 7.6 and 15.2 cm tall was examined 1, 5, and 10 days after treatment in greenhouse and laboratory studies. Large amounts of ^{14}C remained in the leaf area above the foliar treatment area 1 to 10 days after treatment. Less was present in the leaf section below the treatment area. Low amounts of ^{14}C were found in other leaves, roots, rhizomes, and parent tubers. Most of the ^{14}C found in the treated leaf was parent ^{14}C-bentazon. Parent bentazon was also found in other leaves, roots, rhizomes and parent tubers. The metabolism in various plant parts was similar with up to nine ^{14}C-metabolites separated.

Five days after treatment the yellow nutsedge plants 7.6 cm tall and the plants 15.2 cm tall that had been treated with 9 kg/ha of ammonium sulfate had absorbed more ^{14}C-bentazon than the 15.2 cm tall plants, but the percent of ^{14}C remaining as unmetabolized bentazon did not differ. The increased activity of bentazon in combination with ammonium sulfate appears related to bentazon absorption and not an altered pattern of metabolism.

Introduction

Yellow nutsedge, a serious weed problem in the United States (5,14), is propagated by both seeds and tubers, but propagation by tubers is the most important means of dissemination in cultivated cropland (1). Preemergence herbicides frequently fail to control yellow nutsedge as they may kill only the sprouting bud (16), but the tuber has several buds and each may be in a different stage of dormancy (9).

Bentazon is a selective postemergence herbicide that has shown efficacy for yellow nutsedge control (4,10). Parent tubers of small yellow nutsedge plants may be killed (10,11) and there is evidence that ^{14}C from foliarly applied ^{14}C-bentazon translocates to the parent tubers of small plants (13).

Addition of ammonium sulfate to the spray solution may increase efficacy of yellow nutsedge control with bentazon (12) by increasing absorption and translocation of bentazon in yellow nutsedge (13). However, the effect of ammonium sulfate on bentazon metabolism in yellow nutsedge has not been determined.

The objectives of this study were to determine: (a) the extent of bentazon metabolism in yellow nutsedge 7.6 cm tall, (b) whether parent bentazon or its metabolites translocated to other plant parts including the tubers, and (c) the effect of foliarly applied ammonium sulfate on bentazon metabolism.

Materials and Methods

Yellow nutsedge tubers collected at East Lansing, Michigan were sprouted in control environmental chambers at 21 C. Plants with the same size shoots were placed three per cup in 294-ml cups and grown in modified Hoagland No. 1 solution. The plants were placed in the greenhouse at 25 $\pm$ 3 C with supplemental fluorescent lighting to obtain a 14-h day length with 30.2 klux. When the plants reached the desired height, 7.5 or 15 cm tall, they were treated with ^{14}C-bentazon.

^{14}C-bentazon, labelled in the 10 position with a specific activity of 13.7 mC/mmole, was purified to 98%. A 5 µl drop containing 0.2 µCi of ^{14}C-bentazon was applied to the second oldest leaf of each plant. The drop was placed in the middle of the leaf between two lanolin bars perpendicular to the length of the leaf. The plants were harvested 1, 5, and 10 days after treatment. At harvest the roots, rhizomes, and tubers were washed in three successive water baths. The plants were dissected into the above treatment leaf area, below treatment leaf area, other leaves, roots, rhizomes, and tubers and then freeze-dried. For the comparison of metabolism in plants 7.6 and 15.2 cm tall with plants 15.2 cm tall receiving the combination of 9 kg/ha ammonium sulfate and ^{14}C-bentazon, only the treated leaves were harvested and dissected into above treated area and below treated area and then freeze-dried. The treated spot on the leaf was discarded. In this study six plants were used per treatment.

The procedures for studying metabolism were modified from the methods of Mahoney and Penner (6). For ^{14}C extraction following treatment each plant part was cut into small pieces, pulverized with a mortar and pestle,

homogenized in 80% methanol, and the homogenate filtered through Whatman No. 1 filter paper under vacuum. The methanol-insoluble portion was combusted by the method of Wang and Willis (15) and the radioactivity determined by liquid scintillation spectrometry. The methanol-water-soluble fraction was evaporated to dryness in vacuo, resuspended in 15 ml of 33% methanol, and partitioned against 15 ml benzene and then ethyl acetate three times each in 5-ml fractions. All of the samples were then evaporated to dryness in vacuo and resuspended in 0.5 ml of their respective solvents. Fifty µl of each fraction was radioassayed, the remaining 450 µl were reduced to 50 µl by evaporation under N_2 and spotted on 250 µ thick silica gel F-254 thin layer chromatography plates. The plates were developed in a solvent system of chloroform:methanol (7:3, v/v) to 15 cm and radioautographed. The ^{14}C-labelled spots on the plates were removed and radioassayed by liquid scintillation spectrometry.

All data presented are the means of two experiments with two replications each.

Results and Discussion

^{14}C-bentazon translocated from the treated leaf area to other leaves, roots and rhizomes, and parent tubers of yellow nutsedge 7.6 cm tall within 1 day, but most of the ^{14}C-bentazon remained in the leaf area above the treated area even 5 and 10 days after treatment (Tables 1 and 2).

^{14}C-bentazon in the leaf area above the treated spot was rapidly metabolized from 1 to 5 days after treatment (Table 2). The percentage of ^{14}C found in the metabolite fraction increased while the percentage of unmetabolized bentazon decreased (Table 2). Little additional

metabolism occurred during the time period 5 to 10 days after treatment. In the leaf area below the treated spot the percentage of ^{14}C found in the metabolites increased from 1 to 5 days after treatment but decreased from 5 to 10 days after treatment. The percentage of unmetabolized bentazon also decreased from 1 to 5 days after treatment. A large percentage of the ^{14}C was still found in the treated leaf (Table 2) 10 days after treatment. The metabolites or unmetabolized ^{14}C-bentazon appeared mobile in the plant. Since less metabolites of ^{14}C-bentazon were found in parent tubers (Tables 2 and 3) small but measurable amounts of unmetabolized ^{14}C-bentazon were found in the parent tuber and may have caused rot of the parent tuber as previously reported (11). The metabolites of bentazon are 6 and 8 hydroxybentazon in wheat (8) or 6-(3-isopropyl-2,1,3-benzothiadizine-4-one-2,2-dioxide)-0-β-glucopyranoside in rice (7) neither are toxic.

In yellow nutsedge 7.6 cm tall, only one metabolite was found in the ethyl acetate soluble fraction, but eight metabolites were found in the 80% methanol-soluble fraction (Table 3). Six metabolites were found in the leaf area above the treated spot 1 day after treatment, but by 5 and 10 days after treatment nine metabolites were found. These metabolites made up only a very low percentage of the total ^{14}C (Table 3). In the leaf area below the treated spot the number and concentration of metabolites was similar to the area above the treated spot (Table 3). Similarly, in the other plant parts, the number of metabolites appeared to increase with time after treatment.

