

THE INFLUENCE OF OIL AND
ENVIRONMENTAL FACTORS ON
PHYTOTOXICITY AND FOLIAR
PENETRATION OF 2-CHLORO-
4-ETHYLAMINO-6-ISOPROPYLAMINO-
S-TRIAZINE (ATRAZINE)

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2-Chloro-4-Ethylamino-6-Isopropylamino-5-Triazine
(Atrazine)

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William F. Meggett
Major professor

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ABSTRACT

THE INFLUENCE OF OIL AND ENVIRONMENTAL FACTORS ON PHYTOTOXICITY AND FOLIAR PENETRATION OF 2-CHLORO-4-ETHYLAMINO-6-ISOPROPYLAMINO- S-TRIAZINE (ATRAZINE)

By

John W. Schrader

The performance of 2-chloro-4-ethylamino-6-isopropyl-s-triazine (atrazine) as a postemergence treatment for selective weed control in corn (Zea mays L.) has been quite erratic and much controversy exists among researchers concerning this unpredictable performance. Atrazine will penetrate the leaf surface of plants but the amount is usually quite small and often insufficient to control weeds without supplemental root uptake.

Experiments were designed to evaluate the performance of atrazine-oil combinations as postemergence treatments for full-season weed control, to determine the extent of foliar penetration and translocation of atrazine, and to determine what factors affect phytotoxicity and foliar penetration of atrazine.

Weed control evaluation trials with postemergence treatments of atrazine and atrazine-oil were very effective for control of broadleaved weeds and annual grasses when applied at the early stage of growth. Control was

significantly reduced when treatments were applied at a later stage of growth. Weed control from treatments with oil were superior to the treatments without oil.

No significant differences were found between morning vs evening spraying for broadleaf or annual grass control. However, morning spraying was superior to evening spraying for nutsedge (Cyperus esculentus L.) control. Treatments applied in split applications were very effective for nutsedge control, giving over 90% control with 2.0 lb/A atrazine plus oil.

Corn yields were reduced when treatments were delayed until a later stage of weed growth. Yield reductions were due primarily to weed competition since no corn injury was observed.

Controlled environment studies revealed that environmental factors greatly affect the phytotoxicity of post-emergence atrazine. Atrazine was more phytotoxic to yellow foxtail (Setaria glauca (L.) Beauv.) in the high temperature regime than in the two lower regimes. Oil enhanced phytotoxicity at all atrazine levels.

Soil moisture stress significantly affected phytotoxicity from foliar-applied atrazine, decreasing from high to low soil moisture. Phytotoxicity was greater at the high moisture level when spray applications were applied to both soil and foliage. This would indicate that a considerable amount of root uptake of atrazine occurred which complemented foliar penetration and thus increased phytotoxicity.

Autoradiographs showed that foliar-applied ^{14}C -atrazine moved exclusively in the acropetal direction. Foliar penetration and translocation of atrazine was apparent after 30 min and continued to increase with time.

The extent of foliar penetration and translocation was determined by treating an area on the lower portion of the leaf with ^{14}C -atrazine. After a given period of time, the ^{14}C -activity in the leaf section was determined by the Schoniger oxygen combustion technique.

Foliar penetration of atrazine progressively increased with increased temperature and humidity levels. Soil moisture stress decreased penetration. Oil-water emulsions consistently enhanced penetration of atrazine. X-77 enhanced penetration but to a lesser degree.

Penetration was greatly enhanced when leaf surfaces were conditioned with oil-water emulsions before and after atrazine application. Rewetting leaf surfaces with water after the atrazine was applied was also effective for increasing atrazine penetration. The rewetting probably redissolved the atrazine crystals on the leaf surface and allowed for more penetration.

In addition to the spreader effect, the oil-water emulsions doubled penetration of atrazine per unit area of leaf surface. Treatments applied to upper and lower surfaces of corn leaves revealed that more atrazine penetrated the lower surface.

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INTRODUCTION

The advent of chemical weed control has greatly eased man's endless struggle to eliminate competition by undesirable plants from those species which he wishes to cultivate. Of the many herbicides available today, 2-chloro-4-ethylamino-6-isopropylamino-s-triazine (atrazine) is one of the most widely used for selective weed control in corn (Zea mays L.). The potential of this herbicide has not been fully realized because of inefficient methods of getting the chemical into the weeds. Susceptible weeds occasionally escape soil applied atrazine because soil moisture or other soil conditions are such that a barrier is placed between the weeds and the chemical.

Postemergence herbicide activity of atrazine has been known since its introduction, but the chemical was not used extensively in this manner until it was found that adding a non-phytotoxic oil or surfactant enhanced phytotoxicity. The plant foliage presents a serious barrier to atrazine absorption. While some atrazine will penetrate the leaf surface, this amount is usually quite small and often not sufficient to control the weed unless supplemental root uptake occurs.

Most foliar-applied herbicides are effective because they are absorbed and translocated by the plant. While atrazine will move upward in a leaf, it does not appear to move downward out of the treated leaf. Foy (1964) examined five plant species and found that basipetal translocation of foliar-absorbed atrazine and five other foliar-applied s-triazine herbicides was negligible in all cases. Wax and Behrens (1965) reported that almost all movement of foliar-absorbed atrazine in quackgrass (Agropyron repens (L.) Beauv.) was acropetal. Thus, for foliar-applied atrazine to be effective the spray coverage must be complete and absorption quite rapid.

The performance of atrazine as a postemergence treatment has been quite erratic and much controversy exists among researchers concerning this unpredictable performance. The objectives of this study were: (1) to evaluate the performance of atrazine-oil combinations as postemergence treatments for full-season weed control, (2) to determine the extent of foliar penetration and translocation of atrazine, and (3) to determine what factors affect phytotoxicity and foliar penetration of atrazine.

REVIEW OF LITERATURE

Nature of the Cuticular Surface

Plants have a non-living protective membrane which must be traversed before exogenously applied compounds can penetrate the living cell. According to van Overbeek (1956), external membranes of leaves which are considered the first barriers to penetration are called cuticles. The structure of the plant cuticle has been characterized by Franke (1967) and Eglinton and Hamilton (1967). The cuticle is built up of several alternating layers of cellulose, pectin, cutin and wax. The cutin itself is believed to be composed of polymerized long-chain fatty acids and alcohols. This is bound by epicuticular waxes toward the outside and pectin substances toward the cellulose cell wall.

According to Eglinton and Hamilton (1967), surface waxes are complex mixtures of long-chain alkanes, alcohols, ketones, aldehydes, esters and acids. The nature of surface waxes is further complicated by the number of functional groups and by the degree of chain branching and unsaturation. The wax composition of a species may differ for different parts of the same plant and may vary with season, locale, age of plant, humidity, temperature and other internal and

external factors. Jansen (1964) reported that surface wax constitutes an impediment to spray droplet contact but has little influence on the movement of water through the cuticle.

Pathways of Cuticular Penetration

Reviews by Crafts and Foy (1962), Franke (1967), van Overbeek (1956), Currier and Dybing (1959), and Sargent (1965) have contributed greatly to the understanding of penetration of exogenously applied compounds into plant cells.

Stomata and Internal Cuticle

For several years it was thought the hydrophilic molecules entered the leaves mainly through stomatal pores. This hypothesis was proposed by many investigators such as Foy (1962), Sargent and Blackman (1962), and Wittwer and Teubner (1959) who found that upper surfaces without stomates had less solute uptake than lower surfaces. However, most workers agree with van Overbeek (1956) that aqueous solutions do not penetrate through stomatal pores unless the surface tension is very low. The size of the stomatal pore (3-5 μ when fully open) is such that the surface tension of the leaf will prevent the water droplet from gaining entrance into it. Stomatal entry of aqueous solutions must depend, therefore, upon a surface active agent to reduce surface tension.

Investigations conducted by Currier and Dybing (1959), Wittwer and Teubner (1959), and Norris and Bukovac (1968) showed that once the molecule enters the sub-stomatal cavity it must still transgress a lipid membrane called the internal cuticle. The molecule can be considered in the leaf but not in the cell. The cuticular membrane of the stomatal cavity is thinner, more hydrated, and easier to penetrate than the epicuticular surface of the leaf. Norris and Bukovac (1968) have demonstrated that substances applied in aqueous solutions can penetrate intact and isolated astomatous cuticles.

Intercuticular Penetration

Scott, Brystrom and Bowler (1962) were of the opinion that canals may exist in the cuticle, but efforts to show that these canals actually exist have not been successful. If canals were present, they might facilitate the movement of non-polar substances through the cuticle. Using microscopy, Norris and Bukovac (1968) showed the pear cuticle to be a uniformly continuous and poreless membrane. Scott et al. (1962) reported that breaks, fissures or punctures made by insects or mechanical means are sometimes found in the cuticular membrane. The passage of solutes through these imperfections has been termed intercuticular penetration by Wittwer and Teubner (1959).

Epicuticular Surface

Silva Fernandes (1965) suggested that cuticular penetration may occur preferentially through the thinner

cuticle lying over the veins. Other results reveal that foliar-applied chemicals can penetrate the stomata-free cuticle. The cuticular framework exhibits moderate hydrophilic properties. Wientraub et al. (1954) and van Overbeek (1956) reported that after absorbing water the cuticle swells and spreads apart the embedded wax platelets (which exhibit hydrophilic properties). This increases permeability of the cuticle to water and to certain organic substances that tend to move with water. Conversely, low moisture content would move the wax platelets closer together and therefore reduce water and solute movement through the cuticle.

Factors Affecting Cuticular Penetration

Temperature

Warm temperature may promote penetration of solutes through the cuticle. Sargent (1965) and Currier and Dybing (1959) concluded that a temperature of 10 to 37 C indirectly influenced the penetration rate of aqueous solutions by influencing cytoplasmic viscosity, binding, accumulation, metabolic conversion, and translocation of the penetrant, i.e., by regulating processes which influence the concentration gradient across the surface layers. Warm temperatures directly influenced the rate of diffusion of lipophilic substances through lipoid-containing membranes. Rice (1948), Sargent and Blackman (1962), Barrier and Loomis (1957), and Bryan, Staniforth and Loomis (1950) demonstrated that

increased temperatures increased the penetration of 2,4-dichlorophenoxy acetic acid (2,4-D) into plant parts. While working with broad bean (Vicia faba L.), Bennett and Thomas (1954) found that over a 7 hr period ^{32}P -schradan was absorbed in greater quantities at 26 than at 15 C (64% vs 100%). After 72 hr the absorption was essentially the same.

Skoss (1955) reported that the thickest cuticle was produced on plants at a median temperature. The greatest wax content was produced at high temperatures (Skoss, 1955; Hull, 1960).

Light

The leaf surface may be affected by light intensity. Ivy (Hedera helix L.) leaves had less cutin and wax when grown in the shade (Skoss, 1955). Lee and Priestley (1924) suggested that light affected the thickness and consistency of the cuticle by its influence upon the oxidation and condensation of fatty acids.

Stomatal opening is affected by light, and absorption of 2,4-D and 2,2-dichloropropionic acid (dalapon) was greater in leaves of plants kept in the light than in those kept in darkness prior to spraying (Currier, Pickering and Foy, 1964). This difference was associated with a difference in stomatal opening. According to Sargent (1965) light may promote absorption by causing an increase in the export of carbohydrates from the leaf. Several investigators have reported an increase in absorption with increased light

intensity. Sargent and Blackman (1962 and 1965) reported greater penetration of 2,4-D in Phaseolus vulgaris L. and Ligustrum ovalifolium Hassk. in the light than in the dark. However, Bennett and Thomas (1954) found that light was apparently not very important in the absorption of ^{32}P -schradan over a 72 hr period. Brian (1969) demonstrated that foliar uptake of 6,7-dihydrodipyrido (1,2-a: 2',1'-c) pyrazinedinium ion (diquat) and 1,1'-dimethyl-4,4'-bipyridinium ion (paraquat) was doubled and occasionally quadrupled when tomato plants (Lycopersicon esculentum Mill.) were darkened after treatment. The increase was not directly related to the duration of darkness because uptake decreased after a time.

Relative Humidity

The relative humidity (R.H.) of the microclimate will affect herbicidal penetration, both physically and physiologically. Persistence of liquid deposits on leaves is affected by R.H. and penetration appears to cease with droplet desiccation (Rice, 1948). Physiologically, the R.H. will affect the plant's water stress, stomatal opening, and cuticular permeability (Currier and Dybing, 1959). Pallas (1960) found that higher R.H. increased foliar absorption of 2,4-D. The increased absorption and translocation at higher R.H. was correlated with the degree of stomatal opening. Clor et al. (1962 and 1963) demonstrated that the rate and extent of absorption and translocation of 2,4-D and

3-amino-1,2,4-triazole (amitrole) in cotton (Gossypium spp.) was enhanced when the plants were placed in polyethylene bags to produce a high humidity atmosphere.

Prasad, Foy, and Crafts (1967) found that greater amounts of dalapon were absorbed at high (88%) than at medium (60%) or low (28%) post-treatment R.H. Droplets dried less rapidly at high than at low R.H., thus prolonging the period of effective absorption. At low R.H., periodic rewetting of the droplet area enhanced absorption and translocation but never to the extent achieved with high R.H.

Thompson and Slife (1969) demonstrated that high R.H. and rewetting crystalline spray deposits increased foliar absorption and phytotoxicity to giant foxtail (Setaria faberii Herrm.) but phytotoxicity was restricted to treated leaves. Dexter, Burnside and Lavy (1966) found that foliar applications of atrazine plus surfactant were more phytotoxic to large crabgrass (Digitaria sanguinalis (L.) Scop.) at high R.H. (80%).

Moisture Stress

Moisture stress can affect herbicide retention, penetration and absorption. Leaves of tree tobacco (Nicotiana glauca L.) grown under stress had more cuticle per unit area and a lower wettability than leaves from plants not under stress (Skoss, 1955). Decrease in turgidity, even before wilting was evident, reduced maleic hydrazide absorption by tomatoes, and absorption was severely curtailed by wilting (Smith et al., 1959). Plants grown with decreased soil

moisture absorbed 2,4-D more slowly than plants supplied with adequate water (Hauser, 1955). The effects of moisture stress prior to, and at the time of spraying appear to be far from clear and may vary between species.

Adjuvants

In a water solution, incomplete wetting and spreading on waxy leaves can be a problem without an adjuvant (surfactant, wetter, detergent, oil, etc.) to promote thorough coverage. It is logical that the physical form of a herbicide on a plant leaf is a factor in its effectiveness, and it is reasonable to presume that an adjuvant can sometimes maintain the active chemical in a liquid state rather than as a high-viscosity liquid or a crystal (Behrens, 1964).

According to Sargent (1965), surfactants can affect penetration by (1) increasing the area of contact through spreading the solution, (2) eliminating air films between the solution and plant surface, (3) acting as cosolvents or solubilizing agents in cuticular penetration, (4) easing entry through open stomata and subsequent movement through intercellular spaces, and (5) acting as humectants to retard drying out of the solution. Jansen (1964) reported that surfactants can enhance herbicide entry as a function of their concentration, structure, or physical-chemical characteristics. At the same time, surfactants may also be suppressive in their action.

Ginsberg (1930) obtained several petroleum oils that were stained red with an oil-soluble dye. He applied the oils to the upper and lower leaf surfaces of apple (Malus pumila Mill.), peach (Prunis persica (L.) Batsch), and tomato plants. All the oils penetrated through the under-surface of the leaves, the rate of penetration varying indirectly with the viscosity of the oil. Only oils of low viscosity penetrated through the upper surfaces of the leaves.

Most of the knowledge of the use of oils on plants has been learned from the use of insecticides on fruit trees (Chapman, Riehl, Pearce, 1952). Since then, similar oils have been added to atrazine-water spray suspensions to enhance foliar uptake of atrazine (Anderson and Jones, 1963). Oil-water emulsions with atrazine were used at rates up to 50% oil (v/v) in preliminary trials. The safest oils to use on plants were those lowest in aromatic content and other unsaturates. This content was designated as the percentage of unsulfonated residue (U.R.). Most of the oils used on plants had U.R. values ranging from 90 to 96% (4 to 10% aromatic content). Both naphthalenic and paraffinic oils in the range of 70 to 110 S.U.S. viscosity at 100 F were used. Oils with the above specifications were non-phytotoxic; foliar applications of the oils (without herbicide) were not toxic to plants.

Other Factors

Fogg (1944) reported diurnal variations in contact angle on leaves with maxima at dawn and in late afternoon. The differences in angle between maxima and minima were as much as 30° . Leaves, therefore, may be more readily wetted at certain times of the day, but the contact angle of droplets already on the leaf may change, so that any gain in retention and penetration resulting from spraying when contact angles were minimal would be partially lost.

In general, foliar penetration of herbicides into plants decreases with age (Blackman, Bruce and Holly, 1958). Young expanding leaves have a lesser developed cuticle than older leaves, and in studies of cabbage (Brassica oleracea L.) plants, increase in age resulted in decreased wettability. Weintraub et al. (1954) reported that expanding bean leaves passed through a short period of high absorbability to herbicides to a lower and relatively constant level which fell still further as the leaf yellowed.

Ennis (1952) observed more spray retention on pubescent leaves than on glabrous leaves. Leaves in a horizontal position retained more spray than those held at an angle of 45° . Currier and Dybing (1959) reported that both surfaces of the leaf function in absorption of chemicals. Usually the lower surface was more penetrable than the upper. Leaf margin application was less effective than placement over the midrib.

Enhancement of Herbicidal Activity
by Adjuvants

Numerous investigators such as Crafts (1956), Ennis (1951), Ilnicki et al. (1965), Laning and Aldrich (1951), and Prasad et al. (1967) have reported the enhancement of pesticide action by the addition of adjuvants. Sargent and Blackman (1962), Behrens (1964), Jansen et al. (1961), Staniforth and Loomis (1949), and Skoss (1955) reported that 2,4-D penetration was increased by the inclusion of a surfactant. Freed and Montgomery (1959) concluded that although reduction of surface tension was important, the relationship of molecular interaction between surfactant and the herbicide was of equal or greater importance.

Foy (1962) demonstrated that surfactants greatly enhanced cuticular penetration of dalapon in corn leaves. Small amounts of the chemical were absorbed almost instantaneously (15-30 sec). Movement away from the treated area showed first a diffusional pattern, but soon became channeled in veinlets and larger vascular bundles. Dalapon applied off the midvein did not enter the midvein in appreciable quantities during basipetal transport. Dalapon applied on the midvein remained highly concentrated in this channel.

Frank (1963) studied the effect of adding various wetting agents and stickers to atrazine for postemergence weed control in corn and reported no benefit from their use. Baldwin (1964) used atrazine as a postemergence spray in 5 gal of diesel oil with 7 gpa of water. Good control of

broadleaf weeds was reported but annual grasses were not controlled. No corn injury was observed.

Anderson (1963) and Jones and Anderson (1964) reported that weed control with postemergence atrazine was greatly improved when 1 to 2 gpa of an emulsifiable oil was added to the spray mixture. Both broadleaf weeds and annual grasses were controlled with the atrazine-oil treatments when weed growth was less than 2 inches. Annual grasses over 2 inches high were only partially controlled. Ilnicki et al. (1965) found that the addition of surfactants increased the phytotoxicity of atrazine to broadleaf weeds.

