AN ABSTRACT OF THE THESIS OF

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Title: Control of purple nutsedge (Cyperus rotundus L.) with glyphosate.

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Research conducted in El Salvador, Central America, demonstrated that an interval of 3 days between application of glyphosate and tillage was sufficient to cause a 90% reduction in purple nutsedge (Cyperus rotundus L.) plants, while delays of 11-23 days generally gave slightly less control. A second application to the same plots 35 days following tillage resulted in greater than 90% reduction at all intervals. Approximately 3 months after the initial treatment the tuber population had been reduced to one half the original population. Germination of the remaining tubers was reduced more than 50%.

Glyphosate applied during the dry season caused an average of 79% reduction in plant numbers as compared to 88% in the rainy season. However, in the dry season, the remaining plants had no competition from other weeds and after 5 months there was only a 40% reduction in nutsedge population. During the rainy season 1, 2 and 3 kg/ha were equally effective, but 1 kg/ha was not sufficient in the dry season.

In growth chamber studies, glyphosate at 2 kg/ha was more effective in reducing regrowth of purple nutsedge (Cyperus rotundus L.) scapes at 90% than at 50% relative humidity (r.h.), and more effective at -2 bars than at -11 bars of plant water potential. Regrowth of treated plants under water stress of -1 to -8 bars was reduced 54-60% while at -11 bars growth inhibition was only 34%. A time interval of as little as 8 h between application and excision was sufficient to result in a 47% reduction in regrowth at 90% r.h. None of the treated plants, except those clipped immediately after application, produced new shoots from the basal bulb, while all of the non-treated control plants produced one or more new shoots. Experiments using ^{14}C-glyphosate substantiate the results observed in the regrowth studies. Three times more ^{14}C-label was translocated into the underground parts of nutsedge at 90% than at 50% r.h. Twice as much translocated at -2 bars than at -11 bars of water stress.

Control of purple nutsedge
(*Cyperus rotundus* L.)
with glyphosate

by

Richard Lyle Chase

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This thesis is composed principally of two articles written for publication in Weed Research:

I. Effect of intervals between application and tillage on glyphosate control of *Cyperus rotundus* L.

II. Effects of humidity and moisture stress on glyphosate control of *Cyperus rotundus* L.

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EFFECT OF INTERVALS BETWEEN APPLICATION AND TILLAGE ON GLYPHOSATE CONTROL OF *CYPERUS ROTUNDUS* L.

Research conducted in El Salvador, Central America, demonstrated that an interval of 3 days between application of glyphosate and tillage was sufficient to cause a 90% reduction in purple nutsedge (*Cyperus rotundus* L.) plants, while delays of 11-23 days generally gave slightly less control. A second application to the same plots 35 days following tillage resulted in greater than 90% reduction at all intervals. Approximately 3 months after the initial treatment the tuber population had been reduced to one half the original population. Germination of the remaining tubers was reduced more than 50%.

Glyphosate applied during the dry season caused an average of 79% reduction in plant numbers as compared to 88% in the rainy season. However, in the dry season, the remaining plants had no competition from other weeds and after 5 months there was only a 40% reduction in nutsedge population. During the rainy season, 1, 2 and 3 kg/ha were equally effective, but 1 kg/ha was not sufficient in the dry season.

INTRODUCTION

Purple nutsedge (Cyperus rotundus L.) is considered by Holm & Herberger (1969) to be the world's worst weed. Some of the principal reasons for this are its ability to proliferate rapidly, to produce tubers that can remain dormant and to compete vigorously. In El Salvador, plant populations of 2,000 plants/m^2 have been reported (Chase, Vides & Reyes, 1977). A 43% reduction in maize yield resulted from a nutsedge population of 700 plants/m^2 that was not cultivated until 30 days after maize planting (Chase, unpublished).

Other researchers have reported on the effectiveness of glyphosate in controlling this weed. Magambo & Terry (1973) in Tanzania achieved 95-100% control of foliage with 2 kg/ha. In Hawaii, glyphosate applied to nutsedge that had been undisturbed for 12 weeks killed the foliage and more than 75% of the tubers (Zandstra & Nishimoto, 1975). In Colombia, Gomez (1976) found that increased control of foliage, as well as a reduction in tuber number and germination of the remaining tubers, resulted when tillage followed application of glyphosate.

Because glyphosate is readily bound to soil (Sprankle, Meggitt & Penner, 1975), crops can be planted following application with little risk of injury.

In this study, we were interested in determining how many days were necessary between application of glyphosate and tillage to obtain optimum control of purple nutsedge during the rainy and the dry seasons in El Salvador.

MATERIALS AND METHODS

The experiments in this study were conducted at the San Andres Experiment Station, San Andres, El Salvador, from July 1975 to June 1976. The commercial formulation of the isopropylamine salt of glyphosate was used in all experiments. During the rainy season, which lasts approximately 5 months, rainfall averages approximately 13 mm per day. Very little rainfall occurs in the dry season.

Rainy season

Glyphosate was applied at 1, 2 and 3 kg/ha to a heavy infestation (approximately 1000 plants/m^2) of flowering purple nutsedge plants. The sandy loam soil had been disked 35 days earlier. Plots were tilled twice with a rotary tiller to a depth of 10 cm at 3, 7, 11, 15, 19 and 23 days following application. A non-sprayed treatment was tilled 3 days following application. Thirty days following each tillage plants were counted in four 0.1 m^2 quadrats per plot and averaged.

A second application was made 35 days following each tillage in an attempt to further reduce the population by controlling tubers that germinated following the tillage. Plots were again tilled and plants counted as previously described.

Applications were made with a CO_2 pressurized plot sprayer delivering 280 l./ha. Plot size was 2 x 4 m in a randomized block design with a factorial arrangement of treatments. Each treatment was replicated four times.

Sixty days following the last tillage of each treatment, four soil samples 20 cm deep x 20 cm in diameter were taken from each plot and the tubers were counted. One hundred tubers from each plot were covered with moist paper towels, placed at room temperature (about 25°C) for 5 days and checked for germination.