The total amount of ^{14}C-bentazon remaining in the treated leaf of plants 7.6, 15.2 cm tall, and plants 15.2 cm tall that received 9 kg/ha of ammonium sulfate was not different 1 day after treatment (Table 4). Five days after treatment the amount of ^{14}C-bentazon in plants 7.6 cm

tall and plants 15.2 cm tall treated leaves with ammonium sulfate was greater than in plants 15.2 cm tall (Table 4). Therefore, it appears that ^{14}C-bentazon was still being absorbed by the plants 7.6 cm tall and plants 15.2 cm tall treated with leaf ammonium sulfate up to 5 days after treatment. The percent of ^{14}C that was unmetabolized bentazon was 71.1 to 75.9% 1 day after treatment and declined significantly 5 days after all treatments (Table 4).

^{14}C-bentazon was metabolized faster in trifoliate leaves than unifoliate leaves of navy bean and appeared related to the greater susceptibility of the unifoliate leaves (6).

Although yellow nutsedge plants differing in height differed in susceptibility to bentazon (11), they did not differ in the rate of bentazon metabolism (Table 4). The ammonium sulfate treatment increased bentazon activity but did not increase the rate of metabolism.

Analysis of the treated leaf shown no treatment differences in the percent of ^{14}C remaining in the area above or below the treated area from 1 to 10 days after treatment (Table 5). Significantly less ^{14}C was present below the treatment area compared to the area above the treated spot.

In the treated leaf above the treatment area the rate of ^{14}C-bentazon metabolism to soluble ^{14}C-metabolites in plants 7.6 cm tall and plants 15.2 cm tall with ammonium sulfate was greater than in plants 15.2 cm tall 5 days after treatment, the percent of soluble ^{14}C-metabolites was not different 1 and 10 days after treatment (Table 6). The treatments did not differ in the percent of ^{14}C found in the insoluble residue or in the material remaining at the origin of the TLC plates. Ten days after treatment the greatest percent of parent ^{14}C-bentazon was found in the leaf area above the treated spot in the plants 7.6 cm tall. This

difference was not evident in the leaf section below the treatment area (Table 6). The ammonium sulfate treatment did not greatly enhance or decrease metabolism of bentazon in the treated leaf. TLC analysis of the soluble ^{14}C further showed no effect of the ammonium sulfate on bentazon metabolism (Table 7). This ammonium sulfate appears to increase bentazon activity on yellow nutsedge by increasing bentazon absorption and possibly by interacting with bentazon at site of action such as uncoupling oxidative phosphorylation (3), nitrite accumulation (17) or inhibition of phytosynthesis (2).

The stage of plant growth only slightly altered metabolism with less of the metabolite, Rf 0.15, and more of metabolite, Rf 0.28, occurring in the 7.6 cm tall yellow nutsedge leaf sections above the treated area, 10 and 5 days after treatment, respectively (Table 7). Numerous metabolites isolated 1 day after treatment from the treated leaf of 15.2 cm tall plants treated with both ^{14}C-bentazon and ammonium sulfate were not present and detectable amounts in the yellow nutsedge 7.6 cm tall 1 day after treatment (Table 7). Although yellow nutsedge plants form numerous soluble metabolites from ^{14}C-bentazon, the pattern of metabolism appears quite different from that of tolerant navy bean (Phaseolus vulgaris L.) and soybean (Glycine max (L.) Merr.) reported by Mahoney and Penner (6).

Literature Cited

1. Bell, R.S., W.H. Lachman, E.M. Rahn, and R.D. Sweet. 1962. Life and history studies as related to weed control in the Northeast. 1. Nutgrass. Univ. of Rhode Island Agr. Exp. Sta. Bull. 363, 33 pp.

2. Boger, P., B. Beese, and R. Miller. 1977. Long-term effects of herbicides on the photosynthetic apparatus: an investigation on bentazon inhibition. Weed Res. 17:61-67.

3. Good, N.E. and S. Izawa. 1973. Uncoupling and energy transfer inhibition in photophosphoxylation. (In Current Topics in Bioenergetics. Edited by D.R. Sanadi.) Vol. 1, Academic Press, New York, 292 pp.

4. Hendrick, L.W., M.A. Veenstra, and R.E. Ascheman. 1973. Canada thistle and yellow nutsedge control with split application of bentazon. Proc. North Centr. Weed Contr. Conf. 28:64.

5. Jansen, L.L. 1971. Morphology and photoperiod response of yellow nutsedge. Weed Sci. 19:210-219.

6. Mahoney, M.D. and D. Penner. 1975. Bentazon translocation and metabolism in soybean and navy bean. Weed Sci. 23:265-271.

7. Mine, A., M. Miyakado, and S. Matsunaka. 1975. The mechanism of bentazon activity. Pest. Bioch. and Physi. 5:566-574.

8. Ritzlaff, G. and R. Hamm. 1976. The relation between assimilation and the metabolism of bentazon in wheat plants. Weed Res. 16:263-266.

9. Stoller, E.W. 1975. Growth, development and physiology of yellow nutsedge. Proc. North Centr. Weed Contr. Conf. 30:124-125.

10. Stoller, E.W., L.M. Wax, and R.L. Matthiesen. 1975. Response of yellow nutsedge and soybeans to bentazon, glyphosate and perfluidone. Weed Sci. 23:215-221.

11. Suwanketnikom, R., D. Penner, and W.F. Meggitt. Yellow nutsedge control with bentazon and glyphosate. Weed Sci. (Submitted).

12. Suwanketnikom, R. and D. Penner. Additives to increase bentazon and glyphosate activity on yellow nutsedge (Cyperus esculentus). Weed Sci. (Submitted).

13. Suwanketnikom, R. and D. Penner. Influence of stage of growth, environmental factors, and additives on ^{14}C-bentazon and ^{14}C-glyphosate absorption and translocation in yellow nutsedge (Cyperus esculentus). Weed Sci. (Submitted).

14. U.S. Department of Agriculture, Agricultural Research Service, Federal Extension Service, and Economic Research Service. 1968. Extent and cost of weed control with herbicides and an evaluation of important weeds, 1965. ARS 34-102, 85 pp.

15. Wang, C.H. and D.L. Willis. 1965. Radiotracer methodology in biological science. Prentice-Hall Inc., Englewood Cliffs, NJ. 363 pp.

16. Wax, L.M., E.W. Stoller, F.W. Slife, and R.N. Andersen. 1972. Yellow nutsedge control in soybeans. Weed Sci. 20:194-201.

17. Weissman, G.S. 1972. Influence of ammonium and nitrate nutrition on enzymatic activity in soybean and sunflower. Plant Pysiol. 49:138-141.

Table 1. Comparison of total ^{14}C found in various parts of yellow nutsedge plants 7.6 cm tall harvested 1, 5, and 10 days after ^{14}C-bentazon treatment.

Plant parts	1 Day		5 Days		10 Days	
	(% of total)	(dpm/mg)[a]	(% of total)	(dpm/mg)	(% of total)	(dpm/mg)
Above treatment area	53.6 c[b]	2945 b	59.5 c	3923 b	55.6 c	2608 b
Below treatment area	19.3 b	948 a	12.9 ab	853 a	17.5 b	568 a
Other leaves	23.1 b	137 a	25.2 b	85 a	22.1 b	109 a
Roots and rhizomes	3.3 a	35 a	2.1 a	18 a	4.2 a	13 a
Parent tuber	0.7 a	4 a	0.3 a	2 a	0.6 a	3 a

[a]Calculated as dpm/mg of ^{14}C-bentazon.

