AN ABSTRACT OF THE THESIS OF

Gul Hassan for the degree of Doctor of Philosophy in Crop and Soil Science presented on March 6, 1992.

Title: Differential Sensitivity of Italian Ryegrass and Rice Cultivars to Fenoxaprop

Abstract Approved: Redacted for Privacy

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Field, greenhouse, and laboratory studies were initiated to determine the response of 22 Italian ryegrass *(Lolium multiflorum* Lam.*)*, and seven rice *(Oryza sativa* L.*)* cultivars to fenoxaprop {(±)-2-[4-[(6-chloro-2-benzoxazolyl)oxy]phenoxy]propanoic acid}.

Based on GR_{50} estimates (fenoxaprop rate required to reduce growth by 50%), 6-fold differences between the least and the most tolerant Italian ryegrass cultivars existed. Averaged over all Italian ryegrass cultivars, tolerance at the 4-leaf stage was twice that at the 2-leaf stage.

A differential in tolerance was also found for the rice cultivars under greenhouse conditions only. At the 2-leaf growth stage, more than a 4-fold difference in tolerance existed between the least and the most susceptible cultivars. The gain in tolerance with age in rice was greater than that in Italian ryegrass cultivars. Tolerance to fenoxaprop in 4-leaf rice plants was six-times that in the 2-leaf plants. However, in both rice and Italian ryegrass, the age-related gain in tolerance was not proportionate in all the cultivars. Generally higher gain in tolerance was attained by the more

tolerant than the susceptible cultivars. In the last phase of research, attempts were made to integrate the whole plant tolerance with the assumed primary target site of fenoxaprop. Evaluated with I_{50} (mmol fenoxaprop required to inhibit the activity of ACCase by 50%) Marshall, the most tolerant cultivar at the whole plant level, had a three times more tolerant acetyl-Coenzyme A (ACCase) than the least tolerant cultivar at the molecular level. Neither the ACCase inhibition nor the specific activity, alone, explained the tolerance of the cultivars ranked at the whole plant level. However, simultaneous consideration of both the inhibition and the specific activity of ACCase explained the tolerance of most of the cultivars at the whole plant level. A higher ACCase activity at the tillering stage than at the 2-leaf stage was discovered, which could at least partially explain the higher whole plant tolerance at later developmental stages.

Differential Sensitivity of Italian Ryegrass and Rice Cultivars to Fenoxaprop

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Typed by researcher for Gul Hassan

DEDICATED TO MY FATHER, TO COMMEMORATE
HIS THIRTEENTH DEATH ANNIVERSARY

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DIFFERENTIAL SENSITIVITY OF ITALIAN RYEGRASS AND RICE CULTIVARS TO FENOXAPROP

INTRODUCTION

The postemergence graminicide fenoxaprop-ethyl, an aryloxyphenoxypropanoic acid, is registered for use in Italian ryegrass and rice all with other crops. Soon after its registration for use in Italian ryegrass in Oregon in 1987, several fields of cultivar 'Tetrone' were severely injured by fenoxaprop. Similarly, due to differential sensitivity of rice cultivars, damage of susceptible cultivars by fenoxaprop has been reported in Arkansas. In Pakistan, fenoxaprop is also in the process of registration for use in rice, and has the potential for registration in wheat and cotton crops. Therefore, the present studies were undertaken to examine the tolerance of Italian ryegrass and rice to fenoxaprop. Research is presented in five chapters, and each chapter is a complete and self-contained manuscript.

Chapter I presents the preliminary studies conducted on 22 Italian ryegrass cultivars to evaluate their tolerance to fenoxaprop.

Research in Chapter II further explores the tolerance of 10 representative out of the 22 Italian ryegrass cultivars used in the preliminary studies. The effect of age on tolerance was also investigated in this research.

Chapter III, as the last phase of our project we endeavored to integrate the whole plant tolerance of Italian ryegrass cultivars with biochemical data from the target site of fenoxaprop.

Chapter IV involves the research on the tolerance of 6 rice cultivars to fenoxaprop under normal rice growing conditions in Pakistan. The effect of time of application of fenoxaprop was also studied in this research.

In Chapter V we present the tolerance of rice cultivars as affected by the growth-stage under greenhouse conditions.

Chapter 1.

Italian Ryegrass (*Lolium multiflorum*) Germplasm Tolerance to Fenoxaprop[1]

GUL HASSAN[2] AND GEORGE W. MUELLER-WARRANT[3]

Abstract. Soon after registration of fenoxaprop for control of wild oats in Italian ryegrass, perennial ryegrass, and tall fescue, several fields of 'Tetrone' Italian ryegrass were severely injured by this herbicide. Lack of phytotoxicity on other cultivars suggested the possibility of differential tolerance to fenoxaprop. Studies were therefore undertaken in a greenhouse environment to evaluate the tolerance of 22 certified cultivars of Italian ryegrass to fenoxaprop during 1988 and 1989. The application rates of fenoxaprop ranged from 56 to 280 g ai ha^{-1} in whole plant experiment 1 and from 28 to 336 g ha^{-1} in the subsequent studies. Plants were treated at the 3-4 leaf stage in the early studies and at the 2-3 leaf stage of crop growth in the subsequent studies. The response of cultivars to fenoxaprop was evaluated as the proportionate fresh-weight compared to the untreated check. Growth-reduction rates of 50% (GR_{50}) were computed from a

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regression analysis. Substantial variation in tolerance to fenoxaprop was found in the germplasm. The difference in GR_{50} rates was 5-fold between the least and the most susceptible cultivars. The cultivars 'Marshall', 'Gulf', 'Torero', and 'Ellire' were among the most tolerant in both tests, while 'Ace' and 'Futaharu' were the most susceptible. In light of these findings and reported field injury, the commercial label was subsequently modified in late 1988, reducing the recommended rate to 170 instead of 280 g ha^{-1} and allowing treatment only to some of the most tolerant cultivars. Nomenclature: Fenoxaprop[4], (±)-2-[4-[(6-chloro-2-benzoxazolyl)oxy]phenoxy]propanoic acid; Italian ryegrass, *Lolium multiflorum* Lam.#[5] LOLMU.

<u>*Additional index words.*</u> Postemergence application, fresh-weight, GR_{50}, susceptibility.

INTRODUCTION

Weed management is not only important in the production of certified seed of grass seed crops, but is also important

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[4]Mention of trademark or proprietary product does not constitute a guarantee or warranty of the product by the Oregon State University and does not imply its approval to the exclusion of other products that may be equally suitable.

[5]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 309 West Clark Street, Champaign, IL 61820.

in grasslands for eliminating less productive grass species. Fenoxaprop, a postemergence grass-specific systemic herbicide, is tolerated differentially by various grasses and exceptionally well by dicots. It was discovered in the laboratories of Hoechst AG, Frankfurt (4, 39) in 1982. It has emerged as one of the most important herbicides for controlling weeds in C-3 cool-season grasses (3, 5, 13, 33, 34, 35). However, tolerance to fenoxaprop also differs among species in such genera as *Festuca*, *Poa*, *Digitaria*, *Eleusine*, *Setaria*, and *Panicum* (5, 13, 29) and also within a species (20, 21, 25, 31, 40, 45, 46). Fenoxaprop is effective against warm-season problem weeds like wild oats *[Avena fatua* L.# AVEFA*]*, barnyardgrass *[Echinochloa crus-galli* (L.) Beauv. # ECHCG*]*, large crabgrass *[Digitaria sanguinalis* (L.) Scop. # DIGSA*]*, smooth crabgrass *[D. ischaemum* (Schreb.) Muhl. # DIGIS*]*, green foxtail *[Setaria viridis* (L.) Beauv. # SETVI*]*, Johnsongrass *[Sorghum halepense* (L.) Pers. # SORHA*]*, black grass *[Alopecurus myosuroides* Huds. # ALOMY*]*, and bermuda grass *[Cynodon dactylon* (L.) Pers. # CYNDA*]* (4, 5, 30, 37).

Fenoxaprop was registered in Oregon during 1987 for selective weed control in seed crops of Italian ryegrass *[Lolium multiflorum* Lam. # LOLMU*]*, perennial ryegrass *(L. perenne* L. # LOLPE*)*, tall fescue *(Festuca arundinacea* Schreb. # FESAR*)*, and fine fescue *(F. rubra* L. # FESRU*)*. Varietal tolerance in ryegrass to fenoxaprop, however, proved more variable than anticipated, and several fields of the cultivar 'Tetrone' were destroyed by application of 280 to 350 g ha^{-1} fenoxaprop.

The value of screening crop germplasm to determine herbicide GR_{50} (g ha^{-1} fenoxaprop required to reduce shoot weight by 50% as compared to an untreated check) values of a herbicide would be greatest when rates needed to kill weeds are similar to those injuring some cultivars of the crop. Then the herbicide may be safe to use on some cultivars but not on others. Because the tolerance of cultivars within a species is unknown in general and in Italian ryegrass specifically, studies were undertaken with the following objectives: a) to determine the tolerance to fenoxaprop of 22 cultivars of Italian ryegrass, b) to quantify the degree of tolerance, c) to evaluate the behavior of tolerance at varying phenological stages, and d) to correlate the whole plant tolerance with its molecular basis. The first two objectives are the subject of this chapter.

MATERIALS AND METHODS

Responses of 22 cultivars to different rates of fenoxaprop were evaluated in the greenhouse environment in the spring of 1988 (hereafter called Whole Plant Expt. 1) and subsequently repeated in Spring 1989 (hereafter called Whole Plant Expt. 2). Seed of 22 certified cultivars, all belonging to *Lolium multiflorum*, were obtained from the Oregon State

University Seed Testing Laboratory, Corvallis, Oregon. Ten seeds were planted in each 10- by 10-cm plastic pot filled with a peat-loam-sand-pumice potting mixture in a 1:1:1:3 ratio by volume, with *p*H corrected to 6.5. The pots, randomized on greenhouse benches, were watered three times a day until gemination, and then once a day until harvest. Pots were gradually thinned after emergence to an ultimate density of seven seedlings per pot. Soluble fertilizer (N:P:K at 20:20:20) was applied twice during the growth period.

Temperatures of 16/10 C day/night were maintained throughout the growing period. Natural light was supplemented with artificial 400 μmol m^{-2} s^{-1} of phosynthetically active radiation (PAR) to maintain a 12-h photoperiod. At the 3-4 leaf stage in Expt. 1 and the 2-3 leaf stage in Expt. 2, the plants were treated with the commercially formulated emulsifiable concentrate of fenoxaprop-ethyl with a pressurized-air, bicycle sprayer delivering 480 L ha^{-1}. Out of three untreated checks, one was harvested at the time of treatment for recording the initial weight at treatment time, while the other two checks were harvested along with all other treatments 4 wk after treatment. Plants were harvested at 1-cm cutting height to measure fresh weight. Relative fresh weight (R. Fwt) for each treatment was calculated as described by Morrison and Maurice (32) as follows:

$$\text{R. Fwt} = \frac{Fwt_t - Fwt_0}{Fwt_c - Fwt_0} \times 100$$

where:

Fwt_0 = fresh weight per pot at the time of spraying

Fwt_t = fresh weight per pot of treatment at final harvest

Fwt_c = mean fresh weight per pot of check (mean of 2 checks) at final harvest.

The experiments were laid out in a completely randomized design with a factorial arrangement of fenoxaprop rates and ryegrass cultivars. Rates of fenoxaprop (0, 56, 112, 168, 224, and 280 g ha^{-1}) constituted one factor and cultivars the other in the Whole Plant Expt. 1. Based on tolerance to fenoxaprop as estimated by shoot fresh weight relative to check (without subtracting the initial weight; data not reported) from Expt. 1, cultivars were divided into four groups in Expt. 2, viz. susceptible, moderately susceptible, moderately tolerant, and tolerant, and a separate test was run on each group. Highest rates (112 to 336 g ha^{-1}) were applied to the tolerant and lowest rates (28 to 168 g ha^{-1}) to the susceptible group. Each treatment was replicated five times in all the tests. Net fresh weight and relative fresh weight data were subjected to analysis of variance. Means were separated by using Duncan's multiple range test (38). For Expt. 2, each group was analyzed separately and by combining the susceptible with the moderately susceptible, and the moderately tolerant with the tolerant group, respectively, on common rates. Flowering data of plants at the time of harvest also were recorded for Expt. 1. Such flowering data

Table 1.1. Analysis of variance for net fresh-weight in 22 Italian ryegrass cultivars as treated with 5 rates of fenoxaprop (Whole plant Expt. 1).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Cultivar	21	741.6	35.3	5.88	0.0001
Rate	5	2745.3	549.1	91.41	0.0001
Cultivar*rate	105	1056.9	10.1	1.68	0.0001
Error	528	3171.4	6.0		

Table 1.2. Analysis of variance for relative fresh-weight in 22 Italian ryegrass cultivars treated with 5 rates of fenoxaprop (Whole plant Expt. 1).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Cultivar	21	120093.5	5718.7	5.29	0.0001
Rate	5	468268.1	93653.6	86.56	0.0001
Cultivar*rate	105	160133.7	1525.1	1.41	0.0084
Error	528	571268.8	1081.9		

Table 1.3. Analysis of variance for flowering of 22 Italian ryegrass cultivars treated with 5 rates of fenoxaprop (Whole plant Expt. 1).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Cultivar	21	48.8	2.32	16.67	0.0001
Rate	5	3.7	0.74	5.29	0.0001
Cultivar*rate	105	18.5	0.18	1.27	0.0517
Error	528	73.6	0.14		

Table 1.4. Cultivar by fenoxaprop rate interaction for net fresh-weight of 22 Italian ryegrass cultivars (Whole plant Expt. 1).

Cultivar	Ploidy Level†	Fenoxaprop (g ha^{-1})						Cultivar Mean
		0	56	112	168	224	280	
	(*n*)	(g)						
Marshall	2	6.5	4.7	4.9	7.0	3.5	2.5	5.0abcde
Florida 80	2	8.1	8.4	5.3	4.5	3.8	3.4	5.5ab
Gulf	2	7.4	4.6	4.4	7.1	4.0	2.8	5.0abcde
Barspectra	4	9.3	6.5	5.7	7.0	3.1	5.6	6.2a
Torero	4	8.7	5.9	6.6	4.0	4.0	5.0	5.7ab
Promenade	4	6.0	6.8	4.5	3.2	3.8	1.0	3.9defg
Lemtal RvP	2	5.8	4.3	4.8	2.4	1.9	3.0	3.7efgh
Sakurawase 1	2	6.8	6.6	4.2	2.7	3.0	3.1	3.2fgh
Bartolini	2	5.0	5.6	3.8	2.6	2.4	-0.3	3.1fgh
Aubade	4	8.6	6.8	4.8	4.9	5.0	1.2	5.2abcde
Barmultra	4	6.1	6.2	3.9	2.0	2.3	1.7	3.7efgh
Ellire	4	7.1	4.6	5.5	2.5	4.6	0.8	4.2cdefg
Florida R. R‡	2	5.5	3.6	4.6	0.5	3.5	1.1	3.1fgh
Biliken	4	10.1	7.8	4.5	1.9	3.9	1.6	5.0abcde
Yamaaoba	2	9.0	6.8	1.2	5.9	1.8	-0.6	4.0defg
Hitachioba	4	7.6	4.8	3.5	0.3	1.6	1.7	3.2fgh
Tetrone	4	8.0	5.8	2.6	1.1	1.6	1.7	3.4fgh
Ace	2	6.0	5.1	3.0	0.8	-1.2	-0.2	2.3h
Futaharu	4	7.5	3.2	3.7	2.4	-0.3	-0.4	2.7gh
Minamiwase	2	8.4	5.2	3.9	1.2	-0.3	-0.4	3.0fgh
Waseyutaka	2	9.5	5.5	0.8	1.8	-0.3	-0.0	2.9fgh
Sakurawase 2	2	10.6	6.2	1.0	0.4	1.3	-0.3	4.3cdef
Rate Means	-	7.6a	5.5b	3.9c	3.0d	2.4d	1.6e	-

† diploid/tetraploid
‡ Florida R. R = Florida Rust Resistant

Table 1.5. Cultivar by fenoxaprop rate interaction for relative fresh-weight of 22 Italian ryegrass cultivars (Whole plant Expt. 1).

Cultivar	PL†	Fenoxaprop (g ha^{-1}) 56	112	168	224	280	Cultivar Mean
	(*n*)	(%of check)					
Marshall	2	72.3	74.8	106.9	53.5	39.0	74.4a
Florida 80	2	100.7	65.6	56.0	47.4	42.4	68.7ab
Gulf	2	57.7	59.5	95.6	53.9	37.5	67.4ab
Barspectra	4	69.9	61.8	75.8	33.7	60.1	66.9ab
Torero	4	67.9	71.6	45.8	46.3	57.5	64.9ab
Promenade	4	79.0	75.0	52.0	62.3	16.0	64.0ab
Lemtal RvP	2	74.7	83.2	40.8	33.0	51.8	63.9ab
Sakurawase 1	2	91.5	61.9	38.7	44.0	44.6	63.4abc
Bartolini	2	107.7	73.7	52.2	48.6	-7.7	62.4abcd
Aubade	4	79.6	55.7	56.6	58.7	13.9	60.7abcde
Barmultra	4	101.0	62.9	31.9	36.8	27.4	60.0abcde
Ellire	4	64.3	77.7	35.3	64.0	11.3	58.8abcde
Florida R. R††	2	66.2	77.5	8.7	64.3	20.4	56.2abcdef
Biliken	4	77.3	44.9	18.6	38.7	15.6	49.2bcdefg
Yamaaoba	2	70.9	13.6	66.0	19.7	-6.5	43.9cdefg
Hitachioba	4	63.2	45.8	3.8	21.7	23.2	43.0defg
Tetrone	4	72.8	26.0	14.4	20.2	21.2	42.5efg
Ace	2	85.6	49.8	13.4	-19.4	-3.3	37.7fg
Futaharu	4	42.1	49.1	32.2	-4.7	-4.2	35.8g
Minamiwase	2	61.7	45.8	14.5	-3.7	-4.6	35.6g
Waseyutaka	2	58.7	9.1	19.2	-2.7	-0.2	30.7g
Sakurawase 2	2	58.6	9.1	3.2	11.9	-3.4	29.9g
Rate Means‡	-	73.8a	54.3b	40.1c	33.1c	20.5d	-

† PL = Ploidy level (diploid/tetraploid)
†† Florida R. R = Florida Rust Resistant
‡ GR_{50} and R^2 for regression on rate means (across replications and cultivars is 129 g ha^{-1} and 99.7%, respectively.

Table 1.6. GR_{50} estimates of 22 Italian ryegrass cultivars treated with five rates of fenoxaprop (Whole plant Expt. 1).

Cultivar	GR_{50}	(# data point)	Apparent no injury rate	R^2
	Fenoxaprop (g ha^{-1})			
Yamaaoba	88	(6)	0	65.9[a]
Ace	82	(6)	0	88.6
Minamiwase	79	(6)	0	97.9
Futaharu	76	(6)	0	87.8
Bartolini	167	(5)	56	89.1[b]
Barmultra	127	(5)	56	96.5
Tetrone	69	(6)	0	80.4
Waseyutaka	47	(6)	0	94.1
Florida 80	197	(5)	56	98.6[c]
Aubade	163	(6)	0	80.9
Ellire	149	(6)	0	64.9
Biliken	95	(6)	0	90.1
Florida Rust Res.	95	(6)	0	44.2
Hitachioba	73	(6)	0	72.8
Torero	241	(6)	0	70.8[d]
Marshall	234	(3)	68	99.9
Gulf	232	(6)	0	34.9
Barspectra	213	(6)	0	66.5
Lemtal RvP	182	(6)	0	73.8
Sakurawase 1	182	(6)	0	87.0
Promenade	180	(6)	0	80.9
Sakurawase 2[e]	48	(6)	0	94.5

[a]Based on GR_{50} computed by regression on relative fresh weight the four cultivars in this group have been classified as susceptible in subsequent experiments.

[b]Four cultivars in this group represent moderately susceptible in subsequent studies.

[c]Cultivars included in this group have been classified as moderately tolerant in subsequent studies.

[d]Cultivars included in this group have been classified as tolerant in subsequent studies.

[e]Sakurawase from 2 lots of Seed Lab. no. 32498 (tolerant) and no. 35813 (susceptible) showed a varying tolerance. Seed from lot 32498 has been used in other tests.

Table 1.7. Cultivar by fenoxaprop rate interaction for flowering rating of 22 Italian ryegrass cultivars (Whole plant Expt. 1).

Cultivar	Fenoxaprop ($g\ ha^{-1}$) 0	56	112	168	224	280	Cultivar Mean†
Marshall	0.2	0.4	0.6	0.8	0.6	0.2	0.47cde
Florida 80	1.0	0.6	0.8	0.4	0.4	0.8	0.73ab
Gulf	0.6	0.0	0.2	0.6	0.6	0.0	0.33de
Barspectra	1.0	0.6	0.4	0.6	0.0	0.0	0.60de
Torero	0.4	0.4	0.8	0.2	0.2	0.2	0.37de
Promenade	0.8	0.2	0.4	0.2	0.0	0.8	0.30ef
Lemtal RvP	0.0	0.0	0.0	0.0	0.0	0.0	0.03h
Sakurawase 1	0.6	0.6	0.6	0.8	0.4	0.4	0.60abc
Bartolini	0.0	0.0	0.0	0.2	0.2	0.0	0.07gh
Aubade	0.0	0.4	0.8	0.6	0.6	0.4	0.53bcd
Barmultra	0.0	0.2	0.0	0.0	0.0	0.0	0.07gh
Ellire	0.0	0.0	0.0	0.0	0.0	0.0	0.00h
Florida R.Res.	1.0	0.6	0.8	0.4	0.4	0.2	0.67abc
Biliken	1.0	0.6	0.8	0.2	0.0	0.0	0.77a
Yamaaoba	0.0	0.0	0.0	0.0	0.0	0.0	0.00h
Hitachioba	0.8	0.4	0.2	0.0	0.0	0.0	0.27efg
Tetrone	0.0	0.0	0.0	0.0	0.0	0.0	0.00h
Ace	0.2	0.0	0.0	0.0	0.0	0.0	0.03h
Futaharu	0.0	0.0	0.0	0.0	0.0	0.0	0.00h
Minamiwase	1.0	0.4	1.0	0.4	0.4	0.4	0.60abc
Waseyutaka	0.2	0.0	0.2	0.0	0.0	0.4	0.10fghy
Sakurawase 2	0.6	0.6	0.8	0.4	0.8	0.4	0.60abc
Rate Means	0.5a	0.3bc	0.4ab	0.3bc	0.3bc	0.2c	-

† 1 = All flowered
0 = No flowering

were analyzed as an indicator variable (1 = flowered and 0= no flowering) by the procedure mentioned above. For computing GR_{50} for each cultivar separately, relative fresh-weight treatment means were subjected to non-linear regression analyses and GR_{50}'s were computed from the regression equation by interpolation.

