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HERBICIDAL EFFICACY AND PHYSIOLOGICAL ASPECTS OF GLYPHOSATE [N-(PHOSPHONOMETHYL) GLYCINE] ON FIELD BINDWEED (CONVOLVULUS ARVENSIS L.

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HERBICIDAL EFFICACY AND PHYSIOLOGICAL ASPECTS OF GLYPHOSATE [*N*-(PHOSPHONOMETHYL)GLYCINE] ON FIELD BINDWEED (*CONVOLVULUS ARVENSIS* L.)

By

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ABSTRACT

HERBICIDAL EFFICACY AND PHYSIOLOGICAL ASPECTS OF GLYPHOSATE [N-(PHOSPHONOMETHYL)GLYCINE] ON FIELD BINDWEED (CONVOLVULUS ARVENSIS L.)

By

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Postemergence applications of glyphosate [N-(phosphonomethyl) glycine] effectively controlled field bindweed when applied at rates of 1.12 kg/ha and above. An additional application of glyphosate after the second season is necessary for continuous field bindweed control. Glyphosate applications can be made anytime after flower bud initiation through late fall. Tillage prior to treatment with glyphosate reduced field bindweed control and caused proliferation of buds at the nodes of crowns, roots, rhizomes, and stems. Tillage after treatment improved glyphosate performance when the initial control was poor. Glyphosate was not as effective on field bindweed growing on muck soils as on mineral soils. Applications of glyphosate prior to navy beans or following wheat appears to be the most effective time to control field bindweed considering present cropping practices.

High diluent volumes decreased control obtained from applications of glyphosate to field bindweed and quackgrass [*Agropyron repens* (L.) Beauv.] in the field. Additional surfactant did not increase control of quackgrass at high diluent volumes. In the greenhouse, diluent volumes greater than 190 L/ha decreased glyphosate phytotoxicity on tall morningglory. Runoff from high diluent volumes became a factor

when diluent volumes exceeded 190 L/ha. At 375 L/ha 50 to 75 percent of the spray solution ran off the leaf surface. Calcium was antagonistic to glyphosate activity at high spray volumes or at calcium concentrations greater than 0.01 M at low volumes.

^{14}C-glyphosate was translocated throughout the treated plants within 3 days; the greatest accumulation was in the meristimatic regions of roots and shoots in all species tested. In cross and longitudinal sections of stems and roots the ^{14}C-glyphosate was localized in the phloem. Less than 25 percent of the applied herbicide was translocated from the treated leaf in all species. Studies indicated very little metabolism of glyphosate; aminomethylphosphonic acid was the major metabolite found, making up less than 15 percent of the total ^{14}C. Of the applied ^{14}C-glyphosate 50 percent disappeared from excised leaves within 25 days. Neither translocation studies nor thin layer chromatography of metabolites accounted for this loss.

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INTRODUCTION

Excellent selective herbicides are available for annual weed control, which alone or in combination, control most annual weeds in many crops. However, field bindweed (*Convolvulus arvensis* L.) and other perennial weeds often escape control with these herbicides. Because these herbicides provide excellent annual weed control, the number of cultivations are reduced, often eliminated. This practice, along with less competition from annual weeds is allowing field bindweed and other perennial weeds to become established. The infestation of field bindweed in Michigan is increasing rapidly, especially in the thumb and on muck soils. Field bindweed competes with crops resulting in lower yields and increased costs.

Soil sterilants have provided some control of field bindweed, however, they render the soil sterile for 1 or more years. Field bindweed control with 2,4-D and other phenoxy herbicides have been the major means of chemical control in cropping situations. Translocation of 2,4-D is for the most part to meristimatic regions of shoots, therefore, it does not kill the root systems and continual retreatment, often two or three times a season, is required. The use of 2,4-D is limited to crops which are resistant to 2,4-D.

Glyphosate [*N*-(phosphonomethyl)glycine], a non-selective herbicide introduced in 1971 (8) has activity on field bindweed when foliar applied. Glyphosate has no residual activity in most soils, therefore, it can be applied prior to or following a crop with no injury to the crop or future crops. It is essential, however, that the control be at least one season and that glyphosate application be adapted to current cropping systems. The objectives of this study were to (1) evaluate the activity of glyphosate on field bindweed and to establish herbicide and management practices which provide effective control of field bindweed, (2) to evaluate the effects of diluent volume and calcium concentrations on glyphosate phytotoxicity, (3) to study absorption, translocation, and metabolism of glyphosate.

CHAPTER 1

LITERATURE REVIEW

Biology

Field bindweed (Convolvulus arvensis L.) a troublesome perennial weed of European origin (9, 43, 94), was first reported in Virginia in 1739 and then in Topeka, Kansas in 1877. Field bindweed has also been called wild morningglory, European bindweed, creeping jenny, creeping charlie, Russian creeper (23, 24, 27, 80, 101) and possession vine (5). Field bindweed is disseminated by seed, root fragments of almost any size carried by farm equipment, root extensions at the parameters of the infestation, and roots which may be transferred with soil (38, 43, 81). Field bindweed roots have been found as deep as 7 m (9, 27, 28, 94) with the greatest mass of root growth within 0.6 m of the soil surface (15, 27) and to expand the parameter of the infestation by 3 m per year (9, 14, 27, 94). Lateral roots develop from numerous adventitious buds on the root (42). Rhizomes, which are produced from lateral roots, penetrate the soil surface forming new crowns (42, 94). Conditions favorable to growth stimulate bud initiation, buds may be produced by the dozens or even hundreds. This activity occurs especially during warm weather and after destruction of top growth by cultivation. Vegetative reproduction is favored by bud production and large food reserves. After old roots have been severed many times they may send up numerous rhizomes from the severed ends. No fluctuation in carbohydrate reserves occurred in roots in the top 30 cm of soil during the growing season (11). Reserves decreased slightly from May to September in roots 30 to 60 cm deep, and a large decrease in root reserves occurred during the growing season in roots below 60 cm. A greater decrease in root reserves occurred following cultivation.

Field bindweed has flowers about 2 to 2.5 cm in diameter, white to pink in color (95), which are open only in the morning (81). The plant starts blooming in mid-June. Warm, dry, sunny weather favors seed production whereas cloudy weather inhibited flower and seed production (18, 28, 43, 94, 95). Consequently seed set is very low and usually totally fails in Michigan. As many as 1/4 million seeds/ha were found in one crop and one million seeds/ha were found along roadsides (95). Bindweed seed fed to animals often pass through the digestive tract unharmed. The mature seed has a shape similar to closely related genera, it is hard, brown or black in color (80). The seed is born in a two celled capsule which usually contains four seeds shaped like a pear (10, 18). When only one seed develops it is more spherical. The seed is about 0.1 cm in length. Immature seeds can germinate immediately, however, mature seeds may be dormant for 30 to 50 years (18, 95). Twenty-eight days were sufficient for seeds to develop impermeability after flowering (18). Seeds germinate from 0.5 to 40 C with an optimum temperature of 20 to 30 C. Germination occurs from April to September. Bindweed seedlings have heart shaped cotyledonary leaves.

The seedling develops a deep tap root in about 11 weeks and may have lateral spread of 3 m the first year (27, 95). The leaves of field bindweed have many different shapes and sizes (95), which are associated with the amount of moisture available (42). Field bindweed is often confused with hedge bindweed (Convolvulus sepium L.), tall morningglory [Ipomoea purpurea (L.) Roth.], and wild buckwheat (Polygonum convolvulus L.) (43).

Field bindweed causes loss in many crops not only due to competition for light, nutrients, and moisture but also by serving as a host for disease, insects, and other pests (45). It hinders harvesting of many crops by becoming tangled in cutter bars, threshing drums and other moving parts of harvest equipment. It may add moisture content to the grain (55). It prevents penetration of pesticides and increases the number of culls and non-harvestable fruits (38, 45). It increases labor costs and reduces land and loan values (43). Field bindweed has been reported to cause grape losses up to 75 percent (51). Other researchers have reported up to 89 percent yield reduction due to field bindweed (29, 86). Harvey reported $374 million per year loss to weeds in California of which field bindweed was one of the six worst weeds in the state (35). In dense crop stands bindweed will twine to the top of the canopy to get light (9). Field bindweed has been proclaimed a noxious weed in many states (15, 35, 38, 54).

Even though field bindweed was originally introduced on the east coast of the United States, it developed most rapidly in the midwest and western states (9) with some states, Washington, California, North and South Dakota having over 400,000 hectares of field bindweed. Due to dry conditions, even if roots and rhizomes were killed the seed would reinfest the land. Field bindweed has wide distribution in the North Central region, however, it has only been the last few years that field bindweed has become a major weed problem. This is due to the greater use of herbicides for annual weed control which are ineffective in perennial weed control (45). Due to better annual weed control chemicals, less cultivation is applied and cultivation has been a major control method for field bindweed.

"Early" Control

Cultural

Many control methods have been used for field bindweed starting as early as 1908 (9). The conclusion in 1908 was to starve the roots to death by keeping the plant from developing green leaves (20, 81), however, it was observed in 1911 that it had to be cut 30 times to do this at the cost of $3.60 per hectare (15). Salting was used at 22,700 kg per ha with a second application weeks later (18, 43). Salt was expensive and made the soil sterile for crop production. Mulches of manure and straw, piled deep enough to stop all light and air exchange, and tar paper were applied in Utah to smother bindweed and starve the plant to death (81). Hogs, sheep, and goats were used to weaken or kill perennial weeds (81). Rotations of crops such as wheat (22, 24), corn, potatoes, alfalfa (102), and soybeans (83) were used to compete with field bindweed. Researchers (81) even tried digging out the roots which was a hopeless task in areas or large infestations. Cultivation was the major control method, Cox (20) used a V-shaped cutter, some used homemade weed cutters (81). Seely, et al. (74) used plows, duck foot field cultivators, rotary rod weeders, and rod weeders with sweeps. There was no advantage to cultivation deeper than 10 to 15 cm and cultivation was required every 12 days from spring to September 15 (61, 73, 85, 86). Cultivation decreased root reserves more completely than applications of sodium chlorate. Cultivating at emergence did not reduce carbohydrates more than less frequent cultivation (12, 86).

Early Chemicals

Chemical control began in the United States in 1911 (102) with the first chemical to show activity on bindweed being sodium chlorate in 1927 (59, 91). Sodium chlorate was expensive, hazardous, and sterilized the soil for several years. It required 450 to 540 kg/ha (43). K. M. G. (kill morningglory) is an acid solution of arsenic which killed bindweed roots a meter or more deep (43). Other soil sterilants such as monuron [(3-*p*-chlorophenyl)-1,1-dimethylurea], fenuron (1,1-dimethyl-3-phenylurea), TBA (trichlorobenzoic acid), PBA (Polychlorobenzoic acid), and picloram (4-amino-3,5,6-trichloropicolinic acid) became available in the 1950s and 1960s (24, 49, 84) for non-cropland. Non-selective herbicides, such as dicamba (3,6-dichloro-*o*-anisic acid), picloram, 2,3,6-TBA (2,3,6-trichlorobenzoic acid), and fenac [(2,3,6-trichlorophenyl)acetic acid] were applied at relatively low rates after small grains to reduce the stand of field bindweed (24, 31, 40). TBA and PBA leave the soil sterile and are expensive, therefore, they are only used in small areas (58). They prevent economical growth of wheat for 1 or 2 years. At a given rate 2,3,6-TBA was more effective than TBA or than PBA (58). Experimentation with 2,4-D [(2,4-dichlorophenoxy)acetic acid)] began in 1945 (59, 67) and field bindweed control with this and other phenoxy herbicides have been the major means of chemical control since that time. Field bindweed stands were reduced 90 percent or more with three applications over 7 years (24). A single application of dicamba or picloram at rates of 0.6 and 0.2 kg/ha, respectively, resulted in 90 percent or more reduction in stand. Similar control was obtained with 2,4-D (23). Translocation of 2,4-D and picloram is mostly to the young leaves and meristimatic regions of the stem (3). Translocation of 2,4-D and picloram was greatest during the seedling stage of growth of field bindweed (2). Some strains of field bindweed have been claimed to be more susceptible to 2,4-D than other strains (35, 89, 90). Whitworth (89) found a range from 87 percent reduction in weight to 83 percent increase in weight one month after treatment with 2-4-D. More effective control of field bindweed occurred with 2,4-D than 2,4,5-T or MCPA (24). Several retreatments per year were required. Phillips (59) suggested that of the phenoxy's, silvex suppressed bindweed growth for the longest period, then 2,4-T and 2,4-D, however, none of these gave satisfactory control. The effectiveness of silvex is related to longer residual in the soil than the other phenoxy's (98). Effective control with 2,4-D was provided when applied to vigorously growing field bindweed at the bud stage. Wiese (99) reported that 2,4-D was the most effective phenoxy. Bindweed control was most effective when the chemical program included competitive crops, post harvest cultivation, and herbicide treatment (23, 59, 70, 97).

Trifluralin (a, a, a-trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine), dichlobenil (2,6-dichlorobenzonitrile) and other compounds were found to give greater field bindweed control when applied as sub-surface layer, 15 to 30 cm deep (1, 32, 49, 66, 88). Due to extensive injury caused by dichlobenil (32, 41), Trifluralin is used in controlling field bindweed in orchards and vineyards (49). Shoots from rhizomes below the "tarp-like" layer became swollen, twisted, and unable to penetrate the layer (48). Injury occurred to corn and wheat, which are trifluralin sensitive crops, when grown on top of the layer. No injury was seen on crops with resistance to trifluralin.

Control with Glyphosate

Glyphosate is a broad spectrum herbicide introduced in 1971 (8). Because of phloem translocation to the meristematic regions of shoots and roots it provides excellent perennial weed control (78). The mode of action of glyphosate as proposed by Jaworski (39) is the inhibition of the biosynthesis of the aromatic amino acids. It is a foliar applied herbicide which appears to have very limited soil activity (79). Season long control of field bindweed can be obtained from one application of glyphosate (25, 53, 56, 63, 93). However, control of field bindweed has been variable (21), resulting in a large reduction of stand one time and almost no control the next. In all cases a second or third application provided better control than a single application (25).

Davison and Bailey (21) reported less regrowth with 2,4-D, MCPA (2-methyl-4-chlorophenoxy-acetic acid) and MCPB [4-(2-methyl-4-chlorophenoxy) butyric acid] at 2 kg/ha than glyphosate at the same rate. Ogg (56) reported that field bindweed recovered rapidly, usually within 1 year after treatment. He also found 2,4-D to be more effective than glyphosate. Others have suggested at least 2 years of control with glyphosate (71).

Best results were achieved when glyphosate was applied to vigorously growing field bindweed (25) in or after the flower bud stage (76). When glyphosate was applied prior to bud stage, prolific regrowth occurred. Rainfall within 8 hours after treatment reduced glyphosate activity (6, 63). Heavy regrowth required a greater amount of herbicide than light infestations.

Glyphosate is a non-selective herbicide, therefore, treatment of weeds within a crop require special types of application. Using a recirculating sprayer, tall weeds, at least 61 cm taller than the crop, can be controlled in crops which are sensitive to glyphosate (52). This method, however, provided no control for low growing weeds like field bindweed, Post-emergence directed applications have been used in soybeans [Glycine max (L.) Merr.] with a small amount of injury occurring to the soybeans as long as the spray solution did not go above 10 cm on the soybean stem. Others have experimented with shielded sprayers in cotton (Gossypium hirsatum) for field bindweed control (25). Applying glyphosate to 75 to 80 cm between 105 cm rows of cotton effectively controlled field bindweed which was entwined with the cotton plants without injury to the cotton.

Tillage prior to and after glyphosate application is important in fitting this chemical into agronomic systems. Fisher et al. (25), concluded that field bindweed control in a fallowed field was best if tilled in April and then treated in June when the bindweed was vigorously growing. Field bindweed in cultivated fields was more effectively controlled than field bindweed on fallowed fields.

Diluent Volume and Additives

There has been interest in combining glyphosate in tank mixes and split applications with other chemicals such as atrazine

[2-chloro-4-(ethylamino)-6-(isopropylamine)-*s*-triazine], propachlor (2-chloro-*N*-isopropylacetanilide), terbacil (3-*tert*-butyl-5-chloro-6-methyluracil), simazine (2-chloro-4,6-bis(ethylamino)-*s*-triazine), amitrol (3-amino-*s*-triazole), and other wettable powders, especially for no-till applications (60, 75). When combined with certain wettable powders, glyphosate was no longer active (34). Phillips (60) reported that atrazine, propachlor, and non-herbicidial wettable powders decreased glyphosate phytotoxicity on sorghum (*Sorghum vulgare* Pers.). Selleck (75) found amitrol and simazine reduced activity of glyphosate on smooth bromegrass (*Bromus inermis* L.) when sprayed as a tank mix; however, there was no antagonism when sprayed separately the same day or later. He also showed that bromacil (5-bromo-3-*sec*-butyl-6-methyluracil), diuron [3-(3,4-dichlorophenyl)-1,1-dimethylurea], and amitrol reduced glyphosate toxicity to common mildweed (*Asclepias syriaca* L.) and bouncing bet (*Saponaria officinalis* L.). Amitrol did not reduce control to toadflax (*Linaria vulgaris* Hill.) when tank mixed with glyphosate as did all other herbicides tested. No antagonism was seen in combination with any of the herbicides on bluegrass (*Poa pratensis* L.), goldenrod (*Solidago* spp. L.) or brambles (*Rubus* spp. L.). Combinations of glyphosate with liquid nitrogen gave enhanced kill of winter rye [*Secale cereale* (L.) var. Balboa] (57). Nitrogen fertilizers only enhanced the initial injury with complete recovery in 6 weeks on perennial sod species. Peters et al. (57) also reported that complete fertilizers reduced glyphosate activity.