Approximately 8 months following the final application the trial area was disked. Thirty days later the plants were counted.

Dry season

Glyphosate at 1, 2 and 3 kg/ha was applied to nutsedge plants at the beginning of the dry season. Treatments were made to non-flowering plants 21 days following disking of the sandy loam soil and to flowering plants 35 days following disking, as in the rainy season study.

Plots were disked twice to a depth of 15 cm at 3, 11 and 19 days following application. Thirty days following each disking plants were counted as in the rainy season study.

Five months following the application the trial area was disked and plants were counted 30 days later.

Applications were made with a bicycle-wheel plot sprayer delivering 377 l./ha. There were three replications of a factorial arrangement in a randomized block design. Plot size was 3 x 7.5 m.

RESULTS

Rainy season

Three days following the first application severe necrosis was evident. Subsequent applications required from 6-8 days for the same effect.

One, 2 and 3 kg/ha of glyphosate were equally effective (data not shown). A period of 3 days between application and tillage was sufficient for 90% control (Table 1). Delays of 11-23 days generally gave slightly less control after the first application.

No benefit from tillage following application was evident after each of the 2 applications, but after 8 months the non-tilled treatment gave less control than the tilled ones, showing the eventual benefit of tillage.

The second application resulted in more than 90% reduction at all intervals (Table 1). The plant numbers in these treatments were compared with the tilled check, as the complete check was full of annual weeds and the nutsedge had senesced. Had we controlled the annual weeds and been able to use the complete check, the percentage reduction probably would have been even greater.

Glyphosate plus tillage reduced the tuber population by an average of more than 50% (Table 2). This agrees with the work of Gomez (1976) who found a reduction in tuber number after four applications of 2 kg/ha followed by tillage 30 days after each application. Doll & Piedrahita (1977) reduced the tuber population by 72% after three applications of 1.5 kg/ha followed by tillage.

TABLE 1. Percent reduction in number of purple nutsedge plants after different intervals between application of glyphosate and tillage. Rainy season trial.

Days between application & tillage	% Reduction*		
	1st application	2nd application	After 8 months
non-tilled	93 a[+]	94 ab[++]	75 b
3	90 ab	94 ab	84 a
7	89 abc	94 ab	87 a
11	85 cd	95 a	89 a
15	84 d	96 a	89 a
19	87 bcd	95 a	87 a
23	85 cd	92 b	88 a
(tilled check)	(12)		(16)

*Plant counts were made 30 days following tillage. In this table and those following, data are means of results from 1, 2 and 3 kg/ha of glyphosate.

[+] In this table and those following, results from means within a column followed by the same letter do not differ significantly at the 5% level according to Duncan's multiple range test.

[++] The plant populations were compared with the tilled check which was tilled on day 3.

TABLE 2. Percent reduction in number and germination of purple nutsedge tubers after different intervals between application of glyphosate and tillage. Rainy season trial.

Days between application & tillage	Reduction in number of tubers* (%)	Reduction in germination of tubers* (%)
non-tilled	47 a	40 c
3	55 a	60 ab
7	51 a	67 a
11	51 a	59 ab
15	48 a	68 a
19	54 a	53 b
23	55 a	59 ab
(tilled check)	(14)	(25)

*Tuber counts and germination tests were made 60 days following the last tillage of each treatment.

Of those tubers which were not killed after two applications, the reduction in germination ranged from 53-68% in the tilled treatments (Table 2). The non-tilled treatment gave only a 40% reduction. This further points out the advantage of tillage.

Dry season

Two and 3 kg/ha of glyphosate caused a greater reduction of plants (80 and 83%) 30 days after the initial tillage than did 1 kg/ha (74%), but there were no differences after 5 months (data not shown). There was also a slight increase in control after the initial tillage when glyphosate was applied at the flowering stage (81% reduction) as compared to the vegetative stage (77%), but again no differences were detected after 5 months (Table 3). Plant numbers were reduced by 79% after the initial tillage operation. This compares with an average of 88% during the rainy season. Five months after the initial application, control dropped off markedly to an average of 40%.

TABLE 3. Percent reduction of purple nutsedge plants after different intervals between application of glyphosate and tillage. Dry season trial.

Days between application & tillage	% Reduction*		
	Vegetative	Flowering	Average
	Initial tillage		
non-tilled	76	78	77 a
3	77	85	81 a
11	75	83	79 a
19	78	80	79 a
Average	77 b	81 a	79
	Tillage 5 months after application		
non-tilled	47	57	52 a
3	33	38	36 ab
11	35	24	30 b
19	35	45	40 ab
Average	38 a	41 a	40

*Plant counts were made 30 days following tillage. Means within columns can be compared as well as the means between the % reduction of the vegetative and flowering stages.

DISCUSSION

After the last tillage of plots during the rainy season, annual broadleaf weeds germinated, thrived and eventually covered the plots, resulting in senescense of the nutsedge. Therefore, during the remainder of the rainy season and all through the dry season, there were very few plants growing. At the beginning of the following rainy season, there was still an average of 87% reduction 30 days following tillage as compared with the untreated control. Conversely, in the dry season trial, after glyphosate application and subsequent tillage, there was sufficient moisture for growth of nutsedge, but very few annual weeds emerged from the relatively dry surface soil. Almost no rain fell during the dry season. Thus, the nutsedge had no competition and was able to grow well by sending roots deep into the soil. Undoubtedly these plants were producing new tubers. Five months after application, when these plots were disked and the plants were counted, there was an average of only 40% reduction as compared to the 79% after the initial tillage. This demonstrates the need to maintain good control of nutsedge as it will rapidly produce tubers and increase in population. Even the non-tilled treatment gave only a 52% reduction. Although 100% of the plants at the time of application may have been killed in these plots, other tubers germinated, producing new plants to produce tubers during the dry season.

