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EXPLOITATION OF RYE (SECALE CEREALE L.) AND ITS  
RESIDUES FOR WEED SUPPRESSION IN VEGETABLE  
CROPPING SYSTEMS

By  
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## ABSTRACT

### EXPLOITATION OF RYE (SECALE CEREALE L.) AND ITS RESIDUES FOR WEED SUPPRESSION IN VEGETABLE CROPPING SYSTEMS

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This study was initiated to determine if rye (Secale cereale L.) selections or cultivars could be utilized for weed control in a no-tillage vegetable production system. In field studies, vegetable crops were planted into glyphosate-killed rye residues. The residues reduced total weed biomass by 68 to 95% when compared to controls with no residue. Weeds were reduced an additional 35% when comparing rye residues with poplar mulch indicating that allelopathy was involved. Snapbean and pea yields were not adversely affected in rye killed early in the season. Tomatoes were more susceptible to later killed residues. Response to rye residues was influenced by herbicide used and timing. In greenhouse studies, germination of indicator species was not reduced by rye root leachates, however, seedling growth was reduced by 13 to 25%. Toxicity of leachates is additional evidence that allelopathy may be involved in weed suppression with rye.

## DEDICATION

This thesis is dedicated to my dear mother,  
Patricia, whose endless love and ageless  
vitality have been a continual source of  
strength and stability.

## ACKNOWLEDGMENTS

As I look back over the last two years, I realize that it is impossible to mention all of the people who have helped to enlighten this suburbanite. I would especially like to thank Dr. A. R. Putnam for his expert guidance, open-minded nature, and time spent in editing this thesis. I would also like to thank Dr. H. C. Price and Dr. C. Stephens for helping shape the final draft. A special thank you is extended to Bill Chase and Mike Willis for their invaluable technical expertise and to all who have either bent over a square meter or laid a plot of excelsior.

If it were not for the non-academic side of life, this manuscript would never have materialized. I owe my mental sanity to the swimming pool and various other naturally occurring substances. In addition, there are those people who have been very near and dear to me. To the Guys--it's been a real experience. And to Suzanne, my partner in crime, life's been a trip in the fast lane. Y a José, estarás siempre un divertido amigo querido de mía.

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## CHAPTER 1

### LITERATURE REVIEW

#### Introduction

Today, many factors contribute to the high cost of producing vegetable crops. In particular, weed control costs including chemical, mechanical, and cultural methods rise each year. In addition to control costs, yield losses due to ineffective practices also decrease productivity. During the 1920s and 1930s, much effort was expended in improving cultural weed control practices. Since the mid-1940s, research in weed science has centered around chemical control methods. As early as 1970, weeds were reported to have developed resistance to herbicides (Ryan, 1970) and now weed scientists recognize several weed species with resistance to triazines (Radosevich and Appleby, 1973; Radosevich, 1977; Arntzen, 1979). Scientists must integrate methods to provide an ecologically sound and technically feasible weed management approach for vegetable crops. The use of allelopathic cover crops--specifically rye (Secale cereale L.)--for weed control in no-tillage (NT) vegetable crops may provide an environmentally safe, and ecologically sound, management strategy. The objective is to utilize the cover crops' chemical and physical attributes for weed control, as well as to exploit other water and soil conservation advantages.

### Allelopathy

The phenomenon of allelopathy, where one plant influences the growth of other plants through release of chemicals into the environment, has been observed for decades. As early as 1832, de Candolle suggested that the 'soil sickness' problem in agriculture may be due to exudates of crop plants, and that crop rotation may help alleviate the problem. From Molish's noteworthy paper in 1937, to the more recent reviews by Tukey (1969), Putnam and Duke (1978), and Rice (1979), allelopathy is gaining acceptance in the scientific world. Molisch (1937) coined the term "allelopathy" and defined it as the "biochemical interactions between all types of plants including microorganisms." His broad definition was meant to cover both detrimental and beneficial reciprocal biochemical interactions. Rice (1979) modified Molisch's definition by stating that "the effect depends on a chemical being added to the environment." Rice further clarified the difference between allelopathy and competition by stating that, "competition involves the removal or reduction of some factor from the environment that is required by some other plant sharing the same habitat." A major obstacle in proving allelopathic effects has been to eliminate aspects of competition in plant/plant interactions. Perhaps a more appropriate term for the overall influence of one plant on another is interference, which would include both allelopathy (competition) and allelopathy (Muller, 1969).

Allelopathic interactions in the environment may be expressed in many ways. Higher plants may be allelopathic to other higher plants, or to microorganisms (Rice, 1979; Nickell, 1960).

Microorganisms may be allelopathic to higher plants, or other microorganisms (White and Starrat, 1967; VanderMerwe, et al, 1967; Hattingh and Louw, 1969). Thus, the role of allelopathy is important in shaping both natural and agricultural ecosystems where plants and microorganisms coexist. In natural ecosystems allelopathy may play a role in patterning of vegetation or old field succession (Rice, 1979). Whittaker (1975) proposes that allelochemic interrelationships are a major basis of community organization, niche differentiation, and community niche space. The concentration of secondary substances in plants is such, that substantial quantities can often be released into the environment from either the living plant, or by decomposition of the litter. Once in the soil, they may have significant effects on other vascular plants, soil microorganisms, or even on the plant from which they were released (Whittaker, 1975). According to Odum (1969), secondary plant metabolites may be extremely important in preventing populations from overshooting their equilibrium density, thereby reducing oscillations as an ecosystem develops stability.

Allelopathic effects appear to be especially significant in natural communities with a strong dominance of a single species (Whittaker, 1975). Since most agroecosystems consist of vast monocultures of crops, allelopathy may also play a role in these manipulated ecosystems. Much of the early investigations into allelopathy were a result of crop phytotoxicity problems observed in agriculture. McCalla and Duley (1948, 1949) published two papers on the effects

of decaying wheat (Triticum vulgare var. Mida) residues on corn (Zea mays) growth. These were in response to a widespread use of stubble mulch farming for soil erosion problems during the dust bowl era. In many instances, yields were reduced in stubble mulch farming, suggesting that the detrimental effect of crop residues might be due to a combination of toxins released from residues, and from microorganisms that were caused to grow more profusely by substances in the residues. Later, Norstad and McCalla (1963) isolated fungi from stubble mulched field plots which produced a toxin, patulin, toxic to corn plants. The organism was later identified as Pencillium urticae Bain., and was found to comprise 90% of the total soil fungal population (Ellis and McCalla, 1973). When patulin was applied to soil planted with 'Yee' spring wheat, yields were decreased lending the authors to conclude that a single exposure of patulin to growing wheat plants is enough to produce the yield reductions noted in the field.

The benefits from NT, crop rotation, and cover cropping, have been noted for a long time. But with the advent of the chemical age, research interest shifted from conservative cultural practices to chemical control. The study of weed science has similarly progressed in this manner. It now appears that many problems associated with the use of crop rotations, NT, and cover cropping may involve allelopathy. Since surface residues are inherent to NT programs, allelopathic chemicals from the residue leach into the soil and affect the growth of other plants (Patrick,

et al 1963, Patrick, 1971; Guenzi and McCalla, 1962; Guenzi et al, 1967). If the allelopathic chemicals released from the residue were of sufficient activity and selectivity, then allelopathic cover crops may be yet another avenue of weed control for vegetable growers.

Winter rye (Secale cereale L.) is an ideal cover crop for use in NT farming systems (Shear, 1968; Faulkner, 1943). It will germinate well in untilled soils, does well under a wide range of soil moisture levels, soil pH, and soil fertility conditions (Nuttonson, 1958). Also, it will germinate at low temperatures, is very winter hardy; and has limited soil requirements. In addition, rye develops a vigorous and extensive root system which improves soil tilth (Nuttonson, 1958). Rye has often been grown for hay or pasturage, as it produces considerable plant material in the spring. These basic characteristics of rye contribute to it's potential use as a cover crop in NT vegetable production, and as an allelopathic agent for weed control in these systems.

The root system of rye is more extensive than that of wheat, barley, or oats (Nuttonson, 1958). This enables rye to use considerable soil moisture. The branching, slender, and fibrous adventitious roots are functional throughout the life of the plant. The root system of a single rye plant at the milky ripe stage has been found to extend downward as much as 1.5 m, with a lateral spread of over 0.9 m (Nuttonson, 1958). With such an extensive root system permeating throughout the soil horizons, production or release of organic compounds may prove to be a significant factor in the microecology

of the soil environment. This unique environment, which is under the influence of plant roots, is called the rhizosphere. Within this zone, interactions between plants and microorganisms can greatly affect crop production and soil fertility (Richards, 1974).

Rovira (1965) identified several compounds in root exudates. They included carbohydrates, amino acids, and other organic acids; vitamins, nucleic acid derivatives; and various miscellaneous compounds. Exudation of a wide range of sugars appeared to be a general characteristic of plants, while plants tended to differ greatly with respect to the amounts and kinds of amino acids they exude. There may be many qualitative and quantitative differences between exudates of different plant species grown under identical conditions.

Factors which affect root exudation include plant age, stage of development, and conditions under which the plant is grown (Rovira, 1965). Distinct developmental changes, including emergence, tillering, shooting, heading, and flowering, occur in winter rye as it matures. Temperature has the greatest influence on the duration of each stage in a given locality--light, moisture, and plant nutrients being other important factors (Nuttonson, 1958). Cultivars of rye differ in the length of their growing period and amount of time for each stage.

Winter rye produces considerable biomass early in the growing season. For this reason it has often been used as a green manure crop in sandy or low fertility soils. In a comparison of residue production from cereals, rye out produced wheat, oats, and barley

by anywhere from 21 to 70% (Phillips, 1973). The massive production of residue by rye has the potential to influence the growth of succeeding plant species through release of allelopathic chemicals from decaying residue. As early as 1925, Cubbon found a rye crop to inhibit growth of grape plants, and suggested that a chemical might be implicated.

There are many instances in the literature where rye has been noted to influence the growth of other plants (Cubbon, 1925; Kimber, 1973; Patrick, 1971; Overland, 1966; Rice, 1979). Faulkner (1943), in Plowman's Folly, suggested seeding the land to rye to help eliminate weeds. Nuttonson (1958) noted that rye has been used to suppress wild oats and many other weeds. Robertson, et al (1976) found rye residues suppressed weed growth when compared to sod or conventional tillage plots. Another report (Phillips, 1973) indicated that a rye cropping program helped control both dandelions and broadleaf weeds. The mechanism by which rye influences the growth of these plant species has never been ascertained (Overland, 1966), although an allelopathic mechanism of interference between rye and other plant species has been suggested (Rice, 1979).

In recent years there has been more interest in crop phytotoxicity problems associated with stubble mulch crop production. Instances of poor germination and seedling growth were reported by growers in the Salinas Valley, where lettuce was planted too soon after turning in barley or rye cover crops. Patrick, et al (1963) undertook experiments to determine whether severe phytotoxicity could be detected when the cultural practice was repeated in the

greenhouse with soil and plant residue obtained directly from the field. Lettuce root length and fresh weight were reduced in treatments where rye residue was present. Rye extracts with marked phytotoxicity were obtained after residues had been decomposed for 10-25 days. Toxicity of residues declined as the decomposition period increased, until by the 30th day, little or no phytotoxicity was observed. In a later experiment, Patrick (1971) sampled tobacco fields which contained decomposing rye residues previously plowed under as a green manure. He found extracts of decomposing residue fragments to delay germination and reduce root growth of lettuce and tobacco. Similar phytotoxicity was exhibited with extracts of soil which were in contact with decomposing rye residues. No phytotoxicity was obtained with extracts of soil from which all recognizable decomposing rye residues had been removed. Ether extraction and gas chromatographic analysis identified several acids, including acetic, butyric, benzoic, and phenylacetic acid, to be the phytotoxic compounds. It was not determined whether phytotoxic substances were synthesized by soil microorganisms using the plant material as a substrate, or were the breakdown products inherent in the plant tissue. It may have been both, since phytotoxic compounds of significant potency were detectable only after the decomposing plant residue had been freed from most of the adhering soil, prior to extraction.

Kimber (1973) found cold extracts of several grasses, including slightly green rye straw, that had rotted from periods up to 21 days, to inhibit growth of wheat grown under aseptic

conditions. Sterile conditions were used to eliminate the possible interactions of pathogens and microbial products. The degree of inhibition varied from one species to another, and also, with the length of the rotting period. He found slightly green straw to be more toxic than fully matured residue. The most toxic materials found were from extracts of rye straw which had rotted for four days.

Doss et al (1981) found early season growth of tomato transplants was greater in the absence of rye than on plots where rye had grown. Although marketable tomato yields were not significantly affected by rye as a winter crop, over a 3 year period, yields on no rye plots averaged 2.2 mt/ha greater than on rye plots. The decomposition of rye residues, or any organic substrates, is a continuing process which requires rapid and sensitive assay methods to detect phytotoxic compounds during their short interval of production and disappearance (Patrick, 1971). This is evident from the various contradictory results often obtained during decomposition of similar plant residues. The ephemeral nature of such products, and their relatively rapid transition from one type of physiological activity to another, may be reasons why their occurrence is frequently missed. Plant injury is dependent on the frequency of a chance encounter with a growing root system, or with fragments of plant residues, at a time when decomposition is favorable for toxin production.

#### No-till/Cover Crop Production Systems

During the evolution of crop management, conventional tillage operations included a relatively deep primary tillage, as well as,

several secondary cultivations during the season. It was thought that the practices contributed to control of undesirable vegetation. It was also thought that tillage produced and maintained favorable soil conditions for plant growth. As problems of soil erosion and water pollution from cropland runoff continued to increase, interest in alternate management systems for crop production also increased. It is ironic to note that almost forty years have passed since Faulkner wrote the controversial book, Plowman's Folly. In the first paragraph, Faulkner states that a farmer's greatest worry is the result of the unfortunate discovery of the moldboard plow. He also felt that agricultural science would never have developed if man had not invented the plow, for one is the result of problems associated with the use of the other.

Zero-tillage, sod planting, mulch planting, plot planting, no-till, reduced tillage, minimum tillage, or conservation tillage are various names given to reduced tillage production systems. Crop seeds, or transplants, are placed into the soil through the sod or previous crop residues by creating a slot wide and deep enough to receive and cover the seed or transplant (Young, 1973). Early attempts with the system were often failures because undecomposed residues in close association with crop seeds appeared to retard germination (Rutherford, 1976). In addition to problems associated with crop residues, yields were frequently reduced by competition with weeds for moisture, light, and nutrients. Before NT or limited tillage systems will be accepted, the specific problem

of reduced stands and plant vigor often seen must be more clearly understood.

Early studies by Keen and Russel (Russel, 1966) found tillage in excess of the minimum needed to get a seedbed and check weed seeds until the crop is well established, tended to decrease yields. Tillage operations tend to keep natural succession in agricultural fields from progressing past the pioneer weed stage. The clear hint that there could be positive plant growth benefits in avoiding soil disturbance was somehow overlooked by many. This is also ironic since it has long been realized that soil conditions often improve with time, as seen when grassland is left undisturbed.

The idea of destroying or suppressing vegetation with a chemical and growing crops in the undisturbed sod was put forth by Barrons and Fitzgerald in 1952. They reported successful production of wheat (Triticum aestivum L.), oats (Avena sativa L.), flax (Linum usitatissimum L.), soybean (Glycine max (L.) marr.) and corn (Zea mays L.) in a Ladino clover (Trifolium repens) sod killed in the fall with 1.12 Kg/ha and 2,4,5-T. They also suggested that sod planting with little or NT, could be a new approach to the problems of soil conservation. Early work in Scotland attempted to improve hill swards by first killing the natural vegetation with dalapon, and then broadcasting clover and grass seed. The residual activity of dalapon in the soil proved to be excessive for successful culture of grasses. In the late 1950s, the discovery of bipyridyls, and, in particular, the characterization of paraquat (1, 1'-dimethyl-4, 4'-bipyridylium ion) provided an opportunity to examine more closely

the idea of crop establishment without mechanical tillage. Three properties of paraquat proved invaluable to a NT production system (Allen, 1975). It is active on green plant tissue; is absorbed quickly into sprayed foliage; and is immediately inactivated upon contact with most soils. Thus, the discovery of herbicides, especially paraquat, has renewed research interest in reduced tillage, surface residue management systems.

In contrast to clean cultivated fields, a NT site is most always covered with some plant residue. Thus, the environmental and physical conditions of the soil ecosystem under NT will vary, and subsequently, influence crop performance. There have been several reports which indicate that soil moisture is greater under surface residues due to a reduction in evaporation and a decrease in runoff, which may be especially beneficial to crop growth during periods of water stress (Blevins, 1971; Unger et al, 1971; Jones et al, 1968; Gallaher, 1977; Jones et al, 1969; Moody et al, 1963). The mulch or stubble improves penetration and infiltration of water, in addition to reducing surface evaporation. Gallaher (1977) also found no-till plantings of crops in killed rye residue resulted in greater use of soil moisture as a result of crop root removal from deep in the soil profile.

Since the effect of a mulch cover is similar to that of a loosened soil layer, differences in soil temperature between conventionally tilled and zero tilled soil will become larger with increasing amounts of cover (Baeumer and Bakermans, 1973). This will in

turn affect seed germination and plant growth. During cool periods in May, Moody et al (1963) observed higher soil temperatures in mulched soil. The temperature effects may limit the applicability of zero tillage. On compacted, heavy textured soils, a lower frequency of freezing and thawing may not result in the necessary friable tilth and soil porosity essential to good plant growth. The slower warming up in spring may seriously retard the emergence of some crops with specific temperature requirements (Baeumer and Bakermans, 1973).

Reduced tillage systems help to maintain and improve soil structure. Benoit et al (1962) found that three successive cover crops of rye resulted in a measurable improvement in soil structure of a sandy loam when the rye had been plowed under in the spring. They felt that the effects would have been much greater if the sod had not been plowed under. In NT systems, plant residues are not mixed throughout the soil, as after plowing; and the rate of organic matter decomposition may be slower with cover crop systems (Fleige and Baeumer, 1974). Tomlinson (1974) found the accumulation of organic matter near the surface of untilled soil may cause significantly higher stability of soil aggregates. Similarly, Russel (1976) found greater soil aggregate stability in the top inch of soil which was direct drilled versus plowed. Roots also play a role in soil aggregate stability, due to the mucigel they produce and the organic substances they exude (Richards, 1974).

Perhaps the greatest benefit realized with a reduced tillage/cover crop program is the significant reduction of wind and water

erosion. Jones (1969) found that mulches increase water infiltration and, subsequently, decrease water induced soil erosion. Runoff measured during 1965, 66 represented a loss of 27% from the unmulched plots, and only a 4.5% loss from mulched plots. Wind erosion may become a serious problem on soils with surface textures of fine sand, loamy fine sand, or fine sandy loam, especially when cropped intensively with row crops. Woodruff et al (1969) investigated the relative wind erodability of newly prepared or planted corn land in central Wisconsin. Soil loss in the plowed and planted treatment was 84 tons/A, while the NT and planted treatment lost only 15 tons/A of soil. In contrast, soil loss in a standing chemically killed rye cover was only .04 tons/A. Reduced tillage surface residue management systems provide distinct advantages for control of water and wind erosion.

In NT systems, the crop residues, sods, and small grain covers provide protection, moisture, and other conditions favorable to insect and disease development (Phillips, 1973). Armyworm problems have occasionally been encountered where corn was planted into sod or a dense small grain (Shear, 1968). Slugs are more prevalent in fields covered with mulch (Triplett and VanDoren, 1977). Soil insects are a greater problem in NT crops when insecticides must be incorporated, unless it is done at planting with a properly equipped and adjusted NT planter (Phillips, 1973). Development of new insecticides, which do not require incorporation, is a necessity in achieving control of soil borne insect problems in NT systems.

Many diseases overwinter in and on residues from diseased plants of the previous season and thus, may provide inoculum for disease development (Boosalis and Doupnik, 1975). Fungal and bacterial diseases are the greatest problems associated with reduced tillage and relate to the large quantities of undisturbed residues left in the field. Doupnik and Boosalis (1980) found that plant diseases have not increased under ecofallow reduced tillage systems. In fact, they found the incidence of stalk rot of grain sorghum and corn to decrease. They felt that the use of two different crops in the system was an important factor in preventing a build up of diseases that commonly occurred with monoculturing under reduced tillage. Brooks and Dawson (1968) found incidence of take all (Ophiobolus graminis) and eyespot (Cercospora herpotrichoides) was considerably less in winter wheat drilled into stubble or pasture sprayed with paraquat, than wheat drilled after cultivation. They attributed the reduction to be the result of a different rate of spread of the fungus pathogen in direct drilled and plowed soils. Cultivation may result in a greater dispersal of inoculum. Reduced tillage is not the only factor involved in plant disease epidemics (Boosalis and Doupnik, 1975). Also important are weather conditions, temperature and moisture, nutrition of the host and pathogen, variability and virulence of inoculum, variability of the pathogen and host susceptibility. Thus, it appears that crop rotation and other methods of integrated pest management for NT systems will help resolve pest problems associated with reduced tillage.

Regardless of the limitations to the system at the present time, NT appears to hold great promise for the future. It could markedly improve soil and water conservation enabling an increase in the acreage of land adaptable for food crop production, which would otherwise have too great a slope for conventional tillage operations (Young, 1973). In an assessment of minimum tillage published in 1975, the Department of Agriculture predicted that by the year 2010, more than 90% of the acreage of crops will be grown with reduced tillage systems, and that on more than half, some form of NT farming will be the practice.

Economic factors enhanced by NT techniques include grain yield increases, lower equipment investments and farm production costs, increased farming profits, more intensive land use, adaptation and use of certain crops over wider areas, new cropping combinations made possible on many farms previously limited to less diversity of cropping, and reduction of certain weather risks (Young, 1973). Conventional methods of tillage require a considerable amount of power and labor for seedbed preparation (Tripplette and VanDoren, 1977). Direct planting into untilled soil with suitable equipment is a rapid operation with a relatively low demand for power, so that the need for large tractors is reduced. Whenever the moisture of the soil is favorable for tilling of any kind, planting machines can be operated. With less machinery invested in and used, less labor, and fewer field operations, production costs tend to be lower for the NT farmer (Young, 1973). This will

become even more important to commercial farmers who are faced with labor shortages and high costs for fuel. Thus, the soil and water conservation benefits of NT crop production, coupled with decreased energy requirements, will contribute to the increase in NT crop production. Although NT eliminates the need for seedbed preparation, without good management principles, yield increases from NT will not translate into higher income (Phillips and Young, 1973).