Calcium, iron, zinc, and aluminum have been reported to reduce glyphosate phytotoxicity (34, 60, 72, 100), whereas Wills (100) reported potassium, sodium, ammonium, and calcium to increase glyphosate activity in descending order on purple nutsedge (Cyperus rotundus L.). Ammonium sulfate appeared to activate glyphosate either in a tank mix or when applied separately (16, 84, 87). Cations tended to reduce glyphosate activity, whereas anions had little or no effect on activity (60, 100).

High diluent volumes also reduced glyphosate activity both in the field and in the greenhouse (60, 65, 72, 101). Increasing the additional surfactant concentration above that in the formulation produced variable results; however, the negative effect of high diluent volume was partially overcome (65, 72, 101).

Soil Activity

Glyphosate is inactivated when it comes in contact with the soil (33, 47, 64, 79) which allows for crops to be planted after glyphosate application with no injury to the crop. The initial inactivation was provided by rapid bonding of glyphosate to clay and organic matter (33, 64, 67, 77, 79). It appears to be absorbed by the soil similarly to orthophosphate fertilizer (61). There is a correlation between glyphosate adsorption to unoccupied phosphate sorption capacity. Adding other phosphate sources to the soil in addition to glyphosate decreased glyphosate binding (79). Kaolanite did not adsorb or inactivate glyphosate to the same extent as montmorillonite or organic matter (64). Glyphosate has very little mobility in the soil (67, 77).

Microbial degradation of glyphosate to CO_2 is the secondary inactivation process in the soil (67, 79). No chemical degradation appears to be involved in the inactivation process (79). In 28 days up to 50 percent of the applied ^{14}C-glyphosate had been converted to

CO_2 (67, 79). The decomposition rate was decreased when the pH was reduced. Rueppel et al. (69) reported 90 percent conversion to CO_2 of both glyphosate and its major metabolite, aminomethylphosphonic acid (AMP), within 12 weeks. Glyphosate is stable in sunlight, not leached in the soil, and has only a minimal effect on the microbial population of the soil environment (69).

Glyphosate Physiology

The activity of a foliar applied herbicide depends not only on the activity of the compound following absorption into the plant, but also upon how much is absorbed and translocated in the plant. The type of translocation (acropetal or basipetal) is also important in perennial weed control. Basipetal movement is essential to move foliar applied herbicides into the roots and rhizomes. Sprankle et al. (78) reported 30 to 50 percent absorption of applied ^{14}C-glyphosate into quackgrass leaves after 3 days. Wyril and Burnside (91) reported 25 to 67 percent absorption depending on the species. Glyphosate is translocated both acropetally and basipetally (8, 13, 19, 63, 77, 82, 103) with the greatest concentration of glyphosate accumulating in the meristimatic regions of the shoot and roots.

Translocation is rapid, however, tillage of treated quackgrass [_Agropyron repens_ (L.) Beauv.] after 1 day allowed for more buds to survive than tillage after longer intervals (13, 19, 77). Buds developing after sub-lethal doses of glyphosate are chlorotic and deformed along with any subsequent regrowth (72). No effects of glyphosate appeared on foliage present at time of treatment unless the application rate was sufficient to cause death of the foliage.

The contribution of glyphosate metabolism to the variability in perennial weed control is not known, however, very little metabolism of glyphosate has been found in plants (63, 69, 103) AMP was the major metabolite isolated from plants (63, 68, 69).

CHAPTER 2

FIELD BINDWEED CONTROL WITH GLYPHOSATE

Introduction

Field bindweed (Convolvulus arvensis L.) is a troublesome perennial weed of European origin (20, 38). It is also known as wild morningglory, European bindweed, creeping jenny, creeping charlie, and Russian creeper (3, 5, 10, 11, 13, 32). Field bindweed can be spread by means of seed, root fragments carried by farm equipment, root extensions at the parameters of the infestation, and roots which may be transferred with soil (20, 21). Field bindweed roots have been found as deep as 7 m (3, 38) and to expand the parameter of the infestation by 3 m per year (3, 5, 13, 38). From lateral roots, rhizomes are produced which penetrate the soil surface forming new crowns (19, 38). Warm dry weather favors seed production (38), as many as 1/4 million seeds/ha were found in one crop and one million seeds/ha were found along roadsides (95). Seeds have been known to remain dormant for 30 years.

Field bindweed causes loss in many crops due to competition for light, nutrients, and moisture, and is a host for disease, insects, and other pests (22). It hinders harvesting by becoming tangled in cutter bars, threshing drums and other moving parts of harvest equipment, and adds moisture content to the grain (28), prevents penetration of pesticides, and increases the number of culls and non-harvestable fruits (17, 22). Field bindweed has been reported to cause grape losses up to 75 percent (26). Harvey reported $374 million per year loss to weeds in California and field bindweed is one of the six worst weeds in the state (15). Field bindweed has been proclaimed a noxious weed in many states (6, 15, 17, 27). It has been a major problem in the midwest and western United States for many years (33) and has increased as a major weed problem in Michigan over the last few years. This increase is due to a greater use of herbicides for annual weed control which are ineffective in perennial weed control (22).

Beginning as early as 1908 attempts have been made to control field bindweed (8). The conclusion at that time was to starve the roots to death by keeping the plant from developing green leaves (8, 33). Thirty weed cuttings were necessary at the cost of $3.60 per hectare (6) to control field bindweed by this method in 1911. Salting was also used at 22,700 kg/ha with a second application weeks later (7). However, salt was expensive and made the soil sterile for crop production. Mulches of manure and straw, piled deep enough to stop all light and air exchange, and tar paper were applied in Utah to smother and starve the plant to death (33). Hogs, sheep, and goats were used to weaken or kill perennial weeds (33). Rotations of crops such as wheat (39), corn, potatoes, alfalfa (40), and soybeans (34) were used to compete with field bindweed. Researchers (33) even tried digging out the roots which was a hopeless task in areas of large infestations. Cultivation was the major control method used, Cox (8) used a V-shaped cutter, while others used homemade weed cutters (33). Seeley et al. (31) used plows, duck foot field cultivators, rotary rod weeders, and rod weeders with sweeps. There was no advantage to cultivation deeper than 10 to 15 cm and cultivation was required every 12 days (29).

Chemical weed control began in 1911 (40) with the first chemical to show activity on bindweed being sodium chlorate in 1927 (36). Sodium chlorate was expensive, hazardous and sterilized the soil for several years. Other soil sterilants such as monuron [3-(p-chlorophenyl)-1, 1-dimethylurea], fenuron (1,1-dimethyl-3-phenylurea), PBA (polychlorobenzoic acid), and picloram (4-amino-3,5,6-trichloropicolinic acid) (1), became available in the 1950s and 1960s (12) for use on non-cropland. Non-selective herbicides such as dicamba (3,6-dichloro-o-anisic acid), picloram and 2,3,6-TBA (2,3,6-trichlorobenzoic acid) were applied at relatively low rates after small grains to reduce the bindweed stand (11, 18). Experimentation with 2,4-D [(2,4-dichorophenoxy) acetic acid] began in 1945 (29) and is still a major chemical used today.

Trifluralin, (a,a,a-trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine), and other compounds were sub-surface layered for field bindweed control beginning in the early 1970s (16, 24, 30, 35). Control was limited to crops which were tolerant to trifluralin. The layer could not be broken or the rhizomes of the field bindweed would penetrate the surface and again become established.

Glyphosate [N-(phosphonomethyl)glycine] is a broad spectrum herbicide introduced in 1971 (2) which has activity on bindweed (9, 12, 23, 25); however, results have often been inconsistant. Studies were designed to determine the herbicidal efficacy of glyphosate on field bindweed on mineral and muck soil and to determine if eradication, as mentioned by many early bindweed researchers, (6, 20, 21, 33) could be obtained and to evaluate glyphosate phytotoxicity at different stages of growth.

Materials and Methods

Field studies were conducted in 1974 through 1977 at several locations in Michigan. Plots were 3.1 by 6.1, 3.1 by 12.2, or 3.1 by 15.2 m, all treatments were replicated three times. Glyphosate was applied with a tractor mounted sprayer at 2.11 kg/cm^2 pressure and 215 L/ha. The formulation of glyphosate used contained 0.89 kg/L of glyphosate as the isopropylamine salt and 0.45 kg/L of surfactant. Field bindweed control was visually rated on a 0 to 10 scale; 0 equaled no control and 10 equaled 100 percent control.

Field experiments were conducted at three locations on field bindweed and one location on hedge bindweed to determine the effect of rate of application, time of application, length of control, and the benefit of reapplication of glyphosate for bindweed control. The study was a split-split plot in design with three plots in each replication being treated at each glyphosate rate the first year, two plots received reapplication the second year, and one the third year. Field bindweed was treated at three locations with studies initiated in October, 1974 at the first location, June, 1975 at the second location, and August, 1975 at the third location. Hedge bindweed was treated at a fourth location in July, 1975 (Table 1). Terbacil (3-*tert*-butyl-5-chloro-6-methyluracil) was applied at 0.86 kg/ha for annual weed control.

Table 1. The soil type, organic matter, treatment and rating dates of glyphosate studies initiated at four locations in 1974 and 1975

Location	Soil type	Organic matter (percent)	Treatment dates	Rating dates
1	Charity clay loam	3.8	October 3, 1974	September 17, 1975
			October 23, 1975	October 8, 1976
			October 13, 1976	June 3, 1977
				August 17, 1977
2	Sandy clay loam	3.9	June 17, 1975	July 11, 1975
			June 1, 1976	May 18, 1976
			May 26, 1977	May 19, 1977
				July 15, 1977
3	Muck	58.0	August 15, 1975	September 15, 1975
			August 23, 1976	August 4, 1976
			August 19, 1977	August 23, 1977
				September 15, 1977
4	Sandy clay loam	5.9	July 16, 1975	September 25, 1975
			July 14, 1976	September 1, 1976
			August 18, 1977	July 19, 1977
				September 28, 1977

To determine the latest date at which glyphosate could be applied to field bindweed in the fall and achieve desired control, glyphosate applications of 2.24 and 3.36 kg/ha were made to mature field bindweed September 25, and 28, October 8, and 14, and November 5, 1976. The field bindweed was on muck soil with 48 percent organic matter at one location and sandy clay loam with 5.5 percent organic matter at the second location. Each location received tillage in July 1976. Ratings were taken June 3, and August 17, 1977. Terbacil at 1.12 kg/ha was applied for annual weed control.

To evaluate the effect of tillage on glyphosate phytotoxicity, glyphosate was applied June 7, 1975 to pre-blossom field bindweed on a sandy clay loam of 3.9 percent organic matter at 1.12, 1.68, 2.24, and 4.48 kg/ha. On June 21, 1975 half of each plot was plowed 25 cm deep with a moldboard plow. Plots were rated July 11, 1975, May 18, 1976, September 1, 1976, and July 15, 1977. Terbacil at 1.12 kg/ha was applied to control annual weeds. At two other locations, one a muck soil of 48 percent organic matter and the other a sandy clay loam of 5.5 percent organic matter, glyphosate was applied at 2.24 kg/ha to mature field bindweed on September 25, 1976, June 3, 1977, and July 20, 1977. Each location received tillage in July, 1976, preceding the study. Tillage was performed with a moldboard plow on the sandy clay loam and a disc on the muck soil. Tillage occurred on November 6, 1976, May 5, 1977, and June 10, 1977. Ratings were taken August 17, 1977. Terbacil was applied at 1.12 kg/ha for annual weed control.

A rotation study was initiated in 1975 including corn, soybeans, navy beans, and wheat to determine when glyphosate could be most effectively applied. Glyphosate was applied August 15, 1975, June 15, 1976, October 14, 1976, and May 19, 1977 to field bindweed on a muck soil with 33.7 percent organic matter at 1.12 and 2.24 kg/ha. No cultivation had occurred for 3 months prior to August 1975 treatments, plots were cultivated 2 weeks prior to June 1976 treatments. No cultivation preceded October 1976 and May 1977 treatments. Michigan 369 corn, Sanilac navy beans, and Harasoy soybeans were planted June 14, 1976 and May 23, 1977. Tecumpseh wheat was planted October 20, 1976. Seven different rotations were included (table 9). Ratings were taken May 19, 1977 and August 23, 1977.

Results and Discussion

Excellent control of field bindweed was achieved with glyphosate for 1 year after application for all treatment rates above 0.56 kg/ha at each application date (Tables 2, 3, and 4). Satisfactory control of field bindweed did not continue after a single application of glyphosate through the third season after treatment, with a decrease in control observed during the second growing season. A second application of glyphosate made during the second season, in most cases, gave better control of field bindweed early in the third year than a single application. However, the control from two applications were no better than one application by the end of the third season, except for the August treatment. Increased control in August treatments with a second application was observed at rates higher than 0.84 kg/ha, however, when third season August treatments are compared to ratings of June and October treatments rated at a similar time period after application the control was similar. Three applications provided

Table 2. Control obtained from October postemergence applications of glyphosate to mature field bindweed initiated in 1974

Treatment	Years treated[a]	Rate (kg/ha)	Weed control rating[b]			
			9/17/75	10/8/76	6/3/77	8/17/77
Glyphosate	1974	0.84	9.0 g-j	7.0 d-f	4.3 a-c	2.0 a
	1974 & 75	0.84	8.8 f-j	9.5 i-l	7.5 d-h	4.2 a-c
	1974 & 75 & 76	0.84	8.0 e-i	9.3 i-k	9.9 kl	7.2 d-g
	1974	1.68	9.2 h-k	7.0 d-f	2.3 a	3.3 a-c
	1974 & 75	1.68	9.2 h-k	9.8 j-l	9.3 i-k	6.0 c-e
	1974 & 75 & 76	1.68	8.3 f-i	9.8 j-l	10.0 l	9.0 g-j
	1974	3.36	8.3 f-i	7.2 d-g	4.0 a-c	3.0 ab
	1974 & 75	3.36	8.7 f-j	9.3 i-k	8.3 f-i	5.7 b-d
	1974 & 75 & 76	3.36	8.2 e-i	9.5 i-l	9.9 kl	8.3 f-i

[a]Herbicide applications were made October 3, 1974 and reapplications made to specified plots October 23, 1975, and October 13, 1976.

[b]Means with common letters are not significantly different at the 5% level by Duncan's multiple range test. Visual ratings are on a 0 to 10 scale 0 = no control, 10 = 100% control.

Table 3. Control obtained from June postemergence applications of glyphosate to prebloom field bindweed initiated in 1975

Treatment	Years treated[a]	Rate (kg/ha)	Weed control rating[b]			
			7/11/75	5/18/76	5/19/77	7/15/77
Glyphosate	1975	1.12	9.6 h-l	9.9 kl	5.5 a-e	3.2 ab
	1975 & 76	1.12	9.9 kl	9.7 h-l	8.0 d-h	3.4 ab
	1975 & 76 & 77	1.12	9.9 kl	9.8 i-l	7.8 d-g	8.5 f-j
	1975	1.68	9.9 kl	9.8 i-l	8.2 e-i	6.3 b-f
	1975 & 76	1.68	10.0 l	9.8 i-l	9.7 h-l	7.3 c-g
	1975 & 76 & 77	1.68	9.8 i-l	9.9 kl	9.0 g-k	9.7 h-l
	1975	2.24	10.0 l	9.7 h-l	3.8 ab	5.3 a-d
	1975 & 76	2.24	10.0 l	9.8 i-l	9.8 j-l	7.1 c-g
	1975 & 76 & 77	2.24	10.0 l	10.0 l	9.2 g-l	9.8 j-l
	1975	4.48	9.9 kl	9.7 h-l	4.5 a-c	2.3 a
	1975 & 76	4.48	10.0 l	9.8 i-l	9.8 j-l	8.5 f-j
	1975 & 76 & 77	4.48	9.9 kl	9.8 i-l	9.8 j-l	9.9 kl

[a]The herbicide was applied June 7, 1975 and reapplications made to specified plots June 1, 1976, and May 26, 1977.

[b]Means with common letters are not significantly different at the 5% level by Duncan's multiple range test. Visual ratings are on a 0 to 10 scale, 0 = no control, 10 = 100% control.

Table 4. Control obtained from August postemergence applications of glyphosate to mature field bindweed initiated in 1975

Treated	Years treated[a]	(kg/ha)	Weed control rating[b]			
			9/15/75	8/4/76	8/23/77	9/15/77
Glyphosate	1975	0.56	7.0 cd	7.0 cd	1.0 a	1.0 a
	1975 & 76	0.56	6.7 bcd	6.3 bc	5.3 bc	5.0 bc
	1975 & 76 & 77	0.56	6.7 bcd	6.7 bcd	7.0 cd	8.5 de
	1975	1.12	9.8 f-h	8.7 def	0.0 a	0.0 a
	1975 & 76	1.12	9.8 f-h	9.5 e-h	9.7 e-h	9.6 e-h
	1975 & 76 & 77	1.12	9.8 f-h	9.5 e-h	9.8 f-h	10.0 h
	1975	1.68	10.0 h	9.6 e-h	4.0 b	4.0 b
	1975 & 76	1.68	10.0 h	9.3 e-g	9.3 e-g	9.2 e-g
	1975 & 76 & 77	1.68	9.9 gh	9.7 e-h	9.3 e-g	9.8 f-h
	1975	3.36	10.0 h	9.6 e-h	4.2 b	4.2 b
	1975 & 76	3.36	9.9 gh	9.2 e-g	9.6 e-h	9.6 e-h
	1975 & 76 & 77	3.36	9.9 gh	9.4 e-h	9.9 gh	10.0 h

[a]The herbicide was applied August 15, 1975 and reapplications made to specified plots August 23, 1976, and August 19, 1977.