Following the first application and subsequent tillage in the rainy season, we noticed that only a few annual plants germinated, while after the second application and tillage, numerous annuals germinated. Perhaps the high population of tubers in the soil following the first application inhibited the growth of these weeds, while after the second application there was an insufficient number of tubers to inhibit germination of these species. Terry (1974) also observed this phenomenon and noted ". . . one can well understand the growth handicaps faced by crops when they germinate in dense stands of this weed."

Our results indicate that a delay of 3 days between application and tillage is sufficient to give optimum control under the conditions of our trials. Pulver & Romero (1976) found that 3 kg/ha left on the plant for 2.5 days gave complete control of tuber germination. At 1.5 kg/ha, 5 days were needed. Doll et al. (1977) reported that 72 h were needed for the complete translocation of 1 kg/ha of glyphosate in nutsedge, while only 36 h were required for 3 kg/ha.

The number of tubers was reduced by about 50% and the germination percentage of the remaining tubers was reduced by greater than 50%. Terry (1974) found with the tetrazolium test that at 21-24 weeks, tubers that were dormant following application of glyphosate had not been killed. Work by Doll et al. (1977) would indicate that those tubers may not survive. They found that after an application of glyphosate, tubers that had not germinated in 60 days died, some requiring as long as 15 months to completely rot or desiccate.

Differences in rates of 1, 2 and 3 kg/ha of glyphosate were not evident during the rainy season, but in the dry season 2 and 3 kg/ha gave greater control than 1 kg/ha. While under our conditions in the rainy season 1 kg/ha was sufficient, the work of others (Pulver *et al.*, 1976; Zandstra *et al.*, 1975; Doll, 1977; and Gomez, 1976) would indicate that rates from 1.5 to 4 kg/ha are necessary to give much more consistent results.

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EFFECTS OF HUMIDITY AND MOISTURE STRESS ON GLYPHOSATE CONTROL OF CYPERUS ROTUNDUS L.

SUMMARY

Glyphosate at 2 kg/ha was more effective in reducing regrowth of purple nutsedge (Cyperus rotundus L.) scapes at 90% than at 50% relative humidity (r.h.), and more effective at -2 bars than at -11 bars of plant water potential. Regrowth of treated plants subjected to water stress of -1 to -8 bars was reduced 54-60% while at -11 bars growth inhibition was only 34%. A time interval of as little as 8 h between application and excision was sufficient to result in a 47% reduction in regrowth at 90% r.h. None of the treated plants, except those clipped immediately after application, produced new shoots from the basal bulb, while all of the non-treated control plants produced one or more new shoots. Experiments using ^{14}C-glyphosate substantiate the results observed in the regrowth studies. Three times more ^{14}C-label was translocated into the underground parts of nutsedge at 90% than at 50% r.h. Twice as much translocated at -2 bars than at -11 bars of water stress.

INTRODUCTION

Purple nutsedge is an important weed throughout most of the world. Native to India, it has been reported in 70 countries and is limited only by the cold temperatures of the northern countries (Holm & Herberger, 1970). It is a strong competitor with crops and at high populations it can render land almost useless for crop production. If clipped off at the soil surface, nutsedge can produce 1-3 cm of regrowth in a day. Nutsedge is difficult to control because of its ability to proliferate rapidly and its system of tuber chains in which many tubers are dormant due to apical dominance.

Glyphosate is a broad-spectrum post-emergence herbicide that has been shown to be effective in controlling purple nutsedge. Zandstra & Nishimoto (1975) obtained almost complete mortality of the foliage and more than 75% mortality of tubers with 2 kg/ha of glyphosate applied to purple nutsedge plants after 12 weeks of nondisturbance.

Many tropical areas of the world have distinct rainy and dry seasons. Humidity is high during the rainy season. The dry season brings a lower humidity and is accompanied by water stress. Humidity and water stress are important factors in herbicide effectiveness. High levels of humidity increased the amount of dalapon absorbed and translocated (Prasad, Foy & Crafts, 1967). Jordan (1977) reported from five to six times more ^{14}C-labeled glyphosate was translocated into bermudagrass at 100% than at 40% r.h. In a review of the effect of water stress on herbicide efficiency, Shahi (1975) reports that translocation of several foliar-applied herbicides was reduced after advanced water stress, but absorption was not materially affected.

We (Chase & Appleby, 1969) found purple nutsedge to be somewhat more susceptible to glyphosate during the rainy season in El Salvador than during the dry season. This study was undertaken to investigate the influence of humidity and water stress on toxicity of glyphosate to purple nutsedge.

MATERIALS AND METHODS

Tubers were collected from plants grown from tubers collected in El Salvador, Central America. These plants were grown in the glasshouse at Corvallis, Oregon, U.S.A., at approximately 24°C. In all trials, four nutsedge tubers of similar size were planted 2 cm deep in 760 g of sandy loam soil in plastic pots. All pots were placed in a growth chamber under high humidity for 10 days to ensure even germination. Half of the pots were then removed to another growth chamber under low humidity. The photoperiod was a constant 12 h. Temperature was maintained at 29°C during the day and 24°C during the night. Light intensity was approximately 20 klux, from a mixture of fluorescent and incandescent lamps.

Two kg/ha of glyphosate were applied in water at 333 l./ha. Application was made when most plants had flowered, which was 30 to 35 days after planting.

All plants were clipped approximately 1 cm above the soil surface. Except where noted, this was done 24 h following application of the herbicide. Plants were irrigated immediately after clipping. Regrowth of the remaining scape (naked flower stem arising from the ground) was measured 2 and 4 days after excision. Only plants that had flowered were evaluated, as these produced a scape, while vegetative plants continued to produce leaves. Regrowth from treated plants was compared with regrowth from untreated check plants. After the 4-day evaluation, plants were removed to the glasshouse and evaluated after 10 days for new shoot growth.

The statistical design was a randomized block with four replications and a factorial arrangement of treatments, unless otherwise noted. With the exception of the experiment on degree of moisture stress, all experiments were conducted at least twice.

