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# Herbicide Effects on Cultivars of Soybeans [Glycine Max (L.) Merr.]

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HERBICIDE EFFECTS ON CULTIVARS OF SOYBEANS [GLYCINE MAX (L.) MERR.]

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HERBICIDE EFFECTS ON CULTIVARS OF SOYBEANS [GLYCINE MAX (L.) MERR.]

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TABLE OF CONTENTS

Page

## LIST OF TABLES

HERBICIDE EFFECTS ON CULTIVARS OF SOYBEANS [<u>GLYCINE</u> <u>MAX</u> (L.) MERR.]

Mark Daniel Martin August 1985 39 pages

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Breeding herbicide-tolerant cultivars is a means of extending herbicide utilization. In 1983 and 1984, 20 soybean [*Glycine max* (L.) Merr.] cultivars were screened for their reactions to the following herbicides: metribuzin [4-amino-6-(tert)-butyl-3-(methylthio)-as-triazin-5-(4H)-one]; vernolate (S-propyl dipropylthiocarbamate); and fluchloralin [N-(2-chloroethyl)-2,6-dinitro-N-propyl-4-(trifluoromethyl) aniline]. Each herbicide was applied at the recommended rate X, 2X, and 4X in 1983. An 8X rate was added in 1984. The recommended rates (X) for the herbicides were as follows: metribuzin 0.42, vernolate 2.80, and fluchloralin 1.12 kg/ha. The cultivars were Pella, Pixie, Cumberland, Williams, Essex, Union, Semmes, Tracy, Tracy M; North American Plant Breeders 350, 68225, 420, and 330; Northrup King 8069 and 8047; and Farmers Forage Research 339, 340, 560, and 561.

Plant vigor, height, and herbicide injury were the criteria used in estimating herbicide effects. Statistical differences were found among herbicides, rates, and cultivars. Also, there were significant interactions involving herbicides x rates, herbicides x cultivars, rates x cultivars, and herbicides x rates x cultivars. Although not always statistically significant, average vigor ratings decreased with increased herbicide application rate. Pronounced differences in the study results for the two years, likely reflecting rainfall patterns, were evidence of uncontrolled variability. However, a small number of the cultivars exhibited herbicide tolerance.

# INTRODUCTION

Weed control is a major problem in soybean [Glycine max (L.) Merr.] production. According to a 1975 U.S. Department of Agriculture estimate, weeds reduced annual yield and quality of soybeans by as much as 17 percent (19). Soybean yield reductions of 50 and 40 percent have been reported in pigweed and morning glory infested fields, respectively (10).

A relatively new science, herbicide weed control reached commercial popularity in the 1950's and has grown steadily since that time. American farmers use approximately 420 million pounds of herbicides each year (2). Recent state and regional soybean yield increases have been attributed to greater herbicide usage (19).

Although substantial progress has been made in chemical weed control, further improvements are needed. Diversity of weed species which infest a given crop cultivar makes effective weed control difficult and expensive. Also, selective herbicide pressures cause shifts in weed populations. These shifts have become major problems as particular herbicides are being used for longer periods of time. Search for new herbicides has been the traditional response to these problems, an effort which has yielded progressively diminishing returns. If an effective herbicide is found for controlling a particular weed, developmental costs are often prohibitive. Areas contributing to increased cost include more stringent safety requirements and the expanding number of chemicals which must be screened to find effective herbicides.

Since the development of new herbicides is extremely expensive, maximum utilization of existing chemicals is of utmost importance. Breeding herbicide-tolerant cultivars is one feasible solution to the dilemma. The developmental cost for a new cultivar is in the range of one to five percent of that for developing a new herbicide (7). Therefore, when genetic variation permits, breeding herbicide-tolerant crops would be more economical than developing new selective herbicides.

The objective of the present study was to investigate cultivar x herbicide interactions in soybeans [*Glycine max* (L.) Merr.]. Included were effective soybean herbicides which differed in their crop damaging potential. The soybean cultivars represented a sampling of those adapted to Kentucky, those previously studied for their sensitivity to herbicides, and those available from various soybean breeding companies.

## REVIEW OF LITERATURE

### Metribuzin

Some herbicides are limited in their usefulness because of their crop damaging potential. Metribuzin [4-amino-6-(tert)-butyl-3-(methylthio)-as-triazin-5-(4H)-one] is one such herbicide and is used to control a number of weeds in soybeans. It is particularly effective in controlling sicklepod [Cassia obtrusifolia (L.)] and tall morning glory [Ipomoea purpurea (L.) Roth] (9). Metribuzin acts as a photosynthetic inhibitor, being taken up through the roots and translocated to the stems and leaves (3).

Under some environmental conditions, metribuzin causes severe crop damage (3). Efforts to control that damage are being directed toward development of resistant cultivars. Metribuzin damage can be attributed to a combination of genetic and environmental factors. Coble and Schrader (5) determined that plant damage increased significantly when rain occurred within 10 days following metribuzin treatment. They also observed that higher soil organic matter levels were associated with lower soybean injury. Moshier and Russ (14) found a positive association between the amount of rainfall and the extent of crop damage. Inconsistent results were obtained when the time of metribuzin application was varied in relation to the time of planting. Application three weeks before planting reduced soybean damage in one of two years; however, in the remaining year no difference was observed between applications made three weeks before planting and those made at planting. The inconsistent results were attributed to rainfall quantity and distribution.

Seed quality factors--germination, physical condition, and size--have been studied to determine their effects on metribuzin damage (8). Physically damaged and low germination seeds resulted in more seedling injury as well as reduced stand, height, and yield. However, the metribuzin levels x seed condition interactions were not significant. Interactions between metribuzin levels and seed size were significant. In comparison with progeny of small seed, progeny of larger seed exhibited less damage and greater stand, height, and yield.

In addition to environmental effects, some investigations have revealed that metribuzin damage was influenced by genetic factors (3, 9,18). Results of field and greenhouse studies indicated different levels of metribuzin sensitivity among soybean cultivars. Smith and Wilkinson (16) suggested that cultivars differ in their ability to metabolize metribuzin. They compared three soybean cultivars--Brag, Semmes, and Coker 102--and concluded that resistance was due to a unique metabolite. The resistant cultivar, Brag, metabolized metribuzin more effectively because of its glucose conjugate metabolite. In comparison, the two sensitive cultivars, Semmes and Coker 102, had a butyl ester metabolite and, consequently, were less effective in metabolizing metribuzin. The authors concluded that cultivar response to metribuzin resulted from differentiation for herbicide detoxification.

Further study of sensitive and nonsensitive cultivars showed that inheritance of metribuzin sensitivity was controlled by a single recessive gene (6). Semmes and a tolerant cultivar, Hood, were crossed. The $F_2$ population segregated into a 3:1 ratio, strongly suggesting that a single recessive gene controlled metribuzin sensitivity. The recessive gene, hm, that controls sensitivity in Semmes was later found to control metribuzin sensitivity in the Tracy cultivar. The value of this discovery was diminished by the fact that hm was closely linked with the gene controlling resistance to *Phytophthora megasperma* (Drechs), which induces rot in soybeans (12). This linkage will retard efforts to obtain both metribuzin and phytophthora resistance.

## Vernolate

Vernolate (S-propyl dipropyl thiocarbamate) has been found to cause soybean injury (11,15). Vernolate was readily absorbed and translocated to the aerial portions of the plant (4). Evidence suggested that the presence of vernolate inhibited the development of enzyme systems necessary for the degradation of vernolate. Younger seedlings degraded less vernolate than did older seedlings. As the seedlings increased in age, from 0 to 72 hours, a vernolate metabolite increased; however the presence of vernolate retarded further formation of that metabolite. Therefore, the vernolate treatment of soybean seedlings during the early stages of germination decreased vernolate degradation and synthetic utilization.

In studies conducted on essentially weed free soil, Parker and Dowler (15) concluded that vernolate and trifluralin effects were related to different methods of application. The methods of herbicide application were soil surface application with subsequent incorporation and direct soil injection. The injected chemicals were applied 5 cm below the soil surface at the time of planting. Soybeans were planted at a depth of 3.7 cm. Results, for both years of the study, favored the injected treatment of vernolate as evidenced by decreased plant injury and increased yield at the recommended rate (2.24 kg/ha). Soybean yields were 10.6 percent greater for injected than for incorporated treatments. At twice the recommended rate, soybean yields were 12 percent higher for plants subjected to an injection treatment than for plants subjected to an incorporation treatment.