RESULTS AND DISCUSSION

Whole plant Experiment 1: A wide range of tolerance was registered among the cultivars tested (Table 1). Highly significant statistical differences ($P \leq 0.01$) were found among the cultivars, rates, and their interaction for all the variables studied except for flowering where interaction was merely significant ($P=0.05$) (Tables 1.1 to 1.3). The cultivars varied in their tolerance to fenoxaprop. The variance due to fenoxaprop rates formed the major component of total variability estimates (Table 1.1 to 1.2). However, for flowering, cultivars constituted the major portion of total variance (Table 1.3). In untreated checks, more than twice as much biomass was produced by the most vigorous (Sakurawase 2) than the least vigorous cultivar (Bartolini) (Table 1.4). Comparison of the relative fresh-weight means averaged over five fenoxaprop rates showed that the cultivars Marshall, Florida 80, and Torero, although at par with a few other cultivars, had higher mean relative fresh-weight gains than almost half of the tested cultivars (Table 1.5).

Similarly, the rest of the cultivars varied, but

Table 1.8a. Analysis of variance for relative fresh-weight in four Italian ryegrass cultivars previously classified as susceptible to fenoxaprop (Whole plant Expt. 2).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Cultivar	3	4633.4	1544.5	3.48	0.0199
Rate	4	48026.2	12006.5	27.06	0.0001
Cultivar*Rate	12	5997.5	383.1	0.84	0.5865
Error	76	33724.8	443.7		

Table 1.8b. Analysis of variance for relative fresh-weight in four Italian ryegrass cultivars previously classified as moderately susceptible to fenoxaprop (Whole plant Expt. 2).

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Cultivar	3	129.3	43.1	0.11	0.9569
Rate	4	51897.6	12974.4	31.60	0.0001
Cultivar*rate	12	2873.3	239.4	0.58	0.8492
Error	76	31201.1	410.5		

Table 1.8c. Analysis of variance for relative fresh-weight in six Italian ryegrass cultivars previously classified as moderately tolerant to fenoxaprop (Whole plant Expt. 2).

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Cultivar	5	11837.7	2367.5	4.63	0.0007
Rate	4	68676.2	17169.1	33.60	0.0001
Cultivar*rate	20	11137.8	565.9	1.09	0.3698
Error	114	58257.5	511.0		

Table 1.8d. Analysis of variance for relative fresh-weight in seven Italian ryegrass cultivars previously classified as tolerant to fenoxaprop (Whole plant Expt. 2).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Cultivar	6	17568.3	2928.1	5.41	0.0001
Rate	4	127707.0	31926.8	59.00	0.0001
Cultivar*rate	24	9764.2	406.8	0.75	0.7894
Error	133	71999.0	541.3		

Table 1.9a. Analysis of variance for net fresh-weight in eight Italian ryegrass cultivars (susceptible and moderately susceptible combined) treated with fenoxaprop (Whole plant Expt. 2).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Cultivar	7	119.1	17.0	10.08	0.0001
Rates	3	318.0	106.0	62.85	0.0001
Cultivar*Rate	21	40.9	2.0	1.15	0.3042
Error	120	202.4	1.7		

Table 1.9b. Analysis of variance for relative fresh-weight in eight Italian ryegrass cultivars (susceptible and moderately susceptible combined) treated with fenoxaprop (Whole plant Expt. 2).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Cultivar	7	10261.1	1465.9	3.82	0.0009
Rates	3	69503.0	23167.7	60.31	0.0001
Cultivar*Rate	21	8560.7	407.7	1.06	0.3989
Error	120	46094.4	384.1		

Table 1.10a. Analysis of variance for net fresh-weight in 13 Italian ryegrass cultivars (moderately tolerants and tolerants combined) treated with fenoxaprop (Whole plant Expt. 2).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Cultivar	12	208.3	17.4	8.32	0.0001
Rates	3	735.3	245.1	117.48	0.0001
Cultivar*Rate	36	125.4	3.5	1.67	0.0151
Error	195	406.8	2.1		

Table 1.10b. Analysis of variance for relative fresh-weight in 13 Italian ryegrass cultivars (moderately tolerants and tolerants combined) treated with fenoxaprop (Whole plant Expt. 2).

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Cultivar	12	27071.8	2256.0	4.42	0.0001
Rates	3	169028.6	56342.9	110.30	0.0001
Cultivar*Rate	36	20985.1	583.9	1.14	0.2811
Error	195	99614.6	510.8		

Table 1.11. GR_{50} estimates of 21 Italian ryegrass cultivars at 3-leaf growth-stage (Whole plant Expt. 2).

Cultivar	GR_{50}	(# data points)	Apparent max. no injury rate	R^2
	——Fenoxaprop (g ha^{-1})——			
Sakurawase	67	(5)	0	67.8
Hitachioba	75	(5)	0	99.7
Lemtal RvP	76	(5)	0	75.9
Promenade	76	(5)	0	76.3
Biliken	79	(5)	0	89.5
Ace	80	(5)	0	99.3
Futaharu	85	(5)	0	97.8
Gulf	93	(5)	0	97.6
Waseyutaka	97	(5)	0	92.7
Bartolini	103	(5)	0	92.6
Tetrone	105	(5)	0	96.2
Minamiwase	109	(5)	0	99.2
Barmultra	112	(5)	0	94.7
Yamaaoba	>112	(5)	0	86.1
Barspectra	124	(5)	0	93.8
Marshall	138	(5)	0	99.9
Florida 80	145	(5)	0	85.9
Aubade	164	(5)	0	66.8
Fla Rust Resistant	174	(5)	0	99.2
Ellire	233	(5)	0	55.5
Torero	246	(5)	0	97.6

Table 1.12a. Dose response of net fresh-weight in four Italian ryegrass cultivars previously classified as susceptible to fenoxaprop (Whole plant Expt. 2).

Cultivar	Fenoxaprop (g ha^{-1})					Cultivar Mean
	0	28	56	84	112	
	(g)					
Yamaaoba	7.24	5.77	4.30	3.90	4.11	5.00a
Ace	6.68	4.17	3.53	2.23	0.78	3.43b
Futaharu	6.49	4.31	3.05	2.94	0.95	3.35b
Minamiwase	6.15	3.83	3.54	3.07	2.51	3.73b
Rate Means	6.64	4.52b	3.61c	3.05c	2.10d	-

Table 1.12b. Dose response of net fresh-weight in four Italian ryegrass cultivars previously classified as moderately susceptible to fenoxaprop (Whole plant Expt.2).

Cultivar	Fenoxaprop (g ha^{-1})					Cultivar Mean
	0	56	84	112	168	
	(g)					
Bartolini	8.36	6.51	4.63	3.69	3.44	3.45b
Barmultra	8.36	6.51	4.63	3.69	3.44	5.20a
Tetrone	7.77	6.04	4.20	4.14	2.16	4.74a
Waseyutaka	5.85	4.89	3.00	2.95	1.04	3.41b
Rate Means	6.92a	5.27b	3.74c	3.55c	2.08d	-

Table 1.12c. Dose response of net fresh-weight in six Italian ryegrass cultivars previously classified as moderately tolerant to fenoxaprop (Whole plant Expt. 2).

Cultivar	Fenoxaprop ($g\ ha^{-1}$) 0	84	112	168	224	Cultivar Mean
	(g)					
Florida 80	8.11	4.96	6.29	3.49	2.53	4.95a
Aubade	6.50	4.88	4.46	1.86	3.80	4.21ab
Ellire	5.25	3.08	3.83	2.25	3.41	3.49bc
Florida R. Res.	7.02	4.41	4.06	3.70	3.19	4.44ab
Biliken	5.99	3.63	2.80	0.73	1.28	2.74c
Hitachioba	10.19	4.47	3.90	2.74	2.00	4.43ab
Rate Means	7.15a	4.24b	4.22b	2.71c	2.47c	-

Table 1.12d. Dose response of net fresh-weight in seven Italian ryegrass cultivars previously classified as tolerant to fenoxaprop (Whole plant Expt. 2).

Cultivar	Fenoxaprop ($g\ ha^{-1}$) 0	112	168	224	336	Cultivar Mean
	(g)					
Marshall	5.53	3.06	2.50	1.90	0.97	2.78bc
Gulf	7.15	3.50	2.59	1.05	1.05	2.89bc
Barspectra	7.19	3.84	3.60	1.60	1.85	3.48ab
Torero	6.08	4.78	3.59	3.28	2.42	3.94a
Promenade	6.15	1.90	1.71	0.37	-0.09	1.84d
Lemtal RvP	4.39	2.52	0.88	0.21	0.68	1.63d
Sakurawase	6.30	2.36	1.06	0.88	1.83	2.33cd
Rate Means	6.11a	3.14b	2.74c	1.33d	1.31d	-

Table 1.13a. Dose response of relative fresh-weight in four Italian ryegrass cultivars previously classified as susceptible to fenoxaprop (Whole plant Expt. 2)

Cultivar	Fenoxaprop (g ha^{-1}) 0	28	56	84	112	Cultivar Mean[a]
	(% of check)					
Yamaaoba	100	79.7	59.5	53.8	56.8	68.7a
Futaharu	100	66.3	47.0	45.3	14.6	52.8b
Ace	100	62.4	52.9	33.4	11.7	50.1b
Minamiwase	100	62.3	57.5	50.0	40.9	60.6ab
Rate Means[b]	100a	67.7b	54.2bc	45.6c	31.0d	-

Table 1.13b. Dose response of relative fresh-weight in four Italian ryegrass cultivars previously classified as moderately susceptible to fenoxaprop (Whole plant Expt. 2).

Cultivar	Fenoxaprop (g ha^{-1}) 0	56	84	112	168	Cultivar Mean
	(% of check)					
Bartolini	100	64.7	55.0	59.5	29.4	60.1a
Barmultra	100	77.9	55.4	44.1	41.2	62.2a
Tetrone	100	77.7	54.1	53.4	27.8	61.1a
Waseyutaka	100	83.5	51.3	50.3	17.7	58.9a
Rate Means[c]	100a	75.9b	53.9c	51.8c	29.0c	-

[a]Means in a column or row followed by the same letter do not differ significantly (α=0.05) according to Duncan's multiple range test.

[b]GR_{50} and R^2 for regression averaged over replications and cultivars was 63 g ha^{-1} and 98.5%, respectively.

[c]GR_{50} and R^2 for regression averaged over replications and varieties was 105 g ha^{-1} and 97.3%, respectively.

Table 1.13c. Dose response of relative fresh-weight in six Italian ryegrass cultivars previously classified as moderately tolerant to fenoxaprop (Whole plant Expt. 2).

Cultivar	Fenoxaprop (g ha^{-1})					Cultivar Mean
	0	84	112	168	224	
	(% of check)					
Florida 80	100	61.2	77.6	43.1	31.1	61.0a
Aubade	100	75.4	69.1	29.0	58.8	65.1a
Ellire	100	58.7	72.9	42.9	65.1	66.6a
Florida R. Res.	100	62.7	57.8	52.7	45.5	62.2a
Biliken	100	61.6	47.4	12.4	21.7	46.5b
Hitachioba	100	43.9	38.3	26.9	19.6	43.5b
Rate Means[a]	100a	60.6b	60.5b	40.3c	34.5c	-

Table 1.13d. Dose response of relative fresh-weight in seven Italian ryegrass cultivars previously classified as tolerant to fenoxaprop (Whole plant Expt. 2).

Cultivar	Fenoxaprop (g ha^{-1})					Cultivar Mean
	0	112	168	224	336	
	(% of check)					
Marshall	100	55.4	45.2	34.7	25.7	50.2b
Gulf	100	49.2	36.4	14.8	14.7	40.7bc
Barspectra	100	53.4	50.1	22.3	25.7	48.2b
Torero	100	78.6	59.1	53.9	39.7	64.9a
Promenade	100	30.9	27.8	6.1	-1.4	29.9c
Lemtal RvP	100	57.3	20.1	4.8	15.5	37.0bc
Sakurawase	100	37.5	16.8	14.0	29.1	36.9bc
Rate Means[b]	100a	51.8a	36.5b	21.5c	21.3d	-

[a] GR_{50} and R^2 for regression averaged over replications and varieties was 131 g ha^{-1} and 98.3%, respectively.

[b] GR_{50} and R^2 for regression averaged over replications and varieties was 99 g ha^{-1} and 98.3%, respectively.

Table 1.14a. Dose response of net fresh-weight in eight Italian ryegrass cultivars previously classified as susceptible and moderately susceptible to fenoxaprop (Whole plant Expt. 2).

Cultivar	Fenoxaprop (g ha^{-1}) 0	56	84	112	Cultivar Mean
	(g)				
Yamaaoba	7.24	4.30	3.90	4.11	4.77bc
Ace	6.68	3.53	2.23	0.78	3.13e
Futaharu	6.49	3.05	2.94	0.95	3.19de
Minamiwase	6.15	3.54	3.07	2.51	3.70de
Bartolini	8.36	6.51	4.63	3.69	3.87de
Barmultra	8.36	6.51	4.63	3.69	5.66a
Tetrone	7.77	6.04	4.20	4.14	5.41ab
Waseyutaka	5.85	4.89	3.00	2.95	4.08cd
Rate Means	6.78a	4.44b	3.39c	2.81c	-

Table 1.14b. Dose response of relative fresh-weight in eight Italian ryegrass cultivars previously classified as susceptible and moderately susceptible to fenoxaprop (Whole plant Expt. 2).

Cultivar	Fenoxaprop (g ha^{-1}) 0	56	84	112	Cultivar Mean
	(g)				
Yamaaoba	100	59.5	53.8	56.8	65.8a
Futaharu	100	47.0	45.3	14.6	49.2b
Ace	100	52.9	33.4	11.7	46.8b
Minamiwase	100	57.5	50.0	40.9	60.1ab
Bartolini	100	64.7	55.0	59.5	68.2a
Barmultra	100	77.9	55.4	44.1	67.7a
Tetrone	100	77.7	54.1	53.4	69.8a
Waseyutaka	100	83.5	51.3	50.3	69.8a
Rate Means	100a	65.1b	49.8c	41.4c	-

Table 1.15a. Dose response of net fresh-weight in 13 Italian ryegrass cultivars previously classified as moderately tolerant and tolerant to fenoxaprop (Whole plant Expt. 2).

Cultivar	Fenoxaprop (g ha^{-1})				Cultivar Mean
	0	112	168	224	
	(g)				
Florida 80	8.11	6.29	3.49	2.53	4.95a
Aubade	6.50	4.46	1.86	3.80	4.02abc
Ellire	5.25	3.83	2.25	3.41	3.60bc
Florida R. Res.	7.02	4.06	3.70	3.19	4.36ab
Biliken	5.99	2.80	0.73	1.28	2.51de
Hitachioba	10.19	3.90	2.74	2.00	4.42ab
Marshall	5.53	3.06	2.50	1.90	3.13cd
Gulf	7.15	3.50	2.59	1.05	3.38bcd
Barspectra	7.19	3.84	3.60	1.60	3.89bc
Torero	6.08	4.78	3.59	3.28	4.35ab
Promenade	6.15	1.90	1.71	0.37	2.34de
Lemtal RvP	4.39	2.52	0.88	0.21	1.87e
Sakurawase	6.30	2.36	1.06	0.88	2.46de
Rate Means	6.59a	3.64b	2.36c	1.96c	-

Table 1.15b. Dose response of relative fresh-weight in 13 Italian ryegrass cultivars previously classified as moderately tolerant and tolerant to fenoxaprop (Whole plant Expt. 2).

Cultivar	Fenoxaprop (g ha^{-1}) 0	112	168	224	Cultivar Mean
	(% of check)				
Florida 80	100	77.6	43.1	31.1	61.0abc
Aubade	100	69.1	29.0	58.8	62.3abc
Ellire	100	72.9	42.9	65.1	68.7ab
Florida R. Res.	100	57.8	42.7	45.5	62.1abc
Biliken	100	47.4	12.4	21.7	42.5de
Hitachioba	100	38.3	26.9	19.6	43.3de
Marshall	100	55.4	45.2	34.7	56.6abcd
Gulf	100	49.2	36.4	14.8	47.5cde
Barspectra	100	53.4	50.1	22.3	54.1bcde
Torero	100	78.6	59.1	53.9	71.5a
Promenade	100	30.9	27.8	6.1	38.1e
Lemtal RvP	100	57.3	20.1	4.8	42.7de
Sakurawase	100	37.5	16.8	14.0	39.0e
Rate Means	100a	55.8b	35.6c	30.2c	-

cultivars Sakurawase 2, Waseyutaka, Minamiwase, Futaharu, and Ace emerged as the most susceptible to fenoxaprop application, actually losing fresh-weight at the highest fenoxaprop rates. When averaged across the cultivars, relative net fresh-weight gain declined with each increment of fenoxaprop (Table 1.5). The depression in relative fresh-weight was not as drastic in tolerant cultivars, like Marshall, as in the susceptible, including Sakurawase 2, Ace, and Futaharu (Table 1.5).

Flowering also varied with the cultivars. The cultivar Biliken flowered the most (Table 1.7). The cultivars Ace, Tetrone, Yamaaoba, and Futaharu almost entirely failed to flower and were among the susceptible group. Conversely, the cultivars Lemtal RvP, Ellire, and Barmultra fell among the tolerant group, but flowered little, while the most susceptible cultivar, Sakurawase 2 flowered profusely.

To further characterize the cultivars, individual GR_{50} values are computed by using regression analysis of dose-response curves for each cultivar (Table 1.6). Response of cultivars to fenoxaprop as measured by estimates of GR_{50} was similar to the response as measured by growth in proportion to the check (Table 1.5).

About half of the cultivars included in the studies were tetraploids, and about half were diploids (Table 1.4 and 1.5). There was no distinct relationship between ploidy level and tolerance. The tetraploids generally produced higher biomass (Table 1.4) than the diploids, one exception was Sakurawase 2 which, although it was a diploid, outyielded all the cultivars in fresh-weight. On the other hand, the tetraploid Promenade was not very vigorous. Absence of a clear pattern can further be seen where the diploid Marshall was the most tolerant while the tetraploid Futaharu emerged as the least tolerant cultivar.

Whole plant Experiment. 2. Based on the preliminary test (GR_{50} values), the 22 cultivars were divided into four groups according to their fenoxaprop tolerance; susceptible were assigned to lower rates, while the tolerants were subjected to the higher rates of fenoxaprop. Each group of cultivars was analyzed separately, and the two more susceptible groups as well as the two more tolerant groups were analyzed on common rates.

The behavior of the cultivars within each tolerance group (Table 1.8a-1.8d) was almost the same as in the earlier experiment (Table 1.1-1.2). However, the analyses of variance in the later trials showed non-significant interactions between cultivars and herbicide rates in all four groups. Moreover, even cultivars were not different in Group 2 (Table 1.8b). In the merged groups on common rates (Tables 1.10a and 1.10b), the cultivars and rates showed highly significant differences, whereas the interaction of cultivars with fenoxaprop rates was only significant (P=0.05). The main effects and the interaction (Tables 1.11a to 1.15b) exhibited similar trends as in Expt. 1 (Table 1.3 to 1.4). The GR_{50}

range (Table 1.9) showed a depression in over all values regardless of cultivar. This may have occurred because of application of fenoxaprop at a slightly earlier growth-stage, because winter rather than a summer growing period, and because the difference in ambient temperature at the treatment time outside the greenhouse. Most of the better performing cultivars maintained their superiority in these trials, however.

Where phytotoxic symptoms occurred, they included stem and leaf necrosis, chlorosis of younger leaves, and darkening of older leaves. These symptoms are typical of herbicides that inhibit fatty acid biosynthesis, including fenoxaprop (4, 15, 16, 28, 30, 39). Because visual phytotoxicity rating and percentage reduction in fresh-weight are well correlated only fresh-weight was used for screening tolerance among the cultivars we studied.

The difference in inter- and intraspecific tolerance to xenobiotic chemicals (chemicals that are "foreign" to or usually not found in organisms) frequently has been reported (3, 5, 6, 7, 10, 24, 29, 37, 46). For fenoxaprop, the active isomer (R isomer) is more than twice as active as the commercial formulation (mixture of R and S isomers) on cool-season grasses (35). We found a continuum from the most tolerant to the most susceptible cultivar. Similar results have been obtained for *Lolium sp.* and allied genera (2, 3, 5, 6, 7, 10, 13, 18) for a variety of herbicides, and for fenoxaprop (3, 4, 13, 16, 25, 30, 32, 34, 39). The response of fresh-weight to various application rates of fenoxaprop agrees with the earlier studies (2, 10, 26, 43). Butler and Appleby (9) found an enormous difference between red fescue and bentgrass tolerance to sethoxydim--400, 1400, and 12,900 times greater in red fescue in field, greenhouse, and laboratory studies, respectively. For soybean, a ratio of 1:100 was found between susceptible and tolerant cultivars (11) to bentazon. Other literature, however, presents almost no difference in tolerance to BAS 9052 OH, CGA-82725, and RO-13-8895, among soybean cultivars (24). We found only a 6-fold difference between the least and most susceptible Italian ryegrass cultivars for fenoxaprop. This magnitude is analogous with the work reported for rice (40) and ryegrass (46).

The most vigorous cultivars have been reported as the most tolerant in various studies (18, 45). Our findings are only in partial agreement with these reports. Higher ploidy level has been advocated as contributory towards the tolerance of genotypes to herbicides (1, 18, 19). Our studies revealed no clear pattern based on ploidy level. Evans et al. (17) also did not support the higher tolerance in tetraploid as compared to diploid perennial and Italian ryegrass cultivars. Differential herbicide tolerance has been attributed to a differential uptake in wheat (12), barley (40), and other grasses (14). But such a tolerance even in other barley and wheat cultivars was assigned to rapid metabolism in tolerant cultivars (22, 23). Moreover, along with rapid metabolism, differential uptake and translocation was presented as the cause of tolerance in soybean (11). In many cases tolerance has been attributed to a varying target site (42).

The differential tolerance among cultivars indicates that adequate application rates of fenoxaprop (168 g ha^{-1}) to control prevailing weeds in Italian ryegrass are harmless to some cultivars, but detrimental to others. In light of our preliminary studies and the reported field injury on the cultivar Tetrone, the Horizon I EC®[a] (fenoxaprop) registration label was revised in late 1988 to reflect these differences in varietal response to fenoxaprop (25, 34). Unlike for other grass-seed crops, recommendation was specified only for Marshall, Gulf, Promenade, and Barspectra Italian ryegrass cultivars. The genetic variability existing in the form of differential tolerance among the cultivars has already been exploited in evolution of paraquat-tolerant *Lolium perenne*, and forage-type and amenity cultivars of grasses tolerant to dalapon, aminotriazole, and glyphosate (18, 19, 20, 27).

[a]Hoechst-Roussel Agri-Vet Co., Crop Protection Unit, Somerville, NJ 08876-1258. Mention of a commercial or proprietary product does not constitute an endorsement of this product by Oregon State University, Corvallis.

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Chapter 2.