[b]Means within the same parameter with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 2. Metabolism of ^{14}C-bentazon in various parts of yellow nutsedge plants 7.6 cm tall 1, 5, and 10 days after treatment.

Plant parts	Methanol and water insoluble residue			Origin			Soluble ^{14}C-metabolites			Unmetabolized ^{14}C-bentazon		
	1 day (%)	5 days (%)	10 days (%)	1 day (%)	5 days (%)	10 days (%)	1 day (%)	5 days (%)	10 days (%)	1 day (%)	5 days (%)	10 days (%)
Above treated area	0.55 ab[a]	4.03 a-f	6.89 d-h	6.55 c-h	4.6 a-f	4.23 a-f	6.85 d-h	23.01 j	21.22 j	39.69 l	27.85 k	23.25 jk
Below treated area	0.65 ab	0.83 abc	1.28 a-d	2.08 a-d	0.62 ab	1.61 a-d	3.64 a-f	7.87 e-i	5.59 a-g	12.93 i	3.60 a-f	9.03 f-i
Other leaves	0.72 ab	0.95 abc	1.49 a-d	1.61 a-d	2.06 a-d	2.32 a-e	3.98 a-f	10.45 ghi	5.93 b-g	16.81 j	11.71 hi	12.39 i
Roots and rhizomes	0.22 ab	0.18 a	0.4 ab	0.35 ab	0.19 a	0.36 ab	0.49 ab	0.74 ab	1.25 a-d	2.19 a-d	1.04 abc	2.17 a-d
Parent tuber	0.08 a	0.01 a	0.1 a	0.06 a	0.01 a	0.05 a	0.14 a	0.1 a	0.11 a	0.39 ab	0.15 a	0.29 ab

[a]Means within similar letters are not significantly different at the 5% level by Duncan's multiple range test. Values are expressed in terms of percent of total radioactivity in the plant dry weight.

Table 3. Metabolites of ^{14}C-bentazon and corresponding Rf values obtained from various plant parts of yellow nutsedge 7.6 cm tall 1, 5, and 10 days after treatment.

Fraction	Rf of metabolites	Above treatment area			Below treatment area			Other leaves			Roots and rhizomes			Parent tuber		
		1 day (%)	5 days (%)	10 days (%)	1 day (%)	5 days (%)	10 days (%)	1 day (%)	5 days (%)	10 days (%)	1 day (%)	5 days (%)	10 days (%)	1 day (%)	5 days (%)	10 days (%)
Ethyl acetate soluble	.57	1.73abc[a]	1.21a	0.53a	0.62a	0.12a	0.24a	2.18a	0.82a	0.22a	0.11a	0.03a	0.09a	0.04a	0.02a	0.01a
Methanol-water soluble	.00	6.55de	4.6a-d	4.23a-d	2.08ab	0.62a	1.61a	1.61a	2.06a	2.32a	0.35ab	0.19ab	0.36ab	0.06a	0.01a	0.05a
	.06	2.31a-d	.42a	6.37cde	0.95a	1.99ab	1.48a	0.12a	2.39a	0.0 a	0.06a	0.11a	0.0 a	0.02a	0.01a	0.0 a
	.15	0.55a	4.22a-e	1.92abc	0.75a	1.65a	1.18a	0.45a	2.95a	1.33a	0.09a	0.18ab	0.28ab	0.02a	0.03a	0.06a
	.28	0.0 a	8.97e	6.26b-e	0.0 a	1.93ab	1.31a	0.0 a	2.17a	0.19a	0.0 a	0.18ab	0.59b	0.0 a	0.01a	0.02a
	.35	0.59a	2.78a-d	2.18a-d	0.20a	0.97a	0.49a	0.77a	1.76a	3.51a	0.13a	0.13a	0.88a	0.03a	0.01a	0.01a
	.48	0.0 a	1.03a	0.41a	0.0 a	0.49a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a
	.59	0.0 a	0.48a	1.29a	0.0 a	0.09a	0.35a	0.0 a	0.23a	0.0 a	0.0 a	0.0 a	0.18ab	0.0 a	0.0 a	0.01a
	.68	1.67ab	2.9 a-d	2.27a-d	1.12a	0.63a	0.54a	0.46a	0.13a	0.68a	0.10a	0.11a	0.03a	0.03a	0.02a	0.0 a
Bentazon	.42	39.69h	27.85g	23.25f	12.93d	3.60b	9.03c	16.81c	11.71b	12.39b	2.19d	1.04c	2.17d	0.39d	0.15b	0.29c

[a]Means within the same plant part with similar letters are not significantly different at the 5% level by Duncan's multiple range test. Values are expressed in terms of percent of total radioactivity in the plant dry weight.

Table 4. Comparison of foliar absorption of ^{14}C-bentazon and percentage of unmetabolized bentazon in the treated leaves of yellow nutsedge 1, 5, and 10 days after various treatments.

Plant ht (cm)	Treatment	1 day		5 days		10 days	
		Total uptake (dpm/mg)	Unmetabolized bentazon (%)	Total uptake (dpm/mg)	Unmetabolized bentazon (%)	Total uptake (dpm/mg)	Unmetabolized bentazon (%)
7.6	^{14}C-bentazon	3893 ab[a]	71.1 c	4760 b	43.4 ab	3192 ab	44.4 ab
15.2	^{14}C-bentazon	2433 ab	75.9 c	1390 a	53.9 b	1352 a	37.5 a
15.2	^{14}C-bentazon + ammonium sulfate (9 kg/ha)	2357 ab	72.1 c	4461 b	44.8 ab	3656 ab	35.6 a

[a]Means within the same parameter with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 5. Comparison of total ^{14}C found in above and below treated area of yellow nutsedge leaves harvested 1, 5, and 10 days after various treatment of ^{14}C-bentazon.

Plant ht (cm)	Treatment	Above treatment area			Below treatment area		
		1 day (%)	5 days (%)	10 days (%)	1 day (%)	5 days (%)	10 days (%)
7.6	^{14}C-bentazon	69.3 cd[a]	81.7 d	81.7 d	30.7 ab	18.3 a	18.3 a
15.2	^{14}C-bentazon	52.8 bc	69.4 cd	64.4 cd	47.2 bc	30.6 ab	35.6 ab
15.2	^{14}C-bentazon + ammonium sulfate (9 kg/ha)	66.8 cd	71.4 cd	66.7 cd	33.2 ab	28.6 ab	33.3 ab

[a]Means within similar letters are not significantly different at the 5% level by Duncan's multiple range test. Values are expressed in terms of percent of total radioactivity in treated leaves.

Table 6. Metabolism of ^{14}C-bentazon in above and below treated area of yellow nutsedge leaves 1, 5, and 10 days after various treatment.