Johnson (11) conducted a similar study evaluating injected and incorporated vernolate. His findings differed from those reported by Parker and Dowler (15) in that no seed yield differences were detected between incorporated and injected treatments. However, injection resulted in a higher percentage of weed control than did incorporation.

## Fluchloralin

Fluchloralin [N-(2-chloroethyl)-2,6-dinitro-N-propyl-4-(trifluoromethyl)aniline] is a member of the dinitroaniline herbicide family. Its major use is control of annual grasses and broadleaf weeds in soybeans. As is typical of the members of the dinitroaniline family, fluchloralin acts as a mitotic poison which retards cell division and cell wall and membrane development. These damaging effects are expressed through reduced root and shoot growth. Lateral root growth was prevented by application of 0.25 pounds/acre (0.18 kg/ha). Taproot growth was less affected than lateral root growth (13). Marquis et al. (13) reported that fluchloralin was metabolized into several different degradation products. Soybean seedlings were grown in solutions containing [$^{14}C$] labeled fluchloralin to determine the extent of fluchloralin metabolism and to isolate and characterize some of the metabolites. Approximately 76 percent of the administered $^{14}C$ was present in the seedling after 48 hours. Fractionation of the $^{14}C$ remaining in the post treatment solution showed only 26 percent unchanged fluchloralin. The seedling roots exhibited typical dinitroaniline injury symptoms. Root tips enlarged and failed to form secondary roots. Several metabolites were found in the post treatment solution. None of the metabolites represented more than 3 percent of the total radioactivity of the plant. Marquis et al. (13) concluded that these results indicated the availability of several different degradation pathways: N-dealkylation, reduction, cyclization, natural product conjugation, and any combinations thereof. The pattern of several different degradation conjugants and metabolitic pathways is characteristic of dinitroaniline degradation in plants.

## MATERIALS AND METHODS

In 1983 and 1984, soybean cultivars were screened for their reactions to herbicides. Field experiments were conducted on the Western Kentucky University Farm, Bowling Green, Kentucky.

### Herbicides

The herbicides studied were selected because of their importance in soybean production and for their crop damaging potential. The chemicals were as follows: metribuzin [4-amino-6-(tert)-butyl-3-(methylthio)-as-triazin-5-(4H)-one]; vernolate [S-propyl dipropyl-thiocarbamate]; and fluchloralin [N-(2-chloroethyl)-2,6-dinitro-N-propyl-4-(trifluoromethyl) aniline]. Each herbicide was applied at the recommended rate x, 2x, and 4x in 1983. An additional rate of 8x was included in 1984. Required herbicide amounts for the x, 2x, 4x, and 8x rates were as follows: metribuzin 0.37 lb/acre (0.42 kg/ha), 0.75 lb/acre (0.84 kg/ha), 1.50 lb/acre (1.68 kg/ha), 3.00 lb/acre (3.36 kg/ha); vernolate 2.50 lb/acre (2.80 kg/ha), 5.00 lb/acre (5.60 kg/ha), 10.00 lb/acre (11.20 kg/ha), 20.00 lb/acre (22.40 kg/ha); fluchloralin 1.00 lb/acre (1.12 kg/ha), 2.00 lb/acre (2.24 kg/ha), 4.00 lb/acre (4.48 kg/ha), 8.00 lb/acre (8.96 kg/ha).

### Cultivars

The cultivars represented a sampling of those presently recommended for production in Kentucky, those previously studied for their sensitivity to herbicides, and those available from various soybean breeding companies. Cultivars included within these groupings, respectively, are as follows: Pella, Pixie, Cumberland, Williams, and Essex; Union, Semmes, Tracy, and Tracy M; and North American Plant Breeders 350, 68225, 420, and 330, Northrup King 8069, and 8047, and Farmers Forage Research 339, 340, 560, and 561. Semmes and Tracy have been shown to be sensitive to metribuzin (16,5). Tracy M was developed for resistance to metribuzin damage (5).

Soil Characteristics

The experiment was conducted on a Linside silt loam (fine silty, mixed, mesic, Fluvaquentic Eutrochrept) in 1983 and a Pembroke silt loam (fine silty, mixed, mesic, Mollic Paleudalf) in 1984. The soils were low in organic matter (1.6 percent in 1983 and 1.8 percent in 1984). Phosphorus levels, as determined by the Weak Bray Method, were high in 1983 and low in 1984 (57 ppm in 1983 and 9 ppm in 1984). Each year the soybeans followed wheat which had been harvested in the early head stage and the resulting forage removed from the experimental area.

Field Techniques

Planting dates were June 14, 1983, and May 25, 1984. Preparation for planting consisted of moldboard plowing and disking. In 1983, the soil was leveled with a field cultivator. Inoculated soybean seeds were planted using a small, man-powered planter. The seeds were planted in 76 cm rows at a rate of approximately one seed per 2.5 cm.

Vernolate and fluchloralin were surface applied before planting and incorporated with a field cultivator in 1983 and with a disk harrow in 1984. Metribuzin was applied on the soil surface after planting. All herbicides were applied using a small $CO_2$ pressure sprayer.

## Experimental Design and Data Analysis

The experimental design was a split block in which herbicides and cultivars were the main factors. An experimental unit consisted of a 1.5-meter section of a single row for each treatment-cultivar combination. Treatment units were separated by a 0.9-meter unsprayed border treatment. The experiment was replicated twice each year. Plant vigor, height measurements, and herbicide injury observations were made on each treatment-cultivar combination in both replications.

The analysis of variance procedure was used to determine the significance of differences among means and of the various first- and second-order interactions. Herbicide treatment means were calculated and compared across levels and cultivars. Herbicide rate means were calculated and compared across herbicides and cultivars. Likewise, cultivar means were calculated and compared across chemicals and rates. In addition, herbicide rate combination means were compared within each cultivar. Tukey's procedure, as presented by Steel and Torrie (17), was used to separate individual means.

# RESULTS

## Plant Height

Plant height was significantly influenced by cultivars, herbicides, and rates of herbicides (Table 1). These effects were observed over all measurement dates for 1983 and 1984. The first-order interactions--cultivar x rate, cultivar x herbicide, and rate x herbicide--were significant for most height measurement dates in 1983 but were not significant for most dates in 1984. Likewise, the second-order interactions--cultivar x rate x height--were significant in 1983 but not in 1984.

### Rates Within Herbicides

Herbicide rate effects on plant height were compared within each herbicide for both 1983 and 1984 (Table 2). For the first 1983 measurement, there were no significant plant height differences among soybeans treated with the x, 2x, and 4x rate of metribuzin. On subsequent dates, soybeans receiving the 4x rate tended to be significantly shorter than plants receiving the x or 2x rates. In 1984, there were no consistent height differences among soybeans treated with metribuzin rates of x, 2x, 4x, and 8x. In 1983, there were no significant differences attributable to fluchloralin rates. In 1984, plants receiving higher fluchloralin rates tended to be shorter; however, these differences were inconsistent for the various measurement dates. In 1983, plants treated with vernolate at the 4x rate were consistently shorter than the x and 2x

Table 1. F-ratios for treatment effects on height of soybeans at various dates in 1983 and 1984.

