AN ABSTRACT OF THE THESIS OF

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Title: Cyperus esculentus Control with Glyphosate: Time of Application and Addition of Ammonium Sulfate.

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Cyperus esculentus L. var. esculentus is a serious weed problem in northwest Spain. Long-term control from glyphosate and other herbicides has been inconsistent. Field, greenhouse, and laboratory studies were conducted on factors influencing the activity of glyphosate on C. esculentus.

In field studies, glyphosate controlled foliage growth at most growth stages. Number and weight of new tubers were reduced by glyphosate treatment. Reinfestation the following year was reduced most by treatments made when new tubers were beginning to form, thus creating a strong "sink," toward which sugars and glyphosate translocated. Later applications, when tubers were mostly mature, were less effective.

A method was developed that involved marking and comparing growth of new and old leaves in order to measure short-term effects from glyphosate. This method was non-destructive, easier, and gave more consistent results than measuring fresh weights.

Several studies on the effect of adding ammonium sulfate to

glyphosate solutions have been reported previously. Results have been varied. In my studies, the addition of ammonium sulfate to glyphosate solution sometimes caused a greater reduction in leaf growth on a short-term basis. This was especially true when leaves were washed 3 h following treatment or when glyphosate was mixed with simazine or calcium chloride. The ammonium sulfate overcame a slight antagonistic effect from the calcium chloride.

The effect of ammonium sulfate on glyphosate translocation was studied by treating the distal 10 cm of two leaves and removing the treated portions 1 day later. Growth of the remaining leaves was measured. The addition of ammonium sulfate reduced the effect of glyphosate on untreated leaves, indicating that the ammonium sulfate had inhibited glyphosate translocation. Studies with $^{14}C$-glyphosate indicated that ammonium sulfate increased the rate of glyphosate absorption, but did not affect total absorption. Glyphosate translocation from treated portions of the plant was not significantly affected. These results tend to support the concept of adding ammonium sulfate to a glyphosate solution when treating annual weeds, especially when using hard water, but there appears to be no advantage from adding ammonium sulfate when treating C. esculentus.

# *CYPERUS ESCULENTUS* CONTROL WITH GLYPHOSATE: TIME OF APPLICATION AND ADDITION OF AMMONIUM SULFATE

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# CYPERUS ESCULENTUS CONTROL WITH GLYPHOSATE TIME OF APPLICATION AND ADDITION OF AMMONIUM SULFATE

## GENERAL INTRODUCTION

Yellow nutsedge (Cyperus esculentus L.) is a troublesome perennial weed found in many areas of the world. Holm et al. (1977) rank it as one of the world's 20 worst weeds. In spite of vigorous attempts to develop control measures, this weed continues to plague growers in many areas and is threatening to become a problem in higher latitude areas of France (Morin and Sombrun, 1984) and Holland (Rotteveel, 1982). Response of the nutsedge to herbicide treatment is inconsistent from one situation to another. Costa and Appleby (1976) reported that two varieties of C. esculentus responded differently to herbicides, thus possibly explaining part of the inconsistency in control. Other reasons could include a wide range of environmental factors such as temperature, light, crop management, soil type, moisture conditions, and day-length.

Glyphosate is a foliage-applied, translocated herbicide which has controlled yellow nutsedge in many situations. Long-term control from glyphosate is sometimes inadequate, indicating the need to determine optimum conditions for herbicide application.

The purpose of this thesis was to investigate various aspects of yellow nutsedge control with glyphosate. The work was initiated at La Coruña in northwest Spain. Following a transfer to Lerida in northeast Spain and subsequently to Madrid, the work continued

primarily as greenhouse and laboratory research. The work was conducted over several years, beginning in 1977.

# CHAPTER I. Field Studies of *Cyperus esculentus* Control in Northern Spain with Glyphosate

## INTRODUCTION

*Cyperus esculentus* L. var. *esculentus* is an important weed problem in maize grown in northwest Spain (Figure 1-1). Flowering of this weed does not occur in the area and reproduction is entirely by the production of rhizomes and tubers. Infestations of over 5,000 tubers per square meter can occur if appropriate control measures are not taken.

Holm et al. (1977) have described the distribution and biology of yellow nutsedge in various areas of the world. They indicate that this weed is considered a problem in one-third of the crops in which it occurs, and they consider it to be among the 20 worst weeds in the world. Stoller (1981) has reviewed the biology and control measures for yellow nutsedge in the Corn Belt of the United States.

The primary infestations of *C. esculentus* L. var *esculentus* in Spain are in the northwest area near the coast, which is moist during most of the year and has mild winter temperatures. The weed does not flower in this area, although some flowering plants may be found near the coast in north Portugal. The life cycle of *C. esculentus* in northwest Spain is similar to that described for the U.S. Corn Belt with minor exceptions. Sprouting of the tubers usually starts in April and growth continues until frost kills the foliage of the weed, approximately in November (Figure 1-2). Shoot

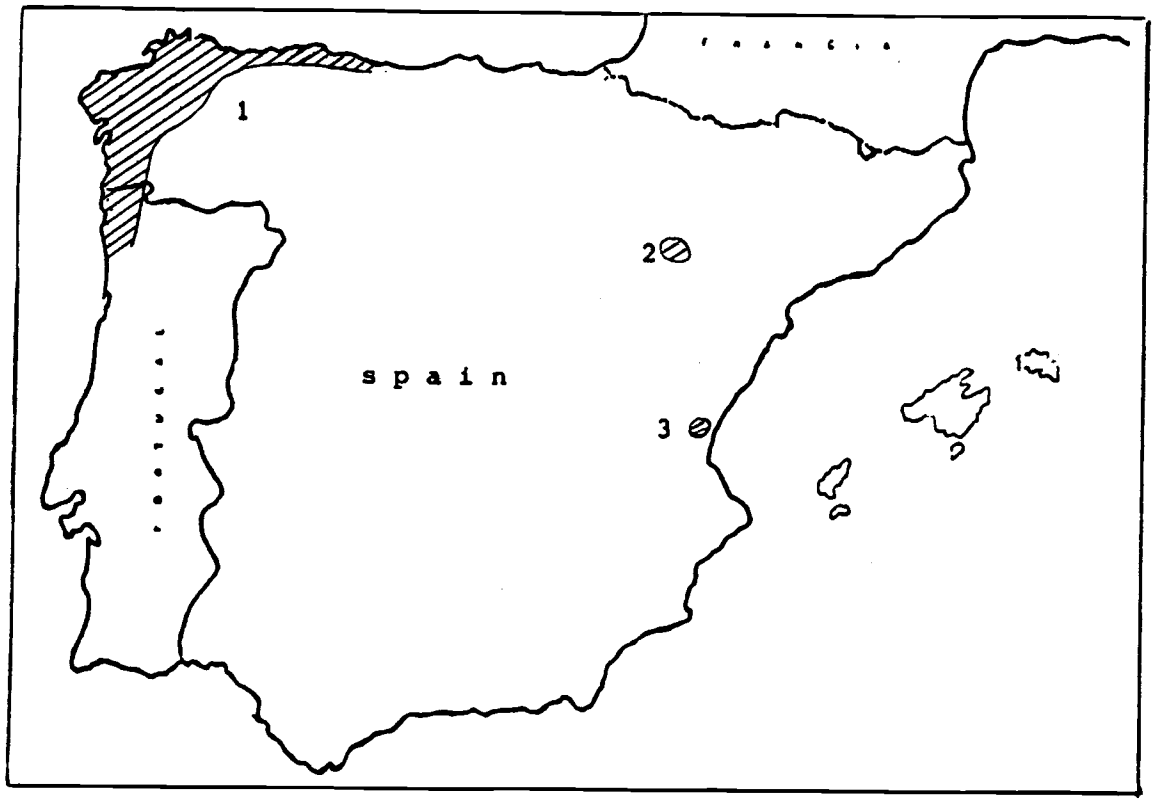


Figure 1-1. Area of distribution of C. esculentus in Spain:
1. Main area infested with C. esculentus var esculentus.
2. Irrigated maize with mixed infestations of C. esculentus and C. rotundus.
3. Irrigated horticulture area with cultivated C. esculentus L. var sativus.

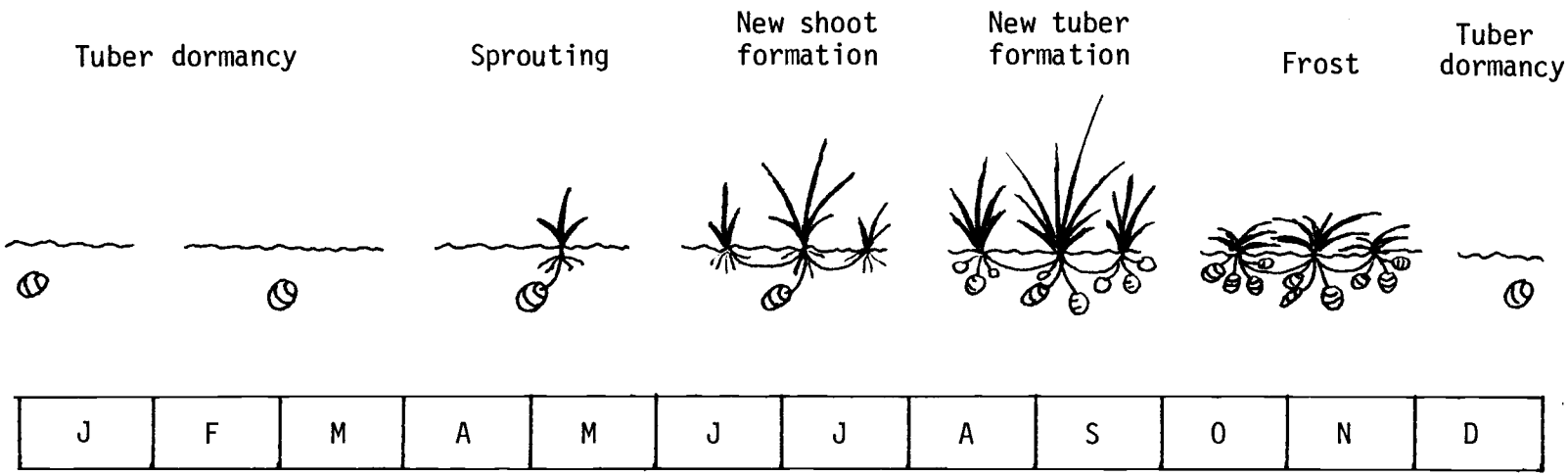


Figure 1-2. Life cycle of undisturbed C. esculentus in northwest Spain.

formation and new tuber differentiation are often simultaneous during July and August in northwest Spain, whereas these growth stages tend to be more separate in north central U.S.

The life cycle of yellow nutsedge is well adapted for survival under a maize crop. This poses serious problems, since there are more than 100,000 hectares of maize presently grown in northwest Spain. The population of nutsedge increases dramatically when the use of selective herbicides removes competition from annual weeds without damaging the nutsedge. Infestations of 176 shoots per square meter have reduced maize yields more than 32% under moist conditions (Moreno and Losada, 1981), and under drier conditions, complete loss of the crop may occur. Damage from nutsedge is reported by Drost et al. (1980) to be from competition, rather than allelopathy.

Glyphosate is a broad spectrum, non-persistent, foliage-active herbicide which has proven useful in long-term control of Cyperus rotundus L. and other perennial weeds in Spain (Gomez de Barreda, 1982). Glyphosate has been effective against C. esculentus in several geographical regions (Stoller, et al., 1975; Dias-Coelho, 1976; Terry, 1985). It has been shown to be useful in herbicide programs to reduce the infestation under California conditions (Keeley et al., 1979), and later studies show that glyphosate effectiveness is optimum when applied before tuber initiation stage (Hunt and Linscott, 1983; Pereira and Crabtree, 1985). The usefulness of glyphosate is based upon its ability to translocate into the underground tubers (Doll and Piedrahita, 1982) and timing must

be properly selected because treatments applied too early will not contact late-emerging shoots and late applications will not result in good translocation into mature tubers (Thullen and Keeley, 1978). In a recent worldwide review, Terry (1985) indicated that C. esculentus can be controlled by glyphosate, but optimum rates and timing need to be determined under local conditions. The addition of ammonium sulfate to glyphosate spray solution has been found to increase weed control in many reports (Turner, 1985), but in some research, there was no effect (Harvey and Potts, 1978; Jensen, 1977).

The objectives of these experiments were to investigate the action of glyphosate on yellow nutsedge tubers in northwest Spain, using different application times and spray additives.

## MATERIALS AND METHODS

### Effect of Development Stage on Glyphosate Activity

Because C. esculentus L. var esculentus does not flower in this region, flowering stage could not be used as a growth stage indicator. Leaf height tends to plateau rather early in the season, depending on environmental conditions. Therefore, the number of leaves may be a more appropriate index for the early development stages.

An infested field in Espiritu Santo, near La Coruña in northwest Spain, was maintained as a cultivated stubble field in the summer of 1977. It contained a heavy infestation of C. esculentus in various growth stages. Glyphosate was applied on August 27,

1977, at 3.6 kg a.e./ha in 380 L/ha of water. Air temperature was 15C. The weeds were healthy at spraying time with moist soil. A 5-mm rain fell approximately 5 h following herbicide application.

One day later, 100 C. esculentus plants were tagged with metallic colored labels along a random intersect of the plot. The colored labels represented three categories of development stages: 2-4 leaves, 6-10 leaves, and 15-20 leaves. No herbicide symptoms were visible at the time of tagging.

Herbicidal damage to each labeled plant was assessed 55 days following application on 72, 69, and 73 plants in each category, respectively. Confidence belts for the percentages of weed control obtained were determined according to Clopper and Pearson Confidence Belt Charts (Steel and Torrie, 1960).

Timing Study in a New Infestation

To obtain a population of plants in a more uniform growth stage than would be possible in a natural infestation, C. esculentus tubers were planted in a non-infested field. Sprouted tubers collected in northwest Spain were planted in a northeast Spain field on May 4, 1977. Rows were 1 meter apart and plants were 25 cm apart within the row. The plot was sprayed with atrazine at 2 kg/ha on May 30 to control Portulaca oleracea, Amaranthus retroflexus, and several other annual weeds.

The soil texture was a sandy silt with a pH of 8.2. Environmental conditions differed from the La Coruña location, having higher summer temperatures and lower relative humidity. The area

was flood irrigated.

The first glyphosate treatment was applied on August 5, when the main shoots had 15 to 17 leaves and lateral shoots had 1 to 8 leaves. Most of the rhizomes were differentiating into shoots, but some were beginning to form tubers.

A second glyphosate treatment was applied on October 2, when the main shoots had more than 20 leaves and most of the rhizomes were differentiating into tubers.

At both times, glyphosate was applied at 2.7 kg/ha in 380 L/ha of water. The experimental design was a randomized block with eight replications. However, four replications were deleted later because of rodent damage to the C. esculentus tubers.

Visible effects from the treatments were assessed November 9, 1977. On November 17, the new tubers produced in 80 cm of row in each plot were collected down to 20 cm deep in the soil. The initially planted parent tubers that could be positively identified also were collected. The tubers were stored under moist conditions at 4C for 2 months. They were then planted in moist sand at 15C-25C for 3 months, at which time the number of sprouted tubers was determined. The data on the number of sprouts were analyzed statistically after transformation to arcsine square root (Steel and Torrie, 1960).

## Timing Study Under No-Tillage Conditions

A timing study was established near La Coruña in a field that had been planted with maize for 5 consecutive years. Atrazine and

mechanical cultivations had been used as the standard weed control practice which resulted in a heavy infestation of C. esculentus. In 1976, a systematic soil sampling procedure at 66 points in the field indicated an average infestation of 5,026 ± 1,936 tubers/$m^2$. This sampling was used for arranging plots into a randomized block design. Soil texture was a loam with a pH of 6.5 and 7.4% organic matter.

In 1977, the plot was not tilled and no crop was planted. The area was infested with C. esculentus and the perennial grass Paspalum distichum L. By the end of July, the most advanced C. esculentus shoots had developed more than 20 leaves and some of the rhizomes were differentiating into new tubers. Glyphosate at 2.16 kg/ha was applied on August 1, August 31, and October 5. One treatment included treatments on both August 1 and October 5. The plots were 3 by 6 m, arranged in a randomized block design with four replications. Visual assessment of foliar injury was made on October 21, 1977, and final evaluation by estimating reinfestation was made on July 10, 1978.

Influence of Tuber Maturity and Additives on Effectiveness of Glyphosate

An experiment was established in the same area as the timing trial under no-tillage conditions, described above. On August 27, 1977, the following treatments were applied: glyphosate alone, glyphosate plus ammonium sulfate at 6 kg/ha, and glyphosate plus sucrose at 10 kg/ha. All glyphosate treatments were 2.16 kg/ha in 380 L/ha of water. In previous trials (Costa, 1979), foliar

application of glucose had been found to increase the leaf growth of C. esculentus under growth chamber conditions. Sucrose was tested as a glyphosate additive for possible improvement of glyphosate translocation under the generally cloudy conditions present when the treatments were applied.

Air temperature was 19C and relative humidity was 92% at the time of spraying. A gentle 2-mm rain occurred 4 h following application. A randomized block design with four replications was used.