The use of a NT/cover crop system for vegetable production has great potential, although minimal research has been done. Phillips and Young (1973) predict NT vegetable production will result in improved quality vegetables from less soil being splashed up on the crop from rain or irrigation. The mulch will contribute to cleaner vegetables grown under the more favorable moisture conditions. Most NT research from Europe has concentrated on cereal fodder crop production (Toosey, 1971). In the U.S., NT work has been primarily concerned with soybean and corn production. There is an obvious gap in the literature on NT vegetable crop production. Currently, sweet corn, popcorn, snapbeans, direct seeded tomatoes, lima beans, and peas have been reported to be successfully grown under NT (Beste and Olson, 1978; Phillips and Young, 1973). Beste (1972) found yields of cucumbers to be lower in NT plots than tilled plots, while tomatoes and lima bean yields were equal to conventionally tilled plots. He felt a NT planting system for vegetables was feasible, and that the protective mulch covering should reduce potential seedling injury from wind erosion of sandy soil.

Carrot production in Delaware is beset with problems in establishing a good stand because of a lack of moisture in the seed-bed and blowing sand. Therefore, Orzolek (1978) examined the feasibility of growing NT carrots, with a primary interest in evaluating the effect of irrigation and cultivation on yield and secondary root development. He found no significant differences in yield of carrot among cover crops regardless of cultivation practice. Rye mulch plots showed a response of higher yields with additional water. The NT rye plots were superior to the conventional plots in reducing the occurrence of secondary root development when irrigation was not supplied during the growing season. Thus, Orzolek concluded that NT carrot production is feasible following a rye cover crop.

Seed production of carrots and onions is very labor intensive. Since energy inputs are reduced in NT crop production, Campbell (1980) investigated the effects of NT and herbicides on growing onions and carrots for seed. A highly significant reduction in carrot and onion seed yield was found in NT plots. Onions grown in the tilled plots exhibited no effect from chemical treatments, while those on the non-weeded control and NT plots showed a significant reduction in onion seed yield. In contrast, carrot seed yield was not affected by chemical treatments in NT.

Standifer and Ismail (1975) compared effects of tillage on a multiple cropping system. The minimum tillage operation consisted of rebuilding raised beds in November of each year and planting, with no other soil preparation. Yields obtained with a cropping

sequence of crimson clover, sweet corn, and southern peas under minimum tillage, were equal or superior to those obtained using conventional methods. They also found that minimum tillage operations left enough time to produce a fourth crop of the season. They experimented with Chinese cabbage, broccoli, and bush snapbeans, but obtained best results with direct seeded cabbage, due to the seasonal constraints in the area. Although this is one example of successful NT vegetable crop production, additional research will undoubtedly provide many more benefits.

Weed control methods in NT cover crop production systems also need further improvements. Incomplete weed control is one of the main obstacles to further adoption of zero-tillage. Any field, undisturbed by tillage, tends to revert back in an ecological succession to its native species (Whittaker, 1980). Leaving an arable soil undisturbed prevents deeply buried, but viable, weed seeds from germinating. This results in a diminishing rate of emerging annual weeds, if weed seed replenishment is curtailed by preventing shedding of weed seeds. Faulkner (1943) suggested seeding rye into fields in fall. In spring, the rye is put into the land before weeds bloom. Within a few years the top inches of soil will have been exhausted of annual weed seeds. Thus, annual weed pressure in NT crop production will decrease with time.

In contrast, deep plowing and cultivation have served to keep many perennial weed species in check. With zero-tillage, many of these weeds remain almost undisturbed and, thus, large populations of perennial weeds can sometimes build up in untilled soil (Cussans,

1975). The discovery of the translocated, nonselective herbicide, glyphosate (N-phosphonomethyl glycine) has greatly improved problems of perennial weed control in NT systems. Like paraquat, it is active on green plant tissue and is quickly bound up by most soils (Anonymous, 1979).

Basic to the NT system is the use of a cover crop. Frequently called "smother crops", they have often been planted to help suppress weed growth (Overland, 1966). Potential smother crops include barley, rye, sorghum, buckwheat, sudangrass, sweet clover, and sunflower. Overland attributed the weed growth reduction to competition. Most of the cover crop species listed by Overland have been reported to be allelopathic to certain test species (Rice, 1979). Thus, the idea of using allelopathic cover crops for weed control may have potential in vegetable production systems under zero-tillage.

Weed control from decaying plant residues in NT systems is a relatively new era of weed control. DeFrank and Putnam (1977) screened numerous cover crops for weed suppressing activity. They found fall planted cover crops to reduce both weed populations and biomass in the next growing season. Fall killed "Balboa" rye reduced weed biomass by 84% over no residue controls. They found spring killed rye to have less toxic action on weeds. In addition, fall killed "Garry" oat residue appeared to stimulate weed germination. Toxicity of water soluble compounds leached from several plant species suggested that allelopathy was a major factor contributing to their effectiveness. Thus, allelopathic cover crops,

which produce and release naturally occurring chemicals may yet become another weed control strategy for the vegetable grower. The economic, energy, and soil benefits of a reduced tillage/cover crop management system should facilitate acceptance of the system when it is perfected.

The purpose of this investigation is to determine if the use of a rye cover crop for weed control is feasible in NT vegetable production. Field evaluations were aimed at determining the response of weeds and vegetable crops to rye residues in NT situations. Greenhouse studies were primarily concerned with separating out the various components of plant interference to determine if allelopathy of rye is responsible for the noted weed reductions. In addition, both greenhouse and field work was concerned with determining if a selection of rye, screened from a portion of the world's collection, varied in its effect on weeds and crops from a standard winter rye cultivar ("Wheeler") commonly planted in Michigan. Differences in activity between the cultivars may be evidence that genetic differences in allelopathic production by plant species exists and could be utilized in breeding allelopathic crops. If the selections do not vary, vegetable grower acceptance of the system may be more rapid since ryes are already available that will fit into their system.

## INFLUENCE OF RESIDUES ON WEEDS AND CROPS

### Abstract

Winter rye is commonly utilized by vegetable growers for increased soil organic matter and soil protection. This study was initiated to determine if a selection of rye ('MSU-13') screened from a portion of the world's collection, or a rye cultivar, could be utilized for weed control in a no-till (NT) vegetable production system. Total weed biomass was reduced by 68-95% when compared to controls with no residue. Snapbean and tomato yields varied with cover crop residue and time of kill. Time of killing cover crops also influenced weed density and biomass, with the greatest reductions occurring in later killed treatments. Weeds and crops responded similarly to the 2 selections of rye. Rye residues reduced weeds an additional 35% over poplar mulch indicating that allelopathy was involved.

## CHAPTER 2

### INFLUENCE OF RESIDUES ON WEEDS AND CROPS

#### Introduction

Concern over destructive effects of current cultural practices on agroecosystems mandates the need for improved weed control strategies in vegetable crop production. High costs for energy, resistance to herbicides, and problems associated with soil erosion are several reasons for developing a vegetable crop production system in which allelopathic cover crops and NT supplement the weed control program.

McCalla and Duley (1948 and 1949) published two papers on the effects of decaying wheat (Triticum aestivum L.) residues on corn (Zea mays L.) growth. Their investigations were in response to a widespread use of stubble mulch farming for soil erosion problems during the dust bowl era. In many instances, yields were reduced suggesting that the detrimental effects of crop residues might be due to a combination of toxins released from residues, and from microorganisms that were caused to grow more profusely by substances in the residue. Guenzi and McCalla (1962) reported that corn residues were inhibitory to seed germination and seedling growth of wheat. They identified several phenolic acids in mature corn plant residues and all were found to inhibit wheat seedling growth (1966). Guenzi, et al (1967) found toxicity of wheat, oat, corn, and sorghum

residues to vary depending on the length of decomposition. While wheat and oat residues contained little water soluble toxic components after eight weeks of decomposition, corn and sorghum were toxic for about 22 weeks.

Hill (1926) noted that the addition of green rye to heavy soils depressed corn growth, while growth was increased in light soils. Roots were more toxic than tops. Patrick and Koch (1958) found that decomposing residues of rye (Secale cereale L.) were very inhibitory to respiration of tobacco seedlings. Instances of poor germination and seedling growth were reported by growers in the Salinas Valley when lettuce was planted too soon after turning barley or rye cover crops in. Patrick et al (1963) undertook experiments to determine whether severe phytotoxicity could be detected when the cultural practice was repeated in the greenhouse with soil and plant residue obtained from the field. Rye extracts with marked phytotoxicity to lettuce were obtained after residues had been decomposed for 10-25 days. Patrick (1971) identified several compounds toxic to lettuce and tobacco in decomposing residues of rye. DeFrank (1979) noted toxicity from several cover crop residues, including winter rye.

In Michigan many vegetable growers plant rye as a fall cover crop for reasons other than weed control. Thus, more research is necessary to determine and fully utilize the allelopathic effects of rye cover crops for weed control in NT vegetable crop production. Several factors, such as vegetable crop and weed tolerance to rye residues, need further examination. If allelopathic cover crops

have the potential to influence weed growth in NT systems, they may also detrimentally influence crop growth. The quantity and release of allelopathic chemicals from rye cover crop residues is dependent on factors which may subsequently influence plant growth. The purpose of this investigation is to determine (1) whether a cultivar ('Wheeler') is superior to a selection ('MSU-13'); (2) which part of rye is most toxic to weeds and crops; (3) whether fall planted rye provides better weed control than a spring planted crop; and (4) what developmental stage of rye its residues are most effective for weed control and least toxic to vegetable crop growth.

### Materials and Methods

#### General

Seeding rates, planting and kill dates, stage at time of kill and residue production of rye are listed in Table 1. All crops were planted with the Moore-Uni-Drill. The drill was also pulled through unplanted control plots to minimize treatment differences due to planting. A right-angle split block with four replications was used for the kill time study and a randomized complete block design for both the fall and spring sown cover crop studies. Granular ammonium nitrate (168 Kg/ha) and weed seeds (Setaria lutescens - 650/m<sup>2</sup>; Chenopodium album - 1200/m<sup>2</sup>) were spread over all fall sown cover crop experiments with a cyclone spreader before covers were killed in spring. Rye was killed back with glyphosate and residue production was measured to determine the control mulch rate. Poplar excelsior (PE) was used as a control to simulate

TABLE 1.--Rye cover crop residue production.

| Experiment         | Seeding<br>Rate<br>(Kg/ha) | Planting<br>Date | Kill Date                   | Rye Stage                  | Residue<br>Biomass<br>(M.T./ha) |
|--------------------|----------------------------|------------------|-----------------------------|----------------------------|---------------------------------|
| Spring Sown<br>Rye | 140                        | 5/21/80          | 7/2/80                      | vegetative                 | 4.7                             |
| Fall Sown<br>Rye   | 168                        | 10/10/80         | 5/5/81<br>5/21/81           | preboot<br>boot            | 4.9<br>6.7                      |
| Rye/Kill<br>Date   | 168                        | 10/10/80         | 5/4/81<br>5/19/81<br>6/1/81 | preboot<br>boot<br>heading | 4.9<br>8.9<br>12.2              |

physical impacts of the mulch, and applied to plots on an equal weight basis. Previous greenhouse experiments had indicated that PE was a suitable control for the mulch effect.

All vegetable crops were planted NT across the plots. Peas were inoculated with Rhizobium spp. before planting. PE was then laid in control plots. Plastic netting (2.5 cm x 5.5 cm) was used to secure PE to the ground. All plots were 3.1 x 3.1 m with six rows of crop spaced 34 cm apart. To evaluate the effect of rye residues on weeds, samples from 93 cm<sup>2</sup> areas were counted, harvested, and dried at 50°-60°C for biomass determination. Four m of row were harvested to evaluate the effect of rye residues on growth and yield of vegetable crops.

#### Effects of Spring Sown Rye on Weeds and Snapbeans

Winter rye ('MSU-13') was drilled in a Spinks loamy sand (Table 1). To evaluate the effect of a living rye cover on weed density, five areas were sampled 34 days after planting. Forty-one days after planting rye, weeds were harvested from 1.0 m<sup>2</sup> areas. All plots were sprayed with glyphosate (0.84 Kg/ha) 42 days after planting rye. Weeds were mowed and their residues removed from control plots 7 days after kill to reduce their effects on crop growth. Rye was cut 13 days after kill and set aside for later application as treatments.

On July 16, 1980 'Spartan Arrow' snapbeans (20 seeds/m) were planted. PE was applied to rye root plots and control plots; and rye shoots were applied to shoot and shoot plus root plots one day

after planting. To evaluate the effect of rye residues on late season weeds, 34 days after rye was killed, weeds were sampled from 1.0 m<sup>2</sup> areas. On August 8 all plots were handweeded and granular ammonium nitrate (33.6 Kg/ha) was spread. Forty-nine days after planting, snapbean stand, fresh and pod weight were obtained.

#### Effects of Fall Sown Rye on Weeds and Vegetables

Two selections of winter rye, 'Wheeler' and 'MSU-13', were drilled in a Marlette fine sandy loam (2-6% slope). Rye was killed early or late (Table 1) with glyphosate (1.12 Kg/ha). 'Sparkle' peas (38 seeds/m) were planted NT through the early killed rye residues on May 26, 1981 or 21 days after kill. Forty-six days after kill (25 days after planting peas), weeds from four sample areas were counted and harvested. To control barnyardgrass, earlier killed plots were then sprayed with a post-emergence grass herbicide, diclofop-methyl (2-[4-(2,4-dichlorophenoxy) phenoxy] propanoic acid)--1.12 Kg/ha. Forty eight days after planting, stand, fresh plant, pod, and pea weights were recorded.

Twenty-eight days after kill, similar areas were sampled to evaluate the effect of late killed, undisturbed rye residues on weeds. 'Heinz 1350' tomatoes (26 seeds/m) and 'Spartan Arrow' snapbeans (20 seeds/m) were NT planted 35 days after rye was killed. Since rainy weather delayed timely planting of vegetable crops, paraquat (1.12 Kg/ha) plus X-77 (0.5% v/v) was sprayed over all late kill treatments before crop emergence to control weeds. Late season weed evaluations were made using the same sampling technique. All

late killed plots were handweeded 33 days after crops were planted. Snapbean stand, fresh and pod weights were determined 59 days after planting. Eighty-eight days after planting, tomato stands and fresh weights were obtained.

#### Effects of Kill Time of Cover Crops on Weeds and Vegetables

Three cover crops (winter rye - 'Wheeler' and 'MSU-13', and winter wheat - 'Yorkstar') were fall sown in a Marlette fine sandy loam. In spring, cover crops were killed back with glyphosate (1.12 Kg/ha) at 2 week intervals. Since rye appeared to produce more biomass than wheat, its residue was measured to determine the control mulch rate for each killdate. Weed counts and harvest in undisturbed cover crop residues were made 46 days after the first killdate. 'Spartan Arrow' snapbeans and 'Heinz 1350' tomatoes were direct seeded through the residue 52 days after the first kill (24 days after the third kill). All plots were sprayed with paraquat (1.12 Kg/ha) plus X-77 (0.5% v/v) before crop emergence to kill any emerged weeds. Incomplete kill of barnyardgrass by paraquat necessitated use of a post-emergence grass herbicide, diclofop-methyl (1.68 Kg/ha), 22 days after crops were planted. All plots were handweeded 35 days after planting.

Application of diclofop eliminated evaluation of late season grass weeds. Eighty-six days after the first kill (58 days after the third kill), broadleaf weeds were counted and harvested. Fifty-nine days after planting, snapbean stands, fresh and pod weights were obtained. Tomato stands and fresh weights from four m of

row were determined 78 days after planting. To evaluate the effect of rye and wheat residues, and PE on nutrient availability, fifty, top, fully mature leaves of snapbeans and tomatoes were harvested for N, P, and K analysis (Ulrick and Berry, 1961).

### Results and Discussion

#### Effects of Spring Sown Rye on Weeds and Snapbeans

A living cover of spring planted winter rye reduced early season biomass of common lambsquarters (Chenopodium album L.) by 98%, large crabgrass (Digitaria sanguinalis (L.) Scop.) by 42% and common ragweed (Ambrosia artemisifolia L.) by 90% over unplanted controls (Table 2). There was no significant difference in the individual and total densities of these weeds, which may have been due to a large variability in the natural weed population. In contrast, the total weed biomass/m<sup>2</sup> was reduced 94% over unplanted plots. Direct rye/weed competition for water, light, and nutrients, in addition to allelopathic chemicals released from rye roots and shoots, may contribute to the noted reductions in weed biomass. Later season evaluations indicated no differences in weed or snapbean yield could be attributed to root, shoot, or root plus shoot treatments of rye. Therefore, rye residue treatments were averaged and compared to the control PE mulch treatment. Although late season densities of large crabgrass, common lambsquarters, and wild buckwheat (Polygonum convolvulus L.) appeared reduced under rye residues, statistical analyses showed no significant differences. In contrast, total weed

TABLE 2.--Effect of a spring planted living rye cover crop on early season biomass/m<sup>2</sup> of large crabgrass (LACG), common ragweed (CORW) and common lambsquarters (COLQ) in a Spinks loamy sand.

| Cover Crop   | LACG<br>(g/m <sup>2</sup> ) | CORW<br>(g/m <sup>2</sup> ) | COLQ<br>(g/m <sup>2</sup> ) | Total*<br>(g/m <sup>2</sup> ) |
|--------------|-----------------------------|-----------------------------|-----------------------------|-------------------------------|
| No Rye       | 12                          | 21                          | 165                         | 265                           |
| 'MSU-13' Rye | 7                           | 2                           | 4                           | 16                            |

\*Means are significantly different at the 5% level.

density/m<sup>2</sup> was reduced 69% and total weed biomass/m<sup>2</sup> was reduced 32% under rye residues when compared to PE controls (Table 3). The control mulch should reflect differences which would arise because of the physical presence of a mulch cover on the soil surface. Thus, the reductions noted in late season total weed density and biomass may be a result of allelopathic chemicals released from the decaying rye residues. Although stand and fresh weight of snapbeans under rye residues were not different from the poplar excelsior treatment, pod weight was increased by 60% in the rye treatment (Table 4). The increase in snapbean pod weight in the rye residue may be a result of a decrease in concentration of allelopathic chemicals to the point where they become stimulatory to plant growth. This sandy soil has little organic matter ( $\approx 1.0\%$ ) to bind compounds which may rapidly leach into the root zone. Possibly, the increased pod yield may have resulted from an improved soil structure due to the extensive nature of rye root systems.

#### Effects of Fall Sown Rye on Weeds and Vegetables

Weed control and pea yields were not different under residues of 'Wheeler' rye, a standard cultivar planted in Michigan, and 'MSU-13'. Although densities of barnyardgrass and redroot pigweed did not differ under rye residues when compared to PE mulch, barnyardgrass biomass was reduced up to 74% and redroot pigweed biomass was reduced up to 55% under rye residues (Table 5). Total weed biomass in NT peas was reduced up to 73% under rye residues

TABLE 3.--Effect of rye residues on total late season weed density and biomass per 1.0m<sup>2</sup> in no-till planted snapbeans on a Spinks loamy sand.

| Cover            | No.*<br>m <sup>2</sup> | wt<br>(g)* |
|------------------|------------------------|------------|
| Poplar excelsior | 243                    | 68         |
| 'MSU-13' rye     | 74                     | 46         |

\*Means were averaged across rye treatments and are significantly different at the 5% level.

TABLE 4.--Yield of no-till planted snapbeans in rye and poplar residues on a Spinks loamy sand.<sup>1</sup>

| Cover            | Stand<br>(#/4m) | Plant wt.<br>(Kg/4m) | Fruit wt.*<br>(Kg/4m) |
|------------------|-----------------|----------------------|-----------------------|
| Poplar excelsior | 60              | 2.7                  | 1.0                   |
| 'MSU-13' rye     | 63              | 3.4                  | 1.6                   |

<sup>1</sup>Means were averaged across rye treatments.

\*Means are significantly different at the 5% level.

TABLE 5.--Effect of early killed rye residues on barnyardgrass (BYGR), redroot pigweed (RRPW), and total biomass per 1.0m<sup>2</sup> in no-till peas on a Marlette fine sandy loam.<sup>1</sup>

| Cover            | BYGR<br>(g) | RRPW<br>(g) | Total<br>(g) |
|------------------|-------------|-------------|--------------|
| Poplar excelsior | 50.2 b      | 1.4 b       | 51.9 b       |
| 'MSU-13' rye     | 22.0 a      | 0.9 a       | 23.9 a       |
| 'Wheeler' rye    | 12.7 a      | 0.5 a       | 13.9 a       |

<sup>1</sup>Means within a column followed by the same letter are not significantly different at the 5% level by Duncan's Multiple Range Test.

when compared to the mulch control, while total weed density remained the same. Yields of peas were not affected by rye residues (Table 6). Thus early killed rye residues appear to suppress total weed growth, but not weed germination or the germination, growth, or yield of peas.

In another experiment, undisturbed late killed rye cover crops reduced densities of redroot pigweed up to 81% when compared to no residue control plots. Biomass of barnyardgrass and redroot pigweed were both reduced under rye residues when compared to no residue plots (Table 7). In addition, total density and biomass of weeds in undisturbed rye residues were reduced up to 54% and 96% respectively. Since no mulch control was present in this experiment it is impossible to conclude that allelopathy is the only factor responsible for the weed reductions noted. It may comprise one component of the interference between rye residues and weed growth. In a third experiment, total weed biomass was reduced up to 83% when compared to PE control mulch plots (Table 8). In this case, where a control mulch was present one might conclude that allelopathy is involved in weed suppression.

There was no treatment difference in NT planted tomato stand or fresh weight (Table 9). Similarly, stand, fresh, weight, and pod weight of snapbeans were not different in rye residue treatments. Thus NT planted tomatoes and snapbeans appear to tolerate rye residues during germination and growth suggesting that they may be managed with this system of vegetable crop production.