| Analysis of Variance | | Date 1983 | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Source | df | 7-05 | 7-12 | 7-20 | 7-27 | 8-03 | 8-11 | 8-24 |
| Cultivar | 19 | 8.63** | 9.73** | 8.41** | 7.89** | 8.20** | 9.29** | 15.50** |
| Rates | 2 | 24.53** | 51.93** | 53.00** | 44.63** | 39.24** | 24.14** | 21.78** |
| Herbicide | 2 | 79.54** | 74.24** | 36.68** | 36.56** | 16.19** | 8.20** | 10.03** |
| Cultivar x Rate | 38 | 1.84** | 1.68** | 1.04 | 1.25 | 1.47* | 1.34 | 2.25** |
| Cultivar x Herbicide | 38 | 3.07** | 4.06** | 4.00** | 2.99** | 3.55** | 3.44** | 4.15** |
| Rate x Herbicide | 4 | 4.51** | 9.99** | 8.83** | 7.26** | 10.25** | 6.68** | 5.41** |
| Cultivar x Rate x Herbicide | 76 | 1.79** | 1.74** | 1.18** | 1.37* | 1.59** | 1.73** | 1.84** |
| | | Date 1984 | | | | | | |
| | | 6-14 | 6-18 | 6-29 | 7-10 | 7-16 | 7-23 | 8-05 |
| Cultivar | 19 | 3.66** | 3.25** | 5.66** | 4.05** | 5.33** | 5.65** | 6.43** |
| Rates | 3 | 6.38** | 6.04** | 8.46** | 9.56** | 9.18** | 10.53** | 6.81** |
| Herbicide | 2 | 21.21** | 6.24** | 35.62** | 35.01** | 36.83** | 24.33** | 18.74** |
| Cultivar x Rate | 57 | 0.81 | 0.56 | 0.61 | 0.58 | 0.71 | 0.54 | 0.51 |
| Cultivar x Herbicide | 38 | 1.12 | 0.88 | 0.68 | 0.76 | 0.72 | 1.20 | 1.23 |
| Rate x Herbicide | 6 | 0.80 | 1.09 | 1.26 | 2.33 | 0.93 | 0.66 | 0.45 |
| Cultivar x Rate x Herbicide | 114 | 0.51 | 0.38 | 0.73 | 0.59 | 0.65 | 0.49 | 0.52 |

* and ** indicate significance at the 0.05 and 0.01 levels of probability, respectively.

Table 2. Effects of rates within herbicides on height of soybeans in 1983 and 1984.

| | | Date 1983 | | | | | | | Date 1984 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Herbicide | Rate+ | 7-05 | 7-12 | 7-20 | 7-27 | 8-03 | 8-11 | 8-24 | 6-14 | 6-18 | 6-29 | 7-10 | 7-16 | 7-23 | 8-05 |
| Metribuzin | X | 17a* | 27a | 44a | 55a | 69a | 71a | 81a | 9a | 14a | 25a | 47a | 57a | 69a | 89a |
| | 2X | 17a | 26a | 42b | 54a | 68a | 70a | 82a | 9a | 12a | 25a | 46a | 53a | 65ab | 82a |
| | 4X | 15a | 22b | 35c | 46b | 57b | 70a | 71b | 9a | 13a | 23a | 40b | 51a | 61ab | 79a |
| | 8X | | | | | | | | 8a | 13a | 23a | 40b | 51a | 60b | 79a |
| | Mean | 16a | 24b | 40a | 52b | 65b | 68b | 79b | 9a | 13a | 24a | 43a | 53a | 64a | 83a |
| Fluchloralin | X | 17a | 26a | 41a | 56a | 70a | 72a | 85a | 9a | 14a | 24a | 42a | 57a | 66a | 85a |
| | 2X | 16a | 25a | 41a | 55a | 70a | 71a | 83a | 9a | 12a | 23ab | 42a | 52ab | 64ab | 80a |
| | 4X | 16a | 26a | 40a | 54a | 68a | 72a | 83a | 8ab | 13a | 23ab | 41ab | 51ab | 61ab | 80a |
| | 8X | | | | | | | | 7b | 12a | 20b | 36b | 46b | 55b | 74a |
| | Mean | 16a | 26a | 41a | 55a | 69a | 72a | 84a | 8a | 13a | 22a | 41a | 51a | 61a | 80a |
| Vernolate | X | 15a | 24a | 39a | 53a | 69a | 73a | 85a | 8a | 13a | 22a | 40a | 49a | 61a | 78a |
| | 2X | 14a | 22b | 36b | 49b | 62b | 67b | 83a | 7a | 12ab | 19ab | 34ab | 42ab | 53ab | 70ab |
| | 4X | 12b | 18c | 30c | 42c | 59c | 63c | 77b | 7a | 11ab | 18ab | 30b | 39b | 50ab | 67ab |
| | 8X | | | | | | | | 7a | 10b | 17b | 29b | 38b | 47b | 63b |
| | Mean | 14b | 21c | 35b | 48c | 65b | 68b | 82a | 7b | 12b | 19b | 33b | 42b | 52b | 70b |

+X indicates recommended rate.

*For a given herbicide and date, rate means followed by the same letter are not significantly different at the 0.05 level of probability. For a given date, herbicide means followed by the same letter are not significantly different at the 0.05 level of probability.

treated plants. In 1984, plants receiving 4x and 8x vernolate rates tended to be shorter than those receiving the x and 2x rates, but the differences were not always significant.

Early in the 1983 season, average heights of soybeans treated with vernolate were significantly shorter than those treated with metribuzin or fluchloralin. Later in the growing season, significant differences among plants receiving metribuzin and vernolate were inconsistent. With few exceptions, soybeans treated with metribuzin or vernolate were significantly shorter than those treated with fluchloralin. In 1984, vernolate treated plants were significantly shorter than metribuzin or fluchloralin treated plants on all measurement dates; however, there were no significant difference in average heights of metribuzin and fluchloralin treated plants on any measurement dates.

Herbicides Within Rates

The herbicides were compared within each application rate (Table 3). On some dates within both 1983 and 1984, plants receiving the x rate of vernolate were significantly shorter than plants receiving metribuzin. On some dates in 1984, plants treated with the x rate of fluchloralin were significantly shorter than those treated with metribuzin. At the 2x rate, metribuzin and fluchloralin treated plants did not differ significantly either year; however, plants in those treatments for both years were significantly taller than vernolate treated plants for most dates. At the 4x rate in 1983, plants treated with fluchloralin were taller than those treated with either metribuzin or vernolate. In 1984, plants receiving the 4x rate of fluchloralin were comparable in height to those treated with metribuzin and taller than those treated with vernolate. At the 8x rate, average plant height decreased progressively for plants treated with metribuzin, fluchloralin and vernolate, respectively.

Table 3. Effects of herbicides within rates on height of soybeans in 1983 and 1984.

| | | Dates 1983 | | | | | | | Dates 1984 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rate+ | Herbicide | 7-05 | 7-12 | 7-20 | 7-27 | 8-03 | 8-11 | 8-24 | 6-14 | 6-18 | 6-29 | 7-10 | 7-16 | 7-23 | 8-05 |
| X | Metribuzin | 17a* | 27a | 44a | 55a | 69a | 71a | 81a | 9a | 14a | 25a | 47a | 57a | 69a | 89a |
| | Fluchloralin | 17a | 26a | 41a | 56a | 70a | 72a | 85a | 9a | 14a | 24ab | 42ab | 57a | 66a | 85a |
| | Vernolate | 15a | 24b | 39b | 53a | 69a | 73a | 85a | 8a | 13a | 22b | 40b | 49b | 61a | 78a |
| | Mean | 17a | 26a | 42a | 54a | 69a | 72a | 84a | 9a | 14a | 24a | 43a | 53a | 65a | 84a |
| 2X | Metribuzin | 17a | 26a | 42a | 54a | 68a | 70a | 82a | 9a | 12a | 25a | 46a | 53a | 65a | 82a |
| | Fluchloralin | 16a | 25a | 41a | 55a | 70a | 71a | 83a | 9a | 12a | 23a | 42a | 52a | 64a | 80a |
| | Vernolate | 14b | 22b | 36b | 49b | 62b | 67a | 83a | 7b | 12a | 19b | 34b | 42b | 53b | 70b |
| | Mean | 15b | 24b | 40b | 53a | 68a | 71a | 83a | 8a | 12b | 22b | 41b | 49b | 61b | 77b |
| 4X | Metribuzin | 15a | 22b | 35b | 46b | 57b | 70ab | 71b | 9b | 13a | 23a | 40a | 51a | 61a | 79a |
| | Fluchloralin | 16a | 26a | 40a | 54a | 68a | 72a | 83a | 8ab | 13a | 23a | 41a | 51a | 61a | 80a |
| | Vernolate | 12b | 18c | 30b | 42b | 59b | 63b | 77a | 7b | 11a | 18b | 30a | 40b | 50a | 67a |
| | Mean | 15c | 22c | 35c | 47b | 62b | 66b | 77b | 8a | 12b | 21bc | 37bc | 48b | 57bc | 75b |
| 8X | Metribuzin | --- | --- | --- | --- | --- | --- | --- | 8a | 13a | 23a | 40a | 51a | 60a | 79a |
| | Fluchloralin | --- | --- | --- | --- | --- | --- | --- | 7b | 12a | 20b | 36a | 46a | 55a | 74ab |
| | Vernolate | --- | --- | --- | --- | --- | --- | --- | 7b | 10b | 17c | 29b | 38b | 47b | 63b |
| | Mean | --- | --- | --- | --- | --- | --- | --- | 7b | 12b | 20c | 35c | 45b | 54c | 72b |

+ X indicates recommended rate.