Environmental effects on glyphosate toxicity

Two experiments were conducted to determine the influence of humidity and moisture stress on glyphosate toxicity as measured by regrowth of the excised scape. Plants were grown at 50% or 90% r.h. in the first experiment, and at 70% or 90% r.h. in the second. All pots were irrigated evenly until 5-6 days before application, at which time water was withheld from plants to be stressed. At the time of application, the water potential of excised scapes was measured with a pressure chamber. Extra plants grown under the same conditions were used for this purpose. In both experiments, water potential was -2 bars or -14 bars. Wilting was evident in the plants under high water stress. In the 24 h following application until excision, water potential in these plants decreased to -20 bars.

Translocation of ^{14}C-glyphosate

^{14}C-methyl labeled glyphosate with a specific activity of 1.95 mCi/mmole was diluted and converted from the acid to the isopropylamine salt by adding 1.27 ml water, 3.69 ul isopropylamine, and 0.133 ml of commercial glyphosate formulation to 2.49 mg of the labeled acid. This gave 1.4 ml of solution. Ten ul (0.2 uCi) were applied to each plant.

Plants were grown at 40% or 90% humidity. The plant water potential at time of application was -2 and -11 bars.

Flowering plants were sprayed with 2 kg/ha of commercially-formulated glyphosate 34 days after planting. The spray was allowed to dry, then 10 ul of the ^{14}C-glyphosate solution was applied in a lanolin ring in the middle of a recently matured leaf. All plants were harvested 24 h later and separated into treated leaf, other leaves and inflorescence, roots, basal bulb and tuber. Plant parts were weighed, placed in plastic bags and frozen. The plant parts were then oxidized in a sample oxidizer and the $^{14}CO_2$ was captured in a liquid scintillation cocktail. Samples were counted in a scintillation counter. Counts per minute were corrected for efficiency and converted to disintegrations per minute (dpm). Total dpm were calculated per plant by adding the dpm from the treated leaf, other leaves and inflorescence, tubers, roots and basal bulb.

Degree of moisture stress on glyphosate toxicity

To determine the plant water potential at which translocation begins to be inhibited, an experiment was conducted in which four levels of plant water potential were evaluated: -1, -3, -8 and -11 bars. Plants were grown at 60% r.h.

Time required for translocation

Two experiments were conducted to determine the time required for glyphosate to inhibit regrowth under environmental stress. Humidity levels were 50% and 90% r.h. in both experiments. In Experiment 2-a, glyphosate was applied and plants were excised immediately following application, and at 8, 16 and 24 h. In Experiment 2-b, plants were excised immediately after application, and at 4 and 8 h.

RESULTS

Environmental effects on glyphosate toxicity

Although regrowth was measured at 2 and 4 days following excision, there were no meaningful differences between the two. Very little regrowth occurred after 4 days.

The effectiveness of glyphosate in reducing regrowth of the nutsedge scape was greater at 90% than at 50% r.h., and was greater at -2 than -14 bars of plant water potential (Table 1). In Experiment 1-a, regrowth was reduced by 73% at 90% r.h. and low moisture stress, but the reduction was less with increased water stress or at 50% r.h. Low moisture stress at 50% r.h. and high moisture stress at 90% r.h. resulted in comparable reductions in regrowth, showing the adverse effect of either low humidity or high moisture stress on glyphosate activity. Jordan (1977) reported similar results with bermudagrass. He found that .56 kg/ha of glyphosate was twice as toxic at 100% as at 40% r.h. Translocation of ^{14}C-labeled 2,4-D was also greatly increased under high humidity (Clor, Crafts & Yamaguchi, 1962). According to Basler, Todd & Meyer (1961), relative turgidity as a measure of water stress was a good indicator of the ability of bean plants to translocate 2,4-D. They found that only trace amounts of 2,4-D translocated in plants with relative turgidity below 80%, while more translocation occurred as turgidity increased in plants with relative turgidity above 80%. Wiebe & Wihrheim (1962) reported that translocation of ^{14}C-labeled photosynthate in wilted sunflower plants with diffusion pressure deficits of 10-12 atm was a third that

TABLE 1. Percent reduction in regrowth of nutsedge scape following application of 2 kg/ha of glyphosate to nutsedge plants under environmental stress.

Relative humidity (%)	Moisture stress (bars)	Reduction in regrowth (%)
	Experiment 1-a	
50	-14	15 c*
	-2	43 b
90	-14	35 b
	-2	73 a
	Experiment 1-b	
70	-14	25 c
	-2	65 a
90	-14	44 b
	-2	77 a

*In this table and those following, means within a column followed by the same letter do not differ significantly at the 5% level according to Duncan's multiple range test.

of translocation in fully turgid plants with a diffusion pressure deficit of 1-2 atm. Magalhaes & Foy (1967) however, found no effect of moisture stress on translocation of dicamba in purple nutsedge.

In Experiment 1-b, glyphosate was more effective in reducing regrowth of plants treated at high than at low humidity levels (Table 1). Under these conditions there was no significant difference in regrowth between humidity levels at -2 bars of plant water potential. However, glyphosate was more effective at 70% r.h. and -2 bars of plant water potential than at 90% r.h. and -14 bars of water potential, indicating that, in this experiment, moisture stress was a more important factor than r.h. in determining translocation.

After measurements of regrowth were taken, plants were removed to the glasshouse and after 10 days were evaluated for any new shoots coming from the basal bulbs. All of the untreated control plants produced new shoots, whereas none of the treated plants did. Even at 50% r.h. and high moisture stress, enough glyphosate translocated in 24 h to the basal bulb to inhibit new shoot growth.