Effect of Growth Stage On the Tolerance of Italian Ryegrass *(Lolium multiflorum)* Cultivars to Fenoxaprop[1]

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Abstract. After discovery of differential tolerance among 22 Italian ryegrass cultivars to fenoxaprop in preliminary studies, trials were established under greenhouse conditions to further investigate the magnitude of the differential tolerance as affected by age. Differential tolerance among the ten cultivars at the 2- and 4-leaf growth-stages was assessed. Based on the GR_{50} estimates and relative fresh-weight means, the cultivars 'Marshall', 'Gulf', and 'Torero' emerged as the most tolerant, while 'Futaharu' and 'Ace' as the least tolerant to fenoxaprop. The difference in level of tolerance between the least susceptible 'Marshall' and the most susceptible 'Futaharu' was about 4-fold. Tolerance to fenoxaprop at the 4-leaf stage was twice that at the 2-leaf stage. The increasing tolerance with age however, was not proportionate among all the cultivars. The evaluated

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tolerance among the cultivars at different ages will be helpful in making weed management decisions in Italian ryegrass. Nomenclature: Fenoxaprop[4], (±)-2-[4-[(6-chloro-2-benzoxazolyl)oxy]phenoxy]propanoic acid; Italian ryegrass, *Lolium multiflorum* Lam. #[5] LOLMU.

Additional index words. Postemergence, fresh-weight, GR_{50}, susceptibility, 2-leaf stage, 4-leaf stage.

INTRODUCTION

Adapted to poorly drained and marginal fertility soils Italian ryegrass is one of the most important grass seed crops of Willamette Valley of Oregon. It exceeds all others in acreage and ranks third in dollar value of the crops grown for seed in this area (Miles, 1992). As most of the crop is grown for seed, weed infestations need to be minimized. Fenoxaprop, an aryloxyphenoxypropionate, was registered in 1987 in Oregon (Anon. 1987) for selective weed control in Italian ryegrass, perennial ryegrass *(L. perenne* L. # LOLPE*)*, fine fescue *(Festuca rubra* L. # FESRU*)*, and tall fescue *(F. arundinacea* Schreb. # FESAR*)*. But the tolerance among Italian ryegrass

[4]*Mention of trademark or proprietary product does not constitute a guarantee or warranty of the product by Oregon State University and does not imply its approval to the exclusion of other products that may be equally suitable.*

[5]*Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989, Available from WSSA, 309 W. Clark Street, Champaign, IL 61820.*

cultivars proved to be variable and several fields of cultivar 'Tetrone' were severely injured (Dave Mehija, Hoechst-Roussel, 1988 personal communication).

Fenoxaprop was discovered by Hoeschst AG Frankfurt, Germany (Beringer et al., 1982). It is a herbicide of choice in controlling warm season grasses in dicotylenodous or grass crops (Matalcosy et al., 1988; Beringer et al., 1982; Peters et al., 1989; Palmer and Read, 1991). Its short half life in soil, which only is a few days (Gillespie and Nalewaja, 1986; Kōcher et al., 1982; Wink and Luley, 1988; Toole and Crosby, 1989), renders it environmentally safe in its foliar applications. In aryloxyphenoxypropanoic acid herbicides, the nature of the aryl group and its substituents confers both the activity and the spectrum of weeds controlled. The molecules of these herbicides exist as mirror images or enantiomers. The commercial synthesis results in a mixture of R (active) and S (inactive) enantiomers known as a racemate. Fenoxaprop-ethyl is a racemate, but its active enantiomer is twice as active as the racemate (Huff et al., 1989; Beringer et al., 1989; Mueller-Warrant, 1992). The active isomer is referred to as fenoxaprop-P-ethyl. Addition of auxin type herbicides and other safeners into fenoxaprop formulations has enabled their use in various cereals, including wheat, rye, and triticale (Beringer et al., 1989; Huff et al., 1989). Fenoxaprop has shown its value as a weed killer in rice (Snipes at al. 1987), red fescue (Wyse, et el., 1985), tall fescue (McCarty et al., 1989; Peters et al., 1989), Italian ryegrass (Anon., 1987), perennial ryegrass (Dernoden, 1987; Mueller-Warrant and Brewster, 1986; Mueller-Warrant, 1990; Mueller-Warrant, 1992; Neal et al., 1990), soybean (Schumacher et al., 1982; Winton-Daniels, 1990), alfalfa (Linscott et al., 1990), orchardgrass (Linscott et al., 1990) and Kentucky bluegrass (Reicher and Christians, 1989).

For selective weed control in crops, the objective is to find the best combination of relatively susceptible growth-stages of weeds, and relatively tolerant growth-stage of the crop. Even if a herbicide affects the crop adversely, the impact on yield under weedy conditions still needs to be evaluated. Our studies carried out during 1988 and 1989 on the tolerance of 22 and 21 Italian ryegrass cultivars, respectively, revealed that the overall behavior of all the cultivars to fenoxaprop was not the same during two years of study. Speculated causes for this discrepancy include the slightly earlier growth-stage timing of the application of fenoxaprop during 1989, temporal differences in application timing, or both. The application of fenoxaprop was made 26 days after planting in 1988 but only 17 days after planting during 1989. Hence, the response of cultivars at different growth-stages of the crop was worth studying. Moreover, the study of the response of the crop at various growth-stages is also important because fenoxaprop, like other graminicides, is only effective in postemergence application to weeds and effectively controls some weeds even in advanced stage of growth (Beringer et el., 1982; Kōcher et el., 1982; Beringer at al., 1989). Therefore, the knowledge of the tolerance of a crop at its various developmental stages is of utmost importance. Many other workers have also reported the enhanced tolerance with advanced age (Kells et el., 1984; Grichar and Boswell, 1986; Derr et el., 1985; Anderson and Nielsen, 1991; Warren et el., 1989). On the other hand, some findings show susceptibility at certain later stages of growth particularly in cereals (Olson et el., 1951; Mohan et el., 1989). The objectives of these studies were: a) to quantify the tolerance of Italian ryegrass cultivars to fenoxaprop, b) quantify the tolerance at different growth-stages, and c) evaluate the proportionate behavior of tolerance among the Italian ryegrass cultivars.

MATERIALS AND METHODS

Whole Plant Experiment 3. The trials were planted during second week of January, 1990. Fenoxaprop was applied on 26 January, 1990, for the first growth-stage and on 22 February, 1990, for the second growth-stage. The production regime under greenhouse conditions was the same as detailed for the Expt. 1 (Chapter I). The experiments consisted of a factorial arrangement of treatments with two application timings (growth-stages) at 2-leaf and 4-leaf stages as one factor, 8 rates of fenoxaprop (including three checks) as the second factor, and ten Italian ryegrass cultivars as the third factor. Each treatment was replicated three times. The range of rates of fenoxaprop was different for each tolerance group based on previous findings. The most susceptible group included 2 cultivars, viz. Ace and Futaharu, which were treated with fenoxaprop rates including 28, 56, 112, 168, 224, and 280 g ai ha^{-1}. The intermediate group included Waseyutaka, Barmultra, and Tetrone. The cultivars included in this group were subjected to fenoxaprop at 56, 112, 168, 224, and 280 g ha^{-1}. The cultivars representing the most tolerant group were Aubade, Torero, Gulf, Marshall, and Sakurawase. These cultivars received 56, 112, 168, 280, and 448 g ha^{-1} of fenoxaprop. Moreover 3 checks were also included in each trial. One of these checks was harvested at the time of fenoxaprop treatment at each date of application, to establish a bench mark fresh-weight for each of the cultivars. The other two checks were harvested at the time of actual harvesting of the experiments, for recording the relative fresh-weight values for each of the cultivars. The mean of the two checks for fresh and dry-weights was used for computing relative fresh (R. Fwt) and dry-weight (R. Dwt) as described by Morrison and Maurice (1984) for all the treatments included in the tests as under:

$$R.\ Fwt = \frac{Fwt_t - Fwt_0}{Fwt_c - Fwt_0} \times 100$$

where:

Fwt_0 = fresh-weight per pot at the time of spraying

Fwt_t = fresh-weight per pot of treatment at final harvest

Fwt_c = mean fresh-weight per pot of check (mean of 2 checks) at final harvest.

$$R.\ Dwt = \frac{Dwt_t - Dwt_0}{Dwt_c - Dwt_0} \times 100$$

where:

Dwt_0 = dry-weight per pot at the time of spraying

Dwt_t = dry-weight per pot of treatment at final harvest

Dwt_c = mean dry-weight per pot of check (mean of 2 checks) at final harvest.

At the time of treatment with fenoxaprop each pot contained 7 plants. Plants were cut at 1 cm height for recording per pot fresh-weight. In addition to fresh-weight, dry-weight data were also recorded for each treatment after drying the plants in an oven for each of the treatments in all the three trials. The ANOVA was run on net and relative fresh and dry-weight data by using the SAS® computer program. Subsequently the differences among the means were established by using Duncan's multiple range test (SAS/STAT™, 1989). GR_{50} (g ha^{-1} fenoxaprop required to reduce the post-treatment fresh or dry-weight by 50% as compared to a check) were computed for relative fresh and dry-weight of each variety separately, by running non-linear regression on means for relative fresh and dry-weight.

Whole Plant Experiment 4. The whole plant experiment 3 referred to above was repeated during summer, 1990. The experiment hereafter referred to as 'whole plant experiment 4' was planted on 6 June, 1990. This also included 10 Italian ryegrass cultivars. A factorial arrangement of growth-stages, varieties, and fenoxaprop rates, was used in Expt. 4, with each treatment replicated three times. But, in light of results from the whole plant experiment 3, tolerance grouping was slightly restructured. All but Gulf, Marshall, and Torero were assigned to the same group and were treated with 28, 56, 84, 112, 168, 224, and 336 g ha^{-1} of fenoxaprop. The tolerant group consisting of Gulf, Marshall and Torero, was subjected to 56, 112, 168, 224, 280, 336, and 448 g ha^{-1} of fenoxaprop. In addition to fenoxaprop treatments, three checks were included in both of the trials in the same way as mentioned for Expt. 3. The plants were treated with fenoxaprop on 13 July, 1990 for the 2-leaf and on 6 August, 1990, for the 4-leaf growth-stage. Like the previous experiment, each pot at the time of fenoxaprop application had 7 plants in it. Plants were harvested for recording the fresh-weight data on 20 August, 1990 for the first growth-stage and 19 September, 1990 for the second growth-stage. Apart from recording the per pot fresh data for the two growth-stages, data were also recorded on flowering at the time of harvesting of the experiment only for the second growth-stage. A 0-4 scale was established for recording the flowering data, zero representing no flowering, with 4 showing all plants flowered in a pot. Relative fresh-weight (R. Fwt), GR_{50}, and ANOVA were employed as reported in Expt. 3. The analyses of the data were also performed by running ANOVA on the combined data for all the varieties on common rates.

Whole Plant Experiment 5. The response of Italian ryegrass cultivars to fenoxaprop as affected by age of the plants was further investigated by partially repeating the experiment for a third time. In contrast to the previous experiments, instead of planting all the plants at the same time and treating them at appropriate growth-stages on different calendar dates, periodic planting was done to attain the required growth-stages simultaneously, when fenoxaprop was applied to all the treatments at the same time. Only five Italian ryegrass cultivars were included in this experiment. Moreover, three growth-stages were employed in these studies as opposed to two stages in the previous two experiments. The cultivars Ace, Futaharu, and Aubade were treated with 28, 56, 84, 112, 196, and 280 g ha^{-1} fenoxaprop, while the previously classified tolerant cultivars Gulf and Marshall were subjected to 56, 84, 112, 168, 196, and 448 g ha^{-1} fenoxaprop. Like previous experiments, three checks were also included in addition to the fenoxaprop rates in each trial. The planting in the greenhouse was done on 6 July, 21 August, and 6 September, 1990, for 2-leaf, 4-leaf, and tillering growth-stages, respectively, when treatments were applied on 21 July, 1990. Each treatment consisted of a single pot having five plants. For recording the fresh-weight data, the trials were harvested on 27 October, 1990. The recording of data and the analysis was performed in the way as described for whole plant experiment 3.

RESULTS AND DISCUSSION

Whole Plant Experiment 3. Based on the previous results, the 10 Italian ryegrass cultivars under study were sub-divided into three groups, and treated with an overlapping series of fenoxaprop rates based on the previously evaluated tolerance level. The cultivars were compared on the basis of relative fresh and dry-weights. Differences among the cultivars were only observed within the tolerant group (Table 2.3a and 2.3b). Differences occurred among rates and rate by growth-stage interaction in almost all three trials (Table 2.1a-2.3b). However, the combined analysis of variance for fresh-weight for all the cultivars on common rates showed significant differences ($P \leq 0.01$) for cultivars and their interaction with rate, growth-stage, and significant ($P=0.05$) third order interaction with rate x growth-stage (Table 2.4a). However, for relative dry-weight, both the 2-way interaction of cultivar with fenoxaprop rate and also the 3-way interaction of cultivar with growth-stage and fenoxaprop rate were non-significant (Table 2.4b). Tolerance of cultivars as evaluated with the GR_{50} criterion (Table 2.5a-2.5b) varied with the cultivars, and typically increased with advancement in age.

Marshall, Gulf, and Torero emerged as the most tolerant, whereas Futaharu and Ace were the most susceptible. The most tolerant Marshall was more than 4-fold as tolerant as the least tolerant, Futaharu, at the 2-leaf stage. In general, higher GR_{50} values were computed for dry-weight as compared to fresh-weight gain. But, the fresh-weight values appear closer to the visual observations in the greenhouse (data not reported). The mean GR_{50} for cultivars was 2.2 times higher at 4-leaf than at the 2-leaf growth-stage of Italian ryegrass. The interaction of cultivars with the growth-stage (Table 2.5a and 2.5b) shows that increase in tolerance was not proportionate for all the cultivars. Only small gains in tolerance are observed in Tetrone and Sakurawase, whereas a static response was observed for Barmultra and Aubade. The highest gain in tolerance (>3 times) was observed for Marshall, as the crop progressed from 2-leaf to the 4-leaf stage.

The main effects for cultivars, growth-stages, and rates for fresh- and dry-weight are detailed in Tables 2.6a-2.9c. A drastic reduction in relative fresh-weight was noticed as the rates of fenoxaprop were elevated from 28 to 280 g ha^{-1} for the susceptible group (Table 2.6a). For the moderately susceptible and the tolerant groups, the decline in relative fresh and dry-weight was more gradual with the ascending rates (Table 2.7a, 2.8a) than in the susceptible group. A similar difference exists between rate response patterns for the moderately susceptible and the tolerant group. The GR_{50} on a fresh-weight basis for the tolerant group averaged over cultivars was twice as high (Table 2.8a) as computed for the susceptible group (Table 2.6a).

The main effect of cultivars for the three tolerance groups are given in Table 2.6b, 2.7b, and 2.8b. Since cultivars having a similar response to fenoxaprop were grouped together, the cultivars lack any differences in the susceptible (Table 2.6b) and moderately susceptible group (Table 2.7b). However, in the tolerant group (Table 2.8b) the cultivars Aubade and Sakurawase were similar to each other, but could be separated from the other three tolerant cultivars. When the analysis was run only on the common rates to all cultivars (Table 2.9a), the tolerant cultivars Gulf, Marshall, and Torero, having the similar response to fenoxaprop among themselves, could be separated from the other cultivars included in the trials. The behavior of the remaining cultivars was somewhat variable, but the Futaharu and Ace were the most susceptible.

The main effects for growth-stage for the three groups are presented in Table 2.6c, 2.7c, and 2.8c, respectively. All the groups show a pronounced increase in tolerance to fenoxaprop with increased age. Similar response due to growth-stage was displayed in the combined analysis (Table 2.9c). The 2-way interaction of cultivar with fenoxaprop rate and growth-stage (Table 2.10a, 2.10b) corroborates the interaction of cultivars with growth-stage and fenoxaprop rates evaluated with GR_{50} estimates (Table 2.5a,2.5b).

The 3-way interaction of growth-stage, cultivar, and fenoxaprop rates (Table 2.11a-2.11b) shows very pronounced differences between the groups and cultivars at different growth-stages and rates. The cultivars in the susceptible group (Ace and Futaharu), despite the gain in tolerance from 2- to the 4-leaf growth-stage, failed to attain any growth in fresh-weight at either of the growth-stages after fenoxaprop application rate of 168 g ha^{-1} (Table 2.11a). In the moderately tolerant or the intermediate group (Table 2.12a), the decline in growth was not as severe as in the susceptible group. The cultivars Tetrone and Barmultra continued growth even at the highest dose of fenoxaprop (280 g ha^{-1}) at the 2-leaf stage, but interestingly tolerance dwindled as they grew older. Conversely, in the same group, Waseyutaka gained tolerance with age. The tolerant group conspicuously shows continued growth even at the highest fenoxaprop rate and younger growth-stage (Table 2.13a) except the relatively susceptible Sakurawase and Aubade. The tolerant cultivars Gulf and Marshall gained tolerance substantially as they grew older. For the 3-way interaction for dry-weight (Table 2.11b-2.13b), the overall values are higher but the pattern among the treatments stays the same as for the relative fresh-weight.

Whole plant experiment 4. The whole plant experiment 4 was carried out during summer, 1990. Due to favorable growth conditions in terms of solar radiation, intraspecific competition within pots and between the rows on benches confounded the observations due to treatments. Dry-weight data were not recorded for these studies. With some exceptions the results endorse the findings of Expt. 3. The analysis of variance for the susceptible group (Table 2.14a) shows the variation in net fresh-weight to be significant ($P<0.01$) for all the sources of variation except the interaction of cultivars with rate, and the 3-way interaction of cultivar by rate by growth-stage. The behavior of the cultivars was not exactly the same as in Expt. 3, because the groups were restructured in this trial. No effect of fenoxaprop rates could be detected on flowering of plants (Table 2.14c). The combined analysis presented in Table 2.15a and 2.15b shows a similar behavior of the sources of variation as in whole plant experiment 3.

The plants which could overcome the complete kill by fenoxaprop grew luxuriantly, due to very favorable growth conditions. The GR_{50} estimates (Table 2.16) exhibit similar behavior of cultivars as had been seen in whole plant experiment 3. For example the cultivar Futaharu emerged as the most susceptible at both the growth-stages under study, while the tolerant cultivars maintained their superiority. As GR_{50} for the tolerant cultivars was not estimable (lying outside the range of the data set), it is difficult to assess the most tolerant cultivars with GR_{50} criterion.

The fenoxaprop main effects (Table 2.17a) shows a trend toward hormaesis up to 56 g ha^{-1} of fenoxaprop application but it is not statistically significant. No differences among the rates were detected for flowering at 4-leaf stage. The main effect of cultivar (Table 2.17b) depicts Futaharu and Ace as the most susceptible cultivars. The cultivars Barmultra, Ace, and Futaharu did not flower at all (Table 2.17b). The main effect of growth-stage does not show as wide a gap between the 2-leaf and the 4-leaf growth-stage (Table 2.17c) as in our previous studies, due to favorable growth conditions and onset of competition. The 3-way interaction of cultivars with growth-stages and fenoxaprop rates manifests the susceptibility of Ace and Futaharu to fenoxaprop application at 2-leaf stage (Table 2.18). There is an abrupt decline in Futaharu after the application of as low as 56 g ha^{-1} fenoxaprop. However, Ace died down after 84 g ha^{-1}, whereas at 2-leaf stage in rest of the five cultivars, Aubade and Sakurawase were not suppressed by any rate of fenoxaprop to the extent of 50%, while Barmultra, Tetrone and Waseyutaka were depressed to 50% level at the highest rate of fenoxaprop (336 g ha^{-1}). Like the previous experiment, Barmultra and Aubade did not gain tolerance with older age, but Tetrone did improve its tolerance with transition from 2- to the 4-leaf stage of growth.

For the tolerant group consisting of Gulf, Marshall, and

Table 2.1a. Analysis of variance for relative fresh-weight in Ace and Futaharu Italian ryegrass previously classified as susceptible to fenoxaprop at 2 growth-stages (Whole plant Expt. 3).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Cultivar	1	1122.2	1122.2	1.98	0.1640
Rate	6	179999.1	29999.8	52.81	0.0001
Cultivar*rate	6	3787.1	631.2	1.11	0.3641
Stage	1	8435.6	8435.6	14.85	0.0002
Cultivar*stage	1	120.6	120.6	0.21	0.6462
Rate*stage	6	18459.4	3076.6	5.42	0.0001
Cultivar*stage*rate	6	646.0	578.5	1.02	0.4198
Error	68	38563.3	567.1		

Table 2.1b. Analysis of variance for relative dry-weight in Ace and Futaharu Italian ryegrass previously classified as susceptible to fenoxaprop at two growth-stages (Whole plant expt. 3).

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Cultivar	1	343.1	343.1	2.15	0.1465
Rate	6	77445.4	12907.6	80.99	0.0001
Cultivar*rate	6	569.3	94.9	0.60	0.7330
Stage	1	39729.3	39729.3	249.35	0.0001
Cultivar*stage	1	145.5	145.5	0.91	0.3425
Rate*stage	6	13844.8	2307.5	14.48	0.0001
Cultivar*stage*rate	6	646.8	107.7	0.66	0.6845
Error	68	11147.3	163.9		

Table 2.2a. Analysis of variance for relative fresh-weight in Barmultra, Waseyutaka, and Tetrone Italian ryegrass previously classified as moderately susceptible to fenoxaprop at two growth-stages (Whole plant Expt. 3).

Source	DF	Sum of Squares	Mean Squares	F value	Pr>F
Cultivar	2	1111.4	555.7	1.01	0.3691
Rate	5	179314.3	35862.9	64.97	0.0001
Cultivar*rate	10	2730.7	273.1	0.49	0.8898
Stage	1	2504.8	2504.8	4.54	0.0356
Cultivar*stage	2	2692.7	1346.3	2.44	0.0925
Rate*stage	5	2871.2	574.2	1.04	0.3983
Cultivar*stage*rate	10	4745.1	474.5	0.85	0.5858
Error	89	48898.0	560.7		

Table 2.2b. Analysis of variance for relative dry-weight gain in Barmultra, Waseyutaka, and Tetrone Italian ryegrass previously classified as moderately susceptible to fenoxaprop at two growth-stages (Whole plant Expt. 3).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Cultivar	2	1166.1	583.0	1.77	0.1755
Rate	5	92633.9	18526.8	56.27	0.0001
Cultivar*rate	10	1056.2	105.6	0.32	0.9740
Stage	1	23418.6	23418.6	71.13	0.0001
Cultivar*stage	2	1397.0	698.5	2.12	0.1253
Rate*stage	5	15059.8	3012.0	9.15	0.0001
Cultivar*stage*rate	10	925.0	92.5	0.26	0.9881
Error	89	31669.4	355.8		

Table 2.3a. Analysis of variance for relative fresh-weight in Aubade, Gulf, Marshall, Sakurawase, and Torero Italian ryegrass previously classified as tolerant to fenoxaprop at two growth-stages (Whole plant Expt. 3).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Cultivar	4	13153.8	3288.5	7.52	0.0001
Rate	6	242730.3	40455.0	92.56	0.0001
Cultivar*rate	24	9964.1	415.2	0.95	0.5345
Stage	1	19945.2	19945.2	45.63	0.0001
Cultivar*stage	4	2766.6	691.6	1.58	0.1805
Rate*stage	6	15769.7	2628.3	6.01	0.0001
Cultivar*stage*rate	24	9523.1	396.8	0.90	0.6071
Error	169	74834.4	442.8		

Table 2.3b. Analysis of variance for relative dry-weight in Aubade, Gulf, Marshall, Sakurawase, and Torero Italian ryegrass cultivars previously classified as tolerant to fenoxaprop at two growth-stages (Whole plant Expt. 3).