* For a given rate and date, herbicide means followed by the same letter are not significantly different at the 0.05 level of probability. For a given date, rate means followed by the same letter are not significantly different at the 0.05 level of probability.

In 1983, average soybean height decreased as the herbicide rate increased (Table 3). Late in the season, height differences among the x and 2x treated plants were not significant; however, 4x treated plants were significantly shorter than plants treated with the lower rates. In 1984, plants treated with the 2x and 4x rates were, with few exceptions, significantly shorter than those receiving the x rate. No significant differences were observed among soybeans treated with the 2x and 4x rate. Plants receiving the 8x rate were significantly shorter than those receiving the x rate, but height differences among the 2x, 4x, and 8x rates were inconsistent.

## Vigor

Plant vigor (plant volume) was estimated using a scale of 1-10 in which 10 represented maximum vigor or volume. Plant vigor was significantly influenced by cultivars, herbicides, and herbicide rates (Table 4). These effects were observed over all measurement dates for 1983 and 1984. The first-order interactions--cultivar x rate, cultivar x herbicide, and rate x herbicide--were significant for most dates in 1983; however, most of those interactions were not significant in 1984. The second-order interaction--cultivar x rate x herbicide--was significant with the exception of two dates in 1983 but was not significant in 1984.

### Rates Within Herbicides

Herbicide rate effects on plant vigor were compared within each herbicide (Table 5). For the first 1983 rating, no significant differences were observed among cultivars treated with the x, 2x, and 4x rate of metribuzin. In subsequent ratings, plants receiving the 4x rate tended to be significantly less vigorous than those treated with

Table 4. F-ratios for treatment effects on vigor ratings at various dates in 1983 and 1984.

| Analysis of Variance | | Date 1983 | | | | | |
|---|---|---|---|---|---|---|---|
| Source | df | 7-05 | 7-12 | 7-20 | 7-27 | 8-03 | 8-11 |
| Cultivar | 19 | 16.31** | 8.66** | 7.40** | 7.12** | 6.67** | 6.58** |
| Rates | 2 | 69.29** | 35.70** | 63.36** | 46.29** | 26.64** | 19.83** |
| Herbicides | 2 | 105.05** | 23.05** | 58.44** | 28.58** | 12.65** | 18.13** |
| Cultivar x Rate | 38 | 1.96** | 1.41** | 1.35 | 1.70* | 1.37 | 1.67* |
| Cultivar x Herbicides | 38 | 5.49** | 3.04** | 4.14** | 4.84** | 3.15** | 4.00** |
| Rates x Herbicides | 4 | 16.75** | 8.58** | 12.14** | 7.88** | 8.25** | 5.63** |
| Cultivar x Rate x Herbicide | 76 | 2.33** | 1.18** | 1.26 | 1.60** | 1.33 | 2.42** |
| | | Date 1984 | | | | | |
| | df | 6-29 | 7-10 | 7-18 | 7-23 | 7-31 | 8-05 |
| Cultivar | 19 | 6.28** | 5.68** | 3.84** | 5.30** | 4.94** | 4.40** |
| Rates | 3 | 21.87** | 16.73** | 27.11** | 24.53** | 17.50** | 13.88** |
| Herbicides | 2 | 48.01** | 42.07** | 41.01** | 32.54** | 30.80** | 24.06** |
| Cultivar x Rate | 57 | 0.87 | 0.58 | 0.71 | 0.56 | 0.62 | 0.62 |
| Cultivar x Herbicides | 38 | 0.64 | 0.70 | 0.68 | 1.00 | 1.03 | 1.07 |
| Rates x Herbicides | 6 | 0.88 | 2.38* | 0.79 | 0.74 | 1.31 | 1.36 |
| Cultivar x Rate x Herbicide | 114 | 0.58 | 0.56 | 0.44 | 1.00 | 0.56 | 0.52 |

* and ** indicate significance at the 0.05 and 0.01 levels of probability, respectively.

Table 5. Effects of rates within herbicides on vigor ratings of soybeans in 1983 and 1984.

| | | Date 1983 | | | | | | Date 1984 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Herbicide | Rate+ | 7-05 | 7-12 | 7-20 | 7-27 | 8-03 | 8-11 | 6-29 | 7-10 | 7-18 | 7-23 | 7-31 | 8-05 |
| Metribuzin | X | 6.55a* | 8.40a | 8.60a | 9.13a | 8/63a | 7.70a | 8.35a | 8.75a | 9.20a | 9.10a | 9.35a | 9.45a |
| | 2X | 6.58a | 8.33a | 8.75a | 8.80a | 8.35a | 7.60a | 7.75a | 8.95a | 8.63a | 8.48a | 9.05a | 9.35a |
| | 4X | 6.00a | 6.75b | 8.73a | 7.50b | 6.95b | 6.60b | 7.60ab | 7.88ab | 8.05a | 8.25a | 8.78ab | 9.03a |
| | 8X | --- | --- | --- | --- | --- | --- | 6.43b | 7.10b | 6.73b | 6.98b | 7.65b | 8.18a |
| | Mean | 6.34a | 7.83b | 8.03b | 8.41b | 7.96b | 7.30b | 7.53a | 8.17a | 8.15a | 8.20a | 8.71a | 9.00a |
| Fluchloralin | X | 6.58a | 8.70a | 8.75a | 9.35a | 8.53a | 7.85a | 7.75a | 7.85a | 8.73a | 8.68a | 9.10a | 9.83a |
| | 2X | 6.73a | 8.43a | 9.05a | 9.10a | 8.50a | 7.93a | 7.23a | 8.02a | 8.28a | 8.53a | 9.33a | 9.60a |
| | 4X | 6.28a | 8.48a | 8.75a | 9.05a | 8.60a | 7.83a | 6.67a | 7.95a | 7.98a | 7.85a | 8.23ab | 8.63ab |
| | 8X | --- | --- | --- | --- | --- | --- | 5.18b | 5.88b | 5.78b | 6.13b | 6.70b | 7.05ab |
| | Mean | 6.53a | 8.53a | 8.95a | 9.17a | 8.54a | 7.83a | 6.70b | 7.43b | 7.69a | 7.79a | 8.34a | 8.78a |
| Vernolate | X | 6.33a | 8.20a | 8.45a | 8.98a | 8.48a | 8.05a | 6.53a | 7.28a | 7.25a | 7.60a | 8.00a | 8.45a |
| | 2X | 5.48b | 8.05a | 7.73b | 8.43b | 8.13a | 8.10a | 5.10b | 5.87ab | 5.90b | 6.35a | 6.80ab | 7.23a |
| | 4X | 4.55c | 7.10b | 6.68c | 7.55c | 7.10b | 7.43b | 4.80b | 5.35b | 5.78b | 6.15ab | 6.43b | 6.90a |
| | 8X | --- | --- | --- | --- | --- | --- | 4.03b | 4.67b | 4.35c | 4.73b | 5.38b | 5.70b |
| | Mean | 5.45b | 7.78b | 7.62c | 8.32b | 7.90c | 7.86a | 5.11c | 5.79c | 5.88b | 6.23b | 6.65b | 7.07b |

+X indicates recommended rate.

*For a given herbicide and date, rate means followed by the same letter are not significantly different at the 0.05 level of probability. For a given date, herbicide means followed by the same letter are not significantly different at the 0.05 level of probability.

the x or 2x rates. In 1984, plants treated with the 4x or 8x metribuzin rates had lower vigor ratings than those receiving x or 2x rates; however, the differences were not always significant. Soybeans treated with the 8x rate were, with few exceptions, less vigorous than those receiving either the x or 2x rate. No consistently significant differences were observed among plants treated with the 4x and 8x rates.

For fluchloralin treated soybeans, in 1983 and 1984, no significant differences in vigor were observed among the x, 2x, and 4x rates. In 1984, 8x treated plants were significantly less vigorous than those receiving x or 2x rates. Prior to the last two estimates, 8x treated plants were less vigorous than x, 2x, and 4x treated plants.