[b]Means with common letters are not significantly different at the 5% level by Duncan's multiple range test. Visual ratings are on a 0 to 10 scale, 0 = no control, 10 = 100% control.

excellent control throughout the duration of the experiment. It appears that glyphosate completely kills the above ground portion of the plant, but not the root system. It inhibits the production of buds for about two seasons, after which buds are produced and field bindweed begins to regrow. In the greenhouse 6 to 9 months were required to obtain new top growth after all top growth had been killed. Hedge, bindweed, however, was completely controlled for 3 years with one application of glyphosate at 1.12 kg/ha (Table 5). Therefore, no additional control was obtained with retreatment. Hedge bindweed roots are more shallow and less extensive when compared to field bindweed. Hedge bindweed roots in the greenhouse were injured more than were field bindweed roots from equal rates of glyphosate (Figure 1). It is observed that when the roots are not completely killed a proliferation of buds occur on the rhizomes and the roots. These buds will grow and develop new rhizomes and new crowns, therefore, a sublethal rate of glyphosate may, in the end proliferate field bindweed instead of control it.

Glyphosate provided excellent control of field bindweed on muck and mineral soils when applied as late as October 14, 1976 and rated June, 1977 (Table 6). No control was obtained from November treatments, eventhough, the field bindweed was green and no apparent freeze injury had occurred at the time of treatment. Reduced control was because of freezing temperatures every night after treatment (Table 7). After treatment the bindweed on mineral soil turned black and appeared dead prior to freezing in the fall. After application of glyphosate on muck soil the field bindweed turned yellow and then regained a green color and the foliage was not killed until frozen by November

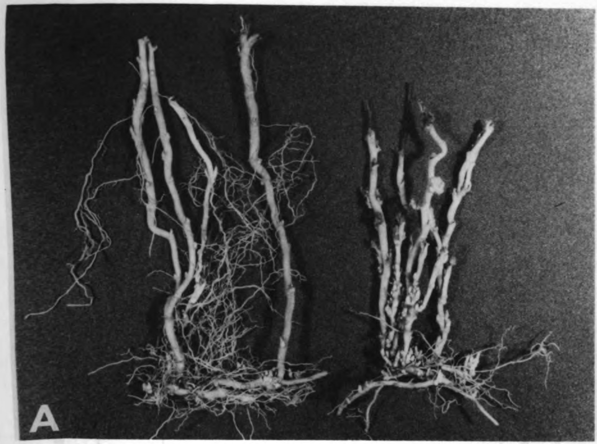
Table 5. Control obtained from July postemergence applications of glyphosate to hedge bindweed in full bloom initiated in 1975

Treatment	Years treated[a]	Rate (kg/ha)	Weed control rating[b]			
			9/25/75	9/1/76	7/19/77	9/28/77
Glyphosate	1975	1.12	9.7 b	10.0 b	10.0 b	10.0 b
	1975 & 76	1.12	9.9 b	9.6 b	9.9 b	9.9 b
	1975 & 76 & 77	1.12	9.9 b	9.5 b	9.8 b	10.0 b
	1975	1.68	9.3 ab	9.0 ab	9.8 b	9.8 b
	1975 & 76	1.68	9.6 b	9.8 b	9.7 b	9.7 b
	1975 & 76 & 77	1.68	9.8 b	8.3 a	9.9 b	10.0 b
	1975	2.24	10.0 b	10.0 b	9.8 b	9.8 b
	1975 & 76	2.24	9.9 b	9.5 b	10.0 b	10.0 b
	1975 & 76 & 77	2.24	9.9 b	10.0 b	10.0 b	10.0 b
	1975	3.36	9.7 b	10.0 b	10.0 b	10.0 b
	1975 & 76	3.36	10.0 b	9.6 b	9.7 b	9.7 b
	1975 & 76 & 77	3.36	9.2 ab	9.6 b	9.8 b	10.0 b

[a]Herbicide applications were made July 16, 1975 and reapplications made to specified plots July 14, 1976 and August 18, 1977.

[b]Means with common letters are not significantly different at the 5% level by Duncan's multiple range test. Visual ratings are on a 0 to 10 scale, 0 = no control and 10 = 100% control.

Figure 1. Proliferation of buds and reduction of growth in roots of (A) field bindweed and (B) hedge bindweed treated with sub-lethal rates of glyphosate. The control roots are on the left, and the treated roots are on the right.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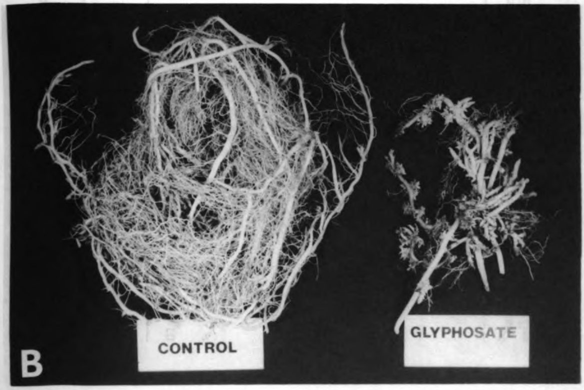

CONTROL
GLYPHOSATE
B

Table 6. Fall postemergence applications of glyphosate for field bindweed control

Treatment	Date treated	Rate (kg/ha)	Weed control ratings[a] Muck 6/3	Muck 8/17	Mineral 6/3	Mineral 8/17
Glyphosate	September 25	2.24	9.4 c	3.3 c	9.9 e-g	9.8 e-g
	" "	3.36	9.6 e-g	3.0 bc	9.6 e-g	9.5 ef
	September 28	2.24	9.6 e-g	6.0 d	9.8 e-g	9.8 e-g
	" "	3.36	9.8 e-g	6.3 d	9.7 e-g	9.8 e-g
	October 8	2.24	9.5 ef	4.3 c	9.6 e-g	9.7 e-g
	" "	3.36	9.8 e-g	4.3 c	9.9 gh	10.0 h
	October 14	2.24	9.5 ef	1.7 ab	9.8 e-g	9.8 e-g
	" "	3.36	9.8 e-g	4.0 c	9.9 gh	10.0 h
	November 5	2.24	0.0 a	0.0 a	0.0 a	0.0 a
	" "	3.36	0.0 a	0.0 a	0.0 a	0.0 a

[a]Means with common letters are not significantly different at the 5% level by Duncan's multiple range test. Visual ratings are on a 0 to 10 scale, 0 = no control, 10 = 100% control.

Table 7. Temperature lows for September, October, and November in Shiawassee and Saginaw Counties

Month	Day	Temperature (C)		Month	Day	Temperature (C)		Month	Day	Temperature (C)	
		Shiawassee	Saginaw			Shiawassee	Saginaw			Shiawassee	Saginaw
September	1	12	12	October	1	5	7	November	1	- 6	- 3
	2	3	6		2	7	8		2	2	2
	3	11	11		3	7	10		3	- 1	2
	4	17	17		4	10	11		4	- 3	- 1
	5	10	19		5	13	15	Treatment	5	- 2	1
	6	4	7		6	5	6		6	0	2
	7	12	13		7	2	3		7	- 2	- 1
	8	14	18	Treatment	8	1	2		8	- 8	- 7
	9	12	15		9	2	3		9	- 6	- 3
	10	9	10		10	2	6		10	- 4	4
	11	11	13		11	6	8		11	- 8	- 7
	12	12	13		12	9	10		12	- 8	- 6
	13	12	14		13	7	9		13	- 5	- 7
	14	14	16	Treatment	14	0	2		14	- 4	- 4
	15	12	13		15	8	10		15	- 8	- 7
	16	14	15		16	- 1	1		16	- 7	- 4
	17	14	15		17	- 2	- 2		17	- 2	- 1
	18	9	11		18	- 6	- 1		18	- 2	- 1
	19	10	11		19	- 1	2		19	0	2
	20	12	14		20	2	2		20	- 6	1
	21	4	5		21	0	1		21	- 5	- 4
	22	1	2		22	- 2	0		22	- 7	- 5
	23	9	9		23	- 3	4		23	- 5	- 3
	24	- 2	1		24	3	4		24	- 6	- 4
Treatment	25	2	4		25	3	2		25	- 7	- 4
	26	9	8		26	- 2	0		26	5	6
	27	9	8		27	- 7	- 5		27	1	2
Treatment	28	1	2		28	- 6	- 4		28	-11	- 8
	29	5	7		29	1	2		29	-16	-15
	30	4	7		30	3	6		30	-14	-12
					31	- 1	3				
Total days 0 C or below		1	0			12	5			26	20

frost. In the spring of 1977 each crown was green with a profusion of buds at each crown (Figure 2). By August there was complete ground cover and control seen as stunted plants, deformity of leaves, and profusion of buds, but no reduction in stand. These symptoms are similar to those identified in greenhouse studies on field bindweed, hedge bindweed, and buckwheat (Figure 3 and Figure 4). There was a profusion of buds in the leaf axil where normally there would be no stems forming. The leaves are cup shaped and chlorotic. On the mineral soils excellent control of bindweed was obtained throughout the season, while control on the muck soil was only effective early in the season and by late summer many of the plots had as low as 20 percent control (Table 6). Control is usually a little less on high organic soils, however, not 30 to 80 percent lower as is the case here. The tremendous decrease in effectiveness on muck soil is attributed to July tillage prior to establishment of the study. It appears that tillage affects the control from glyphosate more on muck soils than it does on mineral soils.

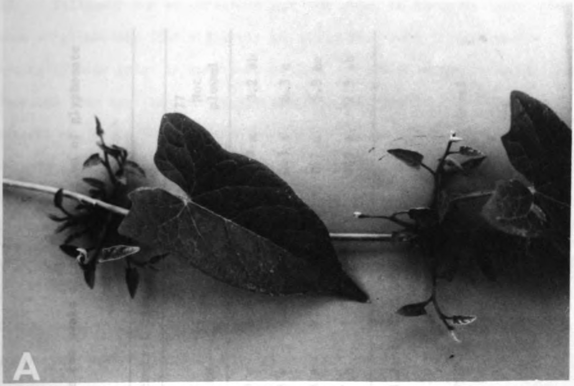
Tillage two weeks after treatment appeared to have no effect on bindweed control during the first year (Table 8). By the end of the second season the plowed subplots provided 50 percent less control than the non-plowed except at the high rate of 4.48 kg/ha. By the middle of the third season the plowed subplots provided essentially no control while those not plowed still provided 50 percent control. This probably occurred because plowing after two weeks separated the roots from the source of glyphosate, the tops, resulting in less glyphosate in the roots, therefore, inhibiting their growth for a shorter period of time.

Figure 2. Glyphosate was applied to field bindweed at 2.24 kg/ha in the fall. Profuse budding occurred at the crown as observed in the photograph the following spring.

Figure 3. Proliferation of buds, deformity, and chlorosis of new leaves in (A) wild buckwheat and (B) field bindweed caused by sub-lethal rates of glyphosate.


B
A

Figure 4. Proliferation of buds, deformity, and chlorosis of new leaves in (A) hedge bindweed and (B) field bindweed caused by sub-lethal rates of glyphosate.


A


B

Table 8. Glyphosate phytotoxicity as effected by tillage two weeks after application of glyphosate on field bindweed

Treatment[a]	Rate (kg/ha)	Weed control rating[b]							
		7/11/75[c]		5/18/76		9/1/76		7/15/77	
		Plowed	Not plowed	Plowed	Not plowed	Plowed	Not plowed	Plowed	Not plowed
Glyphosate	1.12	9.6 a	9.6 a	9.7 a	9.9 a	4.0 a	8.3 b	0.7 a	3.2 ab
	1.68	9.9 a	9.9 a	9.5 a	9.8 a	4.0 a	7.9 b	0.3 a	6.3 c
	2.24	10.0 a	9.9 a	9.5 a	9.8 a	4.0 a	7.9 b	0.7 a	5.3 bc
	4.48	9.9 a	9.9 a	9.7 a	9.7 a	7.8 b	7.3 b	0.0 a	2.3 ab

[a]Herbicide applications were made June 7, 1975 and plowed June 21, 1975.

[b]Visual ratings were on a 0 to 10 scale; 0 = no control, 10 = 100% control.

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

Tillage prior to treatment has been shown to decrease effectiveness of glyphosate (Table 9). It was found that fall tillage and/or spring tillage prior to treatment on June 3, 1977 decreased control obtained from applications of glyphosate on mineral soil by 40 to 70 percent and 30 to 40 percent on muck soil. There was no difference whether tillage occurred in the fall only or fall and spring. This is because the broken roots from tillage lay dormant until spring and did not recover from tillage until then. Fall applications on muck soil provided unsatisfactory control, but excellent control on mineral soil. Tillage after fall treatment either in the fall or in the spring increased the control of the fall treatments by 50 percent on muck soils, and only slightly on mineral soils. When application was not made until July 20, 1977 excellent control was obtained on both muck and mineral soils for all tillage systems, however, the control obtained on the mineral soil was still better than the control on the muck soil.

Two years after treatment, excellent control was obtained from glyphosate applied in August, 1975, with or without retreatment (Table 10). Due to cultivation, no control was observed from the spring 1976 treatments. A second application made on October 14, 1976 to those receiving spring application, provided less than 50 percent control one year after the second application. The October treatment was made after corn harvest, therefore, it appears that field bindweed cannot be treated in most situations after corn and soybean harvest. When a second application was applied to those plots having spring treatments in 1976 in the spring of 1977 excellent control was obtained throughout the season. Except occasional years like 1977, having early springs, field bindweed has not emerged by the middle of May in time

Table 9. Postemergence applications[a] of glyphosate in different tillage systems for field bindweed control

Treatment	Glyphosate (kg/ha)	Weed control ratings Muck 8/17	Mineral 8/17
Fall spray, fall tillage	2.24	8.3 ef	9.0 e-g
Fall spray, spring tillage		7.8 e	9.7 f-h
Fall tillage, spring spray		4.3 b-d	2.7 a-c
Fall tillage, spring tillage, spring spray		4.7 b-d	2.3 ab
Fall spray, no tillage		3.3 bc	8.8 e-g
Fall tillage, spring tillage, July spray		9.3 f-h	10.0 i
Fall tillage, July spray		9.3 f-h	9.9 hi
Spring tillage, July spray		8.8 e-g	10.0 i
July spray, no tillage		9.2 e-g	9.5 f-h
Spring spray, spring tillage		5.0 cd	5.0 cd
Spring spray, no tillage		7.7 e	7.0 e
Spring tillage, spring spray		4.0 b-d	0.3 a

[a]Treatments were made: September 25, 1976, June 3, 1977, July 20, 1977.

[b]Means with common letters within a column are not significantly different at the 5% level by Duncan's multiple range test. Visual ratings are on a 0 to 10 scale; 0 = no control, 10 = 100% control.

Table 10. Postemergence applications[a] of glyphosate for field bindweed control in a corn, soybeans, navy beans, and wheat rotation

Years treated	Rate (kg/ha)	Crop (1976)	Years treated	Rate (kg/ha)	Crop (1977)	Weed ratings[b] 5/19	Weed ratings[b] 8/23
Fall '75	1.12	Corn	Spring '77	1.12	Navy beans	9.7 d	9.8 bc
" "	2.24	"	" "	2.24	" "	9.0 d	9.9 c
" "	1.12	Soybeans	Fall '76	1.12	Corn	9.8 d	9.6 bc
" "	2.24	"	" "	2.24	"	9.9 d	9.9 c
Fall '75	1.12	Corn	No treatment	--	Corn	9.0 d	9.5 bc
" "	2.24	"	" "	--	"	9.8 d	8.8 b
" "	1.12	None	Fall '76	1.12	Corn	9.3 d	9.3 bc
" "	2.24	"	" "	2.24	"	9.9 d	9.9 c
No treatment	--	Corn	No treatment	--	Soybeans	0.0 a	0.0 a
Spring '76	1.12	Navy beans	Fall '76	1.12	Wheat	4.8 bc	3.3 a
" "	2.24	" "	" "	2.24	"	9.0 d	3.3 a
" "	1.12	Soybeans	Spring '77	1.12	Soybeans	1.7 ab	9.8 bc
Spring '76	2.24	Soybeans	Spring '77	2.24	Soybeans	2.0 ab	9.8 bc
" "	1.12	"	" "	1.12	"	2.3 ab	9.4 bc
" "	2.24	"	" "	2.24	"	5.8 c	9.5 bc
No treatment	--	None	No treatment	--	None	0.0 a	0.0 a

[a]Treatments were applied: August 15, 1975, June 15, 1976, October 14, 1976, May 19, 1977.

[b]Means with common letters within a column are not significantly different at the 5% level by Duncan's multiple range test. Visual ratings are on a 0 to 10 scale; 0 = no control, 10 = 100% control.

to be treated prior to seed bed preparation for corn and soybeans. Navy beans, however, are planted late enough in June to allow emergence and growth of field bindweed and glyphosate treatment prior to seed bed preparation. Fall treatments cannot be applied following corn and soybeans due to late fall harvesting, cold temperatures at that time, and harvesting techniques which destroy all or part of the field bindweed foliage. Post harvest applications of lyphosate are best adapted to wheat.

In summary, glyphosate is an effective chemical for controlling field bindweed, however, the roots are only inhibited for two or three seasons after treatment so eradication with one application of glyphosate is not very probable. Retreatment after the second season is necessary to have continual control. Glyphosate can be applied any time during the growing season after flower bud initiation through late fall. Fall applications are effective as long as continuous or extremely low temperatures do not follow treatment. Tillage prior to treatment can completely eliminate glyphosate phytotoxicity, if it occurs close to treatment. Tillage after treatment increased control during the first season with fall applications in marginal control situations, but decreased control after spring treatments during the second season.

Literature Cited

1. Agbakoba, Chuma S. O., and J. R. Goodin. 1970. Picloram enhances 2,4-D movement in field bindweed. Weed Sci. 18:19-21.

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

3. Bakke, A. L. 1939. Experiments on the control of European bindweed (Convolvulus arvensis L.) Agr. Expt. Sta., Iowa State Coll. Agr. Research Bull 294.

4. Bakke, A. L. 1944. Control and eradication of European bindweed. Iowa State College of Agric. Exp. Sta. Bull. P61. pp. 937-960.