<u>Translocation of ^{14}C-glyphosate</u>

To substantiate the results of the preceding study, a ^{14}C-glyphosate translocation experiment was performed. Twice as much of the ^{14}C-label translocated into the tubers at 90% as at 40% r.h. (Table 2). There was also twice as much translocation at -2 bars as at -11 bars of water stress. Movement into the basal bulb was about five times greater at 90% than at 40% r.h., while there were no differences between -2 and -11 bars of stress. The total belowground translocation was

TABLE 2. Translocation of 0.2 uCi ^{14}C-glyphosate to underground parts of purple nutsedge after 24 h at 40% or 90% relative humidity and -2 or -11 bars of moisture stress.

		Percent of recovered ^{14}C activity (dpm) belowground distribution			
Relative humidity (%)	Moisture stress (bars)	Translocated to tubers (%)	Translocated to basal bulbs (%)	Translocated to roots (%)	Total belowground translocation (%)
40	-11	0.25 b	0.18 b	0.16 b	0.59 c
	-2	0.53 b	0.14 b	0.25 b	0.92 bc
90	-11	0.53 b	0.72 a	0.27 b	1.51 b
	-2	1.06 a	0.97 a	1.07 a	3.07 a

three times greater at 90% than at 40% r.h. About twice as much translocated at -2 bars as at -11 bars of water stress. This agrees with the work by Pallas (1959) who reported that bean plants growing in soil near the permanent wilting point translocated only half as much 2,4-D as plants growing in soil at field capacity.

The relative percentage of ^{14}C-label recovered in the below-ground parts at different levels of humidity and moisture stress help explain differences in percent reduction in regrowth (Table 3). At low humidity and high moisture stress there was little ^{14}C-label translocated and little reduction in regrowth. At high humidity and low moisture stress, five times more ^{14}C-label was recovered and there was a comparable amount of reduction in regrowth.

We did not identify the ^{14}C-label as intact glyphosate. However, glyphosate appears to be quite stable in the plant during the time period involved in these studies. Zandstra & Nishimoto (1977) reported no evidence of metabolism of glyphosate in purple nutsedge leaves or tubers.

Degree of moisture stress on glyphosate toxicity

Application of glyphosate under moisture stress of -1, -3 and -8 bars resulted in similar regrowth inhibition (Table 4), while application under -11 bars was much less effective, indicating decreased translocation. These findings do not agree with the results of several researchers who worked with the effects of water stress on phenoxy herbicides (Merkle et al., 1967; Pallas et al., 1962; Basler et al., 1961). They found gradual decreases in translocation with

TABLE 3. Comparison between percent translocation of ^{14}C-glyphosate to underground plant parts and percent reduction in regrowth of nutsedge scape. From Tables 1 and 2.

Relative humidity*	Moisture stress	Recovered ^{14}C-label (%)	Reduction in regrowth (%)	
low	high	.59 c	15 c	
low	low	.92 bc	43 b	r=.91
high	high	1.51 b	35 b	
high	low	3.07 a	73 a	

*Environmental conditions in ^{14}C-labeled experiment were 40% and 90% r.h., and -2 and -11 bars of water stress.

Environmental conditions in regrowth experiment were 50% and 90% r.h., and -2 and -14 bars of water stress.

TABLE 4. Percent reduction in regrowth of nutsedge scape following application of 2 kg/ha of glyphosate under varying levels of moisture stress.

Moisture stress (bars)	Reduction in regrowth (%)
-1	60 a
-3	59 a
-8	54 a
-11	34 b

increasing water stress. Merkle et al. (1967), however, found that moderate water stress in bean plants did not affect the translocation of picloram, while advanced stress did reduce the translocation.

None of the treated plants produced new shoots after being removed to the glasshouse, whereas all of the untreated control plants produced one or more new shoots.

Time required for translocation

There was more reduction in regrowth of the nutsedge scape at 90% than at 50% r.h. (Table 5). At 90% r.h., 8 h was sufficient between application and excision to produce 47% reduction in regrowth. At 50% r.h. nearly 24 h was required to produce the same effect. A time interval of just 4 h at 90% r.h. resulted in 25% reduction in regrowth (Experiment 2-b). Foliar absorption of glyphosate has been shown to occur rapidly (Sprankle, Meggitt & Penner, 1975). They reported 34% of ^{14}C-glyphosate applied to quackgrass was absorbed after 4 h. The percentage increased up to 45% after 24 h.

We have no explanation of why there was a significant increase in regrowth in plants that were sprayed and clipped immediately.

All of the untreated control plants produced new shoots from the basal bulbs 10 days after plants were removed to the glasshouse. None of the treated plants, except those excised immediately after application, produced new shoots.

TABLE 5. Percent reduction in regrowth of nutsedge scapes that were clipped at different time intervals following application of 2 kg/ha of glyphosate at 50% and 90% relative humidity.*

Relative humidity (%)	Time between application and excision (h)	Reduction in regrowth (%)
	Experiment 2-a	
50	immediately	-71 d
	8	19 bc
	16	36 abc
	24	50 ab
90	immediately	2 c
	8	47 ab
	16	73 a
	24	79 a
	Experiment 2-b	
50	immediately	-10 c
	4	3 bc
	8	35 a
90	immediately	6 bc
	4	25 ab
	8	44 a

*Moisture stress level was approximately -2 bars.

DISCUSSION

The amount of glyphosate found in the belowground parts decreased under conditions of high water stress. This poses the question as to whether the reduced movement is due to reduced absorption, translocation or both processes. Pallas (1959) reported that translocation of 2,4-D was reduced when bean plants were grown in soil near the wilting point, but no effect was found on absorption of the herbicide. Foliar absorption of picloram and 2,4,5-T in beans was unaffected by extreme moisture stress, but herbicidal movement was markedly reduced (Merkle et al., 1967). These results, along with similar results (Basler et al., 1961; Pallas & Williams, 1962) indicate that decreases in translocation of some foliar-applied herbicides in plants under water stress are not due to a decrease in absorption, but to movement within the plant. Basler et al. (1961) suggested that the decrease in translocation was due to alterations in metabolism or of cellular structure and composition within the tissue rather than to water stress alone. Their evidence to support this theory was that water-stressed plants required several hours to regain the ability to translocate 2,4-D even though they had regained their turgidity within 1 or 2 h. Crafts (1968) reported that water stress reduced: water movement into the phloem at the source, the volume of the assimilate stream, and the velocity of flow.