For vernolate, soybeans receiving the 4x rate in 1983 and 1984 were significantly less vigorous than those receiving the x rate. Also, soybeans treated with the 8x rate in 1984 were significantly less vigorous than those treated with the x rate. Vigor relationships among plants treated with other rates were inconsistent.

In 1983, soybeans treated with metribuzin and vernolate tended to be less vigorous than those treated with fluchloralin. No consistently significant differences in vigor were observed among plants treated with metribuzin and vernolate. In 1984, no consistently significant differences were observed among those treated with metribuzin and fluchloralin; however, vernolate treated plants were less vigorous than those treated with metribuzin and fluchloralin. The soybeans treated with vernolate largely recovered later in the season.

Herbicides Within Rates

Herbicide effects on plant vigor were compared within each rate of application (Table 6). At the x rate in 1983, no significant differences in plant vigor were observed among soybeans treated with the different herbicides. In 1984, plants treated with vernolate received lower average vigor ratings than plants treated with the other herbicides; however, the differences were not always significant.

At the 2x rate in both years, soybeans treated with vernolate tended to be less vigorous than those receiving metribuzin or fluchloralin. No significant differences were observed between metribuzin and fluchloralin treated soybeans.

At the 4x rate in 1983, vigor ratings for vernolate and metribuzin treated plants were approximately equal but significantly lower than fluchloralin treated plants. In 1984, vernolate treated plants tended to be significantly less vigorous than those treated with metribuzin or fluchloralin. There was little difference in average vigor ratings of metribuzin and fluchloralin treated plants in 1984.

At the 8x rate in 1984, no consistent differences were observed among soybeans treated with vernolate or fluchloralin, or fluchloralin and metribuzin; however, vernolate treated plants were significantly less vigorous than metribuzin treated plants throughout the growing season.

Comparisons of rates over all herbicides indicated that average vigor decreased with increased herbicide application rates. Those decreases were not always statistically significant.

## Herbicide Injury

Herbicide injury was rated on a scale of 1-10, where 10 represented maximum injury. Ratings varied with cultivars, herbicides, and rates

Table 6. Effects of herbicides within rates on vigor ratings of soybeans in 1983 and 1984.

| | | Date 1983 | | | | | | Date 1984 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rate+ | Herbicide | 7-05 | 7-12 | 7-20 | 7-27 | 8-03 | 8-11 | 6-29 | 7-10 | 7-18 | 7-23 | 7-31 | 8-05 |
| X | Metribuzin | 6.55a* | 8.40a | 8.60a | 9.13a | 8.63a | 7.70a | 8.35a | 8.75a | 9.20a | 9.10a | 9.35a | 9.45ab |
| | Fluchloralin | 6.58a | 8.70a | 8.75a | 9.35a | 8.53a | 7.85a | 7.75ab | 7.85ab | 8.73a | 8.68ab | 9.10ab | 9.83a |
| | Vernolate | 6.33a | 8.20a | 8.45a | 8.98a | 8.48a | 8.05a | 6.53b | 7.28b | 7.25b | 7.60b | 8.00b | 8.45b |
| | Mean | 6.48a | 8.43a | 8.70a | 9.15a | 8.53a | 7.86a | 7.54a | 7.96a | 8.39a | 8.46a | 8.81a | 9.08a |
| 2X | Metribuzin | 6.58a | 8.33a | 8.75a | 8.80a | 8.35a | 7.60a | 7.75a | 8.95a | 8.63a | 8.48a | 9.05a | 9.35a |
| | Fluchloralin | 6.73a | 8.43a | 9.05a | 9.10a | 8.50a | 7.93a | 7.23a | 8.02a | 8.28a | 8.53a | 9.33a | 9.60a |
| | Vernolate | 5.48b | 8.05a | 7.73b | 8.43a | 8.13a | 8.10a | 5.10b | 5.87b | 5.90b | 6.35b | 6.80b | 7.23b |
| | Mean | 6.25b | 8.26a | 8.51a | 8.76b | 8.35a | 7.84a | 6.69b | 7.61ab | 7.60b | 7.78b | 8.39ab | 8.73a |
| 4X | Metribuzin | 6.00a | 6.75b | 6.73b | 7.50b | 6.95b | 6.60b | 7.60a | 7.88a | 8.05a | 8.25a | 8.78a | 9.03a |
| | Fluchloralin | 6.28a | 8.48a | 8.75a | 9.05a | 8.60a | 7.83a | 6.67a | 7.95a | 7.98a | 7.85a | 8.23ab | 8.63ab |
| | Vernolate | 4.55b | 7.10b | 6.68b | 7.55b | 7.10b | 7.43ab | 4.80b | 5.35b | 5.78b | 6.15b | 6.43b | 6.90b |
| | Mean | 5.58c | 7.45b | 7.38b | 7.98c | 7.55b | 7.28b | 6.36b | 7.06b | 7.27b | 7.42b | 7.81b | 8.20a |
| 8X | Metribuzin | --- | --- | --- | --- | --- | --- | 6.43a | 7.10a | 6.73a | 6.98a | 7.65a | 8.18a |
| | Fluchloralin | --- | --- | --- | --- | --- | --- | 5.18ab | 5.88ab | 5.78a | 6.13a | 6.70ab | 7.05a |
| | Vernolate | --- | --- | --- | --- | --- | --- | 4.03b | 4.67b | 4.35b | 4.73b | 5.38b | 5.70b |
| | Mean | --- | --- | --- | --- | --- | --- | 5.21c | 5.88c | 5.62c | 5.98c | 6.58c | 6.98b |

+X indicates recommended rate.

*For a given rate and date, herbicide means followed by the same letter are not significantly different at the 0.05 level of probability. For a given date, rate means followed by the same letter are not significantly different at the 0.05 level of probability.

of herbicides (Table 7). These effects were significant over all dates of measurement in 1983 and 1984. The first-order interactions--cultivar x rate, cultivar x herbicide, and rate x herbicide--were significant for injury ratings in 1983; however, those interactions were generally not significant in 1984. The second-order interaction--cultivar x rate x herbicide--followed a similar pattern: significant in 1983 but not in 1984.

Rates Within Herbicides

Metribuzin injury of soybeans was characterized by chlorosis of the early leaves of young plants. Barrentine et al. (3) reported that metribuzin inhibited photosynthesis. In the present study, no injury was detected on plants of some cultivars, whereas injury on plants of other cultivars varied from the dropping of lower leaves to complete death for susceptible cultivars such as Semmes and Tracy. Other workers (3,9,18) have reported cultivar differences in response to metribuzin treatments. In 1983, soybean injury increased significantly with each increase in metribuzin rate (Table 8). In 1984, increases in injury associated with increases in rate were not always significant.

Fluchloralin acts as a mitotic poison, resulting in general reduction in root and shoot development rather than specific injury characteristics (13). For fluchloralin treated soybeans, no significant injury differences were observed for x and 2x rates in either 1983 or 1984. Plants receiving the 4x rate in 1983 and 8x rate in 1984 exhibited significantly more injury than those receiving lower rates.

Vernolate injured plants exhibited smaller, crinkled leaves and a slower growth rate than that of untreated plants. In 1983 and 1984,

Table 7. F-ratios for treatment effects on herbicide injury in 1983 and 1984.

| Analysis of Variance | 1983 | | 1984 | | |
|---|---|---|---|---|---|
| | | Date | | Date | |
| Source | df | 7-14 | df | 6-25 | 7-12 |
| Cultivar | 19 | 8.63** | 19 | 3.13** | 5.21** |
| Rate | 2 | 24.53** | 3 | 28.14** | 43.50** |
| Herbicide | 2 | 79.54** | 2 | 107.15** | 48.60** |
| Cultivar x Rate | 38 | 1.84** | 57 | 0.86 | 1.10 |
| Cultivar x Herbicide | 38 | 3.07** | 38 | 0.98 | 0.97 |
| Rate x Herbicide | 4 | 4.51** | 6 | 3.20* | 1.95 |
| Cultivar x Rate x Herbicide | 76 | 1.79** | 114 | 0.58 | 0.61 |

* and ** indicate significance at the 0.05 and 0.01 levels of probability, respectively.