Samples of tubers were taken from each plot 24 h following treatment. Tubers were divided into two groups:

(a) Young tubers, white to yellow from 2 to 10 mm in diameter, presumably developing and accumulating carbohydrate reserves at the time of treatment.

(b) Mature tubers, brown to dark brown, from 5 to 12 mm in diameter, presumably were much less active in accumulating carbohydrate reserves than the young tubers.

Tubers which were black and showed signs of deterioration were not collected.

The tubers were stored for 1.5 months at 4C in moist conditions within perforated plastic bags. They were then encouraged to sprout in pots of sand maintained at a moist condition by sub-irrigation under 15-20C temperatures for 112 days.

Treated field plots were visually assessed for foliar injury on October 21, 1977, and for reinfestation on July 10, 1978.

Pre-Harvest Glyphosate Treatments in Maize

In northwest Spain, maize is the crop in which C. esculentus presents the most serious and widespread weed problems. Therefore, large plots were treated at four locations on September 9, 1982, when the nutsedge rhizomes were differentiating into tubers and when the maize grain had matured sufficiently to not be affected by the herbicide treatment. Glyphosate was applied at 2.16 and 4.32 kg/ha in 200 L/ha of water. Air temperatures were 23 to 28C. No rain was received within 1 day following treatment. Maize stage and C. esculentus condition at treatment time were as follows:

| Trial location | Stage of maize | C. esculentus conditions | Following crop |
|---|---|---|---|
| Cambados | Senescent with hard, mature grains. Tassels cut. | Some drought stress | Potatoes |
| Sisan | Beginning of senescence with soft dough grains. | Healthy | Maize |
| Bueu | Senescent with soft dough grains. Low density, detasseled maize. | Healthy | Potatoes |
| Sisenla | Senescent with hard dough grains. Tassels cut. | Some drought symptoms and trampling | Tomatoes and maize |

Control was evaluated on June 20, 1983, by counting nutsedge shoots and comparing with untreated areas.

# RESULTS AND DISCUSSION

## Effect of Development Stage on Glyphosate Activity

Glyphosate treatment at all stages of growth caused a high percentage of reduction in green tissue (Table 1-1). Control of foliage was essentially complete at the 6- to 10- and 15- to 20-leaf stages, whereas some green tissue still remained at the 2- to 4-leaf stage. These results indicate that acceptable levels of control can be achieved with glyphosate in a wide range of growth stages. When the plants were quite small, there may have been a reduction in uptake because of reduced surface area for the herbicide to penetrate.

## Timing Study in a New Infestation

C. esculentus grew well from tubers collected in northwest Spain when planted in northeast Spain. The warmer temperatures in northeast Spain still were not adequate to cause flowering of the particular ecotype used. Further, no flowers were observed in an extra row of untreated plants growing from tubers collected in 1976 from a lone flowering plant in northwest Spain.

When treated plants were evaluated on November 9, a high degree of foliar damage was observed from both the August and October treatments (Table 1-2). Plant damage from the October treatment was more uniform than from the August treatment. In the August treatments, some plants were completely destroyed aboveground and others had apparently normal tissue coming from the basal bulb of the transplanted shoot. These surviving, healthy shoots were producing what appeared to be normal rhizomes and new tubers.

Table 1-1. Efficacy as percentage reduction in green tissue of *C. esculentus* following treatment with glyphosate at different development stages.[a]

| Number of leaves | % reduction in green tissue | Confidence belt (%) at the 95% level |
|---|---|---|
| 2 - 4 | 89 | 96 - 77 |
| 6 - 10 | 99 | 100 - 92 |
| 15 - 20 | 100 | 100 - 94 |

[a]Glyphosate rate was 3.6 kg a.e./ha.

Table 1-2. Performance of glyphosate applied at different times to control new C. esculentus infestations (avg of four replications).

| Treatment | % foliage control on November 9 | New tubers produced | | | | | Parent tubers planted initially | |
|---|---|---|---|---|---|---|---|---|
| | | Number | Fresh weight (g) | Weight per tuber (g) | % of tubers sprouted | Number of tubers sprouted the following year | Number of tubers recovered | % of tubers sprouted the following year |
| Untreated check | 0 | 164 a | 150 a | 0.93 a | 59.4 a | 99 a | 7.0 | 42.9 |
| glyphosate 2.7 kg/ha applied August 5 | 86.3 | 47 b | 35 b | 0.67 b | 34.6 b | 18 b | 6.5 | 0.0 |
| glyphosate 2.7 kg/ha applied October 2 | 85.0 | 80 b | 61 b | 0.79 ab | 8.5 c | 7 b | 4.5 | 16.7 |
| $LSD_{.05}$ | n.s. | 51.9 | 38.7g | 0.19 g | 4.7% | 29.0 | n.s. | n.s. |
| C.V. (%) | 9.2 | 31.0 | 27.3 | 13.9 | 7.9 | 40.6 | 41.9 | 110.0 |

Glyphosate at both treatment dates reduced the number and the total weight of tubers produced following treatment. Because tuber formation had already begun prior to treatment in October, tuber production following that treatment was apparently less affected than from August treatment. However, although treatment at both dates caused significant reductions in tubers sprouting in the spring, October treatment was slightly more effective than August treatment. Some unusual tuber growth patterns were observed in plots treated in October. Some tubers grew in pairs from a single rhizome, either chain-like or bifurcated. This may be similar to the breaking of apical dominance observed in aerial shoots following treatment with sublethal rates of glyphosate. Sprouts of tubers from treated plots were often weaker and in higher numbers per tuber than those from untreated plots.

More than 80% of the original parent tubers were recovered, and over 40% of those coming from the untreated check were able to sprout the following year. August and October treatments reduced the percentage of parent tubers germinating the following spring but not completely following October application. We know of no previously published work reporting the ability of tubers to produce new plants over two seasons.

Results from this experiment indicate that glyphosate, applied either in August or October, can reduce infestations of C. esculentus the following year. However, the number of surviving tubers is sufficient to continue the problem and control measures must be practiced in successive years.

Timing Study Under No-Tillage Conditions

When foliar injury was evaluated on October 21, more injury was noted from the August treatments than from the early October treatments. This was expected because of the relatively short time interval between treatment in early October and the evaluation date (Table 1-3).

Of greater interest was the assessment of reinfestation in July the following year. In this study, treatment in early August was most effective at reducing the infestation. This differs from the results obtained in the previous experiment. Treatment in early August followed by an additional treatment in October improved eventual control only slightly.

Under no-tillage conditions, many plants were already forming new tubers in August. These would be strong sinks for glyphosate translocation and could explain the improved control the following year. In October, unlike tubers in previous experiments, tubers were mostly mature and were no longer acting as sinks. This would reduce the amount of glyphosate moving into the tubers and allow a greater degree of survival into the following season.

These two studies demonstrate that stage of growth of the nutsedge is more important than calendar date in selecting the most effective time for glyphosate application. The growth stage of C. esculentus transplanted into a clean field was similar in October to those plants growing in an undisturbed field in August. Evidence from these two studies supports the conclusion that treatment in the early stages of tuber formation are most effective for

Table 1-3. Performance of glyphosate applied at different times to control C. esculentus under no-till conditions.[a]

| Times of application[b] | % foliar injury on October 21, 1977 | % reduction in reinfestation on July 10, 1978 |
|---|---|---|
| August 1, 1977 | 92.3 a | 87.5 a |
| August 31, 1977 | 86.3 b | 61.3 b |
| October 5, 1977 | 27.5 c | 50.0 b |
| August 1 and October 5, 1977 | 91.0 a | 92.3 a |
| Untreated check | 0.0 d | 0.0 c |
| $LSD_{.05}$ | 4.4% | 24.7% |
| C.V. (%) | 3.7 | 21.3 |

[a]Within each column, figures followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

[b]Glyphosate rate in all treatments was 2.16 kg a.e./ha.

reducing C. esculentus reinfestation in the following season.

The other perennial weed present in this experiment, Paspalum distichum L., was completely eradicated by all glyphosate treatments. In untreated plots, maintained without tillage, infestation of P. distichum tended to increase in 1978. In glyphosate-treated plots, the only weeds present in 1978 were C. esculentus plants, plus some scattered annual weeds, such as Chenopodium album L. and Polygonum persicaria L.

## Influence of Tuber Maturity and Additives on Effectiveness of Glyphosate

Addition of ammonium sulfate or glucose did not influence visual estimates of foliar injury, evaluated 55 days following treatment (Table 1-4). Slight increases in necrosis were observed with the addition of ammonium sulfate but differences were slight and were not statistically significant.

All treatments reduced viability of tubers collected 1 day following treatment. Doll and Piedrahita (1977) found that 1 day was not sufficient time for full glyphosate translocation in C. rotundus. Waiting a longer period of time before sampling tubers probably would have improved results. Viability of young developing tubers was reduced more than viability of mature tubers. The young tubers probably were more active sinks at the time of treatment than the mature tubers.

The C. esculentus population was significantly reduced in treated plots the following season. As in previous studies, the

Table 1-4. Performance of glyphosate and tank mixtures with additives on control of developing C. esculentus tubers at different stages of maturity.[a]

| Treatment | % foliage control 55 days following treatment | Number of tubers collected | | % sprouting of tubers | | % reinfestation control 10.5 months following treatment |
|---|---|---|---|---|---|---|
| | | Young | Mature | Young | Mature | |
| glyphosate 2.16 kg/ha | 90.0 a | 24.3 b | 70.8 a | 11.7 d | 27.8 bc | 37.5 a |
| glyphosate 2.16 kg/ha + ammonium sulfate 6 kg/ha | 94.3 a | 34.8 b | 68.5 a | 12.4 d | 25.2 c | 32.5 a |
| glyphosate 2.16 kg/ha + sucrose 10 kg/ha | 87.0 a | 30.5 b | 71.3 a | 20.5 cd | 24.8 c | 42.5 a |
| Untreated check | 0.0 b | 34.0 b | 65.3 a | 45.6 a | 38.8 ab | 0.0 b |
| $LSD_{.05}$ | 9.7% | 14.3 | | 11.2% | | 25.9% |
| C.V. (%) | 8.9 | 19.5 | | 29.5 | | 57.5 |

[a]Within each parameter, figures followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

reduction still was not sufficient from a practical viewpoint and further treatment would be required. In this study, the addition of ammonium sulfate or sucrose was not helpful.

Preharvest Glyphosate Treatments in Maize

C. esculentus infestations in crops grown following glyphosate treatment in maize were reduced at all four locations (Table 1-5). Levels of control were not dramatic, possibly because tillage in the crops had brought previously untreated tubers to the surface. The degree of control may have been improved if the soil had remained in a non-tilled condition. McCue and Sweet (1981) showed that tillage reduced long-term control of C. esculentus treated with glyphosate and other herbicides.

Table 1-5. C. esculentus infestation 8.5 months following treatment with glyphosate applied preharvest of maize in Pontevedra, northwest Spain.

| Treatment | Trial location | | | |
|---|---|---|---|---|
| | Cambados | Sisan | Bueu | Sisenla |
| | Nutsedge survival | | | |
| | (shoots/$m^2$) | | | |
| Untreated check | 15 | 420 | 307 | 470 |
| glyphosate 2.16 kg/ha | 7 | 197 | 190 | - |
| glyphosate 4.32 kg/ha | 2 | 167 | 170 | 214 |

# CHAPTER II. Yellow Nutsedge (Cyperus esculentus L.) Leaf Growth Inhibition by Glyphosate

## INTRODUCTION

More than 1000 references have been published about glyphosate (Chykaliuk et al., 1980), a broad-spectrum postemergence herbicide which is largely inactivated by adsorption on soil components. This herbicide is able to translocate into underground tubers or other reproductive structures of perennial weeds and, therefore, has potential for long-term control of yellow nutsedge (Cyperus esculentus L.) (Terry, 1985).

The effect of ammonium sulfate on glyphosate activity for control of perennial weed species has been the subject of several references (Turner and Loader, 1975; Turner, 1976; Rao et al., 1976; Taylor and Holly, 1976; Rao et al., 1977; Fiveland, 1978; Lee, 1978; O'Keefe and Turner, 1978; Suwanketnikom and Penner, 1978; Yan Zu, 1978; Lund-Hoie, 1979; Zemanek, 1979; Ampong-Nyarko, 1980; Sharma et al., 1980; Turner and Loader, 1980; Turner, 1981; Turner, 1985). The precise mode of action of ammonium sulfate is not known. A recent review supports the idea that this material could affect membrane permeability (Turner, 1985). There is, however, some controversy on the effects of ammonium sulfate on the long-term control of perennial weeds (Jensen, 1977; Harris et al., 1978; Harvey and Potts, 1978; Moshier, 1980; Penner and Ruggenbuck, 1980; Harvey et al., 1981).

Other references have been published about antagonism on

glyphosate effects by spray mixture with simazine (Schepens and Coomans, 1975; Appleby and Somabhi, 1978; Selleck and Baird, 1981) or in spray solutions with water containing relatively high amounts of calcium (Sandberg et al., 1978; Rajkomar and Ashford, 1979; O'Sullivan et al., 1981).

Leaf symptoms in weeds usually appear 1 or 2 weeks following treatment with glyphosate, depending on species and temperature conditions; the higher the temperature, the faster the appearance of visible effects. Nevertheless, recent studies (Shaner, 1978; Brecke and Duke, 1980) have demonstrated that in treated plants of annual species, transpiration and leaf growth are significantly reduced within 24 h following treatment. Measurement of leaf regrowth has been found useful in measuring the response of Cyperus rotundus to glyphosate treatments (Chase and Appleby, 1979).

The objective of this work was to use short-term leaf growth measurements to clarify the effect of ammonium sulfate on the control of C. esculentus L. Leaf growth is one of the first functions affected by glyphosate treatments (Brecke and Duke, 1980), and short-term growth measurements are non-destructive. The method is rather simple in C. esculentus and also of practical interest since the growth of leaves is related to uptake of water and nutrients from the soil in competition with the crops.

Another advantage of the method, from the experimental point of view, is that variability of leaf growth among plants is lower than when dry or fresh weights are assessed. Plant responses 1 or 2 months after glyphosate treatment seem to be well correlated with,

and therefore can be predicted by, short-term measurements.

## MATERIALS AND METHODS

### General Methods

Cyperus esculentus L. var. esculentus plants, each with more than 10 leaves, were transplanted from an infested maize field near La Coruña (northwest Spain) into pots and grown under controlled conditions. Pots, 12 cm high and 10 cm in diameter, were filled with peat and sand mixture, and regularly rotated and sub-irrigated to maintain homogeneous growing conditions.

The pots were kept in a shaded greenhouse or in the open air during August and September. Temperatures ranged between 20 and 28°C in the greenhouse and between 10 and 35°C outside.

Treatments were applied to single plants once they had recovered from transplanting and when leaves were actively growing. Plants were arranged in blocks according to plant size and treatments were replicated at least four times in a randomized block design. The chemicals were sprayed with four applications with a single displacement hand sprayer from a fixed distance resulting in a water volume of 600 l/ha.

Immediately after treatment, all the green leaves of each plant were marked at the same height (between 5 and 15 cm) with waterproof ink. As the younger leaves grew, the marks on the leaves were displaced in relation to non-growing older leaves. The displacement (Figure 2-1) was measured at different time intervals and used as an indicator of leaf growth. In published studies

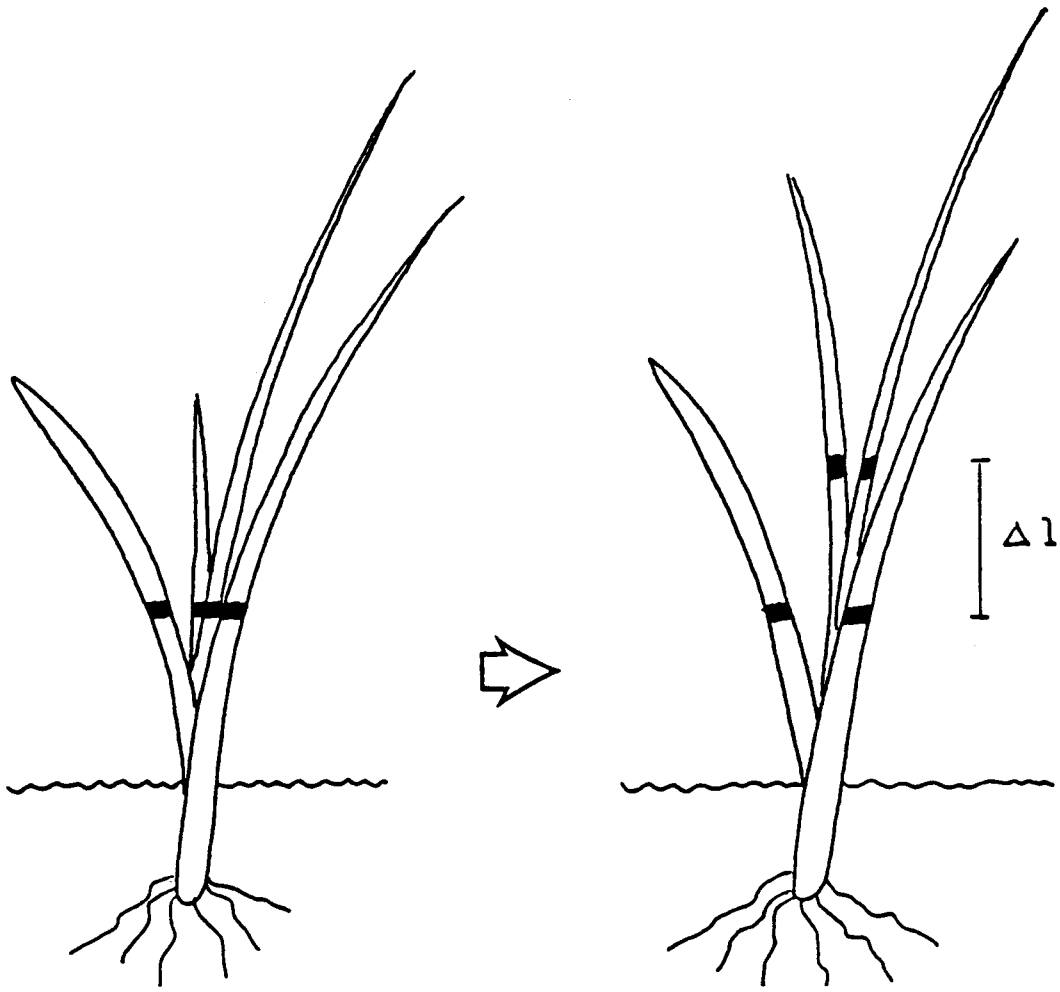


Figure 2-1. Method of measuring differential growth (Δl) as an indicator of leaf growth in C. esculentus.