Source	DF	Sum of Squares	Sum of Squares	F Value	Pr>F
Cultivar	4	4175.8	1043.9	4.00	0.0038
Rate	6	165575.8	27595.9	105.82	0.0001
Cultivar*rate	24	3762.9	156.8	0.60	0.9292
Stage	1	45687.1	45687.1	175.19	0.0001
Cultivar*stage	4	26.0	6.5	0.02	0.9988
Rate*stage	6	28105.4	4684.2	17.96	0.0001
Cultivar*stage*rate	24	4404.6	183.5	0.68	0.8706
Error	169	45927.4	271.8		

Table 2.4a. Combined analysis of variance for relative fresh-weight in 10 Italian ryegrass cultivars previously classified into different tolerance groups on six common rates of fenoxaprop at two growth-stages (Whole plant Expt. 3).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Cultivar	9	38586.6	4287.4	8.56	0.0001
Rate[a]	5	498519.3	99703.9	198.95	0.0001
Cultivar*rate	45	36348.3	807.7	1.61	0.0111
Stage	1	20288.3	20288.3	40.48	0.0001
Cultivar*stage	9	7661.3	851.3	1.70	0.0887
Rate*stage	5	9333.8	1866.8	3.73	0.0028
Cultivar*stage*rate	45	34474.3	766.1	1.53	0.0213
Error	298	149339.8	501.1		

Table 2.4b. Analysis of variance for relative dry-weight in 10 Italian ryegrass cultivars previously classified into different tolerance groups at six common rates of fenoxaprop at two growth-stages (Whole plant Expt. 3).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Cultivar	9	9803.7	1089.3	3.80	0.0001
Rate	5	293960.6	58792.1	205.25	0.0001
Cultivar*rate	45	10048.8	223.3	0.78	0.8436
Stage	1	82146.8	82146.8	286.79	0.0001
Cultivar*stage	9	4940.0	548.9	1.92	0.0493
Rate*stage	5	44604.6	8920.9	31.14	0.0001
Cultivar*stage*rate	45	11519.0	256.0	0.89	0.6677
Error	298	85357.8	286.4		

[a]The common rates of fenoxaprop among all cultivars included 0, 56, 112, 168, and 280 g ha^{-1}.

Table 2.5a. GR_{50} estimates for relative fresh-weight of 10 Italian ryegrass cultivars treated with fenoxaprop at two growth-stages (Whole plant Expt. 3).

Growth Stage	Cultivar	Apparent max. no injury rate	GR_{50}	(# data points)	R^2
		(g ha^{-1})			
2-Leaf	Ace	0	35	(7)	94.9
4-Leaf	Ace	56	94	(6)	82.6
2-Leaf	Futaharu	0	26	(7)	90.9
4-Leaf	Futaharu	56	83	(6)	93.0
2-Leaf	Barmultra	0	83	(6)	93.6
4-Leaf	Barmultra	0	88	(6)	83.0
2-Leaf	Tetrone	0	72	(6)	98.3
4-Leaf	Tetrone	56	82	(5)	74.0
2-Leaf	Waseyutaka	0	69	(6)	97.6
4-Leaf	Waseyutaka	0	149	(6)	89.9
2-Leaf	Aubade	0	82	(7)	94.5
4-Leaf	Aubade	0	96	(7)	95.0
2-Leaf	Gulf	0	102	(7)	96.6
4-Leaf	Gulf	56	315	(6)	57.9
2-Leaf	Sakurawase	0	68	(7)	95.9
4-Leaf	Sakurawase	0	125	(7)	90.9
2-Leaf	Torero	0	83	(7)	94.2
4-Leaf	Torero	0	223	(7)	51.8
2-Leaf	Marshall	0	108	(7)	93.1
4 leaf	Marshall	0	354	(7)	87.7

Table 2.5b. GR_{50} estimates for relative dry-weight of 10 Italian ryegrass cultivars treated with fenoxaprop at two growth-stages (Whole plant Expt. 3).

Growth Stage	Cultivar	Apparent max. no injury rate	GR_{50}	(# data points)	R^2
		($g\ ha^{-1}$)			
2-Leaf	Ace	0	26	(7)	87.6
4-Leaf	Ace	56	256	(5)	89.6
2-Leaf	Futaharu	0	31	(7)	94.3
4-Leaf	Futaharu	28	243	(6)	92.2
2-Leaf	Barmultra	0	95	(6)	91.5
4-Leaf	Barmultra	0	287	(6)	86.1
2-Leaf	Tetrone	0	99	(6)	87.4
4-Leaf	Tetrone	56	>280	(5)	86.6
2-Leaf	Waseyutaka	0	68	(6)	96.7
4-Leaf	Waseyutaka	0	>280	(6)	77.0
2-Leaf	Aubade	0	104	(7)	91.6
4-Leaf	Aubade	0	>448	(7)	47.5
2-Leaf	Gulf	0	100	(7)	98.1
4-Leaf	Gulf	0	>448	(7)	72.7
2-Leaf	Sakurawase	0	65	(7)	96.5
4-Leaf	Sakurawase	0	269	(7)	95.8
2-Leaf	Torero	0	88	(7)	94.5
4-Leaf	Torero	0	458	(7)	62.1
2-Leaf	Marshall	0	99	(7)	97.1
4 leaf	Marshall	0	>448	(7)	57.0

Table 2.6a. Main effect of rates of fenoxaprop on relative fresh and dry-weight in Ace and Futaharu (susceptible) at two growth-stages (Whole plant Expt. 3).

Fenoxaprop Rate	Relative Weight	
	Fresh[a]	Dry[b]
($g\ ha^{-1}$)	(% of check)	
0	100.0	100.0a
28	75.8b	70.8b
56	63.6b	67.8b
112	23.8c	42.2c
168	17.5c	41.3c
224	-15.1d	24.3d
280	-8.3d	26.2d

Table 2.6b. Main effect of cultivar on fresh and dry-weight at two growth-stages in Ace and Futaharu (susceptible) at two growth-stages (Whole plant Expt. 3).

Cultivar	Relative Weight	
	Fresh	Dry
	(% of check)	
Ace	48.1a	61.0a
Futaharu	41.2a	57.2a

[a] GR_{50} and R^2 for regression of relative fresh weight gain averaged over replications, stages, and cultivars are 64 $g\ ha^{-1}$ and 96.8%, respectively.

[b] The GR_{50} and R^2 for regression of relative dry weight gain averaged over replications, stages, and cultivars are 101 $g\ ha^{-1}$ and 95.5%, respectively.

Table 2.6c. Main effect of growth-stage on net fresh and dry-weight in Ace and Futaharu (susceptible) at two growth-stages (Whole plant Expt. 3).

Growth Stage	Relative Weight	
	Fresh	Dry
	(% of check)	
2-Leaf	35.3b	38.7b
4-Leaf	54.0a	79.4a

Table 2.7a. Main effect of rates of fenoxaprop on relative fresh and dry-weight in Barmultra, Tetrone, and Waseyutaka (moderately tolerants) at two growth-stages (Whole plant Expt. 3).

Fenoxaprop Rate	Relative Weight	
	Fresh[a]	Dry[b]
($g\ ha^{-1}$)	(% of check)	
0	100.0	100.0a
56	81.2b	86.8b
112	36.8c	61.3c
168	25.5cd	43.5d
224	6.6e	32.1d
280	12.7de	38.6d

[a]The GR_{50} and R^2 for regression of relative fresh weight averaged over replications, stages, and varieties are 78 $g\ ha^{-1}$ and 91.8%, respectively.

[b]The GR_{50} and R^2 for regression of relative dry weight gain averaged over replications, stages, and varieties are 155 $g\ ha^{-1}$ and 94.8%, respectively.

Table 2.7b. Main effect of cultivar on relative fresh and dry-weight in Barmultra, Tetrone, and Waseyutaka (moderately tolerants) at two growth-stages (Whole plant Expt. 3).

Cultivar	Relative Weight	
	Fresh	Dry
	(% of check)	
Barmultra	54.2a	66.0a
Waseyutaka	54.0a	62.7a
Tetrone	47.8a	70.1a

Table 2.7c. Main effect of growth-stage on relative fresh and dry-weight in Barmultra, Tetrone, and Waseyutaka (moderately tolerants) at two growth-stages (Whole plant Expt. 3).

Growth Stage	Relative Weight	
	Fresh	Dry
	(% of check)	
2-Leaf	47.6b	52.6b
4-Leaf	56.6a	80.0a

Table 2.8a. Main effect of rates of fenoxaprop on relative fresh and dry-weight in Aubade, Gulf, Marshall, Sakurawase, and Torero tolerant Italian ryegrass cultivars, at two growth-stages (Whole plant Expt. 3).

Fenoxaprop Rate	Relative Weight: Fresh[a]	Relative Weight: Dry[b]
($g\ ha^{-1}$)	(% of check)	(% of check)
0	100.0a	100.0a
56	75.6b	78.0b
112	50.8c	58.0c
168	35.9d	43.5d
224	34.8d	41.5d
280	36.3d	38.7d
448	9.5e	29.2e

Table 2.8b. Main effect of cultivar on relative fresh and dry-weight in five tolerant cultivars at two growth-stages (Whole plant Expt. 3).

Cultivar	Relative Weight: Fresh	Relative Weight: Dry
	(% of check)	(% of check)
Gulf	62.4a	64.8a
Marshall	60.5a	62.2a
Torero	56.1a	64.1a
Aubade	45.7b	61.1a
Sakurawase	44.5b	53.1b

[a] GR_{50} and R^2 Estimates for regression of relative fresh weight gain are 136 $g\ ha^{-1}$ and 95.7%, respectively.

[b] GR_{50} and R^2 Estimates for regression of relative dry weight gain are 158 $g\ ha^{-1}$ and 98.7%, respectively.

Table 2.8c. Main effect of growth-stage on fresh and dry-weight in Aubade, Gulf, Marshall, Sakurawase, and Torero, tolerant Italian ryegrass cultivars, at two growth-stages (Whole plant Expt. 3).

Growth Stage	Relative Weight	
	Fresh	Dry
	(% of check)	
2-Leaf	44.8b	47.3b
4-Leaf	63.1a	75.0a

Table 2.9a. Main effect of cultivar in 10 cultivars of Italian ryegrass previously classified into different tolerance groups on five common rates of fenoxaprop at two growth-stages for relative fresh and dry-weights (Whole plant Expt. 3).

Cultivar	Relative Weight	
	Fresh	Dry
	(% of check)	
Gulf	68.9a	70.1a
Marshall	65.4a	66.0ab
Torero	63.4ab	69.2a
Barmultra	54.2bc	66.0ab
Waseyutaka	54.0bc	62.7abc
Aubade	52.1c	65.4ab
Sakurawase	51.4c	58.2bc
Tetrone	47.8c	70.1a
Ace	45.2c	59.6c
Futaharu	35.2d	55.2c

Table 2.9b. Main Effect of fenoxaprop rate on 10 cultivars of Italian ryegrass previously classified into different tolerance groups, at two growth-stages for relative fresh and dry-weights (Whole plant Expt. 3).

Fenoxaprop Rate	Relative Weight	
	Fresh[a]	Dry[b]
($g\ ha^{-1}$)	(% of check)	
0	100.0a	100.0a
56	74.9b	79.1b
112	41.2c	55.8c
168	28.6d	43.0d
224	16.9e	35.2e
280	15.3e	36.2e

Table 2.9c. Main effect of growth-stage on 10 cultivars of Italian ryegrass previously classified into different tolerance groups, at two growth-stages for relative fresh and dry-weights (Whole plant Expt. 3).

Growth Stage	Relative Weight	
	Fresh	Dry
	(% of check)	
2-Leaf	46.9b	50.2b
4-Leaf	60.8a	78.2a

[a] GR_{50} and R^2 for regression of relative fresh weight gain averaged over replications, stages, and cultivars, for the common 6 Fenoxaprop rates are 89.8 g ha^{-1} and 97.7 %, respectively.

[b] GR_{50} and R^2 for relative dry weight averaged over replications, growth stages, and cultivars for the common six rates are 141.3 g ha^{-1} and 98.3%, respectively.

<u>Table 2.10a.</u> Cultivar by fenoxaprop rates interaction in 10 cultivars analyzed at six common rates at two growth-stages for relative fresh and dry-weight (Whole plant Expt. 3).

Cultivar	Fenoxaprop Rate (g ha^{-1}) 56	112	168	224	280
	(% of check)[a]				
Ace	75(73)	31(46)	30(46)	-12(24)	-8(27)
Aubade	71(85)	36(52)	16(36)	21(42)	21(42)
Barmultra	85(86)	44(61)	28(45)	5(44)	18(38)
Futaharu	53(62)	16(38)	5(36)	-19(24)	-8(25)
Gulf	89(85)	59(60)	45(49)	51(45)	39(46)
Marshall	72(72)	71(68)	46(42)	38(42)	31(38)
Sakurawase	76(75)	36(50)	28(36)	19(29)	9(23)
Tetrone	84(68)	26(68)	21(43)	-1(36)	1(23)
Torero	70(76)	52(61)	40(54)	50(50)	32(44)
Waseyutaka	75(76)	41(55)	27(43)	16(28)	19(37)

<u>Table 2.10b.</u> Cultivar by growth-stage interaction in 10 cultivars analyzed at six common rates for relative fresh and dry-weight gain (Whole plant Expt. 3).

Cultivar	Growth-stage 2-Leaf	4-Leaf
	(% of check)	
Ace	36(39)	54(26)
Aubade	59(43)	55(74)
Barmultra	54(56)	54(75)
Futaharu	32(37)	38(73)
Gulf	56(56)	82(83)
Marshall	56(55)	75(77)
Sakurawase	45(46)	58(71)
Tetrone	46(57)	49(84)
Torero	52(56)	75(83)
Waseyutaka	43(45)	65(80)

[a]The values outside and inside the parentheses represent the Relative Fresh and Dry Weights (%check), respectively.

Table 2.11a. Growth-stage by cultivar by fenoxaprop rates interaction for relative fresh-weight in Ace and Futaharu at two growth-stages (Whole plant Expt. 3).

Growth Stage	Cultivar	Fenoxaprop ($g\ ha^{-1}$) 28	56	112	168	224	280
		(% of check)					
2-Leaf	Ace	47.6	38.0	13.5	8.6	-5.0	-2.0
2-Leaf	Futaharu	39.8	36.7	5.7	-4.0	-8.2	-6.0
4-Leaf	Ace	88.7	111.0	49.2	51.8	-18.3	-13.8
4-Leaf	Futaharu	127.1	68.9	26.9	13.5	-28.9	-11.2

Table 2.11b. Growth-stage by cultivar by fenoxaprop rate interaction for relative dry-weight in Ace and Futaharu at two growth-stages (Whole plant Expt. 3).

Growth Stage	Cultivar	Fenoxaprop ($g\ ha^{-1}$) 28	56	112	168	224	280
		(% of check)					
2-Leaf	Ace	42.2	37.4	16.5	13.6	0.6	4.8
2-Leaf	Futaharu	41.1	41.1	11.8	7.6	1.0	1.9
4-Leaf	Ace	98.4	109.6	76.3	78.9	47.7	49.4
4-Leaf	Futaharu	101.3	83.0	64.2	65.0	48.0	48.8

Table 2.12a. Growth-stage by cultivar by fenoxaprop rate interaction for relative fresh-weight in Barmultra, Tetrone, and Waseyutaka at two growth-stages (Whole plant Expt. 3).

Growth Stage	Cultivar	Fenoxaprop ($g\ ha^{-1}$) 56	112	168	224	280
		(% of check)				
2-Leaf	Barmultra	80.9	44.1	19.2	15.5	15.3
2-Leaf	Tetrone	65.2	37.1	13.6	4.4	2.9
2-Leaf	Waseyutaka	65.9	32.2	10.8	-5.2	-2.6
4-Leaf	Barmultra	88.5	44.5	35.9	-5.4	20.9
4-Leaf	Tetrone	102.0	13.7	32.5	-6.6	-1.6
4-Leaf	Waseyutaka	84.6	48.9	43.3	37.2	41.0

Table 2.12b. Growth-stage by cultivar by fenoxaprop rate interaction for relative dry-weight of Barmultra, Tetrone, and Waseyutaka at two growth-stages (Whole plant Expt. 3).

Growth Stage	Cultivar	Fenoxaprop (g ha^{-1}) 56	112	168	224	280
		(% of check)				
2-Leaf	Barmultra	88.6	42.2	27.2	17.6	16.0
2-Leaf	Tetrone	94.6	51.9	24.1	14.1	14.5
2-Leaf	Waseyutaka	67.3	35.2	13.4	-3.1	1.6
4-Leaf	Barmultra	84.2	79.0	62.1	45.5	60.5
4-Leaf	Tetrone	101.0	84.7	71.9	58.7	67.1
4-Leaf	Waseyutaka	85.1	74.3	71.8	59.6	72.2

Table 2.13a. Growth-stage by cultivar by fenoxaprop rate interaction for relative fresh-weight on Aubade, Gulf, Marshall, Sakurawase, and Torero at two growth-stages (Whole plant Expt. 3).

Growth Stage	Cultivar	Fenoxaprop (g ha^{-1}) 56	112	168	224	280	448
		(% of check)					
2-Leaf	Aubade	71.0	28.0	12.5	13.6	17.8	-6.8
2-Leaf	Gulf	81.1	49.4	32.0	18.8	7.7	1.8
2-Leaf	Marshall	57.2	65.1	35.7	20.9	13.9	2.6
2-Leaf	Sakurawase	77.0	36.3	9.0	-1.6	-5.0	-10.7
2-Leaf	Torero	76.9	33.5	34.0	7.3	10.8	2.6
4-Leaf	Aubade	71.8	44.4	18.5	28.4	23.6	8.6
4-Leaf	Gulf	96.6	69.4	57.4	82.7	70.0	31.5
4-Leaf	Marshall	86.9	76.4	56.0	55.4	48.1	50.4
4-Leaf	Sakurawase	75.1	35.2	46.0	40.4	22.9	6.4
4-Leaf	Torero	62.6	70.3	46.5	92.7	52.8	8.4

Table 2.13b. Growth-stage by cultivar by fenoxaprop rate interaction for dry-weight gain of Aubade, Gulf, Marshall, Sakurawase, and Torero Italian ryegrass tolerant to fenoxaprop (Whole plant Expt. 3).

Growth Stage	Cultivar	Fenoxaprop (g ha^{-1}) 56	112	168	224	280	448
		(% of check)					
2-Leaf	Aubade	88.7	36.5	21.2	22.1	23.4	-0.5
2-Leaf	Gulf	79.6	46.4	30.2	18.3	14.9	6.8
2-Leaf	Marshall	59.3	55.8	31.2	19.5	16.8	6.6
2-Leaf	Sakurawase	70.2	38.6	10.1	2.3	-2.0	-5.0
2-Leaf	Torero	80.4	60.7	63.8	55.3	48.7	41.4
4-Leaf	Aubade	82.2	68.0	50.8	61.7	60.9	62.3
4-Leaf	Gulf	90.4	73.3	67.1	72.5	76.3	60.3
4-Leaf	Marshall	85.5	79.4	53.2	83.9	60.0	63.6
4-Leaf	Sakurawase	80.4	60.7	63.8	55.3	48.7	41.4
4-Leaf	Torero	74.0	80.7	68.1	85.7	71.4	45.3

Table 2.14a. Analysis of variance for net fresh-weight in Aubade, Barmultra, Sakurawase, Waseyutaka, Tetrone, Futaharu, and Ace Italian ryegrass at two growth-stages (Whole plant Expt. 4).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Cultivar	6	409.9	68.3	15.57	0.0001
Rate	7	674.5	96.4	21.97	0.0001
Cultivar*Rate	42	233.6	5.6	1.27	0.1340
Stage	1	219.1	219.1	49.96	0.0001
Cultivar*Stage	6	87.8	14.6	3.34	0.0034
Rate*Stage	7	87.7	12.5	2.86	0.0067
Cultivar*Stage*Rate	42	151.5	12.5	0.80	0.8063
Error	266	1199.4	16.8		

Table 2.14b. Analysis of variance for relative fresh-weight in Aubade, Barmultra, Sakurawase, Waseyutaka, Tetrone, Futaharu, and Ace Italian ryegrass (Whole plant Expt. 4).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Cultivar	6	44119.0	7353.2	6.65	0.0001
Rate	7	142425.3	20346.5	18.40	0.0001
Cultivar*Rate	42	56233.0	1338.9	1.21	0.1845
Stage	1	10030.3	10030.3	9.07	0.0028
Cultivar*Stage	6	21824.9	3637.5	3.29	0.0038
Rate*Stage	7	7657.5	1093.9	0.99	0.4392
Cultivar*Stage*Rate	42	38550.0	917.9	0.81	0.7983
Error	266	302121.2	1135.8		

Table 2.14c. Analysis of variance for flowering in Aubade, Barmultra, Sakurawase, Waseyutaka, Tetrone, Futaharu, and Ace Italian ryegrass at 4-leaf stage (Whole plant Expt. 4).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Cultivar	6	152.6	25.4	103.54	0.0001
Rate	7	1.1	0.2	0.65	0.7156
Cultivar*Rate	42	10.3	0.3	1.00	0.4861
Error	133	32.7	0.2		

Table 2.15a. Combined analysis of variance for net fresh-weight in 10 Italian ryegrass cultivars previously classified into different tolerance groups at six common rates of fenoxaprop (Whole plant Expt. 4).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F[a]
Cultivar	9	581.7	64.6	12.40	0.0001
Rate	5	443.1	88.6	17.00	0.0001
Cultivar*Rate	45	323.1	7.2	1.38	0.0635
Stage	1	365.0	365.0	70.03	0.0001
Cultivar*Stage	9	90.1	10.0	1.92	0.0488
Rate*Stage	5	112.7	22.5	4.33	0.0008
Cultivar*Stage*Rate	45	241.8	5.4	1.03	0.4239
Error	299	1558.3	5.2		

[a]The rates common in both tolerance groups were 0, 56, 112, 168, 224, and 336 g ha^{-1}, respectively.

Table 2.15b. Combined analysis of variance for relative fresh-weight in 10 Italian ryegrass cultivars previously classified into different tolerance groups, on common rates of fenoxaprop (Whole plant Expt. 4).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F[a]
Cultivar	9	86188.5	9576.5	7.45	0.0001
Rate	5	83840.0	16768.0	13.04	0.0001
Cultivar*Rate	45	83504.5	1855.7	1.44	0.0403
Stage	1	23340.2	23340.2	18.15	0.0001
Cultivar*Stage	9	45947.4	5105.3	3.97	0.0001
Rate*Stage	5	14365.4	2873.1	2.23	0.0510
Cultivar*Stage*Rate	45	60970.7	1354.9	1.05	0.3870
Error	299	384544.0	1286.1		

[a]The common rates to all 10 cultivars were 0, 56, 112, 168, 224, and 336 g ha^{-1}.