Plant parts	Plant ht (cm)	Treatment	Methanol and water insoluble residue			Origin			Soluble ^{14}C-metabolites			Unmetabolized ^{14}C-bentazon		
			1 day (%)	5 days (%)	10 days (%)	1 day (%)	5 days (%)	10 days (%)	1 day (%)	5 days (%)	10 days (%)	1 day (%)	5 days (%)	10 days (%)
Above treatment area	7.6	^{14}C-bentazon	0.7a[a]	5.6a	9.3a	8.3a	6.3a	6.2a	9.2a	31.5c-f	30.7cde	51.1h	38.3def	35.5def
	15.2	^{14}C-bentazon	0.3a	3.0a	4.2a	7.5a	5.7a	4.0a	4.0a	23.3bc	32.6c-f	41.0fg	37.4def	23.6bc
	15.2	^{14}C-bentazon + ammonium sulfate (9 kg/ha)	0.2a	2.5a	4.2a	9.0a	4.7a	3.1a	8.6a	35.2def	40.0efg	49.0gh	29.0cd	19.4b
Below treatment area	7.6	^{14}C-bentazon	0.8a	1.0a	1.5abc	2.8a-d	0.9a	1.6abc	7.1a-f	11.3c-h	6.3a-e	20.0hi	5.1a-e	8.9a-g
	15.2	^{14}C-bentazon	0.4a	1.7abc	3.2a-d	6.0a-e	2.5a-d	2.3abc	5.9a-e	9.9a-g	16.2f-i	34.9j	16.5ghi	13.9e-h
	15.2	^{14}C-bentazon + ammonium sulfate (9 kg/ha)	0.4a	0.5a	2.0abc	3.3a-d	1.5abc	3.0a-d	6.4a-e	10a-h	12.1d-h	23.1i	15.8f-i	16.2f-i

[a]Means within the same plant part with similar letters are not significantly different at the 5% level by Duncan's multiple range test. Values are expressed in terms of percent of total radioactivity in treated leaves.

Table 7. Metabolites of ^{14}C-bentazon and corresponding Rf values obtained from above and below treated areas of yellow nutsedge leaves, 1, 5, and 10 days after various treatment.

Plant parts	Fraction	Rf of metabolites	^{14}C-bentazon applied when yellow nutsedge was 7.6 cm tall			^{14}C-bentazon applied when yellow nutsedge was 15.2 cm tall			^{14}C-bentazon plus 9 kg/ha ammonium sulfate was applied when yellow nutsedge was 15.2 cm tall		
			1 day (%)	5 days (%)	10 days (%)	1 day (%)	5 days (%)	10 days (%)	1 day (%)	5 days (%)	10 days (%)
Above treatment area	Ethyl acetate soluble	.57	2.4 a-e[a]	1.7 a-d	0.9 ab	0.6 ab	3.1 a-e	1.0 ab	0.8 ab	1.2 abc	0.9 ab
	Methanol-water soluble	.00	8.3 d-h	6.3 a-h	6.2 a-h	7.5 b-h	5.7 a-h	4.0 a-f	9.0 e-h	4.7 a-f	3.1 a-e
		.06	3.1 a-e	2.0 a-e	10.4 fgh	0.8 ab	6.0 a-h	12.7 hi	0.7 ab	17.8 ij	17.6 ij
		.15	0.8 ab	5.7 a-h	3.1 a-e	0.5 ab	5.5 a-g	10.3 fgh	1.7 a-d	6.8 a-h	6.5 a-h
		.28	0.0 a	11.9 ghi	8.2 c-h	0.6 ab	2.6 a-e	1.9 a-d	0.9 ab	3.0 a-e	7.5 b-h
		.35	0.8 ab	3.9 a-f	3.0 a-e	0.8 ab	1.4 a-d	1.9 a-d	1.3 a-d	1.7 a-d	3.0 a-e
		.48	0.0 a	1.4 a-d	0.5 ab	0.0 a	1.7 a-d	1.9 a-e	1.3 a-d	1.7 a-d	2.3 a-e
		.59	0.0 a	0.5 ab	2.0 a-e	0.8 ab	1.3 a-d	2.1 a-e	1.0 ab	0.9 ab	1.5 a-d
		.68	2.2 a-e	4.4 a-f	2.7 a-e	0.0 a	1.8 a-d	0.9 ab	0.9 ab	2.2 a-e	0.6 ab
	Bentazon	.42	51.1 m	38.3 l	35.5 l	41.0 l	37.4 l	23.6 jk	40.9 m	29.0 k	19.4 j

Table 7. (continued)

Plant parts	Fraction	Rf of metabolites	^{14}C-bentazon applied when yellow nutsedge was 7.6 cm tall			^{14}C-bentazon applied when yellow nutsedge was 15.2 cm tall			^{14}C-bentazon plus 9 kg/ha ammonium sulfate was applied when yellow nutsedge was 15.2 cm tall		
			1 day (%)	5 days (%)	10 days (%)	1 day (%)	5 days (%)	10 days (%)	1 day (%)	5 days (%)	10 days (%)
Below treatment area	Ethyl acetate soluble	.57	1.5 abc	0.2 ab	0.2 ab	1.5 abc	2.1 abc	0.7 ab	1.2 ab	0.5 ab	0.5 ab
	Methanol-water soluble	.00	2.8 abc	0.9 ab	1.5 abc	6.0 bcd	2.5 abc	2.3 abc	3.3 a-d	1.5 abc	3.0 abc
		.06	2.4 abc	3.3 a-d	2.1 abc	1.7 abc	2.8 abc	7.4 cd	0.6 ab	5.7 a-d	4.3 a-d
		.15	0.9 ab	2.3 abc	1.1 ab	0.5 ab	1.2 ab	2.7 abc	1.6 abc	1.4 ab	1.5 abc
		.28	0.0 a	2.7 abc	1.1 ab	0.3 ab	1.0 ab	1.7 abc	0.6 ab	0.9 ab	2.7 abc
		.35	0.6 ab	1.9 abc	0.6 ab	0.5 ab	0.6 ab	0.9 ab	0.7 ab	0.5 ab	1.2 ab
		.48	0.0 a	0.7 ab	0.0 a	0.0 a	0.6 ab	1.2 ab	0.1 ab	0.6 ab	0.7 ab
		.59	0.0 a	0.1 ab	0.4 ab	1.4 abc	0.3 ab	0.7 ab	1.1 ab	0.6 ab	0.6 ab
		.68	1.7 abc	0.1 ab	0.7 ab	0.0 a	1.2 ab	1.0 ab	0.4 ab	0.6 ab	0.7 ab
	Bentazon	.42	20.0 fg	5.1 a-d	8.9 d	34.9 h	16.5 ef	13.9 e	23.1 g	15.8 ef	16.2 ef

[a]Means within the same plant part with similar letters are not significantly different at the 5% level by Duncan's multiple range test. Values are expressed in terms of percent of total radioactivity in treated leaves.

CHAPTER 7

SUMMARY AND CONCLUSION

Field, greenhouse, and laboratory studies were initiated to examine the influence of herbicide rate, stage of plant growth on yellow nutsedge control with bentazon and glyphosate, split applications and time lapse between split applications of bentazon, temperature, light intensity, soil moisture, and spray additives on yellow nutsedge control with bentazon and glyphosate. The influence of stage of growth environmental factors and additives on ^{14}C-bentazon and ^{14}C-glyphosate absorption and translocation by yellow nutsedge was examined. Studies were also conducted to examine bentazon metabolism in yellow nutsedge and the effect of foliarly applied ammonium sulfate on ^{14}C-bentazon metabolism.