(Chase and Appleby, 1979), regrowth of Cyperus rotundus plants clipped after treatment was well correlated with final response to glyphosate treatments.

Effect of glyphosate, atrazine, and 2,4-D on C. esculentus growth rate

Plants grown in shaded greenhouse were sprayed with the following herbicide treatments: (1) untreated check, (2) glyphosate 1.5 kg a.e./ha, (3) glyphosate 3.0 kg a.e./ha, (4) atrazine 2.0 kg a.i./ha, and (5) 2,4-D amine salt 1.5 kg a.e./ha.

This experiment compared the response to three postemergence herbicides with different modes of action:

glyphosate: interferes with synthesis of essential aromatic amino acids

atrazine: photosynthesis inhibitor

2,4-D: hormonal imbalance leading to physiological imbalance of plant organs.

Plants were grown under temperatures ranging from 15°C to 24°C. Leaf growth measurements were taken 12, 24, 36, 60, and 156 h following treatment.

The experiment was established as a randomized block design with seven replications and analyzed accordingly.

Short-term effects of glyphosate treatments on growth of yellow nutsedge leaves

Yellow nutsedge plants with the mother tuber and 8 to 10 leaves, transplanted from the field into 10-cm diameter plastic

pots, were left to recover for 15 days until they were again actively growing.

On August 4, 1981, individual plants were sprayed with glyphosate at 1.5 or 3.0 kg a.e./ha or at the same rates in a 2% solution of ammonium sulfate. Some plants served as untreated checks. Treatments were applied in 630 l/ha of distilled deionized water.

Plants were placed in a shaded greenhouse following treatment. Leaf growth measurements were taken at 12, 22, 34, 58, and 130 h following treatment. The experiment was completed 40 days following treatments by recording efficacy as an estimation of green leaf tissue and by taking fresh weights of leaves.

The experiment was established as a randomized block design with six replications and data were subjected to analysis of variance using Duncan's multiple range test to separate means. In the analysis of visual ratings, untreated checks (0% control) were excluded.

Response to washing and leaf-cutting following glyphosate or glyphosate + ammonium sulfate treatments

Established yellow nutsedge plants, as in the preceding experiment, were selected to study the response to different treatments following glyphosate at 1.5 kg/ha or glyphosate at 1.5 kg/ha plus 2% ammonium sulfate applications.

Leaves were marked with waterproof ink 1 day before treatments were applied. Plants were arranged in blocks according to

leaf growth during the day before treatment. Herbicide treatments were sprayed in 630 l/ha of distilled deionized water.

In the washing treatments, yellow nutsedge leaves were washed 3 h following treatment by dipping 5 times in running water. In cutting treatments, the leaves were cut 20 mm above soil level 24 h following treatment.

Leaf growth measurements were taken 1, 2, 3, and 5 days following treatment and the experiment was completed in 34 days, including visual estimation of efficacy and fresh weight of leaves at the end of the experiment.

A randomized block design with five replications was used and data were analyzed as in the preceding experiment.

Effect of ammonium sulfate on glyphosate action in tank mixes with simazine or in water with 200 ppm calcium

Established yellow nutsedge plants, as in the preceding experiments, were selected and maintained in pots under field conditions with subirrigation. Individual yellow nutsedge plants chosen had 8 to 12 developed leaves plus a lateral shoot with one to four leaves which were also marked for growth measurements.

On August 29, 1981, glyphosate at 2.2 kg/ha was sprayed alone or with a 2% ammonium sulfate solution. These two treatments also were compared in tank mixes with simazine at 2.8 kg/ha (from a 465-g/l flowable formulation) and in water containing 200 ppm Ca as calcium chloride. The mixes with calcium chloride were applied either immediately or after standing in the light for 6 h following preparation.

Conditions at treatment time were 32°C air temperature and 60% relative humidity. No rain fell during the first 24 h following treatment. Weather following treatment was typical of a dry summer with no rains and 15 to 35°C air temperatures. Leaves from the main shoot were marked 1 day after treatment, and the lateral shoots were cut at 10 mm above ground level to measure regrowth.

Leaf growth measurements were taken 9 and 20 days following treatment because of the slower growth under field conditions than in former greenhouse experiments. The experiment was completed 72 days following treatment with fresh weight measurements and visual estimations of control in comparison to untreated checks. Four replications were used in a randomized block design and data were analyzed as previously described.

Effect of ammonium sulfate on glyphosate translocation and inhibition of C. esculentus leaf growth

Established yellow nutsedge plants were selected and maintained under field conditions with subirrigation. The effect of adding a 2% ammonium sulfate solution to the glyphosate solution was measured in the following treatments:

- spraying a 0.36% solution of glyphosate in 630 l/ha of water.
- dipping the distal 20 cm of two leaves into a 0.36%, 0.72%, or 1.8% solution of glyphosate. Treated leaves were maintained in a horizontal position to avoid runoff to untreated parts. Leaves were cut off 20 mm below the dipped area 1 day after treatment.

- dipping of distal 20 cm of two leaves into a 0.72% solution of glyphosate without cutting.

These treatments were applied on September 12, 1981, under 28°C air temperature and 60% relative humidity conditions. One day following treatment, the leaves were marked and leaf growth measurements were taken 6 and 15 days following treatments.

Weather following treatment was dry and typical of late summer with 12 to 28°C air temperatures. The experiment was completed by recording fresh weights 58 days after treatment. Four replications were established in a randomized block design and analyzed as previously described.

## RESULTS AND DISCUSSION

### Effect of glyphosate, atrazine, and 2,4-D on C. esculentus growth rate

Differential leaf growth of yellow nutsedge plants was measured at different time intervals. Results are shown in Figures 2-2 and 2-3.

The rate of growth of untreated checks was around 1.5 mm/h. Significant differences in leaf growth between treatments were detected 1 day following treatment, which became wider up to 6.5 days following treatment.

Glyphosate did not show any negative effect on leaf growth rate 12 h after treatment, but leaf growth was significantly inhibited 1.5 days after treatment by 3.0 kg a.e./ha. Leaf growth rate of plants treated with 1.5 kg glyphosate/ha was significantly lower

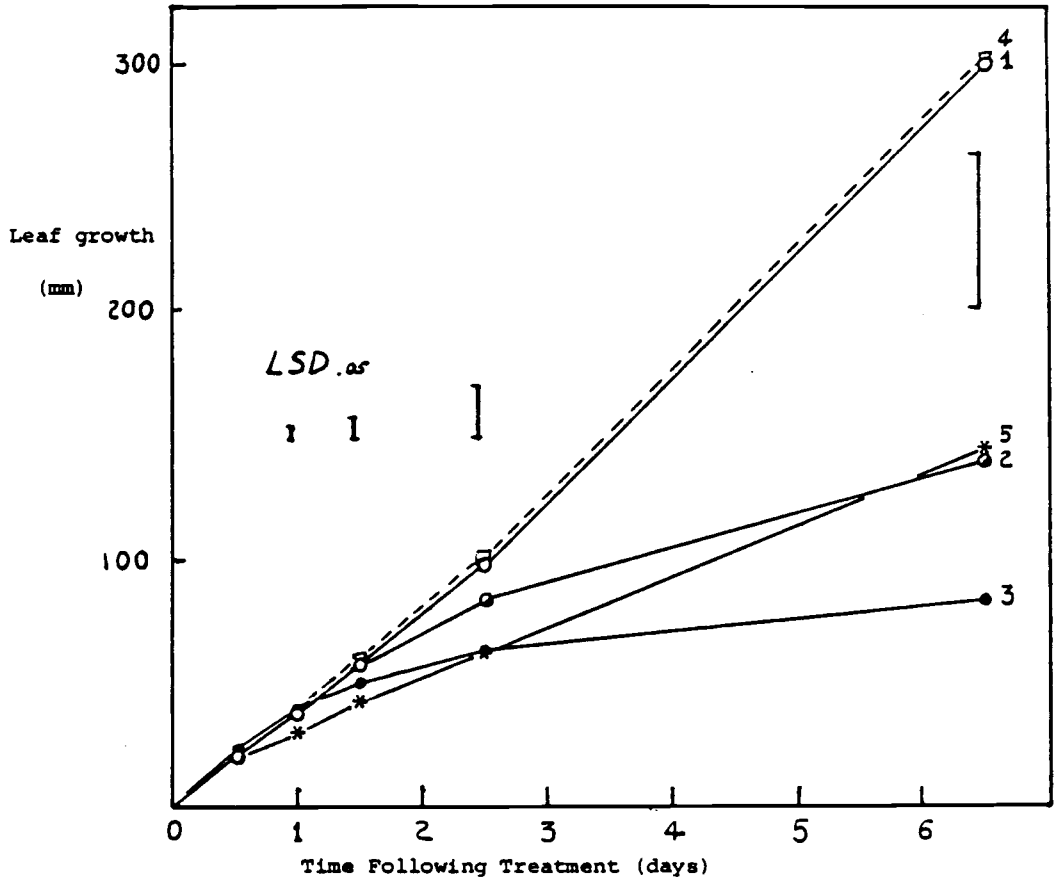


Figure 2-2. Short-term leaf growth of C. esculentus following treatment with several herbicides: 1. untreated check (—o—), 2. glyphosate 1.5 kg/ha (—●—), 3. glyphosate 3.0 kg/ha (—●—), 4. atrazine 2.0 kg/ha (--□--), and 5. 2,4-D amine 1.5 kg/ha (—*—).

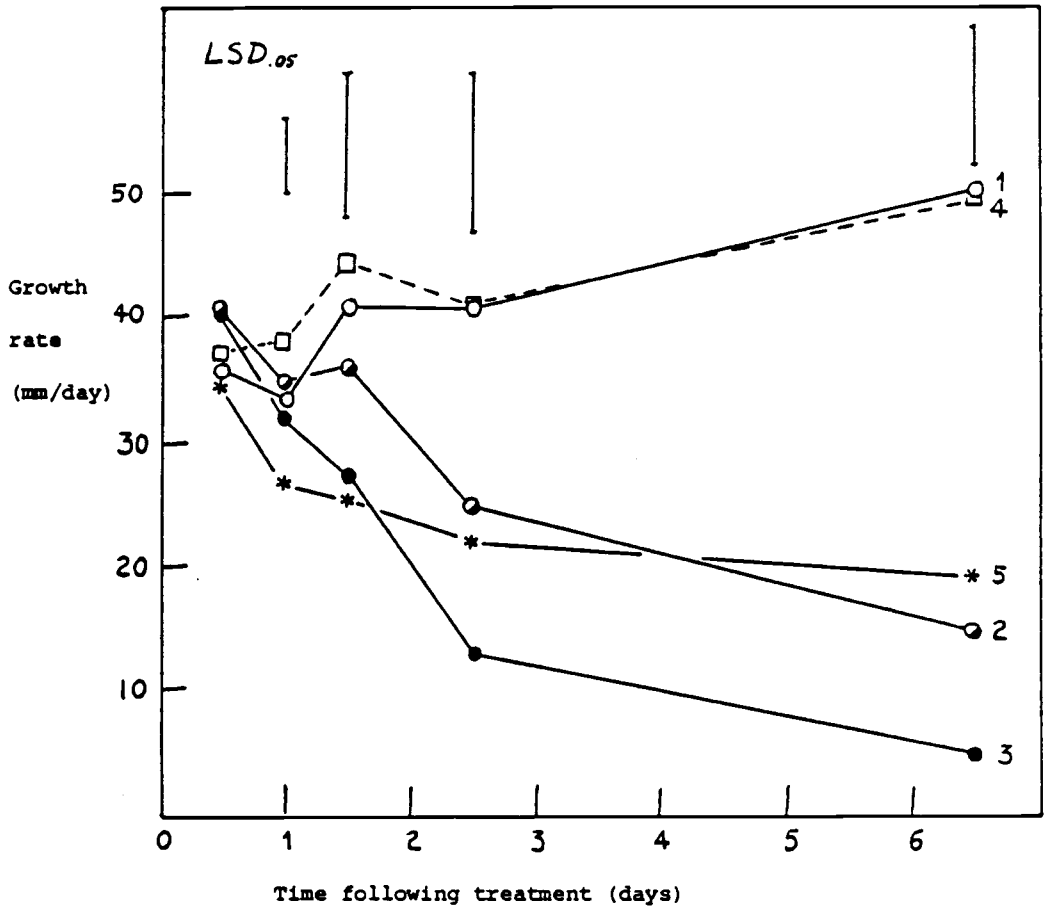


Figure 2-3. Short-term growth rate of C. esculentus leaves following treatment with several herbicides: 1. untreated check (—0—), 2. glyphosate 1.5 kg/ha (—●—), 3. glyphosate 3.0 kg/ha (—●—), 4. atrazine 2.0 kg/ha (--□--), and 5. 2,4-D amine 1.5 kg/ha (—*—).

than untreated checks 2.5 days after treatment.

Using the leaf growth measurements, the effects of atrazine on C. esculentus were not detectable, and the effects of 2,4-D at 1.5 kg/ha appeared faster but were shorter lived than those from glyphosate at 3.0 kg/ha.

Short-term effects of glyphosate treatments on growth of yellow nutsedge leaves

All glyphosate treatments reduced total nutsedge leaf growth (Table 2-1). Significant differences among treatments could be detected 34 h following treatment. No visible symptoms had developed by 130 h following treatment, when leaf growth measurements were completed. Leaf growth measurements indicated significantly (5%) greater reduction in leaf growth with glyphosate at 3.0 kg/ha than with glyphosate at 1.5 kg/ha at 58 and 130 h following treatment. There was a tendency for a greater reduction in leaf growth when ammonium sulfate was added to the spray solution but differences were not statistically significant at the 5% level.

Growth rate at the different time intervals was analyzed and results are summarized in Table 2-2 and Figure 2-4. Despite higher coefficient of variation values, this parameter allowed earlier detection of significant differences, beginning 22 h following treatment. There were indications of growth stimulation by glyphosate 12 h following treatment, but differences were not significant. By 130 h following treatment, no visible symptoms had developed, but growth rate of plants treated with glyphosate at 3 kg/ha was reduced

Table 2-1. Effect of glyphosate alone and with ammonium sulfate on total leaf growth of C. esculentus leaves.

| Treatment | Time following treatment (h) | | | | |
|---|---|---|---|---|---|
| | 12 | 22 | 34 | 58 | 130 |
| | (mm)[a] | | | | |
| Untreated check | 19.3 | 35.3 | 56.7 a | 109.8 a | 239.3 a |
| glyphosate 1.5 kg/ha | 19.7 | 36.7 | 51.5 ab | 71.2 b | 86.7 b |
| glyphosate 1.5 kg/ha + ammonium sulfate 2% | 22.5 | 36.7 | 47.3 b | 65.0 bc | 73.7 bc |
| glyphosate 3.0 kg/ha | 21.3 | 34.2 | 44.7 bc | 54.3 cd | 61.0 cd |
| glyphosate 3.0 kg/ha + ammonium sulfate 2% | 20.7 | 30.5 | 38.3 c | 48.5 d | 53.6 d |
| C.V. (%) | 13.9 | 14.6 | 13.9 | 16.0 | 15.4 |

Table 2-2. Effect of glyphosate alone and with ammonium sulfate on growth rate of C. esculentus leaves.

| Treatment | Time following treatment (h) | | | | |
|---|---|---|---|---|---|
| | 0-12 | 12-22 | 22-34 | 34-58 | 58-130 |
| | (mm/day)[a] | | | | |
| Untreated check | 38.6 | 38.4 a | 42.7 a | 53.3 a | 43.2 a |
| glyphosate 1.5 kg/ha | 39.4 | 40.8 a | 29.5 b | 19.7 b | 5.3 b |
| glyphosate 1.5 kg/ha + ammonium sulfate 2% | 45.1 | 34.1 a | 21.4 c | 17.8 b | 2.9 bc |
| glyphosate 3.0 kg/ha | 42.7 | 30.7 ab | 21.1 c | 9.6 c | 2.2 c |
| glyphosate 3.0 kg/ha + ammonium sulfate 2% | 41.5 | 23.5 b | 15.6 c | 10.1 c | 1.7 c |
| C.V. (%) | 13.9 | 23.3 | 18.1 | 26.3 | 20.9 |

[a]Numbers under the same parameter and time followed by the same letter are not significantly different (5%) according to Duncan's multiple range test.