Table 2.16. GR_{50} estimates of 10 Italian ryegrass cultivars treated with fenoxaprop at two growth-stages (Whole plant Expt. 4).

Growth Stage	Cultivar	Apparent max. no Injury rate	GR_{50}	(# data points)	R^2
		(g ha^{-1})			
2-Leaf	Ace	28	130	(7)	80.3
4-Leaf	Ace	84	287	(5)	47.1
2-Leaf	Aubade	84	325	(7)	45.3
4-Leaf	Aubade	84	$\gg$336	-	-
2-Leaf	Barmultra	84	260	(8)	49.4
4-Leaf	Barmultra	28	311	(7)	63.8
2-Leaf	Futaharu	0	99	(8)	48.8
4-Leaf	Futaharu	28	178	(7)	79.9
2-Leaf	Sakurawase	56	>336	(5)	58.7
4-Leaf	Sakurawase	112	$\gg$336	(4)	0.5
2-Leaf	Tetrone	56	314	(2)	-
4-Leaf	Tetrone	112	326	(4)	95.2
2-Leaf	Waseyutaka	112	322	(4)	29.1
4-Leaf	Waseyutaka	84	300	(5)	37.8
2-Leaf	Gulf	56	$\gg$448	(2)	-
4-Leaf	Gulf	336	$\gg$448	-	-
2-Leaf	Marshall	56	>448	(7)	22.0
4 leaf	Marshall	448	$\gg$448	-	-
2-Leaf	Torero	224	$\gg$448	(4)	86.3
4-Leaf	Torero	336	336	(2)	-

Table 2.17a. Main effect of rates of fenoxaprop on net and relative fresh-weight and flowering in Aubade, Barmultra, Sakurawase, Waseyutaka, Tetrone, Futaharu, and Ace Italian ryegrass (Whole plant Expt. 4).

Fenoxaprop Rate	Fresh-weight	Relative Fresh Weight[a]	Flowering†
($g\ ha^{-1}$)	(g)	(% of check)	
0	6.89a	100.1a	1.76a
28	7.52a	112.3a	1.86a
56	7.11a	105.6a	1.86a
84	5.66b	85.6b	1.91a
112	5.19bc	78.9bc	1.67a
168	4.59c	68.8c	1.76a
224	4.81bc	72.8bc	1.71a
336	3.32d	48.6d	1.70a

† 4 represents all plants flowered, while 1 shows no plant flowering in a pot. Flowering data was recorded and analyzed only for 4-leaf stage.

Table 2.17b. Main effect of cultivar on net and relative fresh-weight and flowering at two growth-stages (Whole plant Expt. 4).

Cultivar	Fresh-weight	Relative Fresh Weight	Flowering†
	(g)	(% of check)	
Aubade	7.81a	85.0b	2.37b
Barmultra	6.18b	83.8b	1.00c
Sakurawase	6.08b	90.2b	3.41a
Waseyutaka	5.96bc	88.5b	2.48b
Tetrone	5.21cd	106.5a	1.07c
Futaharu	4.74d	68.0c	1.00c
Ace	4.45d	79.3bc	1.00c

† 4 represents all plants flowered, while 1 shows no plant flowering in a pot. Flowering data was recorded and analyzed only for 4-leaf stage.

[a] GR_{50} and R^2 for regression averaged over replications, stages, and cultivars, for the six highest rates are 303 $g\ ha^{-1}$ and 60.1%, respectively.

Table 2.17c. Main effect of growth-stage on net and relative fresh-weight in seven cultivars at eight rates of fenoxaprop (Whole plant Expt. 4).

Cultivar	Fresh-weight	Relative Fresh Weight
	(g)	(% of check)
2-Leaf	6.54a	80.7a
4-Leaf	5.01b	91.7b

Table 2.18. Growth-stage by cultivar by fenoxaprop rate interaction for relative fresh-weight in Aubade, Barmultra, Sakurawase, Waseyutaka, Tetrone, Futaharu, and Ace Italian ryegrass at two growth-stages (Whole plant Expt. 4).

Growth Stage	Cultivar	Fenoxaprop Rate ($g\ ha^{-1}$) 28	56	84	112	168	224	336
		(% of check)						
2-Leaf	Ace	103.4	93.3	77.9	42.8	33.1	23.0	30.3
2-Leaf	Aubade	101.7	84.2	71.4	75.8	38.1	68.9	60.9
2-Leaf	Barmultra	106.9	112.8	97.9	75.1	87.3	95.9	34.4
2-Leaf	Futaharu	89.8	91.4	12.0	40.6	46.7	15.2	29.8
2-Leaf	Sakurawase	124.8	107.1	85.8	67.2	82.8	69.0	53.4
2-Leaf	Tetrone	110.7	127.6	72.7	99.0	92.9	71.7	47.3
2-Leaf	Waseyutaka	126.0	121.6	87.1	99.9	52.5	99.5	44.6
4-Leaf	Ace	121.1	121.1	102.5	68.1	109.0	60.2	40.9
4-Leaf	Aubade	108.6	100.2	115.8	69.4	73.2	75.8	86.3
4-Leaf	Barmultra	86.3	79.4	66.8	66.2	81.1	86.6	26.7
4-Leaf	Futaharu	130.4	76.4	80.4	86.1	49.8	61.1	14.6
4-Leaf	Sakurawase	81.0	111.6	97.4	95.2	90.6	63.9	92.3
4-Leaf	Tetrone	177.8	146.9	128.4	155.2	68.6	141.8	76.8
4-Leaf	Waseyutaka	103.4	104.6	102.9	64.0	57.1	88.0	42.2

Table 2.19a. Analysis of variance for net fresh-weight in Gulf, Marshall, and Torero at two growth-stages (Whole plant Expt. 4)).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Cultivar	2	78.8	39.4	6.03	0.0033
Rate	7	86.1	12.3	1.88	0.0792
Cultivar*Rate	14	40.0	2.9	0.44	0.9594
Stage	1	209.4	209.4	32.02	0.0001
Cultivar*Stage	2	8.1	4.1	0.62	0.5390
Rate*Stage	7	110.0	15.8	2.42	0.0239
Cultivar*Stage*Rate	14	138.3	9.9	1.51	0.1183
Error	113	739.1	6.6		

Table 2.19b. Analysis of variance for relative fresh-weight in Gulf, Marshall, and Torero at two growth-stages (Whole plant Expt. 4).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Cultivar	2	11883.4	5941.7	3.79	0.0255
Rate	7	20410.5	2915.8	1.86	0.0826
Cultivar*Rate	14	10657.5	761.3	0.49	0.9367
Stage	1	45745.0	45745.0	29.19	0.0001
Cultivar*Stage	2	35038.0	17519.0	11.18	0.0001
Rate*Stage	7	32286.9	4612.4	2.94	0.0072
Cultivar*Stage*Rate	14	33861.0	2418.6	1.54	0.1070
Error	113	177084.1	1567.1		

Table 2.19c. Analysis of variance for flowering in Torero, Gulf, and Marshall Italian ryegrass at 4-leaf stage (Whole plant Expt. 4).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Cultivar	2	36.6	18.3	45.06	0.0001
Rate	8	4.3	0.5	1.31	0.2557
Cultivar*Rate	16	5.5	0.4	0.97	0.4993
Error	55	22.3	0.4		

Table 2.20a. Main effect of eight rates of fenoxaprop on net and relative fresh-weight and flowering in Gulf, Marshall, and Torero at two growth-stages (Whole plant Expt. 4).

Fenoxaprop Rate	Fresh-weight	Relative Fresh Weight	Flowering†
($g\ ha^{-1}$)	(g)	(% of check)	
0	7.09a[a]	99.9ab	3.00a
56	7.79a	115.7a	3.00a
112	6.79ab	110.4a	2.00b
168	6.65ab	103.6a	2.56ab
224	7.38a	107.6a	2.88ab
280	6.59ab	109.0a	3.11a
336	6.62ab	99.3ab	3.22a
448	5.02b	74.1b	2.67ab

† 4 represents all plants flowered, while 1 shows no plant flowering in a treatment. Flowering data was recorded and analyzed only for 4-leaf stage.

Table 2.20b. Main effect of cultivar on net and relative fresh-weight and flowering at two growth-stages (Whole plant Expt. 4).

Cultivar	Fresh-weight	Relative Fresh Weight	Flowering†
	(g)	(% of check)	
Torero	7.30a	95.7b	2.00a
Gulf	7.21a	96.5b	3.30b
Marshall	5.77b	114.4a	3.54b

† 4 represents all plants flowered, while 1 shows no plant flowering in a treatment. Flowering data was recorded and analyzed only for 4-leaf stage.

[a]Means sharing a letter in common in respective column do not differ significantly (α=0.05) by Duncan's multiple range test.

Table 2.20c. Main effect of growth-stage on net and relative fresh-weight in Gulf, Marshall, and Torero (Whole plant Expt. 4).

Growth Stage	Fresh-weight	Relative Fresh Weight
	(g)	(% of check)
2-Leaf	7.90a	85.4a
4-Leaf	5.62a	119.1b

Table 2.21. Growth-stage by cultivar by fenoxaprop rate interaction for relative fresh-weight in Gulf, Marshall, and Torero at two growth-stages (Whole plant Expt. 4).

Growth Stage	Cultivar	Fenoxaprop ($g\ ha^{-1}$) 56	112	168	224	280	336	448
		(% of check)						
2-Leaf	Gulf	108.2	52.2	59.2	76.2	70.8	109.2	67.2
2-Leaf	Marshall	107.4	64.9	73.3	91.1	49.4	47.5	77.2
2-Leaf	Torero	107.4	113.4	102.2	103.7	81.0	82.5	67.6
4-Leaf	Gulf	90.3	144.3	138.7	141.8	115.4	93.4	75.8
4-Leaf	Marshall	176.6	196.3	169.4	145.0	214.9	148.7	108.3
4-Leaf	Torero	109.8	91.3	78.6	100.3	122.5	114.5	48.4

Table 2.22a. Analysis of variance for net fresh-weight gain in Ace, Aubade, and Futaharu at three growth-stages (Whole plant Expt. 5).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Cultivar	2	39.8	19.9	10.43	0.0080
Rate	6	345.6	57.6	30.21	0.0001
Cultivar*Rate	12	36.9	3.1	1.61	0.0927
Stage	2	98.5	49.2	25.83	0.0001
Cultivar*Stage	4	21.1	5.3	2.76	0.0297
Rate*Stage	12	42.2	3.5	1.84	0.0456
Cultivar*Stage*Rate	24	56.8	2.4	1.24	0.2149
Error	153	292.7	1.9		

Table 2.22b. Analysis of variance for relative fresh-weight in Ace, Aubade, and Futaharu at three growth-stages (Whole plant Expt. 5).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Cultivar	2	9986.5	4993.2	3.84	0.0283
Rate	6	169192.7	28198.8	21.71	0.0001
Cultivar*Rate	12	27036.1	2253.0	1.73	0.0644
Stage	2	19467.2	9733.6	7.49	0.0008
Cultivar*Stage	4	19600.1	4900.0	3.77	0.0059
Rate*Stage	12	15803.9	1317.0	1.01	0.4388
Cultivar*Stage*Rate	24	34078.4	1419.9	1.09	0.3577
Error	153	198715.7	1419.9		

Table 2.23a. Analysis of variance for net fresh-weight gain in Gulf and Marshall at three growth-stages (Whole plant Expt. 5).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Cultivar	1	2.3	2.3	1.08	0.3006
Rate	6	182.1	30.3	14.44	0.0001
Cultivar*Rate	6	24.0	4.0	1.91	0.0868
Stage	2	8.2	4.1	1.94	0.1485
Cultivar*Stage	2	7.3	3.6	1.73	0.1819
Rate*Stage	12	22.8	1.9	0.90	0.5447
Cul.*Stage*Rate	12	43.3	3.6	1.71	0.0742
Error	102	214.4	2.1		

Table 2.23b. Analysis of variance for relative fresh-weight in Gulf and Marshall at three growth-stages (Whole plant Expt. 5).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Cultivar	1	8280.2	8280.2	10.30	0.0018
Rate	6	63509.1	10584.8	13.17	0.0001
Cultivar*Rate	6	5613.4	935.6	1.16	0.3315
Stage	2	3112.0	1556.0	1.94	0.1496
Cultivar*Stage	2	1679.5	839.7	1.04	0.3555
Rate*Stage	12	6829.2	569.1	0.71	0.7405
Cultivar*Rate*Stage	12	13259.7	1105.0	1.37	0.1902
Error	102	184268.9	868.1		

Table 2.24a. Combined analysis of variance for fresh-weight in Ace, Futaharu, Aubade, Gulf, and Marshall previously classified into different tolerance groups, at three growth-stages (Whole plant Expt. 5).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F[a]
Cultivar	4	150.7	37.7	19.05	0.0001
Rate	5	442.3	88.5	44.71	0.0001
Cultivar*Rate	20	72.1	3.6	1.82	0.0197
Stage	2	38.9	19.5	19.84	0.0001
Cultivar*Stage	8	74.3	9.3	4.69	0.0001
Rate*Stage	10	42.6	4.3	2.15	0.0217
Cultivar*Rate*Stage	40	107.3	2.7	1.36	0.0882
Error	225	445.1	2.0		

[a]A separate analysis of variance was performed on common rates to which both groups of varieties were subjected viz. 56, 84, 112, 196, and 280 g ha^{-1}.

Table 2.24b. Combined analysis of variance for relative fresh-weight in Ace, Futaharu, Aubade, Gulf, and Marshall previously classified into different tolerance groups, at three growth-stages (Whole plant Expt. 5).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Cultivar	4	35802.2	8950.5	8.09	0.0001
Rate	5	192691.4	38538.3	34.84	0.0001
Cultivar*Rate	20	42900.0	2145.0	1.94	0.0111
Stage	2	19502.1	9751.0	8.81	0.0002
Cultivar*Stage	8	24486.4	3060.8	2.77	0.0062
Rate*Stage	10	11656.7	1165.7	1.05	0.3995
Cultivar*Stage*Rate	40	53945.9	1348.6	1.22	0.1868
Error	225	248905.2	1106.2		

Table 2.25. GR_{50} estimates of five Italian ryegrass cultivars at three growth-stages (Whole plant Expt. 5).

Growth Stage	Cultivar	Apparent Max. No Injury Rate	GR_{50}	(# Data Points)	R^2
		(g ha^{-1})			
2-Leaf	Ace	0	129	(7)	89.9
4-Leaf	Ace	0	39	(7)	94.8
Tillering	Ace	0	167	(7)	51.3
2-Leaf	Aubade	0	166	(7)	91.5
4-Leaf	Aubade	0	>336	(7)	81.1
Tillering	Aubade	56	188	(5)	17.3
2-Leaf	Futaharu	0	50	(7)	92.4
4-Leaf	Futaharu	0	52	(7)	93.4
Tillering	Futaharu	84	136	(4)	94.5
2-Leaf	Gulf	56	240	(6)	88.3
4-Leaf	Gulf	112	376	(4)	85.6
Tillering	Gulf	280	399	(2)	100.0
2-Leaf	Marshall	0	163	(7)	70.7
4-Leaf	Marshall	0	127	(7)	14.6
Tillering	Marshall	0	236	(7)	71.1

Table 2.26a. Main effect of rates of fenoxaprop on net and relative fresh-weight in Ace, Aubade, and Futaharu at three growth-stages (Whole plant Expt. 5).

Fenoxaprop Rate	Fresh-weight	Relative Fresh Weight[a]
(g ha^{-1})	(g)	(% of check)
0	4.51a	100.0a
28	3.32b	72.6bc
56	3.47b	80.7ab
84	2.41c	55.2d
112	2.13c	46.1de
196	1.32d	29.2ef
280	1.05d	24.2f

Table 2.26b. Main effect of cultivar on net and relative Fresh-weight in Ace, Aubade, and Futaharu at three growth-stages (Whole plant Expt. 5).

Cultivar	Fresh-weight	Relative Fresh Weight
	(g)	(% of check)
Aubade	3.45a	73.5a
Ace	2.68b	59.8b
Futaharu	2.43b	58.1b

Table 2.26c. Main effect of growth-stage on net relative fresh-weight in Ace, Aubade, and Futaharu (Whole plant Expt. 5).

Growth Stage	Fresh-weight	Relative Fresh Weight
	(g)	(% of check)
2-Leaf	2.61b	64.1ab
4-Leaf	2.18b	52.3b
Tillering	3.78a	75.2a

[a]GR_{50} estimates and R^2 for fenoxaprop rate means (averaged over replications, growth stages, and varieties) are 103 g ha^{-1} and 99.2%, respectively.

Table 2.27a. Main effect of rates of fenoxaprop on net and relative fresh-weight in Gulf and Marshall at three growth-stages (Whole plant Expt. 5).

Fenoxaprop Rate	Fresh-weight	Relative Fresh Weight[a]
($g\ ha^{-1}$)	(g)	(% of check)
0	5.26a	100.0a
56	4.25b	82.18ab
84	4.11b	79.7b
112	3.48bc	69.7bc
196	2.87cd	57.2cd
280	2.64cd	51.3cd
448	2.00d	38.3d

Table 2.27b. Main effect of cultivar on net and relative Fresh-weight in Gulf and Marshall at three growth-stages (Whole plant Expt. 5).

Cultivar	Fresh-weight	Relative Fresh Weight
	(g)	(% of check)
Marshall	3.87a	79.7a
Gulf	3.60a	64.8b

Table 2.27c. Main effect of growth-stage on net and relative fresh-weight in Gulf and Marshall (Whole plant Expt. 5).

Growth Stage	Fresh-weight	Relative Fresh Weight
	(g)	(% of check)
2-Leaf	3.82a	72.9a
4-Leaf	3.45a	67.7a
Tillering	3.91a	76.5a

[a] GR_{50} estimates and R^2 for fenoxaprop rate means (averaged over replications, growth stages, and varieties) for Gulf and Marshall are 278 $g\ ha^{-1}$ and 99.1%, respectively.

Table 2.28. Growth-stage by cultivar by fenoxaprop rate interaction for relative fresh-weight in Ace, Aubade, and Futaharu Italian Ryegrass at three growth-stages (Whole plant Expt. 5).

Growth Stage	Cultivar	Fenoxaprop ($g\ ha^{-1}$) 28	56	84	112	196	280
		(% of check)					
2-Leaf	Ace	81.1	69.6	64.4	69.0	45.3	-0.8
2-Leaf	Aubade	90.8	76.6	65.0	65.6	33.0	43.0
2-Leaf	Futaharu	84.4	57.3	28.6	31.0	17.5	18.1
4-Leaf	Ace	51.0	36.6	15.7	25.0	-6.7	-11.0
4-Leaf	Aubade	70.7	88.4	54.9	59.0	68.2	75.8
4-Leaf	Futaharu	63.7	63.7	28.3	-2.2	1.1	-27.8
Tillering	Ace	75.8	44.6	85.3	71.1	34.1	44.6
Tillering	Aubade	76.3	115.0	56.9	24.4	51.6	49.0
Tillering	Futaharu	89.4	112.2	97.9	85.2	18.6	13.3

Table 2.29. Growth-stage by cultivar by fenoxaprop rate interaction for relative fresh-weight in Gulf and Marshall at three growth-stages (Whole plant Expt. 5).

Growth Stage	Cultivar	Fenoxaprop ($g\ ha^{-1}$) 56	84	112	196	280	448
		(% of check)					
2-Leaf	Gulf	100.0	90.1	58.9	57.6	47.7	29.1
2-Leaf	Marshall	81.6	55.6	64.5	29.5	32.1	36.6
4-Leaf	Gulf	89.5	98.4	96.0	80.7	48.5	47.7
4-Leaf	Marshall	64.1	43.4	21.6	37.9	49.8	45.4
Tillering	Gulf	84.3	75.3	94.8	85.8	88.0	41.6
Tillering	Marshall	73.5	115.4	82.3	51.6	41.6	29.3

Torero (Table 2.19a), the ANOVA showed significant differences in net fresh-weight due to cultivars and growth-stages, but there was not a prominent response (P=0.08) to fenoxaprop rates (Table 2.19a). Likewise, response of relative fresh-weight (Table 2.19b), was similar for the different sources of variation except, in addition, the cultivar by growth-stage interaction was also significant.

The main effects for fenoxaprop rates (Table 2.20a) show stimulation at many rates. Suppression can only be seen at the highest rate of fenoxaprop. The cultivar Marshall, irrespective of the growth-stage, surpassed its rivals included in the test for the relative fresh-weight, and it flowered the most as well (2.20b). The growth-stage response (Table 2.20c) showed enormous simulation at the 4-leaf stage. The 3-way interaction (Table 2.21) exhibits greater stimulation of Marshall by fenoxaprop rate at the 4-leaf stage compared to the 2-leaf stage. Stimulation was also visible for Gulf, but Torero failed to exhibit as much gain in tolerance with an advancement in age.

Whole Plant Experiment 5. The whole plant experiment 3, which had included 10 Italian ryegrass cultivars, was partially repeated for the second time. Representative cultivars for each tolerance status were included in these studies. The results presented in Table 2.22a to Table 2.22b are mostly complementary to our previous findings. There existed a variation among the cultivars for tolerance to fenoxaprop.

For the susceptible group (Table 2.22a and 2.22b) the differences among cultivars, rates of fenoxaprop, growth-stage and the interaction of cultivar with growth-stage were assessed (2.22a and 2.22b). The differences were evaluated for cultivar by rate interaction (P=0.09). In the tolerant group (Table 2.23a), there were no differences among the cultivars for net fresh-weight, but differences were ascertained (P=0.0018) for the relative fresh-weight (Table 2.23b). The combined analysis of all cultivars on common rates for net and relative weight (Table 2.24a and 2.24b) showed all other parameters of total variance as significant except the 3-way interaction. GR_{50} estimates (Table 2.25) showed an erratic performance at the 4-leaf stage. The only thing different in this experiment as compared to the previous trials is that at the time of planting 20:20:20 N:P:K fertilizer was added to the potting mixture. Abundant availability of mineral nutrients may have been a factor at the time of application of treatments. All the cultivars except Aubade showed more sensitivity to fenoxaprop at the 4-leaf stage. At the first growth-stage, the availability of fertilizer was limited by root growth, whereas at the third growth-stage the nutrients had probably been exhausted by the large plants. As usual, Futaharu was the most sensitive cultivar at all the growth-stages (Table 2.25). Considering the response at the 4-leaf stage as an aberration, due to differences in fertilization practices, there was no gain in tolerance in Aubade between the 2-leaf and the tillering stage. The tolerance of Marshall and Gulf were further certified in the present studies. The main effects (Table 2.26a and Table 2.27a) show a depression with every increment of fenoxaprop. GR_{50} values were more than twice as high (278 vs 103 g ha^{-1}) (Table 2.26a and Table 2.27a) for the tolerant vs. the susceptible group. Within the susceptible group (Table 2.26b), Aubade was the most tolerant. In the tolerant group (Table 2.29b), Marshall continued to be outstanding. The tolerance increased as treatment was delayed until tillering rather than at the 2-leaf stage (Table 2.26c and 2.27c). However, for the tolerant group the response of growth-stage was not very pronounced. Probably plants already had enough tolerance at 2-leaf stage to overcomes the range of rates applied. The interaction of cultivar by growth-stage by fenoxaprop rate (Table 2.28) exhibits drastic depression due to fenoxaprop rates at all growth-stages. Ace performed better than Futaharu at the 2-leaf stage, but these two cultivars did not differ at the 4-leaf and tillering stages. Aubade attained an exceptional gain at the 4-leaf stage which could not be maintained over to tillering stage. The 3-way interaction for the tolerant group shows a clear inferiority for Marshall at the 2-leaf stage (Table 2.29), but it recoups its superiority at the tillering stage.