5. Best, K. F. 1963. Note on the extent of lateral spread of field bindweed. Can. J. Plant Sci. 43:230-232.

6. Bioletti, Frederic T. 1911. The extermination of morningglory. University of California College of Agric. Circ. No. 69. pp. 1-12.

7. Call, L. E. and R. E. Getty. 1923. The eradication of bindweed. Kansas Agr. Exp. Sta. Cir. 101.

8. Cox, H. R. 1908. The eradication of bindweed or wild morning-glory. USDA Farmers Bull. 368.

9. Davison, J. G. and J. A. Bailey. 1974. The response of Convolvulus arvensis (bindweed) to 2.4-D, MCPA, MCPB, Dichloroprop, Mecoprop, 2,4,5-T Dicamba and glyphosate at various doses and application dates. Proc. Brit. Weed Control Conf. 2:641-648.

10. Derscheid, Lyle A., J. K. Stritzke, and Wayne G. Wright. 1970. Field bindweed control with cultivation, cropping, and chemicals. Weed Sci. 18:590-596.

11. Derscheid, Lyle A., and Keith E. Wallace. 1959. Control and elimination of field bindweed. South Dakota Exp. Sta. Circ. 146. pp. 1-4.

12. Fischer, B. B., F. H. Swanson, D. M. May, A. H. Lange. 1976. Roundup review. Agrichemical Age, June 1976. pp. 16, 17, 21.

13. Frazier, J. C. 1943. Nature and rate of development of root systems of Convolvulus arvensis. Botan. Gaz. 104:417-425.

14. Frazier, John C. 1948. Principal noxious perennial weeds of Kansas, with emphasis upon their root systems in relation to control. Kansas State College of Agricu. Exp. Sta. Bull. 311. pp. 1-45.

15. Harvey, W. A. 1965. Costs and losses from weeds. Proc. 17th Calif. Weed Conf. 17:11-14.

16. Hamilton, W. D., A. H. Lange, C. L. Elmore. 1971. Field bindweed control in vineyards. Calif. Agr. 25(9):9-10.

17. Higgins, Robert E. 1967. Loss caused by noxious weeds in potatoes. Down to Earth 23(1):2, 24.

18. Jones, I. B., and J. O. Evans. 1973. Control of Russian knapweed and field bindweed with dicamba, 2,4-D and their combinations with and without DMSO. Proc. West. Soc. Weed Sci. 26:39-43.

19. Kennedy, P. B., and A. S. Crafts. 1931. The anatomy of Convolvulus arvensis, wild morningglory or field bindweed. California Agric. Exp. Sta. Bull. No. 5:591-622. (Hilgardia).

20. Kiesselbach, T. A., N. F. Peterson, and W. W. Burr. 1934. Bindweeds and their control. University of Nebraska College of Agric. Exp. Sta. Bull. 287. 1-47.

21. Kiesselbach, T. A., P. H. Stewart, and D. L. Gross. 1935. Bindweed eradication. Nebraska Exp. Sta. Circ. 50:1-8.

22. Kleifeld, Y. 1972. Control of annual weeds and Convolvulus arvensis L. in tomatoes by trifluralin. Weed Res. 12:384-388.

23. Kline, W. L., and G. W. Selleck. 1977. Effect of glyphosate applications on hedge bindweed. Proc. N. E. Weed Sci. 31:98.

24. Lange, A. H., B. Fischer, H. Agamalian, H. Kempen. 1969. Weed control in young crops. Calif. Agr. 23(9):11-12.

25. Lange, A. H., B. B. Fischer, C. L. Elmore, H. M. Kempen, J. Schlesselman. 1975. Roundup--The end of perennial weeds in tree and vine crops? California Agriculture. pp. 6-7.

26. Leonard, O. A., D. E. Bayer and R. J. Weaver. 1961. Results of tests using 2,4-D in vineyards. Hormolog. 3:10-11.

27. Mitch, L. W., B. L. Bohmont, H. P. Alley, and N. E. Harrington. 1962. Wyomings primary noxious weeds. Bull. Wyoming Agric. Exp. Sta. 394, p. 40.

28. Neuruer, H. 1961. Weeds which hinder combine harvesting. Pflanzenarzt. 14:61-63.

29. Phillips, W. M. and F. J. Timmons. 1954. Bindweed, how to control it. Kansas Agr. Exp. Sta. Bull. 366.

30. Roncoroni, E. J., C. L. Elmore, A. H. Lange. 1976. Thin layering of herbicides for field bindweed control in established orchards and vineyards. Proc. West. Soc. Weed Sci. 29:195-201.

31. Seely, C. E., K. H. Klages and E. G. Schafer. 1944. Bindweed control. Wash. Agr. Exp. Sta. Popular Bull. 176.

32. Sripleng, Aksorn, and Frank H. Smith. 1960. Anatomy of the seed of Convolvulus arvensis. American Journal of Botany. 47:386-393.

33. Stewart, George, and D. W. Pittman. 1924. Ridding the land of wild morningglory. Utah Agric. Exp. Sta. Bull. 189. 1-30.

34. Sylvester, E. P. 1947. Soybeans as a smother crop for European bindweed. Iowa State College of Agri. Bull.

35. Warner, L. C. 1973. Subsurface layering of trifluralin with a moldboard plow for field bindweed control. Proc. West. Soc. Weed Sci. 26:27-29.

36. Wiese, A. F. 1969. Perennial weed control in northwest Texas. Texas Agr. Exp. Sta. MP-828. pp. 1-4.

37. Wiese, A. F. 1971. Monuron and other soil sterilants for controlling small patches of perennial weeds. Texas Agr. Exp. Sta. MP-1002. pp. 1-7.

38. Wiese, A. F., and W. M. Phillips. 1976. Field bindweed. Weeds Today. 7:22-23.

39. Wiese, A. F., and H. E. Rea. 1955. Bindweed control in the panhandle of Texas. Texas Agri. Exp. Sta. Bull. 802. pp. 3-8.

40. Withycombe, R. 1911-12. Report of the Department of Agronomy. Oregon Agri. Exp. Sta. Report East, Oregon Station.

CHAPTER 3

EFFECT OF DILUENT VOLUME AND CALCIUM ON GLYPHOSATE PHYTOTOXICITY

Abstract

The effects of diluent volume and calcium concentration on glyphosate [*N*-(phosphonomethyl)glycine] phytotoxicity were evaluated by applying 0.0, 0.0025, 0.005, 0.01, 0.02, and 0.04 M $CaCl_2$ and 1.68 kg/ha glyphosate at 130, 190, 375, and 750 L/ha to tall morningglory [*Ipomoea purpurea* (L.) Roth] plants 10 to 12 cm tall. Thirty days after treatment, plant height and fresh and dry weight measurements showed that calcium reduced glyphosate phytotoxicity at high application volumes. However, at 190 L/ha calcium concentrations up to 0.01 M did not cause a reduction of glyphosate phytotoxicity. Increasing the diluent volume above 190 L/ha decreased glyphosate phytotoxicity. Addition of a sulfonine red dye to the spray solution indicated that at 130 and 190 L/ha, runoff from the annual morningglory leaves was negligible. At 375 L/ha or greater diluent volumes, 1/2 to 3/4 of the spray solution as measured by dye retention ran off the leaf surface. At 750 L/ha the spray pattern on the leaf surface was not uniform as the water and dye collected at the leaf margins. Addition of isopropylamine to formulated glyphosate did not counteract the reduction of glyphosate phytotoxicity caused by calcium.

Introduction

Glyphosate was introduced as a herbicide in 1971 (1). It provides wide spectrum weed control, and due to phloem translocation to the meristematic regions of the foliage and the root systems, it provides excellent perennial weed control (9). There has been interest in combining glyphosate in tank mixes and split applications with other chemicals such as atrazine [2-chloro-4-(ethylamino)-6-(isopropylamine)-*s*-triazine], propachlor (2-chloro-*N*-isopropylacetanilide), terbacil (3-*tert*-butyl-5-chloro-6-methyluracil), simazine (2-chloro-4,6-bis (ethyl-amino)-*s*-triazine), amitrol (3-amino-*s*-triazole), and other wettable powders, especially for no-till applications (5, 8). When combined with certain wettable powders, glyphosate was no longer active (3). Phillips (5) reported that atrazine, propachlor, and non-herbicidal wettable powders decreased glyphosate phytotoxicity on sorghum (*Sorghum vulgare* Pers.). Selleck (9) found amitrol and simazine reduced activity of glyphosate on smooth bromegrass (*Bromus inermis* L.) when sprayed as a tank mix; however, there was no antagonism when sprayed separately the same day or later. He also showed that bromacil (5-bromo-3-*sec*-butyl-6-methyluracil), diuron (3-(3,4-dichlorophenyl)-1, 1-dimethylurea), and amitrol reduced glyphosate toxicity to common milkweed (*Asclepias syriaca* L.) and bouncing bet (*Saponaria officinalis* L.). Amitrol did not reduce control of toadflax (*Linaria vulgaris* Hill.) when tank mixed with glyphosate as did all other herbicides tested. No antagonism was seen in combination with any of the herbicides on bluegrass (*Poa pratensis* L.), goldenrod (*Solidago* spp. L.) or brambles (*Rubus* spp. L.). Combinations of glyphosate with liquid nitrogen gave enhanced kill of winter rye [*Secale cereale* (L.) var.

Balboa] (4). Nitrogen fertilizers only enhanced the initial injury with complete recovery in 6 weeks on perennial sod species. Peters et al. (3) also shows that complete fertilizers reduced glyphosate activity.

Calcium, iron, zinc, and aluminum have been shown to reduce glyphosate phytotoxicity (3, 5, 7, 13), whereas Wills (13) reported potassium, sodium, ammonium, and calcium increased glyphosate activity in descending order on purple nutsedge (*Cyperus rotundus* L.). Ammonium sulfate appeared to activate glyphosate either in a tank mix or when applied separately (2, 10, 11). Cations tended to reduce glyphosate activity, whereas anions had little or no effect on activity (5, 13).

High diluent volumes also reduced glyphosate activity both in the field and in the greenhouse (5, 6, 7, 14). Increasing the additional surfactant concentration above that in the formulation produced variable results; however, the negative effect of high diluent volume was partially overcome (6, 7, 14).

Our studies were designed to determine the effects of diluent volume and calcium concentration on glyphosate phytotoxicity and determine the volume and calcium concentration offering maximum phytotoxicity. We were also interested in interactions between diluent volume and calcium. Since high diluent volume alone decreased glyphosate control, a study was designed to determine the diluent volume at which runoff became a factor in reducing activity of glyphosate.

Materials and Methods

The effects of diluent volume and surfactant levels on glyphosate activity were studied in the field in 1975 on quackgrass [*Agropyron repens* (L.) Beauv.] and in 1977 on field bindweed (*Convolvulus arvensis* L.). The quackgrass was treated May 20, 1975 at 25 to 30 cm height with diluent volumes of 140, 280, and 560 L/ha and additional surfactant at 0.25 and 0.5 percent was added to the 365 g/L acid equivalent formulation of glyphosate on a volume-to-volume basis. The field bindweed was treated at full bloom on June 15, 1977 with diluent volumes of 93, 186, 280, and 560 L/ha. No additional surfactant was applied in this study. Glyphosate was applied at rates of 0.56, 0.84, and 1.12 kg/ha to quackgrass and at 0.56, 0.84, 1.68, and 3.36 kg/ha to field bindweed. Variable diluent volumes were obtained by changing nozzle sizes, application speed, and pressure. All treatments were made with a tractor-mounted sprayer.

To evaluate the effects of diluent volume and calcium on glyphosate phytotoxicity in the greenhouse, tall morningglory was grown in 946-ml wax-covered cups using greenhouse potting soil with 10 percent organic matter. Five tall morningglory seeds were planted in each pot and thinned to three uniform plants after emergence. The plants were fertilized twice weekly with a commercial fertilizer containing an analysis of 20-20-20 NPK. The test plants were grown in the greenhouse with supplemental lighting to provide a 14-hour day.

Glyphosate was applied to the tall morningglory plants when they were 10 to 12 cm tall. Glyphosate was applied at 1.68 kg/ha with 0.0, 0.0025, 0.005, 0.01, 0.02, and 0.04 m $CaCl_2$ and dilution volumes of 130, 190, 375, and 750 L/ha were obtained by changing nozzle size and pressure. The plants were harvested 30 days after treatment and plant fresh and dry weights measured. The data were analyzed as a two-way factorial design and presented as the means of three experiments with four replications per experiment.

Tall morningglory plants, 20 to 25 cm tall, were used in a study designed to determine the diluent volume at which runoff became a factor in reducing glyphosate activity. The methods for growing the test plants were the same as in the previous study. Diluent volumes of 130, 190, 375, and 750 L/ha and calcium concentrations of 0.0, 0.0025, 0.01, and 0.04 m as $CaCl_2$ were combined with glyphosate a at 1.68 kg/ha for evaluation of spray retention on the leaf surface. Sulfonine red dye was added to the spray solution at a concentration of 2 g per 500 ml of the spray mixture. The spray remaining on the leaf surface was either washed off the leaves immediately with deionized water and collected in 50-ml beakers or allowed to dry and then washed off with deionized water and collected in 50-ml beakers. All samples were brought to equal volume and absorbance measured spectrophotometrically at 430 nm and absorbance related to leaf area. Treated leaves were photographed while wet and after drying. The data presented are the means of two experiments with four replications per experiment.

A study was designed to determine if calcium and isopropylamine, the salt used in formulating glyphosate, were competing for the same site on the glyphosate molecule. Tall morningglory plants grown as above to 12 to 15 cm in height were sprayed with glyphosate at 1.12 kg/ha, calcium at 0.0 and 5.9 M, and isopropylamine at 0.0, 0.25, 0.5, and 1.0 percent by volume. The isopropylamine was added to the formulated glyphosate or the water if glyphosate was absent. This mixture, together with the calcium, was then added to the spray mixture. Plant height and fresh and dry weights were determined after 45 days.

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

Results and Discussion

Two field studies, one on quackgrass and the other on field bindweed, showed 40 to 50 percent decrease in the control of quackgrass and field bindweed with glyphosate as the diluent volume increased to 560 L/ha (Table 1). Additional surfactant increased glyphosate phytotoxicity only at the 1.12 kg/ha herbicide rate and 560 L/ha diluent volume; however, it did not completely remove the loss of phytotoxicity due to increased diluent volumes. In the greenhouse diluent volume did not reduce glyphosate activity until the volume was greater than 190 L/ha (Table 2), similar to the field studies (Table 1). No difference in plant height and weight was evident between the 130 and 190 kg/ha rate, but a significant increase was evident when the volume was increased to 375 and 750 kg/ha.

Considering calcium averaged over all of the diluent volumes, even the 0.0025 M inhibited glyphosate activity (Table 3). Considering fresh and dry weight, a calcium concentration of 0.01 M or greater appeared to render glyphosate inactive; however, with respect to plant height, calcium did not totally inactivate glyphosate at any of the concentrations tested. These results were due to the profusion of buds which occurred after treatment, which increased

Table 1. The effect of diluent volume and additional surfactant on glyphosate phytotoxicity to quackgrass and field bindweed grown in the field

Glyphosate (kg/ha)	Surfactant[a] (% vol.)	Diluent volume (L/ha) 140	280 (Quackgrass weed control ratings)[b]	560
0.56	0.0	0.0	0.0 a	0.0 a
0.56	0.0	5.8 g-k	3.0 bc	1.0 a
0.56	0.25	3.7 d-f	2.7 b-f	1.3 a
0.84	0.5	4.7 c-h	3.7 b-f	2.7 b-d
0.84	0.25	6.2 g-k	5.5 f-k	4.8 c-i
0.84	0.5	6.5 h-k	7.5 jk	4.3 c-g
1.12	0.0	8.2 kl	5.7 f-k	3.3 b-e
1.12	0.25	8.2 kl	5.3 e-j	5.3 e-j
1.12	0.5	7.8 k	7.2 i-k	6.0 g-k

Glyphosate	Diluent volume (L/ha) 93	186	280 (Field bindweed weed control ratings)[b]	560
0.56	1.7 ab	1.3 a	1.0 a	1.7 ab
0.84	3.3 a-c	5.3 cd	1.7 ab	1.3 a
1.68	6.0 cd	6.9 d-f	4.7 c	1.3 a
3.36	9.9 f	9.6 ef	7.5 df	6.7 df

[a]Additional surfactant (Mon 011) added to that already in the glyphosate formulation.

[b]Means followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test. Visual ratings on a 0 to 10 scale, 0 = no control, 10 = complete control.

Table 2. Effects of diluent volume on glyphosate phytotoxicity at 1.68 kg/ha on tall morningglory 10 to 12 cm in height grown in the greenhouse

Diluent volume (L/ha)	Plant height[a] (cm/plant)	Fresh weight[a] (g/plant)	Dry weight[a] (g/plant)
130	22.9 a	4.2 a	0.8 a
190	30.2 a	5.0 a	0.9 a
375	41.3 b	6.1 b	1.0 b
750	51.0 c	7.7 c	1.2 c

[a]Means within the same column followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

Table 3. The effects of calcium on glyphosate phytotoxicity to tall morningglory grown in the greenhouse

Glyphosate (kg/ha)	Calcium (M)	Plant height[a] (cm/plant)	Fresh weight[a] (g/plant)	Dry weight[a] (g/plant)
1.68	0.0	13.4 a[a]	3.2 a	0.6 a
	0.0025	25.0 b	4.5 b	0.8 a
	0.005	25.4 b	5.4 bc	1.0 bc
	0.01	31.0 bc	5.8 cd	1.1 cd
	0.02	39.4 c	6.8 de	1.1 cd
	0.04	40.2 c	7.0 de	1.1 cd
Control	--	79.8 d	7.8 e	1.3 d

[a]Means within the same column followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

fresh and dry weight of the plants but did not increase their height. A definite reduction of glyphosate phytotoxicity due to high diluent volume was evident (Table 4). Using deionized water as the carrier, no reduction in control was observed in plant height as the diluent volume was increased until the diluent volume was 375 L/ha or greater. Addition of 0.0025 M calcium to the glyphosate mixture caused a reduction in control at 375 L/ha, 0.02 M calcium caused a reduction at 190 L/ha, and 0.04 M calcium caused a reduction at 130 L/ha (Table 4). According to U.S. Department of Interior (12) very few areas in the United States have water with concentrations of calcium greater than 0.0025 M, a few were found to have concentrations of calcium up to 0.005 M, and only one location in New Mexico had a concentration of calcium as high as 0.01 M. Therefore, glyphosate inactivation due to high calcium concentrations are uncommon.