TABLE 6.--Yield response of no-till planted peas to rye residues in a Marlette fine sandy loam.<sup>1</sup>

| Cover            | Stand<br>(No.) | Fresh wt.<br>(Kg) | Pod wt.<br>(Kg) | Pea wt.<br>(g) |
|------------------|----------------|-------------------|-----------------|----------------|
| Poplar excelsior | 141            | 1.0               | 0.60            | 276            |
| 'MSU-13' rye     | 132            | 0.9               | 0.54            | 256            |
| 'Wheeler' rye    | 134            | 1.1               | 0.60            | 283            |

<sup>1</sup>Four meters of crop row were harvested. Means are not significantly different at the 5% level.

TABLE 7.--Effect of undisturbed rye residues on barnyardgrass, redroot pigweed, and total biomass per 1.0m<sup>2</sup> in a Marlette fine sandy loam.<sup>1</sup>

| Cover         | BYGR<br>(g) | RRPW<br>(g) | Total<br>(g) |
|---------------|-------------|-------------|--------------|
| None          | 40.4 b      | 2.7 b       | 53.3 b       |
| 'MSU-13' rye  | 1.6 a       | 0.5 a       | 2.2 a        |
| 'Wheeler' rye | 2.7 a       | 0.0 a       | 2.7 a        |

<sup>1</sup>Means within a column followed by the same letter are not significantly different at the 5% level for barnyardgrass and the 1% level for redroot pigweed and total biomass by Duncan's Multiple range test.

TABLE 8.--Effect of rye residues on total late season broadleaf weed density and biomass per 1.0m<sup>2</sup> in no-till planted vegetables on a Marlette fine sandy loam.<sup>1</sup>

| Cover            | No./m <sup>2</sup> | g/m <sup>2</sup> |
|------------------|--------------------|------------------|
| Poplar excelsior | 38                 | 17.0 b           |
| 'MSU-13' rye     | 38                 | 4.1 a            |
| 'Wheeler' rye    | 65                 | 2.9 a            |

<sup>1</sup> Means within a column followed by the same letter are not significantly different at the 5% level by Duncan's Multiple Range Test.

TABLE 9.--Yield response of no-till planted snapbeans and tomatoes to rye residues in a Marlette fine sandy loam.<sup>1</sup>

| Cover            | Snapbeans |                   | Tomatoes |                   |
|------------------|-----------|-------------------|----------|-------------------|
|                  | Stand     | Fruit wt.<br>(Kg) | Stand    | Fresh wt.<br>(Kg) |
| Poplar excelsior | 99        | 1.8               | 45       | 4.3               |
| 'MSU-13' rye     | 101       | 1.6               | 38       | 3.5               |
| 'Wheeler' rye    | 111       | 1.9               | 41       | 3.9               |

<sup>1</sup> Four meters of crop row were harvested. Means are not significantly different at the 5% level.

### Effects of Kill Time of Cover Crops on Weeds and Vegetables

Eighteen days after the third kill, a linear trend between barnyardgrass density and time of kill was found with a maximum reduction in counts in the third kill treatment (Figure 1). Undisturbed cover crop residues in the first and second kill treatments reduced barnyardgrass biomass, while no difference was found in the later killed treatments (Figure 2). A possible explanation for no differences in biomass of barnyardgrass after the third killing date is that almost all barnyardgrass seeds had germinated by the time of application of glyphosate. Although barnyardgrass germinates best with alternating temperatures of 20 to 30°C and light (Roche and Muzik, 1964), in this study few emerged later in the season. This may be due to the decreased light at the soil surface as a result of an accumulation of plant residue. Total weed density was not reduced under cover crop residues compared to no residue controls in the early killed treatments, while residues reduced total density after both the second and third killing times (Figure 3). In addition, undisturbed rye residues in the first kill and all residues in the second kill reduced total weed biomass over no residue plots, while there was no biomass difference in third kill treatments (Figure 4). Once again, a possible explanation for this may be that the third kill was late enough to kill the germinated weeds and temporarily exhaust the weed seed supply until environmental conditions are right for emergence of later season weeds. Fifty-eight days after the third kill date, total late season broadleaf weed density

Figure 1.--Effect of cover crop kill date on barnyardgrass density  
in a Marlette fine sandy loam.

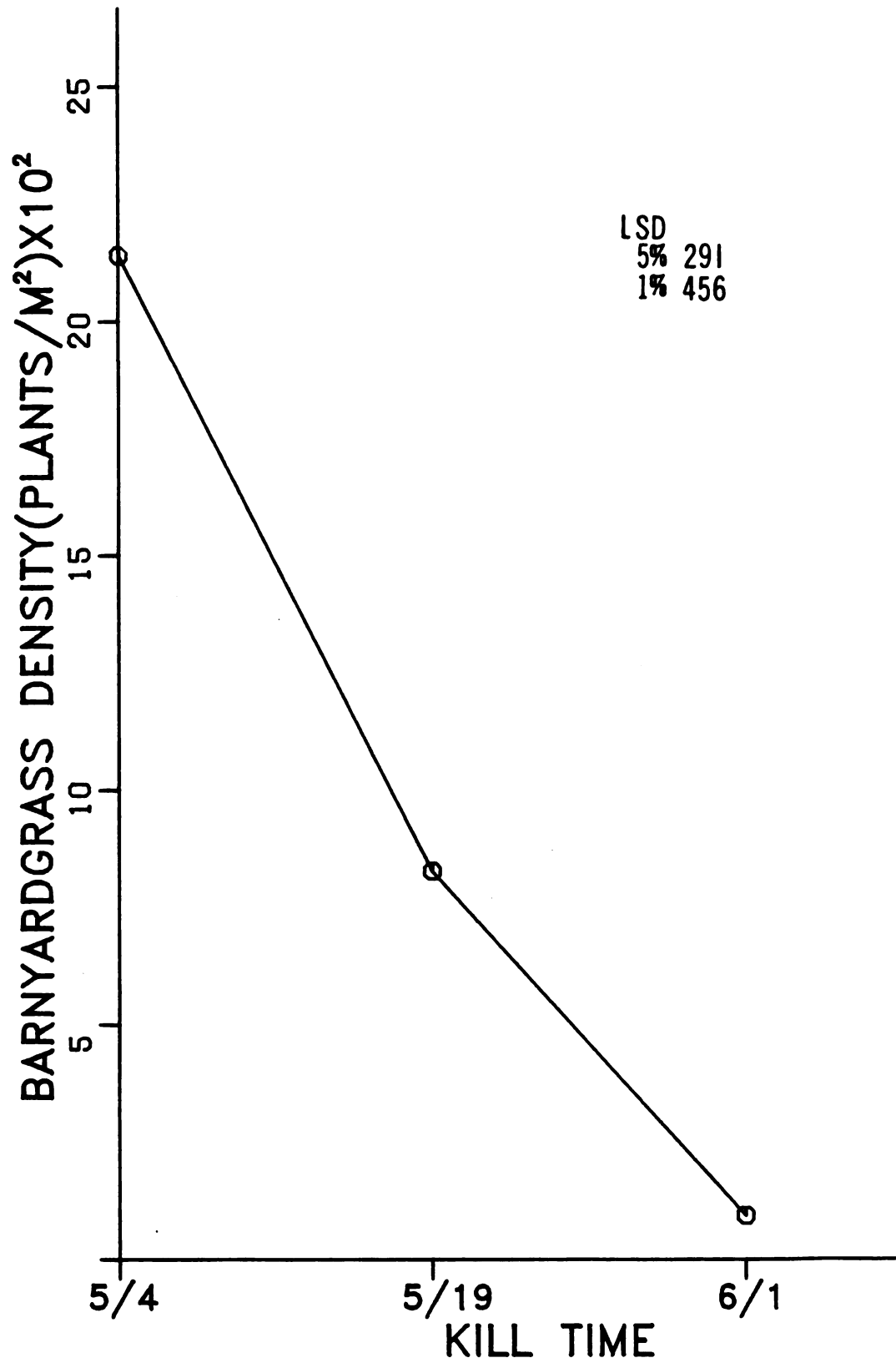


Figure 2.--Effect of undisturbed cover crop residues and time of kill on barnyardgrass biomass in a Marlette fine sandy loam.

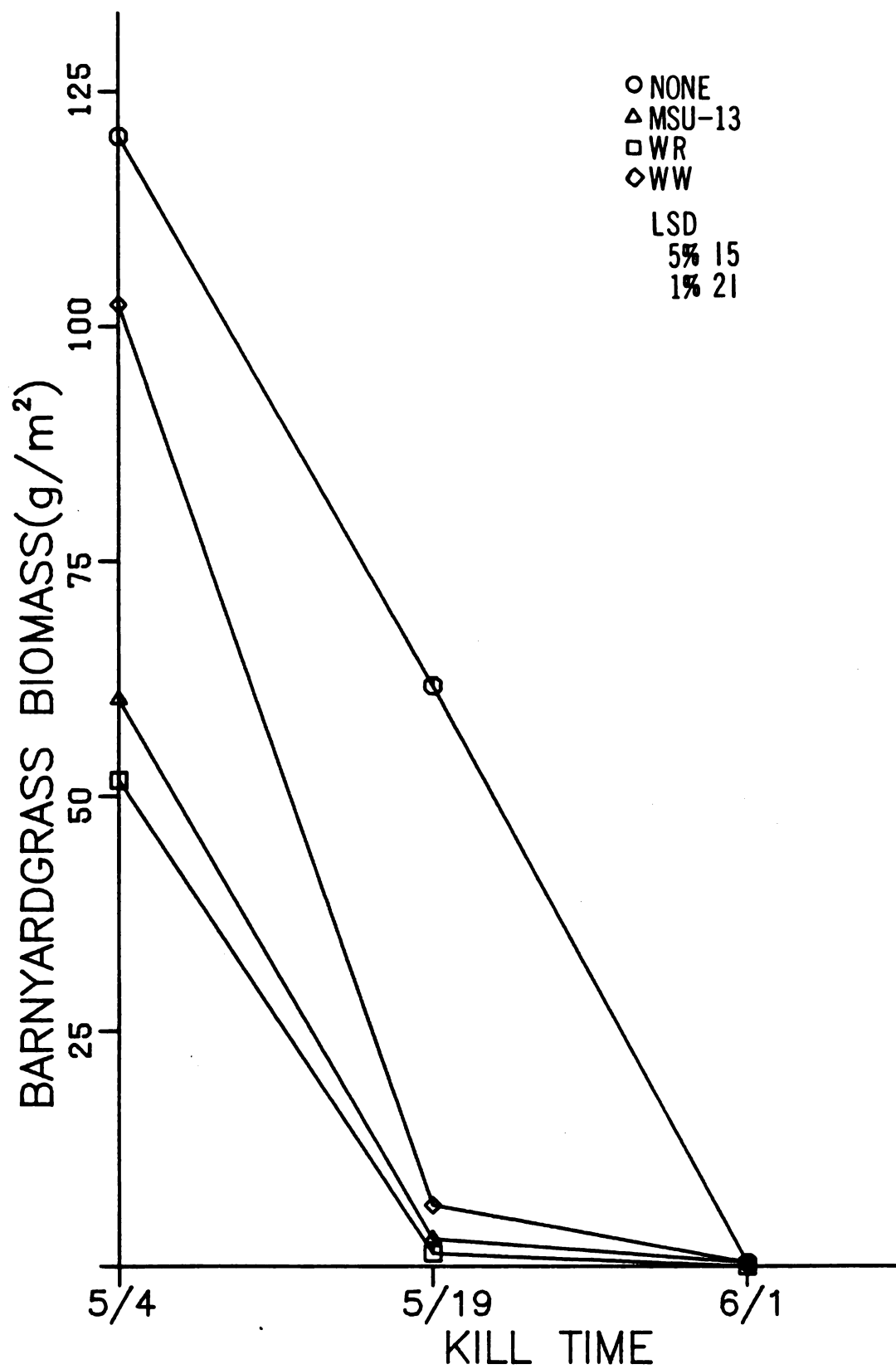


Figure 3.--Effect of undisturbed cover crop residues and time of kill on total weed density in a Marlette fine sandy loam.

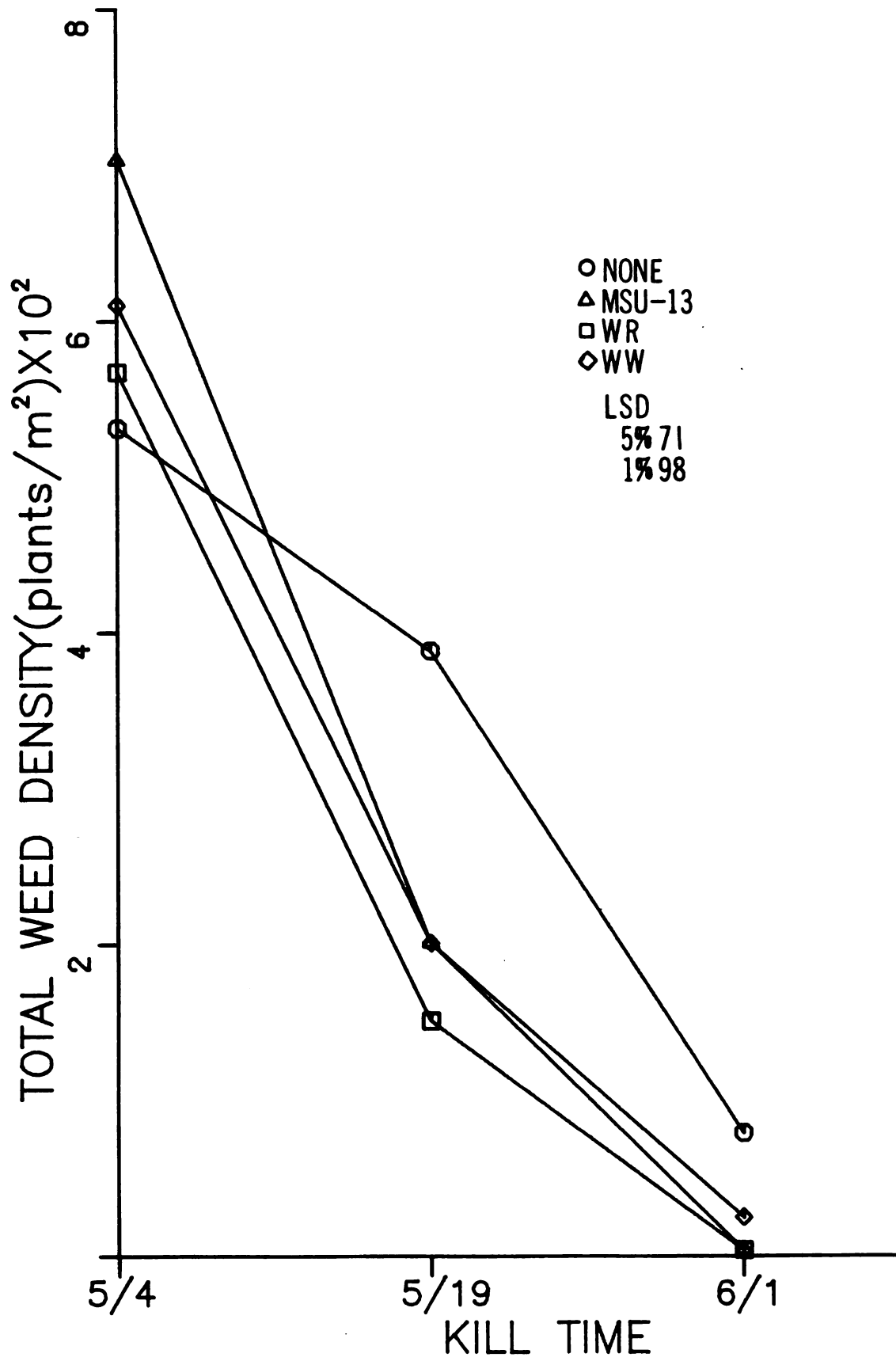
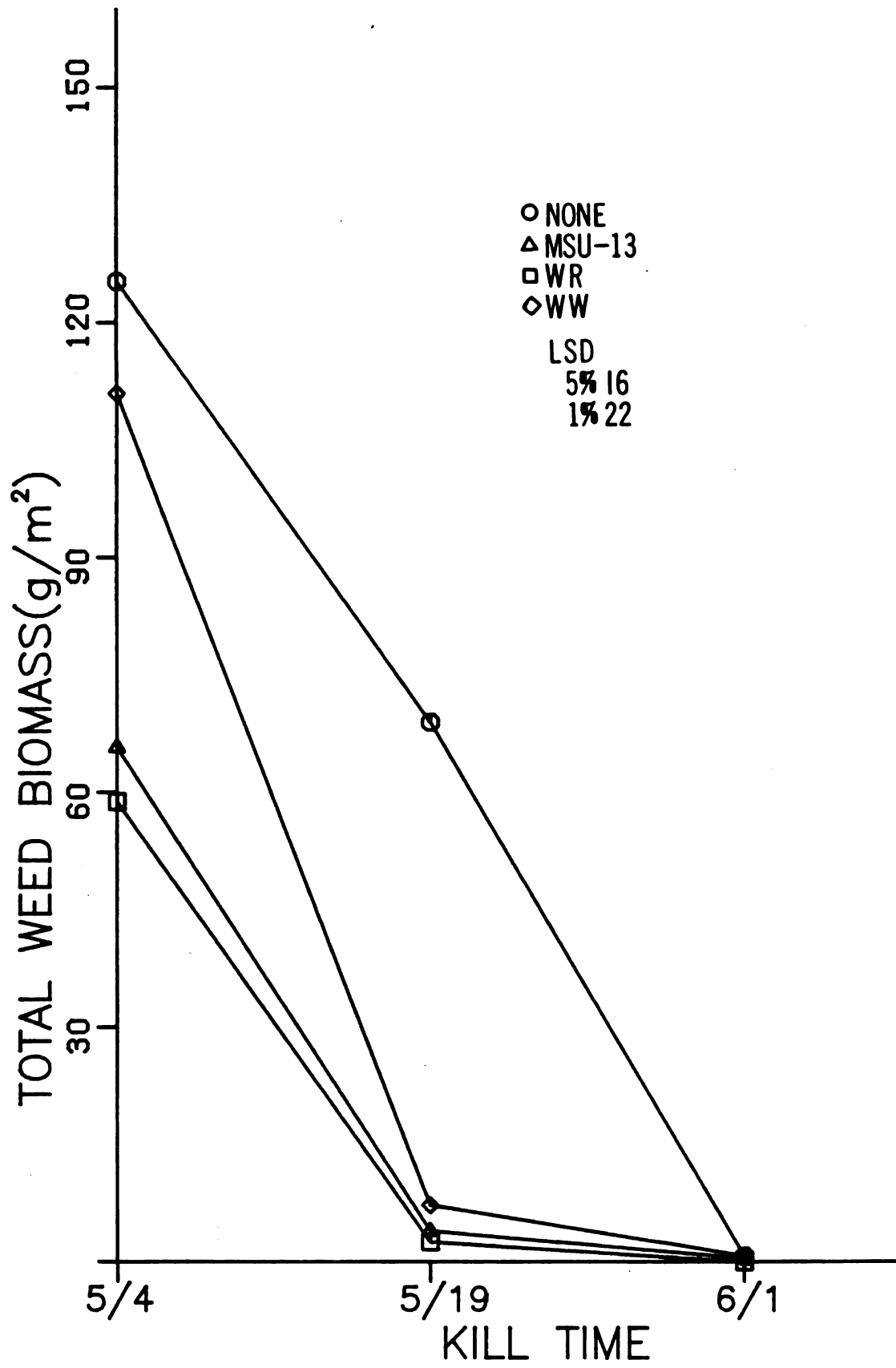


Figure 4.--Effect of undisturbed cover crop residues and time of kill on total weed biomass in a Marlette fine sandy loam.



was reduced greatly, but similarly, by all covers in the late kill treatments when compared to no residue plots (Figure 5). Total late season broadleaf weed biomass decreased in later kills under cover crops and PE treatments, while biomass greatly increased from the first to the third kill in no residue plots (Figure 6). A possible explanation for the increase in late season weed biomass in the bareground plots with kill time is that residues of barnyardgrass were greater in the first kill time. The barnyardgrass residues may have contributed to a mulch or an allelopathic effect on the broadleaf weed populations. Later killed plots never developed the lush barnyardgrass growth that the early killed treatments did. Possibly more weeds were able to germinate and grow where little barnyardgrass was present and subsequently late season weed biomass in the bareground plots increased with later kill times. At the second and third kill time there was no difference in weed biomass between crop residues and control mulch (PE) plots suggesting that the physical mulch effects are an important component of weed control in NT vegetable production.

While stand of NT snapbeans did not vary in any treatments, the total fresh weight of plants was greatest in the third kill, no residue plot (Figure 7). Late killed 'MSU-13' rye reduced snapbean fresh wt. over late kill control mulch plots although residues of 'Wheeler' rye and winter wheat did not affect fresh wt. over control mulch plots. This suggests that the cover crops were affecting snapbean fresh weight in different manners and that

Figure 5.--Effect of cover crop residues and time of kill on total annual late season broadleaf weed density in no-till planted vegetables on a Marlette fine sandy loam.