Currey and Cole (1966) and Wiese, Weir and Chenault (1968) reported that phytotoxicity of foliar-applied atrazine was markedly increased when applied in an oil-water emulsion. Williams and Ross (1966) applied atrazine (2 lb/A) and atrazine (2 lb/A) plus 10% oil (v/v) to giant foxtail 1.5 inches high. The sprayed foliage died but some of the plants recovered and appeared normal in thirty days. Atrazine and atrazine-oil spray treatments gave 12 and 80% plant kill, respectively.

Timing the application of atrazine-oil to the size of the annual grass weeds is highly important (Wright, 1966). Excellent control was obtained when applications were made to annual grasses 0.5-1.5 inches high. Later treatments, when annual grasses were 2-4 inches high resulted in poor grass control. Timing was not as important for broadleaf weed control. Excellent control of broadleaved weeds, both

annuals and top growth of perennials was obtained at all growth stages.

Wright (1966) reported that no permanent damage to corn was obtained from the atrazine-oil treatments. In some instances, slight leaf tip burning was noted. However, the condition disappeared in 2-3 weeks and did not result in any yield reduction. Duke (1968) reported that corn yields were reduced when postemergence spraying with atrazine-oil was delayed until weeds were over 1.5 inches high.

Smith and Nalewaja (1967) determined uptake of atrazine by placing leaf sections in ^{14}C -atrazine solution. Uptake of the label by corn was greater than by yellow fox-tail (Setaria glauca (L.) Beauv.) and lambsquarters (Chenopodium album L.). The uptake and translocation of ^{14}C -atrazine by leaves of intact plants was greater when the atrazine was applied as an oil-water emulsion compared to a water solution. Triplett (1968) attempted to estimate leaf penetration by treating the base of oat (Avena sativa L.) leaves with ^{14}C -atrazine and determining the amount that moved to the leaf tip. ^{14}C -activity in leaf tips increased with increasing rates of oil. As much as 50% of the total sample activity was present in the leaf tips at the high rate of oil. ^{14}C -activity in leaf tips was as much as 5 times higher when the atrazine was applied in oil-water emulsions compared to a water solution.

MATERIALS AND METHODS

Preliminary experiments were performed in 1966 to evaluate several adjuvants that could be used in conjunction with atrazine as a postemergence treatment. Factors investigated included types of oils and surfactants, types and amounts of emulsifiers with the oil, S.U.S. viscosities and unsulfonated residues of the oils, rates and concentration of the oils in the spray solution, and spray volume and pressure.

Based on results of preliminary investigations, a non-phytotoxic oil (Sun 11E) was chosen to use for the rest of the experiments. This oil has the following specifications:

Type of oil: superior highly paraffinic

S.U.S. viscosity: 104.8

Unsulfonated Residue (U.R.): 91.5

Molecular Weight: 360.0

Aromatic Content: 8.5%

Triton X-207 emulsifier: 1% v/v

Field Experiments

In 1967, a set of eight treatments for weed control in corn was randomized and applied both early and late

postemergence at five locations throughout the state of Michigan to evaluate the effect of environmental conditions and stage of growth when sprayed. The eight treatments consisted of combinations of atrazine at 1.5 and 2.0 lb/A with oil at 0, 1.0, 1.5, and 2.0 gal/A. The treatments were replicated four times at each location in a randomized block design and applied early postemergence when weeds were 0-1.5 inches high and again to adjacent plots late postemergence when weeds were 2-4 inches high. Treatments were applied with a tractor-mounted boom-type plot sprayer in 23 gpa of water at 30 psi. Dates of corn planting ranged from May 2 to May 26. Organic matter of the soils ranged from 2.2 to 4.4% and the soil texture at all locations was either a sandy loam or a loamy sand. The major weed species consisted of lambsquarters, pigweed (Amaranthus retroflexus L.), common ragweed (Ambrosia artemisiifolia L.), smartweed (Polygonum pensylvanicum L.), yellow foxtail, green foxtail (Setaria viridis (L.) Beauv.), barnyardgrass (Echinochloa crusgalli (L.) Beauv.), witchgrass (Panicum capillare L.), and quackgrass. Corn injury and weed control (annual grasses and broadleaves) were evaluated approximately 2 wks after the late postemergence treatments were applied. Corn injury and weed control ratings were based on a 0-10 scale (0 = no corn injury or weed kill; 10 = complete kill of corn or complete control of weeds). Corn was harvested for yield determinations at four of the five locations.

A second field experiment was designed to evaluate several factors with respect to the performance of atrazine-oil combinations. The factors included stage of growth of weeds when sprayed (3), date of planting (2), time of day when the treatments were applied (2), rates of atrazine (3), and rates of oil (2). The $3 \times 2 \times 2 \times 3 \times 2$ factorial gives 72 treatment combinations and the experimental design was a randomized block with two replications. The experiment was conducted at E. Lansing on a sandy loam soil with 2.5% organic matter. Major weed species consisted of pigweed, lambsquarters, nutsedge (Cyperus esculentus L.), yellow foxtail, and barnyardgrass. The treatments consisted of post-emergence atrazine at 1.0, 1.5, and 2.0 lb/A in combination with 0 or 1.5 gal/A of Sun 11E oil. Two planting dates, May 10 and May 25, were used to establish two sets of field conditions. The treatments were applied at 7 a.m. and 7 p.m. to determine the effect time of application might have on weed control. To evaluate the effect of stage of growth when sprayed, plots were treated at one of the following stages: (1) early--when weed growth was 0-1.5 inches high, (2) late--when weed growth was 2-4 inches high, or (3) split application--when weed growth was 0-1.5 inches high followed by a second treatment 10 days later. For the split application, the rate of herbicide per application was halved so that the total amount of herbicide was equal to the early and late treatments. The treatments were evaluated for corn injury and weed control including broadleaved weeds, annual

grasses, and nutsedge. Corn was harvested for yield determinations.

Greenhouse and Growth Chamber Experiments

Experiments were conducted to determine what effects certain environmental factors might have on the performance of atrazine and atrazine-oil applied postemergence for annual grass control. Yellow foxtail plants were grown in either 16 or 32 oz disposable containers using a 1:2:1 mixture of sand, soil, and peat. Holes were punched in all containers to allow drainage. The greenhouse temperature was approximately 75 F and the daylength was extended to 14 hr with overhead fluorescent lights. Approximately 20 foxtail seeds were planted in containers and seedlings were thinned to 10 plants per container when 1 inch high. The plants were sprayed when they were approximately 1.5 inches high. Visual injury was evaluated on a 0-10 scale where 0 indicated no apparent injury and 10 indicated that all plants were killed. Ratings were taken 10 days after spraying for all experiments.

To evaluate the effectiveness of atrazine and atrazine-oil as foliar treatments, a technique was devised such that the treatments could be applied only to the plant foliage, thus deleting root uptake of atrazine. This was accomplished by placing a half-inch layer of vermiculite on top of the soil before spraying. Vermiculite is highly

absorbent and prevents atrazine from moving into the soil. Preliminary work, using oats as a bioassay plant, revealed that the atrazine did not move into the soil. The vermiculite layer was removed immediately after spraying.

To evaluate the effect of temperature, three regimes consisting of 90/70, 75/55, and 60/40 F day/night temperatures were established in controlled environment chambers. The R.H. in all chambers was approximately 35% with a 14 hr photoperiod. The plants were grown in the greenhouse until 1.5 inches high and then placed in growth chambers 24 hr prior to spraying. Other factors included in the 3x2x5 factorial included atrazine at .25, .50, 1.0, 1.5, or 2.0 lb/A in combination with 0 or 5% oil (v/v).

High (55-60%) and low (15-20%) R.H. levels were established in controlled environment chambers to evaluate the effect of R.H. on the foliar treatments. Both chambers were maintained at 75/55 F day/night temperatures with a 14 hr photoperiod. Plants (1.5 inches high) were placed in the chambers 24 hr prior to spraying. A 2x2x5 factorial was designed to include high and low R.H., 0 or 5% oil (v/v), and .25, .50, 1.0, 1.5, or 2.0 lb/A atrazine.

The light/dark experiment was conducted to determine the effect light or dark might have on phototoxicity of the treatments. Atrazine rates of .25, .50, 1.0, 1.5, or 2.0 lb/A in combination with 0 or 5% oil (v/v) were sprayed onto foxtail plants 1.5 inches high. One set of plants was placed in the dark chamber 2 hr prior to spraying and remained in

the dark chamber 12 hr after spraying. A second set of plants was placed in the light chamber 2 hr prior to spraying and remained in the light chamber 12 hr after spraying.

Three relative soil moisture regimes were established to evaluate the effect of soil moisture stress on the phytotoxicity of atrazine and atrazine-oil to yellow foxtail. In addition to three moisture levels, the factorial consisted of 5 rates of atrazine (.25, .50, .75, 1.0, 1.5 lb/A), 0 or 5% oil, and spray application to foliage vs soil and foliage. Field capacity (F.C.) and permanent wilting point (P.W.P.) of the soil were determined in preliminary investigations. The difference between the two (F.C.-P.W.P.) is assumed to be the available water. The high moisture regime was maintained at F.C. (100% available water). The medium and low moisture regimes were depleted to 50 and 10% of F.C., respectively, at which time the treatments were applied. The plants were remoistened to F.C. 48 hr after spraying.

The final greenhouse experiment was conducted to determine what effect pre-conditioning yellow foxtail with oil might have on phytotoxicity. Pre-conditioning with the oil implies that oil was sprayed onto the foliage at a predetermined time before atrazine. The 4x2x3 factorial included atrazine at .25, .50, 1.0, or 1.5 lb/A and oil at 5 or 10%. The oil treatments were applied to one set of plants 72 hr before the atrazine was applied. Other plants received the oil treatments 24 hr prior to atrazine and a

third set received the atrazine and oil treatments in combination.

Foliar Penetration Experiments

Experiments using ^{14}C -labeled atrazine were conducted to study foliar penetration in corn and yellow foxtail. The ^{14}C -atrazine was uniformly ring-labeled with a specific activity of 1.32 mc/mM. The plants were grown in the greenhouse, as previously described, and uniform plants were selected for each experiment.

Preliminary studies were conducted using autoradiography. Plants were treated with either ^{14}C -atrazine in a water solution or ^{14}C -atrazine in oil-water emulsions. The oil rates were 5 and 10% (v/v) of the solution. The treatment rate was 0.01 microcurie (μC) of ^{14}C -atrazine per plant applied in 40 μl of solution. The treatments were applied to the third and fourth leaves of corn and yellow foxtail, respectively, and bound by a lanolin enclosure. Duplicate plants were harvested from each series at 30 min, 1 hr, 3 hr, 6 hr, 12 hr, 24 hr, and 48 hr after treatment. Plants were removed from the containers and the treated spots were cleansed with facial tissue to remove lanolin rings. The treated spots were then covered with masking tape to prevent contamination. Each plant was placed between two layers of waxed paper and embedded in pulverized dry ice. The paper layers were used to prevent the leaves from being fractured.

The plants were stacked within screen trays and placed in the freeze-dry tank.

After freeze drying, the plants were remoistened in a humidity chamber and prepared for autoradiography. They were mounted on blotter paper and held in place with a casein glue. The mounts were dried and pressed against masonite to get a flat surface for good contact with X-ray film. After pressing, the mounts were placed in exposure holders with no-screen X-ray film and exposed for 2 wks. After exposure, the film was developed by standard developmental procedures.

Several experiments were conducted to investigate factors that affect foliar penetration and translocation of ^{14}C -labeled atrazine. Since atrazine moves acropetally in the leaves, foliar penetration and translocation can be determined by treating an area on the lower portion of the leaf with ^{14}C -atrazine, sectioning off the leaf blade above the treated area after a given period of time, and determining the amount of ^{14}C -activity in this leaf section.

The leaf sections were cut from the plant, wrapped in preweighed sample wrappers, and subsequently used for the carbon-14 analysis. The technique used was the Schoniger oxygen combustion method (Wang and Willis, 1965). The black paper containing the plant sample was placed in a nichrome wire basket attached to a 14 cm length of nichrome wire. The wire was inserted into a #8 rubber stopper and the stopper and basket were placed in a one-liter suction flask and a

vacuum drawn. The flask was then filled with oxygen and evacuated three times. It was then clamped off, placed in a Thomas-Ogg infrared combustion chamber, and ignited. The evolved $^{14}\text{CO}_2$ was absorbed by 20 ml ethanol-aminoethanol solution, 2:1 (v/v). The trapping solution was injected into the flask through a serum vial cap in a 4x80 mm glass tube in the rubber stopper. Five milliliters of the solution were removed one hr later and placed in a scintillation solution containing 5.0 g 2,5-diphenyloxazole (PPO) and 0.3 g 2-p-phenylene-bis(5-phenyloxazole) (POPOP) in one liter of toluene. The vials were placed in a Packard tricarb liquid scintillation spectrometer and 10 min counts taken. The counts per minute (cpm) were converted to disintegrations per minute (dpm). Color and chemical quenching were determined using internal toluene- ^{14}C standards and the channels ratio method (Herberg, 1965). The counting efficiency was consistently between 71.5 and 72.5%.

Combustion efficiency was determined by spotting known quantities of the ^{14}C -atrazine directly on the sample wrappers. The percent recovery of the carbon-14 was 94-96%. Since this is quite high, no correction was made for the missing radioactivity.

Preliminary work confirmed that none of the ^{14}C -atrazine moved basipetally. Plants were foliar treated with ^{14}C -atrazine and various sections of the plants were analyzed by the combustion technique. None of the sections contained carbon-14 except those acropetal to the treated spot.

Lanolin barriers were placed on corn and foxtail leaves within which the treatments were applied. Unless otherwise stated, the leaf area within the barrier was 1 and 2 cm² for the foxtail and corn, respectively. A dyed oil, provided by the Sun Oil Company, was used to confirm that the treatment solution remained within the lanolin barrier. The fluorescent dye was Patent Chemical's yellow C-4 oil soluble dye and was incorporated into the oil at 0.1% by weight. Oil-water emulsions were spotted on leaf sections within the lanolin barriers and examined in the dark at various time intervals. Results confirmed that the treatment solution did not leak through the lanolin barrier.

A preliminary experiment was designed to establish an adequate treatment time before the leaf sections were to be harvested. Corn and yellow foxtail plants were treated and leaf sections were harvested at 12, 24, and 48 hr after treatment. The 24 hr interval was chosen as the most suitable harvest time and was used for all experiments unless otherwise stated. In all experiments, ¹⁴C-atrazine was applied to plants at the rate of 22,200 dpm (0.01 µc).

Differential foliar penetration of ¹⁴C-atrazine by plant species was determined by treating corn, yellow foxtail, nutsedge, and velvetleaf plants at three stages of growth. Corn plants were 4, 6, and 8 inches high when treated. Yellow foxtail and velvetleaf plants were 1.5, 3, and 5 inches high and nutsedge plants were 2, 4, and 6 inches

high. The treatments consisted of ^{14}C -atrazine in a water solution, ^{14}C -atrazine in oil-water emulsions with 5 and 10% oil (v/v), and ^{14}C -atrazine in a water solution plus 0.1% (v/v) X-77 surfactant. The surfactant was included as a comparative treatment with oil. Plants were treated within a 1x1 cm lanolin barrier and harvested after 48 hr.

The "light" experiment was designed to determine what effect light and dark (before and after treatment) would have on foliar penetration of ^{14}C -atrazine. Four groups of corn and yellow foxtail plants were grown in the green house and placed in controlled environment chambers 24 hr prior to treatment. Each group was exposed to a different "light" treatment. The before/after "light" treatments consisted of light/light, light/dark, dark/dark, and dark/light. The first "light" treatment, for example, was 12 hr light before and 12 hr light after application of ^{14}C -atrazine. The foliar applications consisted of ^{14}C -atrazine in a water solution and ^{14}C -atrazine in oil-water emulsions with 5 and 10% oil (v/v). The corn and yellow foxtail plants for this experiment and all following experiments were 6 inches and 1.5 inches high, respectively.

Three soil moisture regimes were established, as described in a previous experiment, to determine the effect of soil moisture stress on foliar penetration of ^{14}C -atrazine. The high moisture level was at F.C. and the medium and low levels were depleted to 50 and 10% of F.C., respectively, at the time of treatment. Foliar treatments

on corn and yellow foxtail were the same as those in the "light" experiment.

Foliar penetration of atrazine, as affected by temperature, was evaluated in three controlled environment chambers by establishing 90/70, 75/55, and 60/40 F day/night temperatures. Corn and yellow foxtail plants were grown in the greenhouse and placed in the growth chambers 24 hr prior to treatment. The foliar treatments were the same as those in the "light" experiment and were applied at the beginning of the 12 hr photoperiod.

The effect of R.H. on foliar penetration of ^{14}C -atrazine was evaluated by establishing humidity levels of 15-20, 55-60, and 100% R.H. The two lower levels were established in controlled environment chambers and the 100% R.H. was established in a 3 ft cubic glass chamber. Corn and yellow foxtail plants were placed in the chambers 12 hr prior to treatment. The foliar treatments were the same as those in the "light" experiment.

Oil-water emulsions were applied to foliage of corn and yellow foxtail plants before and after the ^{14}C -atrazine was applied to determine what effect oil conditioning would have on foliar penetration of ^{14}C -atrazine. The treatments consisted of applying 40 μl of an oil-water emulsion to plants 48 hr before, 24 hr before, 24 hr after, and 48 hr after foliar applications of ^{14}C -atrazine. Other conditioning treatments consisted of applying oil-water emulsions at

two or more of the times mentioned above. All plants were harvested 72 hr after foliar application of ^{14}C -atrazine.

Corn and yellow foxtail plants were grown in the greenhouse and divided into four groups to evaluate the effect of rewetting the plant foliage with water after foliar applications of ^{14}C -atrazine. The three foliar treatments consisted of ^{14}C -atrazine in a water solution, and ^{14}C -atrazine in oil-water emulsions with 5 and 10% oil (v/v). One set of plants was rewetted (within the lanolin barrier) with 100 μl of water 6 hr after treatment. A second set of plants was rewetted 12 hr after treatment and a third was rewetted with 100 μl of water at both 6 and 12 hr after treatment. The fourth set received no rewetting. All plants were harvested 24 hr after ^{14}C -atrazine application.

Corn plants were treated with ^{14}C -atrazine on the leaf-margin or the midrib to determine if differential penetration occurred on the leaf surface. Treatments consisted of ^{14}C -atrazine in a water solution and ^{14}C -atrazine in oil-water emulsions with 5 and 10% oil (v/v). The treatments were applied within 1 cm^2 lanolin enclosures for both the midrib and leaf-margin applications.

The final experiment was conducted to determine upper vs lower leaf surface penetration and to determine whether the oil-water emulsions enhance penetration through the leaf surface. Treatments consisted of ^{14}C -atrazine in a water solution, ^{14}C -atrazine in oil-water emulsions with 5 and 10% oil (v/v), and ^{14}C -atrazine in a water solution plus

0.1% (v/v) X-77 surfactant. The surfactant was included as a comparative treatment with oil. The treatments were applied to the third leaf of corn plants 6 inches high. Leaves receiving treatment on the lower surface were bent over and taped so that the lower surface was in a horizontal position. One set of plants was treated on the lower surface within a 1 cm x 2 cm lanolin barrier. The second set of plants was treated on the upper surface within a 1 cm x 2 cm lanolin barrier. The third and fourth sets of plants were treated on the lower and upper leaf surfaces, respectively, but the treatments were applied within 5 mm glass tubes attached to the leaves. Following treatment, the top of the glass tubes was sealed to prevent evaporation. Treating within the glass tubes allowed for all treatments to be exposed to equal surface area.