Sulfonine red dye was used to measure spray runoff from the leaf surface to determine the critical diluent volume at which runoff became a factor. As the diluent volume was increased from 130 to 190 L/ha, spray retention, as determined by absorbance, increased from 0.0076 and 0.0136 O.D./cm^2 (Table 5). Since the dye concentration in the water was the same, the dye retained should have doubled as diluent volume increased from 190 L/ha to 375 L/ha; however, this did not occur. Thus runoff became a factor in the reduction of glyphosate phytotoxicity only if the diluent volume was greater than 190 L/ha. Similarly in the field 93, 140, and 186 L/ha diluent volumes caused no reduction in phytotoxicity, but 280 L/ha and greater caused a significant reduction. The photographs in Figure 1 indicate that the 130 L/ha diluent volume treatment resulted in uniform spray droplets

Table 4. The interaction of calcium and diluent volume on tall morningglory height grown in the greenhouse

Diluent volume (L/ha)	Calcium as $CaCl_2$ (M)[a]					
	0.0 plant height (cm/plant)	0.0025 plant height (cm/plant)	0.005 plant height (cm/plant)	0.01 plant height (cm/plant)	0.02 plant height (cm/plant)	0.04 plant height (cm/plant)
130	5.0 a	7.3 a	10.0 ab	6.5 a	16.3 a-c	30.3 c-e
190	7.9 a	8.1 a	8.0 a	18.6 a-d	8.6 e	41.6 de
375	11.0 ab	33.3 c-e	39.5 c-e	46.3 e	43.7 e	44.4 e
750	30.0 c-e	51.5 e	44.1 e	52.8 e	48.9 e	44.7 e

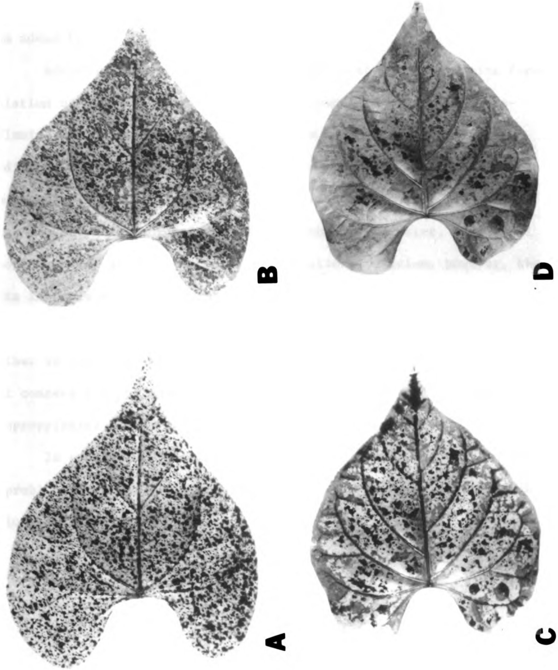
[a]Means followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

Table 5. The influence of calcium on the retention of sulfonine red dye on the leaf surfaces of tall morningglory grown in the greenhouse

Diluent volumes (L/ha)	Calcium (M)	Absorbance[a] (O.D./cm^2)
130	0.0	0.0076 a
190	0.0	0.0136 bc
375	0.0	0.0147 cd
750	0.0	0.015 cd
130	0.0025	0.0097 ab
130	0.015	0.008 a
130	0.04	0.0088 a
750	0.0025	0.0111 a-c
750	0.01	0.019 d
750	0.04	0.016 cd

[a]Means followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

Figure 1. Glyphosate and sulfonine red dye retention on tall morningglory leaves when applied at 130 and 750 L/ha and photographed while wet and dry. (A) 130 L/ha wet, (B) 130 L/ha dry, (C) 750 L/ha wet, (D) 750 L/ha dry.


B
D
A
C

on the leaf surface compared to the 750 L/ha rate which deposited large spots that ran off the leaf surface. Very little of the spray mixture was retained at 750 L/ha. No decrease in spray retention was observed either visually or by absorbance of dye retained when calcium was added to the spray mixture (Table 5).

Additional isopropylamine was added to the isopropylamine formulation of glyphosate to determine the competitiveness of isopropylamine and calcium for the same site on the glyphosate molecule. Additional diluent, if the water contained calcium, would increase the amount of calcium available for inactivating glyphosate. Thus, if high concentrations of calcium were present in the water, additional isopropylamine should counteract the additional calcium; however, the data in Table 6 indicates that there was no difference in glyphosate phytotoxicity as the isopropylamine rates varied from 0 to 1 percent either in deionized water or 5.9 M calcium mixture. Either they did not compete for the same site on the glyphosate molecule or additional isopropylamine could not replace the calcium.

In summary, calcium in the spray water does not appear to be a problem in reducing glyphosate phytotoxicity as long as the diluent volume is less than 185 L/ha.

Table 6. The interaction of additional isopropylamine above that in the normal formulation and calcium on glyphosate activity to tall morningglory

Glyphosate (kg/ha)	Calcium (M)	Isopropylamine[a] (%)	Plant height[b] (cm/plant)	Fresh weight[b] (g/plant)	Dry weight[b] (g/plant)
1.12	0.0	0.0	32.4 a	3.8 ab	0.51 ab
1.12	0.0	0.25	24.6 a	3.1 a	0.47 ab
1.12	0.0	0.5	23.7 a	2.9 a	0.43 a
1.12	0.0	1.0	55.8 abc	3.9 ab	0.73 abcd
1.12	5.88	0.0	34.9 a	4.5 abc	0.77 abcd
1.12	5.88	0.25	38.7 ab	3.9 ab	0.59 abc
1.12	5.88	0.5	37.4 ab	3.6 ab	0.47 ab
1.12	5.88	1.0	46.9 ab	4.6 ab	0.6 abc
0.0	0.0	0.0	81.4 cd	5.2 bc	0.84 bcd
0.0	0.0	0.25	69.9 bc	4.8 bc	0.77 bcd
0.0	0.0	0.5	108.7 d	6.1 c	0.99 d
0.0	0.0	1.0	70.2 bc	5.6 bc	0.93 cd

[a]The percentages of isopropylamine added is in addition to the amount in the 0.36 kg/L acid equivalent formulation of glyphosate.

[b]Means followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

Literature Cited

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

2. Blair, A. M. 1975. The addition of ammonium salts or phosphate ester to herbicides to control Agropyron repens (l.) Beauv. Weed Res. 15:101-105.

3. Hanson, C. L. and C. E. Rieck. 1976. The effect of iron and aluminum on glyphosate toxicity. Proc. South. Weed Sci. Soc. 29:49.

4. Peters, R. A., W. M. Dest, and A. C. Triolo. 1974. Preliminary report on the effects of mixing liquid fertilizers and residual herbicides with paraquat and glyphosate. Proc. N. E. Weed Sci. Soc. 28:35-40.

5. Phillips, W. M. 1975. Glyphosate phytotoxicity as affected by carrier quality and application volume. Proc. North Cent. Weed Contr. Conf. 30:115.

6. Riemer, D. M. 1973. Effects of rate, spray volume, and surfactant on the control of phragmites with glyphosate. Proc. N. E. Weed Sci. Soc. 27: 101-104.

7. Sandberg, C. L., W. F. Meggitt, and D. Penner. 1976. Influence of spray volume and calcium of glyphosate phytotoxicity. Proc. North Cent. Weed Contr. Conf. 31:31.

8. Selleck, G. W. 1975. Antagonistic effects with glyphosate herbicide plus residual herbicide combinations. Proc. N. E. Weed Sci. Soc. 29:327.

9. Sprankle, P., W. F. Meggitt, and D. Penner. 1972. Absorption, action, and translocation of glyphosate. Weed Sci. 23:235-240.

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

11. Turner, D. J. and M. P. C. Loader. 1975. Further studies with additives: effects of phosphate esters and ammonium salts on the activity of leaf-applied herbicides. Pestic. Sci. 6:1-10.

12. U.S. Department of Interior. 1966-1970. Quality of Surface Waters of the United States. Paper Nos. 2144, 1-367; 2146, 1-540; 2109, 1-633; 2157, 1-532; 2149, 1-349.

13. Wills, G. D. 1973. Effects of inorganic salts on the toxicity of glyphosate to purple nutsedge. Abstr. Weed Sci. Soc. Amer. p. 59.

14. Wills, G. D. 1973. Toxicity of glyphosate to purple nutsedge as affected by surfactant K_2CO_3 and diluent volume. Proc. South. Weed Sci. Soc. 26:408-412.

CHAPTER 4

ABSORPTION, TRANSLOCATION, AND METABOLISM OF ^{14}C-GLYPHOSATE IN SEVERAL WEED SPECIES

Abstract

The pattern and extent of ^{14}C-glyphosate [*N*-(phosphonomethyl) glycine] translocation from the treated leaf and metabolism of ^{14}C-glyphosate was studied in field bindweed (*Convolvulus arvensis* L.), hedge bindweed (*Convolvulus sepium* L.), Canada thistle (*Cirsium arvense* (L.) Scop.), tall morningglory (*Ipomoea purpurea* (L.) Roth.) and wild buckwheat (*Polygonum convolvulus* L.) that received a 0.2 to 0.3 uCi drop of ^{14}C-glyphosate on a leaf midway on the parent stem. ^{14}C was translocated throughout the plants within 3 days; the greatest concentration accumulated in the meristematic tops of the roots and shoots. ^{14}C was localized in the phloem in cross and longitudinal sections of stems and roots. Minor, but significant, relocation occurred in Canada thistle and wild buckwheat after 3 days. Of the ^{14}C applied to the treated leaf, field bindweed translocated 3.5 percent, hedge bindweed 21.6 percent, Canada thistle 7.8 percent, tall morningglory 6.5 percent, and wild buckwheat 5 percent. Metabolism studies in field bindweed, Canada thistle, and tall morningglory indicated very little metabolism of the parent glyphosate. Aminomethylphosphonic acid was the major metabolite found, making up less than 15 percent of the total ^{14}C. Of the total ^{14}C applied to excised

leaves, 50 percent had disappeared within 25 days. Neither translocation nor thin layer chromotography of the metabolites could account for this loss.

Introduction

Glyphosate is a broad spectrum postemergence herbicide (1, 2, 5, 6, 8). Although glyphosate is active on most perennial weed species, the control of specific species such as field bindweed may be less than desired under certain environmental and tillage conditions. Glyphosate is absorbed and translocated in the phloem in both annual and perennial weeds (2, 3, 4, 7, 13, 16, 18). Translocation is rapid; however, tillage of treated quackgrass (*Agropyron repens* (L.) Beauv.) after 1 day allowed more buds to survive than tillage after longer time intervals (3, 4, 13). The contribution of glyphosate metabolism to the variability in perennial weed control is not know. However, very little metabolism of glyphosate has been found in plant material (7, 11, 18). Glyphosate is broken down in soil and water to CO_2 (9, 10, 12, 14). Aminomethylphosphonic acid (AMP) was the major metabolite isolated from both soil and plants (7, 10, 11).

The objectives of this investigation were to study absorption, translocation, and metabolism of glyphosate by Canada thistle and field bindweed. Because a number of viney weed species are often confused with field bindweed, hedge bindweed, a perennial, and tall morningglory and wild buckwheat, both annuals, were also included in several of the studies for comparison.

Materials and Methods

For abscrption and translocation experiments tall morningglory, 'Clarke's Heavenly Blue', and wild buckwheat were planted three seeds per 946-ml wax cup filled with 860 g of white quartz sand and thinned to one plant per pot after emergence. Field bindweed and Canada thistle were grown from root cuttings 8 to 10 cm long and hedge bindweed from root cuttings 12 to 15 cm long. Each root cutting had a large shoot (hereafter referred to as the parent plant) at one end and a smaller or less mature shoot at the other end (hereafter referred to as the daughter plant). The parent plant received the ^{14}C-glyphosate treatment. Root cuttings were planted 6 cm deep in 946-ml wax cups with 860 g of white quartz sand. The sand was saturated with modified Hoagland's No. 1 solution and sub-irrigated throughout the experiment with the same. Plants were grown under supplemental lighting giving 16-hour days. The temperature was maintained at 25 $\pm$ 2 C. Plants received a 5 um drop containing 0.2 uCi of ^{14}C-glyphosate on a leaf midway along a parent stem. The ^{14}C-methyl-labeled glyphosate (spec. act. = 1.51 mCi/mmole, purity 95% by TLC) was converted from acid to the isopropylamine salt by addition of 4 ul of isopropylamine to 4.4 mg of acid followed by the addition of 1.0 ml of deionized water and 0.8 percent MON 0818 (nonionic polyethoxylated tallow amine) surfactant for all experiments. Treatments were applied when field bindweed and hedge bindweed shoots were 18 to 20 cm long, Canada thistle 14 to 18 cm, tall morningglory 12 to 14 cm, and wild buckwheat 16 to 18 cm. Plants were harvested 3 and 14 days after treatment, those used for radioautography were immediately frozen with dry ice, freeze-dried, rehydrated, mounted, and radioautographed. (The radioautographs represent each harvest time and plant species from two experiments with two replications each.) Stems and roots used to determine where the ^{14}C-glyphosate was located in the vascular system were cut into cross and longitudinal sections at harvest prior to freezing. Plants to be oxidized were dissected into several parts. Field bindweed, hedge bindweed, and Canada thistle were dissected into above treated leaf, below treated leaf, root, daughter plant, and treated leaf. Tall morningglory and wild buckwheat were dissected into above treated leaf, below treated leaf, root, and treated leaf. Plants were freeze-dried and then pulverized with a mortar and pestle. A representative sample was combusted by the Schoeniger method of Wang and Willis (17) to determine by liquid scintillation radioassay the quantity of ^{14}C translocated to each plant part. The combustion data were analyzed as a two-way factorial with two replications. To determine the amount of applied ^{14}C-glyphosate that left the treated leaf, the total ^{14}C in all plant parts excluding the treated leaf were added together and divided by the total ^{14}C applied.

Field bindweed, Canada thistle, and tall morningglory plants for metabolism experiments were grown as described above. When the plants were 10 to 12 cm long, they received a 5 ul drop containing 0.125 uCi of isopropylamine salt of ^{14}C-glyphosate on each of two leaves midway on the parent stem. Field bindweed and Canada thistle were harvested at 3, 7, and 30 days and tall morningglory 1, 7, and 21 days after treatment. Field bindweed and Canada thistle and tall morningglory as described above were dissected. Plant parts were immediately placed in dry ice and kept in the freezer at -10 C. The samples were homogenized in a Sorvall omni-mixer in 10 to 20 ml of glass distilled acetone to remove chlorophyll and other acetone-soluble substances. The maserates were centrifuged at 17,300 x G at 0 to 3 C and washed three or more times with acetone until no green color remained in the acetone fraction. Less than 1 percent of ^{14}C was lost in the acetone fraction. They were then washed three times with 30 ml of deionized water. The procedure was 85 percent efficient in extracting the ^{14}C-glyphosate. The 90-ml water sample was concentrated to approximately 0.5 ml. The concentrated liquid was removed from the evaporation flask and a 20 ul sample was assayed by liquid scintillation radioassay to determine the total radioactivity for each sample. A 20 ul sample was removed from the 0.5-ml sample and spotted on 500 um thick cellulose TLC plates and chromatographed with a standard containing glyphosate, AMP, glycine, and sarcosine. The plates were developed with a solvent system of 55 ml ethanol, 35 ml water, 2.5 ml of 15 N ammonium hydroxide (NH_4OH), 3.5 g trichloroacetic acid (TCA), and 2 ml acetic acid (15). The standard was sprayed with ninhydrin, placed in an 80 C oven, then radioautographed. The Rf values of the mixture were: glyphosate 0.28 to 0.32, AMP 0.4 to 0.44, glycine 0.54 to 0.58, and sarcosine 0.68 to 0.72. Following radioautography, the radioactive spots on the plates from the ^{14}C-glyphosate metabolism study were removed for quantative assay by liquid scintillation radioassay.

Loss of ^{14}C-glyphosate from the treated leaf was determined by using field bindweed and tall morningglory leaves excised from the plant and spotted with 0.3 uCi of ^{14}C-glyphosate. Leaves were kept in an aluminum tray at 25 C until combustion at 0, 1, 6, and 12 hours and 1, 2, 3, 11, 18, and 25 days. Radioactivity was determined by liquid scintillation radioassay. The treatments in the excised leaf study were replicated four times and completely randomized.