General Discussion. The influence of growth-stage on the tolerance of Italian ryegrass to fenoxaprop was investigated under the greenhouse conditions. Ten cultivars, two growth-stages and several fenoxaprop regimes were included in the trials. Experiments were repeated one time with all ten cultivars, during the second repeat only five cultivars were included. However, an additional growth-stage was included during the second repeat of the experiment.

Variability in tolerance of cultivars to fenoxaprop was evaluated. Our findings agree with the results obtained by Faulkner (1974), Faulkner (1984), Wright (1966), and Wright (1968) on Italian ryegrass with herbicides other than fenoxaprop. We evaluated Marshall, Gulf, and Torero as tolerant cultivars, whereas Futaharu and Ace were among the susceptible. About four-fold differences in GR_{50} were found between the least and the most tolerant cultivars. These findings are in line with the earlier research (Andersen, 1976; Schreiber et al., 1979; Morrison et al., 1984; Grichar and Boswell, 1986; Leys et al., 1988; Warren et al., 1989, Smeda and Putnam, 1990) which showed inter- and/or intra-specific varying response to other aryloxyphenoxypropanoic acid herbicides. For fenoxaprop such a response has been reported in several species (Mueller-Warrant and Brewster, 1986; Dernoden, 1987; Snipes et al., 1987; Mueller-Warrant, 1990; Hassan and Mueller-Warrant, 1990; Deschamps et al., 1990). About twice as much tolerance was estimated at the 4-leaf growth-stage than at the 2-leaf growth-stage of Italian ryegrass. Increased tolerance with age has been communicated in several studies (Agbakoba and Goodin, 1969; Schreiber et al., 1979; Ahmadi et al., 1980; Dernoden, 1987; Kells et al., 1989; Smeda and Putnam, 1990). Although, tolerance generally increased with age, the cultivars Aubade and Barmultra failed to increase in tolerance as they grew older. Disproportionate increase in tolerance with age has already been reported by Todd and Stobbe (1977); Mohan et al., (1988); and Warren et el., (1989). Neal et el., (1990) however, did not find any difference for fenoxaprop tolerance at 2-leaf, 5-leaf, and tillering stages of crabgrass under normal growth conditions. Lefsrud and Hall (1989) reported a decline in tolerance of crabgrass to fenoxaprop with age.

A physiological basis for enhanced tolerance with age has been suggested by Kells et al., (1984) and Harker and Dekker (1988), i.e, the tolerance to fluazifop at 5- to 7-leaf rather than 2- to 3-leaf stage in quackgrass was due to more extensive distribution of the herbicide within the foliage of younger plants. Moreover, they washed more fluazifop from the 5- to 7- than from the 2-to 3-leaf stage. Agbakoba and Goodin (1969) and Ahmadi et el., (1980) are of the opinion that absorption and translocation of xenobiotics was higher in seedlings than in older plants. Buhler and Burnside (1984) reported the metabolically active tissue to be injured the most. We found (data not reported) higher activity of the enzyme acetyl Co-A carboxylase in Italian ryegrass and rice, the proposed primary target site of fenoxaprop, at the older growth-stage, which could also explain the tolerance at later growth-stages.

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Chapter 3.
Target Site Sensitivity of Italian Ryegrass *(Lolium multiflorum)* Cultivars to Fenoxaprop

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Abstract. Laboratory experiments were conducted to study the target site sensitivity to fenoxaprop in 11 Italian ryegrass cultivars differing in their whole plant tolerance to fenoxaprop. Acetyl-Coenzyme A carboxylase (ACCase) was extracted from the leaf tissue at the 2-leaf, 4-leaf, and the tillering plants of 11 Italian ryegrass cultivars which had differential tolerance to fenoxaprop at the whole plant level. Enzyme activity was assayed in the presence of 0, 0.316, 1, and 3.16 mM fenoxaprop parent-acid (racemic mixture of R and S enantiomers). I_{50} values (fenoxaprop dose inhibiting ACCase activity by 50%) were computed with regression analysis. ACCase activity expressed as nmol $[^{14}C]HCO_3$ incorporated min^{-1} mg $protein^{-1}$ and g fresh $weight^{-1}$ increased with plant age. However, at any given growth-stage, the specific activity alone was not related to differences among cultivars in their whole plant tolerance. At the tillering stage when the activity of ACCase was the highest, there existed about a 4-fold difference in I_{50} between the most tolerant cultivar,

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Marshall, and the least tolerant cultivars, Aubade and Ace. These differences at the enzyme approximately agreed with differences at the whole plant tolerance. The tolerance and sensitivity of Gulf and Futaharu at the whole plant level, however, did not correspond to their sensitive and tolerant ACCase. However, simultaneous consideration of both the inhibition and the specific activity of ACCase explained the tolerance of most of the cultivars at the whole plant level.

INTRODUCTION

Diclofop, fenoxaprop, fluazifop, haloxyfop, propaquizafop, and quizalofop are classified as aryloxyphenoxypropanoic acid herbicides. These herbicides have emerged as important tool for the control of *poaceous* weeds in dicotyledonous crops and have shown their worth in cereals and grass seed crops (Andersen, 1976; Brewster et al., 1977; Palmer and Read, 1991). The herbicidal properties of aryloxyphenoxypropionates are similar to those of cyclohexane-1,3-diones like sethoxydim, alloxydim, cycloxydim, tralkoxydim, and clethodim (Butler and Appleby, 1986). Both groups of compounds have been reported as the potent inhibitors (Rendina at al., 1989; Rendina and Felts, 1988; Gronwald, 1991) of the enzyme acetyl-CoA carboxylase (ACCase), a biotin-containing high molecular weight multifunctional protein catalyzing the ATP-dependent carboxylation of acetyl-CoA to malonyl-CoA in various pathways including fatty acid synthesis (Harwood, 1989; Stahl and

Sparace, 1991). ACCase catalyzes two partial reactions, viz. the carboxylation of the biotin prosthetic group and a transcarboxylase reaction which transfers the carboxyl group from biotin to acetyl-CoA to form malonyl-CoA. The mechanism is termed as two a site "ping pong" (Harwood, 1989; Burton et al., 1989; Rendina et al., 1989). This enzyme has been reported to be the target site of the two groups of herbicides described above, which of course have diverse chemistries (Burton et al., 1987; Secor and Csèke, 1988; Secor et al., 1989; Rendina et al., 1988; Rendina and Felts, 1988; Walker et al., 1989a; Walker at al., 1989b, Agũero-Alvardo, et al., 1991). Very recently a new group of herbicides (triazinediones) has been added which also inhibits the activity of ACCase (Babczinski and Fischer, 1991). The inhibition of the fatty acid biosynthetic pathway causes an inhibition of thylakoid membrane formation, chloroplast multiplication and biogenesis, membrane lipid biosynthesis, and cell division (Lichtenthaler, 1989).

The importance of ACCase in plant metabolism can be recognized by the fact that in leaves it is required in a number of different cell types to supply malonyl-CoA for at least six biosynthetic pathways, viz. citric acid cycle, fatty acid and cuticular compound synthesis pathway, isoprenoids like carotenoid, phytol of chlorophylls, gibberillins and terpenes, and several aromatic compounds such as ring A of flavanoids (Grownwald, 1991; Matthews et al., 1990; Salisbury and Ross, 1985).

Fatty acid biosynthesis occurs in chloroplasts of leaves, leucoplasts of buds, germinating seeds, and roots (Nikolau et al., 1984; Stahl and Sparace, 1991).

Our greenhouse studies have shown about 6-fold differences in tolerance between the least and the most tolerant cultivars of Italian ryegrass *(Lolium multiflorum* Lam.*)* to fenoxaprop at the whole plant level. Moreover, we also observed cultivars differences in tolerance to fenoxaprop in rice cultivars. Tolerance was also observed to increase with age in both species.

Absorption, translocation, and metabolism of aryloxyphenoxypropanoic acid herbicides do not differ in such a diverse genotypes as diverse as dicots and monocots (Burton et al., 1989; Grownwald, 1991), suggesting that differential sensitivity resides at the target site. There is also an evidence that tolerance to aryloxyphenoxypropanoic acid herbicides is due to overproduction of the target site (Parker et al., 1990, Shah et al., 1986). The stereospecificity of R(+) and S(-) enantiomers of aryloxyphenoxypropionates at whole plant and molecular level has been reported (Mueller-Warrant, 1992; Hoppe and Zacher, 1985; Rendina et al., 1988).

The present studies were undertaken to determine whether the differential whole plant tolerance of Italian ryegrass to fenoxaprop is the result of differences in ACCase activity or inhibition of fenoxaprop.

MATERIALS AND METHODS

Chemicals. Acetyl-CoA, and adenosine 5-triphosphate (ATP) were obtained from Sigma Chemical Co. [^{14}C]Na_2CO_3 was obtained from NEN-Dupont. Analytical grade parent acid racemate fenoxaprop was obtained from Hoechst. The molecular weight of fenoxaprop acid is 333.8, and purity was 97.5%. To obtain desired concentrations in 1 M Tricine (*p*H 8.0), fenoxaprop was first dissolved in HPLC grade methanol (1.6% final concentration in reaction mixture). Equal concentrations of methanol were maintained in all the treatments including check (no herbicide). To make 1 ml stock of highest concentration, i.e. 31.6 mM, 10.97 mg of Hoe 053022 (fenoxaprop-free acid) were dissolved in 160 μl methanol with a subsequent addition of 840 μl of 1 M Tricine. Checks with and without 160 μl methanol ml^{-1} were compared and no adverse effect of methanol on the activity of ACCase was detected.

Plant Material. Seed was sown in flats filled with pasteurized potting mixture of sand, peat, loam, and pumice in a ratio of 1:1:1:3 by volume and *p*H corrected to 6.5. Each of the 10 cultivars at the respective growth-stages were planted in individual flats, and the flats were randomized on the greenhouse benches. Temperatures of 20 C day/15 C night were maintained throughout the growing period. No artificial light was provided in the greenhouse.

The experiment was carried out in two runs of extraction of the enzyme. Both runs consisted of 10 Italian ryegrass cultivars. All the cultivars were the same in the two runs except Barmultra used in the first run was substituted with Biliken in the second run due to the unavailability of seed of the former cultivar. For the first extraction, seed was planted fortnightly during early summer of 1991. After one and a half months, the enzyme was extracted simultaneously on September 1, 1991 from all the cultivars at 3 growth-stages, viz. 2- leaf, 3-4 leaf, and >2 tiller stages. The plants in the second extraction were raised during late summer, planting all of them at the same time and extracting at intervals of about 2 wk between the respective growth-stages.

Extract Preparation. At the 2-leaf stage whole plants were harvested, whereas at the 4-leaf stage whole plants were harvested for grinding in the first run, while the youngest two leaves were taken in the second run of extraction. However, at the tillering stage only the two youngest expanding leaves were taken in both runs. The tissues were collected from the greenhouse in an ice box. The plant material was thoroughly washed with distilled water, wiped dry, and then ground in liquid nitrogen using a mortar and pestle. When the tissue was in a powdered form, buffer was added in a w/v ratio of 1:2.5 (fresh weight to buffer). The extraction buffer comprised of 100 mM Tricine (*p*H 8.0, HCl), containing 15% ethylene glycol and 0.2% 2-ß-mercaptoethanol (v/v/v). The macerate was filtered through a single layer of miracloth (Calbiochem). The filtrate was centrifuged at

14,000 g for 30 min. The pellet was discarded and the supernatant was either used immediately or stored at -20 C until use.

Protein Determination. The protein content (mg ml^{-1}) of the enzyme supernatants were assayed using Bio-Rad method and BSA as a standard (Bradford, 1976). For assay the supernatants were diluted 15-fold.

Acetyl-CoA Carboxylase Assay. ACCase activity was assayed as described by Stoltenberg et al., (1989) with minor modifications. The activity was assayed in reaction volumes of 250 μl in a fume hood by the acetyl-CoA dependent incorporation of $[^{14}C]HCO_3$ in 7 ml mini vials. The reaction mixtures (final volume) contained 100 mM Tricine (*p*H 8.0, HCl), 0.5 mM dithiothreitol [DTT], 2 mM $MgCl_2$, 2 mM ATP, 50 mM KCl, 3 mM acetyl-CoA, 15 mM $NaH^{14}CO_3$ (375 dpm/nmol) and 0.1 ml of crude enzyme extract. The reaction was started with the addition of enzyme and the cocktail was incubated at 35±2 C (Stahl and Sparace, 1991; Secor and Cséke, 1988; Rendina and Felts, 1988) for 15 min. The reaction was terminated by the addition of 25 μl 12 M HCl. All the steps of the enzyme assay, from addition of enzyme onwards, were carried out in a fume hood. The reaction mixtures were subsequently dried in an evaporation rack to allow vaporization of unreacted $^{14}CO_2$. After evaporation the solids were redissolved in 2 ml boiling double distilled water. Radioactivity incorporated into the acid and heat stable fraction was estimated by liquid scintillation spectroscopy after adding 5 ml of scintillation cocktail[a] into the above solution. The readings from the scintillation counter were corrected for background, counting efficiency, and acetyl-CoA and ATP-independent incorporation of radioactivity.

Conduct of Experiments. Since there was a relatively very high expression of the ACCase activity at the tillering stage, the cultivars were primarily screened at this stage. However, separate experiments were conducted to evaluate the behavior of ACCase at the 2-leaf, 4-leaf, and the tillering stages. Experiments 1 to 4 were carried out for the assay at tillering stage alone. The extract used in experiment 1 was from the first run of extraction, whereas experiments 2 to 4 were from the extraction run 2. The growth-stage response was studied in experiments 5 to 7. Experiment 5 was from the extract from run 1, while experiment 6 used the enzyme extract from run 2. The data in experiment 2 (tillering stage cultivar comparison) is also shared by the growth-stage response test. All the experiments were factorial treatment arrangements in completely randomized designs. The factors included growth-stages, cultivars, and fenoxaprop concentrations. All the experiments were replicated from 2 to 4 times in the laboratory analyses.

Statistical Analyses. In the ACCase activity experiment, the specific activity of individual cultivars in terms of g fresh

[a]ICN, Biomedicals Inc. Irvine California.

weight^{-1} and mg of protein^{-1} in both tillering stage alone and the growth-stage experiments was subjected to GLM technique using SAS® (SAS/STAT™, 1987) and means were separated by Duncan's multiple range test. In inhibition studies, the specific activity per mg per min at three fenoxaprop regimes was converted to % of check and subsequently subjected to linear regression analysis (Quattro® Pro, 1990) after averaging each treatment across replications. I_{50} (mmol fenoxaprop required to retard [^{14}C]HCO_3 incorporation by 50% as compared to an untreated check) was computed by interpolation for each cultivar. The I_{50} values from experiment 1 to 4 were subsequently subjected to GLM for tillering stage. I_{50} values from experiment 6 and 7 along with a partial set of I_{50} values from experiment 2 were used in analysis for growth-stage responses. Means were separated by SAS® (SAS/STAT™, 1989).

RESULTS AND DISCUSSION

ACCase Sensitivity at Tillering Stage. Italian ryegrass cultivars varied in their whole plant tolerance to fenoxaprop (Table 3.1a). Based on GR_{50} (fenoxaprop rate required to reduce the fresh-weight by 50%) the cultivars Marshall, Torero, and Gulf were ranked as the most tolerant, and the cultivars Ace and Futaharu as the least tolerant (Table 3.1b) in individual tests. The mean ranking of GR_{50} estimates can not be calculated as in some tests the GR_{50} for the tolerant cultivars lied outside the range of our data set (Table 3.1b).

The ACCase assay revealed differences among the cultivars for specific activity and inhibition of ACCase at the tillering stage. ACCase activity expressed per g fresh weight and per mg protein differed significantly ($P=0.0001$) among the cultivars (Table 3.2a to 3.2b). The amount of $[C^{14}]HCO_3$ incorporated was also different among the cultivars (Table 3.2c). Similarly, the ACCase from the 11 cultivars exhibited a differential tolerance ($P=0.0001$) to fenoxaprop (Table 3.2d). The ACCase activity expressed per g fresh weight and disintegrations min^{-1} (DPM) was the highest in Biliken (Table 3.3a). When expressed per mg protein, ACCase activity was highest in Biliken and Ace, although statistically at par with all other cultivars except Futaharu, Sakurawase, Marshall, and Ellire (Table 3.3a). Our whole plant studies have revealed the tolerance of Marshall, Gulf, and Ellire, whereas Waseyutaka was among the susceptible cultivars (Table 3.1). So, unlike the findings of Parker et al., (1990) and Shah et al., (1986) enhanced expression of the target site alone does not explain the tolerance at the whole plant level and indeed, frequently contradicted it.

The inhibition of ACCase by 0.316, 1.0, and 3.16 mmol concentrations of fenoxaprop was linear for this range (Fig. 3.1). The sensitivity of the ACCase from the cultivars to fenoxaprop, as estimated by I_{50} values for inhibition, indicates a tolerance of Marshall over all other cultivars included in the tests (Table 3.3b). There existed a 4-fold difference between the most and the least tolerant ACCase to fenoxaprop. For the cultivars Marshall, Ace, and Tetrone, the relative inhibition of their Accase by fenoxaprop (Table 3.2b) conforms to their whole plant tolerance (Table 3.1). The tolerance of ACCase in Futaharu does not correspond with the whole plant sensitivity to fenoxaprop. However, when activity of ACCase (g fresh weight^{-1} and DPM) and inhibition (I_{50}) (Table 3.2a and Table 3.2c) are viewed simultaneously, the whole plant tolerance can be explained reasonably well based on these studies at the enzyme level. Futaharu is apparently sensitive to fenoxaprop at the whole plant level because of the low expression of the tolerant form of the enzyme. Previous work has shown an increased tolerance to graminicides at the whole plant level due to a tolerant ACCase among genotypes of different genera (Boldt and Barrett, 1991, Kobek at al., 1987; Lichtenthaler et al., 1989; Hoppe and Zacher, 1985), or between the species within the same genus (Stoltenberg et al., 1989; Butler and Appleby, 1986). Recently Aũgero-Alvardo and Appleby (1991), however, attributed the tolerance of red fescue over the tall fescue to higher retention of haloxyfop in roots. At the intraspecific level, the differential tolerance among biotypes has been evaluated in the cases of acquired resistance to herbicides. A tolerant *Lolium multiflorum* biotype from Oregon (Stanger and Appleby, 1989) has been reported to differ from the wild type due to a different isozyme (Grownwald et al., 1989a), whereas resistant biotypes of *Lolium rigidum* L. have been reported to differ due to enhanced metabolism (Matthews et al., 1991; Powles et. al., 1990) or faster regaining of membrane potential (Snipes et al., 1987; Shimabukuro and Hoffer, 1991). We did not study the absorption, translocation, or the metabolism of fenoxaprop, nor did we evaluate the biophysics of the membranes, any of which could be other possible explanations of the differential tolerance to fenoxaprop at the whole plant level in addition to our target site findings (Shimabukuro et al., 1979; Wright and Shimabukuro, 1987; Lefsrud and Hall, 1989; Christopher, et al., 1991; Shimabukuro, 1990; Yaacoby et al., 1991). Although we did not specifically identify the compound to which the radioactivity was incorporated, several other studies have identified this heat and acid-tolerant compound as malonyl Coenzyme-A (Burton et al., 1989).

ACCase Tolerance at Different Growth-stages. A serious problem in terms of loss of the activity of ACCase was noticed during storage. A recent report shows a drastic deterioration of ACCase activity during storage even at -20 C (Babczinski and Fischer, 1991).

The analysis of variance did not detect any differences among the five cultivars for ACCase activity measured per g fresh weight or per mg protein. However, growth-stages responded differently (P=0.0001) for both parameters (Table 3.4a and 3.4b). The interaction of cultivar with the growth-stage was non-significant for g fresh weight^{-1}, but a marginal significance (Table 3.4b) was achieved for mg protein^{-1} ($P \leq 0.058$). The inhibitory response of ACCase to fenoxaprop (Table 3.4c) did not show any difference for cultivar, growth-stage and their interaction.

Averaged over cultivars, a three-times higher activity of ACCase at the tillering stage was observed (Table 3.5a) as compared to the 2- and 4-leaf growth-stages. We also observed an elevated activity of ACCase in our studies on rice (data not reported). Averaged over growth-stages, the cultivars Aubade and Futaharu have been evaluated to have the least activity expressed either as g fresh weight^{-1} or mg protein^{-1} (Table 3.5b). The contrast shows that the enzyme from Aubade was more susceptible than the enzyme from the rest of the cultivars (Table 3.5c). Inhibition studies showed no differences in tolerance of ACCase among the three growth-stages (Table 3.5d).

The interaction of cultivar by growth-stage for the activity of ACCase as g fresh weight^{-1} averaged over the cultivars was manifold at the tillering stage (Table 3.6a). However, the two-way interaction for I_{50} did not show superiority of any of the cultivars over the others (Table 3.6b).

In earlier studies on ACCase by other researchers, mostly very young seedlings or in some cases even young etiolated seedlings have been used. Our work shows that not only the plants at older stage can be used for such studies, but also the activity is also more pronounced when expanding leaves at advanced growth-stages are used for extraction. This could minimize the number of plants to be raised for extraction which is crucial in tests such as biochemical genetic studies.

Although our studies of Italian ryegrass cultivars at various growth-stages were not definitive due to the loss of activity of ACCase in storage, the enhanced activity of ACCase in advanced growth-stages may account for the tolerance of grasses to ACCase inhibitors in older plants at whole plant level.

Table 3.1a. Tolerance of 10 Italian ryegrass cultivars in several whole plant tests under greenhouse conditions, based on fresh weight relative to check in individual tests.

Cultivar	Summer 1988	Spring 1989	Winter 1990	Summer 1990	Mean	Rank†
	(% of check)[a]					
Marshall	74.4a	56.6abcd[b]	65.4a	115.0a	77.9	1
Torero	64.9ab	71.5a	63.4ab	100.3abc	75.0	2
Gulf	67.4ab	47.5cde	68.9a	100.6abc	71.1	3
Aubade	60.7abcde	62.3abc	52.1c	80.9de	64.0	4
Barmultra	60.0abcde	67.7a[c]	54.2bc	82.1d	61.6	5
Tetrone	42.5efg	69.8a	47.8c	101.9ab	61.0	6
Sakurawase	63.9abc	39.0e	51.4c	88.1bcd	60.6	7
Waseyutaka	30.7g	69.8a	54.0bc	83.9cd	55.1	8
Ace	37.7fg	46.8b	45.2c	73.0de	47.6	9
Futaharu	35.8g	49.2b	35.2d	65.1e	43.1	10

†Ranking is in the descending order of tolerance

[a]Means sharing the same letter in common do not differ statistically in the same column at 0.05 probability level by Duncan's multiple range test.