(—*—) untreated check

(—o—) glyphosate 1.5 Kg/Ha

(- -o- -) " + am. sulphate 2%

(—□—) glyphosate 3.0 Kg/Ha

(- -□- -) " + am. sulphate 2%

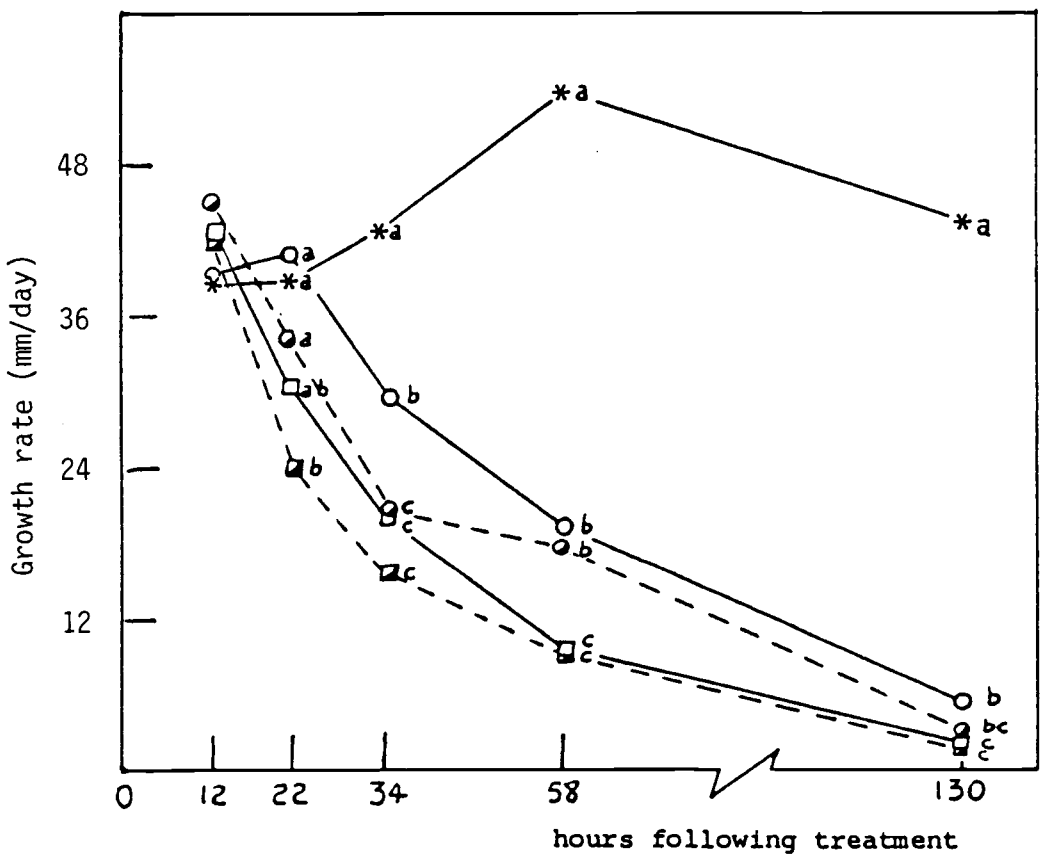


Figure 2-4. Effect of glyphosate treatments on growth rate of C. esculentus leaves (within each date, points followed by the same letter are not significantly different (5%) according to Duncan's multiple range test).

by 95%. Addition of ammonium sulfate tended to give more growth rate reduction, but the difference was only significant 34 h following treatment with glyphosate at 1.5 kg/ha.

These results were related with visual evaluations of efficacy and fresh weight of leaves at the end of the experiment as shown in Table 2-3.

The advantage of the growth rate measurements is that detection of effects on growth is much earlier and also it is possible to identify growth responses at different times following treatment (since it is not destructive).

From the results in this experiment, addition of ammonium sulfate appears to give faster control of C. esculentus by glyphosate at 1.5 kg/ha, but differences with glyphosate at 3.0 kg/ha were not significant.

Response to washing and leaf cutting following glyphosate or glyphosate + ammonium sulfate treatments

As in previous experiments, significant growth inhibitions by glyphosate treatments could be detected after 2 days following treatment (Table 2-4). The growth inhibition was significantly (5% level) greater when 2% ammonium sulfate was added to the glyphosate solution. This effect from ammonium sulfate was maintained when treated leaves were washed 3 h after treatment but the difference was smaller and not significant when washed leaves were cut 1 day after treatment. This agrees with published data on C. rotundus (Ampong-Nyarko, 1980) where ammonium sulfate increased

Table 2-3. Efficacy of glyphosate treatments in reducing C. esculentus foliage 40 days following treatments.[a]

| Treatment | Percentage of control according to visual estimation of green leaf tissue | Fresh weight of leaves |
|---|---|---|
| | (%) | (g) |
| Untreated check | 0.0 c | 19.4 a |
| glyphosate 1.5 kg/ha | 93.0 b | 3.5 b |
| glyphosate 1.5 kg/ha + ammonium sulfate 2% | 97.8 a | 2.2 b |
| glyphosate 3.0 kg/ha | 99.7 a | 1.8 b |
| glyphosate 3.0 kg/ha + ammonium sulfate 2% | 98.5 a | 2.2 b |
| C.V. (%) | 2.15 | 28.9 |

[a]Numbers under the same parameter followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

Table 2-4. Leaf growth of C. esculentus leaves following different glyphosate treatments.[a]

| Treatment[b] | Days following treatment | | | | Total growth 5 days following treatment |
|---|---|---|---|---|---|
| | 0 - 1 | 1 - 2 | 2 - 3 | 3 - 5 | |
| | (mm/day) | | | | (mm) |
| Untreated check | 51.6 | 58.4 a | 57.4 a | 50.6 a | 268.6 a |
| glyphosate | 47.8 | 51.4 ab | 39.4 b | 24.3 b | 187.2 bc |
| glyphosate + ammonium sulfate 2% | 49.0 | 35.0 c | 14.2 e | 7.3 c | 112.8 d |
| glyphosate + wash | 51.6 | 56.6 a | 50.2 a | 26.4 b | 211.2 b |
| glyphosate + ammonium sulfate + wash | 53.2 | 44.0 bc | 22.8 de | 15.9 bc | 151.8 cd |
| glyphosate + wash + cut | 47.6 | 40.8 c | 36.0 bc | 28.6 b | 134.0 d |
| glyphosate + ammonium sulfate + wash + cut | 51.8 | 38.4 c | 28.0 cd | 22.0 b | 110.4 d |
| Coefficient of variation (%) | 13.0 | 15.6 | 22.1 | 41.1 | 19.0 |

[a]Within any column, figures followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

[b]Glyphosate rate in all treatment was 1.5 kg/ha.

the activity of glyphosate but not when shoots were removed 24 h after spraying.

These short-term effects may be due to some enhancement of glyphosate penetration into the leaves by ammonium sulfate, as reported in some papers, but without positive effects on glyphosate translocation to the underground growing points.

Conclusions based on visual evaluations and fresh leaf weights (Table 2-5) generally agree with those from leaf growth measurements. The correlation coefficient between leaf growth 5 days following treatment and final green weight was highly significant, 0.868. However, when treatments were not followed by washing or cutting, the difference in visible injury from glyphosate and glyphosate + ammonium sulfate was not significant and the growing points of yellow nutsedge plants were found to be completely dead, confirming the need of some time to allow for absorption and translocation of the herbicide (Chase and Appleby, 1979).

Effect of ammonium sulfate on glyphosate action in tank mixes with simazine or in water with 200 ppm calcium

Growth reduction by glyphosate was enhanced slightly by ammonium sulfate, but the effect was small and not significant when these treatments were applied in distilled deionized water (Table 2-6). When simazine was added, adding ammonium sulfate significantly improved activity, both in reducing total growth of the main shoot 20 days following treatment and in visual evaluations (Table 2-7). The higher growth inhibition when ammonium sulfate was added to a tank

Table 2-5. Percentage of control and fresh weight of C. esculentus following different glyphosate treatments.[a]

| Treatment[b] | % control according to visual estimation of green leaves 34 days following treatment | Fresh weight of leaves 34 days following treatment |
|---|---|---|
| | (%) | (g) |
| Untreated check | (0.0) | 18.4 a |
| glyphosate | 80.0 a | 7.3 c |
| glyphosate + ammonium sulfate 2% | 93.6 a | 3.2 d |
| glyphosate + wash | 20.0 c | 13.7 b |
| glyphosate + ammonium sulfate 2% + wash | 51.0 b | 8.7 c |
| glyphosate + wash + cut | 43.0 b | 6.5 c |
| glyphosate + ammonium sulfate 2% + wash + cut | 51.0 b | 5.8 cd |
| Coefficient of variation (%) | 28.6 | 24.9 |

[a]Within any column, figures followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

[b]Glyphosate rate in all treatments was 1.5 kg/ha.

Table 2-6. Leaf growth of C. esculentus leaves following treatments with glyphosate mixtures with ammonium sulfate, simazine, or calcium chloride.[a]

| Treatment[b] | Main shoot growth | | Lateral shoot growth | |
|---|---|---|---|---|
| | Days following treatment | | Days following treatment | |
| | 1 - 9 | 1 - 20 | 1 - 9 | 1 - 20 |
| | (mm) | | (mm) | |
| Untreated check | 245 a | 393 a | 261 a | 384 a |
| glyphosate | 70 bc | 74 bc | 62 cd | 90 bcd |
| glyphosate + ammonium sulfate 2% | 53 bc | 56 cd | 47 d | 67 cd |
| glyphosate + simazine 2.8 kg/ha | 72 bc | 79 bc | 85 bcd | 94 bcd |
| glyphosate + simazine 2.8 kg/ha + ammonium sulfate 2% | 47 c | 42 d | 57 d | 59 d |
| glyphosate + Ca 200 ppm | 81 b | 90 b | 101 b | 137 b |
| glyphosate + Ca 200 ppm + ammonium sulfate 2% | 42 c | 39 d | 51 d | 47 d |
| glyphosate + Ca 200 ppm[c] | 79 b | 95 b | 98 bc | 125 bc |
| glyphosate + Ca 200 ppm + ammonium sulfate 2%[c] | 47 c | 38 d | 55 d | 59 d |
| Coefficient of variation (%) | 23.4 | 19.5 | 27.3 | 32.9 |

[a]Within any column, figures followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

[b]Glyphosate rate in all treatments was 2.2 kg/ha.

[c]Solution prepared 6 h before application.

mixture of glyphosate and simazine agrees with the results reported previously on Agropyron repens (Turner, 1981).

The differences between glyphosate and glyphosate mixed with ammonium sulfate, when water with 200 ppm calcium was used, were always larger and significant at the 5% level in all measurements taken, regardless of whether the solution was prepared 6 h in advance or immediately before treatment. The enhancement by ammonium sulfate in hard water was reported previously by Rajkomar and Ashford (1979).

The addition of Ca alone tended to reduce the effect of glyphosate, although differences were not significant at the 5% level. Simazine alone had no consistent effect on glyphosate action.

The conclusion from these results is that the effect of ammonium sulfate addition to glyphosate treatments can be more dramatic under hard water conditions or in tank mixes with simazine. Hard water and medium to large (400-800 l/ha) spray volumes are common in the Mediterranean area for directed applications of herbicides in perennial crops.

Water hardness can affect the activity of surfactants contained in commercial herbicide formulations (Hull et al., 1982). The effect of ammonium sulfate in hard waters could be a lowering of the pH of the herbicide solution (Crafts, 1975) and a precipitation of calcium. Since the water solubility product of calcium sulfate is $6.4 \times 10^{-5}$ (Babor and Ibarz, 1958), the addition of 2% ammonium sulfate to hard water with 200 ppm calcium would, theoretically, reduce soluble calcium levels to less than 20 ppm.

Growth data from lateral shoots were similar to data from the main shoot except that the antagonism of glyphosate from 200 ppm calcium was larger in some cases. This suggests more effects on glyphosate translocation than on glyphosate leaf absorption. Final fresh weight at the end of the experiment (Table 2-7) was highly significantly correlated with leaf growth from days 1 to 9 following treatment, with a correlation coefficient of 0.9565.

Effect of ammonium sulfate on glyphosate translocation and inhibition of C. esculentus leaf growth

Ammonium sulfate affected the inhibition of leaf growth by glyphosate only at glyphosate concentrations of 0.72% and 1.8% when the treated parts were removed 1 day following treatment (Table 2-8).

This is another indication that ammonium sulfate can delay or reduce translocation of glyphosate, perhaps because of increased deterioration of treated leaf tissues. This was particularly noticed with a 0.72% glyphosate solution when the treated leaf parts were not removed; foliar necrosis in leaf tips appeared earlier in treatments with ammonium sulfate.

Ammonium sulfate did not affect glyphosate activity on leaf fresh weight (Table 2-8), although fresh weight data were significantly (1% level) correlated with leaf growth at 1 to 15 days following treatment (correlation coefficient = 0.8083).

Table 2-7. Percentage of control and fresh weight of C. esculentus following treatments with glyphosate mixtures with ammonium sulfate, simazine, or calcium chloride.[a]

| Treatment[b] | % control according to visual estimation of green leaves 72 days following treatment | Fresh weight of leaves 72 days following treatment |
|---|---|---|
| | (%) | (g) |
| Untreated check | - | 17.8 a |
| glyphosate | 63.8 cd | 4.4 bc |
| glyphosate + ammonium sulfate 2% | 67.5 bc | 4.4 bc |
| glyphosate + simazine 2.8 kg/ha | 51.3 d | 4.9 bc |
| glyphosate + simazine 2.8 kg/ha + ammonium sulfate 2% | 80.3 ab | 3.2 c |
| glyphosate + Ca 200 ppm | 62.5 cd | 5.6 b |
| glyphosate + Ca 200 ppm + ammonium sulfate 2% | 85.5 a | 2.8 c |
| glyphosate + Ca 200 ppm[c] | 53.3 d | 6.5 b |
| glyphosate + Ca 200 ppm + ammonium sulfate 2%[c] | 76.5 abc | 3.3 c |
| Coefficient of variation (%) | 13.2 | 25.2 |

[a]Within any column, figures followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

[b]Glyphosate rate in all treatments was 2.2 kg/ha.

[c]Solution prepared 6 h before application.

Table 2-8. Effect of ammonium sulfate and post-treatment leaf cutting on glyphosate inhibition of C. esculentus leaf growth[a]

| Treatments (*spray) (**leaf dipping) | Leaf growth | | Fresh weight of leaves 58 days following treatment |
|---|---|---|---|
| | 1 - 6 DAT[b] | 1 - 15 DAT | |
| | (mm) | | (g) |
| Untreated check | 124 a | 286 a | 15.9 a |
| glyphosate 0.36%* | 58 def | 67 de | 7.9 cd |
| glyphosate 0.36% + ammonium sulfate* | 58 def | 67 de | 7.5 d |
| glyphosate 0.36%** + cut 1 DAT | 87 b | 187 b | 12.5 b |
| glyphosate 0.36% + ammonium sulfate** + cut 1 DAT | 94 b | 200 b | 11.9 b |
| glyphosate 0.72%** + cut 1 DAT | 64 cde | 109 cd | 11.9 b |
| glyphosate 0.72% + ammonium sulfate** + cut 1 DAT | 84 bc | 174 b | 11.8 b |
| glyphosate 0.72%** | 36 g | 40 e | 6.8 d |
| glyphosate 0.72% + ammonium sulfate** | 45 efg | 48 e | 8.1 cd |
| glyphosate 1.8%** + cut 1 DAT | 41 fg | 53 e | 9.4 bcd |
| glyphosate 1.8% + ammonium sulfate** + cut 1 DAT | 73 bcd | 126 c | 10.8 bc |
| Cefficient of variation (%) | 19.8 | 25.1 | 19.0 |

[a]Within any column, figures followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

[b]DAT = days after treatment.

# CONCLUSIONS

Measurement of leaf growth by the method described in this paper provided an earlier and somewhat more precise indication of glyphosate action in yellow nutsedge than visual estimation of leaf chlorosis or necrosis or fresh weight measurements. The measured leaf growth was highly correlated with fresh weight of leaves at the end of the experiment and could be useful in screening glyphosate additives for short-term inhibition of leaf growth.

Leaf growth inhibition by glyphosate appeared slightly later than with 2,4-D, but reduction in growth rate was significant before 2.5 days following treatments. During the first 12 h following treatment, some slight enhancement of leaf growth was noticed with glyphosate. Stimulation of plant growth by sublethal concentrations of herbicides is not uncommon (Wiedman and Appleby, 1972).