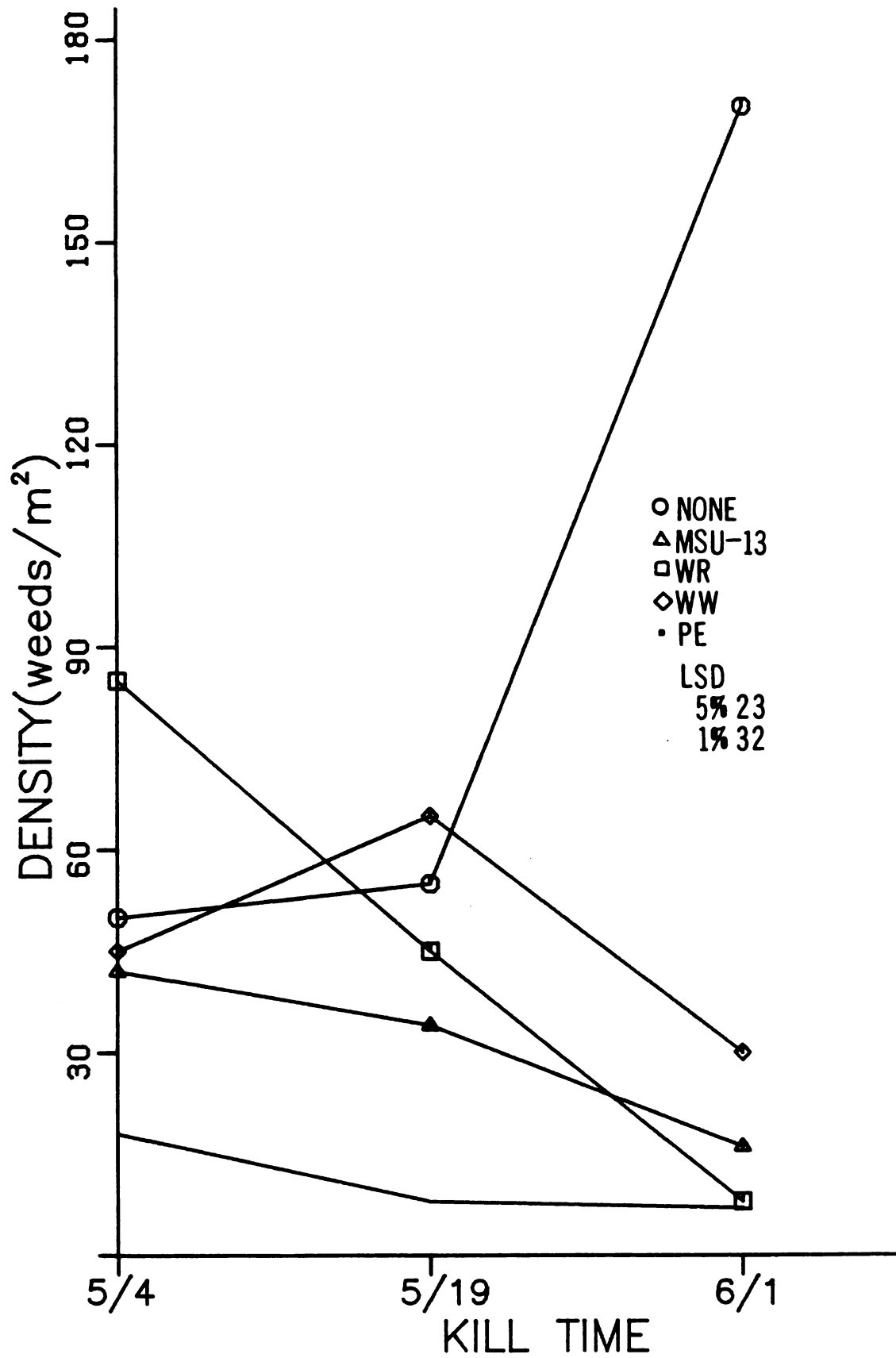


Figure 6.--Effect of cover crop residues and time of kill on total annual late season broadleaf weed biomass in no-till planted vegetables on a Marlette fine sandy loam.

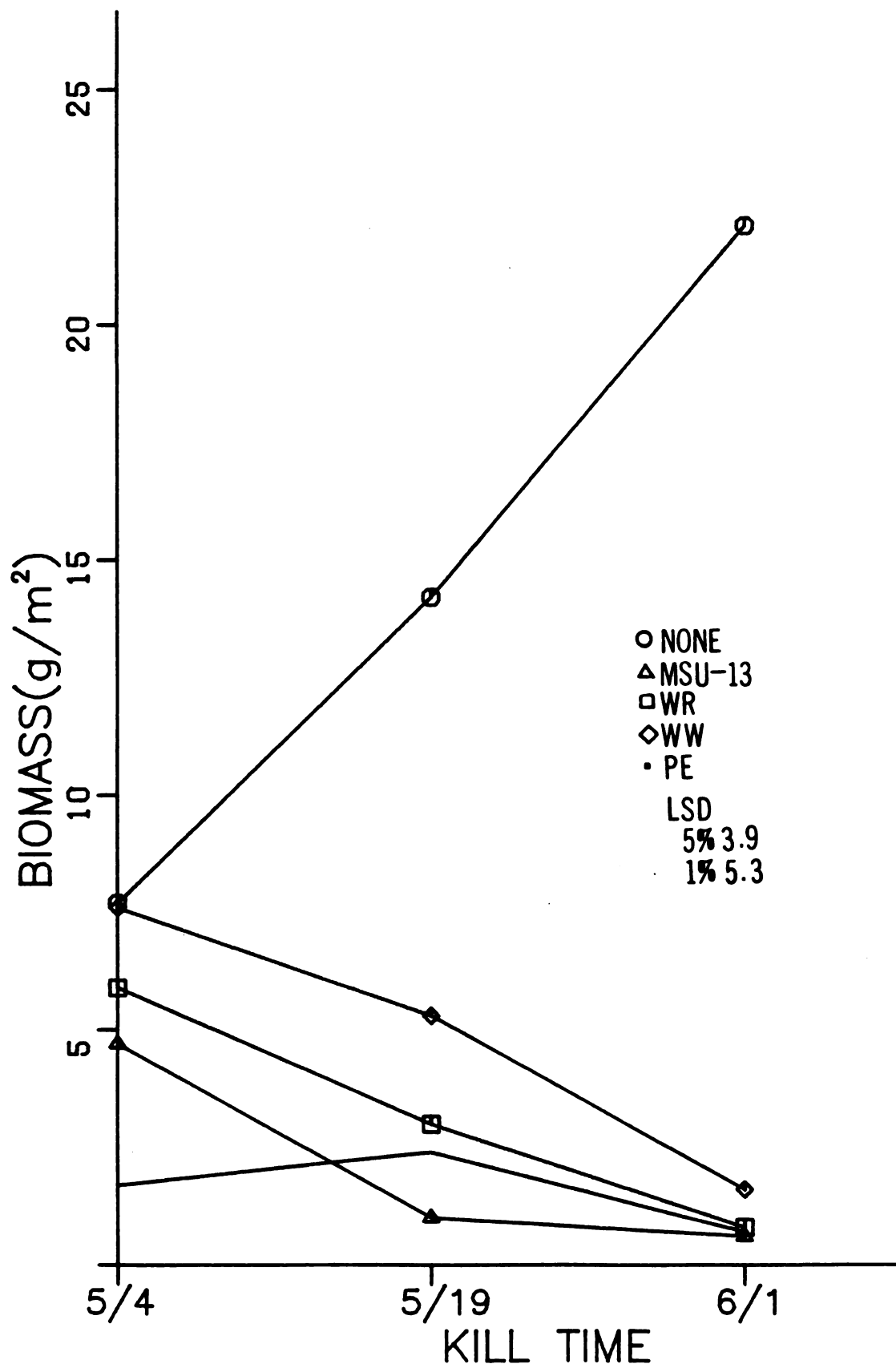
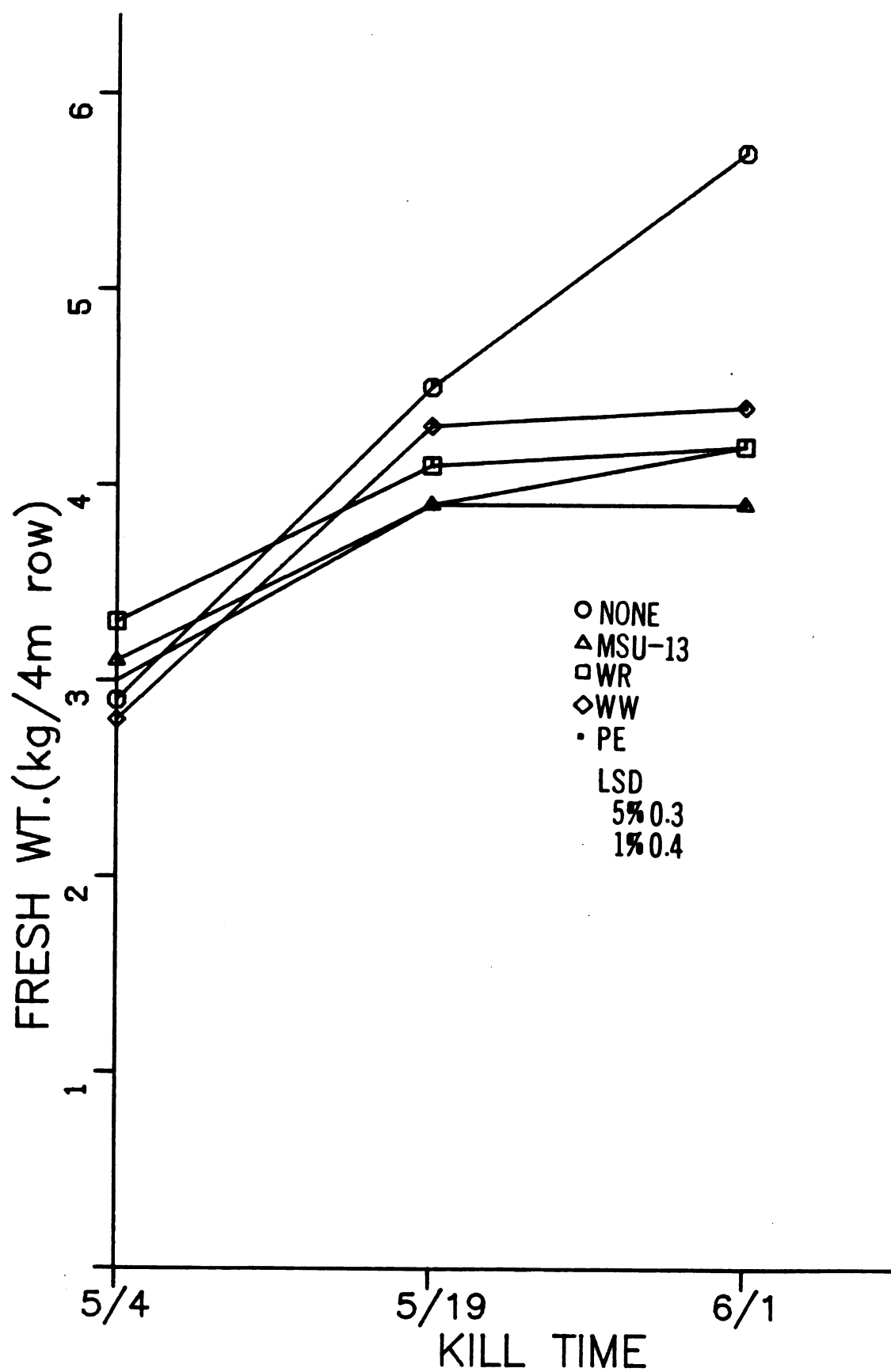


Figure 7.--Effect of cover crop residues and time of kill on fresh weight of no-till planted snapbeans in a Marlette fine sandy loam.



'MSU-13' may be allelopathic to snapbeans. Snapbean fresh weight was significantly less in the earliest kill treatment which was attributed more to competition from emerged weeds rather than allelopathy. All cover crop residues in the first and second kill treatments stimulated pod weight of snapbeans over control mulch plots, while rye residues and control mulch decreased pod yield over bare ground plots in the second and third kill treatments (Figure 8). Tomato stand was reduced in the presence of late killed residues and PE mulch. In fact, the PE mulch also reduced tomato stand in the first and second kill treatments (Figure 9). Apparently tomato seedlings cannot tolerate excessive residues of any sort. The energy reserves in the relatively small seeded tomato may not have been great enough to sustain early seedling growth through the mulch until the photosynthesis apparatus was fully operational. Residues of 'MSU 13' rye reduced tomato stand more than winter wheat residues in the second and third kill treatments, but did not affect the stand in the first kill treatment. Thus rye residues may be more allelopathic than wheat residues. Rye residues in third kill treatments reduced fresh weight of tomatoes over both the control mulch and no residue control plots (Figure 10). Tomato fresh weight was least in first and second kill control mulch plots with cover crop residues decreasing fresh weight over no residue controls in the first, but not second kill date. Fresh weight of tomatoes under residues was greatest in second kill treatments at which time it did not vary from no residue control plots.

Figure 8.--Effect of cover crop residues and time of kill on  
pod yield of no-till planted snapbeans in a Marlette  
fine sandy loam.

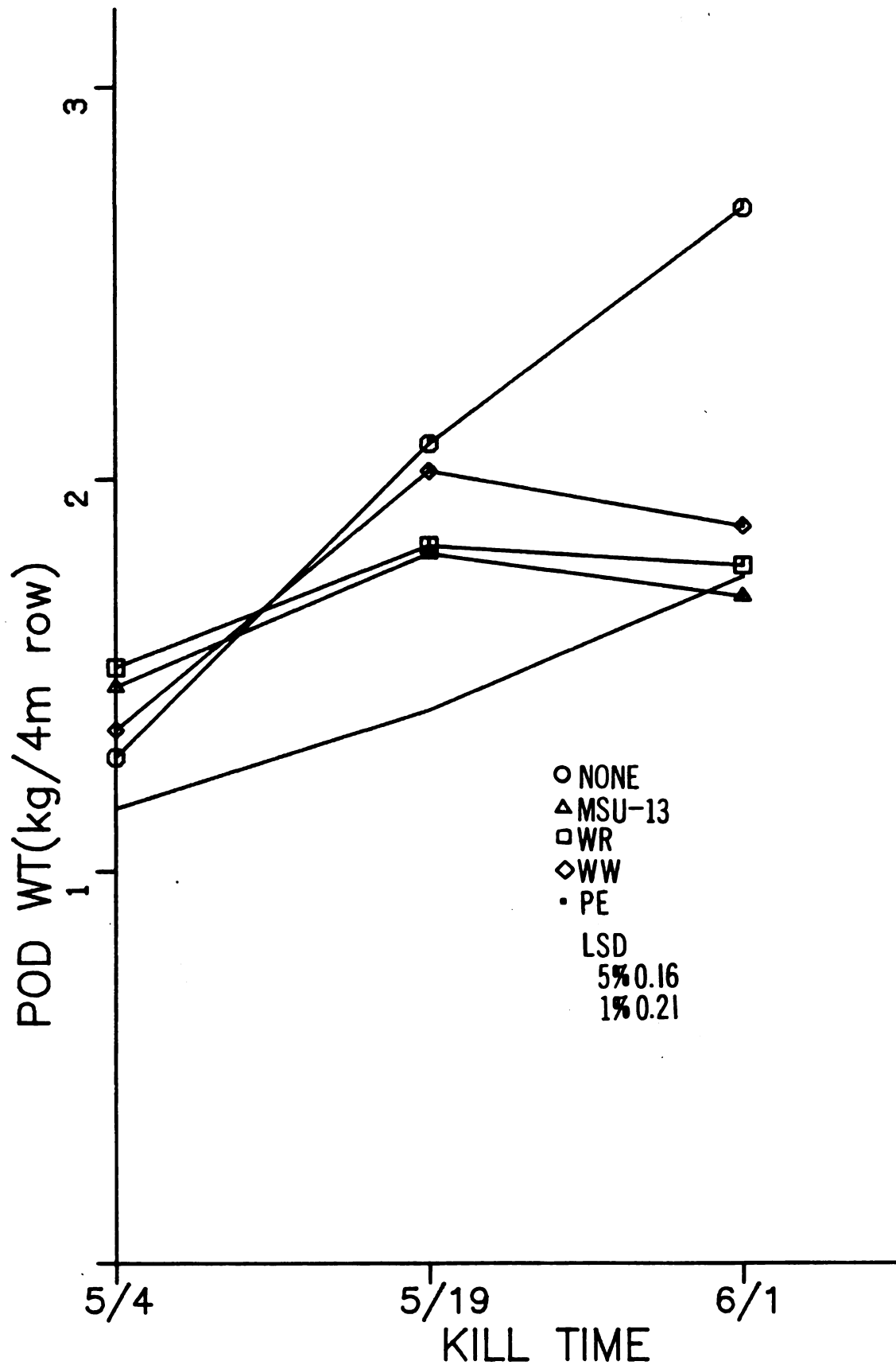


Figure 9.--Effect of cover crop residues and time of kill on stand of no-till planted tomatoes in a Marlette fine sandy loam.

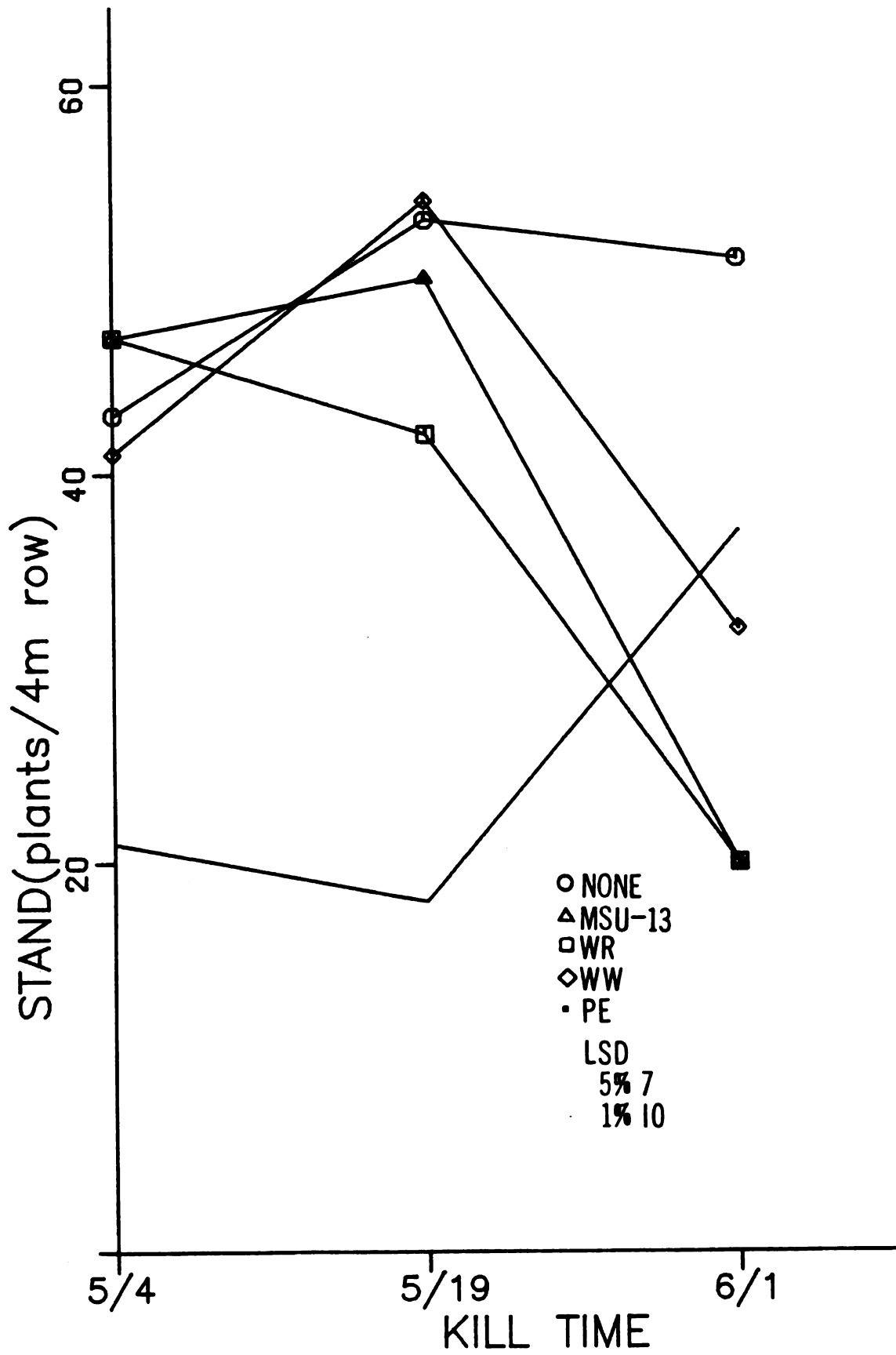
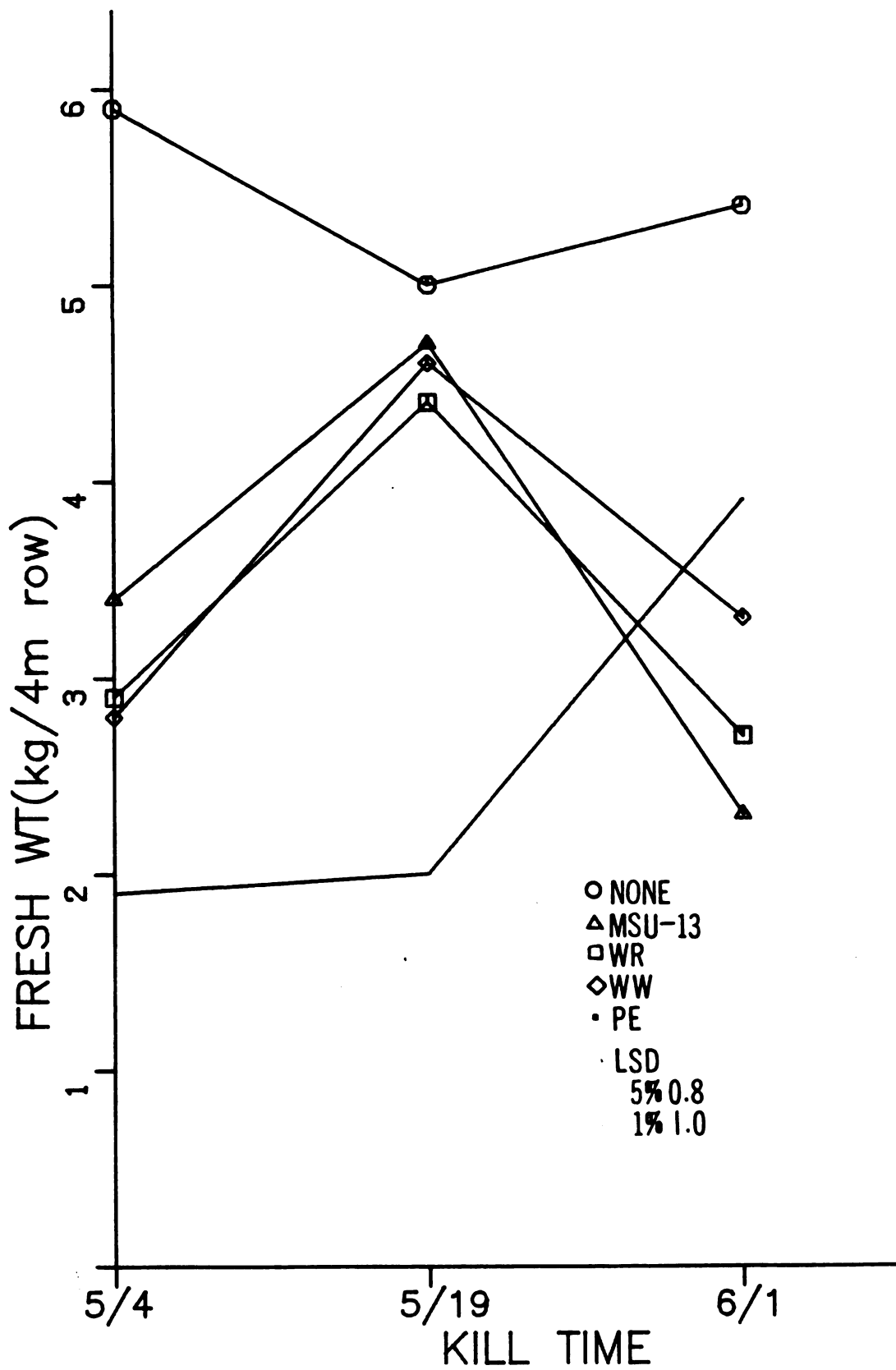


Figure 10.--Effect of cover crop residues and time of kill on fresh weight of no-till planted tomatoes in a Marlette fine sandy loam.