RESULTS AND DISCUSSION

Weed Control

Summary of weed control evaluations from atrazine and atrazine-oil at five locations revealed that the post-emergence treatments were very effective for broadleaf weed control when applied at the early stage of growth (Figure 1). Broadleaf weed control was nearly 100% at all locations from all the early postemergence treatments. When the treatments were applied late postemergence, broadleaf control was significantly reduced. The results reveal the importance of applying the postemergence treatments when weed growth is less than 1.5 inches high. The treatments without oil gave less control than treatments with oil but all treatments controlled 85% or more of the broadleaved weeds. There were no significant differences among rates of oil (1.0, 1.5, and 2.0 gal/A) or rates of atrazine (1.5 and 2.0 lb/A).

The early postemergence treatments gave significantly greater control of annual grasses than the late postemergence treatments (Figure 2). These results support the recommendation to apply postemergence treatments when annual grasses are less than 1.5 inches high. Beyond this stage of growth, the grasses have developed a relatively thick cuticle and

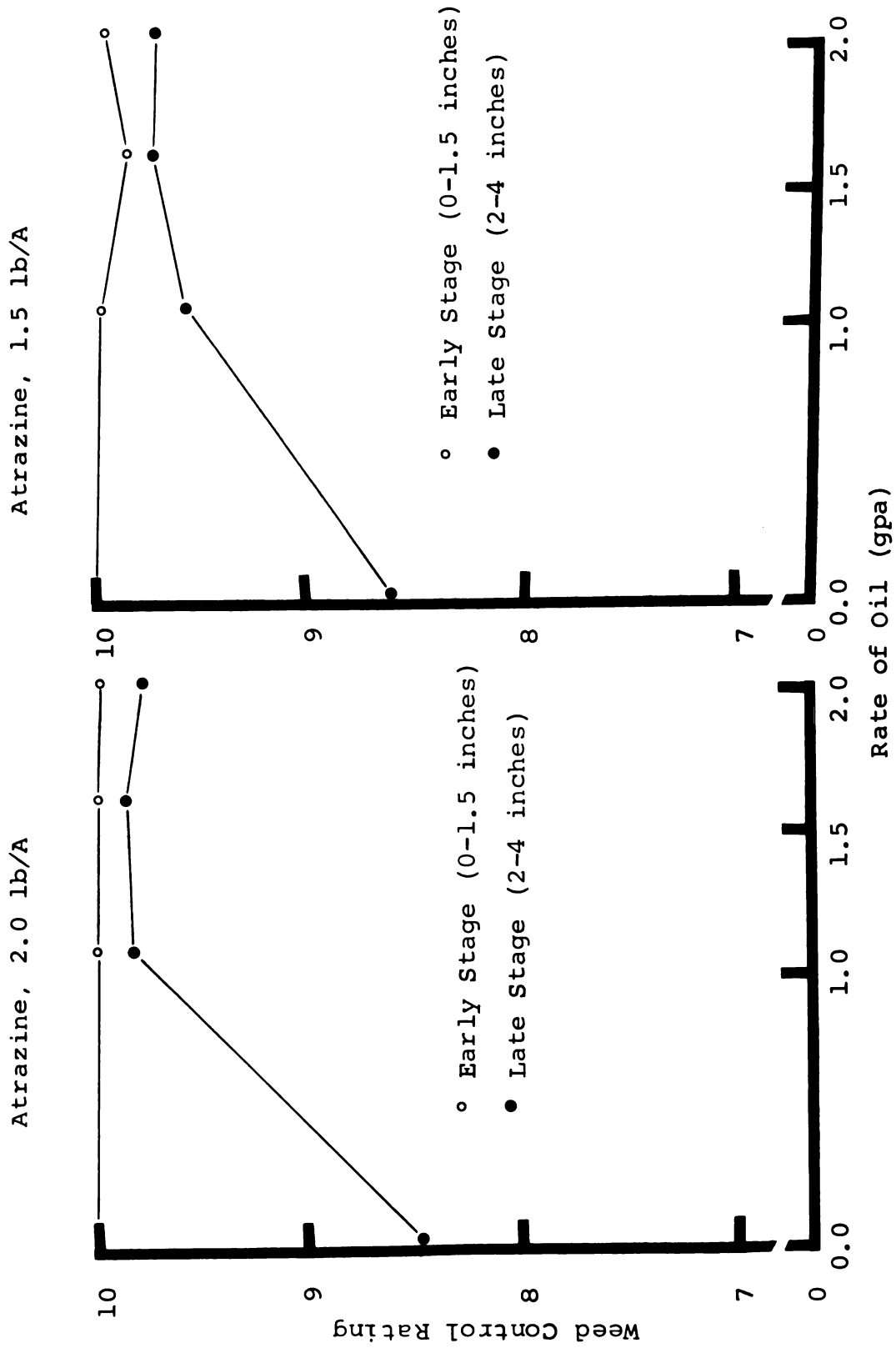


Figure 1. Effect of stage of growth and rates of atrazine and oil on broadleaf weed control (0 = no control; 10 = complete control).

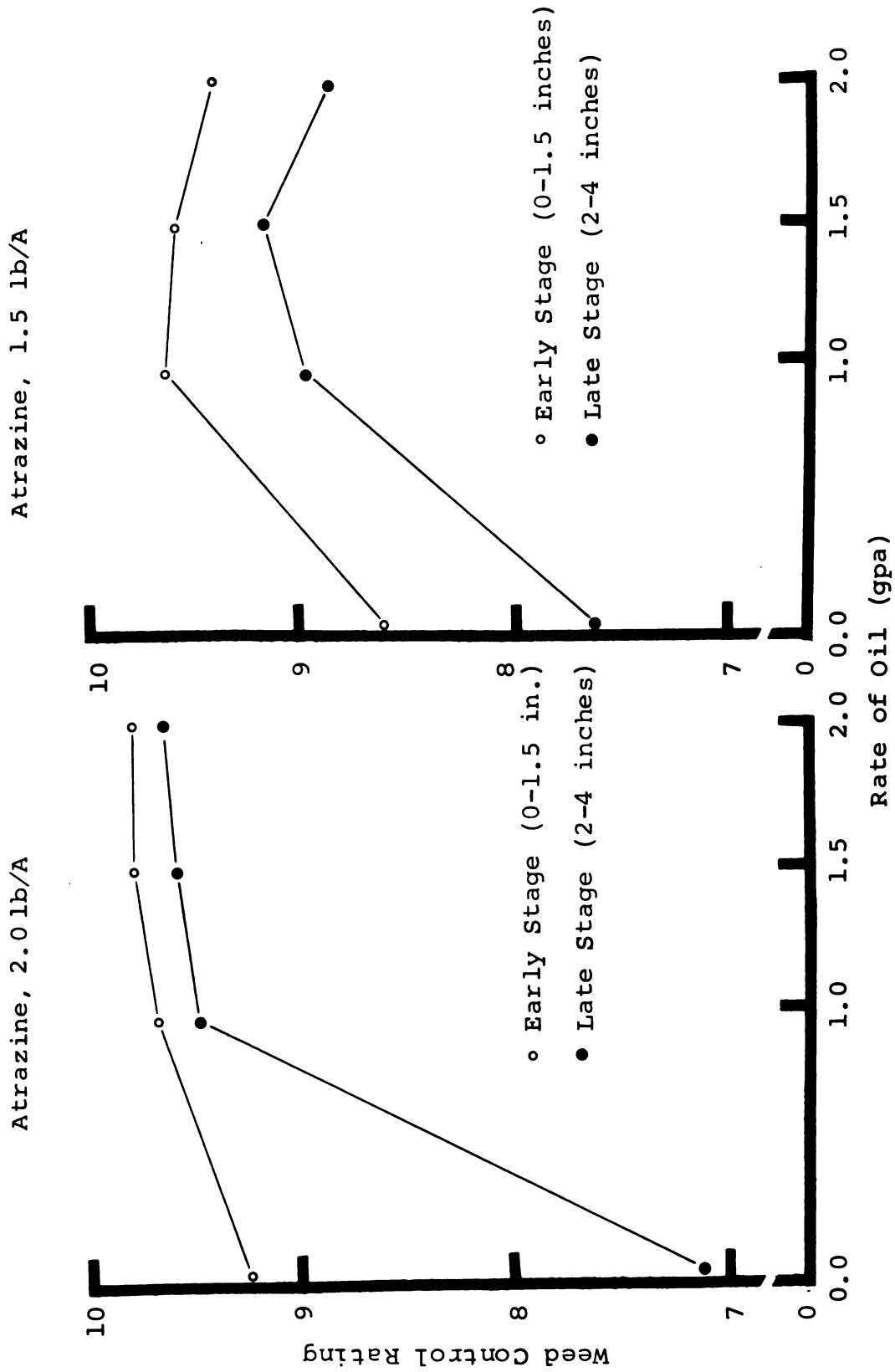


Figure 2. Effect of stage of growth and rates of atrazine and oil on annual grass control (0 = no control; 10 = complete control).

are quite resistant to foliar penetration of atrazine. Both early and late postemergence treatments of atrazine were enhanced by oil but the addition of oil did not prevail the necessity of applying the treatments at the early stage of growth. There were no significant differences among rates of oil (1.0, 1.5, and 2.0 gal/A) or rates of atrazine (1.5 and 2.0 lb/A). At locations where rainfall was insufficient from May to July 1, the atrazine-oil treatments gave much better grass control than treatments without oil. During this dry period, there was probably very little root uptake of atrazine and thus most of the grass control resulted from foliar uptake. These results are in agreement with reports by Jones and Anderson (1964) and Wright (1966).

Quackgrass infested the plots at two locations. Quackgrass control was enhanced when oil was added to the atrazine treatments. Oil at 2.0 gal/A enhanced quackgrass control more than the lower rates. Atrazine at 2.0 lb/A gave better control than 1.5 lb/A but none of the treatments gave adequate control. The results were not atypical since it normally takes 3.0 to 4.0 lb/A atrazine for full-season quackgrass control.

Corn yields were significantly higher from plots sprayed at the early stage of growth vs the late stage (Figure 3). This was probably due to less weed competition. The results are in agreement with Duke (1968) who reported that corn yields were reduced when postemergence spraying was delayed until weeds were over 1.5 inches high.

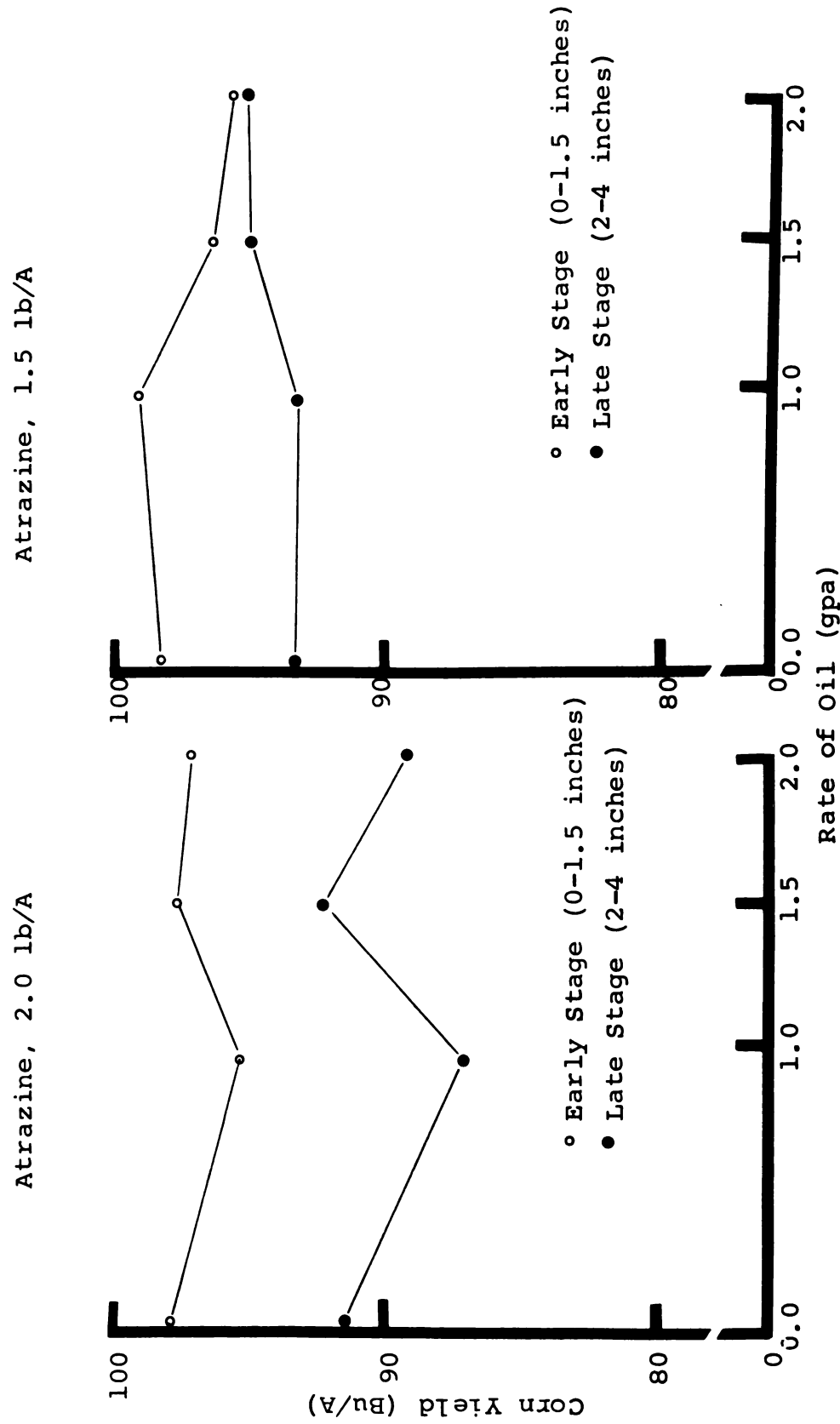


Figure 3. Corn yield as influenced by atrazine and oil applications and stage of growth when weeds were sprayed.

When the two rates of atrazine were compared, the slope of the lines appeared different and would indicate that corn yields were less from the higher rate of atrazine. However, the difference between the 1.5 and 2.0 lb/A rates of atrazine were not significant. The visual difference was probably due to a high degree of variability within replications. The yields from plots treated with atrazine were equal to those treated with atrazine plus 1.0, 1.5, or 2.0 gal/A oil. The expected results would be an increase in corn yield from the atrazine-oil treatments compared to the atrazine treatments since the oil significantly enhanced control of broadleaved weeds and annual grasses. One explanation for the yield data is that the atrazine-oil treatments may have caused a slight amount of corn injury which could not be detected visually.

The second field experiment evaluated several factors with respect to the performance of atrazine-oil combinations. Excellent control of broadleaved weeds was obtained when atrazine at 1.0, 1.5, and 2.0 lb/A was applied early postemergence or in a split application treatment (Table 1). The split applications imply that one-half the atrazine was applied when weed growth was 0-1.5 inches high followed by a second application 10 days later. Broadleaf weed control was reduced when the atrazine treatments were applied late postemergence. Atrazine treatments with oil gave 92% control vs 79% control without oil. Treatments

Table 1. Broadleaf weed control with atrazine and atrazine-oil as influenced by time of spraying and stage of growth when sprayed

Stage of Growth When Sprayed	Broadleaf Weed Control ^a					
	0-1.5 inches		2-4 inches		Split Application ^c	
	7 a.m.	7 p.m. avg	7 a.m.	7 p.m. avg	7 a.m.	7 p.m. avg
<u>Atrazine-oil^b</u>						
2.0 lb/A	10.0	10.0 10.0	10.0	9.5 9.8	10.0	10.0 10.0
1.5	10.0	10.0 10.0	9.0	9.5 9.2	10.0	10.0 10.0
1.0	9.8	9.8 9.8	8.5	8.8 8.6	10.0	10.0 10.0
avg	10.0	9.9 9.9	9.2	9.2 9.2	10.0	10.0 10.0
<u>Atrazine</u>						
2.0 lb/A	9.8	9.8 9.8	8.0	8.6 8.3	9.5	9.6 9.6
1.5	9.5	9.4 9.4	8.5	9.2 8.9	9.2	9.5 9.4
1.0	9.2	9.8 9.5	7.0	6.2 6.6	9.0	9.2 9.1
avg	9.5	9.6 9.6	7.8	8.0 7.9	9.2	9.4 9.4
avg for Atrazine and Atrazine-oil	9.7	9.8 9.8	8.5	8.6 8.6	9.6	9.7 9.7

^a0 = no control; 10 = complete control.

^bOil was applied at 1.5 gpa.

^cHalf the herbicide rate was applied when weed growth was 0-1.5 inches high and the other half applied 10 days later.

applied in the morning (7 a.m.) vs the evening (7 p.m.) were not significantly different.

Annual grass control from early postemergence treatments and split applications was superior to the late postemergence treatments (Table 2). All treatments were markedly improved by the addition of oil (1.5 gal/A). No significant differences were noted between the morning vs evening application. Grass control from the 1.0, 1.5, and 2.0 lb/A rates of atrazine was progressively better when atrazine was applied in split applications. When the treatments were applied early and late postemergence, the 2.0 lb/A rate was superior to the two lower rates but no difference was obtained between the two lower rates with respect to grass control.

Nutsedge control with postemergence atrazine was improved by the addition of oil (Table 3). Early postemergence applications and split applications were more effective than late postemergence applications. The split applications were the most effective treatments, giving 90 to 95% control with 2.0 lb/A atrazine plus oil. All the postemergence treatments, with or without oil, excelled the preemergence atrazine treatments for nutsedge control. The superior performance of the postemergence treatments could be explained by the fact that the atrazine was entering the plant through both the foliage and the rhizome system. In contrast to broadleaf and annual grass control, there was a highly significant difference between morning and evening spraying for

Table 2. Annual grass control with atrazine and atrazone-oil as influenced by time of spraying and stage of growth when sprayed

Stage of Growth When Sprayed	Annual Grass Control ^a					
	0-1.5 inches		2-4 inches		Split Application ^c	
Time of Spraying	7 a.m.	7 p.m.	avg	7 a.m.	7 p.m.	avg
<u>Atrazine-oil</u> ^b						
2.0 lb/A	10.0	10.0	10.0	9.6	9.1	9.4
1.5	10.0	8.2	9.1	7.8	9.4	8.6
1.0	9.7	9.5	9.6	7.6	7.5	7.6
avg	9.9	9.2	9.6	8.3	8.6	8.5
<u>Atrazine</u>						
2.0 lb/A	9.1	7.8	8.5	3.0	4.2	3.6
1.5	6.2	6.1	6.2	4.8	3.1	3.9
1.0	7.2	5.8	6.6	4.8	3.0	3.9
avg	7.5	6.6	7.1	4.2	3.4	3.8
avg for Atrazine and Atrazine-oil	8.7	7.9	8.3	6.2	6.0	6.1
				7.4	8.2	7.8

^a0 = no control; 10 = complete control.

^bOil was applied at 1.5 gpa.

^cHalf the herbicide rate was applied when weed growth was 0-1.5 inches high and the other half applied 10 days later.