Leaf growth inhibition by glyphosate sometimes was enhanced by ammonium sulfate, particularly in short-term measurements 2 to 3 days following treatments. With 1.5 kg/ha of glyphosate, the enhancement effect was reduced when leaves were removed 1 day after treatment, suggesting that uptake but not translocation of glyphosate out of treated leaves was enhanced by addition of ammonium sulfate. In another experiment involving localized treatment with glyphosate at 0.72% and 1.8% solutions followed by post-treatment cutting after 1 day, ammonium sulfate seemed to delay glyphosate translocation out of the treated leaves. These results are in general agreement with those from field studies in northwest Spain in which ammonium sulfate

did not increase glyphosate effects on nutsedge tubers in the spring following fall treatments.

Ammonium sulfate increased the efficacy of glyphosate in mixtures with simazine or with water containing 200 ppm of calcium. Although the mechanisms involved are not known, these effects could have practical ramifications. If the addition of ammonium sulfate, a relatively inexpensive compound, could reduce the detrimental effect of hard water on glyphosate activity, this could reduce the amount of herbicide required and/or improve nutsedge control.

These results are in agreement with those reported at a recent review on glyphosate additives (Turner, 1985) in which ammonium sulfate increased glyphosate uptake by other plant species, but without affecting translocation directly. Turner (1985) suggested that ammonium sulfate could modify membrane permeability.

# CHAPTER III. Influence of Ammonium Sulfate on $^{14}$C-glyphosate Absorption and Translocation

## INTRODUCTION

The use of radiolabeled herbicides has long been established as a useful tool for quantification of herbicide absorption, translocation, and degradation (Ford, Eastin, and Basler, 1977). In the case of glyphosate, the situation is simplified because published studies indicate no substantial metabolism of $^{14}$C-glyphosate within plants in short-term experiments (Wyrill and Burnside, 1976; Sprankle, et al., 1978; Schultz and Burnside, 1980).

Although glyphosate is able to move to areas of high metabolic activity of C. esculentus, such as untreated shoots and developing tillers (Sprankle, Meggitt, and Penner, 1975), the percentage of applied $^{14}$C-glyphosate translocated into C. rotundus tubers is low (Chase and Appleby, 1979). A broadcast treatment to hemp dogbane (Apocynum cannabinum L.) with unlabeled herbicide did not significantly affect subsequent absorption or translocation of $^{14}$C-glyphosate (Schultz and Burnside, 1980). Absorption of $^{14}$C-glyphosate in soybeans was greater when the herbicide was applied to mature rather than immature leaves (McWhorter, Jordan, and Wills, 1980).

The objective of this experiment was to determine if differences in C. esculentus leaf growth inhibition following glyphosate compared to glyphosate + ammonium sulfate treatments could be related to differences in absorption and/or translocation of the herbicide.

# MATERIALS AND METHODS

Single non-flowering C. esculentus plants with 10 to 12 green leaves and 50 to 60 cm in height were grown in 15-cm diameter plastic pots filled with peat and sand mixture and subirrigation.

$^{14}$C-methyl labeled glyphosate with a specific activity of 2.26 mCi/m mole was diluted and converted from the acid to the isopropylamine salt by adding 0.5 ml water, 2 µl isopropylamine, 1 µl Mon 0818 surfactant, and 75 µl of commercial glyphosate formulation[1] to 2.17 mg of the labeled acid. Ten microliters of this solution, equivalent to 0.5 µCi were applied in two 5-µl droplets to one mature C. esculentus leaf within 5 minutes after the following herbicide treatments:

1. glyphosate 0.63 kg/ha
2. glyphosate 0.63 kg/ha + ammonium sulfate at 7 kg/ha
3. glyphosate 2.52 kg/ha (treated leaf to be removed after 24 h
4. glyphosate 2.52 kg/ha + ammonium sulfate at 7 kg/ha (treated leaf to be removed after 24 h)
5. glyphosate 2.52 kg/ha
6. glyphosate 2.52 kg/ha + ammonium sulfate at 7 kg/ha

Herbicide treatments were applied with a hand-sprayer in 350 l/ha of water. The trial was arranged in a randomized block design with five replications. $^{14}$C-glyphosate application was made on C. esculentus leaves maintained in a horizontal position to avoid runoff of labeled droplets.

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[1]Roundup, 360 g/l formulation manufactured by Monsanto.

Plants were kept in open field conditions for 1 day following treatment, with 13 to 28°C air temperatures. At 24 h following treatment, 20 cm of the treated leaves from treatments 3 and 4 were removed (10 cm below point of application of $^{14}$C-glyphosate) in 5-cm pieces and rinsed three times with 3 ml of deionized water within 10-ml vials to separate non-absorbed from absorbed $^{14}$C-glyphosate. Detached leaves and the rinsing liquid were kept in the freezer at -15°C until absorbed $^{14}$C-glyphosate was extracted.

Also, 1 day following treatment, all the leaves of treated plants and untreated controls were marked with waterproof ink 10 cm above the soil level to determine growth of developing leaves. All of the C. esculentus plants were maintained under greenhouse conditions in 4 to 20°C air temperatures.

Nine days following treatment, growth of developing leaves was measured, and C. esculentus plants were separated into three parts:

- leaf (20 cm treated with $^{14}$C-glyphosate
- other leaves plus basal bulbs
- developing tubers

The leaves treated with $^{14}$C-glyphosate were cut and rinsed with water as described for treatments 3 and 4. The different plant parts were kept in the freezer at -15°C for 2 months until extraction of radiolabeled herbicide.

$^{14}$C-glyphosate was extracted from the developing tubers by fine grinding with mortar and pestle of the tuber slices frozen in liquid nitrogen. The tuber powder was suspended in 30 ml of deionized water and centrifuged at 15,000 g for 10 minutes. The supernatant was saved and the sedimented material was extracted with 50 ml of the 0.72%

glyphosate solution. This operation was repeated three times for each sample and a 5-ml aliquot of the 100 ml extract was taken for liquid scintillation counting.

$^{14}$C-glyphosate from untreated leaves was extracted by homogenization in a Waring blender for 10 minutes in 100 ml of deionized water with 0.72% glyphosate (commercial formulation). The homogenized extract was centrifuged at 15,000 g for 10 minutes. The supernatant was saved and the sedimented material was extracted with 50 ml of the 0.72% glyphosate solution. This solution was shaken for 5 minutes and centrifuged at 15,000 g for 10 minutes. A 4-ml aliquot of the 160-ml of supernatant was treated with 1 ml of 30% $H_2O_2$ for 1 h at 35°C prior to liquid scintillation counting.

Methods for extraction of $^{14}$C-glyphosate from treated leaves were similar except 40 ml of water was used for homogenization. Also, after centrifugation, the sediment was extracted with two consecutive additions of 30 ml of 0.72% glyphosate solution rather than with 50 ml once.

Liquid scintillation counting was done by adding the prepared aliquots to 15 ml of scintillation fluid[2], shaking, and assaying in a scintillation counter. Counts per minute were corrected for background and efficiency and converted to disintegrations per minute (dpm). Counting efficiency was 87% for leaf wash and tuber extracts and 85% for treated and untreated leaf tissue extracts.

The treatments were replicated five times. Data were subjected to analysis of variance and means were separated by Duncan's multiple range test.

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[2]Aquasol scintillation fluid from New England Nuclear.

## RESULTS AND DISCUSSION

Leaf growth measurements were made 9 days following treatment when no visible symptoms of foliar phytotoxicity were evident, probably because of the relatively low temperatures. Leaf growth was significantly reduced by all glyphosate treatments (Table 3-1), but growth of the untreated check and differences between treatments were much lower than in previous experiments under higher temperatures and light intensities. As days become shorter, a higher proportion of C. esculentus photosynthate accumulates in developing tubers and a lower proportion is used in growth of leaves. The differences between the two glyphosate rates applied were not significant at the 5% level. The addition of ammonium sulfate may have reduced glyphosate toxicity when the treated leaf section was removed after 1 day, but the difference was not significant at the 5% level.

The percentages of the applied $^{14}$C-glyphosate which were recovered in the different plant fractions are summarized in Table 3-2. Since no $^{14}$C-glyphosate metabolism in plants has been reported in short-term experiments, all counts were assumed to represent intact $^{14}$C-glyphosate.

The total of $^{14}$C-glyphosate recovered per individual plant ranged from 21% to 69%, but most of the values were around the 52% average recovery with a standard deviation of 9.5%. The reason for the relatively low percentages of recovery is believed to be due to some extraction problems from tubers and leaves and also to the fact that C. esculentus roots were not extracted. However, since there is no

Table 3-1. Leaf growth of C. esculentus leaves from days 1 to 9 following treatments with glyphosate alone or tank-mixed with ammonium sulfate.

| Treatment | Leaf growth[c] |
|---|---|
| | (mm) |
| Untreated check | 78.4 a |
| glyphosate 0.63 kg/ha[a] | 28.4 b |
| glyphosate 0.63 kg/ha + ammonium sulfate 7 kg/ha[a] | 26.8 b |
| glyphosate 2.52 kg/ha[b] | 17.2 b |
| glyphosate 2.52 kg/ha + ammonium sulfate 7 kg/ha[b] | 26.6 b |
| glyphosate 2.52 kg/ha[a] | 21.4 b |
| glyphosate 2.52 kg/ha + ammonium sulfate 7 kg/ha[a] | 21.2 b |
| C.V. = 24.3% | $LSD_{.05}$ = 10.0 mm |

[a]0.5 μCi of $^{14}$C-glyphosate applied on one leaf.

[b]0.5 μCi of $^{14}$C-glyphosate applied on one leaf which was removed 24 h following treatment.

[c]Figures followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

Table 3-2. Percentage of $^{14}$C-glyphosate applied on C. esculentus leaves recovered in the different plant fractions following glyphosate treatments.

| Treatment | Rate (kg/ha) | % of $^{14}$C-glyphosate[c] recovered in | | | |
|---|---|---|---|---|---|
| | | Leaf wash (non-absorbed) | Treated leaf | Untreated leaves | Tubers |
| glyphosate[a] | 0.63 | 10.7 b | 5.0 | 35.7 | 0.9 |
| glyphosate[a] + ammonium sulfate | 0.63 + 7 | 9.8 b | 6.0 | 40.7 | 0.5 |
| glyphosate[b] | 2.52 | 17.9 a | 8.2 | 20.9 | 1.0 |
| glyphosate[b] + ammonium sulfate | 2.52 + 7 | 6.3 b | 2.4 | 35.9 | 0.5 |
| glyphosate[a] | 2.52 | 8.0 b | 4.9 | 37.2 | 0.5 |
| glyphosate[a] + ammonium sulfate | 2.52 + 7 | 10.1 b | 4.8 | 41.0 | 1.1 |
| C.V. (%) | | 44.4 | 106.2 | 35.3 | 60.4 |
| $LSD_{.05}$ | | 6.12% | n.s. | n.s. | n.s. |

[a] 0.5 µCi of $^{14}$C-glyphosate applied on one leaf.

[b] 0.5 µCi of $^{14}$C-glyphosate applied on one leaf which was cut 24 h following treatment.

[c] Within each column, figures followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

reason to believe that ammonium sulfate application affected the counting efficiency, and the main objective was to detect the influence on absorption and translocation by ammonium sulfate, the results could still be valid.

In plants in which treated leaf portions were removed 24 h after treatment, less $^{14}C$ remained on the outside of the leaf when ammonium sulfate was added. Also, more $^{14}C$ had moved from the treated leaf to untreated leaves, although the difference was not significant at the 5% level of probability. When the plants remained intact for 9 days, absorption and uptake were not affected by ammonium sulfate. These results indicate that ammonium sulfate may increase the rate of glyphosate uptake into the leaf, but probably not the eventual total uptake if the plants are undisturbed. Also, ammonium sulfate seems to have little or no effect on translocation of glyphosate to nutsedge tubers. This supports observations made in Chapter I and II of this thesis. Monsanto Company has indicated an interest in adding ammonium sulfate to glyphosate solutions for treating annual weeds in chemical fallow. The more rapid absorption seen in these studies may well be advantageous, but our results in the field, greenhouse, and laboratory do not suggest any benefit when treating C. esculentus where translocation is a principal objective.

As a result of the high variability, the objective of this experiment was accomplished only partially. The recovery ratio was rather low despite fine grinding of leaf tissue, the use of "cold"

glyphosate solution as extraction liquid to counteract possible weak adsorption of $^{14}$C-glyphosate in the cell tissue (Richard and Slife, 1979), and the use of water which is an adequat solvent for $^{14}$C-glyphosate extraction (Devine, et al., 1984). The use of a sample oxidizer has been successful in many studies (Bucholtz and Hess, 1983), but it was not available for our use.

Statistical analysis of the total $^{14}$C-glyphosate recovered shows a relatively low (18.3%) coefficient of variation compared with the variability within the different plant fractions, and which suggests that physiological differences between individual plants at the pre-senescent stage may have influenced $^{14}$C-glyphosate translocation patterns, particularly those related to tuber maturity (Thullen and Keeley, 1978).

# GENERAL CONCLUSIONS

Cyperus esculentus is a serious weed problem in northwest Spain. Its importance has not been reduced by adoption of modern weed control techniques. It is threatening to become a problem in higher latitude areas of France (Morin and Sombrun, 1984) and Holland (Rotteveel, 1982).

Glyphosate can effectively control C. esculentus plants that it contacts. However, in most infestations, there are numerous tubers in the soil that have not sprouted at the time of glyphosate treatment and, therefore, are not harmed. These tubers then can sprout at a later date, maintaining the infestation. A delay in glyphosate application until the maximum number of tubers had sprouted would be desirable. Field experiments in northwest Spain were directed toward comparing effectiveness at different times late in the growing season. In a newly infested area, treatment on August 5 and October 2 reduced production of new tubers by 75% and 50%, respectively. The viability of the tubers, however, was reduced more by the October treatment, resulting in no difference in reinfestation potential in the spring. In the untreated check and following treatment in October, some of the mother tubers were still able to sprout and form new plants 1 year after the first sprouting. This phenomenon has not been reported previously.

In a timing trial under no-tillage conditions, glyphosate application was more effective when applied on August 1 than on August 31 or October 5. In this case, the nutsedge plants had

not been disturbed and were actively forming tubers at the first date. Apparently, glyphosate moved effectively into the newly-forming tubers at the early time of application but was less able to move into more mature tubers at the later dates of treatment. These results show that timing of glyphosate treatment is important and should be determined by tuber development stage rather than by calendar date. More effective, long-term control can be obtained under no-tillage conditions and when the nutsedge plants are in the early stage of tuber formation. Glyphosate applied beyond that time will fail to move into the mature tubers, thus allowing the infestation to be maintained the following season.

In greenhouse experiments, a simple method of measuring growth of young C. esculentus leaves was developed. Most of the previously reported experimental work with glyphosate has involved measuring dry or fresh weight of treated foliage or visually estimating foliage chlorosis or necrosis. These effects may be a valid means of measuring glyphosate toxicity, but they are relatively slow to appear and they reflect herbicide effects that are more secondary than are growth inhibition effects on young leaves. The method developed is non-destructive and enables treatment evaluation with a few days following glyphosate treatment. This is in contrast with most other methods which require 1 to 2 months following treatment. This method is useful for comparisons among treatments of glyphosate, but it may not be valid for comparing glyphosate effects with those from other herbicides.

Control from glyphosate was clearly superior to that from atrazine. Nutsedge responded more quickly to 2,4-D than to glyphosate, but the effect of glyphosate was superior after several days. In an attempt to improve translocation by augmenting the carbohydrate source, sugar was mixed with the glyphosate. No improvement in control could be observed.

Ammonium sulfate has been reported to improve the effects from glyphosate on numerous weeds. Field, greenhouse, and laboratory experiments were conducted to test the effect of this fertilizer salt on glyphosate activity on nutsedge. No benefit was observed with treatments in the field. In the greenhouse, the addition of a 2% ammonium sulfate solution to glyphosate treatments caused a significantly greater growth inhibition 34 h following treatment than from glyphosate alone. This more rapid expression of glyphosate symptoms with the addition of ammonium sulfate was confirmed in another trial, especially when treated leaves were washed 3 h following treatment. However, when foliage was removed 24 h after spraying, ammonium sulfate appeared to reduce the effect of glyphosate. In laboratory studies using $^{14}C$-glyphosate, ammonium sulfate increased the rate of glyphosate uptake, but total absorption and translocation were not affected.

The addition of ammonium sulfate overcame antagonistic effects of calcium salt or simazine in the water used for glyphosate application.

The addition of ammonium sulfate may be useful as an additive for glyphosate on yellow nutsedge if speed of uptake is important

or when hard water or mixtures with other herbicides are being used. Under most conditions, however, ammonium sulfate does not appear to be beneficial and may even be detrimental if the nutsedge plants are disturbed following treatment. The manufacturer recommends the addition of ammonium sulfate for certain uses of glyphosate. Further research should be conducted to determine whether this use should be restricted to annual weeds, where rapid uptake and action is desirable, or whether the use should be extended to specific perennial weeds in which translocation is a more important consideration than speed of action. Research also is needed to clarify the specific mechanism of ammonium sulfate on glyphosate uptake and translocation, in order to improve its efficiency.