Tomatoes and beans under residues of rye and wheat, poplar excelsior, and no residue were analyzed for their relative nitrogen, phosphorous, and potassium levels eighty-one days after planting. Statistical analyses revealed no significant differences between any of the treatments. Thus the reductions in fresh weight under residues are probably not due to differences in soil fertility. This suggests that the yield differences in snapbeans and tomatoes may be attributed to either the leaching of allelopathic chemicals from residues or to toxic microbial intermediates formed during decomposition of the residue.

### Conclusions

Generally weeds and crops responded similarly to residues of two rye selections and residues had no apparent effect on accumulation of N, P, and K in beans and tomatoes. Fall sown cover crop residues suppressed weed growth over both no residues and PE controls, which suggests that allelopathy, in addition to the physical presence of the mulch, is responsible for the weed biomass reductions. Yields of peas, snapbeans, and tomatoes were not reduced under rye residues suggesting that they may be successfully managed in a NT/rye cover crop system. A fall sown rye provides soil protection during winter and allows for more timely management of crop production in spring. Although spring sown rye also reduced weed biomass, production of early season crops, such as peas, is not always feasible since rye will still be growing. Thus, to realize the greatest

benefits from the system, fall sown cover crops may result in improved weed control and crop yields.

Spring kill time of fall sown cover crops should depend on the crop to be planted and the amount of residue present. With early crops, such as peas, kill time should be earlier than when planting warmer season crops such as snapbeans or tomatoes. If covers are killed too soon before planting, competition from emerged weeds tends to be severe. When crops are planted soon after killing covers, they tend to compete better with weeds. Early season weed growth was more affected by the timing of the kill rather than to the residues themselves. In contrast, cover crop residues differentially affected later season weed growth. Density and biomass of weeds were reduced under rye residues when compared to no residue plots. Also, PE mulch severely reduced weed density and growth over no residue plots indicating that the mulch effect is an important component of weed control in NT systems. With timely management, successful production of peas, snapbeans, and tomatoes appears possible with this system.

## GREENHOUSE EVALUATION OF RYE RESIDUE TOXICITY TO WEEDS AND CROPS

### Abstract

Greenhouse experiments were initiated to more clearly define the nature of interactions of rye (Secale cereale L.) residues with weeds and vegetable crops observed in the field. 'MSU-13' rye, and a cultivar, 'Wheeler', were tested for their toxicity to several weeds and crops. Germination and growth varied with kill method and age of residues. Chemically desiccated rye residue reduced germination of lettuce and barnyardgrass and reduced growth of tomato. Studies on toxicity of residues of rye killed back at different ages, revealed growth of indicators was suppressed the most in the 50 day-old rye residues. The presence of rye residues accounted for most of the variability in germination and growth of indicators suggesting that allelopathy may be a component of the weed/crop interference noted in the field.

## CHAPTER 3

### GREENHOUSE EVALUATION OF RYE RESIDUE TOXICITY TO WEEDS AND CROPS

#### Introduction

Greenhouse experiments were initiated to more clearly define the nature of interactions of rye residues with weeds and vegetable crops, observed in the field. For greenhouse studies to be meaningful, it is important to simulate field conditions as closely as possible. Detection of allelopathic chemicals is difficult due to the ephemeral nature of the products (Patrick, 1971). Since growth regulators are present in plants in extremely small quantities, bioassays are frequently the only methods of analysis sensitive enough for detection of leached compounds (Tukey, 1969). Phytotoxic materials liberated by plants or plant residues may gradually accumulate and inhibit further growth of plants (McCalla and Haskins, 1964). Thus the rye may influence the growth of other plant species through leaching of chemicals from the plant residues or indirectly by microbial products formed upon decay. In addition, the physical presence of the mulch cover (which changes environmental conditions at the seed/soil interface) may influence the growth of other plant species (Phillips, 1973). Therefore, to separate out the allelopathic effects from the physical effects, a control for the mulch effect would be desirable. Poplar excelsior (PE) has been used to

stabilize new plantings along roadsides while the grass sod becomes established. It's appearance is more similar to rye residues than either vermiculite or peat, two common horticultural mulches; and it can be handled for field application. Therefore, it was necessary to determine if poplar excelsior had any adverse effects on plant growth.

There have been reports on phytotoxicity associated with surface residues of cover crops (McCalla and Duley, 1948, 1949; Overland, 1966). In addition, there have been various reports on toxicity of decomposing rye residues (Patrick, et al, 1963; Patrick, 1971). Therefore, the greenhouse investigations were directed at determining if rye residues interfere with plant growth through allelopathy, in NT studies similar to the field situation.

There are many factors which influence quantity and quality of substances leached from foliage including factors associated directly with the plant as well as those associated with the environment (Tukey, 1969). The age or stage of plant development may be one factor. Young actively growing tissue is relatively immune to loss of mineral nutrients and carbohydrates, whereas more mature tissue approaching senescence is very susceptible to leaching (Cholodny, 1932; Schoch, 1955). Plant introductions of Avena sativa L. were assayed and several lines were found to inhibit weed growth (Fay and Duke, 1977). Several accessions from the germplasm collection of Cucumis sativus and related Cucumis spp. were screened and allelopathic activity was demonstrated in sand culture (Putnam and Duke, 1974). Thus, cultivar differences may exist in rye germplasm

also. An objective of this study was to evaluate differences between residues of a selection of rye ('MSU-13') screened from a portion of the world's collection for weed suppressing ability, and 'Wheeler' rye, a standard cultivar grown as a cover crop in Michigan.

Numerous environmental factors have an influence on leaching of metabolites (Tukey, 1969). It has been shown that leaching of carbohydrates from young bean leaves directly paralleled light intensity received by plants (Tukey, Wittwer, and Tukey, 1957). Plant injury, or stress, by mechanical, pathological, or physiological action may also influence production and release of metabolites (Tukey and Morgan, 1963). Commercial herbicides may also represent stress factors for affected plants (Rice, 1974). Thus, it is important to determine what effects these factors have on the inhibitor content in the residue. Dieterman et al (1964) discovered that tobacco plants sprayed with 2,4-D had a greater concentration of scopolin in the leaves, stems, and roots 30 days after application. Therefore, methods of plant stress were also evaluated for their effect on toxicity of rye residues. Roots and shoots of plants may also vary in their phytotoxic compound production (Rice, 1974). Bioassays were used to determine if toxicity of residues of rye varied by chemical, mechanical and physiological factors.

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## Materials and Methods

### Evaluation of Poplar Excelsior (PE) as a Non-Toxic Control Mulch

In a greenhouse study of surface mulches, 30 seeds of both 'Petoeary' tomatoes and barnyardgrass (Echinochloa crusgalli L. Beauv.) were planted in Spinks loamy sand ( $\approx 1.0\%$  cm) in 10 cm x 15 cm styrofoam pots. PE, vermiculite, and peat were applied over planted seeds at rates which produced light reductions equivalent to 4.4 g of rye residue or  $450\mu\text{E}/\text{cm}^2 \text{ sec}^{-1}$ . The sensor of a LI-COR Quantum/Radiometer/Photometer was placed in a pot with a glass plate over the top to determine light reduction measurements. Weights of mulches were determined after light meter readings and mulches were then applied on a weight basis. Plants were grown in the greenhouse under 16 hr of metal halide light. The experimental design was a randomized complete block with 4 replications. To determine if poplar excelsior was an adequate control for the mulch effect, and whether it adversely affected plant growth, germination counts of tomato and barnyardgrass were taken 7 days after planting (DAP). Rows were also thinned to ten plants per row at this time. In addition, barnyardgrass and tomato were harvested 14 and 19 DAP respectively, dried at 50-60°C, and weighed to evaluate the effect of mulches on dry weights of plants. Relative N, P, K, in tomato under rye, poplar excelsior, and no mulch treatments was determined to see if nutrition was altered under the poplar excelsior.

### General Materials and Methods for No-till Greenhouse Bioassay

Two cultivars of rye, 'MSU-13', screened from a portion of the world's collection, and 'Wheeler' rye, a standard cultivar in Michigan, were planted into plastic flats (25 cm x 25 cm x 7.5 cm) containing a Spinks loamy sand and grown under metal halide lighting ( $500 \mu\text{E}/\text{cm}^2\text{sec}^{-1}$ ). While growing, rye was watered with soluble fertilizer (1.0/L. of Peters 20-20-20) every other day with water and was weeded prior to herbicide treatment. Thirty to 40 days after planting, treatments were applied to rye. Unplanted controls of PE were watered, weeded and fertilized as rye. To evaluate residue toxicity, indicator species of weeds and crops were planted into the residue 7 to 10 days after herbicides were applied to rye. It was necessary to develop a system to plant indicators through the residue in a manner similar to a NT situation in the field. To facilitate accurate seed placement and to insure good seed/soil contact necessary for germination, a planting board was designed to evaluate the response of four test species at one time. Four rows, with ten holes each, were drilled into the board. Plastic syringes (5cc) in which the tip was cut off, were inserted through the drilled holes. The plungers were used to push seeds down through the residue to a uniform depth in the soil. Control flats were also planted with the board, although the physical characteristics of the PE necessitated removing it during planting. In all cases, the experimental design was a randomized complete block with four replications. To assess germination, the number of plants

which emerged out of 30 seeds planted were recorded. Plants were then thinned to 10 plants per row. Later, shoots were harvested, dried at 50-60°C, and weighed. Species which were planted, time, and dates for germination counts and harvest dates are listed in Table 1.

#### Evaluation of Residue Toxicity in Killed Ryes

Top-killing treatments were applied 37 days after planting rye. Glyphosate at 1.12 Kg/ha was considered to be the standard practice and compared to other kill methods which included: chemical kill by paraquat at 1.12 Kg/ha plus X-77 (0-5% v/v); low temperature kill by freezing rye at -12°C for 15 hr; desiccation kill by withholding water for 5 days; and mechanical kill by severing shoots from roots at the soil surface.

#### Evaluation of Residue Toxicity in Paraquat Sprayed Rye

After 36 days, paraquat treatments (0.56 Kg and 1.12 Kg/ha) were applied to both ryes, a poplar excelsior control and a bare soil control. To help eliminate differences due to the presence of the mulch cover, PE was laid over the soil sprayed treatments. Rye, frozen at -12°C for 16 hr, was used as a control for the chemically killed rye treatments.

#### Evaluation of Residue Toxicity in Rye Killed Back at Different Ages

In this study, rye was planted at 10 day intervals over a 30 day period. The youngest rye treatment was 20 days old at

TABLE 1.--Crop and weed indicators, and intervals for data collections.

| Experiment       | Indicators                | Germ.<br>Count<br>(DAP) | Harvest<br>Date<br>(DAP) |
|------------------|---------------------------|-------------------------|--------------------------|
| Kill Method      | 'Ithaca' lettuce          | 9                       | 20                       |
|                  | 'Petoeary' tomato         | 9                       | 15                       |
|                  | Barneyardgrass (BYGR)     | 9                       | 15                       |
|                  | Wild Mustard (WIMU)       | 9                       | 20                       |
| Paraquat Study   | Lettuce                   | 7                       | 16                       |
|                  | Tomato                    | 7                       | 16                       |
|                  | BYGR                      | 7                       | 12                       |
|                  | WIMU                      | 7                       | 16                       |
| Age/Residue      | Lettuce                   | 11                      | 19                       |
|                  | Tomato                    | 11                      | 22                       |
|                  | BYGR                      | 11                      | 19                       |
|                  | Yellow Foxtail (YEFT)     | 13                      | 22                       |
| Weed/Crop Screen | 'Harvestmore' onions      | 15                      | 25                       |
|                  | 'Dawson' cert. Alfalfa    | 15                      | 25                       |
|                  | 'Spartanfancy' carrots    | 15                      | 25                       |
|                  | '264 excel' cabbage       | 15                      | 25                       |
|                  | 'Perfect freezer' peas    | 9                       | 9                        |
|                  | 'Spartan Arrow' snapbeans | 9                       | 9                        |
|                  | 'Greenstar' cucumbers     | 9                       | 9                        |
|                  | 'Sweet Sue' sweet corn    | 9                       | 9                        |
|                  | YEFT                      | 10                      | 20                       |
|                  | Green foxtail (GRFT)      | 10                      | 20                       |
|                  | Common ragweed (CORW)     | 10                      | 20                       |
|                  | Redroot pigweed (RRPW)    | 10                      | 20                       |
|                  | Common purslane (COPU)    | 10                      | 20                       |
|                  |                           |                         |                          |
| Plant Part       | Velvet leaf (VELE)        | 8                       | 18                       |
|                  | YEFT                      | 14                      | 18                       |
|                  | COPU                      | 19                      | 28                       |
|                  | Prostrate spurge (PRSP)   | 19                      | 28                       |

the time when 1.12 Kg/ha of glyphosate was applied. Sprayed and unsprayed PE were utilized as controls for the chemical and mulch effects. The rate of PE was determined from residue production in the 50 day old rye treatment since the mulch effect would be greatest in this treatment. In addition to harvesting indicator species, rye residues were also harvested, and fresh weights were taken, to determine if germination or plant growth correlated with the quantity of residues present.

#### Evaluation of Residue Toxicity to Several Weeds and Crops

Rye was killed with 1.12 Kg/ha glyphosate 31 days after planting. Sprayed and unsprayed PE were controls for the chemical and mulch effects. Small and large seeded vegetable crops as well as grass and broadleaf weeds were screened for their response to rye residues (Table 1).

#### Evaluation of Toxicity by Roots and Shoots of Rye on Weeds

Rye was grown for 38 days and then killed back with 1.12 Kg/ha of glyphosate. Twelve days later all shoots were mechanically severed from the roots with razor blades and set aside while weed seeds were planted. Severed shoots of rye were then reapplied as a shoot only treatment or as a shoot + root treatment, while PE was laid over the roots only treatment and the no rye control treatment.

## Results and Discussion

### Evaluation of Poplar Excelsior (PE) as a Non-Toxic Control

In the initial study (Test 1) percent emergence of both tomato and barnyardgrass were unaffected by the various surface mulches (Table 2). In a second study (Test 2) which included 'MSU-13' rye residue as a surface mulch, percent germination of both barnyardgrass and tomato under poplar excelsior was not different from peat, vermiculite, or no residue treatments. In contrast, 'MSU-13' rye residues decreased germination of tomato by 44% over PE and the rest of the mulches, while barnyardgrass germination was not affected by the rye residue. Decomposition of residues is a continuing process where products released may rapidly change from one physiological activity to another i.e. inhibition or stimulation (Patrick, 1971). With tomato, it appeared that germination was delayed more than inhibited by rye residues, because after two weeks, more tomatoes had germinated in the rye treatment. Tomato biomass was greatest in PE treatments with almost a 100% increase noted over all other treatments (Table 3). The poplar excelsior may have improved moisture relationships to the growing plants since there was much more depth to it than the other treatments. In contrast, barnyardgrass dry weight was greatest under residues of 'MSU-13' rye, with a 48% increase over PE treatments. Thus barnyardgrass may have been stimulated by chemicals released from rye residue, while tomato appeared unaffected. Nutrient analyses of tomatoes revealed no statistical differences in the relative levels

TABLE 2.--Percent emergence of barnyardgrass and tomato in several surface mulches.

| Mulch            | Test 1   |            | Test 2   |              |
|------------------|----------|------------|----------|--------------|
|                  | BYGR (%) | Tomato (%) | BYGR (%) | Tomato** (%) |
| None             | 80       | 68         | 74       | 68 b         |
| Vermiculite      | 83       | 63         | 81       | 65 b         |
| Peat             | 76       | 83         | 78       | 68 b         |
| Poplar excelsior | 88       | 72         | 81       | 68 b         |
| 'MSU-13' rye     | --       | --         | 76       | 38 a         |

\*\*Means within a column followed by the same letter are not significantly different at the 15% level by Duncan's Multiple Range Test.

TABLE 3.--Dry weight/plant (mg) of barnyardgrass and tomato in several surface mulches.<sup>1</sup>

| Mulch            | Test 1    |             | Test 2    |             |
|------------------|-----------|-------------|-----------|-------------|
|                  | BYGR (mg) | Tomato (mg) | BYGR (mg) | Tomato (mg) |
| None             | 24        | 60          | 28 a      | 37 a        |
| Vermiculite      | 24        | 63          | 31 a      | 57 a        |
| Peat             | 25        | 61          | 25 a      | 56 a        |
| Poplar excelsior | 21        | 63          | 22 a      | 117 b       |
| 'MSU-13' rye     | --        | --          | 43 b      | 52 a        |

<sup>1</sup>Means within a column followed by the same letter are not significantly different at the 5% level by Duncan's Multiple Range Test.

of nitrogen, phosphorous or potassium under poplar excelsior when compared to rye residues or no mulch. Thus PE does not differentially alter nutrient uptake and therefore appears to be a suitable control for the mulch effect.

#### Evaluation of Residue Toxicity in Killed Ryes

Residues of paraquat-sprayed 'Wheeler' rye reduced percent germination of barnyardgrass over all other treatments (Figure 1). Many which emerged appeared chlorotic and somewhat less vigorous. Those which grew out the injured stage appeared to recover. Thus, there was greater variability in biomass per plant of barnyardgrass within the other treatments, but paraquat killed residues of 'Wheeler' rye reduced barnyardgrass dry weight more than residues of 'MSU-13' rye (Figure 2).

In contrast, residues of the two rye selections did not appear to differ significantly in their effect on germination or growth of lettuce, tomato, and wild mustard (Table 4). Paraquat-sprayed rye residues did not reduce germination and growth of these species as much as glyphosate-sprayed residues did. Percent emergence of both lettuce and wild mustard was reduced in glyphosate sprayed residues and plants which emerged often appeared chlorotic. Although germination of tomato, which preceded more slowly than the other species, was not significantly different between the treatments, growth appeared somewhat suppressed in glyphosate sprayed residues (Table 5).

**Figure 1.--Percent emergence of barnyardgrass in rye residues  
killed back by serveral methods.**

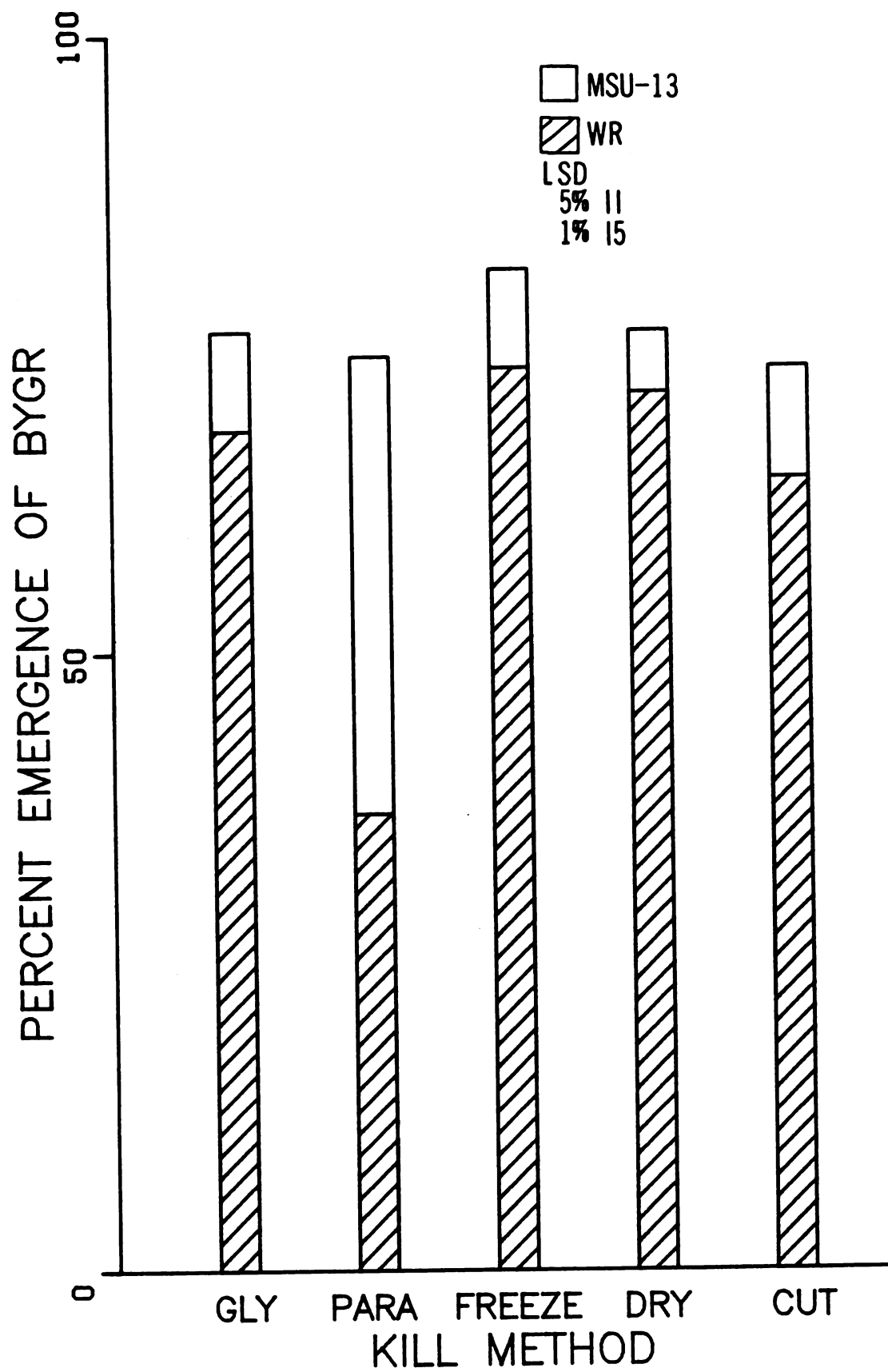


Figure 2.--Biomass of barnyardgrass in rye residues killed back  
by several methods.