Table 3. Yellow nutsedge control with atrazine and atrazine-oil as influenced by time of spraying and stage of growth when sprayed

Stage of Growth When Sprayed	Yellow Nutsedge Control ^a					
	0-1.5 inches		2-4 inches		Split Application ^c	
	7 a.m.	7 p.m.	avg	7 a.m.	7 p.m.	avg
Time of Spraying	7 a.m.	7 p.m.	avg	7 a.m.	7 p.m.	avg
<u>Atrazine-oil^b</u>						
2.0 lb/A	9.0	7.0	8.0	7.5	6.5	7.0
1.5	6.0	4.5	5.2	6.0	5.5	5.8
1.0	5.0	4.5	4.8	4.5	5.5	5.0
avg	6.7	5.3	6.0	6.0	5.8	5.9
<u>Atrazine</u>						
2.0 lb/A	6.0	5.5	5.8	3.5	3.5	3.5
1.5	4.0	5.0	4.5	5.0	4.0	4.5
1.0	3.0	4.0	3.5	4.5	3.0	3.8
avg	4.3	4.8	4.6	4.3	3.5	3.9
avg for Atrazine and Atrazine-oil	5.5	5.1	5.3	5.2	4.7	4.9
				6.4	6.6	6.5

^a0 = no control; 10 = complete control.

^bOil was applied at 1.5 gpa.

^cHalf the herbicide rate was applied when weed growth was 0-1.5 inches high and the other half applied 10 days later.

nutsedge control. When averaged over all treatments, the morning spraying was superior to evening spraying. No explanation is offered for this difference.

Corn yields (Table 4) from early postemergence treatments and split applications were superior to the late postemergence treatments. Yield reductions were due primarily to weed competition since the treatments applied late postemergence gave significantly less control of broadleaved weeds, annual grasses, and nutsedge. There were no significant differences between the oil rates or atrazine rates with respect to corn yields. This would indicate that 1.0 lb/A atrazine without oil was as sufficient as 2.0 lb/A atrazine plus 1.5 gal/A oil. However, it is doubtful that these results could be repeated every growing season. The yield data could be partially explained by the adverse weather conditions and by the variability (i.e., soil type, drainage, weed species, etc.) within replications.

Phytotoxicity

Phytotoxicity to yellow foxtail from atrazine applied postemergence was significantly affected by temperature levels (Figure 4). As the rate of atrazine increased, the phytotoxicity rating increased. The oil (5%) significantly enhanced the phytotoxicity of atrazine at all five levels. There was a significant interaction between atrazine and temperature. Atrazine, at all rates, was more phytotoxic at the high temperature (70/90 F) than at the two

Table 4. Corn yields from atrazine and atrazine-oil applications as influenced by time of spraying and stage of growth when weeds were sprayed

Stage of Growth When Sprayed	Corn Yield, bu/A ^a							
	0-1.5 inches				2-4 inches			
	7 a.m.	7 p.m.	avg		7 a.m.	7 p.m.	avg	
Time of Spraying	7 a.m.	7 p.m.	avg		7 a.m.	7 p.m.	avg	
<u>Atrazine-oil</u> ^b								
2.0 lb/A	88.1	86.8	87.5		90.6	77.6	84.1	85.5 82.7 84.1
1.5	91.7	81.5	86.6		86.4	80.5	83.5	86.1 86.2
1.0	90.5	78.2	84.3		76.9	77.0	76.9	78.0 92.1 85.1
avg	90.1	82.2	86.1		84.7	78.4	81.5	83.2 87.0 85.1
<u>Atrazine</u>								
2.0 lb/A	93.5	91.7	92.6		70.7	85.3	78.0	91.2 86.5 88.8
1.5	81.1	76.6	78.9		86.2	85.9	86.0	85.4 80.6 83.0
1.0	93.1	95.1	94.1		85.9	86.8	86.3	88.6 84.2 86.4
avg	89.2	87.8	88.5		80.9	86.0	83.4	88.4 83.8 86.1
avg for Atrazine and Atrazine-oil	89.7	85.0	87.3		82.8	82.2	82.5	85.8 85.4 85.6

^aCorrected to 15.5% moisture.

^bOil was applied at 1.5 gpa.

^cHalf the herbicide rate was applied when weed growth was 0-1.5 inches high and the other half applied 10 days later.

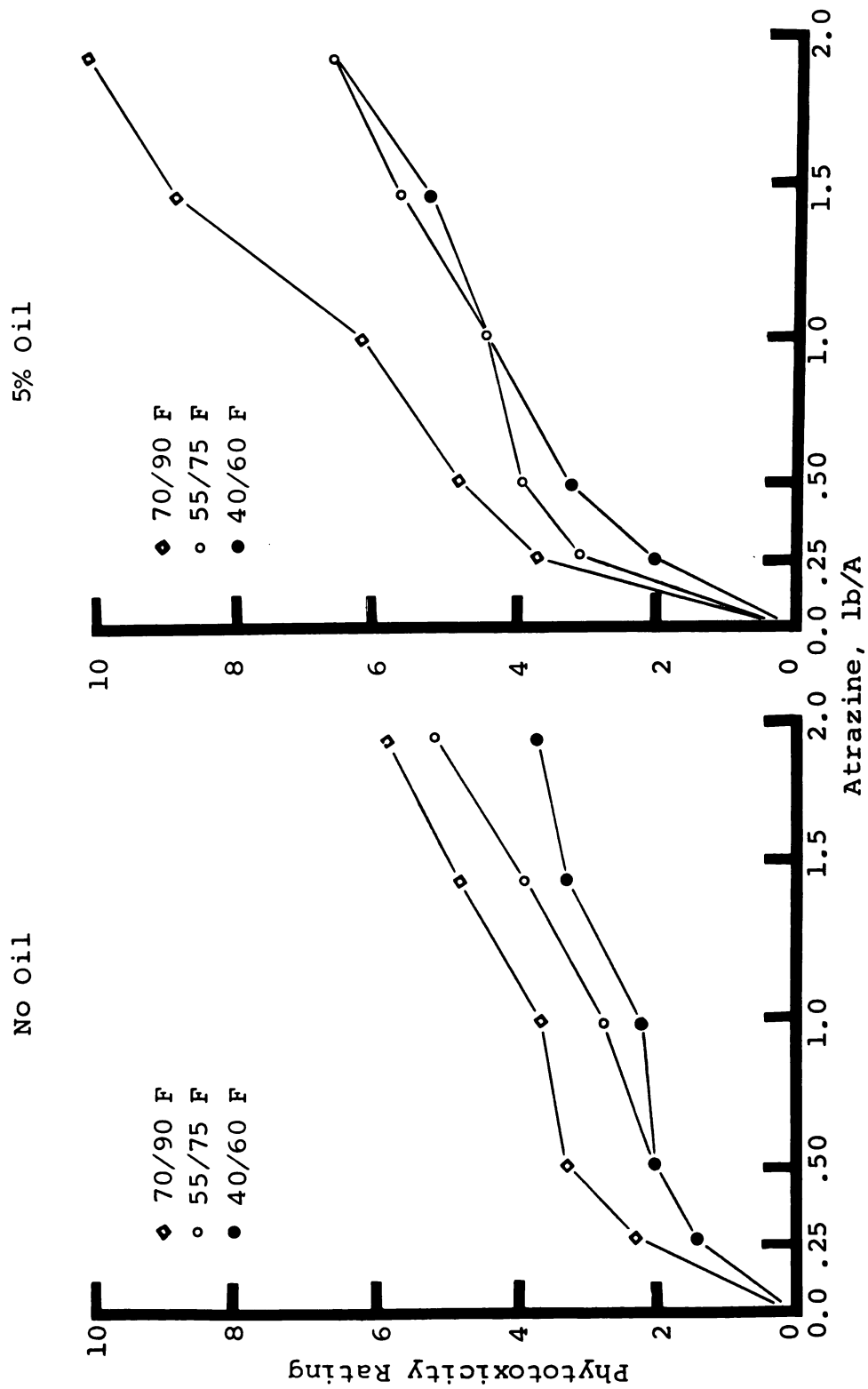


Figure 4. Phytotoxicity of atrazine to yellow foxtail as affected by temperature levels and oil vs no oil (0 = no control; 10 = complete control).

lower temperatures (55/75 and 40/60 F). The higher temperatures apparently enhanced penetration of atrazine through the cuticle. This could be due to the affect of temperature on binding, accumulation, metabolic conversion, and translocation of atrazine. The atrazine x oil x temperature interaction was highly significant. At the high temperature, the phytotoxicity ratings were much greater from all rates of atrazine when oil was added. Atrazine, without oil, was more phytotoxic in the 55/75 F regime than in the 40/60 F regime at the three highest rates. Atrazine, plus 5% oil, revealed no difference between the two lower temperature levels.

Phytotoxicity ratings were significantly different for the two humidity levels (Figure 5). All treatments were more phytotoxic at the higher humidity. This difference could be attributed to the affect of R.H. on the plant's water stress, stomatal opening, and cuticular permeability. These results are similar to those of Pallas (1960) where he found that higher R.H. increased foliar penetration of 2,4-D. There was a linear relationship between the atrazine rates (.25 to 2.0 lb/A) and phytotoxicity rating. The ratings ranged from 1.7 to 10.0 on the 0 to 10 rating scale. Phytotoxicity from all atrazine treatments was significantly enhanced by the addition of oil to the spray mixture. The atrazine x oil interaction was significant. When averaged over the humidity levels, the oil enhanced phytotoxicity to

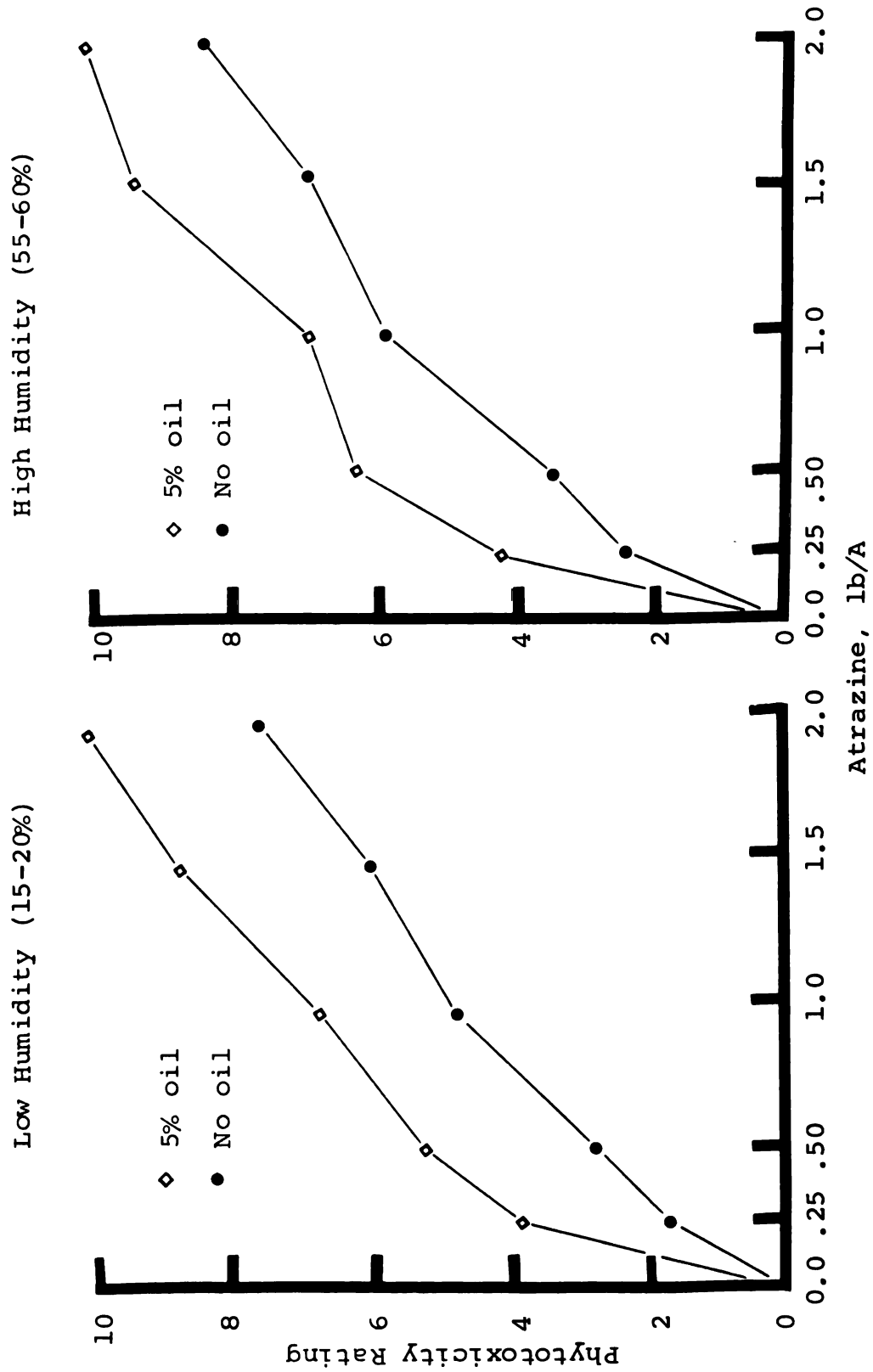


Figure 5. Phytotoxicity of atrazine to yellow foxtail as affected by humidity levels and oil vs no oil (0 = no control; 10 = complete control).

a greater degree at the lower rates of atrazine. The other interactions consisting of atrazine x humidity, oil x humidity, and atrazine x oil x humidity were not significant.

The light/dark experiment was conducted in growth chambers to complement the field experiment where morning vs evening spraying was evaluated. Results were similar to the field data. When phytotoxicity ratings from the atrazine and oil treatments were averaged, there was no significant difference between spray application in the light or dark (Figure 6). In contrast, Currier et al. (1964) reported greater foliar penetration of 2,4-D and dalapon by plants kept in the light than in those kept in darkness prior to spraying. They attributed the difference to stomatal opening which allowed for more penetration. Since this difference was not found for atrazine, it may be that penetration occurs primarily through the cuticle rather than through the stomatal openings. The atrazine x oil interaction was significant while the main effects of atrazine and oil were highly significant. Phytotoxicity was increased with each increment of atrazine and the oil enhanced phytotoxicity at every atrazine level. The light treatments did not significantly interact with either atrazine or oil. In addition, the light x atrazine x oil interaction was not significant.

Phytotoxicity from postemergence atrazine was significantly affected by the high, medium, and low soil moisture levels (100, 50, and 10% available water, respectively).

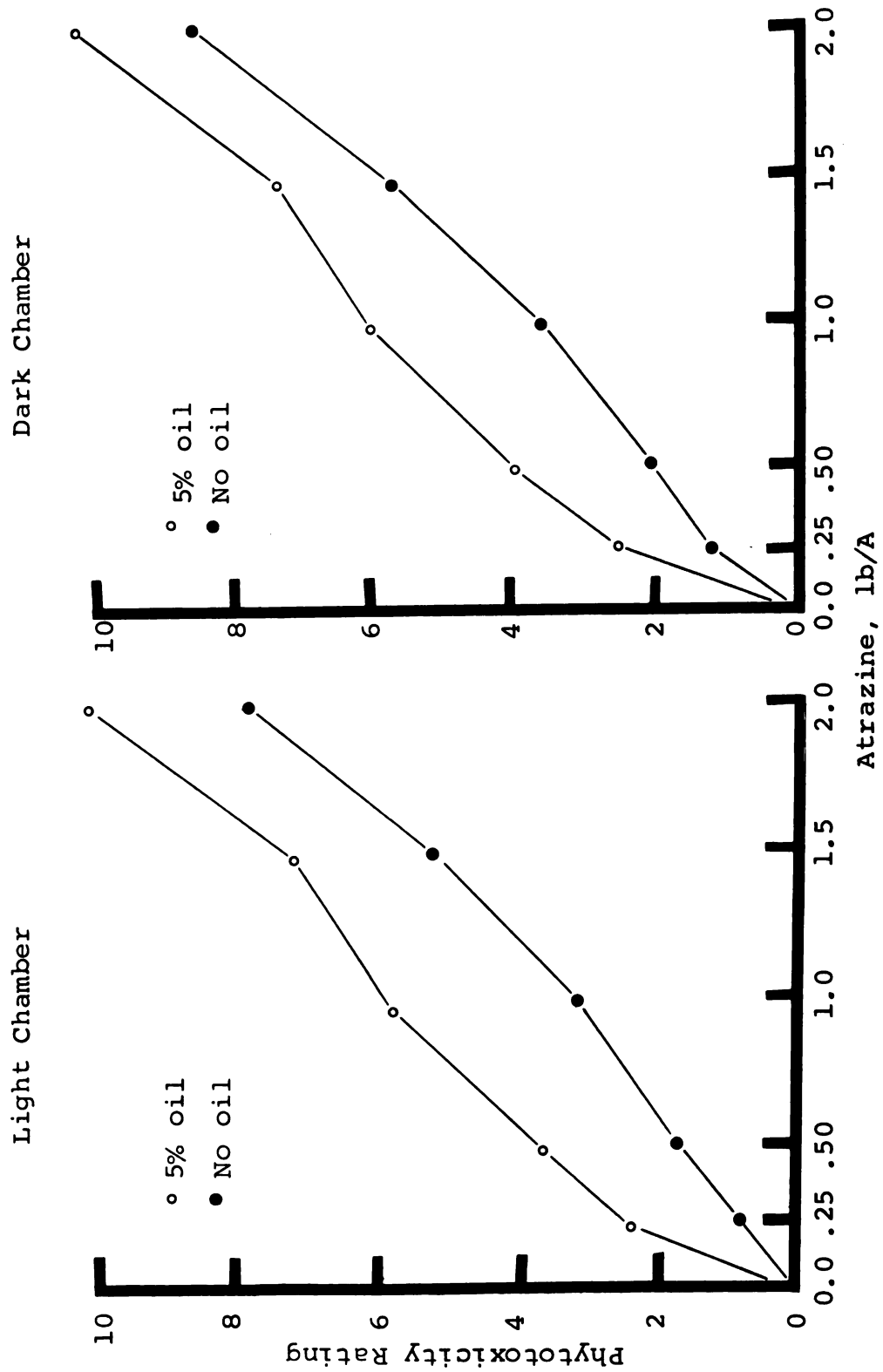


Figure 6. Phytotoxicity of atrazine to yellow foxtail as affected by light vs dark and oil vs no oil (0 = no control; 10 = complete control).

When averaged over the atrazine and oil factors, the phytotoxicity ratings decreased in sequence from high to low soil moisture for both foliage and soil-foliage applications (Table 5). There was a significant difference between spray application on the foliage vs the soil and foliage. Phytotoxicity was much greater at the high moisture level when the spray application was applied to both soil and foliage. Only a slight difference was obtained at the medium moisture level and no difference at the low moisture level. At the high moisture level, there was apparently more water movement into the plant. This water movement facilitated root uptake of atrazine which complemented foliar penetration and thus increased the phytotoxicity ratings. At the low moisture level, the atrazine was probably adsorbed to clay and organic matter since there would be little or no water movement to facilitate root uptake. The atrazine x oil interaction was highly significant. The oil enhanced phytotoxicity from atrazine at all levels but to a greater degree at the lower levels. Moisture interacted significantly with both atrazine and oil. Oil enhanced phytotoxicity from atrazine to the greatest degree at the medium moisture level. Increasing increments of atrazine enhanced phytotoxicity to the greatest degree at the high moisture level. The moisture x atrazine x oil interaction was highly significant. Phytotoxicity from the lower atrazine rates was enhanced the most by oil when applications were made at the low moisture

Table 5. Phytotoxicity of atrazine to yellow foxtail as affected by soil moisture levels and oil vs no oil (0 = no control; 10 = complete control)

Soil Moisture Level	Phytotoxicity Ratings					
	High		Medium		Low	
Spray Application	Foliage ^a	Soil- b Foliage	avg	Foliage ^a	Soil- b Foliage	avg
<u>Atrazine-oil^c</u>						
0.25 lb/A	3.7	4.9	4.3	2.6	3.0	2.8
0.50	3.9	5.1	4.5	3.2	3.4	3.3
0.75	4.3	6.2	5.2	3.9	4.6	4.2
1.00	6.8	10.0	8.4	4.5	5.5	5.0
1.50	7.3	10.0	8.6	6.2	6.5	6.4
avg	5.2	7.2	6.2	4.1	4.6	4.3
				2.7	2.8	2.8
						4.4
<u>Atrazine</u>						
0.25 lb/A	2.5	3.3	2.9	1.2	2.1	1.6
0.50	2.8	3.3	3.0	1.5	2.3	1.9
0.75	3.5	3.9	3.7	2.3	2.4	2.4
1.00	3.9	6.3	5.1	2.5	3.5	3.0
1.50	4.5	7.7	6.1	3.7	3.7	3.7
avg	3.4	4.9	4.2	2.2	2.8	2.5
				1.7	1.7	1.7
						2.8
avg for Atrazine and Atrazine-Oil	4.3	6.0	5.2	3.2	3.7	3.4
				2.2	2.2	2.2
						3.6

^a Applied only to foliage.