Table 8. Effects of rates within herbicides on injury ratings of soybean plants in 1983 and 1984.

| | | Date 1983 | Date 1984 | |
|---|---|---|---|---|
| Herbicide | Rate+ | 7-14 | 6-25 | 7-12 |
| Metribuzin | X | 0.05a* | 0.65a | 1.00a |
| | 2X | 1.03b | 0.80ab | 2.95bc |
| | 4X | 3.88c | 1.38ab | 2.45b |
| | 8X | --- | 2.44b | 4.00c |
| | Mean | 1.65b | 1.32a | 2.60a |
| Fluchloralin | X | 0.05a | 1.95a | 1.53a |
| | 2X | 0.05a | 2.18a | 1.80a |
| | 4X | 0.20b | 3.33a | 2.50a |
| | 8X | --- | 5.98b | 5.38b |
| | Mean | 0.10a | 3.36b | 2.80a |
| Vernolate | X | 0.58a | 3.68a | 2.95a |
| | 2X | 0.65b | 5.92b | 4.80b |
| | 4X | 3.28c | 6.03b | 4.95b |
| | 8X | --- | 7.05b | 6.20b |
| | Mean | 1.50b | 5.67c | 4.73b |

+X indicates recommended rate.

*For a given herbicide and date, rate means followed by the same letter are not significantly different at the 0.05 level of probability. For a given date, herbicide means followed by the same letter are not significantly different at the 0.05 level of probability.

soybeans receiving the x rate showed significantly less injury than those treated with higher rates. In 1983, soybeans treated with the 2x rate had significantly less injury than those treated with the 4x rate; however, no significant injury differences were observed among plants treated with the 2x, 4x, and 8x rates in 1984.

In 1983 and 1984, the average injury rating for soybeans treated with vernolate was significantly higher than for those treated with fluchloralin. In 1983, injury ratings for soybeans treated with metribuzin were not significantly different from those treated with vernolate; however, plants treated with metribuzin showed less injury in 1984 and were given significantly lower injury ratings than vernolate treated plants. No consistent injury rating differences were observed among soybeans treated with fluchloralin and metribuzin in 1984.

Herbicides Within Rates

Herbicides were compared for plant injury within each rate of application (Table 9). Within the x rate in 1983 and 1984, vernolate treated plants had significantly higher injury ratings than fluchloralin or metribuzin treated plants. No consistent injury differences were found among fluchloralin and metribuzin treated soybeans within the x rate. Within the 2x and 4x rates in 1983 and 1984, fluchloralin treated plants exhibited less injury than those treated with vernolate. Within the 2x and 4x rates in 1983, vernolate treated plants received significantly lower injury ratings than metribuzin treated plants. Within the 2x and 4x rates in 1984, no significant injury differences were observed among fluchloralin and metribuzin treated plants, and both herbicides resulted in significantly lower injury ratings than did vernolate. Within

Table 9. Effects of herbicides within rates on injury ratings of soybean plants in 1983 and 1984.

| | | Date 1983 | Date 1984 | |
|---|---|---|---|---|
| Rate+ | Herbicide | 7-14 | 6-25 | 7-12 |
| X | Metribuzin | 0.05a* | 0.65a | 1.00a |
| | Fluchloralin | 0.05a | 1.95b | 1.53a |
| | Vernolate | 0.58b | 3.68c | 2.95b |
| | Mean | 0.23a | 2.09a | 1.83a |
| 2X | Metribuzin | 1.03c | 0.80a | 2.95a |
| | Fluchloralin | 0.05a | 2.18a | 1.80a |
| | Vernolate | 0.65b | 5.92b | 4.80b |
| | Mean | 0.58b | 2.97b | 3.18b |
| 4X | Metribuzin | 3.88c | 1.38a | 2.45a |
| | Fluchloralin | .20a | 3.33b | 2.50a |
| | Vernolate | 3.28b | 6.03c | 4.95b |
| | Mean | 2.45c | 3.58b | 3.30b |
| 8X | Metribuzin | --- | 2.44a | 4.00a |
| | Fluchloralin | --- | 5.98b | 5.38b |
| | Vernolate | --- | 7.05b | 6.20b |
| | Mean | --- | 5.16c | 5.19c |

+X indicates recommended rate.

*For a given rate and date, herbicide means followed by the same letter are not significantly different at the 0.05 level of probability. For a given date, rate means followed by the same letter are not significantly different at the 0.05 level of probability.

the 8x rate, no significant injury differences were observed among fluchloralin and vernolate treated plants; however, both treatments resulted in more injury than did treatment with metribuzin.

In 1983 and 1984, average herbicide injury for the x rate was significantly less than that for higher rates. Soybeans treated with the 2x rate exhibited significantly less injury than those treated with the 4x rate in 1983. No significant differences between the 2x and 4x rates were observed in 1984; however, injury ratings for plants receiving the 2x or 4x rate were significantly lower than injury ratings for plants receiving the 8x rate.

## Cultivars

The significant differences among cultivars for height and vigor (Tables 1 and 4) likely resulted from inherent characteristics of the cultivars rather than from herbicide treatment effects. In an attempt to eliminate this inherent variation from treatment comparisons, the herbicide-rate treatments were compared within each cultivar. In 1983 and 1984, there were 9 and 12 treatments, respectively, within each cultivar.

When plant height was used as the measure (Table 10), pronounced treatment differences were found within cultivars such as Tracy and Semmes, but none was found within Essex or Pixie. Treatment effects within cultivars varied between years, being more common in 1983 than 1984.

Using plant vigor as the measure of herbicide treatment effects (Table 11), there were significant differences among treatments within Tracy, FFR 339, NK 8069, NAPB 350 and 330, Williams and Union in both

Table 10. F-ratios of plant height comparisons for herbicide-rate treatment means within individual soybean cultivars in 1983 and 1984.

| | Date 1983 | | | | | | | Date 1984 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cultivar | 7-05 | 7-12 | 7-20 | 7-27 | 8-03 | 8-11 | 8-24 | 6-14 | 6-18 | 6-29 | 7-10 | 7-16 | 7-23 | 8-05 |
| Tracy M | 5.13** | 1.85 | 3.34* | 0.69 | 0.91 | 0.44 | 0.19 | 0.30 | 0.21 | 5.50** | 3.57** | 2.34 | 2.72* | 6.09** |
| Tracy | 5.00** | 21.53** | 51.10** | 56.34** | 77.61** | 67.00** | 30.94** | 1.44 | 0.99 | 2.91* | 1.93 | 3.02* | 2.67* | 1.38 |
| Semmes | 4.42* | 6.96 | 6.56** | 4.97** | 4.14** | 4.96** | 4.73** | 0.29 | 0.30 | 0.32 | 0.29 | 0.34 | 0.24 | 0.24 |
| Hood | 0.57 | 1.12 | 0.65 | 1.43 | 0.51 | 0.61 | 0.13 | 2.06 | 0.84 | 2.71* | 0.84 | 2.41 | 1.26 | 1.24 |
| FFR 340 | 3.78* | 9.77** | 6.07** | 3.31* | 4.47** | 1.20 | 0.68 | 1.14 | 0.65 | 0.49 | 0.73 | 0.63 | 0.98 | 0.97 |
| FFR 560 | 4.38* | 1.13 | 3.12 | 0.99 | 0.82 | 0.43 | 0.76 | 0.97 | 0.41 | 0.69 | 0.73 | 0.99 | 0.62 | 0.66 |
| FFR 339 | 4.18* | 3.40* | 6.37** | 3.93* | 9.32** | 1.00 | 2.78 | 1.45 | 0.34 | 1.13 | 1.25 | 1.73 | 1.34 | 1.11 |
| FFR 561 | 1.13 | 2.26 | 0.31 | 1.64 | 0.69 | 1.64 | 0.19 | 0.53 | 1.02 | 4.07 | 2.20 | 1.50 | 3.25* | 5.85** |
| NK 8047 | 3.07* | 4.58* | 9.36* | 10.28** | 2.09 | 2.77 | 0.75 | 1.03 | 0.74 | 1.62 | 0.94 | 1.05 | 1.03 | 1.15 |
| NK 8069 | 5.79** | 1.91 | 4.80** | 0.75 | 1.69 | 0.45 | 0.76 | 1.21 | 1.37 | 1.74 | 2.83* | 3.29* | 2.30 | 2.56 |
| NAPB 68225 | 8.38** | 2.62 | 1.13 | 0.85 | 1.17 | 0.78 | 0.59 | 0.83 | 0.06 | 0.67 | 1.20 | 1.03 | 1.35 | 1.21 |
| NAPB 420 | 1.54 | 1.42 | 0.99 | 1.10 | 0.39 | 0.17 | 1.47 | 1.32 | 0.85 | 3.65** | 2.37 | 1.17 | 2.19 | 1.41 |
| NAPB 350 | 3.11* | 6.58** | 1.85 | 0.85 | 0.75 | 0.50 | 0.61 | 0.90 | 0.88 | 2.04 | 1.37 | 1.50 | 1.68 | 1.28 |
| NAPB 330 | 3.77* | 4.11* | 1.99 | 2.56 | 0.68 | 2.26 | 0.82 | 1.52 | 0.50 | 3.58** | 3.44** | 1.80 | 2.60* | 1.99 |
| Pella | 3.38* | 1.80 | 1.22 | 0.79 | 0.56 | 0.72 | 0.64 | 2.67 | 0.64 | 1.27 | 0.63 | 1.34 | 1.17 | 1.18 |
| Pixie | 2.75 | 2.39 | 1.59 | 1.30 | 1.50 | 1.05 | 0.91 | 0.53 | 0.93 | 1.13 | 1.63 | 1.52 | 1.19 | 1.12 |
| Cumberland | 3.46* | 2.72 | 3.76* | 1.06 | 0.86 | 0.31 | 0.37 | 0.69 | 0.16 | 1.04 | 0.94 | 1.17 | 0.89 | 1.14 |
| Essex | 1.39 | 1.65 | 0.64 | 1.71 | 1.28 | 0.30 | 0.57 | 2.20 | 0.55 | 2.35 | 1.78 | 1.38 | 1.32 | 0.95 |
| Williams | 6.20** | 4.29* | 3.88* | 2.78 | 1.32 | 0.46 | 0.49 | 1.51 | 1.47 | 1.23 | 1.32 | 1.54 | 1.57 | 1.46 |
| Union | 2.63 | 4.84** | 2.27 | 0.84 | 0.80 | 1.28 | 0.66 | 0.94 | 2.03 | 2.60** | 3.44* | 1.89 | 2.27 | 1.15 |