Our results show increased glyphosate toxicity at high humidity. High humidity is generally accepted as having a significant influence on increased uptake as shown by several workers (Clor et al., 1962;

Prasad, 1967; Jordan, 1977). This may be due to a number of factors: delay in evaporation of the droplet, promotion of stomatal opening and hydrated cuticle (Richardson, 1967).

That glyphosate is absorbed and translocated rapidly is shown by the 25% reduction in regrowth of scapes when plants were excised only 4 h following application. Furthermore, no new shoots were produced from the basal bulbs of any plants that were treated, while all of the untreated control plants produced new shoots. Evidently only a small amount of glyphosate is sufficient to inhibit regrowth of these shoots; even at 50% r.h., plants were able to translocate sufficient glyphosate in just 4 h to inhibit new shoot growth. Radiotracer studies indicate that much less than 1% of the applied glyphosate was translocated to belowground parts in 4 h.

Measuring scape regrowth of purple nutsedge grown from single tubers is a new method that we developed to obtain fast reliable data. One problem encountered is that when the scape of mature plants is cut, it produces only a small amount of regrowth and the reduction in regrowth is difficult to detect. Therefore, it is necessary to make the application when most plants have flowered but before some are too mature. An unavoidable problem is that regrowth of the scape appears to be dependent on the number of new shoots and developing tubers that are being formed by the parent plant. A scape may produce twice as much regrowth if the parent plant has only one new shoot as compared to a plant with more than one new shoot and a new tuber being formed.

In summary, glyphosate effectiveness was reduced under high moisture stress and low humidity. Moderate water stress did not affect movement. Glyphosate was absorbed and translocated rapidly in purple nutsedge, as shown by a reduction in regrowth of the scape and by inhibition of new shoot growth from the basal bulbs.

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APPENDICES

Appendix A

Analyses from experiments reported in text

I. Effect of intervals between application and tillage on glyphosate control of Cyperus rotundus L.

A. Percent reduction in number of purple nutsedge plants after different intervals between application of glyphosate and tillage. Rainy season trial.

First application

Analysis of variance

Source	df	SS	MS	F
Replications	3	273.46	91.15	4.03*
Herbicide	2	6.93	3.46	0.15
Days	6	770.98	128.50	5.68**
Herb. x Days	12	343.24	28.60	1.27
Error	60	1356.27	22.60	
Total	83	2750.89		

Second Application

Analysis of variance

Source	df	SS	MS	F
Replications	3	118.61	39.53	5.30**
Herbicide	2	46.45	23.23	3.12
Days	6	106.57	17.76	2.38*
Herb. x Days	12	70.21	5.85	0.79
Error	60	447.14	7.45	
Total	83	788.99		

After 8 months

Analysis of variance

Source	df	SS	MS	F
Replications	3	375.08	125.03	1.70
Herbicide	2	710.31	355.15	4.84*
Days	6	1780.12	296.69	4.03**
Herb. x Days	12	936.52	78.04	1.06
Error	60	4406.65	73.44	
Total	83	8208.70		

B. Percent reduction in number of tubers after different intervals between application of glyphosate and tillage. Rainy season trial.

Analysis of variance

Source	df	SS	MS	F
Replications	3	1086.14	362.05	1.79
Herbicide	2	417.24	208.62	1.03
Days	6	1181.14	196.85	0.97
Herb. x Days	12	1185.93	157.16	0.78
Error	60	12144.39	202.40	
Total	83	16714.81		

C. Percent reduction in germination of purple nutsedge tubers after different intervals between application of glyphosate and tillage. Rainy season trial.

Analysis of variance

Source	df	SS	MS	F
Replications	3	1567.04	522.35	2.37
Herbicide	2	296.00	148.00	0.67
Days	6	6879.14	1146.52	5.22**
Herb. x Days	12	1956.50	163.04	0.74
Error	60	13186.45	219.77	
Total	83	23885.14		

D. Percent reduction of purple nutsedge after different intervals between application of glyphosate and tillage. Dry season trial.

Initial tillage

Analysis of variance

Source	df	SS	MS	F
Replications	2	4413.25	2206.63	30.38**
Herbicide	2	1002.08	501.04	6.90**
Days	3	257.50	85.83	1.18
Time	1	392.00	392.00	5.39*
Time x Herb.	2	38.58	19.29	0.27
Time x Days	3	131.11	43.70	0.60
Herb. x Days	6	1092.92	182.15	2.50*
Time x Herb. x Days	6	751.31	125.21	1.72
Error	46	3340.74	72.62	
Total	71	11419.50		

Tillage 5 months after application

Analysis of variance

Source	df	SS	MS	F
Replications	2	10169.44	5084.72	9.38**
Herbicide	2	2131.69	1065.85	1.97
Days	3	4587.11	1529.04	2.82
Time	1	128.00	128.00	0.23
Time x Herb.	2	716.08	358.04	0.66
Time x Days	3	1329.11	443.04	0.82
Herb. x Days	6	4514.97	752.49	1.39
Time x Herb. x Days	6	1645.47	274.25	0.51
Error	46	24923.00	541.81	
Total	71	50145.00		

II. Effects of humidity and moisture stress on glyphosate control of Cyperus rotundus L.

A. Percent reduction in regrowth of nutsedge scape following application of 2 kg/ha of glyphosate to nutsedge plants under environmental stress.