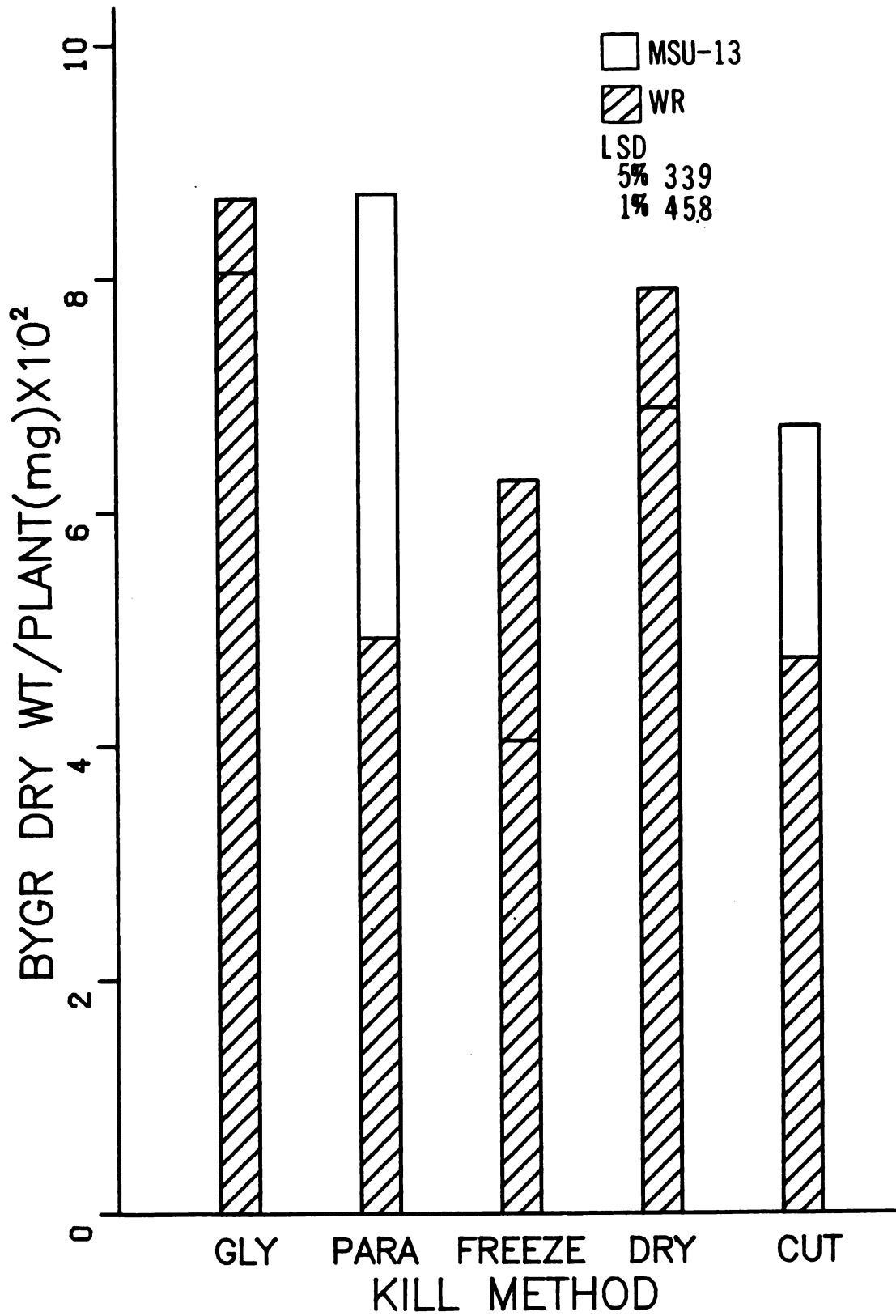


TABLE 4.-- Percent emergence of indicator species in residues of two greenhouse grown rye selections which were killed back by several methods.<sup>1</sup>

| Kill Method | Tomato (%) | Lettuce* (%) | Wild Mustard* (%) |
|-------------|------------|--------------|-------------------|
| Glyphosate  | 48         | 28 a         | 10 a              |
| Paraquat    | 62         | 58 b         | 14 ab             |
| Freeze      | 60         | 56 b         | 10 a              |
| Dry         | 61         | 56 b         | 18 bc             |
| Cut         | 64         | 51 b         | 21 c              |

<sup>1</sup>There was no significant difference between selections, thus means were averaged across ryes.

\*Means within a column followed by the same letter are not significantly different at the 5% level by Duncan's Multiple Range test.

TABLE 5.--Dry weight (mg/ plant) of indicator species in residues of two greenhouse grown rye selections which were killed back by several methods.<sup>1</sup>

| Kill Method | Tomato*<br>(mg) | Lettuce<br>(mg) | Wild Mustard<br>(mg) |
|-------------|-----------------|-----------------|----------------------|
| Glyphosate  | 389 a           | 132             | 101                  |
| Paraquat    | 584 b           | 263             | 309                  |
| Freeze      | 573 b           | 245             | 386                  |
| Dry         | 646 b           | 229             | 407                  |
| Cut         | 585 b           | 321             | 365                  |

<sup>1</sup>There was no significant difference between selections; thus means were averaged across ryes.

\*Means within a column followed by the same letter are not significantly different at the 5% level by Duncan's Multiple Range test.

The reduction in germination and growth of the indicator species in the glyphosate-sprayed rye residues was unexpected. Studies with  $^{14}\text{C}$ -labelled glyphosate have indicated that after foliage applications, herbicide is exuded into culture solution or soil from the roots of treated plants and may cause stimulatory or inhibitory effects on adjacent plants depending on the concentration (Rodrigues, 1979). Thus, exudation of glyphosate from rye roots or shoots may be responsible for the reductions in germination and growth of the indicator species. It is also possible that the stress of the chemical treatment caused rye to produce and release more toxic natural products which subsequently influenced the germination and growth of the species. A final possibility is that the glyphosate remained on the plant tissue where it was absorbed by the plants as they emerged through the residue.

Paraquat's action is somewhat different from glyphosate in that once absorbed, it forms a free radical which disrupts membrane structure. Thus, it usually kills quickly, and only where it contacts green tissue (Anonymous, 1979). Barnyardgrass germination was reduced most in residues of paraquat-sprayed 'Wheeler' rye, which leads one to hypothesize an interaction between the stress of the chemical and the residues of 'Wheeler' rye which decreased germination and growth of barnyardgrass.

#### Evaluation of Residue Toxicity in Paraquat Sprayed Rye

Percent germination of barnyardgrass was reduced as the rate of paraquat used to kill the rye cover crop was increased to

1.12 Kg/ha (Figure 3). Again barnyardgrass which emerged were often chlorotic. Germination was about 50% less in rye residues when compared to poplar and soil treatments sprayed with paraquat at the high rate. Where no paraquat was applied, 'MSU 13' rye residues still reduced germination by 17% over the PE controls. This suggests that allelopathy may contribute to the germination reductions of barnyardgrass in residues of paraquat sprayed rye. A significant negative linear trend was also found in lettuce germination as paraquat rate increased (Figure 4). Paraquat, at 1.12 Kg/ha, reduced lettuce emergence by 15%. In contrast, germination of tomato and wild mustard were unaffected by paraquat at any rate.

Many emerging seedlings appeared chlorotic and soon died, while others grew normally. Thus, paraquat did not seem to affect later growth of the individual plants. Instead, rye residues were more responsible for the reductions of biomass in all species planted (Table 6). In addition, there were no significant differences between either poplar treatments or rye cultivar treatments, suggesting that paraquat affects emergence more than plant growth. Rye residues appear to contribute more suppressive action than the paraquat used to kill the rye.

#### Evaluation of Residue Toxicity in Rye Killed Back at Different Ages

Residues of 'Wheeler' rye reduced germination of both lettuce and yellow foxtail in a linear fashion as the age of the rye at time of kill increased from 20 to 50 days (Figure 5). In contrast, percent emergence of tomato and barnyardgrass did not vary between

**Figure 3.--Percent emergence of barnyardgrass in residues of paraquat sprayed rye.**

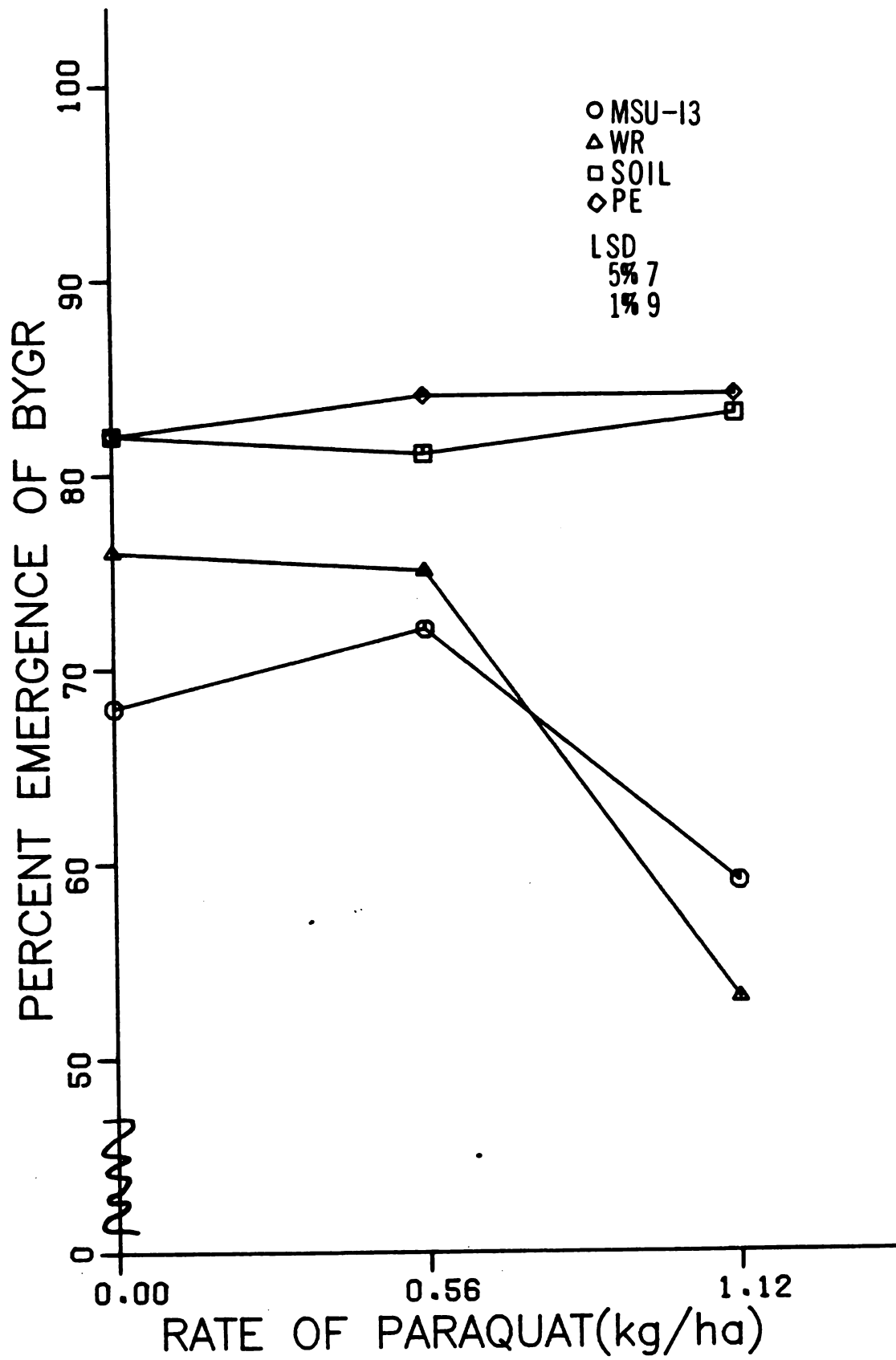


Figure 4.--Percent emergence of lettuce in residues of rye  
killed back with 3 rates of paraquat.

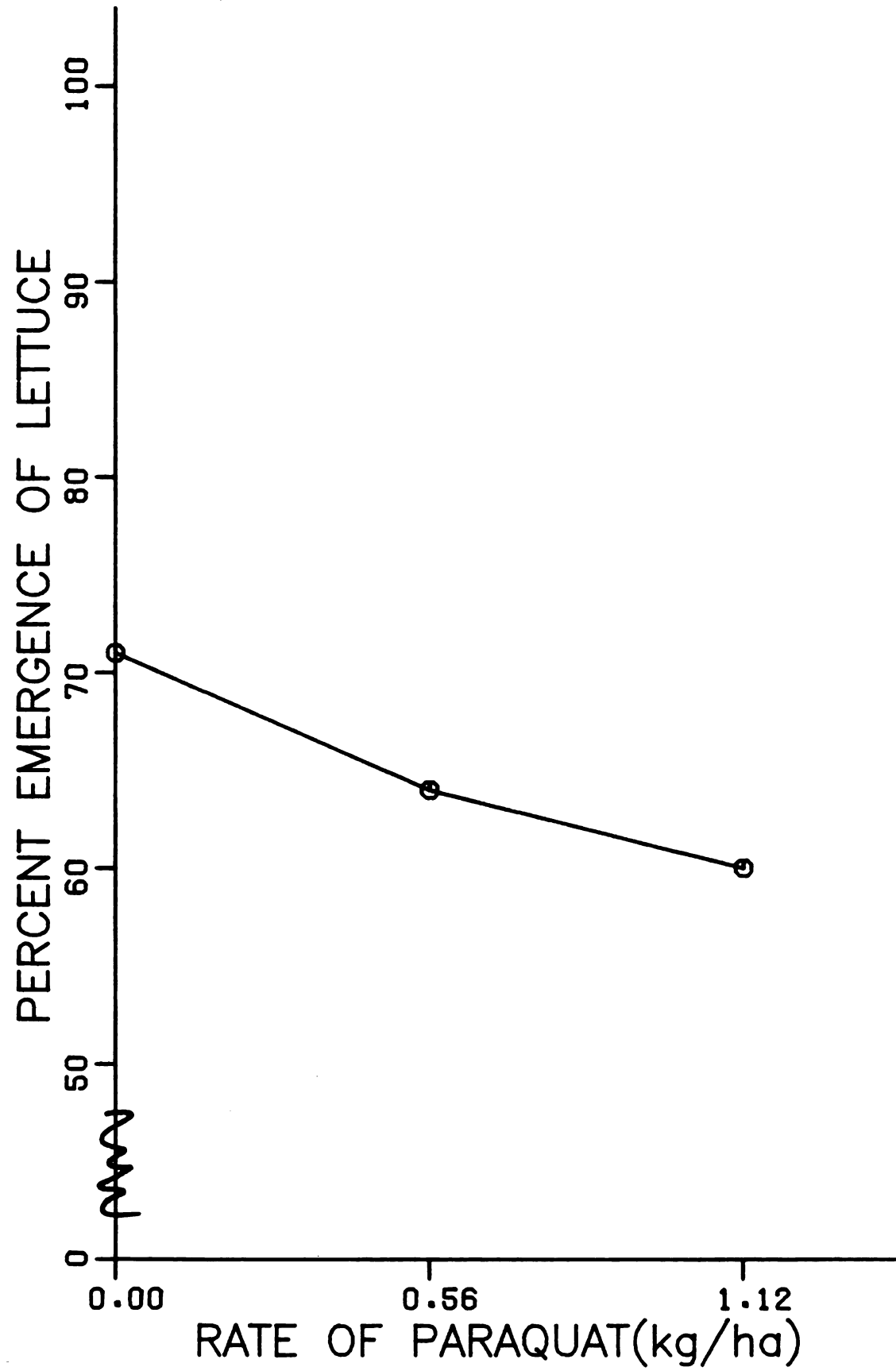


Figure 5.--Percent emergence of yellow foxtail and lettuce in residues of 'Wheeler' rye killed back at different ages.

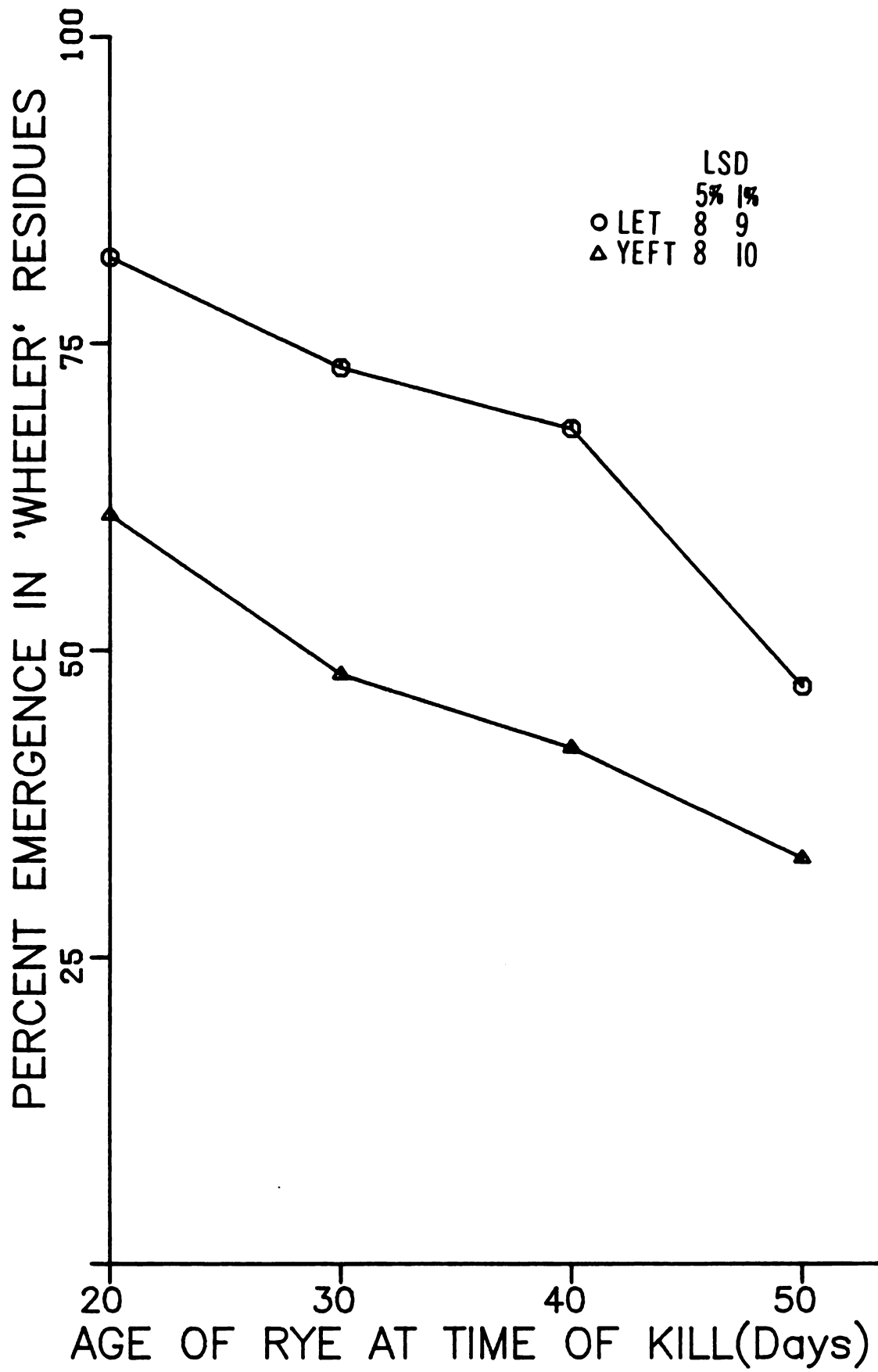


TABLE 6.--Biomass (mg/plant) of indicator species in residues of two greenhouse grown rye selections killed back with two rates of paraquat.<sup>1</sup>

| Treatment             | Tomato**<br>(mg) | Lettuce*<br>(mg) | BYGR**<br>(mg) | WIMU**<br>(mg) |
|-----------------------|------------------|------------------|----------------|----------------|
| PE and spray          | 808 b            | 523 b            | 683 b          | 680 b          |
| Soil and spray and PE | 784 b            | 563 b            | 615 b          | 811 b          |
| 'MSU-13' rye          | 458 a            | 355 a            | 243 a          | 185 a          |
| 'Wheeler' rye         | 528 a            | 422 ab           | 249 a          | 219 a          |

<sup>1</sup>There was no significant difference in rates of paraquat. Thus, means were averaged across the rates.

\*All means within a column followed by the same letter are not significantly different at the 5% level by the Duncan's Multiple Range Test.