* and ** indicate significance at the 0.05 and 0.01 level of probability, respectively. Within each cultivar were 9 herbicide-rate treatments in 1983 and 12 in 1984.

Table 11. F-ratios of plant vigor comparisons for herbicide-rate treatment means within individual soybean cultivars in 1983 and 1984.

| | Date 1983 | | | | | | Date 1984 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cultivar | 7-05 | 7-12 | 7-20 | 7-27 | 8-03 | 8-11 | 6-29 | 7-10 | 7-18 | 7-23 | 7-31 | 8-05 |
| Tracy M | 2.00 | 1.08 | 0.85 | 0.41 | 1.13 | 2.08 | 4.58** | 3.96** | 3.52* | 3.78** | 3.99** | 2.78* |
| Tracy | 22.50** | 53.30** | 53.00** | 109.58** | 29.58** | 44.90** | 8.64** | 2.44 | 2.51 | 4.10** | 2.83* | 2.43 |
| Semmes | 6.27** | 2.95 | 5.68** | 5.64** | 5.94** | 5.37** | 0.18 | 0.10 | 0.19 | 0.13 | 0.15 | 0.16 |
| Hood | 2.25 | 0.17 | 0.69 | 0.92 | 0.34 | 0.68 | 1.86 | 4.09** | 3.84** | 4.40** | 9.80** | 20.55** |
| FFR 340 | 9.90** | 1.20 | 5.89** | 1.63 | 1.34 | 2.07 | 1.60 | 1.41 | 1.24 | 1.09 | 0.98 | 0.87 |
| FFR 560 | 0.94 | 0.88 | 1.26 | 1.06 | 0.94 | 1.09 | 0.95 | 0.76 | 0.89 | 0.56 | 0.77 | 0.56 |
| FFR 339 | 19.63** | 3.46* | 14.63** | 4.02* | 2.77 | 1.61 | 1.87 | 1.76 | 2,82* | 2.08 | 1.34 | 1.34 |
| FFR 561 | 1.57 | 1.63 | 1.68 | 2.08 | 0.79 | 0.31 | 1.49 | 1.42 | 1.18 | 1.90 | 1.61 | 0.86 |
| NK 8047 | 4.11* | 1.83 | 6.79** | 3.38* | 3.13* | 0.54 | 1.23 | 0.95 | 0.72 | 0.86 | 0.93 | 0.76 |
| NK 8069 | 16.88** | 0.98 | 3.54* | 3.25* | 0.40 | 0.70 | 3.42 | 2.37* | 3.02* | 3.01* | 3.07* | 2.86* |
| NAPB 68225 | 7.88** | 1.23 | 2.89 | 2.73 | 0.89 | 3.38* | 1.07 | 1.72 | 1.83 | 1.83 | 1.98 | 1.42 |
| NAPB 420 | 2.54 | 0.82 | 1.25 | 0.40 | 0.35 | 0.78 | 2.23 | 1.57 | 2.12 | 2.18 | 2.29 | 1.75 |
| NAPB 350 | 3.88* | 1.23 | 2.18 | 1.05 | 0.45 | 0.49 | 4.74** | 1.35 | 1.58 | 1.33 | 1.35 | 1.15 |
| NAPB 330 | 11.25** | 6.30** | 10.88** | 12.58** | 14.40** | 5.40** | 1.91 | 1.18 | 1.75 | 2.45 | 2.80* | 4.40** |
| Pella | 5.08** | 4.50** | 2.58 | 0.58 | 0.77 | 0.62 | 1.00 | 1.17 | 1.53 | 2.18 | 1.69 | 2.18 |
| Pixie | 3.13* | 1.12 | 1.10 | 1.83 | 0.76 | 1.58 | 1.29 | 1.78 | 1.54 | 1.58 | 1.54 | 1.51 |
| Cumberland | 2.48 | 0.62 | 0.73 | 0.69 | 0.23 | 2.30 | 0.96 | 2.10 | 2.57* | 0.99 | 0.67 | 0.74 |
| Essex | 3.50* | 1.61 | 1.68 | 1.40 | 0.81 | 1.75 | 1.55 | 1.13 | 1.86 | 2.17 | 1.30 | 1.14 |
| Williams | 6.20** | 1.32 | 2.22 | 3.44* | 1.73 | 0.68 | 1.99 | 1.95 | 1.62 | 2.29 | 2.54 | 2.93* |
| Union | 6.58** | 3.03* | 2.85 | 1.46 | 1.31 | 0.66 | 1.93 | 2.74* | 1.81 | 1.98 | 2.82* | 2.18 |

* and ** indicate significance at the 0.05 and 0.01 level of probability, respectively. Within each cultivar were 9 herbicide-rate treatments in 1983 and 12 in 1984.

years, but none among treatments within FFR 560, FFR 561, or NAPB 420 in either year. Again, treatment effects within cultivars were more common in 1983 than 1984.

When injury ratings were used to compare treatments within cultivars (Table 12), some significant effects were found within all cultivars in 1983 and/or 1984. In 1983, no significant differences among treatments were observed within NAPB 350, NAPB 330, Pixie, Essex, or Williams. In 1984, no significant differences were observed among treatments within Tracy M, Semmes, FFR 560, NK 8047, NAPB 420, or Pella.

The differential response of the cultivars to herbicide treatments indicated a degree of genetic control. For example, in 1983 Semmes and Tracy plants were killed by the 4X rate of metribuzin but showed little, if any, response to the 4X rate of fluchloralin. Failure of the 4X rate of metribuzin to be lethal in 1984 indicated the environmental impact of the herbicides on the soybeans. Previous researchers have observed both genetic (3,9,18) and environmental (8) effects on metribuzin damage to soybeans.

## Year Effects

Although year effects were not compared statistically, the study results were greatly different for 1983 and 1984. The two experiments were conducted on different soils, and plantings were on different dates (see Materials and Methods). However, the year effects are believed to have resulted from differences in amounts and patterns of rainfall (Table 13).