Experiment 1

Analysis of variance

Source	df	SS	MS	F
Replications	3	978.25	362.08	1.28
Humidity	1	2782.63	2782.63	7.85**
Moisture	1	4590.13	4590.13	12.95**
Hum. x Moist.	1	52.50	52.50	0.15
Error	9	3189.80	354.40	
Total	15	11593.00		

Experiment 2

Analysis of variance

Source	df	SS	MS	F
Replications	3	270.75	90.25	0.89
Humidity	1	900.00	900.00	8.91**
Moisture	1	5476.00	5476.00	54.23**
Hum. x Moist.	1	30.25	30.25	0.29
Error	9	908.75	100.97	
Total	15	7585.75		

B. Translocation of 0.2 uCi ^{14}C-glyphosate to underground parts of purple nutsedge after 24 h at 40% or 90% relative humidity and -2 or -11 bars of moisture stress. Percent of recovered ^{14}C activity (dpm).

Translocated to tubers

Analysis of variance

Source	df	SS	MS	F
Replications	3	0.544	0.181	2.20
Humidity	1	0.636	0.636	7.75*
Moisture	1	0.652	0.652	7.95*
Hum. x Moist.	1	0.061	0.061	0.74
Error	9	0.739	0.082	
Total	15	2.632		

Translocated to basal bulbs

Analysis of variance

Source	df	SS	MS	F
Replications	3	0.194	0.065	0.73
Humidity	1	1.891	1.891	21.25**
Moisture	1	0.048	0.048	0.53
Hum. x Moist.	1	0.087	0.087	0.98
Error	9	0.801	0.089	
Total	15	3.021		

Translocated to roots

Analysis of variance

Source	df	SS	MS	F
Replications	3	0.259	0.087	1.97
Humidity	1	0.856	0.856	19.45**
Moisture	1	0.783	0.783	17.80**
Hum. x Moist.	1	0.490	0.490	11.26**
Error	9	0.892	0.044	
Total	15	2.780		

Total below-ground translocation

Analysis of variance

Source	df	SS	MS	F
Replications	3	1.491	0.497	1.90
Humidity	1	9.440	9.440	36.03**
Moisture	1	3.563	3.563	13.60**
Hum. x Moist.	1	1.482	1.482	5.66*
Error	9	2.356	0.262	
Total	15	18.332		

C. Percent reduction in regrowth of nutsedge scape following application of 2 kg/ha of glyphosate under varying levels of moisture stress.

Analysis of variance

Source	df	SS	MS	F
Replications	3	768.75	256.25	2.75
Stress levels	3	1794.25	598.08	6.42*
Error	9	838.75	93.19	
Total	15	3401.75		

D. Percent reduction in regrowth of nutsedge scapes that were excised at different time intervals following application of 2 kg/ha of glyphosate at 50% and 90% relative humidity.

Experiment a

Analysis of variance

Source	df	SS	MS	F
Replications	3	3537.63	1179.21	1.69
Humidity	1	13695.13	13695.13	19.61**
Time Interval	3	48207.13	16069.04	23.00**
Hum. x Time	3	2755.63	918.54	1.32
Error	21	14667.38	698.45	
Total	31	82862.87		

Experiment b

Analysis of variance

Source	df	SS	MS	F
Replications	3	901.46	300.48	1.37
Humidity	1	1457.04	1457.04	6.63*
Time Interval	2	7150.75	3575.38	16.27**
Hum. x Time	2	169.08	84.54	0.38
Error	15	3296.25	219.75	
Total	23	12974.63		

Appendix B

Data and analyses from experiments not reported in text

I. Effect of intervals between application and tillage on glyphosate control of <u>Cyperus rotundus</u> L.

All data reported in text.

II. Effects of humidity and moisture stress on glyphosate control of <u>Cyperus rotundus</u> L.

A. Percent reduction in regrowth of nutsedge scapes following application of 2 kg/ha of glyphosate to plants under environmental stress.

<u>Experiment 1</u>

Summary

This experiment was a preliminary one to establish a technique for promoting moisture stress. Water was added almost daily to the pots in order to maintain levels of stress. This method was not effective and was abandoned. However, differences in regrowth due to varying levels of humidity were apparent. Regrowth was also inhibited more when plants were excised at 48 hours than those excised at 24 hours.

Results

Humidity (%)	Moisture (%)	Time* (hrs.)	Reduction in regrowth (%)
50	13	24	69.3 d
50	13	48	80.8 b
50	26	24	73.9 cd
50	26	48	87.1 a
80	13	24	74.0 cd
80	13	48	90.3 a
80	26	24	76.6 bc
80	26	48	89.0 a

*Time between application of glyphosate and excision.

Reduction in regrowth means

Humidity		Moisture		Time	
50%	77.79 b	13%	78.62 a	24 hrs.	73.44 b
80%	82.47 a	26%	81.64 a	48 hrs.	86.82 a

Analysis of variance

Source	df	SS	MS	F
Replications	3	168.17	56.05	3.32*
Humidity	1	175.58	175.78	10.41**
Moisture	1	73.21	73.21	4.33*
Time	1	1431.13	1431.13	84.73**
Hum. x Moist.	1	46.56	46.56	2.75
Hum. x Time	1	7.41	7.41	0.44
Moist. x Time	1	2.64	2.64	0.16
Hum. x Moist. x Time	1	15.96	15.96	0.95
Error	21	354.62	16.89	
Total	31	2275.48		

Experiment 2

Summary

Although there was a lot of variability in regrowth and no differences were significant, the trend of less reduction in regrowth with more stress (either humidity or moisture) was evident.

Results

Humidity (%)	Moisture stress (bars)	Reduction in regrowth (%)
65	-11	-14.75 a
65	-2	49.50 a
85	-11	58.50 a
85	-2	73.00 a

Analysis of variance

Source	df	SS	MS	F
Replications	3	7983.75	2661.25	1.31
Humidity	1	9360.62	9360.62	2.97
Moisture	1	6201.00	6201.00	4.62
Hum. x Moist.	1	2635.38	2635.38	1.30
Error	9	18197.00	2021.89	
Total	15	44218.00		

Reduction in regrowth means
(%)

Humidity		Moisture stress	
65%	17.4 a	-11 bars	21.9 a
85%	65.7 a	-2 bars	61.2 a

Experiment 3

Summary

In this experiment there was only slight differences between the two moisture levels, -2 bars as compared with -4 bars of stress. As a result no differences in regrowth were apparent. There was, however, a large difference in regrowth between the two humidity levels.