In the field, a 10-day time lapse between a split application of 1.1 kg/ha of bentazon increased activity on yellow nutsedge 5 to 7.5 to 10 to 15.2 cm tall more than a 20-day time lapse. Bentazon at 2.2 kg/ha or a split application of 2.2 and 1.1 kg/ha did not control plants 20 or 30.5 cm tall and caused soybean yield reduction. Bentazon did not reduce the regrowth of yellow nutsedge shoot, although greenhouse experiments showed that the parent tuber could be killed. Due to tuber dormancy, shoots from a late sprouting tuber did not receive the herbicide.

In greenhouse and laboratory studies ^{14}C-bentazon was absorbed more by 7.6 than 15.2 cm tall yellow nutsedge consistent with the greater susceptibility of 7.6 than 15.2 cm tall plant to 2.2 kg/ha of bentazon.

However, the rate of bentazon metabolism was not different between plants 7.6 and 15.2 cm tall. Bentazon was translocated acropetally and basipetally in yellow nutsedge 7.6 and 15.2 cm tall. Parent ^{14}C-bentazon was found to translocate to other plant parts such as other leaves, roots, rhizomes and into parent tubers of plants 7.6 cm tall. The metabolism of ^{14}C-bentazon in various plant parts was similar with up to nine metabolism separated.

Split applications of bentazon allowed greater absorption of ^{14}C-bentazon from the second application than from a single application of ^{14}C-bentazon, and supported observations that split applications of bentazon were more effective than single applications.

Bentazon and glyphosate rate and stage of yellow nutsedge growth are the main factors affecting yellow nutsedge control.

Bentazon and glyphosate activity on yellow nutsedge control was governed by environmental conditions. Low rates (1.1 kg/ha) of glyphosate had greater activity under high light intensity (48.4 klux). Under low light intensity (16.1 klux) less ^{14}C-glyphosate was absorbed and translocated in yellow nutsedge 15.2 cm tall. However, the low light intensity increased bentazon (2.2 kg/ha) activity on plants 15.2 cm tall. High moisture conditions increased the injury from both bentazon and glyphosate to yellow nutsedge 15.2 cm tall. Under dry soil conditions the cuticle may have been less hydrated with less herbicide absorbed. ^{14}C-bentazon was absorbed and translocated less in plants grown in dry soil conditions 15.2 cm tall than plants grown in normal soil conditions.

Bentazon caused more injury to plants 7.6 cm tall at 15 than 25 and 35 C. Higher temperatures may have increased cuticle thickness and prevented bentazon from penetrating into the leaves. However, if the plants

were 30.5 cm tall greater bentazon injury occurred at 25 C, the optimum growth temperature. Glyphosate at 2.2 kg/ha caused severe injury to plants 7.6 cm tall at 15, 25, and 35 C. But when the plants were 30.5 cm tall, the same rate of glyphosate provided control only at 25 and 30 C.

Spray additives were also an important factor increasing bentazon and glyphosate activity on yellow nutsedge control. Ammonium phosphate, ammonium chloride, ammonium sulfate, and ammonium thiocyanate in combination with bentazon increased injury rating, reduced the stand density, plant height and dry weight of shoots. Ammonium sulfate increased ^{14}C-bentazon absorption and translocation in yellow nutsedge plants 15.2 cm tall. But ammonium sulfate did not have an effect on bentazon metabolism. These ammonium salts as well as 2,4-D, ethephon, and urea increased glyphosate activity by increased injury rating primarily by reducing the stand density compared to glyphosate alone. Ammonium sulfate and ethephon increased absorption and basipetal movement of ^{14}C-glyphosate in yellow nutsedge 15.2 cm tall.

LIST OF REFERENCES

1. Abernathy, J.R. and L.M. Wax. 1973. Bentazon mobility and adsorption in twelve Illinois soils. Weed Sci. 21:224-227.

2. Andersen, R.N., W.F. Lueschen, D.D. Warnes, and W.W. Nelson. 1974. Controlling broadleaf weeds in soybeans with bentazon in Minnesota. Weed Sci. 22:136-142.

3. Antogini, J., J. Pearson, and D. Yoder. 1977. Bentazon: review of results and registration status on corn, dry bean, peanut and rice. Weed Sci. Soc. of Amer. Abstr. No. 224.

4. Armstrong, T., W.F. Meggitt, and D. Penner. 1973. Yellow nutsedge control with alachlor. Weed Sci. 21:354-357.

5. Armstrong, T., W.F. Meggitt, and D. Penner. 1973. Absorption translocation and metabolism of alachlor by yellow nutsedge. Weed Sci. 21:357-359.

6. Ashton, F.M. and A.S. Crafts. 1973. Mode of action of herbicides. John Wiley and Sons, Inc., 504 pp.

7. Baird, D.D., R.P. Upchurch, W.B. Homesley, and J.E. Franz. 1971. Introduction of new broad spectrum postemergence herbicide class with utility for herbaceous perennial weed control. Proc. North Centr. Weed Contr. Conf. 26:64-68.

8. Baur, J.R., R.W. Bovey, and J.A. Veech. 1977. Growth responses in sorghum and wheat induced by glyphosate. Weed Sci. 25:238-240.

9. Binning, L.K., D. Penner, and W.F. Meggitt. 1971. The effect of 2-chloroethyl phosphonic acid on dicamba translocation in wild garlic. Weed Sci. 19:73-75.

10. Bingham, S.W. 1977. Yellow nutsedge (Cyperus esculentus) control in cool season turfgrass. Weed Sci. 25:487-491.

11. Behrens, R. and M. Elakkad. 1973. Yellow nutsedge control in corn. Res. Rpt. North Centr. Weed Contr. Conf. 30:154-155.

12. Bell, R.S. and E. Larssen. 1960. Experiments with germination of northern nutgrass seed. Proc. Northeast Weed Contr. Conf. 14: 45-48.

13. Bell, R.S., W.H. Lachman, E.M. Rahn, and R.D. Sweet. 1962. Life history studies related weed control in the northeast. I. Nutgrass. Univ. of Rhode Island, Agr. Exp. Sta. Bull. 364, 33 pp.

14. Bendixen, L.E. 1970. Altering growth form to precondition yellow nutsedge for control. Weed Sci. 18:599-603.

15. Bendixen, L.E. 1970. Validity of evaluating transformation of primary rhizomes in yellow nutsedge. Weed Sci. 18:408-409.

16. Bendixen, L.E. 1973. Anatomy and sprouting of yellow nutsedge tubers. Weed Sci. 21:501-503.

17. Black, C.C., T.M. Chum, and R.H. Brown. 1969. Biochemical basis for plant competition. Weed Sci. 17:338-344.

18. Blair, A.M. 1975. The addition of ammonium salts on a glyphosate ester to herbicides to control Agropyron repens. Weed Res. 15:101-105.