Coble and Schrader (5) found soybean damage resulting from treatment with metribuzin increased significantly when rain occurred within

Table 12. F-ratios of plant injury comparisons for herbicide-rate treatment means within individual soybean cultivars in 1983 and 1984.

| Cultivar | Date 1983<br>7-14 | Date 1984<br>6-25 | <br>7-12 |
|---|---|---|---|
| Tracy M | 9.00** | 2.43 | 2.15 |
| Tracy | 18.72** | 2.24 | 2.68* |
| Semmes | 15.26** | 0.17 | 0.24 |
| Hood | 22.54** | 3.31* | 8.25** |
| FFR 340 | 3.54* | 4.35** | 1.79 |
| FFR 560 | 9.96** | 1.84 | 1.30 |
| FFR 339 | 3.82* | 3.58** | 3.17* |
| FFR 561 | 4.95** | 2.23 | 6.28** |
| NK 8047 | 5.46** | 1.93 | 0.98 |
| NK 8069 | 25.08** | 4.35** | 2.82* |
| NAPB 68225 | 5.87** | 1.62 | 4.04** |
| NAPB 420 | 4.30* | 1.82 | 2.38 |
| NAPB 350 | 2.85 | 2.96* | 1.47 |
| NAPB 330 | 2.52 | 2.68* | 1.75 |
| Pella | 3.20* | 2.41 | 1.73 |
| Pixie | 2.41 | 2.66* | 2.28 |
| Cumberland | 10.13** | 4.61** | 1.65 |
| Essex | 1.80 | 4.30* | 2.62* |
| Williams | 2.14 | 2.83* | 2.04 |
| Union | 16.58** | 2.01 | 3.01* |

* and ** indicate significance at the 0.05 and 0.01 level of probability, respectively. Within each cultivar were 9 herbicide-rate treatments in 1983 and 12 in 1984.

Table 13. Precipitation during the soybean growing seasons, 1983 and 1984, Western Kentucky University Farm, Bowling Green, Kentucky.+

| 1983 | | Precipitation(cm) | 1984 | | Precipitation(cm) |
|---|---|---|---|---|---|
| June | 3 | 2.0 | May | 25 | 2.9 |
| | 15 | 0.2 | | 26 | 1.1 |
| | 16 | 0.3 | | 28 | 1.4 |
| | 17 | 0.5 | June | 12 | 0.5 |
| | 19 | 1.6 | | 16 | 0.6 |
| | 27 | 0.4 | | 19 | 0.7 |
| | 28 | 0.5 | | 20 | 1.3 |
| | 30 | 0.9 | | 23 | 3.0 |
| July | 1 | 0.2 | | 28 | 0.2 |
| | 3 | 1.8 | July | 2 | 0.5 |
| | 4 | 0.5 | | 5 | 2.7 |
| | 5 | 3.2 | | 6 | 0.8 |
| | 25 | 2.5 | | 11 | 1.4 |
| August | 11 | 2.5 | | 16 | 3.2 |
| | 15 | 0.1 | | 17 | 0.2 |
| | 16 | 0.1 | | 27 | 1.7 |
| | 28 | 0.6 | | 31 | 0.5 |
| | 29 | 0.1 | August | 2 | 0.6 |
| | | | | 4 | 0.1 |
| | | | | 5 | 0.2 |
| | | | | 6 | 0.2 |
| | | | | 10 | 1.0 |
| | | | | 18 | 1.0 |

+Planting dates were June 14, 1983 and May 25, 1984.

10 days following application. In the present study, 2.6 cm of rainfall occurred within 4 days following planting and the application of metribuzin in 1983, whereas no rainfall was recorded within the 10 days following the application of metribuzin in 1984. (In 1983, planting and metribuzin application occurred on the same day; however, in 1984, planting was followed by 5.4 cm of rainfall, delaying metribuzin application by 4 days.) Effects of the 4X rate of metribuzin were more pronounced in 1983 than in 1984. For example, Semmes and Tracy plants were killed in 1983 but not in 1984.

During the 1983 soybean growing season, rainfall was below normal and was approximately 60 percent of that for the comparable period in 1984. Thus, the soybean plants were subjected to serious moisture stress in 1983. Comparisons of the herbicide treatment effects on plant height and vigor within cultivars (Tables 10 and 11) resulted in considerably more significant differences in 1983 than in 1984. Furthermore, the various first- and second-order interactions among the herbicides, rates, and cultivars were significant more frequently in 1983 than 1984 (Tables 1, 4, and 7). Given that the modes of action of these herbicides inhibit photosynthesis (metribuzin), mitosis (fluchloralin), and normal growth (vernolate), it follows that their effects would be greater when plants are subjected to other environmental stress conditions.

# DISCUSSION

Variation in plant responses results from genetic, environmental, and genetic x environmental interaction effects. The purpose of the present study was to explore these effects in soybeans following the treatment of cultivars with different levels of herbicides. When soybean plant response was measured through height, vigor, or injury, there was evidence of the three effects--genetic, environmental, and genetic x environmental interactions (Tables 1, 4, and 7).

The genetic effects, or cultivar differences, suggest that breeding herbicide resistant cultivars is a possible solution to the more expensive process of developing additional herbicides. There was evidence of both qualitative and quantitative response to the herbicides. Tracy and Semmes were killed by the 4X metribuzin treatment in 1983, further supporting literature reports (6) that metribuzin sensitivity is qualitative in some cultivars. Other cultivars' responses to metribuzin as well as to fluchloralin and vernolate were a matter of degree, suggesting quantitative control. Cultivars such as Essex, Pixie, FFR 560, FFR 561, and NAPB 420 exhibited resistance when response was measured through plant height or vigor (not necessarily both).

The environmental or year effects demonstrated the need to sample environments such as years and locations. Also, research efficiency could be improved by controlling some environmental conditions, especially soil moisture. In field studies, such as this one, soil irrigation facilities would be most helpful.

The cultivar treatment interactions indicated that the relative response of cultivars was not consistent for the various herbicide-rate treatment combinations (Tables 1, 4, and 7). In other words, cultivar response was specific for herbicides and rates, suggesting that the testing of new herbicides must involve a range of herbicide rates and soybean cultivars. Since new herbicide/cultivar development requires years, the testing needs to be included in the early stages of each process.

In the present study, average vigor of the soybean plants decreased as the rate of herbicide application increased. Although not always significant, this relationship existed for all herbicides. This observation provides a basis for questioning whether the regular use of herbicides in soybean culture causes a reduction in yield. The observed reduction was insignificant in comparison with yield reductions associated with weed infestations (10).

Reduced plant vigor and height or increased plant injury in the early growth stages do not necessarily result in reduced seed yield of mature soybean plants. Soybeans have remarkable ability to compensate for stand differences through branching and to respond to more favorable growing conditions as the season progresses. For example, early in 1983, the vernolate treated plants were shorter in height and lower in vigor than fluchloralin or metribuzin treated plants; however, those differences had disappeared by the end of the season (Tables 2 and 5).

Yield data were not reported. To maximize genetic diversity, cultivars were selected from different maturity groups. It was appropriate to compare the diverse cultivars for vegetative growth and herbicide injury but not for grain yield. Also, to include the maximum number of cultivars and herbicide treatments, an experimental unit was restricted to one row rather than multiple rows as needed for yield data.

Results of the present study justify further evaluations of the interactions of soybean cultivars and herbicide treatments. The next step would be to select a small number of the more herbicide-tolerant cultivars that are adapted to this location and to subject them to herbicide-rate treatments on a scale that would permit yield testing.

## SUMMARY

The objective of the present study was to investigate soybean cultivar x herbicide interactions. In 1983 and 1984, 20 cultivars were screened for their reaction to three herbicides--metribuzin, fluchloralin, and vernolate. Each herbicide was applied at the recommended rate X, 2X, and 4X in 1983. An 8X rate was added in 1984. The experimental design was a split block in which herbicides and cultivars were the main factors. The experiment was replicated twice each year. Plant vigor, height, and herbicide injury were the criteria used in estimating herbicide effects.

Statistical differences were found among herbicides, rates, and cultivars. Also, there were significant interactions involving herbicides x rates, herbicides x cultivars, rates x cultivars, and herbicides x rates x cultivars. Although not always statistically significant, average vigor ratings decreased with increased herbicide application rate. Pronounced differences in the study results for the two years, likely reflecting rainfall patterns, were evidence of uncontrolled variability. However, a small number of the cultivars exhibited herbicide tolerance.

The results justify further evaluations of the interactions of soybean cultivars and herbicide treatments. Development of herbicide-tolerant cultivars may be an effective means of extending the usefulness of existing herbicides, thereby avoiding the tremendous costs of developing new ones.

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