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

Results and Discussion

There are certain inherent problems in the measurement of foliar absorption of herbicides including incomplete removal of nonabsorbed or bound herbicide on the surface of the leaf and the elution of herbicide already absorbed by washing the leaf with various solvents. Using techniques involving the removal of the ^{14}C-glyphosate treated spot from the leaf or washing the leaf surface after treatment, past research has shown foliar absorption of glyphosate to be 25 to 50 percent of the amount applied (13, 18). The efficacy for perennial weed control of a phloem translocated herbicide such as glyphosate is related to stage of plant growth, sink-source relationships and the amount of herbicide absorbed. By measuring the amount of ^{14}C that moved out of the treated leaf under controlled conditions over a period of time, it appeared that absorption of glyphosate did not continue beyond 3 days after treatment in field bindweed, hedge bindweed, and Canada thistle (Table 1). Tall morningglory and wild buckwheat, however, did show additional absorption and movement out of the treated leaf after 3 days (Table 1). Hedge bindweed absorbed and translocated considerably more ^{14}C-glyphosate from the treated leaf than the other species. Experiments designed to localize the movement of the ^{14}C label showed that significant basipetal translocation of ^{14}C occurred in both Canada thistle and wild buckwheat between 3 and 14 days after treatment (Table 2). This translocation was not evident

Table 1. ^{14}C-glyphosate absorption and movement from the treated leaf expressed as percent of ^{14}C applied

Time (days)	^{14}C in plant minus treated leaf				
	Field bindweed (%)	Hedge bindweed (%)	Canada thistle (%)	Tall morningglory (%)	Wild buckwheat (%)
3	3.8 a	20.4 a	6.8 a	2.8 a	2.7 a
14	3.5 a	21.6 a	7.8 a	6.5 b	5.0 b

[a] Means within a column having similar letters are not significantly different at the 5% level by the students' T test.

Table 2. Translocation of ^{14}C-glyphosate in 12 to 14 cm tall tall morningglory, 18 to 20 cm long field bindweed, 18 to 20 cm long hedge bindweed, 16 to 18 cm tall wild buckwheat, and 14 to 18 cm tall Canada thistle harvested and dissected into plant parts[a] 3 and 14 days after treatment expressed as percent of total ^{14}C applied

Weed species	Time (days)	Plant part[b]			
		Above (%)	Below (%)	Root (%)	Daughter (%)
Field bindweed	3	33 a	12 a	22 a	33 a
	14	5 a	20 a	36 a	39 a
Hedge bindweed	3	15 a	19 a	29 a	37 a
	14	12 a	26 a	35 a	27 a
Canada thistle	3	48 c	14 ab	22 ab	17 ab
	14	25 ab	4 a	33 bc	38 c
Tall morningglory	3	29 a	11 a	59 b	
	14	26 a	12 a	55 b	
Wild buckwheat	3	86 c	13 a	1 a	
	14	51 b	41 b	8 a	

[a]Above (plant part above treated leaf), Below (plant part below treated leaf), Root (root), and Daughter (shoot opposite end of root from parent shoot).

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

for field bindweed, hedge bindweed, and tall morningglory. The radioautographs presented in Figures 1 through 5 support this observation. It is interesting to note that the greatest movement to mature leaves throughout the plant occurred in hedge bindweed (Figure 2) and the least in wild buckwheat (Figure 5). These results are consistent with observation of controls in the field. The translocation pattern in all five species indicated phloem transport. Radioautographs of longitudinal and cross sections of field bindweed root and stem confirm the localization of ^{14}C label in the phloem (Figures 6 and 7).

The TLC system employed in the metabolic studies afforded excellent separation of glyphosate and three potential metabolites. Evaluation of glyphosate metabolism in the various plant organs of field bindweed, Canada thistle, and tall morningglory showed the least parent ^{14}C-glyphosate in the daughter plants for perennials 3 days after harvest and in the root of tall morningglory 1 day after harvest (Tables 3, 4, and 5). The percent parent compound increase with time. Since achieving ^{14}C-glyphosate purity greater than 95 percent was difficult, the potential metabolite found in the metabolic studies may be no more than contaminants in the applied ^{14}C-glyphosate. If so, the increase in the percent parent glyphosate in the daughter plants or roots with time indicates more rapid translocation of the aminomethylphosphonic acid than glyphosate. The results indicate that very little if any metabolism of glyphosate to aminomethylphosphonic acid occurred. Determination of the total ^{14}C in all three species over the 30-day period indicated a marked decrease in ^{14}C for Canada thistle and tall morningglory (Tables 4 and 5). Combustion of the

Figure 1. Translocation of ^{14}C-glyphosate in field bindweed 18 to 20 cm in length. The treated plant (A) and corresponding radioautograph (B) of field bindweed harvested 3 days after treatment. The treated plant (C) and corresponding radio-autograph (D) of field bindweed harvested 14 days after treatment. The treated leaf is marked with an arrow.

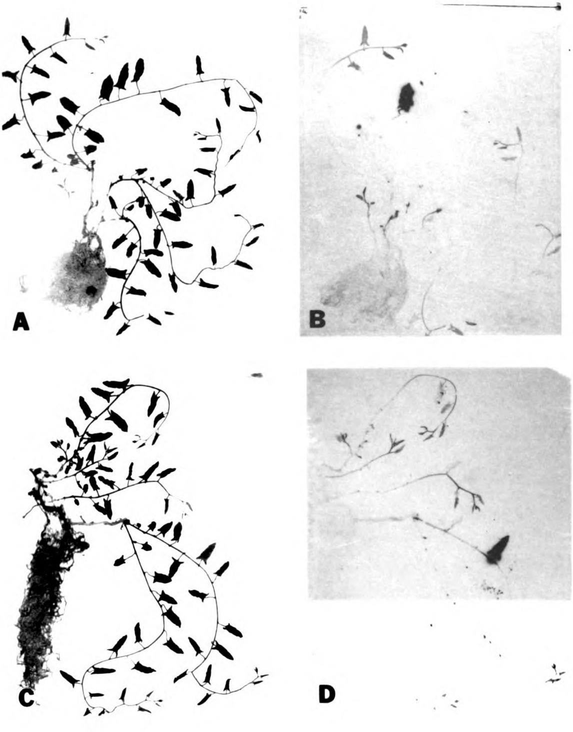

A
B
C
D

Figure 2. Translocation of ^{14}C-glyphosate in hedge bindweed 18 to 20 cm in length. The treated plant (A) and corresponding radioautograph (B) of hedge bindweed harvested 3 days after treatment. The treated plant (C) and corresponding radioautograph (D) of hedge bindweed harvested 14 days after treatment. The treated leaf is marked with an arrow.

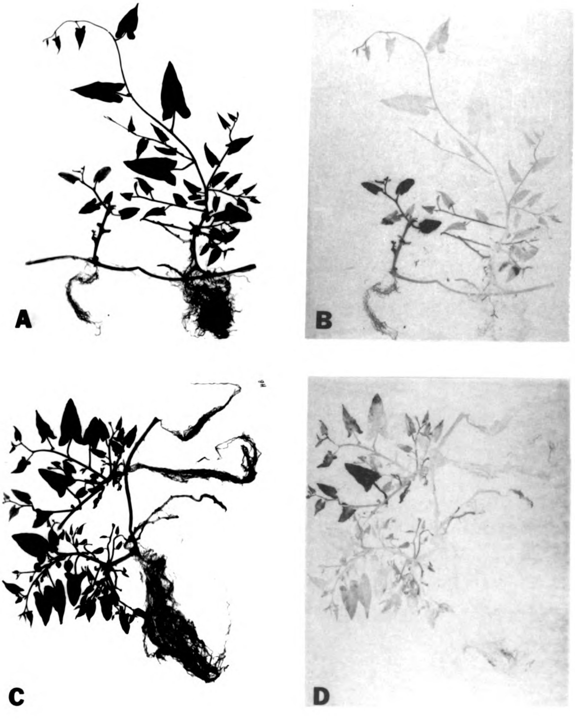

A
B
C
D

Figure 3. Translocation of ^{14}C-glyphosate in Canada thistle 14 to 18 cm tall. The treated plant (A) and corresponding radioautograph (B) of Canada thistle harvested 3 days after treatment. The treated plant (C) and corresponding radioautograph (C) of Canada thistle harvested 14 days after treatment. The treated leaf is marked with an arrow.

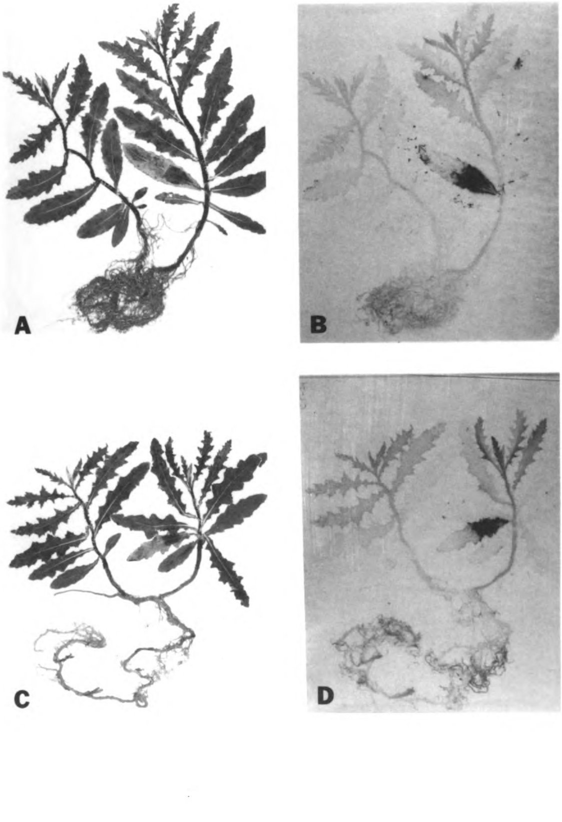


Figure 4. Translocation of ^{14}C-glyphosate in tall morningglory 12 to 14 cm tall. The treated plant (A) and corresponding radioautograph (B) of tall morningglory harvested 3 days after treatment. The treated plant (C) and corresponding radioautograph (C) of tall morningglory harvested 14 days after treatment. The treated leaf is marked with an arrow.

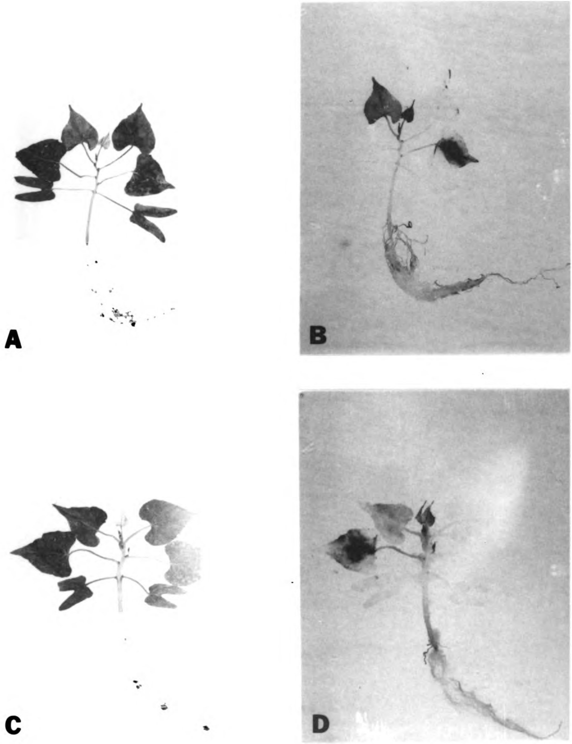

A
B
C
D

Figure 5. Translocation of ^{14}C-glyphosate in wild buckwheat 16 to 18 cm tall. The treated plant (A) and corresponding radio-autograph (B) of wild buckwheat harvested 3 days after treatment. The treated plant (C) and corresponding radio-autograph (C) of wild buckwheat harvested 14 days after treatment. The treated leaf is marked with an arrow.

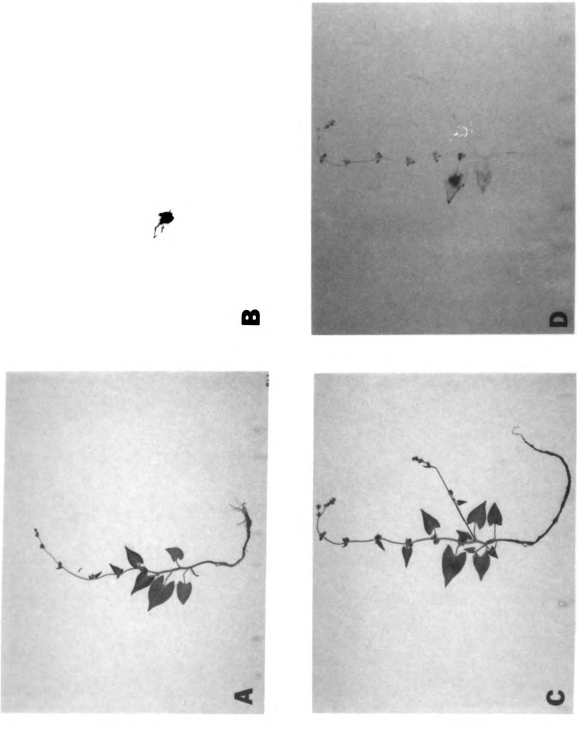

A
B
C
D

Figure 6. Location of ^{14}C-glyphosate in field bindweed stems harvested 3 days after treatment. Treated plant (A) and corresponding radioautograph (B) of a stem longitudinal section. Treated plant (C) and corresponding radioautograph (C) of a stem cross section.

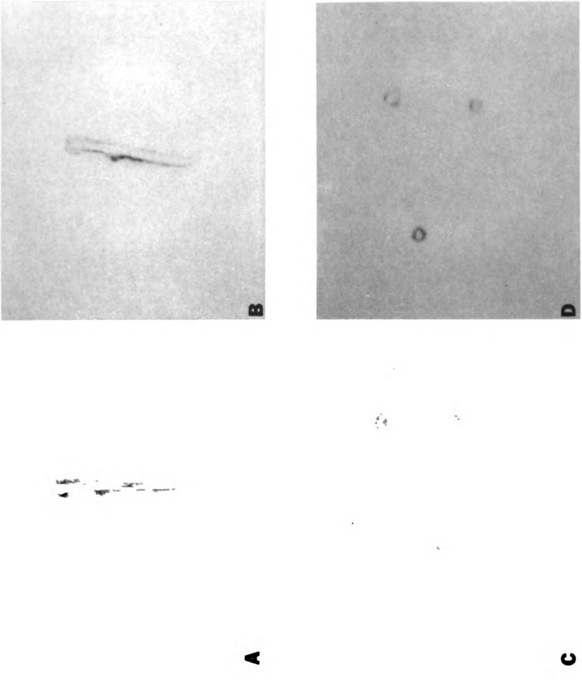


Figure 7. Location of ^{14}C-glyphosate in field bindweed roots harvested 3 days after treatment. Treated plant (A) and corresponding radioautograph (B) of a roots longitudinal section. Treated plant (C) and corresponding radioautograph (C) of a stem cross section.

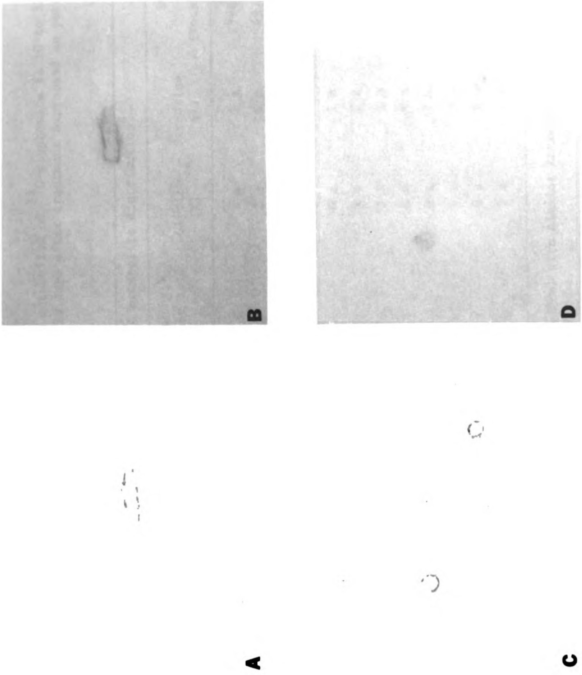

B
D
A
C

Table 3. The effect of time and plant organs on the metabolism of ^{14}C-glyphosate in 10 to 12 cm length field bindweed harvested 3, 7, and 30 days after treatment expressed as percent of total ^{14}C in each plant part

Time after treatment (days)	Plant parts	^{14}C metabolite distribution[a]				
		Glyphosate (%)	Aminomethyl-phosphonic acid (%)	Glycine (%)	Sarcosine (%)	^{14}C (Total DPM)
3	Treated leaf	94 fg	4 a	1 a	1 a	276865 c
	Parent	91 f	4 a	2 a	3 a	49725 ab
	Root	78 cd	7 a	7 a	8 a	4053 a
	Daughter	69 b	11 a	10 a	10 a	3720 a
7	Treated leaf	97 g	2 a	0 a	1 a	222613 b
	Parent	93 f	4 a	1 a	2 a	64896 ab
	Root	85 e	7 a	5 a	3 a	6583 ab
	Daughter	72 bc	11 a	8 a	9 a	8435 ab
30	Treated leaf	92 f	6 a	0 a	2 a	179592 b
	Parent	85 e	8 a	4 a	3 a	91069 ab
	Root	81 de	7 a	6 a	6 a	4326 a
	Daughter	83 de	6 a	5 a	6 a	34131 ab

[a]Means within a parameter (percent of total or total DPM) with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 4. The effect of time and plant organs on the metabolism of ^{14}C-glyphosate in 10 to 12 cm length Canada thistle harvested 3, 7, and 30 days after treatment expressed as percent of total ^{14}C in each plant part

Time after treatment (days)	Plant parts	^{14}C metabolite distribution[a]				
		Glyphosate (%)	Aminomethyl-phosphonic acid (%)	Glycine (%)	Sarcosine (%)	^{14}C (Total DPM)
3	Treated leaf	97 h	2 a	0.6 a	0.4 a	392195 f
	Parent	91 e-g	2 a	3 a	4 a	7495 ab
	Root	92 e-g	2 a	4 a	2 a	9229 ab
	Daughter	75 c	8 ab	8 ab	8 ab	5935 a
7	Treated leaf	89 d-f	6 ab	4 a	1 a	148796 e
	Parent	95 gh	3 a	1 a	1 a	25592 d
	Root	93 fg	3 a	2 a	2 a	19496 cd
	Daughter	86 d	10 b	2 a	2 a	8736 ab
30	Treated leaf	89 d-f	4 a	4 a	3 a	27072 d
	Parent	91 e-g	3 a	3 a	3 a	17599 b-d
	Root	94 gh	2 a	2 a	2 a	15678 abc
	Daughter	93 eg	3 a	2 a	2 a	23387 d

[a]Means within a parameter (percent of total or total DPM) with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

Table 5. The effect of time and plant organs on the metabolism of ^{14}C-glyphosate in 10 to 12 cm length tall morningglory harvested 1, 7, and 21 days after treatment expressed as percent of total ^{14}C in each plant part

Time after treatment (days)	Plant parts	^{14}C metabolite distribution[a]				
		Glyphosate (%)	Aminomethyl-phosphonic acid (%)	Glycine (%)	Sarcosine (%)	^{14}C (Total DPM)
1	Treated leaf	88 cd	7 a	3 a	2 a	392298 e
	Above	95 f	3 a	1 a	1 a	2085 a
	Below	89 c-e	7 a	1 a	3 a	1974 a
	Root	79 b	11 a	4 a	6 a	4812 ab
7	Treated leaf	88 cd	6 a	2 a	4 a	167973 d
	Above	88 cd	6 a	2 a	4 a	6669 b
	Below	84 bc	10 a	3 a	3 a	3654 a
	Root	89 cd	6 a	2 a	3 a	6533 b
21	Treated leaf	93 ef	4 a	1 a	2 a	88659 c
	Above	86 cd	6 a	3 a	5 a	5520 ab
	Below	91 de	4 a	2 a	3 a	3211 a
	Root	89 cd	4 a	5 a	2 a	8894 b

[a]Means within a parameter (percent of total or total DPM) with similar letters are not significantly different at the 5% level by Duncan's multiple range test.

extraction precipitate or insoluble residue indicated negligible accumulation of ^{14}C in that fraction. In search of an explanation, excised field bindweed and tall morningglory leaves received foliar applications of ^{14}C-glyphosate and the loss of ^{14}C was monitored. No loss was evident for 2 days (Table 6). However, from 3 to 25 days after treatment the leaves of field bindweed and tall morningglory lost 47 and 43 percent of the ^{14}C applied, respectively.