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# APPENDIX

Appendix Table 1. Recovered C. esculentus plants 55 days after being sprayed at different growth stages with glyphosate at 3.6 kg a.e./ha.

| Number of leaves at treatment time | Number of plants with necrosed foliage | Number of plants with green foliage | % reduction in green tissue |
|---|---|---|---|
| 2-4 | 64 | 8 | 89 |
| 6-10 | 68 | 1 | 99 |
| 15-20 | 73 | 0 | 100 |

Binomial confidence limits for above parameters following a binomial distribution (Steel and Torrie, 1960).

| Number of leaves at treatment time | Confidence limits at 95% level | |
|---|---|---|
| | Sample size 50 | Sample size 100 |
| 2-4 | 88.46-64.05 | 94.38-81.17 |
| 6-10 | 99.95-89.34 | 99.98-94.55 |
| 15-20 | 100 -92.89 | 100 -96.38 |

Appendix Table 2. Timing study in a new infestation; percentage (%) foliage control and (in brackets) number of new tubers produced.

| Treatment | Replications A | B | C | D |
|---|---|---|---|---|
| Untreated check | 0 (162) | 0 (200) | 0 (153) | 0 (139) |
| glyphosate 2.7 kg/ha, applied August 5 | 90 (26) | 70 (108) | 90 (22) | 95 (32) |
| glyphosate 2.7 kg/ha, applied October 2 | 85 (130) | 80 (72) | 95 (51) | 80 (67) |

Analysis of variance for percentage (%) foliage control

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 3.125 | 1 | 3.1250 | <1 |
| Replications | 334.375 | 3 | 111.4583 | 1.8136 |
| Error | 184.375 | 3 | 61.4583 | |
| Total | 521.875 | 7 | | |

C.V. = 9.16%

Analysis of variance for number of new tubers

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 28844.6667 | 2 | 14422.3333 | 16.0149** |
| Replications | 5227.6667 | 3 | 1742.5556 | 1.9350 |
| Error | 5403.3333 | 6 | 900.5555 | |
| Total | 39475.6667 | 11 | | |

C.V. = 30.99% $LSD_{.05}$ = 51.925

Appendix Table 3. Timing study in a new infestation; fresh weight of tubers produced and (in brackets) fresh weight per new tuber.

| Treatment | Replications A | B | C | D |
|---|---|---|---|---|
| Untreated check | 151.0(0.93) | 159.0(0.80) | 140.0(0.92) | 148.5(1.07) |
| glyphosate 2.7 kg/ha applied August 5 | 16.0(0.62) | 88.5(0.82) | 11.5(0.52) | 23.0(0.72) |
| glyphosate 2.7 kg/ha applied October 2 | 86.0(0.66) | 56.0(0.78) | 43.0(0.84) | 59.0(0.88) |

Analysis of variance for fresh weight of tubers

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 28986.292 | 2 | 14493.146 | 28.9972** |
| Replications | 2082.063 | 3 | 694.021 | 1.3886 |
| Error | 2998.875 | 6 | 499.812 | |
| Total | 34067.229 | 11 | | |

C.V. = 27.33% $LSD_{.05}$ = 38.683 g

Analysis of variance for fresh weight per tuber

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 0.13547 | 2 | 0.06773 | 5.5519* |
| Replications | 0.04100 | 3 | 0.01367 | 1.1202 |
| Error | 0.07320 | 6 | 0.01220 | |
| Total | 0.24967 | 11 | | |

C.V. = 13.86% $LSD_{.05}$ = 0.1911 g

Appendix Table 4. Timing study in a new infestation; number of tubers sprouted the following year and (in brackets) percentage of tubers sprouted transformed to arc sin $\sqrt{\%}$.

| Treatment | Replications A | B | C | D |
|---|---|---|---|---|
| Untreated check | 89(47.83) | 141(57.10) | 100(53.94) | 64(42.73) |
| glyphosate 2.7 kg/ha applied August 5 | 9(36.04) | 48(41.80) | 7(34.34) | 9(32.03) |
| glyphosate 2.7 kg/ha applied October 2 | 12(17.69) | 8(19.47) | 4(16.26) | 4(14.14) |

Analysis of variance for number of tubers sprouted.

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 19918.50 | 2 | 9959.2500 | 35.5370** |
| Replications | 2634.25 | 3 | 878.0833 | 3.1332 |
| Error | 1681.50 | 6 | 280.2500 | |
| Total | 24234.25 | 11 | | |

C.V. = 40.58% $LSD_{.05}$ = 28.966

Analysis of variance for arc sin $\sqrt{\%}$ tubers sprouted.

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 2261.2963 | 2 | 1130.6482 | 154.4695** |
| Replications | 146.3410 | 3 | 48.7803 | 6.6644* |
| Error | 43.9173 | 6 | 7.3196 | |
| Total | 2451.5546 | 11 | | |

C.V. = 7.85% $LSD_{.05}$ = 4.681

Appendix Table 5. Timing study in a new infestation; number of parent tubers recovered and (in brackets) number of parent tubers sprouted the following year.

| Treatment | Replications | | | |
|---|---|---|---|---|
| | A | B | C | D |
| Untreated check | 8(3) | 10(5) | 4(0) | 6(4) |
| glyphosate 2.7 kg/ha applied August 5 | 6(0) | 7(0) | 8(0) | 5(0) |
| glyphosate 2.7 kg/ha applied October 2 | 7(0) | 2(0) | 7(2) | 2(1) |

Analysis of variance for percentage of parent tubers sprouted after transformation to arc sin $\sqrt{\%}$ .

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 2375.4935 | 2 | 1187.7486 | 3.0632 |
| Replications | 968.9958 | 3 | 322.9986 | <1 |
| Error | 2326.4541 | 6 | 387.7424 | |
| Total | 5670.9433 | 11 | | |

C.V. = 110.0%

Appendix Table 6. Timing study under no-tillage conditions; visual evaluation of percentage of foliar injury on October 21, 1977.

| Time of application of glyphosate 2.16 kg a.e./ha | Replications | | | |
|---|---|---|---|---|
| | A | B | C | D |
| August 1, 1977 | 90 | 96 | 93 | 90 |
| August 31, 1977 | 90 | 90 | 85 | 80 |
| October 5, 1977 | 30 | 30 | 30 | 20 |
| August 1 and October 5, 1977 | 93 | 92 | 89 | 90 |
| Untreated check | 0 | 0 | 0 | 0 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 11736.5 | 3 | 3912.1667 | 525.5181** |
| Replications | 111.5 | 3 | 37.1667 | 4.9926* |
| Error | 67.0 | 9 | 7.4444 | |
| Total | 11915.0 | 15 | | |

C.V. = 3.67% $LSD_{.05}$ = 4.364%

Appendix Table 7. Timing study under no-tillage conditions; visual evaluation of percentage of reduction in reinfestation on July 10, 1978.

| Time of application of glyphosate 2.16 kg a.e./ha | Replications | | | |
|---|---|---|---|---|
| | A | B | C | D |
| August 1, 1977 | 80 | 95 | 90 | 85 |
| August 31, 1977 | 50 | 75 | 45 | 75 |
| October 5, 1977 | 40 | 20 | 65 | 75 |
| August 1 and October 5, 1977 | 90 | 93 | 93 | 93 |
| Untreated check | 0 | 0 | 0 | 0 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 4990.5 | 3 | 1663.500 | 6.9602* |
| Replications | 599.5 | 3 | 199.833 | <1 |
| Error | 2151.0 | 9 | 239.000 | |
| Total | 7741.0 | 15 | | |

C.V. = 21.25% $LSD_{.05}$ = 24.73%

Appendix Table 8. Influence of tuber maturity and additives on effectiveness of glyphosate; percent foliage control 55 days following treatment and (in brackets) percent reinfestation control 10.5 months following treatment.

| Treatment | Replications A | B | C | D |
|---|---|---|---|---|
| glyphosate 2.16 kg/ha | 85(10) | 90(40) | 90(60) | 95(40) |
| glyphosate 2.16 kg/ha + am. sulfate 6 kg/ha | 95(30) | 92(10) | 95(30) | 95(60) |
| glyphosate 2.16 kg/ha + sucrose 10 kg/ha | 95(20) | 70(20) | 93(70) | 90(60) |
| Untreated check | 0(0) | 0(0) | 0(0) | 0(0) |

Analysis of variance for percent foliage control.

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 24631.6870 | 3 | 8210.5625 | 225.2468** |
| Replications | 126.6875 | 3 | 42.2292 | 1.1585 |
| Error | 328.0625 | 9 | 36.4514 | |
| Total | 25086.4370 | 15 | | |

C.V. = 8.9% $LSD_{.05}$ = 9.66%

Analysis of variance for percent reinfestation control.

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 4418.75 | 3 | 1472.9167 | 5.6260* |
| Replications | 2268.75 | 3 | 756.2500 | 2.8886 |
| Error | 2356.25 | 9 | 261.8056 | |
| Total | 9043.75 | 15 | | |

C.V. = 57.5% $LSD_{.05}$ = 25.9%

Appendix Table 9. Influence of tuber maturity and additives on effectiveness of glyphosate; number of young tubers produced and (in brackets) number of mature tubers produced.

| Treatment | Replications | | | |
|---|---|---|---|---|
| | A | B | C | D |
| glyphosate 2.16 kg/ha | 31(72) | 12(78) | 32(62) | 22(71) |
| glyphosate 2.16 kg/ha + am. sulfate 6 kg/ha | 38(72) | 35(73) | 31(79) | 35(50) |
| glyphosate 2.16 kg/ha + sucrose 10 kg/ha | 33(63) | 29(72) | 29(68) | 31(82) |
| Untreated check | 48(70) | 29(70) | 30(81) | 29(40) |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 11954.969 | 7 | 1707.8527 | 18.0189** |
| Replications | 309.344 | 3 | 103.1146 | 1.0879 |
| Error | 1990.406 | 21 | 94.7813 | |
| Total | 14254.719 | 31 | | |

C.V. = 19.51% $LSD_{.05}$ = 14.319

Appendix Table 10. Influence of tuber maturity and additives on effectiveness of glyphosate; percent sprouting of young tubers and (in brackets) percent sprouting of mature tubers.

| Treatment | Replications | | | |
|---|---|---|---|---|
| | A | B | C | D |
| glyphosate 2.16 kg/ha | 32(26) | 0(19) | 0(19) | 5(23) |
| glyphosate 2.16 kg/ha + am. sulfate 6 kg/ha | 0(21) | 14(19) | 3(11) | 9(22) |
| glyphosate 2.16 kg/ha + sucrose 10 kg/ha | 24(19) | 21(17) | 7(10) | 3(26) |
| Untreated check | 60(47) | 55(49) | 37(30) | 52(33) |

Analysis of variance after transformation to arc sin $\sqrt{\%}$

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 3884.4241 | 7 | 554.9177 | 9.5626** |
| Replications | 442.9526 | 3 | 147.6509 | 2.5444 |
| Error | 1218.6311 | 21 | 58.0301 | |
| Total | 5546.0078 | 31 | | |

C.V. = 29.46% $LSD_{.05}$ = 11.204

Appendix Table 11. Effect of glyphosate, atrazine, and 2,4-D on *C. esculentus* growth rate; leaf growth (mm) 12 h following treatments.

| Treatments | Replications | | | | | | | Avg |
|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | |
| 1 | 18 | 18 | 16 | 16 | 23 | 19 | 15 | 17.9 |
| 2 | 16 | 20 | 20 | 22 | 23 | 21 | 21 | 20.4 |
| 3 | 23 | 22 | 21 | 18 | 18 | 19 | 19 | 20.0 |
| 4 | 19 | 21 | 18 | 20 | 20 | 16 | 16 | 18.6 |
| 5 | 12 | 17 | 18 | 18 | 19 | 17 | 21 | 17.4 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 48.286 | 4 | 12.0715 | 2.1038 |
| Replications | 28.286 | 6 | 4.7143 | <1 |
| Error | 137.714 | 24 | 5.7381 | |
| Total | 214.286 | 34 | | |

C.V. = 12.7%

| Treatments | Herbicides |
|---|---|
| 1 | Untreated check |
| 2 | glyphosate 1.5 kg a.e./ha |
| 3 | glyphosate 3.0 kg a.e./ha |
| 4 | atrazine 2.0 kg a.i./ha |
| 5 | 2,4-D amine 1.5 kg a.e./ha |

Appendix Table 12. Effect of glyphosate, atrazine, and 2,4-D on *C. esculentus* growth rate; leaf growth (mm) 1 day following treatment.

| Treatments* | Replications | | | | | | | Avg |
|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | |
| 1 | 34 | 35 | 30 | 33 | 42 | 34 | 34 | 34.6 |
| 2 | 36 | 34 | 39 | 36 | 42 | 39 | 39 | 37.9 |
| 3 | 35 | 40 | 36 | 35 | 38 | 35 | 33 | 36.0 |
| 4 | 36 | 40 | 35 | 42 | 40 | 33 | 37 | 37.6 |
| 5 | 24 | 28 | 34 | 39 | 32 | 31 | 29 | 31.0 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 218.114 | 4 | 54.5285 | 5.4283** |
| Replications | 111.200 | 6 | 18.5333 | 1.8450 |
| Error | 241.086 | 24 | 10.0453 | |
| Total | 570.400 | 34 | | |

C.V. = 8.95% $LSD_{.05}$ = 3.50 mm

*Treatments listed in Appendix Table 11.

Appendix Table 13. Effect of glyphosate, atrazine, and 2,4-D on C. esculentus growth rate; leaf growth (mm) 1.5 days following treatment.

| Treatments* | Replications | | | | | | | Avg |
|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | |
| 1 | 53 | 58 | 48 | 53 | 60 | 56 | 57 | 55.0 |
| 2 | 53 | 49 | 55 | 50 | 60 | 62 | 62 | 55.9 |
| 3 | 42 | 64 | 48 | 52 | 55 | 47 | 40 | 49.7 |
| 4 | 56 | 63 | 60 | 60 | 65 | 54 | 61 | 59.9 |
| 5 | 32 | 37 | 58 | 64 | 42 | 42 | 33 | 44.0 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 1056.400 | 4 | 264.1000 | 4.5997** |
| Replications | 307.143 | 6 | 51.1905 | <1 |
| Error | 1378.000 | 24 | 57.4167 | |
| Total | 2741.543 | 34 | | |

C.V. = 14.3% $LSD_{.05}$ = 8.36 mm

*Treatments listed in Appendix Table 11.

Appendix Table 14. Effect of glyphosate, atrazine, and 2,4-D on *C. esculentus* growth rate; leaf growth (mm) 2.5 days following treatment.

| Treatments* | Replications | | | | | | | Avg |
|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | |
| 1 | 90 | 106 | 87 | 95 | 97 | 94 | 104 | 96.1 |
| 2 | 70 | 71 | 69 | 70 | 86 | 110 | 89 | 80.7 |
| 3 | 47 | 93 | 62 | 65 | 70 | 56 | 46 | 62.7 |
| 4 | 93 | 107 | 102 | 95 | 112 | 91 | 110 | 101.4 |
| 5 | 43 | 45 | 110 | 111 | 58 | 54 | 42 | 66.1 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 8406.2857 | 4 | 2101.5714 | 6.1804** |
| Replications | 1241.3715 | 6 | 206.8953 | <1 |
| Error | 8160.9143 | 24 | 340.0381 | |
| Total | 17808.5715 | 34 | | |

C.V. = 22.6% $LSD_{.05}$ = 20.34 mm

*Treatments listed in Appendix Table 11.

Appendix Table 15. Effect of glyphosate, atrazine, and 2,4-D on *C. esculentus* growth rate; leaf growth (mm) 6.5 days following treatment.

| Treatments* | Replications | | | | | | | Avg |
|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | |
| 1 | 324 | 333 | 281 | 274 | 304 | 301 | 263 | 297.1 |
| 2 | 102 | 103 | 93 | 114 | 154 | 277 | 136 | 139.9 |
| 3 | 57 | 153 | 80 | 67 | 88 | 79 | 55 | 82.7 |
| 4 | 300 | 323 | 278 | 281 | 332 | 299 | 285 | 299.7 |
| 5 | 109 | 130 | 257 | 287 | 90 | 83 | 60 | 145.1 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 276577 | 4 | 69144.33 | 21.6431** |
| Replications | 9648 | 6 | 1607.92 | <1 |
| Error | 76674 | 24 | 3194.75 | |
| Total | 362899 | 34 | | |

C.V. = 29.3% $LSD_{.05}$ = 62.36 mm

*Treatments listed in Appendix Table 11.