19. Boger, P., B. Beese, and R. Miller. 1977. Long-term effects of herbicides on the photosynthetic apparatus: an investigation on bentazon inhibition. Weed Res. 17:61-67.

20. Boldt, P.F. and R.D. Sweet. 1974. Glyphosate study on yellow nutsedge. Proc. Northeast Weed Sci. Soc. 28:197-204.

21. Boldt, P.F., D.P. Yip, and R.D. Sweet. 1976. Phenotype studies of five New York yellow nutsedge selections. Weed Sci. Soc. of Amer. Abstr. No. 155.

22. Boldt, P.F. and A.R. Putnam. 1978. Evidence for soil activity of glyphosate in coarse-textured soils of low absorptive capabity. Weed Sci. Soc. of Amer. Abstr. No. 182.

23. Brecke, B.J. and W.B. Duke. 1977. Effect of glyphosate on intact bean plants, leaf discs and isolated cells. Weed Sci. Soc. of Amer. Abstr. No. 179.

24. Britton, N.L. and H.A. Brown. 1896. Illustrated flora of the Northern United States, Canada and the British possessions. Vol. 1. Charles Scribner's Sons, New York. 612 pp.

25. Buchholtz, K.P., B.H. Grigsby, O.C. Lee, F.W. Slife, C.J. Willard, and N.J. Volk. 1960. Weeds of the north central states. North Central Regional Publication. No. 36. Circular 718 of the Univ. of Ill. Agr. Exp. Sta.

26. Bundy, O.M., W.F. Donally, and E.M. Rahn. 1960. Growth and development of northern nutgrass as affected by certain environmental conditions. Proc. Northeast Weed Contr. Conf. 14:44.

27. Casta, J. and A.P. Appleby. 1976. Response of two yellow nutsedge varieties to three herbicides. Weed Sci. 24:54-58.

28. Claus, J.S. and R. Behrens. 1976. Glyphosate translocation and quackgrass rhizome bud kill. Weed Sci. 24:149-152.

29. Cornelius, A.J., W.F. Meggitt, and D. Penner. 1976. Relationship of yellow nutsedge control to soil persistence and mobility of several acetanilide herbicides. Proc. North Centr. Weed Contr. Conf. 31:33.

30. Cornelius, A.J., W.F. Meggitt, and R.C. Bond. 1976. Response of yellow nutsedge to acetanilide herbicides in corn and soybean. Res. Rpt. North Centr. Weed Contr. Conf. 33:52.

31. Davis, D.G. and K.K. Dusbabek. 1975. Translocation and effects of perfluidone on cotton and yellow nutsedge. Weed Sci. 23:81-86.

32. Davis, D.G. 1978. Cuticle development on Citrus mitis leaves as a function of light quality and intensity. Weed Sci. Soc. of Amer. Abstr. No. 171.

33. Dixon, G.A., E.W. Stoller, and M.D. Glamery. 1978. Acetanilide herbicide for yellow nutsedge (Cyperus esculentus). Weed Sci. Soc. of Amer. Abstr. No. 30.

34. Donally, W.F. and S.K. Ries. 1964. Amitrole translocation in Agropyron repens increased by the addition of ammonium thiocyanate. Science 145:497-498.

35. Doran, D.L. and R.N. Andersen. 1975. Effects of simulated rainfall on bentazon activity. Weed Sci. 23:105-109.

36. Fernandez, C.H. and D.E. Bayer. 1977. Penetration, translocation and toxicity of glyphosate in bermuda grass (Cynedon dactylon). Weed Sci. 25:396-400.

37. Garge, D.K., L.E. Bendixen, and S.R. Anderson. 1967. Rhizome differentiation in yellow nutsedge. Weed Sci. 15:124-128.

38. Genterer, W.A. 1973. Yellow nutsedge control with MBR-8251. Weed Sci. 21:122-124.

39. Good, N.E. and Izawa. 1966. Uncoupling and energy transfer inhibition in photophorylation. (In Current Topics in Bioenergetics. Edited by Sanadi, D.R.), Vol. 1, Academic Press, New York, 292 pp.

40. Hauser, E.W., J.L. Butler, J.L. Shepherd, and S.A. Parham. 1966. Response of yellow nutsedge, Florida pusley, and peanuts to thiocarbamate herbicides as affected by method of placement in soil. Weed Res. 6:338-345.

41. Hauser, E.W., L.E. Samples, and S.A. Parham. 1969. Incorporated versus subsurface vernolate for weed control in peanuts. Weed Res. 9:173-184.

42. Hauser, E.W. 1968. Yellow nutsedge - problems, research trends and outlook. Proc. Northeast Weed Contr. Conf. 22:37-48.

43. Hauser, E.W., C.C. Dowler, M.D. Jellum, and S.R. Cecil. 1974. Effects of herbicide - crop rotation on nutsedge, annual weeds and crops. Weed Sci. 22:172-176.

44. Hayes, R.M. and L.M. Wax. 1975. Differential intraspecific responses of soybean cultivars to bentazon. Weed Sci. 23:516-521.

45. Hoagland, R.E. and R. Paul. 1978. Ultra structural effects of glyphosate on Lemma gibba L. Weed Sci. Soc. of Amer. Abstr. No. 170.

46. Hendrick, L.W., M.A. Veenstra, and R.E. Ascheman. 1973. Canada thistle and yellow nutsedge control with split application of bentazon. Proc. North Contr. Weed Contr. Conf. 28:64.

47. Hill, E.R., W.H. Lachman, and D.N. Maynard. 1963. Note reproductive potential of yellow nutsedge by seed. Weeds 11:163-171.

48. Hill, E.R., J. Bochle, Jr., J.W. Peck, and J.F. Ellis. 1978. Yellow nutsedge control with metolachlor. Weed Sci. Soc. of Amer. Abstr. No. 31.

49. Holm, L.G., D.L. Plucknett, J.V. Pancho, and J.P. Herberger. 1977. The World's Worst Weeds (distribution and biology). The University Press of Hawaii. Honolulu. 609 pp.

50. Jagschitz, J.A. 1976. Selective control of yellow nutsedge in turfgrass with herbicides. Weed Sci. Soc. of Amer. Abstr. No. 67.

51. Jansen, L.L. 1971. Morphology and photoperiodic response of yellow nutsedge. Weed Sci. 19:210-219.

52. Jaworski, E.G. 1972. Mode of action of N-phophonomethyl glycine: interaction of aromatic amino acid biosynthesis. J. of Agr. Food Chem. 20:1195-1198.

53. Jordan, T.N. 1977. Factors affecting glyphosate toxicity to bermuda grass (Cynodon dactylon (L.) Pers). Weed Sci. Soc. of Amer. Abstr. No. 62.

54. Justice, O.L. and M.D. Whitehead. 1964. Seed production viability and dormancy in the nutgrass, Cyperus rotundus and C. esculentus. J. of Agric. Res. 73:303-318.

55. Kapusta, G. and J.A. Tweedy. 1973. Yellow nutsedge control in soybean. Res. Rpt. North Centr. Weed Contr. Conf. 30:108 and 110-11.

56. Kapusta, G., J.A. Tweedy, and C.F. Strieker. 1974. Herbicidal control of yellow nutsedge in soybean. Res. Rpt. North Centr. Weed Contr. Conf. 31:144-145.