Since these were excised leaves, absorption and translocation could not account for the loss. The rate of loss was similar to that observed in soil for the conversion of ^{14}C-glyphosate to $^{14}CO_2$ (9, 11, 12, 14). The action of microbial organism on the leaf may account for this loss, however, metabolism of ^{14}C-glyphosate to a volatile ^{14}C-labeled metabolite, perhaps but not necessarily CO_2, by the excised leaves cannot be discounted. The loss of ^{14}C from the excised leaves of the two species was very similar (Table 6), whereas the loss of ^{14}C from the treated leaves on the intact plant was more pronounced for tall morningglory and Canada thistle than for field bindweed (Tables 3, 4, and 5). Differences in leaf area treated or differences in metabolism may account for the observed differences among species in the loss of ^{14}C.

In conclusion, differences in absorption and translocation appear associated with variability in glyphosate efficacy. Furthermore, greater basipetal translocation could be achieved if translocation were allowed to proceed for more than 3 days in Canada thistle and wild buckwheat. In Canada thistle control, this could be of significance in tillage operations.

Table 6. The loss of ^{14}C-glyphosate from treated leaves of field bindweed and tall morningglory detached from plants at time of treatment

Time	Total ^{14}C [a]	
	Field bindweed (DPM/treated leaf)	Tall morningglory (DPM/treated leaf)
0 hr	570612 de	571304 de
1 hr	585711 e	584650 e
6 hr	581667 de	580659 de
12 hr	586772 de	586634 de
1 day	559201 d	559180 d
2 days	617703 de	617669 de
3 days	485219 c	487274 c
11 days	417899 b	416308 b
18 days	395615 b	393676 b
25 days	323113 a	329598 a

[a]Means, within a column, followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

Literature Cited

1. Baird, D. D., N. J. Shaulis, and C. G. Waywell. 1974. Glyphosate for herbaceous perennial weed control in northeastern apple orchards and vineyards. Proc. N. E. Weed Sci. Soc. 28:205-212.

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

3. Behrens, R. and M. Elakkad. 1972. Quackgrass control with glyphosate. Proc. North Centr. Weed Contr. Conf. 27:54.

4. Claus, J. S. and R. Behrens. Gluphosate translocation and quackgrass rhizome bud kill. Weed Science. 24:149-452.

5. Davison, J. C. 1972. The response of 21 perennial weed species to glyphosate. Proc. Brit. Weed Contr. Conf. 1:11-16.

6. Hemphill, D. D., R. L. Baumgartner, and A. D. Hibbard. 1975. Control of weeds in orchards and vineyards with glyphosate. Weed Sci. Soc. Amer. Abstr. p. 14.

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

8. Putnam, A. R., A. P. Love, and G. Pagano. 1974. Response of deciduous fruit trees and several orchard weeds to glyphosate. Weed Sci. Soc. Amer. Abstr. p. 116.

9. Rieck, C. W., T. H. Wright, and T. R. Harger. 1974. Fate of glyphosate in soil. Weed Sci. Soc. Amer. Abstr. p. 119.

10. Rueppel, M. L., J. T. Marvel, and B. B. Brightwell. 1975. The metabolism and dissipation of N-phosphonomethyl glycine in soil and water. Amer. Chem. Soc. Div. Pesticide Chem. Abstr. p. 8.

11. Rueppel, M. L., J. T. Marvel, and L. A. Suba. 1975. The metabolism of N-phosphonomethylglycine in corn, cotton, soybeans, and wheat.

12. Sprankle, P., W. F. Meggitt, and D. Penner. 1972. Adsorption, mobility and microbial degradation of glyphosate in the soil. Weed Sci. 23:229-234.

13. Sprankle, P., W. F. Meggitt, and D. Penner. 1972. Adsorption, action and translocation of glyphosate. Weed Sci. 23:235-240.

14. Sprankle, P., W. F. Meggitt, and D. Penner. 1974. Adsorption and metabolism of glyphosate in the soil. Weed Sci. Soc. Amer. Abstr. p. 119.

15. Sprankle, P., C. L. Sandberg, W. F. Meggitt, and D. Penner. Separation of glyphosate and several possible metabolites by thin-layer chromatography. Weed Sci. (Submitted).

16. Stoller, E. W., and L. M. Wax. 1972. Response of yellow nutsedge to bentazon, glyphosate, and MBR 8251. Proc. North Centr. Weed Contr. Conf. 27:55.

17. Wang, C. H., and D. L. Willis. 1965. Radiotracer methodology in biological science. Prentice Hall, Inc., Englewood, N.J. p. 363.

18. Wyrill, J. B., III, and O. C. Burnside. 1976. Adsorption, translocation, and metabolism of 2, 4-D and glyphosate in common mildweed and hemp dogbane. Weed Sci. 24:557-566.

CHAPTER 5

SUMMARY AND CONCLUSIONS

Studies were initiated in the field, greenhouse, and laboratory to evaluate the activity of glyphosate on field bindweed and to determine herbicide and management practices which provide effective control of field bindweed, to establish the effects of diluent volume and calcium on glyphosate phytotoxicity, and to study absorption, translocation, and metabolism of glyphosate.

In the field, foliar application of glyphosate at rates of 1.12 kg/ha and greater, treated from flower bud stage in the spring to late fall, provided effective field bindweed control. A single application of glyphosate provided satisfactory control for two growing seasons, after which additional glyphosate treatments were required at similar intervals to establish continual control. Glyphosate did not completely kill roots and rhizomes of field bindweed, but, growth of these underground organs was inhibited for 2 or 3 seasons. Tillage prior to application of glyphosate reduced the control obtained. For example, tillage in the fall and/or spring rendered June treatments inactive. Tillage after treatment increased control of glyphosate only when the control obtained from glyphosate was marginal.

Glyphosate phytotoxicity was decreased when diluent volumes were increased above 190 L/ha because of runoff and inactivation by calcium in the water. Runoff, calcium, and their interaction, all contributed to decreased performance by themselves as well as interacting. As an example, as diluent folume increased the concentration of calcium per unit of glyphosate increased. Even a small amount of calcium decreased effectiveness at high diluent volumes, however, at low volumes 190 L/ha and lower, calcium did not become a factor except at exaggerated levels.

Absorbance of chemicals is usually the evaluation of the amount of the applied material which enters the treated leaf. In perennial weed studies it is important to determine how much material actually leaves the treated leaf and is translocated in the plant. Only a small fraction of the applied glyphosate was absorbed and translocated, 3 to 21 percent depending on the species, with little absorption and translocation occurring after 3 days. The greatest concentration of glyphosate was located in the meristimatic regions of roots and shoots in both the parent and daughter plants. This may help to account for the inhibition of root growth instead of complete kill of the root of field bindweed. The phloem in roots appears to act as a conduit for glyphosate to meristimatic regions, with accumulation in these areas and very little accumulation in the root. The concentration in the root is not high enough to kill the root, therefore, inhibition of growth occurs until the concentration of glyphosate in the root is decreased enough to allow normal growth. The concentration of glyphosate in the root may be decreased as new buds are produced on the root and glyphosate is translocated to these buds.

Glyphosate appears to be a very stable material once in the plant with only 15 percent of the parent compound metabolized within 30 days, the major metabolite being AMP. As much as 50 percent of the applied glyphosate which is not absorbed in lost within 25 days from the treated leaf. Microbial breakdown of glyphosate to CO_2 in the soil occurs at approximately the same rate, therefore, this loss is probably due to microbial activity on the surface of the leaf.

LIST OF REFERENCES

LIST OF REFERENCES

1. Addison, D. A., J. C. Walker, and W. R. Arnold. 1974. Trifluralin applied as a subsurface layer for perennial weed control in the southwest. Proc. South. Weed Sci. Soc. 27:155-160.

2. Agbakoba, Chuma S.O. and J. R. Goodin. 1969. Effect of stage of growth of field bindweed on absorption and translocation of ^{14}C-labeled 2,4-D and picloram. Weed Sci. 17:436-438.

3. Agbakoba, Chuma S. O. and J. R. Goodin. 1970. Absorption and translocation of ^{14}C-labeled 2,4-D and picloram in field bindweed. Weed Sci. 18: 168-170.

4. Agbakoba, Chuma S. O. and J. R. Goodin. 1970. Picloram inhances 2,4-D movement in field bindweed. Weed Sci. 18:19-21.

5. Baird, D. D. and G. F. Begeman. 1972. Postemergence characterization of a new quackgrass herbicide. Proc. N. E. Weed Sci. Soc. 26:100-106.

6. Baird, D. D., S. C. Phytak, R. P. Upchurch, and G. F. Begeman. 1972. Glyphosate activity on quackgrass as influenced by mowing and rhizome density. Proc. N. E. Weed Sci. Soc. 27:13-20.

7. Baird, D. D., N. J. Shaulis, and C. G. Waywell. 1974. Glyphosate for herbaceous perennial weed control in northeastern apple orchards and vineyards. Proc. N. E. Weed Sci. Soc. 28:205-212.

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

9. Bakke, A. L. 1939. Experiments on control of European bindweed (Convolvulus arvensis L.) Agr. Exp. Sta., Iowa State Coll. Agric. Res. Bull.

10. Bakke, A. L. 1944. Control and eradication of European bindweed. Iowas State Coll. of Agric. Exp. Sta. Bull. P61. pp. 937-960.

11. Bakke, A. L., W. G. Gaessler, L. M. Pats and S. C. Salmon. 1944. Relation of cultivation and depletion of root reserves in European bindweed at different soil horizons. J. Agric. Res. 69:137-147.

12. Barr, C. G. 1940. Organic reserves in roots of bindweed. J. Agric. Res. 60:391-413.

13. Behrens, R. and M. Elakkad. 1972. Quackgrass control with glyphosate. Proc. North Centr. Weed Contr. Conf. 27:54.

14. Best, K. F. 1963. Note on the extent of lateral spread of field bindweed. Can. J. Plant Sci. 43:230-232.

15. Bioletti, F. T. 1911. The extermination of morningglory. Univ. Calif. Coll. of Agric. Circ. No. 69. pp. 1-12.

16. Blair, A. M. 1975. The addition of ammonium salts or phosphate ester to herbicides to control Agropyron repens (L.) Beauv. Weed Res. 15:101-105.

17. Brown, E. O. and R. H. Proter. 1942. The viability and germination of seeds of Convolvulus arvensis L. and other perennial weeds. Iowa State Agric. Exp. Sta. Bull. 294. pp. 473-504.

18. Call, L. E. and R. E. Getty. 1923. The eradication of bindweed. Kansas Agric. Exp. Sta. Cir. 101.

19. Claus, J. S. and R. Behrens. 1975. Glyphosate translocation and quackgrass rhizome bud kill. Weed Sci. 24:149-152.

20. Cox, H. R. 1908. The eradication of bindweed or wild morning-glory. USDA Farmers Bull. 368.

21. Davison, J. C. 1972. The response of 21 perennial weed species to glyphosate. Proc. Brit. Weed Contr. Conf. 10:11-16.

22. Davison, J. G. and J. A. Bailey. 1974. The response of Convolvulus arvensis (bindweed) to 2,4-D, MCPA, MCPB, Dichloroprop, Mecoprop, 2,4,5-T, Dicamba, and Glyphosate at various doses and application dates. Proc. Brit. Weed Contr. Conf. 12:641-648.

23. Derscheid, L. A., J. K. Stritzke, and W. G. Wright. 1970. Field bindweed control with cultivation, cropping, and chemicals. Weed Sci. 18:590-596.

24. Derscheid, L. A., and K. E. Wallace. 1959. Control and elimination of field bindweed. South Dakota Exp. Sta. Circ. 146. pp. 1-4.

25. Fischer, B. B., A. H. Lange, D. M. May, and D. E. Johnson. 1974. Toward more effective bindweed control "A progress report." Univ. of Calif. Ext. pp. 1-31.

26. Fischer, B. B., F. H. Swanson, D. M. May, and A. H. Lange. 1976. Roundup review. Agrichemical Age, June 1976. pp. 16, 17, 21.

27. Frazier, J. C. 1943. Nature and rate of development of root systems of Convolvulus arvensis. Botan. Gaz. 104:417-425.

28. Frazier, J. C. 1948. Principal noxious perennial weeds of Kansas, with emphasis upon their root systems in relation to control. Kansas State Coll. Agric. Exp. Sta. Bull. 331. pp. 1-45.

29. Franzke, C. J. and A. N. Hume. 1936. Field bindweed and control methods for South Dakota. South Dakota Agr. Exp. Sta. Bull. 350.

30. Gebhardt, M. R. 1974. Post-directed applications of glyphosate for weed control in soybeans. Weed Sci. Soc. Amer. Abstr. p. 117.

31. Goodin, J. R., L. S. Jordon, and W. H. Isom. 1967. Low rates of tordon for field bindweed control. Down to Earth. 23:6-7.

32. Hamilton, W. D., A. H. Lange, C. L. Elmore. 1971. Field bindweed control in niveyards. Calif. Agric. 25:9-10.

33. Hance, R. J. 1976. Adsorption of Glyphosate by soils. Pestic. Sci. 7:363-366.

34. Hanson, C. L. and C. E. Rieck. 1976. The effect of iron and aluminum on glyphosate toxicity. Proc. South. Weed Sci. Soc. 29:49.

35. Harvey, R. G. and T. J. Muzik. 1973. Effects of 2,4-D and amino acids of field bindweed in vitro. Weed Sci. 21:135-138.

36. Harvey, W. A. 1965. Costs and losses from weed. Proc. 17th Calif. Weed Conf. 17:11-14.

37. Hemphill, D. D., R. L. Baumgartner, and A. D. Hibbard. 1975. Control of weeds in orchards and vineyards with glyphosate. Weed Sci. Soc. Amer. Abstr. p. 14.

38. Higgins, R. E. 1967. Loss caused by noxious weeds in potatoes. Down to Earth. 23:2, 24.

39. Jaworski, E. G. 1972. Mode of action of (N-phosphonomethyl) glycine: inhibition of aromatic amino acid biosynthesis. J. Agric. Food Chem. 20:1195-1198.

40. Jones, I. B. and J. O. Evans. 1973. Control of Russian Knapweed and field bindweed with dicamba, 2,4-D, and their combinations with and without DMSO. Proc. West. Soc. Weed Sci. 26:39-43.

41. Kempen, H. M. 1972. A "Chemical Tarp" to control field bindweed. "A Progress Report" Univ. of Calif. Ext. pp. 1-3.

42. Kennedy, P. B. and A. S. Crafts. 1931. The anatomy of Convolvulus arvensis, wild morningglory or field bindweed. California Agric. Exp. Sta. (Hilgardia). 5:591-622.

43. Kiesselbach, T. A., N. F. Peterson, and W. W. Burr. 1934. Bindweeds and their control. Univ. Neb. Coll. of Agric. Exp. Sta. Bull. 287:1-47.

44. Kiesselbach, T. A., P. H. Stewart, and D. L. Gross. 1935. Bindweed eradication. Nebraska Exp. Sta. Circ. 50:1-8.

45. Kleifeld, Y. 1972. Control of annual weeds and Convolvulus arvensis L. in tomatoes by trifluralin. Weed Res. 12:384-388.

46. Kline, W. L. and G. W. Selleck. 1977. Effect of glyphosate applications on hedge bindweed. Proc. N. E. Weed Soc. 31:98.

47. Klingman, D. L. and J. J. Murray. 1976. Germination of seeds of turf grasses as affected by glyphosate and paraquat. Weed Sci. 24:191-193.