Appendix Table 16. Short-term effects of glyphosate treatments on growth of yellow nutsedge leaves; leaf growth (mm) 12 h following treatment.

| Treatments | Replications | | | | | | Avg |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | |
| 1 | 20 | 18 | 25 | 21 | 16 | 16 | 19.3 |
| 2 | 25 | 15 | 20 | 19 | 16 | 23 | 19.7 |
| 3 | 21 | 23 | 23 | 23 | 23 | 22 | 22.5 |
| 4 | 21 | 25 | 22 | 21 | 21 | 18 | 21.3 |
| 5 | 21 | 15 | 26 | 21 | 19 | 22 | 20.7 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 39.4666 | 4 | 9.8666 | 1.1878 |
| Replications | 62.7000 | 5 | 12.5400 | 1.5096 |
| Error | 166.1334 | 20 | 8.3067 | |
| Total | 268.3000 | 29 | | |

C.V. = 13.92%

| Treatments | Herbicides |
|---|---|
| 1 | Untreated check |
| 2 | glyphosate 1.5 kg a.e./ha |
| 3 | glyphosate 1.5 kg a.e./ha + ammonium sulfate 2% |
| 4 | glyphosate 3.0 kg a.e./ha |
| 5 | glyphosate 3.0 kg a.e./ha + ammonium sulfate 2% |

Appendix Table 17. Short-term effects of glyphosate treatment on growth of yellow nutsedge leaves; leaf growth (mm) 22 h following treatment.

| Treatment* | Replications | | | | | | Avg |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | |
| 1 | 31 | 36 | 47 | 38 | 26 | 34 | 35.3 |
| 2 | 41 | 35 | 34 | 33 | 35 | 42 | 36.7 |
| 3 | 31 | 36 | 38 | 40 | 39 | 36 | 36.7 |
| 4 | 35 | 42 | 33 | 33 | 32 | 30 | 34.2 |
| 5 | 29 | 22 | 34 | 37 | 29 | 32 | 30.5 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 156.3333 | 4 | 39.0834 | 1.5241 |
| Replications | 83.4667 | 5 | 16.6933 | <1 |
| Error | 512.8667 | 20 | 25.6433 | |
| Total | 752.6667 | 29 | | |

C.V. = 14.61%

*Treatments listed in Appendix Table 16.

Appendix Table 18. Short-term effects of glyphosate treatments on growth of yellow nutsedge leaves; leaf growth (mm) 34 h following treatment.

| Treatment* | Replications | | | | | | Avg |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | |
| 1 | 52 | 56 | 71 | 62 | 44 | 55 | 56.7 |
| 2 | 59 | 46 | 49 | 47 | 51 | 57 | 51.5 |
| 3 | 42 | 45 | 47 | 52 | 51 | 47 | 47.3 |
| 4 | 44 | 57 | 43 | 46 | 40 | 38 | 44.7 |
| 5 | 35 | 32 | 41 | 49 | 36 | 37 | 38.3 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 1151.4666 | 4 | 287.8667 | 6.5863** |
| Replications | 160.7000 | 5 | 32.1400 | <1 |
| Error | 874.1334 | 20 | 43.7067 | |
| Total | 2186.3000 | 29 | | |

C.V. = 13.86% $LSD_{.05}$ = 7.96 mm

*Treatments listed in Appendix Table 16.

Appendix Table 19. Short-term effects of glyphosate treatments in growth of yellow nutsedge leaves; leaf growth (mm) 58 h following treatment.

| Treatment* | Replications | | | | | | Avg |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | |
| 1 | 101 | 108 | 134 | 118 | 89 | 109 | 109.8 |
| 2 | 77 | 56 | 63 | 67 | 75 | 89 | 71.2 |
| 3 | 55 | 70 | 58 | 72 | 70 | 65 | 65.0 |
| 4 | 60 | 66 | 46 | 60 | 49 | 45 | 54.3 |
| 5 | 45 | 39 | 54 | 62 | 43 | 48 | 48.5 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 13922.87 | 5 | 2784.5733 | 22.4605** |
| Replications | 346.97 | 4 | 86.7417 | <1 |
| Error | 2479.53 | 20 | 123.9767 | |
| Total | 16749.37 | 29 | | |

C.V. = 15.96% $LSD_{.05}$ = 13.41 mm

*Treatments listed in Appendix Table 16.

Appendix Table 20. Short-term effects of glyphosate treatments on growth of yellow nutsedge leaves; leaf growth (mm) 130 h following treatment.

| Treatment* | Replications | | | | | | Avg |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | |
| 1 | 246 | 228 | 281 | 237 | 202 | 242 | 239.3 |
| 2 | 94 | 69 | 78 | 79 | 90 | 110 | 86.7 |
| 3 | 63 | 73 | 68 | 84 | 80 | 74 | 73.7 |
| 4 | 70 | 76 | 56 | 62 | 55 | 47 | 61.0 |
| 5 | 47 | 42 | 58 | 70 | 48 | 57 | 53.6 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 143470.13 | 4 | 35867.53 | 142.64** |
| Replications | 708.27 | 5 | 141.65 | <1 |
| Error | 5029.07 | 20 | 251.45 | |
| Total | 149207.47 | 29 | | |

C.V. = 15.42% $LSD_{.05}$ = 19.10 mm

*Treatments listed in Appendix Table 16.

Appendix Table 21. Short-term effects of glyphosate treatments on growth of yellow nutsedge leaves; visual percentage of control (%) 40 days following treatment.

| Treatment* | Replications | | | | | | Avg |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | |
| 1 | (0) | (0) | (0) | (0) | (0) | (0) | (0.0) |
| 2 | 96 | 92 | 92 | 90 | 91 | 97 | 93.0 |
| 3 | 95 | 96 | 100 | 97 | 100 | 99 | 97.8 |
| 4 | 100 | 100 | 99 | 99 | 100 | 100 | 99.7 |
| 5 | 96 | 99 | 100 | 99 | 100 | 97 | 98.5 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 154.8333 | 3 | 51.6111 | 11.7893** |
| Replications | 12.0000 | 5 | 2.4000 | <1 |
| Error | 65.6667 | 15 | 4.3778 | |
| Total | 232.5000 | 23 | | |

C.V. = 2.15% $LSD_{.05}$ = 2.52%

*Treatments listed in Appendix Table 16

Appendix Table 22. Short-term effects of glyphosate treatments on growth of yellow nutsedge leaves; fresh weight of leaves (g) 40 days following treatment.

| Treatment* | Replications | | | | | | Avg |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | |
| 1 | 24.0 | 22.5 | 16.0 | 17.0 | 16.5 | 20.5 | 19.4 |
| 2 | 3.0 | 4.5 | 3.5 | 5.0 | 3.0 | 2.0 | 3.5 |
| 3 | 3.0 | 1.5 | 2.5 | 3.5 | 1.0 | 1.5 | 2.2 |
| 4 | 1.0 | 2.0 | 2.5 | 2.0 | 1.5 | 2.0 | 1.8 |
| 5 | 2.5 | 2.5 | 2.0 | 2.0 | 2.0 | 2.0 | 2.2 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 1397.0334 | 4 | 349.2584 | 123.7044** |
| Replications | 13.7417 | 5 | 2.7483 | <1 |
| Error | 56.4666 | 20 | 2.8233 | |
| Total | 1467.2417 | 29 | | |

C.V. = 28.89% $LSD_{.05}$ = 2.02 g

*Treatments listed in Appendix Table 16.

Appendix Table 23. Response to washing and leaf cutting following glyphosate or glyphosate + ammonium sulfate treatments; leaf growth (mm) 1 day following treatment.

| Treatments | Replications | | | | | Avg |
|---|---|---|---|---|---|---|
| | A | B | C | D | E | |
| 1 | 48 | 49 | 51 | 62 | 48 | 51.6 |
| 2 | 57 | 49 | 42 | 51 | 40 | 47.8 |
| 3 | 61 | 50 | 44 | 43 | 47 | 49.0 |
| 4 | 56 | 51 | 49 | 47 | 55 | 51.6 |
| 5 | 62 | 55 | 58 | 44 | 47 | 53.2 |
| 6 | 46 | 55 | 54 | 55 | 28 | 47.6 |
| 7 | 59 | 52 | 55 | 47 | 46 | 51.8 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 146.1714 | 6 | 24.3619 | <1 |
| Replications | 448.4571 | 4 | 112.1143 | 2.5984 |
| Error | 1035.5429 | 24 | 43.1476 | |
| Total | 1630.1714 | 34 | | |

C.V. = 13.04%

| Treatments | Herbicides |
|---|---|
| 1 | Untreated check |
| 2 | glyphosate 1.5 kg a.e./ha |
| 3 | glyphosate 1.5 kg a.e./ha + ammonium sulfate 2% |
| 4 | glyphosate 1.5 kg a.e./ha + wash |
| 5 | glyphosate 1.5 kg a.e./ha + ammonium sulfate 2% + wash |
| 6 | glyphosate 1.5 kg a.e./ha + wash + cut |
| 7 | glyphosate 1.5 kg a.e./ha + ammonium sulfate 2% + wash + cut |

Appendix Table 24. Response to washing and leaf cutting following glyphosate or glyphosate + ammonium sulfate treatments; leaf growth (mm) from days 1 to 2 following treatments.

| Treatments* | Replications | | | | | Avg |
|---|---|---|---|---|---|---|
| | A | B | C | D | E | |
| 1 | 58 | 61 | 61 | 61 | 51 | 58.4 |
| 2 | 61 | 50 | 52 | 36 | 58 | 51.4 |
| 3 | 39 | 47 | 25 | 24 | 40 | 35.0 |
| 4 | 64 | 49 | 60 | 60 | 50 | 56.6 |
| 5 | 54 | 43 | 53 | 40 | 30 | 44.0 |
| 6 | 44 | 45 | 46 | 30 | 39 | 40.8 |
| 7 | 42 | 42 | 50 | 30 | 28 | 38.4 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 2520.5714 | 6 | 420.0952 | 7.9909** |
| Replications | 681.8857 | 4 | 170.4714 | 3.2427* |
| Error | 1261.7143 | 24 | 52.5714 | |
| Total | 4464.1714 | 34 | 131.2992 | |

C.V. = 15.64% $LSD_{.05}$ = 9.465 mm

*Treatments listed in Appendix Table 23.

Appendix Table 25. Response to washing and leaf cutting following glyphosate or glyphosate + ammonium sulfate treatments; leaf growth (mm) from days 2 to 3 following treatments.

| Treatment* | Replications | | | | | Avg |
|---|---|---|---|---|---|---|
| | A | B | C | D | E | |
| 1 | 58 | 60 | 58 | 51 | 60 | 57.4 |
| 2 | 64 | 36 | 36 | 26 | 35 | 39.4 |
| 3 | 13 | 25 | 11 | 3 | 19 | 14.2 |
| 4 | 61 | 43 | 58 | 49 | 40 | 50.2 |
| 5 | 41 | 21 | 22 | 18 | 12 | 22.8 |
| 6 | 41 | 44 | 41 | 22 | 32 | 36.0 |
| 7 | 35 | 31 | 40 | 23 | 11 | 28.0 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 6911.7714 | 6 | 1151.9619 | 18.7427** |
| Replications | 1335.7143 | 4 | 333.9286 | 5.4331* |
| Error | 1475.0857 | 24 | 61.4619 | |
| Total | 9722.5714 | 34 | | |

C.V. = 22.13% $LSD_{.05}$ = 10.23 mm

*Treatments listed in Appendix Table 23.

Appendix Table 26. Response to washing and leaf cutting following glyphosate or glyphosate + ammonium sulfate treatments; leaf growth (mm) from days 3 to 5 following treatments.

| Treatment* | Replications | | | | | Avg |
|---|---|---|---|---|---|---|
| | A | B | C | D | E | |
| 1 | 117 | 78 | 97 | 105 | 109 | 101.2 |
| 2 | 76 | 29 | 82 | 24 | 32 | 48.6 |
| 3 | 12 | 24 | 12 | 10 | 15 | 14.6 |
| 4 | 80 | 39 | 65 | 41 | 39 | 52.8 |
| 5 | 105 | 17 | 17 | 9 | 11 | 31.8 |
| 6 | 54 | 73 | 92 | 29 | 38 | 57.2 |
| 7 | 48 | 48 | 72 | 41 | 11 | 44.0 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 21517.371 | 6 | 3586.2286 | 8.4752** |
| Replications | 6686.114 | 4 | 1671.5286 | 3.9502* |
| Error | 10155.486 | 24 | 423.1452 | |
| Total | 38358.971 | 34 | | |

C.V. = 41.12% $LSD_{.05}$ = 26.85 mm

*Treatments listed in Appendix Table 23.

Appendix Table 27. Response to washing and leaf cutting following glyphosate or glyphosate + ammonium sulfate treatments; visual percentage (%) of control 34 days following treatment.

| Treatment* | Replications | | | | | Avg |
|---|---|---|---|---|---|---|
| | A | B | C | D | E | |
| 1 | (0) | (0) | (0) | (0) | (0) | (0.0) |
| 2 | 70 | 90 | 80 | 85 | 75 | 80.0 |
| 3 | 95 | 90 | 92 | 98 | 93 | 93.6 |
| 4 | 30 | 20 | 20 | 20 | 10 | 20.0 |
| 5 | 15 | 40 | 70 | 70 | 60 | 51.0 |
| 6 | 45 | 25 | 25 | 50 | 70 | 43.0 |
| 7 | 45 | 60 | 25 | 40 | 85 | 51.0 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 17518.1670 | 5 | 3503.6333 | 13.4299** |
| Replications | 989.5333 | 4 | 247.3833 | <1 |
| Error | 5217.6667 | 20 | 260.8833 | |
| Total | 23725.3670 | 29 | | |

C.V. = 28.62% $LSD_{.05}$ = 21.31%

*Treatments listed in Appendix Table 23.

Appendix Table 28. Response to washing and leaf cutting following glyphosate or glyphosate + ammonium sulfate treatments; fresh weight (g) of leaves 34 days following treatment.

| Treatments* | Replications A | B | C | D | E | Avg |
|---|---|---|---|---|---|---|
| 1 | 19.0 | 17.5 | 16.5 | 17.5 | 21.5 | 18.4 |
| 2 | 11.5 | 5.0 | 7.5 | 5.0 | 7.5 | 7.3 |
| 3 | 3.0 | 4.0 | 2.5 | 2.5 | 4.0 | 3.2 |
| 4 | 11.0 | 13.0 | 16.5 | 14.5 | 13.3 | 13.7 |
| 5 | 12.5 | 8.0 | 7.5 | 5.8 | 9.5 | 8.7 |
| 6 | 6.0 | 9.5 | 8.8 | 4.3 | 4.0 | 6.5 |
| 7 | 7.0 | 4.5 | 10.0 | 4.8 | 2.5 | 5.8 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 816.6674 | 6 | 136.1112 | 26.6764** |
| Replications | 23.4486 | 4 | 5.8621 | 1.1489 |
| Error | 122.4554 | 24 | 5.1023 | |
| Total | 962.5714 | 34 | | |

C.V. = 24.9% $LSD_{.05}$ = 2.949 g

*Treatments listed in Appendix Table 23.

Appendix Table 29. Effect of ammonium sulfate on glyphosate action in tank mixes with simazine or in water with 200 ppm calcium; leaf growth (mm) in main shoot 1-9 days following treatment.

| Herbicide treatment | Replications A | B | C | D | Avg |
|---|---|---|---|---|---|
| 1. Untreated check | 265 | 238 | 270 | 205 | 244.5 |
| 2. glyphosate 2.2 kg a.e./ha | 75 | 60 | 74 | 71 | 70.0 |
| 3. glyphosate 2.2 kg a.e./ha + ammonium sulfate 2% | 47 | 46 | 71 | 48 | 53.0 |
| 4. glyphosate 2.2 kg a.e./ha + simazine 2.8 kg a.i./ha | 85 | 65 | 40 | 96 | 71.5 |
| 5. glyphosate 2.2 kg a.e./ha + simazine + ammonium sulfate 2% | 40 | 46 | 60 | 41 | 46.8 |
| 6. glyphosate 2.2 kg a.e./ha + Ca 200 ppm | 108 | 60 | 78 | 76 | 80.5 |
| 7. glyphosate 2.2 kg a.e./ha + Ca 200 ppm + ammonium sulfate 2% | 71 | 24 | 20 | 51 | 41.5 |
| 8. glyphosate 2.2 kg a.e./ha + Ca 200 ppm* | 81 | 83 | 50 | 103 | 79.3 |
| 9. glyphosate 2.2 kg a.e./ha + Ca 200 ppm + ammonium sulfate 2%* | 48 | 24 | 54 | 60 | 46.5 |

*Solution prepared 6 h in advance.

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 126608.5 | 8 | 15826.06 | 43.7075** |
| Replications | 1746.3 | 3 | 582.11 | 1.6076 |
| Error | 8690.2 | 24 | 362.09 | |
| Total | 137045.0 | 35 | | |

C.V. = 23.35% $LSD_{.05}$ = 27.77 mm

Appendix Table 30. Effect of ammonium sulfate on glyphosate action in tank mixes with simazine or in water with 200 ppm calcium; leaf growth (mm) in main shoot 1-20 days following treatment.

| Treatment* | Replications | | | | Avg |
|---|---|---|---|---|---|
| | A | B | C | D | |
| 1 | 420 | 398 | 363 | 390 | 392.8 |
| 2 | 76 | 61 | 78 | 79 | 73.5 |
| 3 | 45 | 48 | 78 | 54 | 56.3 |
| 4 | 98 | 70 | 46 | 103 | 79.3 |
| 5 | 30 | 48 | 60 | 28 | 41.5 |
| 6 | 110 | 64 | 102 | 84 | 90.0 |
| 7 | 60 | 22 | 21 | 53 | 39.0 |
| 8 | 86 | 105 | 57 | 130 | 94.5 |
| 9 | 45 | 25 | 31 | 51 | 38.0 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 399457.72 | 8 | 49932.215 | 130.3579** |
| Replications | 1952.31 | 3 | 650.769 | 1.6990 |
| Error | 9192.94 | 24 | 383.039 | |
| Total | 410602.97 | 35 | | |

C.V. = 19.47% $LSD_{.05}$ = 28.56 mm

*Treatments listed in Appendix Table 29.