^b Applied to both soil and foliage.

^c 5% oil by volume.

level. In contrast, higher rates of atrazine benefited more from oil at the high moisture level.

Preconditioning the plant foliage with oil-water emulsions before atrazine application revealed a significant difference (Table 6). No difference was noted between the 5 and 10% oil-water emulsions applied with the atrazine. However, the 10% oil-water emulsion applied 24 hr prior to atrazine enhanced phytotoxicity. In contrast, the 5% oil-water emulsion applied 72 hr prior to atrazine gave less phytotoxicity compared to no preconditioning. The decrease from the 72 hr preconditioning could have been due to partial evaporation and runoff of the oil prior to the atrazine application. Thus, the oil would be less effective in spreading the atrazine water suspension and in enhancing foliar penetration.

Foliar Penetration

Autoradiographs of corn and yellow foxtail plants revealed that foliar-applied ^{14}C -atrazine penetrated the leaf surface and moved acropetally. There was no basipetal translocation in either species. These results are in agreement with Foy (1964), Wax and Behrens (1965) and many others. Corn (Figures 7 and 8) and yellow foxtail plants (Figures 9, 10, and 11) are shown with autoradiographs after foliar treatment with ^{14}C -atrazine in a 5% oil-water emulsion.

Table 6. Effect of preconditioning with oil on the phytotoxicity of atrazine to yellow foxtail (0 = no control; 10 = complete control)

Rate of Oil	No Preconditioning ^a			24 hr Preconditioning ^b			72 hr Preconditioning ^c		
	5%	10%		5%	10%		5%	10%	
Atrazine (lb/A)	Phytotoxicity Ratings								
0.25	2.0	2.0		3.0	3.0		2.0	2.0	
0.50	3.0	3.0		2.0	3.0		2.0	3.0	
1.00	7.0	7.0		7.0	7.0		6.0	7.0	
1.50	8.0	8.0		9.0	9.0		8.0	8.0	
avg	5.0	5.0		5.2	5.5		4.5	5.0	

^aOil applied in combination with atrazine.

^bOil applied 24 hr prior to atrazine.

^cOil applied 72 hr prior to atrazine.

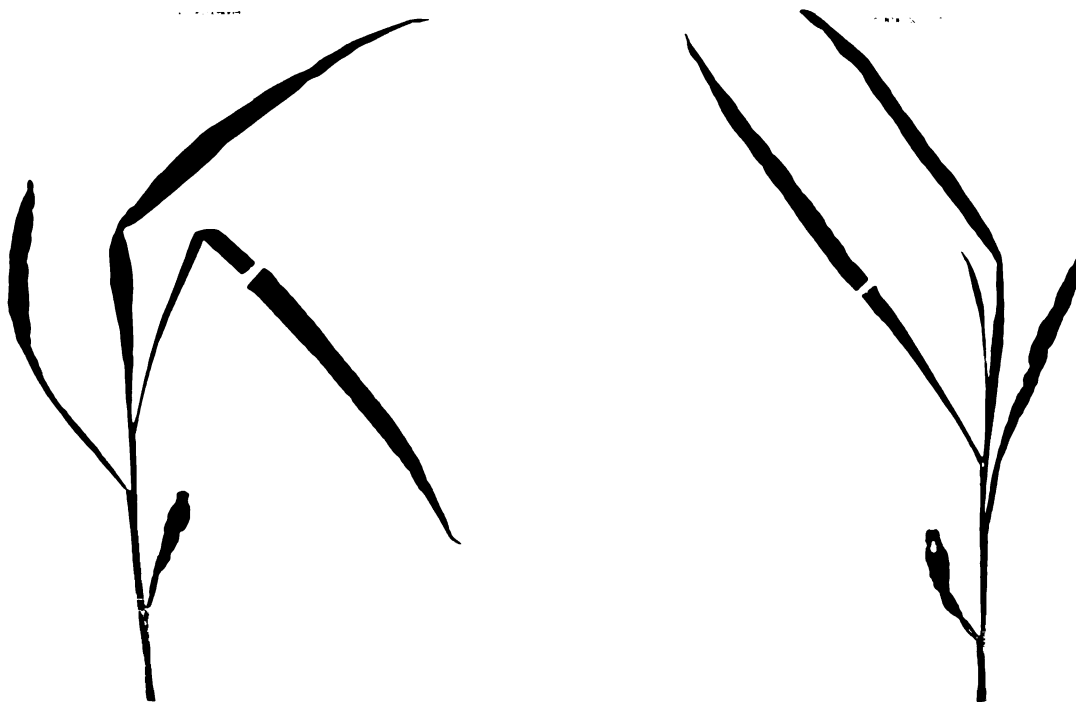


Figure 7. Corn plants and autoradiographs after foliar treatment with ^{14}C -atrazine in a 5% oil-water emulsion. Left: Control plant (no treatment). Right: Plant harvested 30 min after atrazine treatment.



Figure 8. Corn plants and autoradiographs after foliar treatment with ^{14}C -atrazine in a 5% oil-water emulsion. Left: Plant harvested 12 hr after atrazine treatment. Right: Plant harvested 48 hr after atrazine treatment.

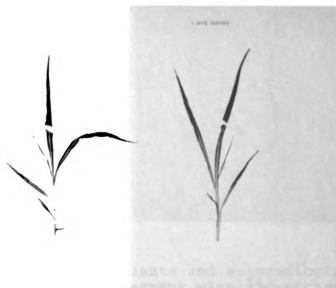


Figure 9. Yellow foxtail plants and autoradiographs after foliar treatment with ^{14}C -atrazine in a 5% oil-water emulsion. Left: Plant harvested 30 min after atrazine treatment. Right: Plant harvested 1 hr after atrazine treatment.



Figure 10. Yellow foxtail plants and autoradiographs after foliar treatment with ^{14}C -atrazine in a 5% oil-water emulsion. Left: Plant harvested 6 hr after atrazine treatment. Right: Plant harvested 12 hr after atrazine treatment.



Figure 11. Yellow foxtail plants and autoradiographs after foliar treatment with ^{14}C -atrazine in a 5% oil-water emulsion. Left: Plant harvested 24 hr after atrazine treatment. Right: Plant harvested 48 hr after atrazine treatment.

Foliar penetration and translocation was apparent in both species after 30 min of exposure and continued to increase with time. Other treatments consisted of ^{14}C -atrazine in a water solution and in a 10% oil-water emulsion. No visual differences in the autoradiographs were observed between the 5 and 10% oil-water emulsions. However, penetration and translocation from the water solution was much less than from the oil-water emulsions.

Foliar penetration of ^{14}C -atrazine (measured by the combustion technique) was progressively greater from the 12, 24, and 48 hr periods of treatment (Figures 12 and 13). However, penetration of ^{14}C -atrazine was not linear with time. When averaged over all treatments, foliar penetration of corn by ^{14}C -atrazine after 12, 24, and 48 hr was 8.3, 14.9, and 22.7%, respectively, of the amount applied. Penetration of yellow foxtail was less than corn at all three time intervals. This could be due to more exposed surface area on the corn leaves since the lanolin barrier enclosed 2 cm^2 compared to 1 cm^2 for yellow foxtail. Foliar entry of ^{14}C -atrazine was significantly enhanced when applied in oil-water emulsions compared to a water solution. The first increment of oil (5%) greatly increased foliar penetration of corn and yellow foxtail. However, the higher rate of oil (10%) was only slightly superior to the 5% rate. The oil reduced the surface tension of water and facilitated the spray droplets to spread evenly over the entire leaf area

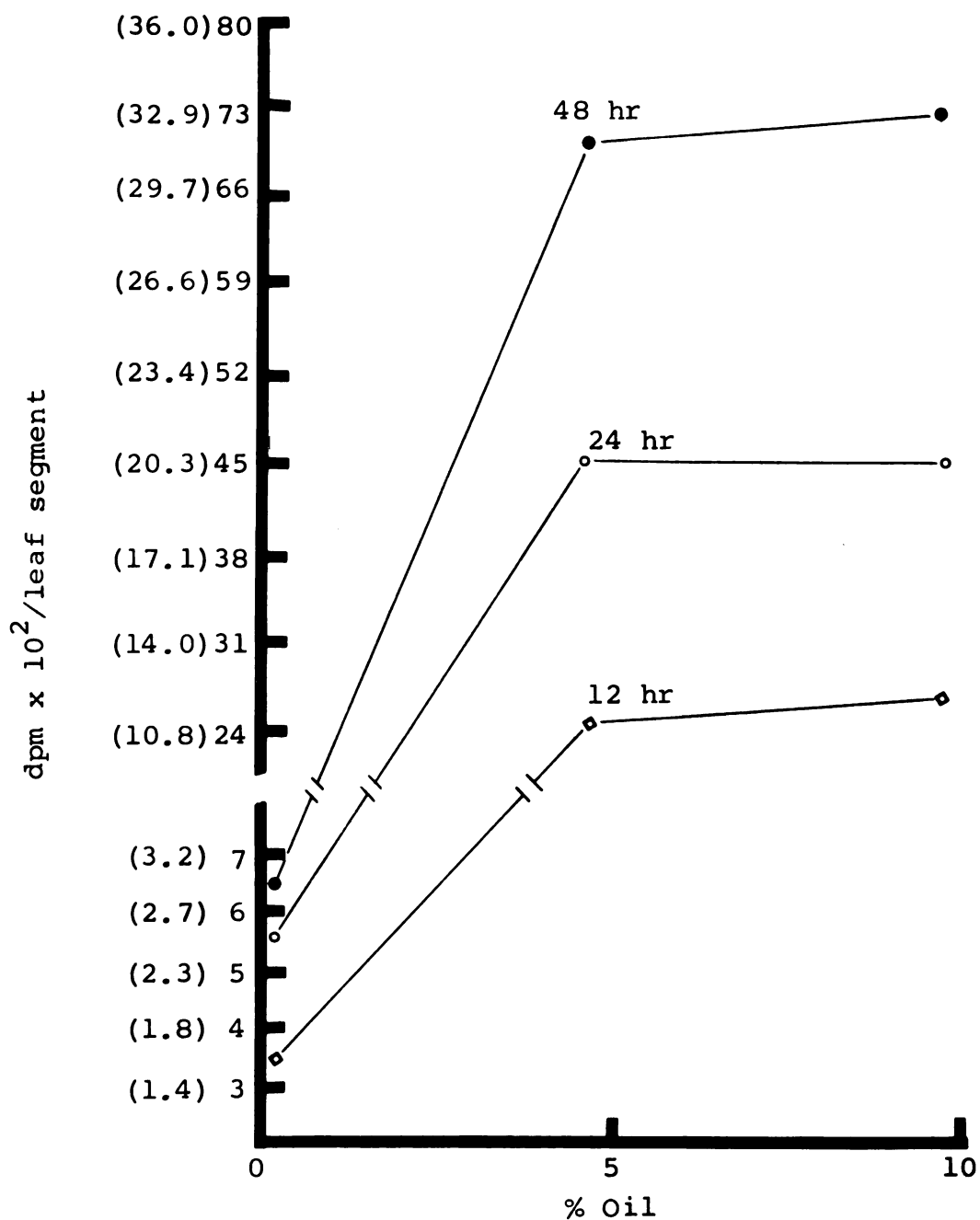


Figure 12. Effect of oil-water emulsions on foliar penetration of corn by ^{14}C -atrazine after 12, 24, and 48 hr (values within parentheses equal percent of total radioactivity applied).

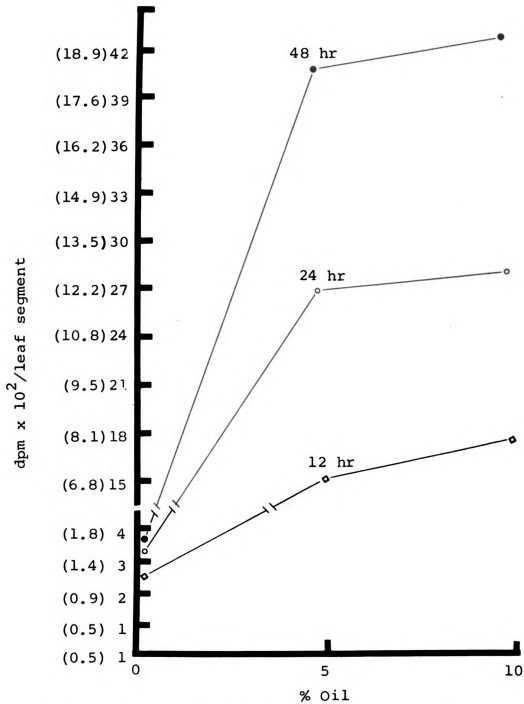


Figure 13. Effect of oil-water emulsions on foliar penetration of yellow foxtail by ^{14}C -atrazine after 12, 24, and 48 hr (values within parentheses equal percent of total radioactivity applied).

inside the lanolin barrier. The oil may also have functioned as a cosolvent or solubilizing agent to enhance cuticular penetration of ^{14}C -atrazine. The slight enhancement from the second increment of oil may have been due to the humectant effect. Drying out of the treatment solution would have been retarded, thus allowing more foliar penetration of ^{14}C -atrazine.

Evaluation of corn, yellow foxtail, nutsedge and velvetleaf each at three stages of growth revealed a significant difference among species and among stages of growth with respect to foliar penetration of ^{14}C -atrazine (Table 7). For all adjuvant treatments, foliar penetration was inversely related to stage of growth for all plant species. Similar results have been shown by Blackman et al. (1958) and Weintraub et al. (1954). Young expanding leaves have a lesser developed cuticle than older leaves and thus are more easily penetrable. Foliar penetration was greatest into velvetleaf while the least penetration was into nutsedge. This could be attributed to the differences in the cuticular surfaces of the two species. Velvetleaf has a pubescent leaf surface which tends to retain spray droplets. In contrast, the nutsedge leaf surface is glabrous and repels spray droplets. Foliar penetration of velvetleaf was equally enhanced by oil-water emulsions and X-77 surfactant. However, the surfactant was inferior to oil-water emulsions for the other plant species. Perhaps the differential penetration among species was due to the physical form of the herbicide

Table 7. Effect of adjuvants and stage of growth on foliar penetration of corn, yellow foxtail, nutsedge and velvetleaf by ¹⁴C-atrazine

Plant Species	Stage of Growth When Treated (inches)	Total dpm/leaf segment				
		Adjuvant				avg
		None	5% Oil	10% Oil	.1% X-77	
Corn	4.0	730	7200	7180	4110	4800
	6.0	530	5140	5160	4050	3720
	8.0	220	4070	4120	3830	3060
	avg	490	5470	5490	4000	3860
		(2.2) ^a	(24.6)	(24.7)	(18.0)	(17.4)
Yellow Foxtail	1.5	600	6130	6170	6020	4730
	3.0	440	5010	4950	4710	3780
	5.0	300	3800	3920	3760	2940
	avg	450	4980	5020	4830	3820
		(2.0)	(22.4)	(22.6)	(21.7)	(17.2)
Nutsedge	2.0	310	4220	4620	2980	3030
	4.0	250	3980	4020	3910	3040
	6.0	140	3790	3780	3670	2850
	avg	230	4000	4140	3520	2970
		(1.0)	(18.0)	(18.6)	(15.9)	(13.4)
Velvetleaf	1.5	2120	8830	8900	8610	7110
	3.0	1710	7460	7550	7270	6000
	5.0	1660	7330	7380	7440	5950
	avg	1830	7880	7940	7770	6350
		(8.2)	(35.5)	(35.8)	(35.0)	(28.6)

^aValues within parentheses equal percent of total radioactivity applied.

solutions on the leaf surfaces. The X-77 surfactant may have functioned primarily as a spreading agent while the oil-water emulsions may have functioned both as spreaders and as solubilizing agents to enhance penetration through the glabrous leaf surfaces.

The "light" treatments significantly affected foliar penetration of ^{14}C -atrazine in corn and yellow foxtail (Figures 14 and 15). The interaction between light and oil was also significant. The greatest amount of foliar entry for both corn and yellow foxtail was from the light/dark treatment. Similar results with dalapon and 2,4-D were reported by Currier et al. (1964). They found greater penetration in leaves of plants kept in the light than in those kept in darkness prior to spraying. The least amount of penetration was from the dark/dark treatment for both species. No difference in foliar entry by corn was noted between the light/light and dark/light treatments. However, penetration by yellow foxtail was greater from the dark/light treatment than from the light/light treatment. The differential penetration among the "light" treatments could be attributed partially to stomatal opening since light affects this process. If the atrazine enters through the stomates, then it would be expected to find a greater amount of penetration into leaves of plants exposed to light. Sargent (1965) suggested that light may promote foliar penetration by causing an increase in the export of carbohydrates

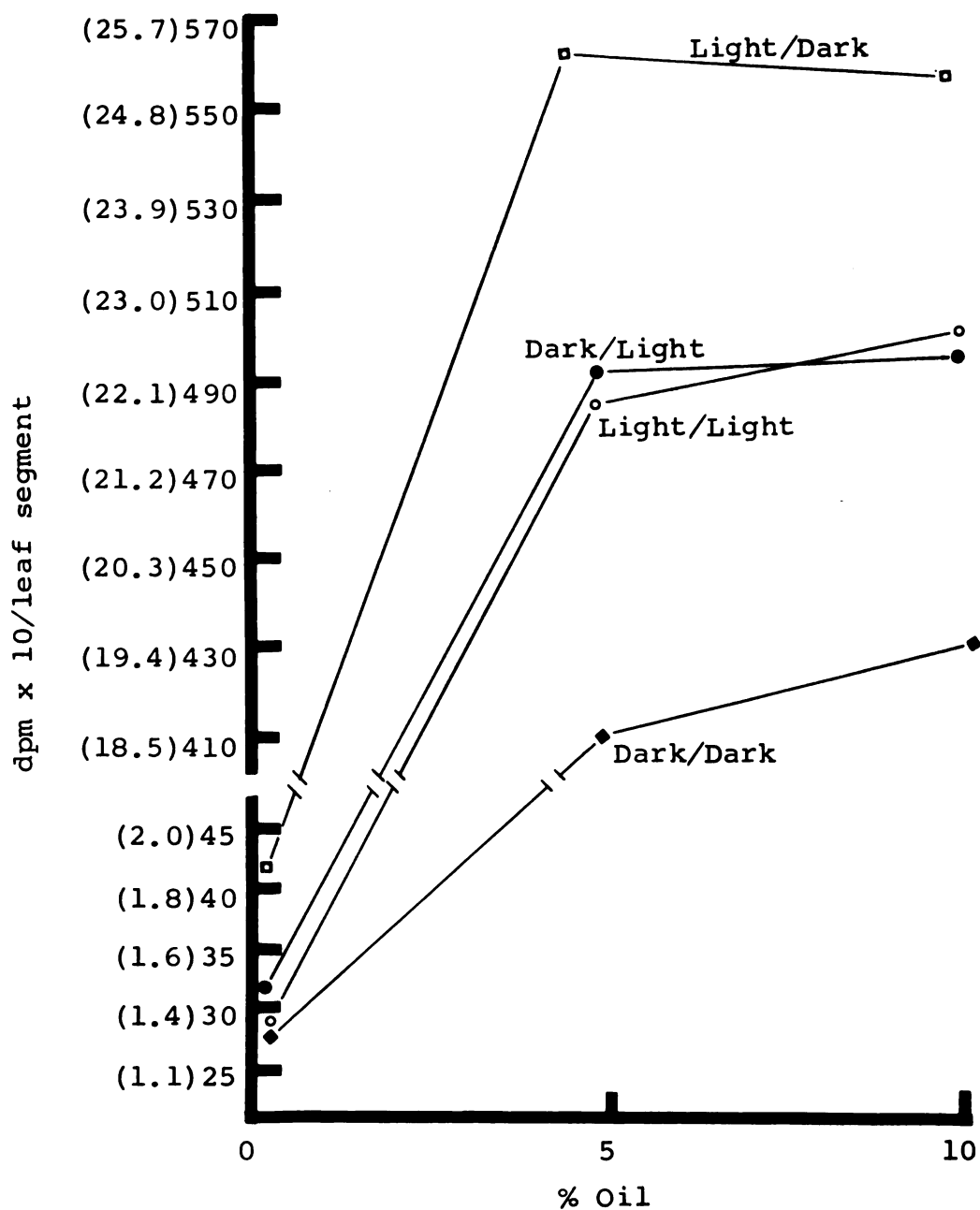


Figure 14. Foliar penetration of corn by ^{14}C -atrazine as influenced by oil-water emulsions and "light" treatments (values within parentheses equal percent of total radioactivity applied).