\*\*All means within a column followed by the same letter are not significantly different at the 1% level by the Duncan's Multiple Range Test.

selections, although BYGR emergence was significantly correlated ( $r^2 = 40$ ) with the age of rye at time of kill (Figure 6). There was also a linear correlation ( $r^2 = 77$ ) between residue biomass and age of rye at time of kill (Figure 7). Percent germination of both barnyardgrass and lettuce was correlated ( $r^2 = 40,37$ ) with rye residue biomass suggesting that the amount of residue present may influence their germination.

There was no significant difference on plant dry weight in sprayed or unsprayed poplar excelsior controls (Table 7). Generally, as the age of rye at time of kill increased from 20 to 50 days, all plant growth was reduced (Figures 8 and 9). While residues of both selections of rye reduced biomass of barnyardgrass in a linear manner, increasing amounts of 'Wheeler' rye residues were associated with greatest reduction in tomato, lettuce, and yellow foxtail biomass (Figure 8). There was no significant linear correlation between quantity of rye residue and plant dry weight, although growth was suppressed the most in 50 day-old rye residues.

#### Evaluation of Residue Toxicity to Several Weeds and Crops

Germination of all weeds and crops tested was not different in residues of 'Wheeler' or 'MSU-13'. Similarly, germination did not vary between the sprayed and unsprayed poplar treatments. Data analyses indicated that the reduction in germination could be attributed only to the main effect of rye residues, thus, means were averaged across rye residues and PE treatments. Germination of

Figure 6.--Percent emergence of barnyardgrass and tomato in  
residues of rye killed back at different ages.

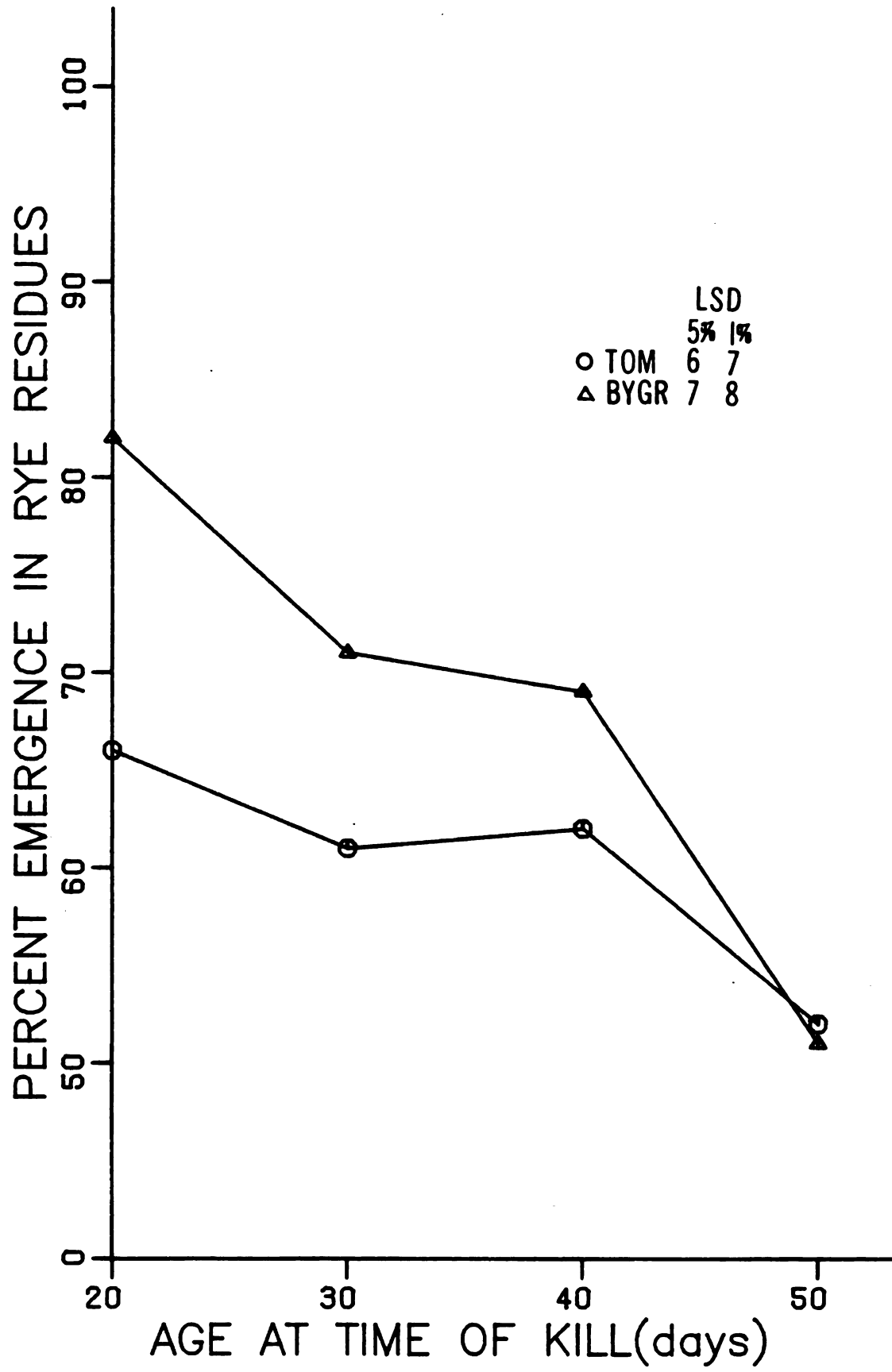


Figure 7.--Residue production of rye killed back at different ages.

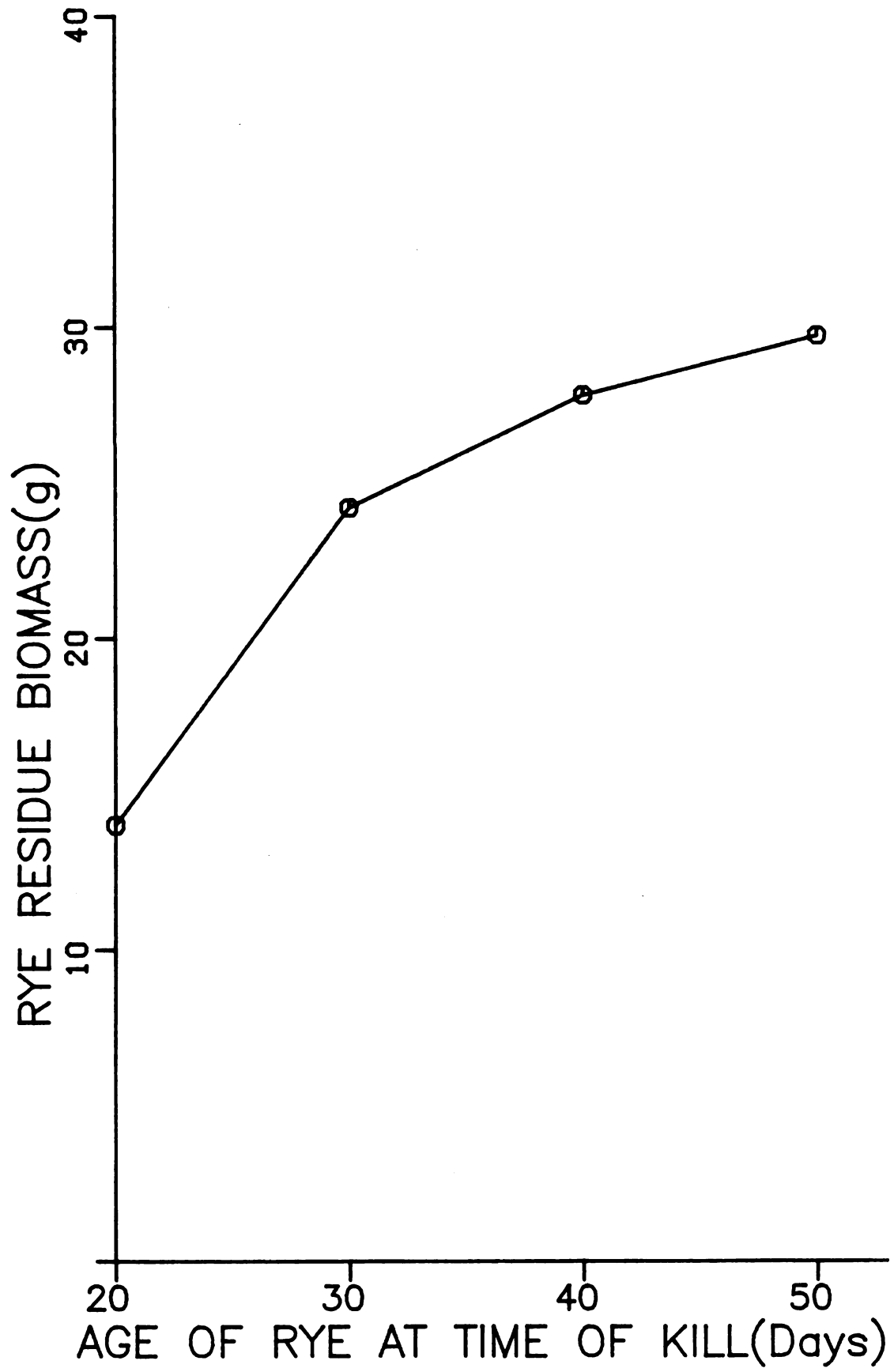


TABLE 7.--Biomass (mg) of weeds and crops in glyphosate sprayed and unsprayed poplar excelsior.<sup>1</sup>

| Treatment       | Lettuce<br>(mg) | Tomato<br>(mg) | BYGR<br>(mg) | YEFT<br>(mg) |
|-----------------|-----------------|----------------|--------------|--------------|
| PE              | 60              | 155            | 77           | 69           |
| PE + glyphosate | 24              | 190            | 83           | 84           |

<sup>1</sup>There was no significant difference between means within a column.

Figure 8.--Biomass of lettuce, tomato, and yellow foxtail in residues of 'Wheeler' rye killed back at different ages.

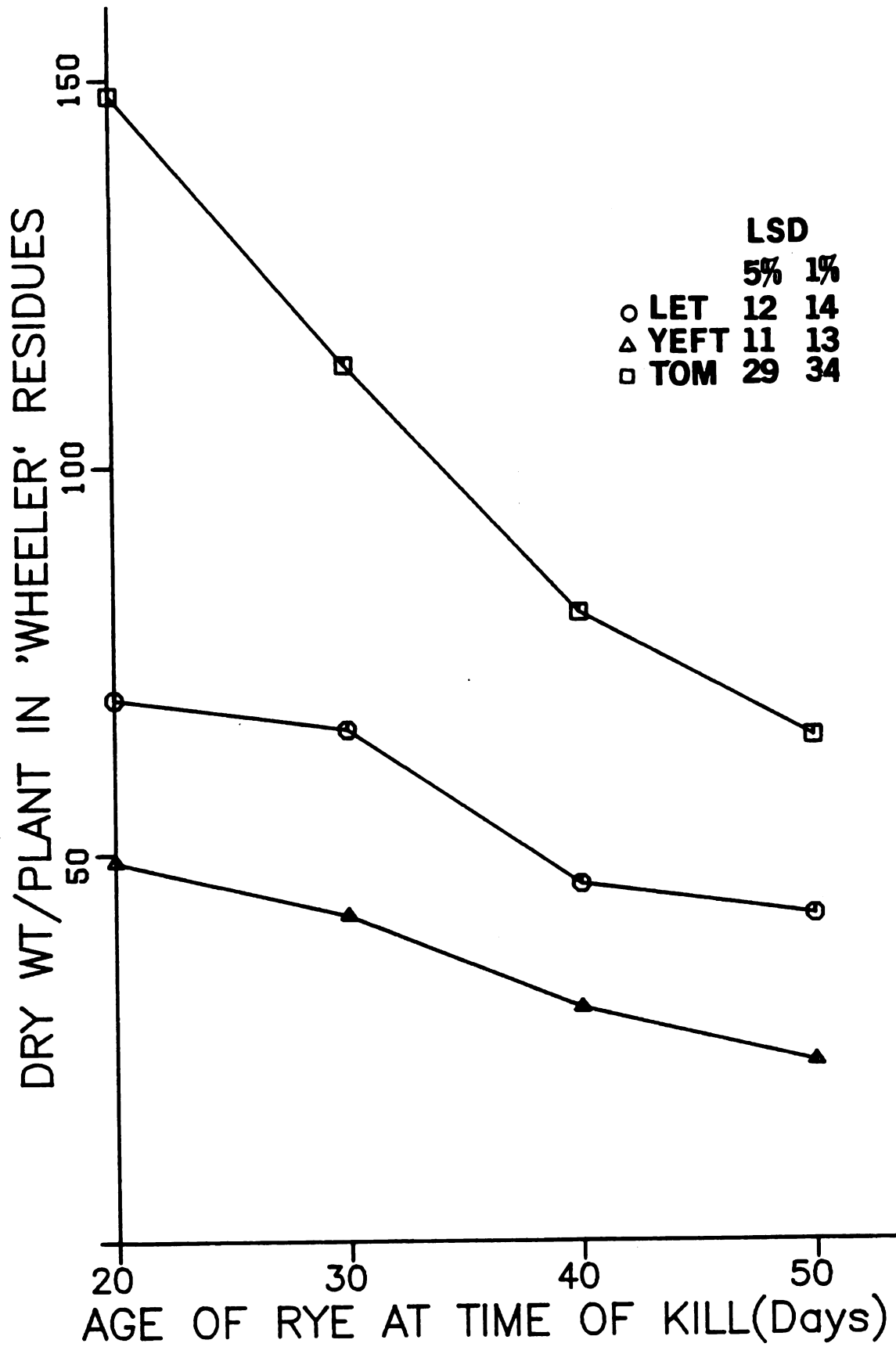
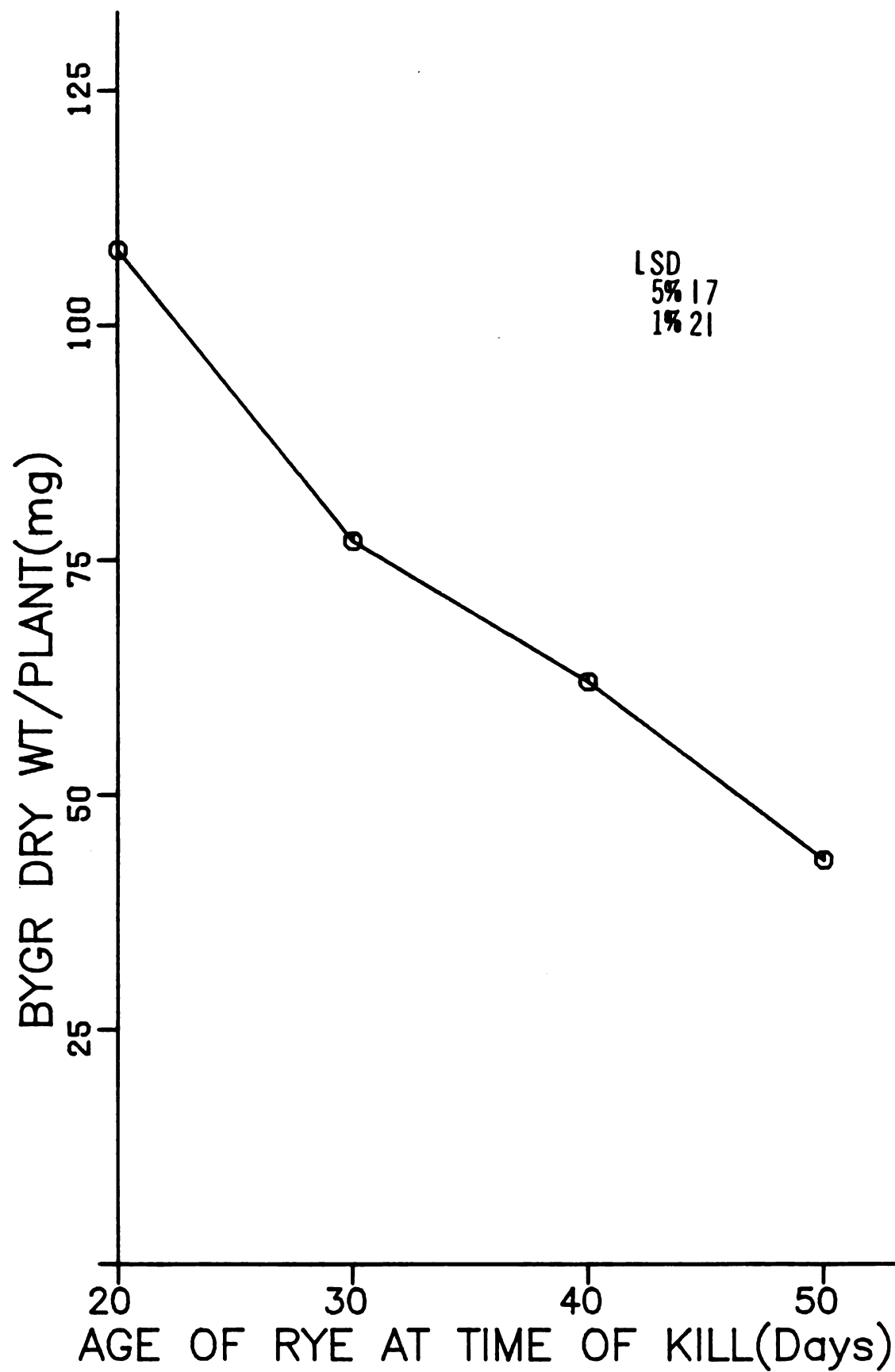


Figure 9.--Biomass of barnyardgrass in residues of rye killed back at different ages.



redroot pigweed and green foxtail were reduced by 94% and 80%, respectively, under rye residues, whereas no common purslane emerged in the rye treatments (Table 8). In addition, germination of all crops tested was reduced in rye residue treatments (Table 9). Many plants which emerged through rye residues were chlorotic and appeared slightly injured.

Rye residues reduced biomass of pigweed by 91% (Table 10). With the exception of cucumber, early growth of all crops evaluated was suppressed under rye residues (Table 11). In this study, seed size did not appear to influence germination or growth of crops under rye residues. Reductions in germination and growth could be attributed to inhibitors released from the rye residues. Since there were controls for both glyphosate and mulch influences, residue toxicity could be the result of either natural toxins leached from rye or from microbial intermediates produced during the decomposition process

#### Evaluation of Toxicity by Roots and Shoots of Rye

Rye plant parts similarly affected emergence of weeds. There was no statistical significance between ryes, thus means were averaged across the cultivars. Rye residues reduced germination of prostrate spurge when compared to the no residue poplar excelsior control (Table 12). In contrast, germination of yellow foxtail was 45% greater in rye residues.

There was no difference between rye plant part, rye cultivar, or rye residues on growth of any weed species evaluated. Weed dry

TABLE 8.--Percent emergence of weeds in undisturbed residues of greenhouse grown rye.<sup>1</sup>

| Weed            | - Rye (%) | + Rye (%) |
|-----------------|-----------|-----------|
| Common ragweed  | 21        | 12        |
| Redroot pigweed | 36        | 2**       |
| Common purslane | 58        | 0**       |
| Yellow foxtail  | 30        | 29        |
| Green foxtail   | 54        | 11**      |

<sup>1</sup>Means were averaged across 2 rye selections and 2 poplar excelsior treatments.

\*\*Means within a row are significantly different at the 1% level.

TABLE 9.--Percent emergence of vegetable crops in undisturbed residues of greenhouse grown winter rye.<sup>1</sup>

| Vegetable  | - Rye (%) | + Rye (%) |
|------------|-----------|-----------|
| Cabbage    | 36        | 7         |
| Onion      | 40        | 6         |
| Carrot     | 61        | 11        |
| Alfalfa    | 65        | 11        |
| Peas       | 55        | 12        |
| Cucumber   | 57        | 35        |
| Sweet Corn | 58        | 29        |
| Snapbean   | 61        | 21        |

<sup>1</sup>Means were averaged across 2 cultivars of rye and 2 treatments of poplar excelsior. All are significant at the 1% level.

TABLE 10.--Dry wt./plant (mg) of weeds in undisturbed residues of greenhouse grown winter rye.<sup>1</sup>

| Weed            | - Rye<br>(mg) | + Rye<br>(mg) |
|-----------------|---------------|---------------|
| Common Ragweed  | 246           | 168           |
| Redroot Pigweed | 265           | 23*           |
| Yellow foxtail  | 9             | 9             |

<sup>1</sup>Means were averaged across 2 cultivars of rye and 2 treatments of poplar excelsior.

\*Means are significantly different at the 5% level.

Table 11.--Dry wt./plant (mg) of vegetables in undisturbed residues of greenhouse grown winter rye.<sup>1</sup>

| Vegetable  | - Rye<br>(mg) | + Rye<br>(mg) |
|------------|---------------|---------------|
| Cabbage    | 230           | 80**          |
| Onion      | 530           | 40**          |
| Carrot     | 41            | 17**          |
| Alfalfa    | 77            | 30**          |
| Peas       | 66            | 31**          |
| Cucumber   | 94            | 110*          |
| Sweet Corn | 89            | 50**          |
| Snapbean   | 312           | 193**         |

<sup>1</sup>Means were averaged across cultivars of rye and 2 treatments of poplar excelsior.

\*Means are significantly different at the 5% level.

\*\*Means are significantly different at the 1% level.

TABLE 12.--Percent emergence of yellow foxtail (YEFT), common purslane (COPU), prostrate spurge (PRSP), and velvetleaf (VELF) in roots, shoots, or roots and shoots of rye.

| Plant Part     | YEFT <sup>2</sup><br>(%) | COPU <sup>1</sup><br>(%) | PRSP <sup>2</sup><br>(%) | VELE <sup>1</sup><br>(%) |
|----------------|--------------------------|--------------------------|--------------------------|--------------------------|
| PE             | 28                       | 66                       | 58                       | 36                       |
| Roots + PE     | 51                       | 43                       | 48                       | 39                       |
| Shoots         | 51                       | 59                       | 43                       | 37                       |
| Roots + Shoots | 52                       | 54                       | 38                       | 42                       |

<sup>1</sup>Means were averaged across 2 rye selections and are not significantly different at the 5% level.

<sup>2</sup>F value for orthogonal comparison of rye vs. none is significant at 5% level.



weights per plant were quite variable and may have been the result of disturbing the rye residues or due to natural variability inherent in the gene pool of the weeds.