Appendix Table 31. Effect of ammonium sulfate on glyphosate action in tank mixes with simazine or in water with 200 ppm calcium; leaf growth (mm) in lateral shoot 1-9 days following treatment.

| Treatments* | Replications | | | | Avg |
|---|---|---|---|---|---|
| | A | B | C | D | |
| 1 | 262 | 240 | 312 | 229 | 260.8 |
| 2 | 59 | 60 | 53 | 75 | 61.8 |
| 3 | 63 | 51 | 21 | 53 | 47.0 |
| 4 | 88 | 97 | 47 | 106 | 84.5 |
| 5 | 53 | 56 | 55 | 63 | 56.8 |
| 6 | 115 | 104 | 100 | 85 | 101.0 |
| 7 | 81 | 42 | 37 | 43 | 50.8 |
| 8 | 67 | 108 | 58 | 158 | 97.8 |
| 9 | 70 | 39 | 56 | 56 | 55.3 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 143457.06 | 8 | 17932.132 | 29.3603** |
| Replications | 1195.22 | 3 | 398.407 | <1 |
| Error | 14658.28 | 24 | 610.762 | |
| Total | 159310.56 | 35 | | |

C.V. = 27.27% $LSD_{.05}$ = 36.07 mm

*Treatments listed in Appendix Table 29.

Appendix Table 32. Effect of ammonium sulfate on glyphosate action in tank mixes with simazine or in water with 200 ppm calcium; leaf growth of lateral shoot 1-20 days following treatment.

| Treatments* | Replications A | B | C | D | Avg |
|---|---|---|---|---|---|
| 1 | 425 | 347 | 368 | 394 | 383.5 |
| 2 | 68 | 67 | 98 | 128 | 90.3 |
| 3 | 69 | 50 | 82 | 65 | 66.5 |
| 4 | 122 | 90 | 50 | 115 | 94.3 |
| 5 | 40 | 59 | 71 | 64 | 58.5 |
| 6 | 137 | 78 | 218 | 115 | 137.0 |
| 7 | 86 | 40 | 35 | 28 | 47.3 |
| 8 | 77 | 135 | 59 | 230 | 125.3 |
| 9 | 75 | 37 | 62 | 60 | 58.5 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 349904.56 | 8 | 43488.07 | 28.8313** |
| Replications | 5086.22 | 3 | 1695.41 | 1.1240 |
| Error | 36200.78 | 24 | 1508.37 | |
| Total | 389191.56 | 35 | | |

C.V. = 32.94% $LSD_{.05}$ = 56.68 mm

*Treatments listed in Appendix Table 29.

Appendix Table 33. Effect of ammonium sulfate on glyphosate action in tank mixes with simazine or in water with 200 ppm calcium; visual percentage (%) of control 72 days following treatment.

| Treatments* | Replications A | B | C | D | Avg |
|---|---|---|---|---|---|
| 1 | (0) | (0) | (0) | (0) | (0.0) |
| 2 | 50 | 80 | 65 | 60 | 63.8 |
| 3 | 65 | 70 | 60 | 75 | 67.5 |
| 4 | 40 | 75 | 40 | 50 | 51.3 |
| 5 | 85 | 83 | 70 | 83 | 80.3 |
| 6 | 55 | 70 | 70 | 55 | 62.5 |
| 7 | 83 | 98 | 78 | 83 | 85.5 |
| 8 | 40 | 68 | 65 | 40 | 53.3 |
| 9 | 60 | 85 | 88 | 73 | 76.5 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 4294.875 | 7 | 613.5536 | 7.6998** |
| Replications | 1527.625 | 3 | 509.2083 | 6.3903** |
| Error | 1673.375 | 21 | 79.6845 | |
| Total | 7495.875 | 31 | | |

C.V. = 13.21% $LSD_{.05}$ = 13.129%

*Treatments listed in Appendix Table 29.

Appendix Table 34. Effect of ammonium sulfate on glyphosate action in tank mixes with simazine or in water with 200 ppm calcium; fresh weight (g) of leaves 72 days following treatments.

| Treatments* | Replications A | B | C | D | Avg |
|---|---|---|---|---|---|
| 1 | 19.5 | 14.5 | 18.5 | 18.5 | 17.8 |
| 2 | 5.0 | 4.0 | 4.0 | 4.5 | 4.4 |
| 3 | 5.0 | 3.5 | 5.0 | 4.0 | 4.4 |
| 4 | 5.5 | 2.5 | 5.0 | 6.5 | 4.9 |
| 5 | 2.0 | 2.5 | 4.3 | 4.0 | 3.2 |
| 6 | 8.5 | 4.0 | 5.0 | 5.0 | 5.6 |
| 7 | 5.0 | 1.0 | 2.5 | 2.5 | 2.8 |
| 8 | 5.0 | 5.5 | 4.5 | 11.0 | 6.5 |
| 9 | 4.5 | 3.0 | 2.5 | 3.0 | 3.3 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 683.1089 | 8 | 85.3886 | 39.2641** |
| Replications | 27.0867 | 3 | 9.0289 | 4.1517* |
| Error | 52.1933 | 24 | 2.1747 | |
| Total | 762.3889 | 35 | | |

C.V. = 25.18% $LSD_{.05}$ = 2.152 g

*Treatments listed in Appendix Table 29.

Appendix Table 35. Effect of ammonium sulfate on glyphosate translocation and inhibition of C. esculentus leaf growth; leaf growth (mm) 1-6 days following treatment.

| Herbicide treatment ( * spray) (** leaf dipping) | Replications A | B | C | D | Avg |
|---|---|---|---|---|---|
| 1. Untreated check | 138 | 139 | 104 | 113 | 123.5 |
| 2. glyphosate* 0.36% | 78 | 40 | 60 | 54 | 58.0 |
| 3. glyphosate + am. sulfate* | 52 | 53 | 52 | 76 | 58.3 |
| 4. glyphosate** 0.36% + cut 1 DAT | 117 | 58 | 83 | 90 | 87.0 |
| 5. glyphosate + am. sulfate** + cut 1 DAT | 108 | 85 | 95 | 89 | 94.3 |
| 6. glyphosate 0.72% + cut 1 DAT | 62 | 70 | 67 | 58 | 64.3 |
| 7. glyphosate + am. sulfate** + cut 1 DAT | 78 | 110 | 69 | 78 | 83.8 |
| 8. glyphosate** 0.72% | 38 | 33 | 40 | 31 | 35.5 |
| 9. glyphosate + am. sulfate** | 41 | 43 | 47 | 50 | 45.3 |
| 10. glyphosate** 1.8% + cut 1 DAT | 58 | 38 | 34 | 35 | 41.3 |
| 11. glyphosate + am. sulfate** + cut 1 DAT | 74 | 95 | 68 | 55 | 73.0 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 27514.4090 | 10 | 2751.4409 | 14.5496** |
| Replications | 877.2727 | 3 | 292.4242 | 1.5463 |
| Error | 5673.2273 | 30 | 189.1076 | |
| Total | 34064.9090 | 43 | | |

C.V. = 19.80% $LSD_{.05}$ = 19.856 mm

Appendix Table 36. Effect of ammonium sulfate on glyphosate translocation and inhibition of C. esculentus leaf growth; leaf growth (mm) 1-15 days following treatment.

| Treatment* | Replications | | | | Avg |
|---|---|---|---|---|---|
| | A | B | C | D | |
| 1 | 296 | 296 | 278 | 272 | 285.5 |
| 2 | 93 | 46 | 67 | 62 | 67.0 |
| 3 | 60 | 57 | 58 | 91 | 66.5 |
| 4 | 242 | 110 | 182 | 214 | 187.0 |
| 5 | 245 | 176 | 208 | 171 | 200.0 |
| 6 | 94 | 147 | 100 | 93 | 108.5 |
| 7 | 157 | 257 | 141 | 142 | 174.3 |
| 8 | 41 | 38 | 46 | 35 | 40.0 |
| 9 | 43 | 46 | 49 | 54 | 48.0 |
| 10 | 80 | 50 | 41 | 41 | 53.0 |
| 11 | 169 | 149 | 93 | 92 | 125.8 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 252069.23 | 10 | 25206.9230 | 26.3286** |
| Replications | 3974.63 | 3 | 1324.8766 | 1.3838 |
| Error | 28721.87 | 30 | 957.3957 | |
| Total | 284765.73 | 43 | | |

C.V. = 25.1% $LSD_{.05}$ = 44.68 mm

*Treatments listed in Appendix Table 35.

Appendix Table 37. Effect of ammonium sulfate on glyphosate translocation and inhibition of C. esculentus leaf growth; fresh weight (g) of leaves 58 days following treatment.

| Treatment* | Replications | | | | Avg |
|---|---|---|---|---|---|
| | A | B | C | D | |
| 1 | 19.0 | 15.5 | 15.5 | 13.5 | 15.9 |
| 2 | 12.0 | 5.0 | 6.5 | 8.0 | 7.9 |
| 3 | 11.0 | 4.5 | 6.5 | 8.0 | 7.5 |
| 4 | 18.5 | 10.5 | 12.0 | 9.0 | 12.5 |
| 5 | 14.5 | 11.5 | 11.0 | 10.5 | 11.9 |
| 6 | 11.5 | 14.5 | 12.0 | 9.5 | 11.9 |
| 7 | 13.5 | 14.5 | 11.5 | 7.5 | 11.8 |
| 8 | 8.0 | 8.0 | 5.5 | 5.5 | 6.8 |
| 9 | 7.5 | 10.0 | 7.5 | 7.5 | 8.1 |
| 10 | 10.0 | 10.5 | 9.5 | 7.5 | 9.4 |
| 11 | 10.5 | 13.5 | 9.5 | 9.5 | 10.8 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 300.0568 | 10 | 30.0057 | 7.7245** |
| Replications | 79.3409 | 3 | 26.4470 | 6.8084** |
| Error | 116.5341 | 30 | 3.8845 | |
| Total | 495.9318 | 43 | | |

C.V. = 18.98% $LSD_{.05}$ = 2.846 g

*Treatments listed in Appendix Table 35.

Appendix Table 38. Influence of ammonium sulfate on $^{14}$C-glyphosate absorption and translocation; leaf growth (mm) 1-9 days following treatment.

| Treatment | Replications A | B | C | D | E | Avg |
|---|---|---|---|---|---|---|
| 1. Untreated check | 85 | 93 | 57 | 88 | 69 | 78.4 |
| 2. glyphosate 0.63 kg/ha | 34 | 26 | 33 | 27 | 22 | 28.4 |
| 3. glyphosate + am. sulfate 7 kg/ha | 31 | 25 | 33 | 24 | 21 | 26.8 |
| 4. glyphosate[1] 2.52 kg/ha | 22 | 5 | 17 | 25 | 17 | 17.2 |
| 5. glyphosate + am. sulfate[1] 7 kg/ha | 24 | 23 | 27 | 43 | 16 | 26.6 |
| 6. glyphosate 2.52 kg/ha | 23 | 20 | 22 | 21 | 21 | 21.4 |
| 7. glyphosate + am. sulfate 7 kg/ha | 23 | 26 | 22 | 19 | 16 | 21.2 |

[1]Leaf with applied $^{14}$C-glyphosate removed 24 h following treatment.

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 13339.3710 | 6 | 2223.2286 | 38.0178** |
| Replications | 391.7143 | 4 | 97.9286 | 1.6746 |
| Error | 1403.4857 | 24 | 58.4786 | |
| Total | 15134.5710 | 34 | | |

C.V. = 24.3% $LSD_{.05}$ = 9.983 mm

Appendix Table 39. Influence of ammonium sulfate on $^{14}C$-glyphosate absorption and translocation; percent of $^{14}C$-glyphosate applied recovered in leaf wash (non-absorbed).

| Treatment* | Replications | | | | | Avg |
|---|---|---|---|---|---|---|
| | A | B | C | D | E | |
| 2 | 10.79 | 10.95 | 5.60 | 12.47 | 13.66 | 10.70 |
| 3 | 8.30 | 13.46 | 6.85 | 11.33 | 9.07 | 9.80 |
| 4 | 14.60 | 19.94 | 29.21 | 6.14 | 19.41 | 17.86 |
| 5 | 4.19 | 4.39 | 4.39 | 13.80 | 4.50 | 6.25 |
| 6 | 7.51 | 8.52 | 7.43 | 10.96 | 5.82 | 8.05 |
| 7 | 6.14 | 12.84 | 11.57 | 8.88 | 11.20 | 10.13 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 394.3368 | 5 | 78.8674 | 3.6578* |
| Replications | 31.1187 | 4 | 7.7797 | <1 |
| Error | 431.2262 | 20 | 21.5613 | |
| Total | 856.6817 | 29 | | |

C.V. = 44.375% $LSD_{.05}$ = 6.126%

*Treatments listed in Appendix Table 38.

Appendix Table 40. Influence of ammonium sulfate on $^{14}C$-glyphosate absorption and translocation; percent of $^{14}C$-glyphosate applied recovered in treated leaf.

| Treatment* | Replications | | | | | Avg |
|---|---|---|---|---|---|---|
| | A | B | C | D | E | |
| 2 | 4.44 | 5.84 | 2.44 | 4.58 | 7.45 | 4.95 |
| 3 | 7.63 | 7.71 | 3.38 | 3.92 | 7.22 | 5.97 |
| 4 | 0.48 | 5.83 | 30.15 | 1.87 | 2.59 | 8.18 |
| 5 | 1.32 | 2.34 | 1.42 | 6.35 | 0.55 | 2.40 |
| 6 | 4.28 | 5.18 | 6.63 | 6.10 | 2.32 | 4.90 |
| 7 | 2.63 | 3.88 | 6.10 | 5.09 | 6.27 | 4.79 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 88.3940 | 5 | 17.6788 | <1 |
| Replications | 83.4305 | 4 | 20.8576 | <1 |
| Error | 609.3200 | 20 | 30.4660 | |
| Total | 781.1445 | 29 | | |

C.V. = 106.15%

*Treatments listed in Appendix Table 38.

Appendix Table 41. Influence of ammonium sulfate on $^{14}C$-glyphosate absorption and translocation; percent of $^{14}C$-glyphosate applied recovered in untreated leaves.

| Treatment* | Replications | | | | | Avg |
|---|---|---|---|---|---|---|
| | A | B | C | D | E | |
| 2 | 41.69 | 31.27 | 32.39 | 43.21 | 30.15 | 35.74 |
| 3 | 42.98 | 42.51 | 40.85 | 34.58 | 42.37 | 40.66 |
| 4 | 35.25 | 22.15 | 0.34 | 33.71 | 13.11 | 20.91 |
| 5 | 43.50 | 34.60 | 47.99 | 0.38 | 53.06 | 35.91 |
| 6 | 35.81 | 44.00 | 40.62 | 31.18 | 34.61 | 37.24 |
| 7 | 48.35 | 43.64 | 27.40 | 54.45 | 31.01 | 40.97 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 1360.9539 | 5 | 272.1908 | 1.7544 |
| Replications | 345.6161 | 4 | 86.4040 | <1 |
| Error | 3102.9597 | 20 | 155.1480 | |
| Total | 4809.5297 | 29 | | |

C.V. = 35.34%

*Treatments listed in Appendix Table 38.

Appendix Table 42. Influence of ammonium sulfate on $^{14}C$-glyphosate absorption and translocation; percent of $^{14}C$-glyphosate applied recovered in C. esculentus tubers.

| Treatment* | Replications | | | | | Avg |
|---|---|---|---|---|---|---|
| | A | B | C | D | E | |
| 2 | 0.44 | 0.70 | 1.97 | 0.61 | 0.80 | 0.90 |
| 3 | 0.40 | 0.23 | 0.44 | 0.41 | 1.06 | 0.51 |
| 4 | 0.75 | 1.07 | 1.40 | 0.75 | 0.89 | 0.97 |
| 5 | 0.34 | 0.69 | 0.64 | 0.39 | 0.26 | 0.46 |
| 6 | 0.59 | 0.57 | 0.32 | 0.44 | 0.44 | 0.47 |
| 7 | 0.78 | 0.75 | 0.78 | 0.55 | 2.52 | 1.08 |

Analysis of variance

| Source | SS | DF | MS | F |
|---|---|---|---|---|
| Treatments | 1.975587 | 5 | 0.395117 | 2.0188 |
| Replications | 1.118653 | 4 | 0.279663 | 1.4289 |
| Error | 3.914347 | 20 | 0.195717 | |
| Total | 7.008587 | 29 | | |

C.V. = 60.38%

*Treatments listed in Appendix Table 38.