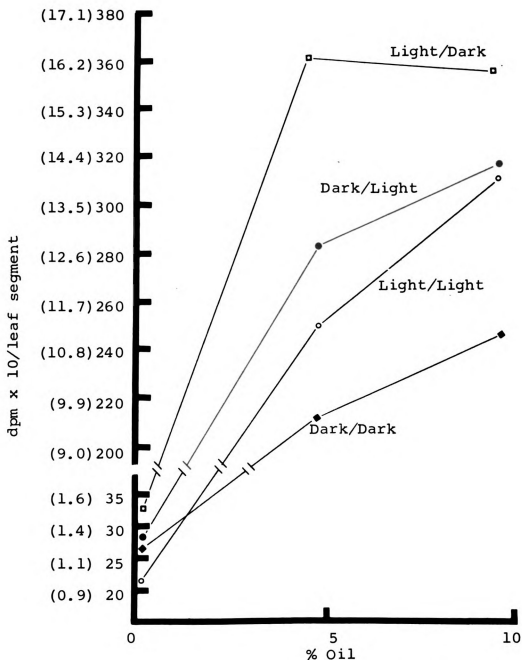


Figure 15. Foliar penetration of yellow foxtail by ^{14}C -atrazine as influenced by oil-water emulsions and "light" treatments (values within parentheses equal percent of total radioactivity applied).

from the leaf. With this latter suggestion in mind, plants exposed to light before treatment with ^{14}C -atrazine would be more receptive to penetration than plants exposed to darkness before treatment. Another possible explanation for increased penetration in plants exposed to light is that the "light" treatments may differentially affect the rate of atrazine metabolism and thus would influence the concentration gradient across the leaf surface.

Soil moisture significantly affected foliar penetration of ^{14}C -atrazine into corn and yellow foxtail (Figures 16 and 17). When averaged over all treatments, foliar entry into corn was decreased from 16.3 to 9.5 and 3.7% of the total applied when soil moisture was depleted to 50 and 10% of F.C., respectively. The trend was similar for yellow foxtail but foliar entry was retarded to a greater degree at the 50% moisture level. Similar results have been reported with other compounds. Smith et al. (1959) found that maleic hydrazide absorption was severely curtailed by decreasing turgidity in tomato plants and Hauser (1955) reported that plants grown with decreased soil moisture absorbed 2,4-D more slowly than plants supplied with adequate water. Weintraub et al. (1954) reported that after absorbing water the plant cuticle swells and spreads apart the embedded wax platelets which have hydrophilic properties. Plants with adequate moisture would function in this manner and thus foliar penetration would be increased. In contrast, plants under moisture stress would result in the wax platelets

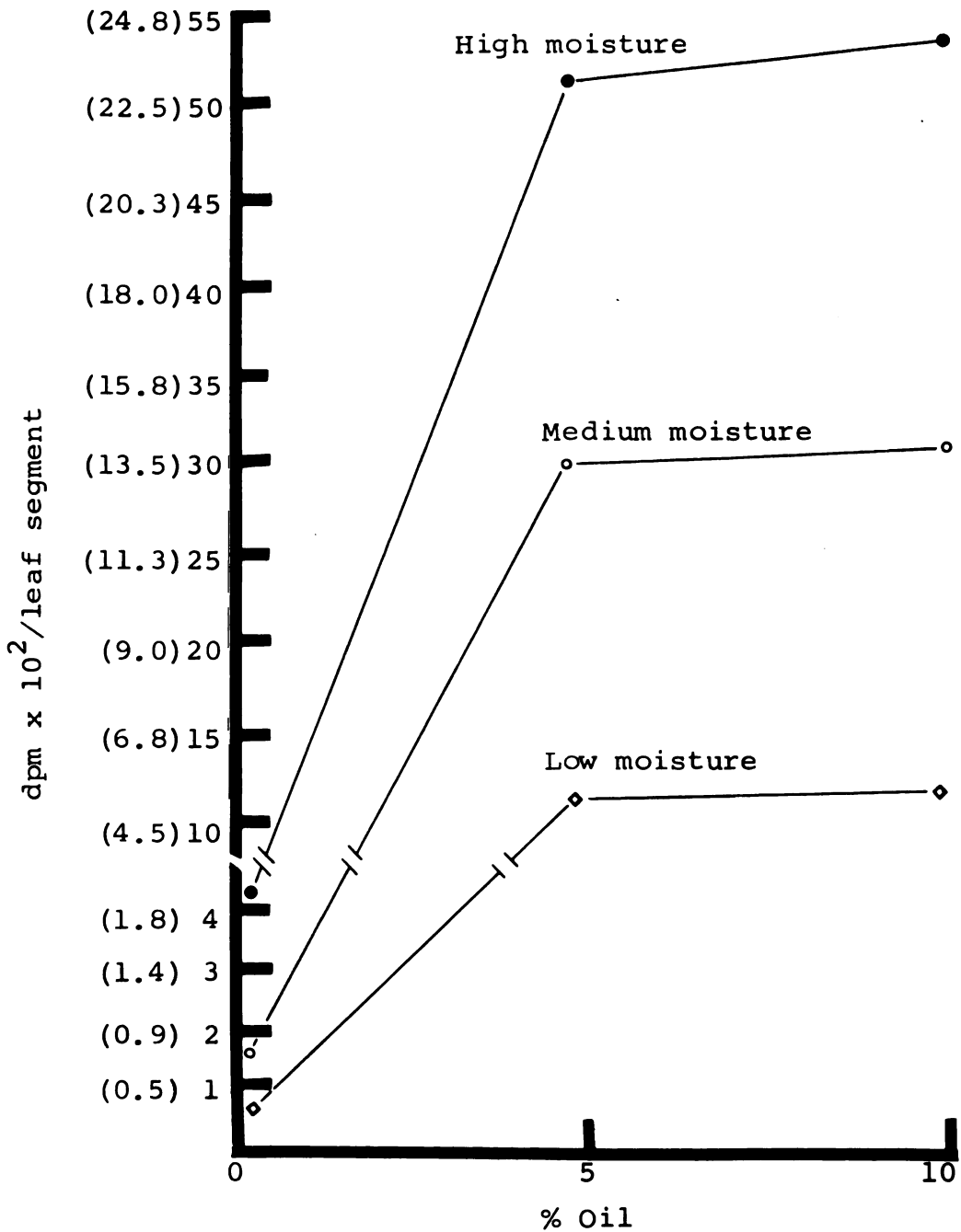


Figure 16. Foliar penetration of corn by ^{14}C -atrazine as influenced by oil-water emulsions and soil moisture levels (values within parentheses equal percent of total radioactivity applied).

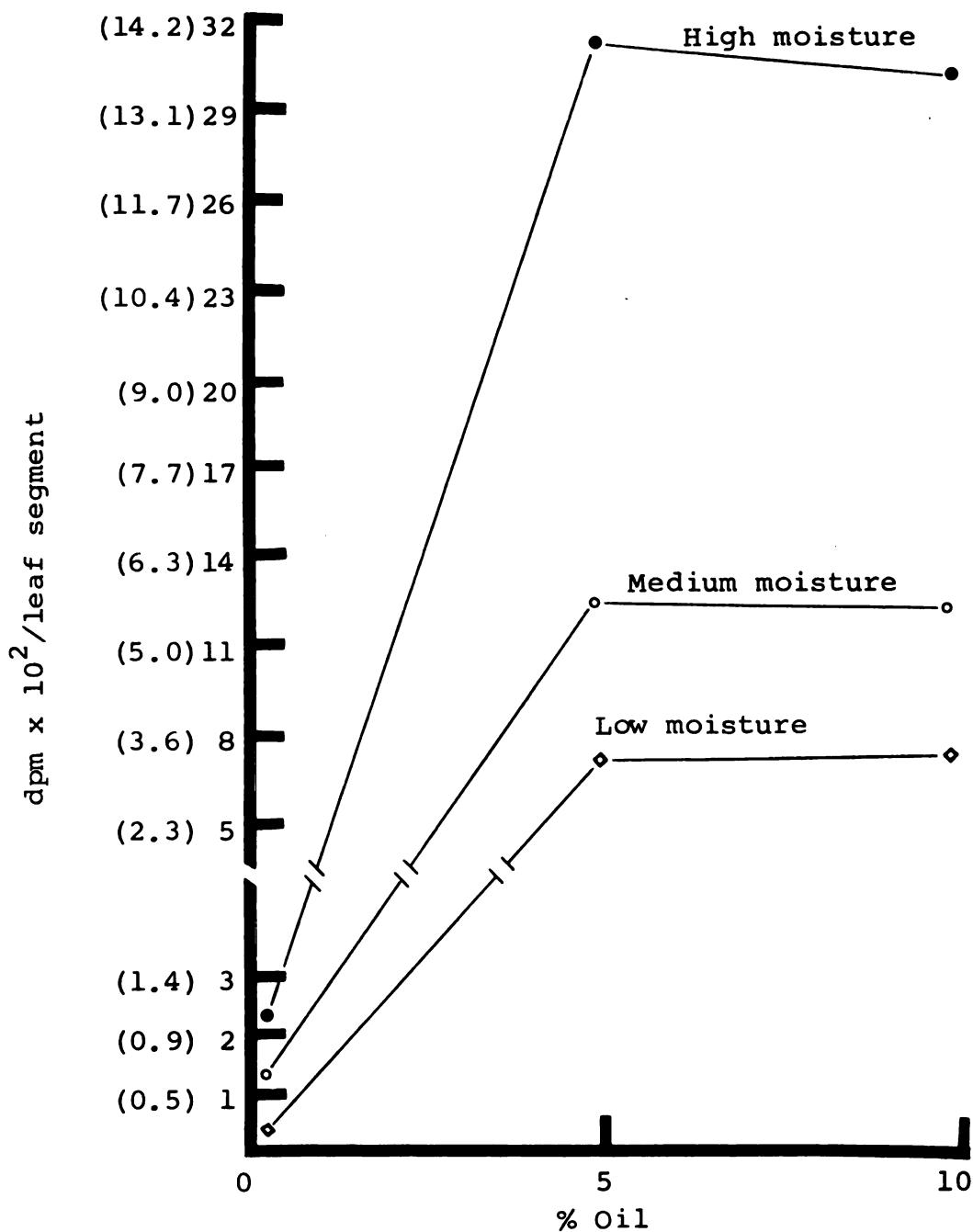


Figure 17. Foliar penetration of yellow foxtail by ^{14}C -atrazine as influenced by oil-water emulsions and soil moisture levels (values within parentheses equal percent of total radioactivity applied).

being closer together and therefore reduce penetration through the cuticle. Oil greatly enhanced entry but no difference was found between the 5 and 10% rates. The oil x moisture interaction was highly significant. Oil enhanced ^{14}C -atrazine entry at all moisture levels but to the greatest degree at the high moisture level.

Foliar penetration of corn by ^{14}C -atrazine (Figure 18) was progressively higher with 60/40, 75/55, and 90/70 F day/night temperatures. These results are similar to those of Barrier and Loomis (1957) who reported that increased temperatures increased foliar penetration of 2,4-D. However, there was no difference in penetration of yellow foxtail (Figure 19) between the two lower temperature regimes. Foliar entry was enhanced by oil-water emulsions at all three temperature levels. The oil x temperature interaction was highly significant for both corn and yellow foxtail. At the high temperature, no difference was noted between 5 and 10% oil. However, foliar penetration was increased with the higher rate of oil at the two lower temperatures. The higher temperatures may have directly affected foliar penetration of ^{14}C -atrazine by increasing the diffusion rate through the cuticular surface. Enhancement of penetration by higher temperatures may also be attributed to increased metabolic conversion of the atrazine and increased translocation from the treated area.

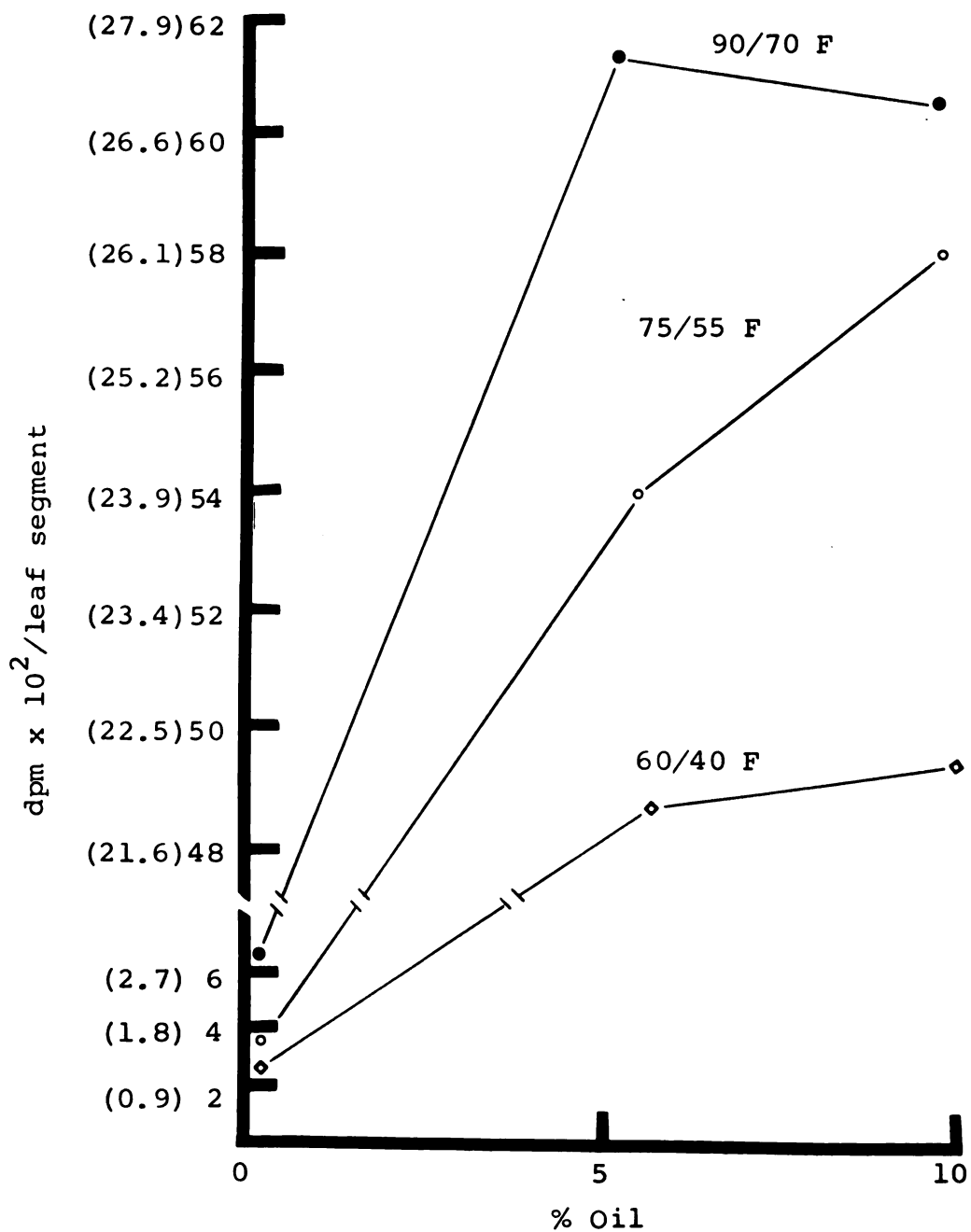


Figure 18. Foliar penetration of corn by ^{14}C -atrazine as influenced by oil-water emulsions and temperature regimes (values within parentheses equal percent of total radioactivity applied).