[b]Grouped with tolerant varieties, data averaged over 0, 112, 168, and 224 g/ha.

[c]Grouped with susceptible varieties, data averaged over 0, 56, 84, and 112 g/ha.

Table 3.1b. Tolerance of 10 Italian ryegrass cultivars in several greenhouse tests based on GR_{50} estimates of fresh-weight in individual tests.

Cultivar	Summer 88	Spring 89	Winter 90		Summer 90	
			2-leaf	4-leaf	2-leaf	4-leaf
	(g ha^{-1})					
Marshall	234	138	108	354	>448	$\gg$448
Torero	241	246	83	223	$\gg$448	336
Gulf	232	93	102	315	$\gg$448	$\gg$448
Aubade	163	164	82	96	325	>336
Barmultra	127	112	83	88	260	311
Tetrone	69	105	72	82	314	326
Sakurawase	182	67	68	125	>336	$\gg$336
Waseyutaka	47	97	69	149	322	300
Ace	82	80	35	94	130	287
Futaharu	76	85	26	83	99	178

Table 3.2a. Analysis of variance for ACCase activity as nmol $H^{14}CO_3$ incorporated min^{-1} g fresh $weight^{-1}$ at tillering stage in Italian ryegrass (Lab Expt. 1).

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Greenhouse run	1	19291.0	19291.0	87.37	0.0001
Cultivar	10	10655.3	1065.5	4.83	0.0001
Error	47	19377.3	220.8		

Table 3.2b. Analysis of variance for ACCase activity as nmol $H^{14}CO_3$ incorporated min^{-1} mg $protein^{-1}$ in untreated check at tillering stage in Italian ryegrass (Lab Expt. 1)

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Greenhouse run	1	0.3	0.006	0.0	0.9526
Cultivar	10	116.5	11.66	6.6	0.0001
Error	47	83.0	1.77		

Table 3.2c. Analysis of variance for ACCase activity as disintegrations min^{-1} (DPM) in untreated check at tillering stage in Italian ryegrass (Lab Expt. 1)

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Greenhouse run	1	1062448623	1062448622	147.7	0.0001
Cultivar (Cult.)	10	589800631	58980063	8.2	0.0001
Green. run*Cult.	8	366446080	45805760	6.4	0.0001
Error	40	2585106619	7194304		

Table 3.2d. Analysis of variance for inhibition of ACCase by fenoxaprop at tillering stage in Italian ryegrass (mean of Lab Expt. 2 to 5).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Lab runs	3	4.62	1.48	10.02	0.0001
Cultivar	10	10.26	1.03	6.96	0.0001
Error	26	3.54	0.15		

Table 3.3a. Activity of ACCase in untreated extract as nmol $H^{14}CO_3$ incorporated min^{-1} and DPM in 11 Italian ryegrass cultivars at tillering stage (mean of Lab Expt. 1).

Cultivar	ACCase Activity‡		
	g fresh $weight^{-1}$	mg $protein^{-1}$	DPM
Marshall	102.41b[a]	6.71bcd	20463c
Gulf	101.37b	7.36abc	22919bc
Ellire	65.11c	5.70cde	14797e
Aubade	96.27b	8.39ab	22425bc
Barmultra	66.66c	7.58ab	15386e
Tetrone	101.76b	8.31ab	22967bc
Sakurawase	84.99bc	4.78e	19206cd
Biliken	128.54ab	8.84a	30099a
Waseyutaka	104.80b	8.15ab	24395b
Ace	91.09b	9.00a	21211c
Futaharu	70.68c	5.52de	15971de

‡mean of six determinations

[a]Means sharing a letter in common in the same column do not differ significantly by New Duncan's multiple range test at P≤0.05.

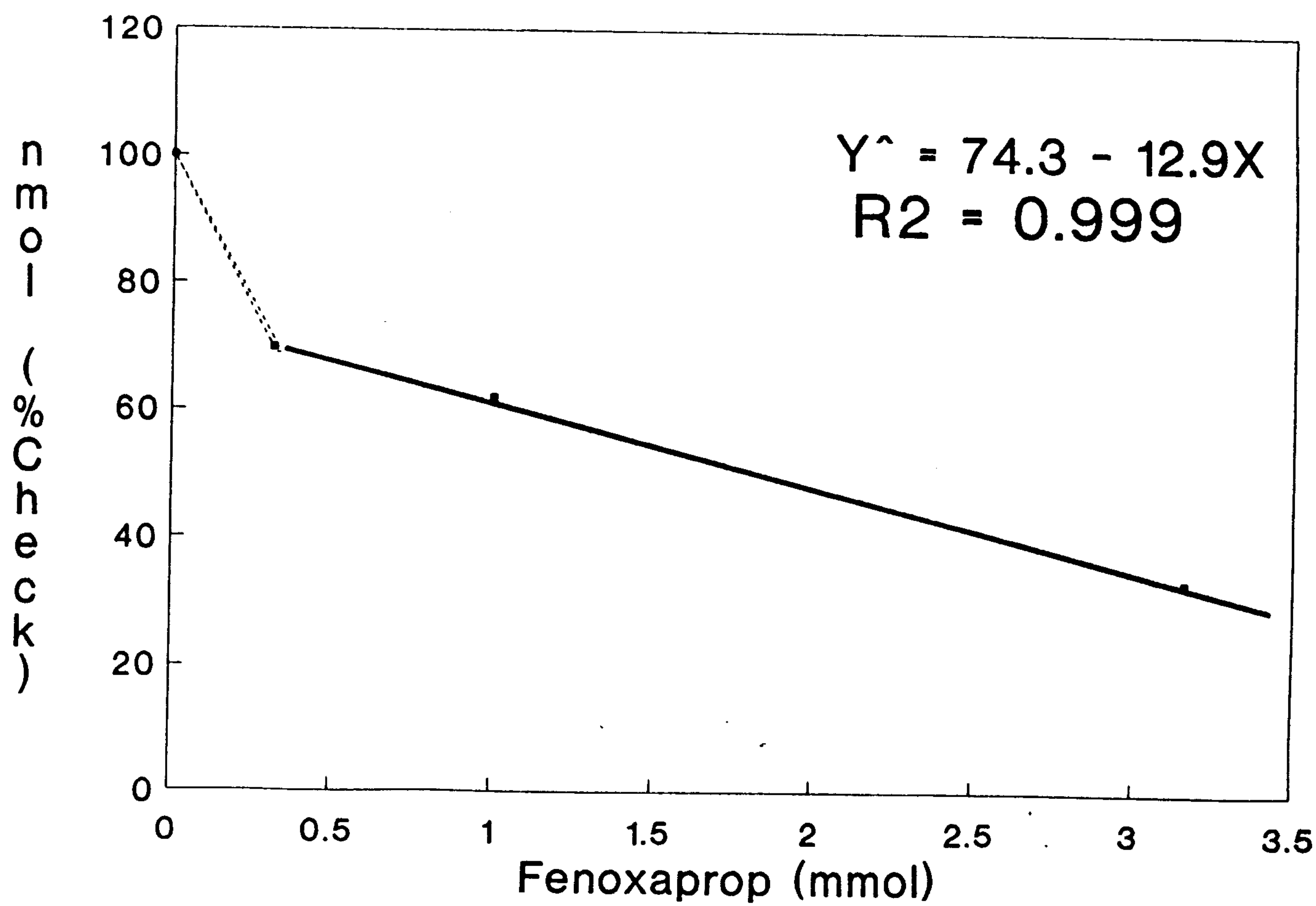

Fig. 3.1. Inhibition of acetyl Co-A carboxylase (ACCase) by fenoxaprop.

Table 3.3b. Dose response of ACCase to fenoxaprop in 11 Italian ryegrass cultivars at tillering stage (mean of Lab Expt. 2 to 5).

Cultivar	I_{50}†
	(mmol)
Marshall	2.74a
Gulf	1.50bcd
Ellire	1.86b
Aubade	0.77d
Barmultra	1.49bcd
Tetrone	1.52bcd
Sakurawase	1.92b
Biliken	1.13bcd
Waseyutaka	1.66bc
Ace	0.85cd
Futaharu	1.65bc

†mean of 10 determinations

Table 3.4a. Analysis of variance for ACCase activity as nmol $H^{14}CO_3$ incorporated g fresh weight^{-1} min^{-1} at 2-leaf, 4-leaf, and tillering stages in five Italian ryegrass cultivars (mean of Lab Expt. 6 to 7).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Stage	2	40816.9	20408.5	25.66	0.0001
Cultivar	4	4193.6	1048.4	1.32	0.2753
Stage*Cultivar	8	7893.2	986.6	1.24	0.2946
Error	53	42159.2	795.5		

Table 3.4b. Analysis of variance for ACCase activity as nmol $H^{14}CO_3$ incorporated mg protein^{-1} min^{-1} at 2-leaf, 4-leaf, and tillering stages in five Italian ryegrass cultivars (mean of Lab Expt. 6 to 7).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Stage	2	148.3	74.16	34.49	0.0001
Cultivar	4	15.6	3.91	1.82	0.1394
Stage*Cultivar	8	35.2	4.41	2.05	0.0580
Error	53	114.0	2.15		

Table 3.4c. Analysis of variance for inhibition of ACCase by fenoxaprop in five Italian ryegrass cultivars (mean of Lab Expt. 6 to 7).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
4 Cult. vs. Aubade	1	2.78	2.78	6.41	0.0500
Among 4 cultivars	3	0.44	0.11	0.25	>0.0500
Error	18	7.81	0.43		

† Cult. = Cultivar

Table 3.5a. Main effect of growth-stage on ACCase activity as nmol $H^{14}CO_3$ incorporated min^{-1} g fresh $weight^{-1}$ and mg $protein^{-1}$ at 2-leaf, 4-leaf, and tillering stages of five Italian ryegrass cultivars (mean of Lab Expt. 6 and 7).

Growth-stage†	ACCase Activity[a]	
	g fresh $weight^{-1}$	mg $protein^{-1}$
2-Leaf	20.4b	1.71b
4-Leaf	11.8b	1.63b
Tillering	70.8a	5.08a

†mean of 20 determinations

Table 3.5b. Main effect of cultivar on ACCase activity as nmol $H^{14}CO_3$ incorporated min^{-1} g fresh $weight^{-1}$ and mg $protein^{-1}$ averaged over the 2-leaf, 4-leaf, and tillering stages of Italian ryegrass (mean of Lab Expt. 6 and 7).

Cultivar	ACCase Activity†	
	g fresh $weight^{-1}$	mg $protein^{-1}$
Marshall	43.5a	3.38a
Gulf	45.9a	3.66a
Aubade	36.7ab	2.78ab
Waseyutaka	40.1a	3.22a
Futaharu	16.5b	1.97b

†mean of 12 determinations

[a]Means sharing a letter in common in the same column do not differ significantly by Duncan's multiple range test at $P \leq 0.05$.

Table 3.5c. Main effect of cultivar on inhibition of ACCase by fenoxaprop averaged over stages (mean of Lab Expts. 6 and 7).

Cultivar	I_{50}[a]
	(mmol)
Marshall	2.54a
Gulf	2.48a
Aubade	1.37b
Waseyutaka	1.74ab
Futaharu	2.30ab

Table 3.5d. Main effects of growth-stage on inhibition of ACCase by fenoxaprop (mean of Lab Expt. 6 and 7) averaged over five cultivars.

Growth-stage	I_{50}[b]
	(mmol)
2-Leaf†	2.38a
4-Leaf	2.03a
Tillering	1.85a

†mean of 20 determinations

[a]Means sharing the same letter do not differ significantly by L.S.D test at P≤0.05.

[b]Means sharing the same letter do not differ significantly by L.S.D test at P≤0.05.

Table 3.6a. ACCase activity as nmol $H^{14}CO_3$ incorporated per min in five Italian ryegrass cultivars at 2-leaf, 4-leaf, and tillering stages (mean of Lab Expt. 6 and 7).

		ACCase Activity†	
Stage	Cultivar	g fresh weight^{-1}	mg protein^{-1}
2-leaf	Marshall	12.30a[a]	0.82a
2-leaf	Gulf	33.67a	2.96abcde
2-leaf	Aubade	19.37a	1.28ab
2-leaf	Waseyutaka	14.57a	1.20a
2-leaf	Futaharu	21.90a	2.26abcd
4-leaf	Marshall	14.58a	2.52abcde
4-leaf	Gulf	9.01a	1.65abc
4-leaf	Aubade	10.62a	0.91a
4-leaf	Waseyutaka	13.88a	1.60ab
4-leaf	Futaharu	9.68a	1.61abc
Tillering	Marshall	83.13b	5.37de
Tillering	Gulf	90.18b	6.08e
Tillering	Aubade	66.51b	5.02bcde
Tillering	Waseyutaka	73.46b	5.47de
Tillering	Futaharu	17.83a	2.03abcd

†mean of four determinations

[a]Means sharing a common letter in the same column do not differ significantly by L.S.D at $P \leq 0.05$.

Table 3.6b. Protein content and inhibition of ACCase (I_{50}) by fenoxaprop in five Italian ryegrass cultivars at 2-leaf, 4-leaf, and tillering stages (mean of Lab Expt. 6 and 7).

Stage	Cultivar	Protein Content	I_{50}†
		(mg ml^{-1})	(mmol)
2-leaf	Marshall	5.09	1.56a
2-leaf	Gulf	5.06	2.17a
2-leaf	Aubade	4.94	2.11a
2-leaf	Waseyutaka	4.44	2.14a
2-leaf	Futaharu	5.25	1.94a
4-leaf	Marshall	5.43	1.78a
4-leaf	Gulf	5.98	3.78a
4-leaf	Aubade	4.66	1.84a
4-leaf	Waseyutaka	5.18	1.97a
4-leaf	Futaharu	4.38	2.92a
Tillering	Marshall	6.63	3.10a
Tillering	Gulf	5.41	1.94a
Tillering	Aubade	4.83	0.75a
Tillering	Waseyutaka	5.59	1.48a
Tillering	Futaharu	5.14	2.09a

†mean of four determinations for inhibition

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Chapter 4.

Fenoxaprop for Weed Control in Transplanted Rice *(Oryza sativa)* under Field Conditions in Pakistan

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Abstract. Field trials were established under rice growing conditions at the Agricultural Research Institute, Dera Ismail Khan, Pakistan, to evaluate the tolerance of rice germplasm to fenoxaprop. Fenoxaprop was applied at 28 to 336 g ai ha^{-1} at 20, 30 and 40 d after transplanting (DAT). Even at the highest rate (336 g ha^{-1}) which is twice that of the field recommended rate, only moderate injury occurred in two cultivars at the youngest growth-stage. Averaged over fenoxaprop rate and cultivar, relative fresh-weight increased when fenoxaprop was applied 30 rather than 20 DAT, whereas further delay in application slightly reduced relative fresh-weight. These findings reveal that fenoxaprop can be safely used for the control of grassy weed flora within one month of

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transplanting rice. Nomenclature: Fenoxaprop[3], (±)-2-[4-[(6-chloro-2-benzoxazolyl)oxy]phenoxy]propanoic acid; Rice, *Oryza sativa* L.

<u>*Additional index words.*</u> Postemergence application, fresh-weight, Growth-stage, cultivars, 20 DAT, 30 DAT, 40 DAT

INTRODUCTION

Rice *(Oryza sativa* L.*)* is a staple food of the teeming millions of people in the world. In Pakistan it not only furnishes food for the population, but its export also adds a huge amount of foreign exchange to the national exchequer. Losses in rice yield in the Indian sub-continent due to weed competition have been estimated to the extent of 9 to 63% (Mani, et al., 1968; Ahmad and Majeed, 1975; Ghauri et al., 1979). Smith (1988a) estimated a 17% loss in U.S. rice production due to weeds, exceeding the cumulative losses due to insects and diseases. Grasses are the major competitors of rice. Among the grasses in order of economic importance are red rice *(Oryza sativa* L.*)*, barnyardgrass *[Echinochloa crus-galli* (L.) Beauv.*]*, bearded sprangletop *[Leptochloa fascicularis* (Lam.) Gray.*]*, and broadleaf signalgrass *[Brachiaria platyphylla* (Griseb.) Nash*]* (Smith 1988a). Up to

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82% losses in rice yield have been estimated due to season-long competition with either barnyardgrass or red rice (Smith, 1968; Smith, 1974b; Khodayari et al., 1988; Diarra et al., 1985).

Weeds infesting Pakistani paddy fields include *Echinochloa crus-galli* (barnyardgrass), *Echinochloa colonum* [(L.) Link.] (jungle rice), *Oryza sativa* (red rice), *Cynodon dactylon* [(L.) Pers.] (bermuda grass), and several sedges (Hassan et al., 1985).

Grass-specific aryloxyphenoxypropanoic acid herbicides, which disrupt the fatty acid biosynthesis pathway in plants via inhibition of acetyl-CoA carboxylase activity in the susceptible species, offer good control of grasses in dicotyledonous as well within *Poeaceous* crops (Hosaka et el., 1984; Andersen, 1976; Warren et al., 1989; Beardmore and Linscott, 1989; Leys et al., 1989; Harker and Blackshaw, 1991). They share this property with the cyclohexanedione herbicides. Fenoxaprop-ethyl, a member of the aryloxyphenoxy-propionates group, discovered in the laboratories of Hoechst AG Frankfurt, Germany (Bieringer et al., 1982), has emerged as a prominent warm season annual and perennial grass-killer (Beringer et al., 1982, Matolcsy et al., 1988, Peters et al., 1989, Snipes and Street, 1987b). The crops of economic importance tolerant to fenoxaprop include cotton, alfalfa, potatoes, soybean, tobacco, ryegrass, and rice (Anon., 1987; Bieringer et al., 1982, Snipes and Street, 1987b).

Economically important highly susceptible weed species include blackgrass *(Alopecurus myosuroides* Huds.*)*, oats *(Avena* spp.*)*, foxtail *(Setaria* spp.*)*, johnsongrass *(Sorghum halepense)*, barnyardgrass, crabgrass *(Digitaria* spp.*)* and red rice. Bermudagrass is classified as susceptible, whereas quackgrass *[Elytrigia repens* (L.) Nevski.*]*, annual bluegrass *(Poa annua* L.*)* and sedges *(Cyprus* spp.*)* have been reported to be moderately resistant to fenoxaprop (Bieringer et el., 1982, Anon., 1987). For weed control in rice, propanil, molinate, and acifluorfen have been recommended (Smith, 1974a; Smith and Khodayari, 1985; Hassan et al., 1986; Barker et al., 1986; Wills and Street, 1988). However, one problem with the aerial applications of propanil and other herbicides is that adjoining cotton and soybean crops can suffer setbacks due to spray drift. In Pakistan, the diversity of crops in a locality can pose a similar problem with the spray drift. One advantage with fenoxaprop is that it is selective on all dicotyledonous species along with having the potential to selectively control the prevailing grasses in rice (Snipes and Street, 1987a, Snipes and Street, 1987b, Snipes et al., 1987, Smith 1988b, Smith 1988c, Stauber, et al. 1991). However, Minton et al. (1990) reported that fenoxaprop did not control red rice as well as other graminicides did.

Timing of chemical weed control has an important impact on the efficacy of herbicides. For best economic returns, it needs to be applied at the most tolerant stage of the crop coupled with the most vulnerable stage of weeds. An increased tolerance to herbicides due to age has been reported in several weed and crop species (Wu and Santelmann, 1976; Street and Richard, 1983; Kells et al., 1984; Buhler and Burnside, 1984; Warren et al., 1988; Peters et al., 1989; Neal et al., 1990). Increased tolerance to fenoxaprop with age has been reported by Snipes et al., 1987; Snipes and Street, 1987b. Snipes and Street (1987b), however, reported reduced yield with fenoxaprop application at booting and heading stages of rice. In some studies no influence of growth-stage on tolerance or decreased tolerance with growth even in the vegetative phase of growth has been reported (Lefsrud and Hall, 1989; Carlson and Wax, 1970). Sensitivity to 2,4-D at the floral initiation stage of wheat and barley (Olsen et al., 1951) and rice (Smith, 1958) has also been shown. Smith (1988c) also reported a decline in tolerance of rice to propanil and other herbicides at the late booting stage.

Tolerance in U.S rice to fenoxaprop has already been documented, but the tolerance among the Pakistani rice germplasm to fenoxaprop has never been investigated. Despite the availability of labor, hand weeding is sometimes impracticable due to hot standing water in the crop coupled with hot weather and morphological resemblance of weedy grasses to rice and the morphological mimicry existing in barnyardgrass.

Therefore, present studies were undertaken under field conditions at the Agricultural Research Institute, Dera Ismail Khan, Pakistan, with the following objectives: a) to determine if there was any tolerance among the local rice germplasm to fenoxaprop, b) to quantify the degree of tolerance, and c) to evaluate possible differential response of cultivars at different growth-stages.

MATERIALS AND METHODS

Two separate experiments were conducted at the Agricultural Research Institute, Dera Ismail Khan, Pakistan. The soil was silty clay loam with a *p*H of 7.8, 0.79% organic matter content and an electrical conductivity ($E.Cx10^6$) of 800 m.mhos. The first experiment laid out in a split-split plot in randomized block design consisted of three growth-stages, 8 rates (including two checks), and 5 varieties. The growth-stages were in main plots, herbicide rates were applied in sub-plots, whereas varieties were assigned to the sub-sub-plots. Each treatment was replicated 3 times and was randomly assigned once to each block. Individual sub-sub-plots were 2.5 by 1 m. The growth-stages included 4-5 leaf stage (20 days after transplanting, DAT), tillering stage (30 DAT), jointing stage (40 DAT). The herbicide rates included two checks (one of them to be harvested for recording initial weight and the other along with rest of the treatments), 28, 56, 112, 168, 224, and 336 g ai ha^{-1} of fenoxaprop-ethyl. The cultivars occupying the sub-sub plots were JP 5, IR 6, KS 282, Basmati 385, and Basmati 370. The cultivar JP 5 is an early maturing coarse, IR 6 and KS 282 are intermediate both in quality and maturity, while Basmati 385 and Basmati 370 are fine quality, long grain, full-season cultivars. An approximately 45 days old nursery was obtained from Rice Breeding section of the Institute and was transplanted manually into a well-prepared seedbed on July 12, 1989. The nursery for the variety JP 5 was very weak at the time of transplanting due to its dense growth in the nursery bed. Prior to planting phosphorus and potassium were added in the form of single superphosphate and potassium sulphate at 90 and 60 kg ha^{-1}, respectively. Nitrogen was added in the form of urea at 120 kg ha^{-1} in two split doses. Half was applied at transplanting and another half was applied one month later. Experiment was flooded twice a week. Due to scarcity of irrigation water, permanent flood could not be maintained. Fenoxaprop treatments were applied with a backpack sprayer by using a calibrated quantity of water. Furadon granules at 8 kg ha^{-1} were applied for the control of rice stem borers (*Tryporyza* spp.). There was a differential tolerance to stem borer among the varieties, and JP 5 appeared to be most susceptible in this experiment. Data were recorded on plant height (cm) and fresh-weight (g) per plot. For fresh-weight the central two rows (2.50 X 0.50 m^2) were harvested from each sub-sub plot 30 days after the treatment. Relative fresh weight (R. Fwt) for each treatment was determined as reported by Morrison and Maurice (1984) as under:

$$R.\ Fwt = \frac{Fwt_t - Fwt_0}{Fwt_c - Fwt_0} \times 100$$

where:

Fwt_0 = fresh-weight/plot at the time of spray

Fwt_t = fresh-weight/plot of treatment

Fwt_c = fresh-weight/plot of check

Per plot data were subjected to ANOVA and significant means were separated by using Duncan's multiple range test by using SAS® computer program (SAS/STAT™).