57. Keeley, P.E., C.H. Carter, and J.H. Miller. 1972. Evaluation of the relative phytotoxicity of herbicide to cotton and nutsedge. Weed Sci. 20:71-74.

58. Keeley, P.E., C.H. Carter, and J.H. Miller. 1973. Yellow nutsedge and cotton response to several herbicides. Weed Sci. 21:327-329.

59. Keeley, P.E. and R.J. Thullen. 1974. Yellow nutsedge control with soil-incorporated herbicides. Weed Sci. 22:378-383.

60. Keeley, P.E. and R.J. Thullen. 1975. Influence of yellow nutsedge competition on furrow-irrigated cotton. Weed Sci. 23:171-175.

61. Keeley, P.E. and R.J. Thullen. 1978. Light requirement of yellow nutsedge (Cyperus esculentus) and light interception by crops. Weed Sci. 26:10-16.

62. Kern, A.D., W.F. Meggitt, and R.C. Bond. 1973. Yellow nutsedge control with preplant incorporated and postemergence herbicide treatments in corn. Res. Rpt. North Centr. Weed Contr. Conf. 30: 167.

63. Kern, A.D., W.F. Meggitt, and D. Penner. 1978. Yellow nutsedge (Cyperus esculentus) control in Kentucky bluegrass (Poa pratensis) with bentazon, cyperquat and perfluidone. Weed Sci. 26:280-283.

64. Klepper, L.A. 1974. A mode of action of herbicides: Inhibition of the normal process of nitrite reduction. Nebraska Exp. Sta. Res. Bull. 259. 42 pp.

65. Klepper, L.A. 1975. Inhibition of nitrite reduction by photosynthetic inhibitor. Weed Sci. 23:188-190.

66. Ladlie, J.S., W.F. Meggitt, and R.C. Bond. 1973. Preplant incorporated, preemergence and postemergence application on yellow nutsedge in soybeans. Res. Rpt. North Centr. Weed Contr. Conf. 30: 112-113.

67. Lewis, W.M. and A.D. Worsham. 1970. The ten worst weeds of field crops. Nutsedge. Crops and Soils 22:14-16.

68. Mahoney, M.D. and D. Penner. 1975. Bentazon translocation and metabolism in soybean and navy bean. Weed Sci. 23:265-271.

69. Mahoney, M.D. and D. Penner. 1975. The basis for bentazon selectivity in navy beans, cocklebur and black nightshade. Weed Sci. 23:272-276.

70. Matthiesen, R.L. and E.W. Stoller. 1976. Response of yellow nutsedge ecotypes of varied photoperiods. Weed Sci. Soc. of Amer. Abstr. No. 183.

71. McWhorter, C.G. and J.M. Anderson. 1976. Bentazon applied postemergence for economical control of common cocklebur in soybeans. Weed Sci. 24:391-396.

72. McWhorter, C.G. 1977. Weed control in soybeans with glyphosate applied in the recirculating sprayer. Weed Sci. 25:135-141.

73. Mine, A., M. Miyakado, and S. Matsunaka. 1975. The mechanism of bentazon selectivity. Pest. Bioch. and Physiol. 5:566-574.

74. Mine, A. and S. Matsunaka. 1975. Mode of action of bentazon: effect on photosynthesis. Pest. Bioch. and Physiol. 5:444-450.

75. Morey, P.R., R.E. Sosebec, and B.E. Dahl. 1976. Histological effects of ethephon and 2,4,5-T on mesquite. Weed Sci. 24:292-297.

76. Moshier, L., A.J. Turgeon, and D. Penner. 1976. Effects of glyphosate and siduron on turfgrass establishment. Weed Sci. 24:445-448.

77. Moshier, L. and D. Penner. 1978. Use of glyphosate in sod seedling alfalfa (Medicago sativa) establishment. Weed Sci. 26:163-166.

78. Nalewaja, J.D., J. Rudelka, and K.A. Adamczewski. 1975. Influence of climate and additives on bentazon. Weed Sci. 23:504-507.

79. Nalewaja, J.D. and K.A. Adamczewski. 1977. Redroot pigweed (Amaranthus retroflexus) control with bentazon plus additives. Weed Sci. 25:506-510.

80. Nalewaja, J.D. and K.A. Adamczewski. 1977. Uptake and translocation of bentazon with additives. Weed Sci. 25:309-315.

81. Nash, R.G. 1968. Synergistic phytotoxicities of herbicide insecticide combination in soil. Weed Sci. 16:74-77.

82. Oliver, L.R., M. McClelland, and W.D. Mathis. 1977. Response of six morning-glory species to bentazon. Proc. Southern Weed Sci. Soc. 30:37.

83. Parker, C. 1976. Effects on the dormancy of plant organs (in Herbicides, Physiology, Biochemistry, Ecology Edited by L.J. Audus.) Vol. I. Academic Press, London, 608 pp.

84. Parochetti, J.V. 1974. Yellow nutsedge, giant green foxtail and fall panicum control in corn. Weed Sci. 22:80-82.

85. Potter, J.R. and W.P. Wergin. 1975. The role of light in bentazon toxicity to cocklebur: physiology and ultrastructure. Pest. Bioch. and Physiol. 5:458-470.

86. Putnam, A.R. 1976. Fate of glyphosate in deciduous fruit trees. Weed Sci. 24:425-430.

87. Retzlaff, G. and R. Hamm. 1976. The relation between assimilation and the metabolism of bentazone in wheat plants. Weed Res. 16:263-266.

88. Richard, E.P., Jr., J.R. Goss, C.J. Arntzen, and F.W. Slife. 1977. Analysis of glyphosate inhibition of electron transport and phosphorelation in Pea (Pisum sativum) chloroplasts. Weed Sci. Soc. of Amer. Abstr. No. 177.

89. Sandberg, C., W.F. Meggitt, and D. Penner. 1976. 1976. Response of viney weed species to glyphosate. Weed Sci. Soc. of Amer. Abstr. No. 190.

90. Schonherr, J. 1976. Water permeability of isolate cuticular membranes: the effect of pH and cation on diffusion, hydrodynamic permeability and size of polar pores in the cutin matrix. Panta 128:113-126.

91. Segura, J., S.W. Bingham, and C.L. Foy. 1978. Phytotoxicity of glyphosate to Italian ryegrass (Lolium multiflorum Lam.) and red clover (Trifolium pratense L.). Weed Sci. 26:32-36.

92. Shimabukuro, R.H., V.J. Masteller, and W.C. Walsh. 1976. Atrazine injury: relationship to metabolism, substrate level, and secondary factors. Weed Sci. 24:336-340.

93. Sprankle, P., W.F. Meggitt, and D. Penner. 1975. Rapid inactivation of glyphosate in the soil. Weed Sci. 23:224-228.

94. Sprankle, P., W.F. Meggitt, and D. Penner. 1975. Adsorption, mobility and microbial degradation of glyphosate in the soil. Weed Sci. 23:229-234.

95. Sprankle, P., W.F. Meggitt, and D. Penner. 1975. Absorption, action, translocation of glyphosate. Weed Sci. 23:235-240.