48. Lange, A. H., H. Agamaian, D. R. Donaldson, C. L. Elmore, W. D. Hamilton, O. A. Leonard, and H. M. Kemper. 1972. Bindweed control in niveyards. Agr. Ext. Univ. Calif. MA-41. pp. 1-13.

49. Lange, A. H., B. Fischer, H. Agamaliam, and H. Kempen. 1969. Weed control in young grapes. Calif. Agric. 23:11-12.

50. Lange, A. H., B. B. Fischer, C. L. Elmore, H. M. Kempen, and J. Schlesselman. 1975. Roundup--the end of perennial weeds in tree and vine crops? Calif. Agric. 29:6-7.

51. Leonard, O. A., D. E. Bayer, and R. J. Weaver. 1961. Results of tests using 2, 4-D in vineyards. Hormolog. 3:10-11.

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

53. Messersmith, C. G. 1972. Glyphosate for control of leafy spurge and other perennial weeds. Proc. N. Cent. Weed Contr. Conf. 27:55.

54. Mitch, L. W., B. L. Alley, and N. E. Harrington. 1962. Wyomings primary noxious weeds. Wyoming Agric. Exp. Sta. Bull. 394, pp. 1-40.

55. Neuruer, H. 1961. Weed which hinder combine harvesting. Pflanzenarzt. 14:61-63.

56. Ogg, A. J., Jr. 1975. Control of Canada thistle and field bindweed in asparagus. Weed Sci. 23:458-461.

57. Peters, R. A., W. M. Dest, and A. C. Triolo. 1974. Preliminary report on the effects of mixing liquid fertilizers and residual herbicides with paraquat and glyphosate. Proc. N. E. Weed Sci. Soc. 28:35-40.

58. Phillips, M. 1959. New chemicals to control field bindweed. Kansas Agric. Exp. Sta. Bull. 408. pp. 1-6.

59. Phillips, W. M. 1961. Control of field bindweed by cultural and chemical methods. Tech. Bull. 1249. USDA pp. 1-30.

60. Phillips, W. M. 1975. Glyphosate phytotoxicity as affected by carrier quality and application volume. Proc. N. Cent. Weed Contr. Conf. 30:115.

61. Phillips, W. M. and F. J. Timmons. 1954. Bindweed, how to control it. Kansas Agric. Exp. Sta. Bull. 366.

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

63. Putnam, A. R., A. P. Love, and G. Pagano. 1974. Response of deciduous fruit trees and several orchard weeds to glyphosate. Weed Sci. Soc. Amer. Abstr. p. 116.

64. Rieck, C. W., T. H. Wright, and T. R. Harger. 1974. Rate of glyphosate in soil. Weed Sci. Soc. Amer. Abstr. p. 119.

65. Riemer, D. M. 1973. Effects of rate, spray volume, and surfactant on the control of phragmites with glyphosate. Proc. N. E. Weed Sci. Soc. 27:101-104.

66. Roncoroni, E. J., C. L. Elmore, and A. H. Lange. 1976. Thin layering of herbicides for field bindweed control in established orchards and vineyards. Proc. West. Soc. Weed Sci. 29:195-201.

67. Rueppel, M. L., B. B. Brightwell, J. Schaefer, and J. T. Marvel. 1977. Metabolism and degradation of glyphosate in soil and water. J. Agric. Food Chem. 25:517-527.

68. Rueppel, M. L., J. T. Marvel, and B. B. Brightwell. 1975. The metabolism and dissipation of (N-phosphonomethyl)glycine in soil and water. Amer. Chem. Soc. Div. Pest. Chem. Abstr. p. 8.

69. Rueppel, M. L., J. T. Marvel, and L. A. Suba. 1975. The metabolism of N-phosphonomethyl glycine in corn, cotton, soybeans, and wheat.

70. Russ, O. G. and L. E. Anderson. 1960. Field bindweed control by conbinations of cropping, cultivation, and 2,4-D. Weeds 8:397-401.

71. Sandberg, C. L., W. F. Meggitt, and D. Penner. 1976. Can glyphosate control field bindweed. Proc. North Cent. Weed Contr. Conf. 31:93.

72. Sandberg, C. L., W. F. Meggitt, and D. Penner. 1976. Influence of spray volume and calcium on glyphosate phytotoxicity. Proc. North Cent. Weed Contr. Conf. 31:31.

73. Seeley, C. I. 1952. Controlling perennial weeds with tillage. Idaho, Agric. Exp. Sta. Bull. 288. pp. 3-29.

74. Seely, C. E., K. H. Klages, and E. G. Schafer. 1944. Bindweed control. Wash. Agric. Exp. Sta. Popular Bull. 176.

75. Selleck, G. W. 1975. Antagonistic effects with glyphosate herbicide plus residual herbicide combinations. Proc. N. E. Weed Sci. Soc. 29:327.

76. Selleck. G. W., T. Zabadal, and S. M. McCargo. 1975. Glyphosate for weed control in vineyards. Proc. N. E. Weed Sci. Soc. 29:237-238.

77. Sprankle, P., W. F. Meggitt, and D. Penner. 1972. Adsorption, mobility, and microbial degradation of glyphosate in the soil. Weed Sci. 23:229-234.

78. Sprankle, P., W. F. Meggitt, and D. Penner. 1972. Absorption, action, and translocation of glyphosate. Weed Sci. 23:235-240.

79. Sprankle, P., W. F. Meggitt, and D. Penner. 1974. Adsorption and metabolism of glyphosate in the soil. Weed Sci. Soc. Amer. Abstr. p. 119.

80. Sripleng, A. and F. H. Smith. 1960. Anatomy of the seed of Convolvulus arvensis. Amer. J. of Bot. 47:386-393.

81. Stewart, G. and D. W. Pittman. 1924. Ridding the land of wild morningglory. Utah Agric. Exp. Sta. Bull. 189. pp. 1-30.

82. Stoller, E. W. and L. M. Wax. 1972. Response of yellow nutsedge to bentazon, glyphosate, and MBR 8251. Proc. North Cent. Weed Contr. Conf. 27:55.

83. Sylwester, E. P. 1947. Soybeans as a smother crop for European bindweed. Iowa State Coll. Agric. Bull.

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

85. Timmons, F. L. 1941. Results if bindweed control experiments at the Fort Hays Branch Station, Hays, Kansas, 1935 to 1940. Kansas Agric. Exp. Sta. Bull. 296. pp. 3-50.

86. Timmons, F. L. and V. F. Bruns. 1951. Frequency and depth of shoot-cutting in eradication of certain creeping perennial weeds. Agr. J. 43:371-375.

87. Turner, D. J. and M. P. C. Loader. 1975. Further studies with additives: effects of phosphate esters and ammonium salts on the activity of leaf-applied herbicides. Pestic. Sci. 6:1-10.

88. Warner, L. C. 1973. Subsurface layering of trifluralin with a mold-board plow for field bindweed control. Proc. West. Soc. Weed Sci. 26:27-29.

89. Whitworth, J. W. 1964. The reaction of strains of field bindweed to 2, 4-D. Weeds 12:57-58.

90. Whitworth, J. W. and T. J. Muzik. 1967. Differential response of selected clones of bindweed to 2,4-D. Weeds 15:275-280.

91. Wiese, A. F. 1969. Perennial weed control in northwest Texas. Texas Agr. Exp. Sta. MP-828. pp. 1-4.

92. Wiese, A. F. 1971. Monuron and other soil sterilants for controlling small patches of perennial weeds. Texas Agric. Exp. Sta. MP-1002. pp. 1-7

93. Wiese, A. F. 1976. Glyphosate on perennial weeds. Proc. South. Weed Sci. Soc. 29:88-93.

94. Wiese, A. F. and W. M. Phillips. 1976. Field bindweed. Weeds Today. 7:22-23.

95. Wiese, A. F. and H. E. Rea. 1955. Bindweed control in the panhandle of Texas. Texas Agric. Exp. Sta. Bull. 802. pp. 3-8.

96. Wiese, A. F. and H. E. Rea. 1957. Bindweed control with new soil sterilants. Texas Agr. Exp. Sta. Prog. Report 1954. pp. 1-2.

97. Wiese, A. F. and H. E. Rea. 1959. Bindweed (<u>Convolvulus arvensis</u> L.) control and seedling emergence as affected by tillage, 2,4-D, and competitive crops. Agron. J. 51:672-675.

98. Wiese, A. F. and H. E. Rea. 1960. Field bindweed (<u>Convolvulus</u> arvensis L.) control with soil applications of phenoxy herbicides. Weeds 8:418-421.

99. Wiese, A. F. and H. E. Rea. 1962. Factors affecting the toxicity of phenoxy herbicides to field bindwwed. Weeds. 10:58-62.

100. Wills, G. D. 1973. Effects of inorganic salts on the toxicity of glyphosate to purple nutsedge. Abstr. Weed Sci. Soc. Amer. p. 59.

101. Wills, G. D. 1973. Toxicity of glyphosate to purple nutsedge as affected by surfactant, K_2CO_3, and diluent volume. Proc. South. Weed Sci. Soc. 26:408-412.

102. Withycombe, R. 1911-12. Report of the Department of Agronomy. Oregon Agric. Exp. Sta. Report East, Oregon Station.

103. Wyrill, J. B., III, and O. C. Burnside. 1976. Adsorption, translocation, and metabolism of 2,4-D and glyphosate in common milkweed and hemp dogbane. Weed Sci. 24:557-566.

APPENDICES

APPENDIX A

Modified No. 1 Hoagland's Solution

1.	1 M KH_2PO_4	2 ml/L
2.	1 M KNO_3	2 ml/L
3.	1 M $Ca(NO_3)_2 \cdot 4H_2O$	3 ml/L
4.	1 M $MgSO_4 \cdot 7H_2O$	2 ml/L
5.	1.5 g/L $MnCl_3 \cdot 4H_2O$	
	2.5 g/L H_3BO_4	
	0.1 g/L $ZnCl_2$	1 ml/L
	0.05 g/L $CuCl_2 \cdot 2H_2O$	
	0.05 g/L MoO_3	
6.	26.3 g/L Sequestrene	1 ml/L
	pH 6.5 to 6.8 with 1 M NaOH	

APPENDIX B

Table B-1. The effect of glyphosate on flower bud initiation in tall morningglory

Treatment	Rate (kg/ha)	Flower[a] Buds/plant
Glyphosate	0.22	48.5 d
	0.56	24.2 c
	0.78	9.9 ab
	1.12	8.7 a
	1.68	0.2 a
No treatment	0.0	49.7 d

[a]Means followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

APPENDIX C

Table C-1. The effect of Glyphosate on vegetative bud initiation in annual morningglory

Treatment	Rate (kg/ha)	Vegetative Buds/Plant
Glyphosate	0.22	0.3 a
	0.56	5.8 abc
	0.78	25.2 de
	1.12	15.7 cd
	1.68	0.0 a
No treatment	0.0	0.0 a

[a]Means followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

APPENDIX D

Table D-1. The effect of glyphosate on vegetative bud initiation in hedge bindweed

Treatment	Rate (kg/ha)	Vegetative Buds/plant
Glyphosate	0.22	39.2 ab
	0.56	96.2 cd
	0.78	111.8 d
	1.12	175.2 e
	1.68	77.3 bcd
No treatment	0.0	0.0 a

[a]Means followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

APPENDIX E

Table E-1. The effect of glyphosate on fresh weight of annual morningglory 39 days after treatment

Treatment	Rate (Kg/ha)	Fresh weight[a] (grams/plant)
Glyphosate	0.22	17.0 abcd
	0.56	18.6 cd
	0.78	20.4 d
	1.12	15.3 abc
	1.68	14.2 ab
No treatment	0.0	15.9 abc

[a]Means followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

APPENDIX F

Table F-1. The effect of glyphosate on fresh weight of wild buckwheat 22 days after treatment

Treatment	Rate (kg/ha)	Fresh weight[a] (Grams/plant)
Glyphosate	0.22	22.8 abc
	0.56	27.6 c
	0.78	24.8 bc
	1.12	21.7 ab
	1.68	17.9 a
No treatment	0.0	20.6 ab

[a]Means followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

APPENDIX G

Table G-1. The effect of glyphosate on fresh weight of field bindweed harvested 28 and 40 days after treatment

Treatment	Rate (kg/ha)	Grams/plant[a] 28 days	40 days
Glyphosate	0.22	78.4 c	26.7 d
	0.56	72.4 c	19.9 cd
	0.78	32.8 a	12.5 bc
	1.12	34.2 a	1.6 a
	1.68	56.2 abc	6.3 ab
No treatment	0.0	68.0 bc	20.2 cd

[a]Means within a column followed by the same letter are not significantly different at the 5% level by Duncan's multiple rang test.

APPENDIX H

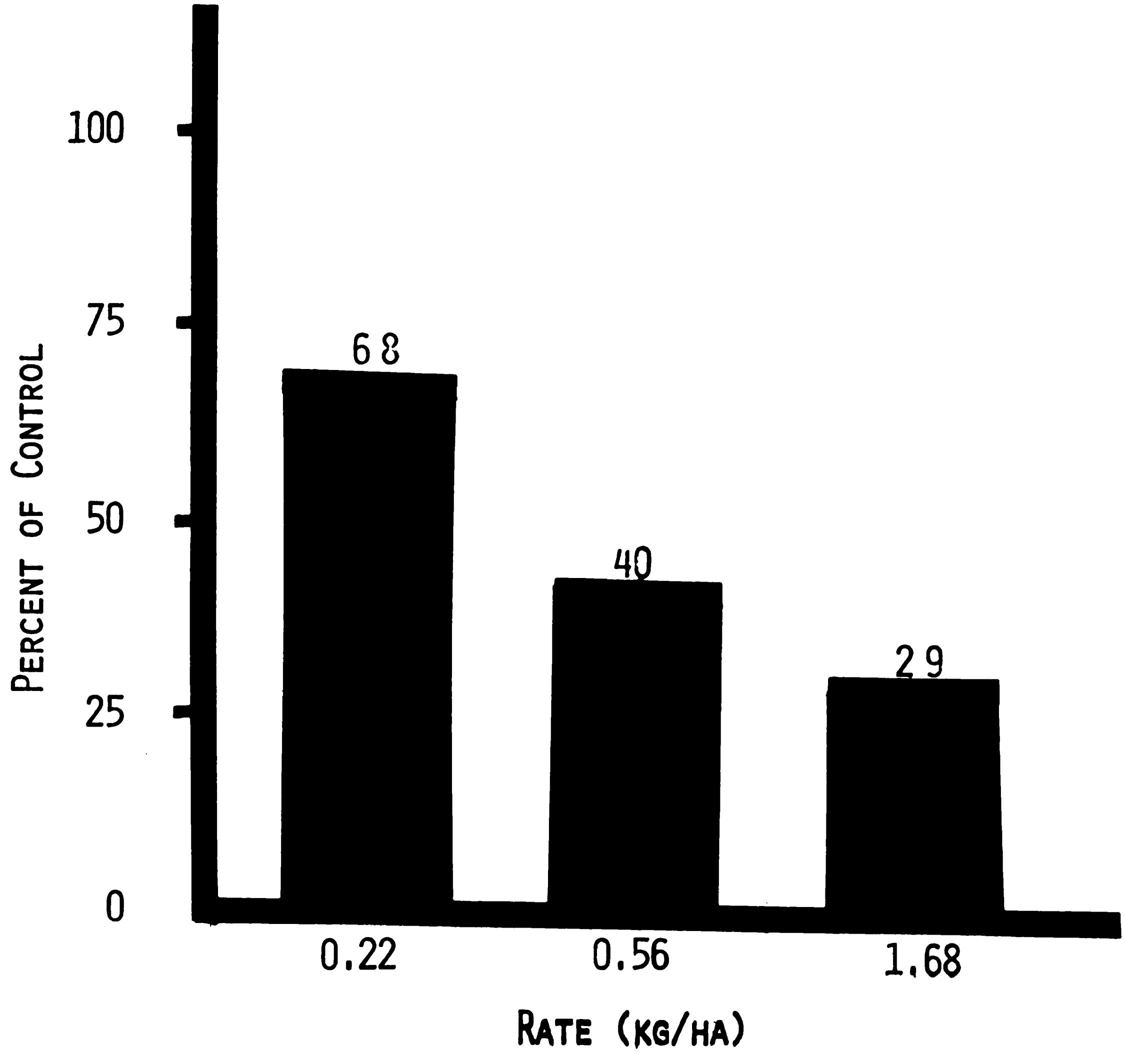
Table H-1. The effect of glyphosate on fresh weight of hedge bindweed 29 days after treatment

Treatment	Rate (kg/ha)	Fresh weight[a] (grams/plant)
Glyphosate	0.22	47.8 cd
	0.56	35.4 abcd
	0.78	40.5 bcd
	1.12	31.9 abc
	1.68	25.7 ab
No treatment	0.0	43.3 cd

[a]Means followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

APPENDIX I

FIGURE I-1. THE EFFECT OF GLYPHOSATE ON SHOOT GROWTH IN ANNUAL MORNINGGLORY 15 DAYS AFTER TREATMENT



APPENDIX J

Table J-1. The antagonistic effect of 2,4-D on glyphosate activity on tall morningglory

Rate (kg/ha)	Plant viability
0.78	Alive
1.12	Dead
1.68	Dead
0.78 + 2,4-D	Alive
1.12 + 2,4-D	Alive
1.68 + 2,4-D	Alive

APPENDIX K

Chemical and Physical Properties of Glyphosate

Molecular formula: $C_3H_8NO_5P$

Structure:

```
   O            O
   ‖            ‖
HO-C-CH2-NH-CH2-P-OH
                |
                OH
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Weight: 169.1

Physical State, Color and Odor: Solid, White, Odorless

Density: 0.5 gm/cc

Vapor Pressure: Negligible

Solubility;

Solvent	Temperature	Solubility
Water	25 C	1.2
Other solvents		None