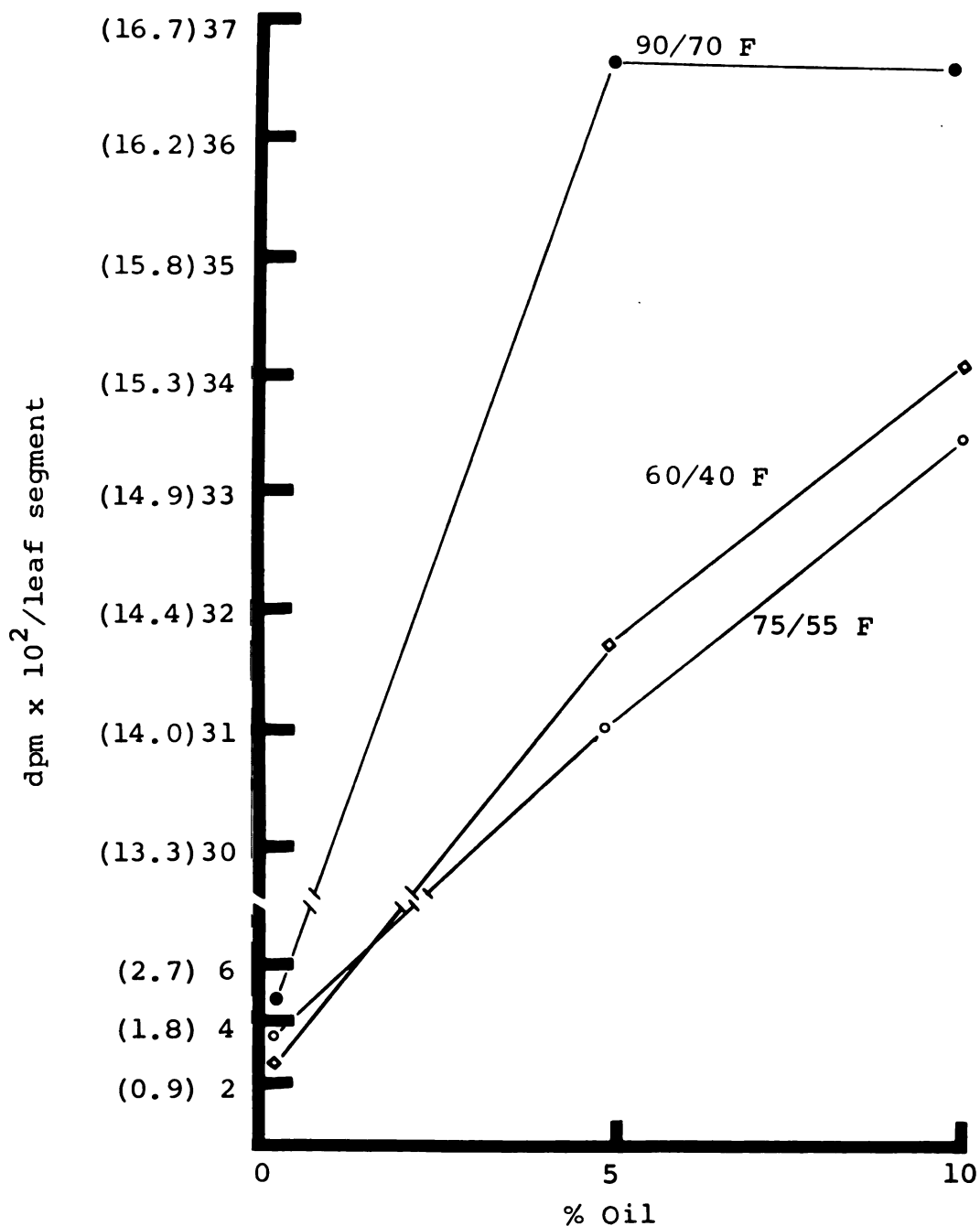


Figure 19. Foliar penetration of yellow foxtail by ^{14}C -atrazine as influenced by oil-water emulsions and temperature regimes (values within parentheses equal percent of total radioactivity applied).

Relative humidity significantly affected foliar uptake of ^{14}C -atrazine by corn and yellow foxtail (Figures 20 and 21). The 100% R.H. greatly enhanced uptake while very little difference was noted between the two lower humidity regimes. Droplets dried less rapidly at the high R.H., thus prolonging the period of effective absorption. Condensation may have occurred at the treated spots which would maintain the ^{14}C -atrazine in solution for foliar uptake. The 5 and 10% oil-water emulsions enhanced foliar entry at all humidity levels. The oil x humidity interaction was highly significant for both corn and yellow foxtail. At the two lower humidities, no difference in foliar entry was observed between the 5 and 10% oil-water emulsions. At the high humidity, however, foliar entry was enhanced by the higher rate of oil. Similar results with amitrole and 2,4-D were reported by Clor et al. (1962) who found that the rate of penetration and translocation was enhanced when plants were placed in a high humidity atmosphere. The increased penetration of ^{14}C -atrazine at the high humidity level could be attributed to the affect of high R.H. on physiological phenomena such as water stress within the plant, stomatal opening, and cuticular permeability.

Conditioning leaves of corn and yellow foxtail significantly enhanced foliar penetration of ^{14}C -atrazine (Table 8). Penetration was greatly enhanced when the ^{14}C -atrazine was applied in an oil-water emulsion. Oil-water

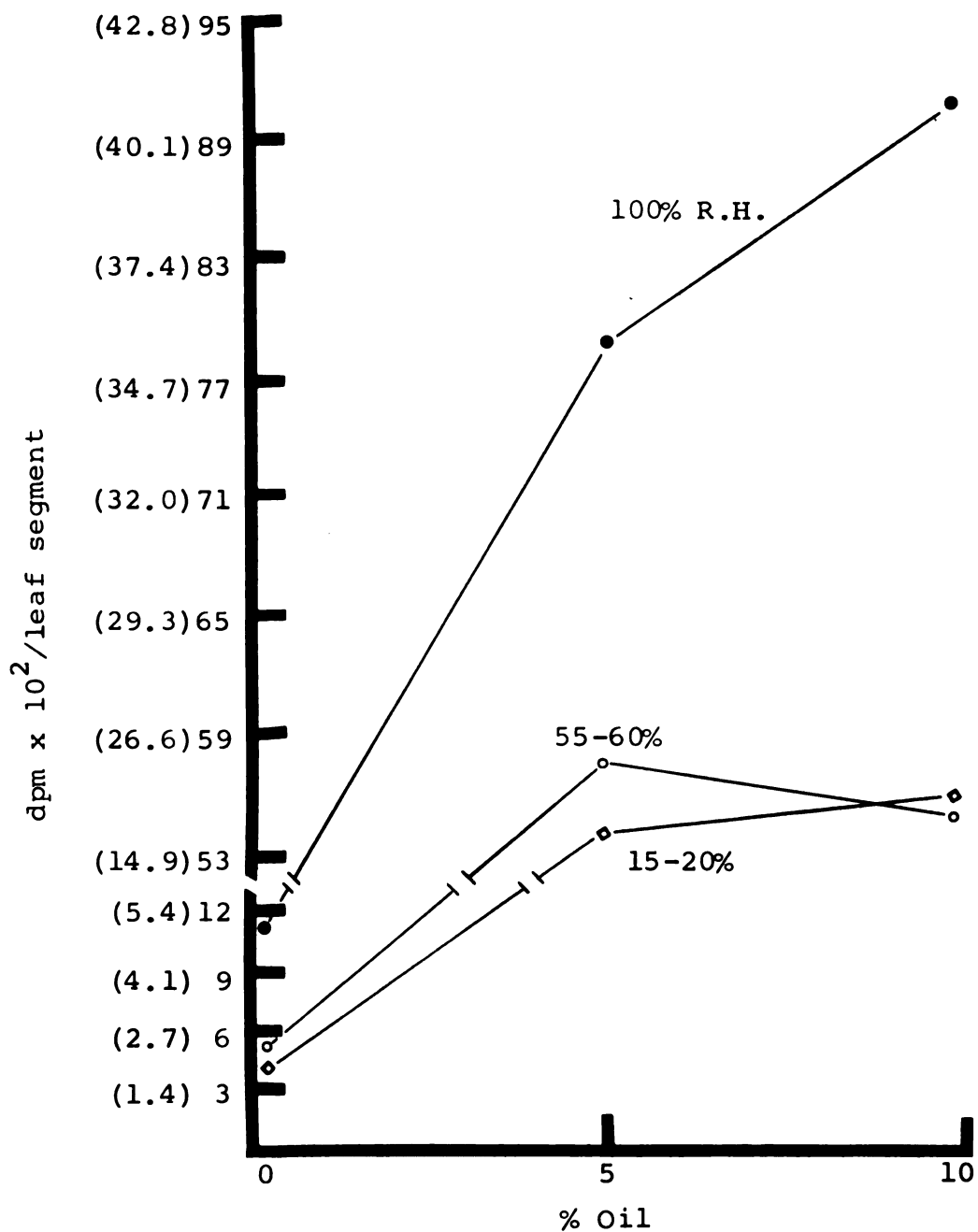


Figure 20. Foliar penetration of corn by ^{14}C -atrazine as influenced by oil-water emulsions and humidity regimes (values within parentheses equal percent of total radioactivity applied).

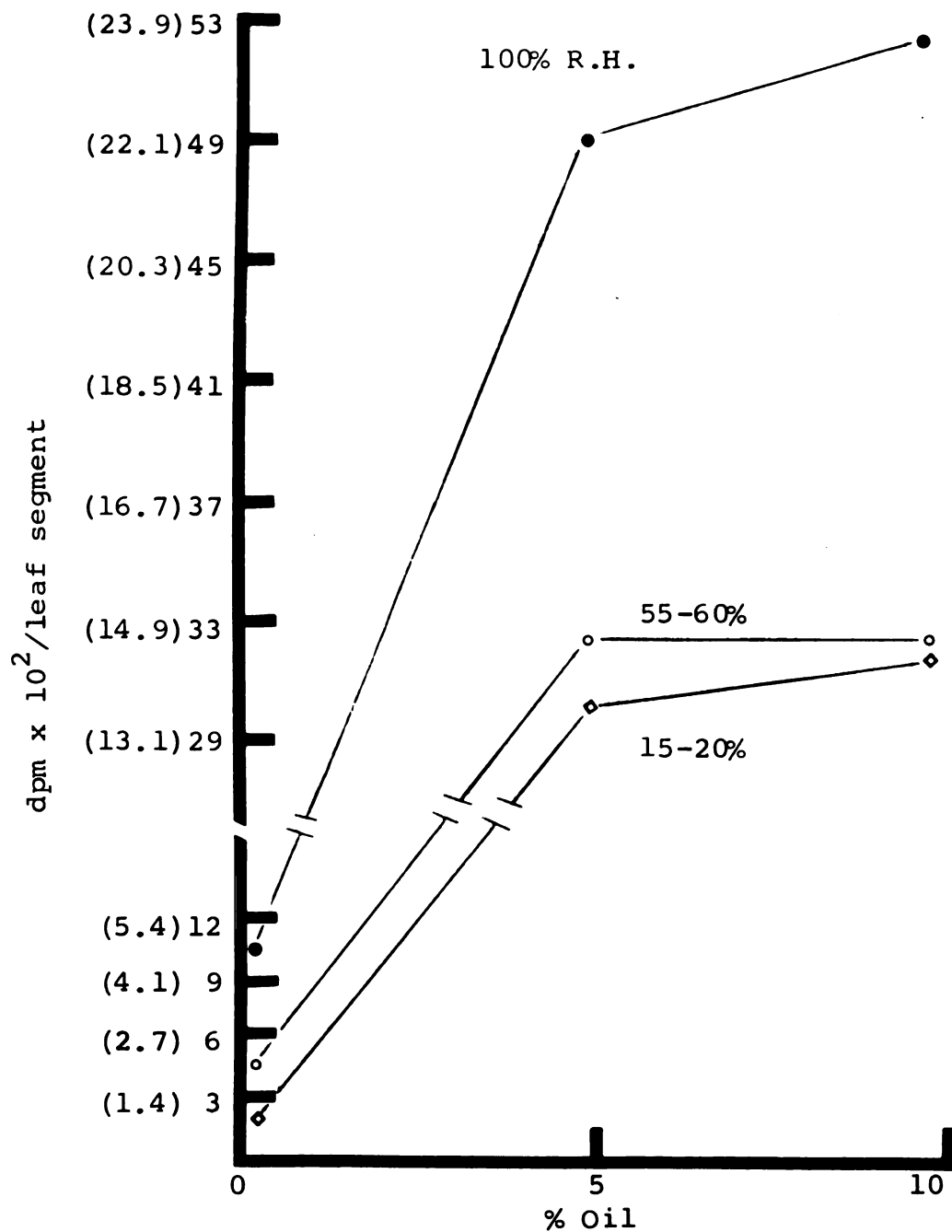


Figure 21. Foliar penetration of yellow foxtail by ^{14}C -atrazine as influenced by oil-water emulsions and humidity regimes (values within parentheses equal percent of total radioactivity applied).

Table 8. Foliar penetration of ^{14}C -atrazine as influenced by conditioning the plant foliage with an oil-water emulsion before and/or after treatment

Oil Conditioning				Total dpm/leaf segment	
48 hr prior ^a	24 hr prior ^a	24 hr after ^b	48 hr after ^b	^{14}C -atrazine ^c	Yellow Foxtail
..	..	..	..	..	500 (02.3)
..	..	..	..	X	4310 (19.4)
X	..	..	..	..	2910 (13.1)
..	X	..	..	..	3400 (15.3)
..	..	X	..	..	2710 (12.2)
..	..	..	X	..	3140 (14.1)
..	X	X	..	..	3510 (15.8)
..	X	X	..	X	8190 (36.9)
X	..	..	X	..	4800 (21.6)
X	..	..	X	X	5420 (24.4)
X	X	X	X	..	7900 (35.6)
X	X	X	X	X	8060 (36.3)

^aX denotes that an oil-water emulsion was applied 24 and/or 48 hr prior to ^{14}C -atrazine.

^bX denotes that an oil-water emulsion was applied 24 and/or 48 hr after ^{14}C -atrazine.

^cX denotes that ^{14}C -atrazine was applied in an oil-water emulsion.

^dValues within parentheses equal percent of total radioactivity applied.

emulsions applied 48 hr before, 24 hr before, 24 hr after, or 48 hr after ^{14}C -atrazine application were all effective for enhancing foliar penetration. However, none of the above treatments were as effective as applying the ^{14}C -atrazine in an oil-water emulsion. The most effective single oil conditioning treatment was the application of an oil-water emulsion 24 hr prior to applying ^{14}C -atrazine. Applying ^{14}C -atrazine in an oil-water emulsion to foliage that received additional oil-water applications (prior to and after ^{14}C -atrazine application) proved to be very effective. Applying oil-water emulsions 24 hr prior and 24 hr after ^{14}C -atrazine application were as effective as applying the ^{14}C -atrazine in an oil-water emulsion. In contrast, when the oil-water emulsions were applied 48 hr prior and 48 hr after ^{14}C -atrazine, less penetration occurred compared to the application of ^{14}C -atrazine in an oil-water emulsion. Foliar penetration of ^{14}C -atrazine applied in a water solution was equal to penetration of ^{14}C -atrazine applied in an oil-water emulsion when the leaf surfaces received oil-water emulsions at all four conditioning times. The conditioning treatments of oil-water emulsions may have functioned as solubilizing agents to facilitate penetration of atrazine through the leaf surface. They may have facilitated movement into the sub-stomatal cavities and enhanced penetration through the internal cuticle. The repeated applications of oil-water emulsions may have functioned as humectants to

retard the ^{14}C -atrazine from crystallizing, thus allowing foliar penetration for a greater period of time.

Rewetting the plant foliage with water 6 and/or 12 hr after ^{14}C -atrazine application significantly enhanced foliar penetration of corn and yellow foxtail (Figures 22 and 23). Oil-water emulsions significantly enhanced all rewetting treatments. The oil x rewetting interaction was highly significant for both species. When averaged over the oil treatments, no difference in penetration of corn by atrazine was noted between the 12 hr rewetting and no rewetting. In contrast, penetration of yellow foxtail was enhanced by the 12 hr rewetting period. Rewetting at both 6 and 12 hr after ^{14}C -atrazine application was the most effective treatment for both corn and yellow foxtail. The most plausible explanation for the increased penetration from the rewetting treatments is that the ^{14}C -atrazine deposits were redissolved. This would allow for additional penetration until the ^{14}C -atrazine deposits crystallized again.

Foliar penetration of corn by ^{14}C -atrazine was greater from treatments applied on the midrib than from treatments applied on the leaf-margin (Figure 24). The oil-water emulsions greatly enhanced foliar entry at both treatment sites. No difference was found between 5 and 10% oil-water emulsions. Greater penetration in the midrib area could be due to a thinner cuticle and less wax in this area.

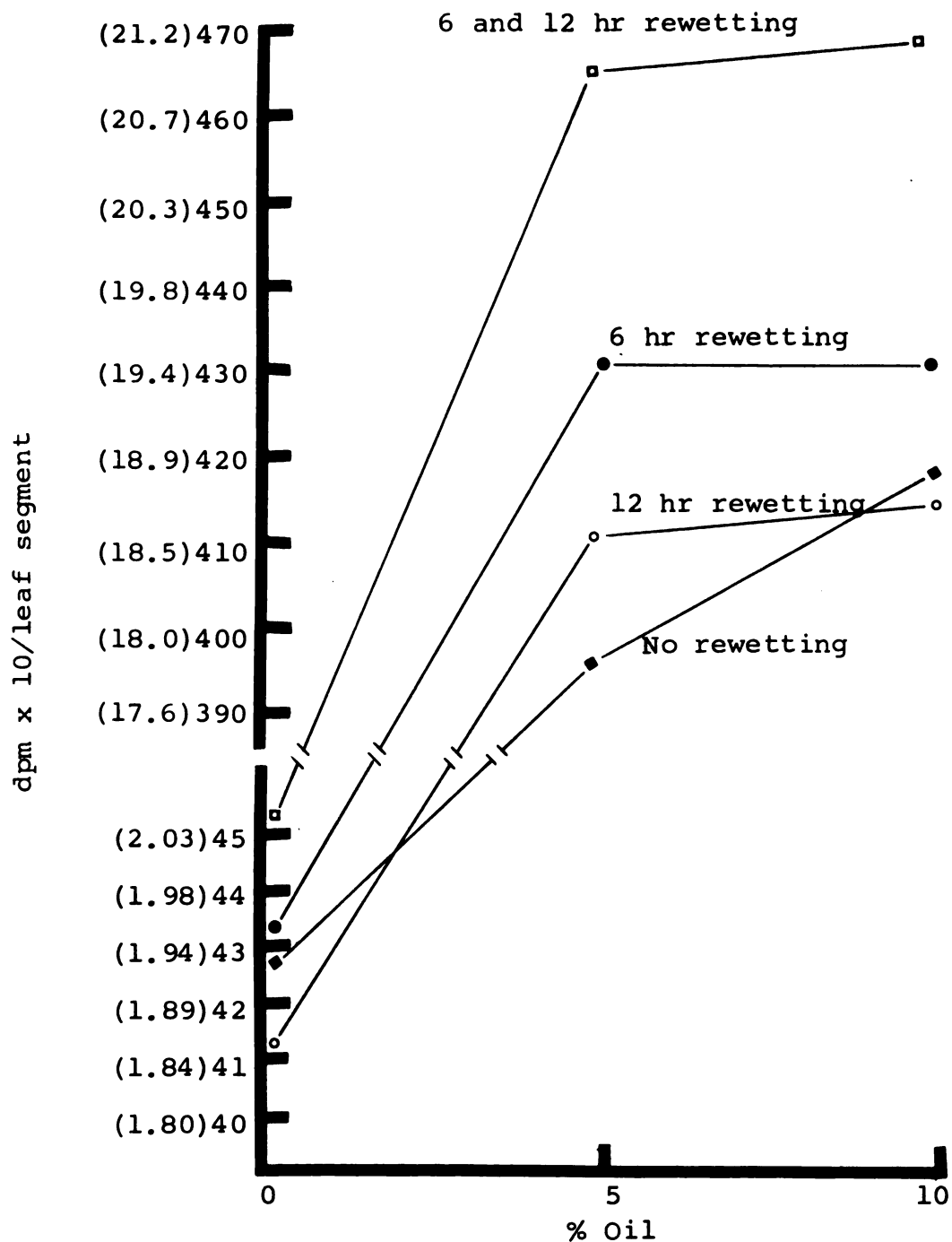


Figure 22. Foliar penetration of corn by ^{14}C -atrazine as influenced by oil-water emulsions and rewetting the plant foliage with water (values within parentheses equal percent of total radioactivity applied).