Results

Humidity (%)	Moisture stress (bars)	Reduction in regrowth (%)
50	-4	35.75 a
50	-2	41.75 a
85	-4	73.00 a
85	-2	64.50 a

Analysis of variance

Source	df	SS	MS	F
Replications	3	4687.50	1562.50	2.75
Humidity	1	3600.00	3600.00	6.33*
Moisture	1	6.25	6.25	0.01
Hum. x Moist.	1	210.25	210.25	0.37
Error	9	5119.00	568.80	
Total	15	13623.00		

Reduction in regrowth means
(%)

Humidity		Moisture stress	
65%	38.75 b	-4 bars	54.37 a
85%	68.75 a	-2 bars	53.12 a

B. Percent reduction in regrowth of nutsedge scapes that were clipped at different time intervals following application of 2 kg/ha of glyphosate at 50% and 80% relative humidity.

Summary

This experiment was conducted in different growth chambers than the ones used in previous experiments. Although humidity levels were the same as other experiments, no differences in regrowth due to those levels were detected. The trend of less regrowth with more time between application and excision was the same as in previous trials however.

Results

Humidity (%)	Time (hrs.)	Reduction in regrowth (%)
50	immediately	-7.5 c
50	8	39.5 b
50	16	51.5 ab
50	24	60.2 ab
80	immediately	-8.5 c
80	8	49.0 ab
80	16	52.0 ab
80	24	68.0 a

Analysis of variance

Source	df	SS	MS	F
Replications	3	3121.34	1040.45	3.66
Humidity	1	140.28	140.28	0.49
Time	3	24213.09	8071.03	28.39**
Hum. x Time	3	162.84	54.28	0.19
Error	21	5964.40	284.26	
Total	31	33606.97		

Reduction in regrowth means (%)

Humidity		Time	
50%	35.94 a	immediately	-8.00 c
80%	40.11 a	8	44.25 b
		16	51.75 ab
		24	64.12 a

C. Percent reduction in regrowth of nutsedge scapes that were clipped at different time intervals following application of 2 kg/ha of glyphosate.

Summary

Inhibition of new shoot growth from basal bulbs following excision was observed in previous trials when the interval between application and excision was as little as 4 hours. In this experiment the interval was reduced to 3 hours. New shoot growth was observed from the 3-hour, but not the 6-hour interval.

There was a trend toward stimulation of regrowth by glyphosate when the plants were excised immediately following application.

Results

Time (hrs.)	Reduction in regrowth (%)
immediately	-48.0 a
3	3.0 a
6	31.0 a

Analysis of variance

Source	df	SS	MS	F
Replications	3	8304.00	2768.00	1.89
Time	2	13065.00	6533.00	4.47
Error	6	8780.00	1463.00	
Total	11	30149.00		

D. Translocation of 0.2 uCi ^{14}C-glyphosate to underground parts of purple nutsedge after 24 hours at 50% or 80% relative humidity and -2 or -14 bars of moisture stress.

Summary

This experiment was performed in growth chambers different from the ones in which the previously reported radioactive experiment was conducted. There were no differences in translocation at 50 or 80% relative humidity, which corresponds to a similar lack of difference in regrowth in another experiment conducted in the same growth chambers (see Appendix B, section B). Although not significant, translocation at -2 bars of moisture stress was twice that of translocation at -14 bars of stress, the same ratio reported in the previous radioactive experiment (see recovered ^{14}C means, p. 51).

Percent of recovered ^{14}C activity (dpm) in basal bulbs

Results

Humidity (%)	Moisture stress (bars)	Recovered ^{14}C (%)
50	-14	0.08 a
50	-2	0.24 a
80	-14	0.13 a
80	-2	0.10 a

Analysis of variance

Source	df	SS	MS	F
Replications	2	0.0065	0.0032	0.36
Humidity	1	0.0075	0.0075	0.83
Moisture	1	0.0133	0.0133	1.47
Hum. x Moist.	1	0.0261	0.0261	2.89
Error	6	0.0550	0.0090	
Total	11	0.0960		

Percent of recovered ^{14}C means

Humidity		Moisture stress	
50%	0.16 a	-14 bars	0.10 a
80%	0.11 a	-2 bars	0.17 a

Percent of recovered ^{14}C activity (dpm) in tubers

Results

Humidity (%)	Moisture stress (bars)	Recovered ^{14}C (%)
50	-14	0.14 a
50	-2	0.49 a
80	-14	0.26 a
80	-2	0.47 a

Analysis of variance

Source	df	SS	MS	F
Replications	2	0.0889	0.0444	0.370
Humidity	1	0.0080	0.0080	0.067
Moisture	1	0.2269	0.2269	1.910
Hum. x Moist.	1	0.0140	0.0140	0.118
Error	6	0.7120	0.1187	
Total	11	1.0497		

Percent of recovered ^{14}C means

Humidity		Moisture stress	
50%	0.32 a	-14 bars	0.20 a
80%	0.37 a	-2 bars	0.48 a

Percent of recovered ^{14}C activity (dpm) in below-ground plant parts

Results

Humidity (%)	Moisture stress (bars)	Recovered ^{14}C (%)
50	-14	0.23 a
50	-2	0.73 a
80	-14	0.39 a
80	-2	0.55 a

Analysis of variance

Source	df	SS	MS	F
Replications	2	0.0692	0.0346	0.200
Humicity	1	0.0004	0.0004	0.002
Moisture	1	0.3300	0.3300	1.960
Hum. x Moist.	1	0.0884	0.0884	0.520
Error	6	1.0104	0.1684	
Total	11	1.4985		

Percent of recovered ^{14}C means

Humidity		Moisture stress	
50%	0.48 a	-14 bars	0.31 a
80%	0.47 a	-2 bars	0.64 a

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