### General Discussion

The NT bioassay for greenhouse evaluation of rye residues appeared to be sensitive enough to detect differences in germination and plant growth of the species investigated. Rye residues appeared to reduce germination and growth of several weeds and crops. All treatments were fertilized on a regular schedule and thus, it was assumed that the nutritional conditions of the soil were not significantly different under rye residues when compared to PE. It is important to remember that conditions associated with greenhouse culture of plants are not identical to field conditions. Direct observations of root and shoot morphology revealed fall planted field grown rye to differ considerably from greenhouse grown winter rye. Root growth is restricted and soil mixture conditions in pot culture are also radically different from field conditions (Spomer, 1975 and 1976). In addition, quantity and quality of light in the greenhouse, diurnal temperature fluctuations, and microbial activity, which may influence allelopathic activity of rye residues, also all vary from field situations (Rice, 1979). Thus one must be careful in drawing conclusions from the greenhouse results and applying them to field conditions.



### Conclusions

Poplar excelsior appears to be a suitable non-toxic control for the physical mulch effect. Residues of glyphosate killed rye reduced lettuce germination and suppressed early growth of tomato when compared to other kill methods. In contrast, barnyardgrass emergence was reduced the greatest in paraquat killed rye. Where no paraquat was applied, 'MSU-13' residues still reduced emergence by 17% over PE controls suggesting that allelopathy may contribute to the reduction of barnyardgrass emergence. Plant growth was suppressed much greater by rye residues than by herbicides used to kill the rye.

Percent emergence of both barnyardgrass and lettuce was correlated with rye residue biomass suggesting that the amount of residue may influence emergence. In contrast, indicator biomass was not correlated with residue production, although growth was suppressed the most in 50 day old rye residues. 'MSU-13' and 'Wheeler' rye similarly reduced germination and growth of several weeds and crops. In addition, rye shoots and roots similarly reduced emergence and growth of indicator weeds. Since there were controls for both the chemical and mulch effects, residue toxicity could be the result of either natural toxins leached from rye or from microbial intermediates produced during the decomposition process.

EVIDENCE OF TOXIC EXUDATES IN RYE  
(Secale cereale L.)

Abstract

Greenhouse studies were initiated to determine if reductions of weed biomass observed in field evaluations where winter rye (Secale cereale L.) was present could be due, in part, to toxins released from living rye. Root and shoot leachates of two rye selections, 'MSU-13' and 'Wheeler', were tested for their effects on germination and growth of several plant species. Rye root leachates and shoot leachates had no effect on germination of barnyardgrass or 'Curly' cress. The type of rye did not differ and age of rye was not a factor. When leachates were passed through two pots of rye, total biomass of lettuce and tomato were reduced 25% and 18%, respectively, suggesting that root leachates of rye are more inhibitory to lettuce and tomato growth than leachates from other tomato and lettuce plants. Thus, in addition to toxicity from residues, allelopathy from living rye root leachates may be a component of the total interference noted between weeds and rye in the field.

## CHAPTER 4

### EVIDENCE OF TOXIC EXUDATES IN RYE (Secale Cereale L.)

#### Introduction

Reduction of weed biomass observed in field evaluations where winter rye was present could be due to the accumulation of growth inhibitors in the soil. According to Chapman (1966), root excretions, leaf washings, plant residues, and microbial activity on plant residues, all contribute to the presence of growth inhibitors in soils. Numerous persons have demonstrated that many kinds of organic compounds are exuded by living roots of many species (Katznelson et al, 1955; Petrii and Chrastil, 1955; Rovira, 1956, 1965, 1969 and 1971). It has been clearly shown that numerous kinds of organic compounds can exude from roots of donor plants and can be taken up by adjacent plants (Rovira, 1960; Foy et al, 1971). Root exudate is often used in a broad sense, but generally refers to inhibitors resulting from the presence of living roots where no leachates, volatiles, or residues from the tops of plants are present (Rice, 1979).

Bell and Koeppel (1972) demonstrated that giant foxtail (Setaria faberii) has an allelopathic effect on maize. They used a stairstep method of culture where nutrient solution was passed from the rhizosphere of giant foxtail into the rhizosphere of corn

and was recycled through the system. Mature giant foxtail inhibited corn growth approximately 35% through an allelopathic mechanism. Kossanel et al (1977) reported that water solutions in which Chenopodium album L. previously grew and water extracts of ground roots inhibited growth of maize. An old Swedish agricultural practice to rid fields of infestations of wild oats (Avena fatua) is to plant rye. Osvald (1953) found rye root exudates reduced the germination of wild oats, while exudates from barley and wheat had no effect. Thus, the potential for root exudation by rye exists and may play a role in its weed suppressing ability.

In addition, leaf washings of living rye may influence growth of other plant species. There are several cases where leaf washings have been shown to be responsible for the growth inhibiting effect of one plant or another (Chapman, 1966). Wormwood inhibits certain plant species growing in close proximity, owing to the alkaloid, absinthin, which is secreted by the leaf hairs of this plant and washed into the soil by rain (Bode, 1940; Funke, 1943). Naqvi (1972) found, in greenhouse and field tests, that Italian ryegrass (Lolium multiflorum Lam.) suppresses germination and growth of many species in its vicinity. Later Naqvi and Muller (1975) reported that leachates of living tops, obtained through artificial rain, and leachates of soil previously occupied by ryegrass and decomposing residues, were toxic to seedling growth of oats, Bromus sp., lettuce, and Trifolium sp. Keoppe et al (1970) discovered that the concentration of scopolin and total chlorogenic acids decreased with age

of leaves in tobacco, although total amounts of the compounds increased with age due to the increase in leaf area.

The purpose of this study was to determine if living rye non-competitively interferes with seed germination or plant growth. Rye roots may exude compounds, or upon watering, may leach compounds which subsequently effect the growth of other species of plants. A second purpose of this investigation was to determine if two rye selections (a cultivar and 'MSU-13'), vary in the quantity or quality of toxic exudates and leachates with age.

### Materials and Methods

#### Evaluation of Rye Root Leachates on Plant Growth

Generally, rye and indicator species were grown in quartz sand in the greenhouse under metal halide lamps (16 hr days). To insure no nutrient or water deficiencies, all plants recieved half-strength Hoagland's solution (Hoagland and Arnon, 1939), adjusted to a pH of 6.5, when needed. All controls were monocultures of indicator species which also received Hoagland's solution. It was necessary to cover the pots with plastic film until emergence, because of the low moisture holding capacity of the quartz sand. When growth of algae became a problem, a chelated copper algicide, Cutrene (0.05% v/v), was applied with the half-strength Hoaglands solution. In all cases, the experimental design was a randomized complete block with four replications. Roots were separated from quartz sand and dried at 50-60°C for biomass determinations. In

addition, shoots were harvested and dried for individual biomass determination.

A compartmentalized styrofoam pot with four sections was used in evaluating root leachate toxicity without direct plant/plant competition. Pregerminated rye was planted to two of the four sections. Indicator species of 'Ithaca' lettuce, 'Curly' cress, 'Greenstar' cucumbers, and 'Petoeary' tomato were planted in the other two sections. Aluminum pans (18 cm diameter) were placed below pots to accumulate the Hoagland's solution which had been passed through the rye sections only. Care was taken to not get foliage of rye or indicators wet during watering. A second pan was fit over the pot to prevent light from reaching the solutions, and to prevent algae growth. Light meter readings indicated 550 microeinsteins/m<sup>2</sup>/sec. for all plants. Lettuce and cress were harvested 17 DAP for biomass determination. Cucumbers and tomatoes were harvested 18 DAP.

In a second study to evaluate rye root leachate toxicity, rye and indicator species were grown in separate pots (10 cm diameter) and half-strength Hoagland's solution was manually transferred through a four pot system (Figure 1). The associations consisted of either a monoculture of four pots of the indicator species, or a biculture of two pots of rye and two pots of the indicator species. The quantity and quality of light was similar for all pots in the series. Indicator species tested were 'Ithaca' lettuce and 'Petoeary' tomato, and were harvested 30 DAP for biomass evaluation.

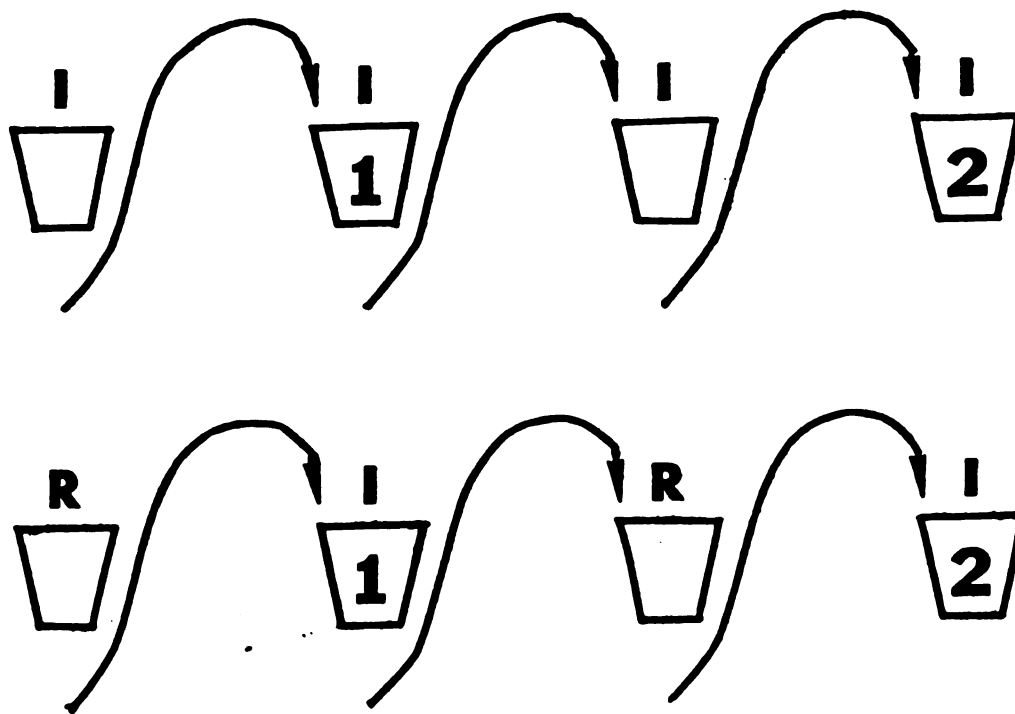


Figure 1.--Design of monoculture and biculture treatments for root leachate transfer studies.

Using the same four-pot series of transfers to evaluate the effect of age of rye on root leachate toxicity, (a third study) involved testing 30, 20, 10, and 0 day old rye at time of planting indicators. Two selections of rye ('Wheeler' and 'MSU-13' selected at Cornell University) were evaluated for their effect on biomass of 'Petoeearly' tomato. Pots of rye which had been growing for twenty and thirty days developed algae growth on the outside; therefore all pots were scrubbed with a solution of Cu chelate (0.05% v/v) and rinsed with water prior to planting tomatoes. Tomatoes were harvested 21 days after planting.

#### Effect of Rye Root and Shoot Leachates on Germination

Different aged rye, which had been growing in quartz sand in the greenhouse, was leached with 300 ml. of half-strength Hoagland's solution for bioassay. The leachate was collected and combined across all replications. Controls were half-strength Hoaglands, which had not been passed through rye roots, and distilled water. Five ml. of solution was bioassayed in disposable petri dishes (100 mm x 60 mm) which contained 2 Whatman #1 filter papers. Petri dishes were then placed in a dark growth chamber (32°C/24°C). Four days later, the number of 'Curly' cress, barnyardgrass, and common labmsquarters which germinated out of thirty seeds were counted.

Shoot leachates of rye for bioassay were collected by artificially simulating rain with a CO<sub>2</sub> back-pack sprayer. Distilled

water (600 ml) was applied at 35 psi. with a 730385 tee jet nozzle to shoots of rye aged 20, 30, 40 and 50 days. Leachates were collected, filtered with Whatman's #1 paper, and 5 ml. was bioassayed. The control was distilled water. Petri dishes were placed in a dark growth chamber (27°C/21°C). The number of lettuce, barnyardgrass, cress, and tomato which germinated out of thirty seeds were recorded. In addition, root and hypocotyl length per germinated seed of tomato were measured to determine if shoot leachates differentially affected the processes of cell division and cell elongation.

### Results and Discussion

#### Evaluation of Rye Root Leachates on Plant Growth

In the initial study where a compartmentalized pot with four sections was used for leachate evaluation, total biomass of cucumber was reduced 13% in rye treatments (Table 1). Although root, shoot, and total biomass of both tomato and cress appeared reduced in rye treatments, the reductions were not statistically significant. Growth of lettuce appeared stimulated, but, once again, the apparent increases were not statistically significant. The three cultivars of rye ('MSU-13', 'Wheeler', and 'Aroostock'), which were evaluated for their root leachate toxicity, did not vary in their effect on plant growth. Thus, it appears that leachates of rye roots are more inhibitory to growth of cucumber, than leachates of cucumber are on itself.

In a second study, 'MSU-13' rye and indicator species were grown in separate pots and Hoagland's solution was manually

TABLE 1 .--Effect of root leachates of rye on biomass as a percent of control.<sup>1</sup>

|       | Cucumber | Tomato | Lettuce | Cress |
|-------|----------|--------|---------|-------|
| Root  | 73       | 66     | 133     | 71    |
| Shoot | 93       | 62     | 104     | 62    |
| Total | 87**     | 63     | 109     | 65    |

<sup>1</sup>There was no significant difference between rye cultivars; thus means were averaged across cultivars.

\*\*Percent biomass is significantly reduced from control at the 1% level.

transferred through the four-pot series. In the biculture treatment of rye and test species, indicator pot #1 received leachates from one pot of rye only. In contrast, indicator pot #1 received leachates from two pots of rye. Root, shoot, and total biomass of lettuce and tomato were unaffected by leachates from one pot of rye (Table 2). In contrast, shoot and total biomass of lettuce were reduced 27% and 25% respectively when it had received leachates from two pots of rye. Total biomass of tomato was reduced by 18% where solutions had passed through two pots of rye. This indicates that root leachates of rye are more inhibitory to tomato and lettuce growth, than leachates from other tomato and lettuce plants. Since biomass was reduced where solutions had passed through two pots of rye, it may also suggest a concentration effect of rye root toxins.

In a second experiment, where rye root leachates were manually transferred, root, shoot, and total biomass of tomato were again reduced in pot #2 (Table 3). Both rye cultivars at all ages similarly reduced root, shoot, or total biomass of tomato in pot #2. Tomato growth in pot #1 was affected differently by the two cultivars of rye and various ages. 'MSU-13' was more inhibitory to tomato growth than 'Wheeler' rye, especially when the rye was planted the same time as tomato (Figure 2).

#### Effect of Rye Root and Shoot Leachates on Germination

Rye root leachates did not appear to reduce germination of cress, barnyardgrass, or common lambsquarters (Table 4). Cultivars

TABLE 2.--Effect of rye root leachates on biomass as a percent of control.

| Pot # | Lettuce |       | Tomato |       |
|-------|---------|-------|--------|-------|
|       | Shoot   | Total | Shoot  | Total |
| 1     | 94      | 100   | 97     | 105   |
| 2     | 73*     | 75*   | 86     | 82*   |

\*Percent biomass is significantly different from control at the 5% level.

TABLE 3.--Effect of rye root leachates on biomass of tomatoes as a percent of control.<sup>1</sup>

| Pot # | Root | Total |
|-------|------|-------|
| 1     | 68** | 70**  |
| 2     | 71** | 75*   |

<sup>1</sup> Means were averaged across cultivars and age of rye.

\*Percent biomass is significantly reduced from control at the 5% level.

\*\*Percent biomass is significantly reduced from control at the 1% level.

Figure 2.--Effect of rye root leachates on biomass of tomato shoots.

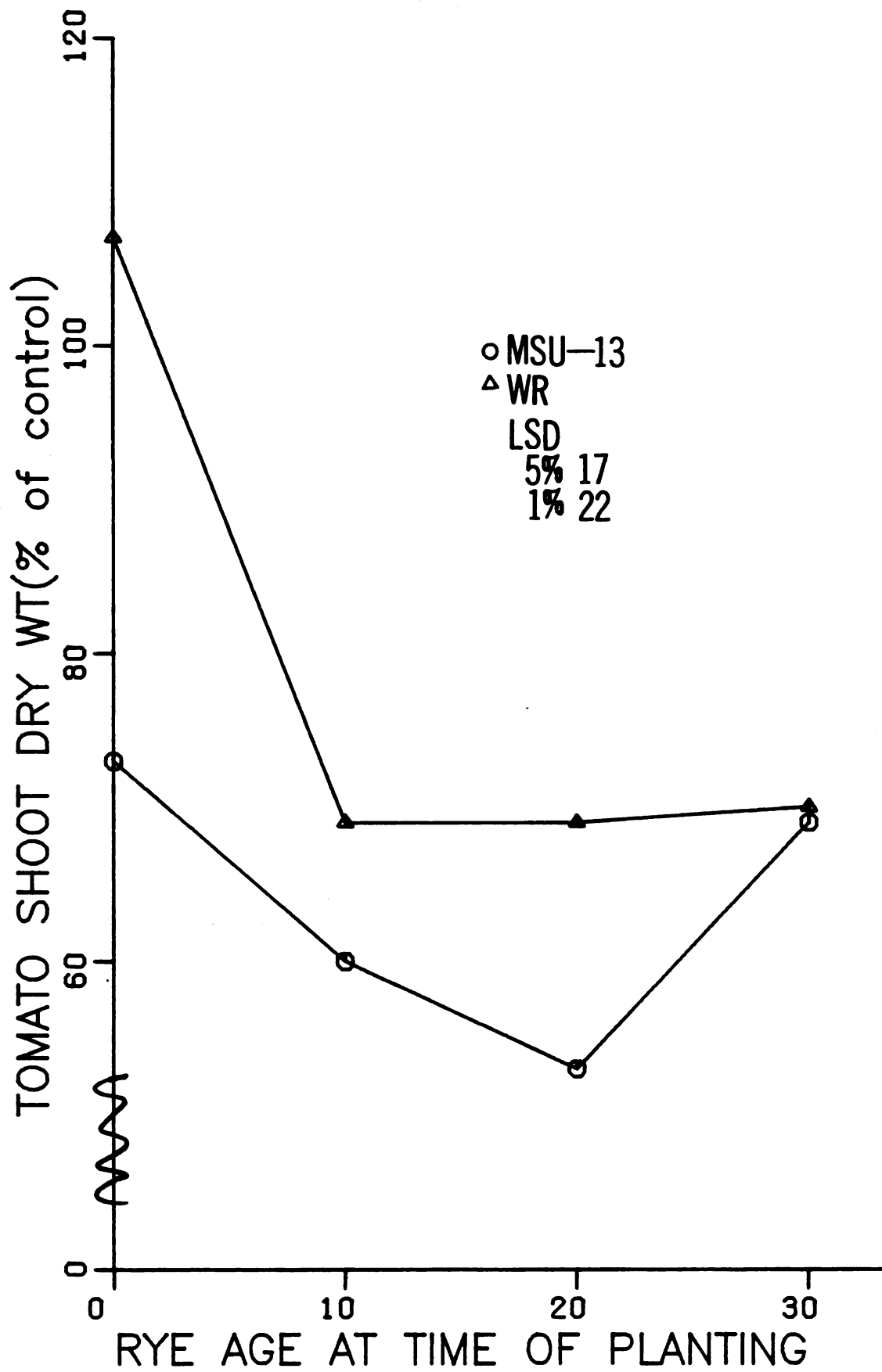


TABLE 4.--Effect of root leachates of rye on percent germination.<sup>1</sup>

| Treatment | Cress<br>(%) | BYGR<br>(%) | COLQ<br>(%) |
|-----------|--------------|-------------|-------------|
| No Rye    | 98           | 85          | 8           |
| Rye       | 97           | 88          | 10          |

<sup>1</sup>Means were averaged across rye cultivars and age and were not significantly different at the 5% level.

of rye did not differ and age of rye was not a factor. In addition, shoot leachates of different aged rye had no effect on percent germination of lettuce, barnyardgrass, cress, or tomato (Table 5). Also, shoot leachates did not appear to differentially affect processes of cell division or elongation during the early stages of tomato growth after germination (Table 6).

This study suggests that inhibitory compounds from rye roots may be released and taken up by other plants. But, without radioactive tracer studies, it is very difficult to determine the origin of the compounds (Rice, 1974). Toxicity of leachates may result from compounds sloughed off outer cells, or produced by microbial activity, in addition to those actually exuded by the roots. It appears that living rye interferes more with plant growth, rather than with the processes associated with germination. Since effects of direct plant/plant competition were minimized, adequate nutrients and water were always available, and quality and quantity of light received was equal, the reductions in biomass of tomato and lettuce are evidence that rye root leachates are inhibitory to growth of tomato and lettuce. Thus, in addition to toxicity from residues, allelopathy from living rye root leachates may be a component of the total interference noted between weeds and rye in the field. Leachates from leaves have no apparent influence on the growth of other plants.

TABLE 5.--Effect of shoot leachates of rye on percent germination.<sup>1</sup>

| Treatment | Let<br>(%) | BYGR<br>(%) | Cress<br>(%) | Tom<br>(%) |
|-----------|------------|-------------|--------------|------------|
| No Rye    | 98         | 85          | 92           | 85         |
| Plus Rye  | 98         | 87          | 92           | 85         |

<sup>1</sup>Means were averaged across rye cultivars and age and were not significantly different at the 5% level.

TABLE 6.--Effect of shoot leachates of rye on tomato germination and growth.<sup>1</sup>

| Treatment | Germ.<br>(%) | Root Length<br>(mm) | Shoot Length<br>(mm) | Total Length<br>(mm) |
|-----------|--------------|---------------------|----------------------|----------------------|
| No Rye    | 85           | 50.6                | 35.0                 | 85.6                 |
| Rye       | 85           | 50.5                | 35.9                 | 85.3                 |

<sup>1</sup>Means were not significantly different across cultivars of rye or age. Thus they were averaged and are not significantly different at the 5% level.

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## LITERATURE CITED

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