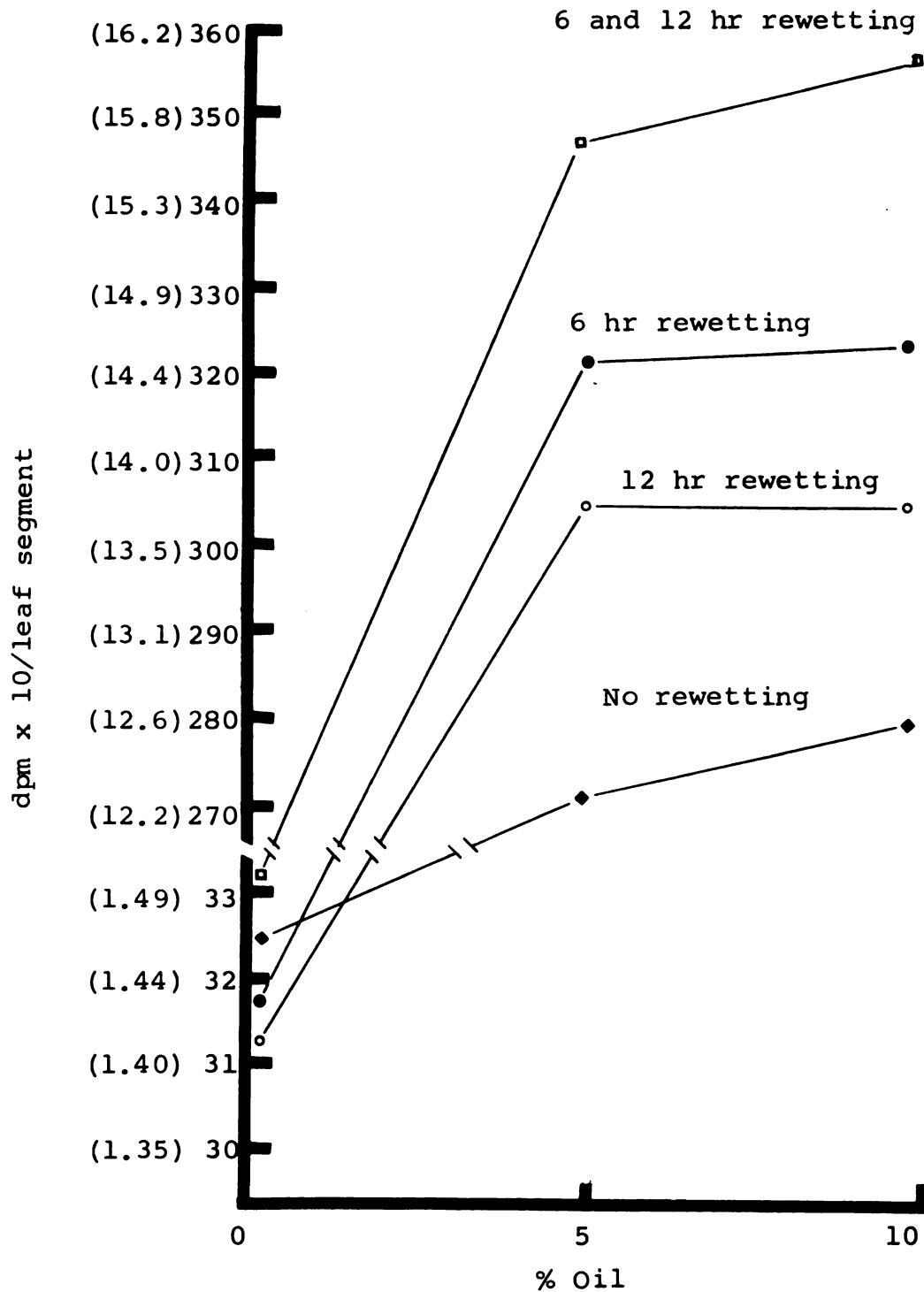


Figure 23. Foliar penetration of yellow foxtail by ^{14}C -atrazine as influenced by oil-water emulsions and rewetting the plant foliage with water (values within parentheses equal percent of total radioactivity applied).

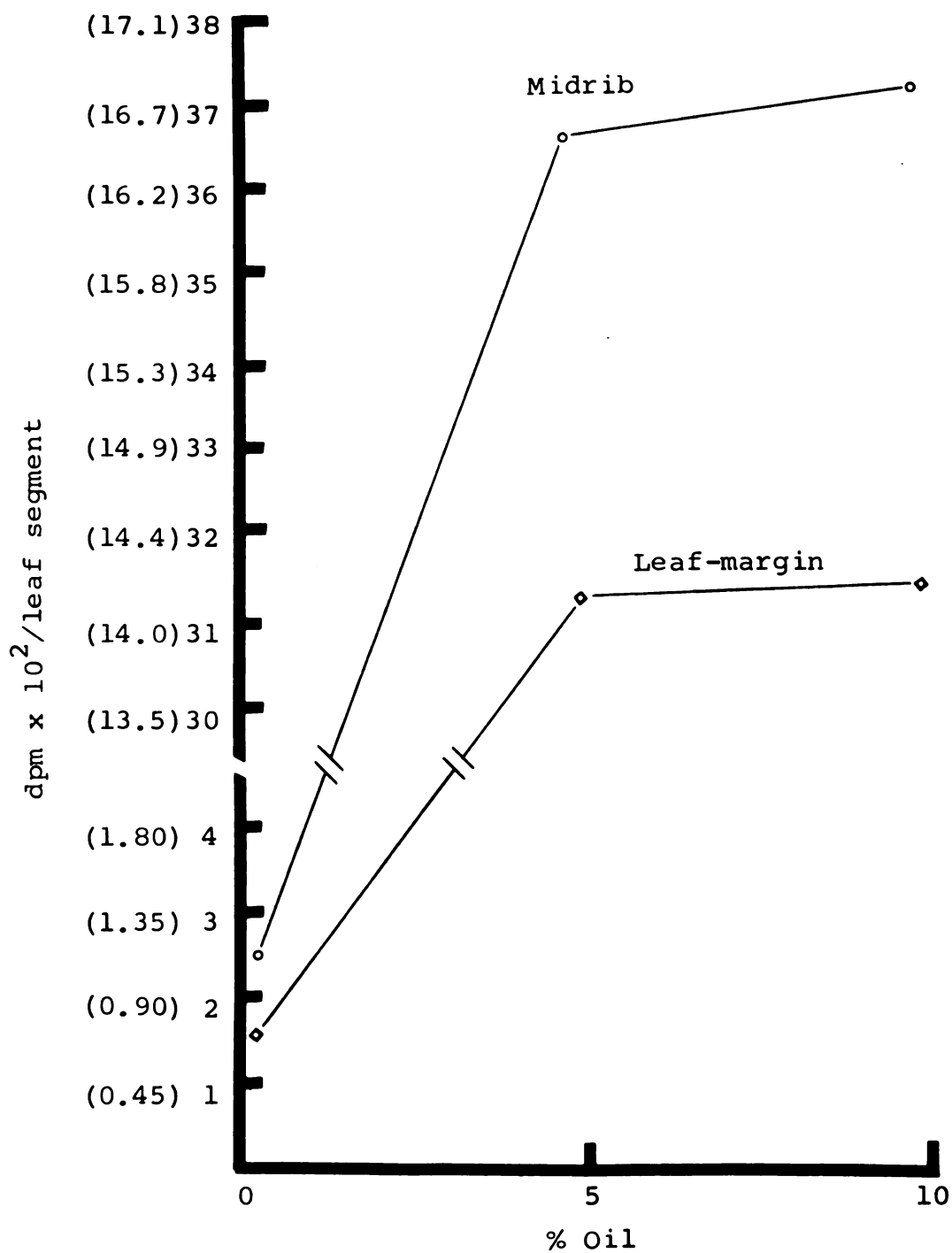


Figure 24. Comparison of the midrib and leaf-margin and the effect of oil-water emulsions on foliar penetration of corn by ¹⁴C-atrazine at both sites (values within parentheses equal percent of total radioactivity applied).

Silva Fernandes (1965) suggested that penetration may occur preferentially through the thinner cuticle over the veins.

When ^{14}C -atrazine was applied within a 1 cm x 2 cm lanolin barrier on corn leaves, the 5 and 10% oil-water emulsions and the X-77 solution spread evenly over the entire leaf area inside the barrier (Table 9). The water solution, however, remained as a droplet within the barrier. This spreader effect allows for penetration of ^{14}C -atrazine over a larger surface area. The oil-water emulsions enhanced penetration 9 to 10 fold while the X-77 surfactant enhanced penetration 7 to 9 fold within the lanolin barriers.

The treatments within the 5 mm sealed glass tubes exposed all treatments to equal surface area and prevented evaporation. Foliar penetration of ^{14}C -atrazine in the water solution was greater from the glass tube than from the lanolin barrier. This was probably due to rapid evaporation of the water from the lanolin barrier. Foliar penetration of ^{14}C -atrazine within the glass tubes was enhanced by oil-water emulsions and with X-77. The oil-water emulsions doubled penetration through the surface area within the glass tube. The X-77 surfactant also enhanced penetration but only by 30-40%. These results indicate that the oil-water emulsions were not only functioning as spreaders but were enhancing penetration of ^{14}C -atrazine per unit area of leaf surface. The X-77 surfactant functioned in a similar manner but to a lesser degree.

Table 9. Foliar penetration of corn leaves by ¹⁴C-atrazine as influenced by leaf surface and leaf area treated

Leaf Surface Treated	Total dpm/leaf segment					
	1 cm x 2 cm Lanolin Barrier ^a			5 mm Glass Tube ^b		
	Lower	Upper	avg	Lower	Upper	avg
<u>Adjuvant</u>						
None	610 (2.7) ^c	430 (1.9)	520 (2.3)	710 (3.2)	630 (2.8)	670 (3.0)
5% oil	5330 (24.0)	4650 (20.9)	4990 (22.5)	1460 (6.6)	1220 (5.5)	1340 (6.0)
10% oil	5440 (24.5)	4700 (21.2)	5070 (22.8)	1460 (6.6)	1270 (5.7)	1360 (6.1)
X-77	4320 (19.4)	3720 (16.8)	4020 (18.1)	950 (4.3)	890 (4.0)	920 (4.1)
avg	3920 (17.7)	3370 (15.2)	3650 (16.4)	1140 (5.1)	1000 (4.5)	1070 (4.8)

^aTreatments within lanolin barriers spread differentially as affected by the adjuvants.

^bTreating within the glass tubes allowed for all treatments to be exposed to equal surface area; the top of the glass tubes were sealed after treatment to prevent evaporation.

^cValues within parentheses equal percent of total radioactivity applied.

A comparison of upper vs lower leaf surfaces revealed that more ^{14}C -atrazine penetrated the lower surface than the upper surface of corn leaves. This was true for the water solution, the oil-water emulsions, and the X-77 solution. Dybing (1959) reported that for most plant species, both surfaces of the leaf function in absorption of chemicals but usually the lower surface was more penetrable than the upper surface. This differential penetration between surfaces could be due to the nature of the cuticular surfaces such as thickness of cuticle, wax content and stomatal density.

SUMMARY

Atrazine applied postemergence was evaluated in field studies to find effective control measures for broad-leaved weeds and annual grasses. Phytotoxicity and foliar penetration of atrazine were studied to determine the extent of foliar penetration and translocation and to determine what factors affect phytotoxicity and foliar penetration of the herbicide.

Field studies showed that postemergence treatments of atrazine and atrazine-oil were very effective for control of broadleaved weeds and annual grasses when applied at the early stage of growth. Control was significantly reduced when treatments were applied at a later stage of growth. Weed control from treatments with oil were superior to the treatments without oil.

No significant differences were found between morning vs evening spraying for broadleaf or annual grass control. However, morning spraying was superior to evening spraying for nutsedge control. Treatments applied in split applications were very effective for nutsedge control, giving over 90% control with 2.0 lb/A atrazine plus oil.

Corn yields were reduced when treatments were delayed until a later stage of weed growth. Yield reductions were due primarily to weed competition since no visual corn injury was observed.

Controlled environment studies revealed that environmental factors greatly affect the phytotoxicity of atrazine applied postemergence. Atrazine was more phytotoxic to yellow foxtail in the high temperature regime than in the two lower regimes. Oil enhanced phytotoxicity at all atrazine levels.

Soil moisture stress significantly affected phytotoxicity from foliar-applied atrazine, decreasing from high to low soil moisture. Phytotoxicity was greater at the high moisture level when spray applications were applied to both soil and foliage. This would indicate that a considerable amount of root uptake of atrazine occurred which complemented foliar penetration and thus increased phytotoxicity.

Autoradiographs showed that foliar-applied ^{14}C -atrazine moved in the acropetal direction exclusively. Foliar penetration and translocation of atrazine was apparent after 30 min and continued to increase with time.

The oxygen combustion technique was used to determine foliar penetration and translocation of ^{14}C -atrazine. To determine if differential penetration occurred among plant species, several species at various stages of growth were investigated. Penetration was greatest into velvetleaf

followed by corn, yellow foxtail, and nutsedge. As plants increased in age, penetration decreased for all plant species.

Foliar penetration of atrazine progressively increased with increased temperature and humidity levels. Soil moisture stress decreased penetration. Oil-water emulsions consistently enhanced penetration of atrazine. X-77 enhanced penetration but to a lesser degree.

Penetration was greatly enhanced when leaf surfaces were conditioned with oil-water emulsions before and after atrazine application. Rewetting leaf surfaces with water after the atrazine was applied was also effective for increasing atrazine penetration. The rewetting probably redissolved the atrazine crystals on the leaf surface and allowed for more penetration.

In addition to the spreader effect, the oil-water emulsions doubled penetration of atrazine per unit area of leaf surface. Treatments applied to upper and lower surfaces of corn leaves revealed that more atrazine penetrated the lower surface.

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APPENDIX

Table 10. Weed control and corn yield as influenced by atrazine, oil, and stage of growth when sprayed

Mean Square				
Source	DF	Weed Control		Corn Yield
		Broadleaves	Annual Grasses	
Replication	3	1.58**	12.77**	1154.5**
Stage of growth (A)	1	6.19**	10.32**	229.9**
Oil (B)	3	2.43**	11.13**	13.6
AB	3	2.37**	2.12	52.7
Atrazine (C)	1	0.11	1.86	49.9
AC	1	0.03	0.00	11.3
BC	3	0.03	0.22	18.5
ABC	3	0.04	0.84	29.9
Error	45	0.36	0.88	23.4

*Significant at the 5% level.

**Significant at the 1% level.

Table 11. Phytotoxicity of atrazine to yellow foxtail as influenced by temperature, oil, and atrazine rates

Source	DF	MS
Temperature (A)	2	19.81**
Oil (B)	1	67.84**
AB	2	1.91**
Atrazine (C)	4	28.11**
AC	8	0.77**
BC	4	1.14**
ABC	8	0.61**
Error	30	0.01

Table 12. Phytotoxicity of atrazine to yellow foxtail as influenced by humidity, atrazine rates, and oil

Source	DF	MS
Humidity (A)	1	4.27**
Atrazine (B)	4	72.19**
AB	4	0.06
Oil (C)	1	68.27**
AC	1	0.60
BC	4	0.81*
ABC	4	0.14
Error	40	0.30

*Significant at the 5% level.

**Significant at the 1% level.

Table 13. Phytotoxicity of atrazine to yellow foxtail as influenced by soil moisture, site of application, oil, and atrazine rates

Source	DF	MS
Moisture (A)	2	89.25**
Application site (B)	1	17.25**
AB	2	7.51**
Oil (C)	1	81.18**
AC	2	2.45**
BC	1	0.37**
ABC	2	0.19**
Atrazine (D)	4	44.94**
AD	8	1.31**
BD	4	0.71**
ABD	8	0.75**
CD	4	2.17**
ACD	8	0.33**
BCD	4	0.17**
ABCD	8	0.11**
Error	60	0.01

**Significant at the 1% level.

Table 14. Phytotoxicity of atrazine to yellow foxtail as influenced by atrazine rates, oil, and oil conditioning

Source	DF	MS
Atrazine (A)	3	153.48**
Oil (B)	2	17.39**
AB	6	0.65**
Oil conditioning (C)	2	1.56**
AC	6	0.37**
BC	4	0.22**
ABC	12	0.37**
Error	36	0.00

Table 15. Phytotoxicity of atrazine to yellow foxtail as influenced by light, atrazine rates, and oil

Source	DF	MS
Light (A)	1	1.42
Atrazine (B)	5	127.56**
AB	5	0.09
Oil (C)	1	44.02**
AC	1	0.12
BC	5	2.17*
ABC	5	0.04
Error	48	0.75

*Significant at the 5% level.

**Significant at the 1% level.

Table 16. Foliar penetration of ^{14}C -atrazine as affected by species, time, and oil

Source	DF	MS
Species (A)	1	36448720**
Time (B)	2	33566560**
AB	2	4263520**
Oil (C)	2	92895110**
AC	2	6180580**
BC	4	7044380**
ABC	4	826010**
Error	54	5020

Table 17. Foliar penetration of ^{14}C -atrazine as affected by species, stage of growth, and adjuvants

Source	DF	MS
Species (A)	3	50683120**
Stage of growth (B)	2	12091480**
AB	6	1329500**
Adjuvant (C)	3	133808480**
AC	9	1794050**
BC	6	1357480**
ABC	18	385060**
Error	48	4870

**Significant at the 1% level.

Table 18. Foliar penetration of ^{14}C -atrazine as affected by species, rewetting, and oil

Source	DF	MS
Species (A)	1	7835980**
Rewetting (B)	3	449870**
AB	3	16770**
Oil (C)	2	59821830**
AC	2	1495390**
BC	6	104920**
ABC	6	5910**
Error	24	1140

Table 19. Foliar penetration of ^{14}C -atrazine as affected by species, humidity, and oil

Source	DF	MS
Species (A)	1	62131520**
Humidity (B)	2	29412060**
AB	2	1046530**
Oil (C)	2	162551415**
AC	2	12566890**
BC	4	3189380**
ABC	4	343370**
Error	54	20810

**Significant at the 1% level.

Table 20. Foliar penetration of ^{14}C -atrazine as affected by species, temperature, and oil

Source	DF	MS
Species (A)	1	36978570**
Temperature (B)	2	2157220**
AB	2	497470**
Oil (C)	2	137538210**
AC	2	8797890**
BC	4	166490**
ABC	4	127950**
Error	54	880

Table 21. Foliar penetration of ^{14}C -atrazine as affected by species, soil moisture, and oil

Source	DF	MS
Species (A)	1	17999000**
Soil moisture (B)	2	30126520**
AB	2	2319630**
Oil (C)	2	41665070**
AC	2	3775390**
BC	4	5769070**
ABC	4	485130**
Error	54	1000

**Significant at the 1% level.

Table 22. Foliar penetration of ^{14}C -atrazine as affected by leaf area, adjuvants, and leaf surface

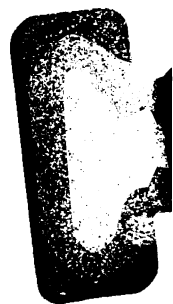
Source	DF	MS
Leaf area (A)	1	106244560**
Adjuvant (B)	3	24119060**
AB	3	13514750**
Leaf surface (C)	1	1915460**
AC	1	657720**
BC	3	100110**
ABC	3	43360**
Error	48	950

Table 23. Foliar penetration of ^{14}C -atrazine as affected by species, oil, and light

Source	DF	MS
Species (A)	1	43668490**
Oil (B)	2	143761890**
AB	2	9915410**
Light (C)	3	3195140**
AC	3	4040**
BC	6	736200**
ABC	6	2670*
Error	72	970

*Significant at the 5% level.

**Significant at the 1% level.



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