96. Stoller, E.W., D.P. Nema, and V.M. Bhan. 1972. Yellow nutsedge tuber germination and seedling development. Weed Sci. 20:93-97.

97. Stoller, E.W. 1973. Effect of minimum soil temperature on differential distribution of Cyperus rotundus and C. esculentus in the United States. Weed Res. 13:209-217.

98. Stoller, E.W. and L.M. Wax. 1973. Yellow nutsedge shoot emergence and tuber longevity. Weed Sci. 21:76-81.

99. Stoller, E.W. 1975. Growth, development and physiology of yellow nutsedge. Proc. North Centr. Weed Contr. Conf. 30:124-125.

100. Stoller, E.W. and E.J. Weber. 1975. Difference cold temperature, starch, sugar, protein and lipid of yellow and purple nutsedge tuber. Plant Physiol. 55:859-863.

101. Stoller, E.W., L.M. Wax, and R.L. Matthiesen. 1975. Response of yellow nutsedge and soybean to bentazon, glyphosate and perfluidone. Weed Sci. 23:215-221.

102. Stoller, E.W., L.W. Wax, and F.W. Slife. 1977. Competition and control of yellow nutsedge in corn. Proc. North Centr. Weed Contr. Conf. 32:83.

103. Suwanketnikom, R. and D. Penner. 1975. Yellow nutsedge control with Bentazon and glyphosate. Proc. North Centr. Weed Contr. Conf. 30:115.

104. Suwanketnikom, R. and D. Penner. 1976. Environmental influence on yellow nutsedge control with bentazon and glyphosate. Proc. North Centr. Weed Contr. Conf. 31:141.

105. Suwanketnikom, R., D. Penner, and W.F. Meggitt. Yellow nutsedge control with bentazon and glyphosate. Weed Sci. (Submitted).

106. Suwanketnikom, R. and D. Penner. Additives to increase bentazon and glyphosate activity or yellow nutsedge (Cyperus esculentus). Weed Sci. (Submitted).

107. Suwanketnikom, R. and D. Penner. Influence of stage of growth, environmental factors, and additives on ^{14}C-bentazon and ^{14}C-glyphosate absorption and translocation in yellow nutsedge (Cyperus esculentus). Weed Sci. (Submitted).

108. Suwunnamek, U. and C. Parker. 1975. Control of Cyperus rotundus with glyphosate: the influence of ammonium sulfate and other additives. Weed Res. 15:13-19.

109. Taylorson, R.B. 1967. Seasonal variation in sprouting and available carbohydrate in yellow nutsedge tuber. Weeds 15:22-24.

110. Thomas, P.E.L. 1969. Effects of dessication and temperature on survival of Cyperus esculentus tubers and Cynodon dactylon rhizomes. Weed Res. 9:1-8.

111. Thullen, R.J. and P.E. Keeley. 1975. Yellow nutsedge sprouting and resprouting potential. Weed Sci. 23:333-337.

112. Tumbleson, M.E. and T. Kommedahl. 1961. Reproduction potential of Cyperus esculentus by tubers. Weeds 9:646-653.

113. Tumbleson, M.E. and T. Kommedahl. 1962. Factors affecting dormancy in tubers of Cyperus esculentus. Bot. Gaz. 123:186-189.

114. Tweedy, J.A., G. Kapusta, and O. Kale. 1972. The effect of several herbicides on nutsedge control in soybeans. Proc. North Centr. Weed Contr. Conf. 27:28-29.

115. Tymonko, J.M. and C.L. Foy. 1978. Influence of glyphosate on the metabolism of separate soybean leaf cells. Weed Sci. Soc. of Amer. Abstr. No. 152.

116. U.S. Department of Agriculture, Agricultural Research Service, Federal Extension Service, and Economic Research Service. 1968. Extent and cost of weed control with herbicides and an evaluation of important weeds. 1965. ARS. 34-102, 85 pp.

117. U.S. Department of Agriculture, Agricultural Research Service. 1970. Selected weeds of the United States Agr. Handbook No. 336, 463 pp.

118. Wang, C.H. and D.L. Willis. 1965. Radiotracer methodology in biological science. Prentice-Hall, Inc., Englewood Cliffs, NJ. 363 pp.

119. Wax, L.M., E.W. Stoller, E.W. Slife, and R.N. Andersen. 1972. Yellow nutsedge control in soybean. Weed Sci. 20:194-201.

120. Wax, L.M., R.L. Bernard, and R.M. Hayes. 1974. Response of soybean cultivars to bentazon, bromoxynil, chloroxuron, and 2,4-DB. Weed Sci. 22:35-41.

121. Wax, L.M. 1975. Control of yellow nutsedge in field crops. Proc. North Centr. Weed Contr. Conf. 30:125.

122. Weed Science Society of America. 1974. Herbicide Handbook. Champaign, IL. 430 pp.

123. Weissman, G.S. 1972. Influence of ammonium and nitrate nutrition on enzematic activity. Plant Physiol. 49:138-141.

124. Wills, G.D. and G.A. Briscoe. 1970. Anatomy of purple nutsedge. Weed Sci. 18:631-635.

125. Wills, G.D. 1974. Effect of temperature, relative humidity, soil moisture and surfactant on the toxicity of glyphosate to cotton and purple nutsedge. Weed Sci. Soc. of Amer. Abstr. No. 275.

126. Wills, G.D. 1975. Taxonomy, morphology, anatomy, and composition of yellow nutsedge. Proc. North Centr. Weed Contr. Conf. 30:121-124.

127. Wills, G.D. 1976. Translocation of bentazon in soybean and common cocklebur. Weed Sci. 24:536-540.

128. Wilson, B.J. and R.K. Nishimoto. 1975. Ammonium sulfate enhancement of picloram activity and absorption. Weed Sci. 22:289-296.

129. Wilson, B.J. and R.K. Nishimoto. 1975. Ammonium sulfate enhancement of picloram absorption by detached leaves. Weed Sci. 23:297-301.

130. Wyrill, J.B. and O.C. Burnside. 1977. Glyphosate toxicity to common milkweed and hemp dogbane. Weed Sci. 25:275-287.

131. Wyse, D.L., W.F. Meggitt, and D. Penner. 1976. The interaction of atrazine and EPTC on navy bean. Weed Sci. 24:4-10.

132. Yip, C.P. and R.D. Sweet. 1978. Biotypes of yellow nutsedge (Cyperus esculentus L.) I. morphological characteristics. Weed Sci. Soc. of Amer. Abstr. No. 127.

133. Yip, C.P. and R.D. Sweet. 1978. Biotypes of yellow nutsedge (Cyperus esculentus L.) II. tuber dormancy and responses to photoperiod and herbicides. Weed Sci. Soc. of Amer. Abstr. No. 128.

134. Zandstra, B.H. and R.K. Nishimoto. 1977. Movement and activity of glyphosate in purple nutsedge. Weed Sci. 25:268-274.

135. Zawawi, M.A. and D.E. Bayer. 1977. Enhanced herbicidal activity of bentazon with surfactants. Weed Sci. Soc. of Amer. Abstr. No. 181.