Transplanted on July 19, 1989, the details of the second experiment were similar to the first experiment except that it was conducted at a 4-5 leaf growth-stage. It was laid out in a split plot design and the nursery was obtained from the Rice Research Institute Kala Shah Kaku, Lahore, Pakistan, 250 miles away from the site of the experiment. Also, the cultivar JP 5 was substituted with Basmati 198, a medium stature fine rice. The data were recorded on number of tillers per plant, plant height (cm), and per plot fresh-weight (g). Data were analyzed and interpreted as detailed above.

RESULTS AND DISCUSSION

Field Experiment 1. No visual injury symptoms of fenoxaprop were noticed on any of the cultivars at any of the growth-stages. The cultivars and the application dates differed

(Table 4.1a) in the post-treatment accumulation of fresh-weight (P=0.0001), while there was no overall response of fenoxaprop application rate (P=0.2573). All the interactions involving fenoxaprop rate were also non-significant (Table 4.1a). Likewise, the same pattern existed for relative fresh-weight (Table 4.1b). However, for relative fresh-weight significant differences also existed for the interaction of cultivar with date of fenoxaprop application (P=0.0006). There were no significant differences among fenoxaprop rates for relative fresh-weight (P=0.2776). Similarly the interaction of fenoxaprop rates with the cultivar was also non-significant (Table 4.1b). The cultivars differed for plant height and the relative plant height (P=0.0001), while the interaction of cultivars with date of fenoxaprop application was significant (P=0.0002) only for the relative plant height (Table 4.1c-4.1d).

The main effects for fenoxaprop rate showed substantial variability for net fresh-weight and relative fresh-weight (Table 4.2a). The variability was not related to fenoxaprop injury, but may have been due to differential stimulation/weed competition of the cultivars. These findings are in line with the earlier work of Street and Richard (1983), Wills and Street (1988), and Smith (1988), who treated rice at different growth-stages with herbicides other than fenoxaprop, and found generally adequate tolerance within the rice germplasm. However, Smith (1958) and Smith (1988a) were concerned about the injurious effect of herbicides applied during reproductive phase. For fenoxaprop Khodayari et al., 1989; Snipes and Street, 1987a; and Snipes et al., 1989 did not record any injury to rice under field conditions even at 336 g ha^{-1} fenoxaprop. Our highest rate also was 336 g ha^{-1}. Although non-significant statistically, there is a trend of decreasing plant height with the increasing fenoxaprop rate (4.2b).

The main effect of growth-stage (Table 4.2c) shows that the tolerance increased when the application of fenoxaprop was delayed from 20 DAT to 30 DAT, but a further delay (40 DAT) in treatment reduced plant growth. The decrease in fresh-weight can most probably be ascribed to prolonged weed competition in 40 DAT treatments. However, Smith (1958); Smith (1974a); Smith (1988b); Snipes et al., (1987) also noticed injury at booting or later growth-stages of rice.

Two-way interaction of cultivar by fenoxaprop rate (Table 4.2d) did not show a severe inhibition of any of the cultivars at any of the rates, when averaged across the growth-stages. Similarly, the interaction of cultivar by growth-stage (Table 4.2e) did not severely injure the cultivars at any of the growth-stages, when averaged across fenoxaprop rates except Basmati 385 and JP 5 at 20 DAT. Three-way interaction (Table 4.2f) shows the susceptibility of JP 5 and Basmati 385. Some of the values do not follow the trend, which can be attributed to saline patches in the soil, and lack of precise land levelling. The nursery for JP 5 was very weak as compared to rest of the cultivars. Therefore, its susceptibility at 20 DAT is not unexpected. Once JP 5 plants had a chance to establish in the soil their tolerance went up. At 40 DAT, despite being in the booting stage, JP 5 exhibited improved tolerance as compared to the previous stages (Table 4.2f).

Field Experiment 2. Field Experiment 2 was a short version of field experiment 1. There was only a single treatment date, and due to limited availability of nursery stock, Basmati 198 was substituted for JP 5. In addition to plant height and fresh-weight, data were also recorded for no. of tillers/hill. In this experiment, chlorosis of the leaf tips was noticed, which was more pronounced with the increased rate of fenoxaprop application. The symptoms were not as reported by Oosterhuis et al., (1990), or as we subsequently observed in the greenhouse studies (Chapter V). All the cultivars fully recovered after 3 wk.

Like Field Expt. 1 there was no response to fenoxaprop rate for all the traits under study (Table 4.3a-4.3e) as well as their interaction with the cultivars. However, the cultivars showed differences (P=0.0001) for the tiller number (Table 4.3a), plant height (Table 4.3c), relative fresh-weight (Table 4.3d) and relative plant height (Table 4.3e). The main effects for fenoxaprop rate do not show any statistical differences for fresh-weight, relative fresh-weight, and plant height (Table 4.4a). The highest number of tillers were obtained in 112 g ha^{-1}. Below that rate there was probably substantial weed competition and possibly some slight rice injury. Apparently, 112 g ha^{-1} was near a compensation point where the benefit from fenoxaprop application in terms of weed control nullified any direct injurious effects.

A higher relative fresh-weight (Table 4.4b) was harvested from the taller cultivars Basmati 370, Basmati 385, and Basmati 198, as compared to the short-statured cultivars KS 282 and IR 6. Probably the taller cultivars at lower rates of fenoxaprop could compete with weeds better than the shorter ones. Differential competitive ability of rice cultivars with weeds has already been documented (Smith, 1974b; Diarra et al., 1985; Kwon et al., 1991; Stauber et al., 1991a). The interaction of cultivars with fenoxaprop rates shows slight injury in KS 282 and IR 6 (Table 4.4c).

Despite some variability in the experiments the data provide good evidence that fenoxaprop can be used at normal recommended field use rates of 180 g ha^{-1} (WHIP®) under the prevailing conditions of Pakistan. We observed (data not reported) about 90% control of tillering barnyardgrass with 224 g ha^{-1}. Nearly the same rates of fenoxaprop have been used for barnyardgrass control in the U.S (Snipes and Street, 1989). Possible synergistic mixtures with other graminicides (Harker and O'Sullivan, 1991) might be a good avenue for exploration with fenoxaprop. The method of screening tolerance to herbicides as advocated by Hubbard and Whitewell (1991) could prove a useful tool in assessing the tolerance.

Table 4.1a. Analysis of variance for fresh-weight in five cultivars of rice treated at three dates under field conditions of Dera Ismail Khan, Pakistan (Field Expt. 1)

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
Rep	2	50806.1	25403.1	1.74	0.2854
Date	2	208693.9	104347.0	7.16	0.0477
Error a	4	58281.1	14570.3		
Rate	6	14735.7	2455.9	1.36	0.2573
Rate*date	12	22358.0	1863.2	1.03	0.4429
Error b	36	65042.7	1806.7		
Cultivar	4	134630.3	33657.6	26.42	0.0001
Cultivar*date	8	33020.6	4127.6	3.24	0.0020
Rate*cultivar	24	34836.5	1451.6	1.14	0.3085
Rate*cultivar*date	48	59458.6	1238.7	0.97	0.5313
Error c	151	192367.0	1274.0		

Table 4.1b. Analysis of variance for relative fresh-weight in five cultivars of rice treated with fenoxaprop at three dates under field conditions of Dera Ismail Khan, Pakistan (Field Expt. 1)

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
Rep	2	25803.7	12901.9	2.12	0.2358
Date	2	20742.7	10371.3	1.70	0.2917
Error a	4	24362.1	6090.5		
Rate	6	11383.3	1897.2	1.31	0.2776
Rate*date	12	15611.8	1301.0	0.90	0.5568
Error b	36	52118.9	1447.7		
Cultivar	4	28825.0	7206.3	7.43	0.0001
Cultivar*date	8	28553.4	3569.2	3.68	0.0006
Rate*Cultivar	24	27717.1	1154.9	1.19	0.2587
Rate*cultivar*date	48	41549.8	865.6	0.89	0.6692
Error c	151	146419.0	969.7		

Table 4.1c. Analysis of variance for plant height in five cultivars of rice treated at two dates under field conditions of Dera Ismail Khan, Pakistan (Field Expt. 1)

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
Rep	2	2090.1	1045.0	0.72	0.5814
Date	1	23681.5	23681.5	16.32	0.0562
Error a	2	2902.8	1451.4		
Rate	6	543.5	90.6	0.73	0.6289
Rate*date	6	1035.0	172.5	1.39	0.2577
Error b	24	2971.2	123.8		
Cultivar (Cul.)	4	6108.3	1527.1	13.88	0.0001
Cul.*date	4	745.9	186.5	1.70	0.1568
Rate*Cultivar	24	3002.5	125.1	1.14	0.3188
Rate*cul.*date	24	2238.8	93.3	0.85	0.6685
Error c	102	11218.6	110.0		

Table 4.1d. Analysis of variance for relative plant height in five cultivars of rice treated with fenoxaprop at two dates under field conditions of Dera Ismail Khan, Pakistan (Field Expt. 1)

Source	DF	Sum of Squares	Mean Squares	F value	Pr > F
Rep	2	1905.3	952.6	0.63	0.6146
Date	1	412.0	412.1	0.27	0.6544
Error a	2	3037.8	1518.9		
Rate	6	746.5	124.4	0.69	0.6580
Rate*date	6	1177.5	196.3	1.09	0.3954
Error b	24	4313.2	179.7		
Cultivar (Cul.)	4	7217.1	1804.3	12.53	0.0001
Cul.*date	4	3435.0	858.7	5.96	0.0002
Rate*Cultivar	24	3782.4	157.6	1.09	0.3640
Rate*cul.*date	24	3214.8	133.9	0.93	0.5625
Error c	102	14693.0	144.0		

Table 4.2a. Main effect of fenoxaprop rate on net and relative fresh-weight, plant height, and relative height of five rice cultivars under field conditions of Dera Ismail Khan, Pakistan (Field Expt. 1).

Fenoxaprop Rate	Fresh Weight	Rel. Fresh Weight	Plant Height	Rel. Plant Height
(g ha^{-1})	(g)	(% of check)	(cm)	(% of check)
0	132.1ab	100.0ab	89.5a	100.4a
28	139.0a	108.1a	89.8a	101.3a
56	127.9ab	96.3ab	88.3a	99.3a
112	134.8ab	102.8ab	91.3a	103.2a
168	118.8b	89.4b	88.2a	100.1a
224	120.9b	90.9b	87.2a	98.3a
336	123.1ab	94.9ab	85.9a	96.8a

Table 4.2b. Main effect of cultivar on net and relative fresh-weight, plant height, and relative plant height of five rice cultivars under field conditions of Dera Ismail Khan, Pakistan (Field Expt. 1).

Cultivar	Fresh Weight	Rel. Fresh Weight	Plant Height	Rel. Plant Height
	(g)	(% of check)	(cm)	(% of check)
KS282	147.5a	98.9a	84.3cd	95.6c
IR6	148.2a	103.6a	81.1d	102.1b
Basmati 385	132.3b	89.2bc	93.1ab	94.6c
Basmati 370	113.4c	110.1a	95.8a	110.3a
JP5	89.3d	81.5c	89.0bc	96.0c

Table 4.2c. Main effect of growth-stage on fresh-weight, relative fresh-weight, plant height, and relative plant height of five rice cultivars under field conditions of Dera Ismail Khan, Pakistan (Field Expt. 1).

Growth Stage	Fresh Weight	Rel. Fresh Weight	Plant Height	Rel. Plant Height
(DAT†)	(g)	(% of check)	(cm)	(% of check)
20	92.5a	87.3a	77.7a	98.5a
30	154.4c	107.7c	99.7b	101.4b
40	138.9b	98.0b	††	††

† DAT = Days after transplanting
†† Data not recorded for 40 DAT

<u>Table 4.2d.</u> Cultivar by fenoxaprop rate interaction for relative fresh-weight in five rice cultivars under field conditions of Dera Ismail Khan, Pakistan (Field Expt. 1).

	Fenoxaprop (g ha^{-1})					
Cultivar	28	56	112	168	224	336
	(% of check)					
KS282	112.3	86.6	104.5	98.1	94.4	96.2
IR6	108.1	103.2	113.0	113.4	98.9	88.5
Basmati 385	94.2	89.7	98.6	75.5	89.1	75.8
Basmati 370	141.7	118.3	115.9	82.5	89.2	123.3
JP5	77.7	77.2	76.2	74.3	80.3	86.8

<u>Table 4.2e.</u> Cultivar by growth-stage interaction for relative fresh-weight in five rice cultivars under field conditions of Dera Ismail Khan, Pakistan (Field Expt. 1).

	Growth-stage (DAT)		
Cultivar	20	30	40
	(% of check)		
KS282	106.6	94.6	95.5
IR6	101.0	112.4	97.5
Basmati 385	61.5	117.0	87.8
Basmati 370	98.4	119.7	112.3
JP5	65.8	88.1	96.2

<u>Table 4.2f</u>. Cultivar by growth-stage by fenoxaprop rate interaction for relative fresh-weight in five rice cultivars under field conditions of Dera Ismail Khan, Pakistan (Field Expt. 1).

Cultivar	Growth Stage	Fenoxaprop (g ha^{-1}) 28	56	112	168	224	336
	(DAT)[4]	(% of check)					
KS282	20	150.8	82.7	104.4	110.4	91.7	105.8
KS282	30	88.8	87.2	95.4	98.1	96.2	96.8
KS282	40	97.4	89.8	113.8	85.9	95.3	85.9
IR6	20	96.3	82.4	117.4	131.1	98.4	81.5
IR6	30	125.7	116.2	123.5	103.9	110.2	106.9
IR6	40	102.4	111.0	98.2	105.3	88.4	77.1
Basmati 385	20	43.1	72.6	62.5	59.6	51.3	30.9
Basmati 385	30	148.3	112.3	144.2	79.9	130.7	103.8
Basmati 385	40	91.1	84.1	90.0	87.1	85.2	77.8
Basmati 370	20	147.4	79.2	79.6	79.6	72.5	92.7
Basmati 370	30	166.4	136.8	66.3	66.3	92.9	171.7
Basmati 370	40	111.3	138.8	101.5	101.5	102.3	105.4
JP 5	20	57.5	71.2	73.0	70.9	52.0	28.0
JP 5	30	82.5	82.3	84.6	69.7	101.2	95.4
JP 5	40	103.1	78.2	72.6	83.9	101.0	134.4

<u>Table 4.3a.</u> Analysis of variance for tiller number in five cultivars of rice under field conditions of Dera Ismail Khan, Pakistan (Field Expt. 2).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
Rep	2	65.4	32.7	3.07	0.0840
Rate	6	54.3	9.0	0.85	0.5573
Error a	12	127.9	10.7		
Cultivar	4	70.0	17.5	2.31	0.0176
Rate*cultivar	24	102.4	4.3	0.93	0.5688
Error b	56	258.0	4.6		

[4]DAT = Days after transplanting

Table 4.3b. Analysis of variance for net fresh weight in five cultivars of rice treated with seven rates of fenoxaprop under field conditions of Dera Ismail Khan, Pakistan (Field Expt. 2).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Rep	2	2113464.6	1056732.3	8.89	0.0043
Rate	6	506880.0	84480.0	0.70	0.6477
Error a	12	1425700.2	118808.4		
Cultivar	4	505519.4	126379.8	1.29	0.2844
Rate*cultivar	24	2560608.4	106692.0	1.09	0.3834
Error b	56	5479555.9	97849.2		

Table 4.3c. Analysis of variance for plant height in five cultivars of rice treated with seven rates of fenoxaprop under field conditions of Dera Ismail Khan, Pakistan (Field Expt. 2).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Rep	2	4.5	2.5	0.04	0.9567
Rate	6	325.6	54.3	0.98	0.4817
Error a	12	667.4	55.6		
Cultivar	4	6411.1	1602.8	38.50	0.0001
Rate*cultivar	24	923.9	38.1	0.91	0.5828
Error b	56	2331.2	41.6		

Table 4.3d. Analysis of variance for relative fresh-weight in five cultivars of rice treated with seven rates of fenoxaprop under field conditions of Dera Ismail Khan, Pakistan (Field Expt. 2).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
Rep	2	22984.1	11492.1	10.86	0.0020
Rate	6	5640.8	940.1	0.89	0.5326
Error a	12	12700.8	1058.4		
Cultivar	4	51398.0	12849.5	12.32	0.0001
Rate*cultivar	24	26693.7	1112.2	1.07	0.4081
Error b	56	58396.6	1042.8		

Table 4.3e. Analysis of variance for relative plant height in five cultivars of rice treated with seven rates of fenoxaprop under field conditions of Dera Ismail Khan, Pakistan (Field Expt. 2).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr>F
Rep	2	6.7	3.4	0.04	0.9649
Rate	6	586.0	97.7	1.04	0.4458
Error a	12	1124.9	93.7		
Cultivar	4	1910.5	477.6	6.97	0.0001
Rate*cultivar	24	1550.7	64.6	0.94	0.5493
Error b	56	3839.2	107.9		

Table 4.4a. Main effect of fenoxaprop rate on tiller number, net and relative fresh-weight, plant height, and relative height of five rice cultivars under field conditions of Dera Ismail Khan, Pakistan (Field Expt. 2).

Fenoxaprop Rate	Tiller Number	Fresh Weight	Rel. Fresh Weight	Plant Height	Rel. Plant Height
($g\ ha^{-1}$)		(kg)	(% of check)	(cm)	(% of check)
0	11.5ab	1.03a	100.0a	76.1a	100.0a
28	10.2b	1.08a	114.5a	73.1a	96.2ab
56	10.3b	1.07a	107.0a	75.8a	99.6a
112	12.4a	1.17a	117.1a	74.1a	97.3ab
168	11.6ab	1.19a	121.5a	75.8a	99.2ab
224	11.5ab	1.02a	105.4a	74.3a	97.5ab
336	11.7ab	1.00a	103.4a	70.7a	92.6b

Table 4.4b. Main effect of cultivar on net and relative fresh-weight, plant height, and relative plant height of five rice cultivars under field conditions of Dera Ismail Khan, Pakistan (Field Expt. 2).

Cultivar	Tiller Number	Fresh Weight	Rel. Fresh Weight	Plant Height	Rel. Plant Height
		(kg)	(% of check)	(cm)	(% of check)
KS282	11.6a	1.17a	81.1b	68.1d	93.8c
IR6	12.2a	1.03a	86.5b	63.9e	95.3bc
Basmati 385	10.7ab	1.16a	119.0a	79.8b	93.6c
Basmati 370	10.0b	1.03a	125.0a	85.6a	104.5a
Basmati 198	12.0a	1.02a	137.5a	74.0c	100.3ab

Table 4.4c. Cultivar by fenoxaprop rate interaction for relative fresh-weight in five rice cultivars under field conditions of Dera Ismail Khan, Pakistan (Field Expt. 2).

Cultivar	Fenoxaprop rate (g ha^{-1})					
	28	56	112	168	224	336
	(% of control)					
KS282	60.4	99.9	89.4	86.1	65.7	66.5
IR6	82.5	71.6	99.9	90.3	81.2	79.8
Basmati 385	116.2	109.1	149.7	139.0	118.2	101.0
Basmati 370	130.5	118.0	115.4	163.1	132.2	115.5
Basmati 198	182.6	136.3	131.1	128.9	129.8	153.9

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Chapter 5.

The Influence of Rate and Time of Application of Fenoxaprop on Rice *(Oryza sativa)* Genotypes under Greenhouse Conditions.

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Abstract. Experiments were carried out in greenhouse to evaluate the tolerance in six exotic (from Pakistan) and one local (Mars) rice cultivars to fenoxaprop as influenced by growth-stage. The cultivars differed in tolerance to fenoxaprop. Due to the high tolerance of the tolerant cultivars at the 4-leaf or jointing growth-stages, GR_{50} values could not be estimated in all cases. However, there were several-fold differences between the most and the least tolerant cultivars at all stages. About a 6-fold increase in tolerance was measured at the 4-leaf compared to the 2-leaf growth-stage. However, based on cultivar mean, no further gain in tolerance occurred be attained after the 4-leaf stage. JP 5 and the KS 282 were the most tolerant, whereas Basmati 198 and Mars were the most susceptible cultivars. The tolerant cultivars continued increasing in tolerance until the jointing stage, but susceptible cultivars like Mars failed to attain any greater tolerance with age. Nomenclature:

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Fenoxaprop[2], (±)-2-[4-[(6-chloro-2-benzoxazolyl)oxy]phenoxy]-propanoic acid; Rice, *Oryza sativa* L.

<u>*Additional index words.*</u> Postemergence application, fresh-weight, dry-weight, GR_{50}, susceptibility, 2-leaf stage, 4-leaf stage, jointing stage.

INTRODUCTION

Rice *(Oryza sativa* L.*)* is a staple food of the teeming millions of people in the world. Losses due to weed competition have been estimated at 9 to 63% of the rice crop in the Indian sub-continent (Mani et al., 1968; Ahmad and Majeed, 1975; Ghauri et al., 1979). At the International Institute for Tropical Agriculture, Nigeria, losses of 73% in rice yield due to weed infestation occurred (Diop and Appleby, 1989). Smith (1988a) reported a 17% loss of rice grain yield due to weed competition in United States exceeding the cumulative loss due to insects and diseases. Grasses are the most competitive and costly weeds of rice. Among the grasses in the order of their economic importance are red rice *(Oryza*

[2]Mention of trademark or proprietary product does not constitute a guarantee or warranty of the product by the Oregon State University and does not imply its approval to the exclusion of other products that may equally be suitable.

sativa L. #[3] ORYSA*)*, barnyardgrass *[Echinochloa crus-galli* (L.) Beauv. # ECHCG*]*, bearded sprangletop *[Leptochloa fascicularis* (Lam.) Gray. #LEFFI*]*, and broadleaf signalgrass *[Brachiaria platyphylla* (Griseb.) Nash # BRAPP*]*. Up to 90% losses in rice have been reported for season-long competition with barnyardgrass or red rice (Smith, 1968; Smith, 1974b; Smith, 1988a; Khodayari et al., 1989; Diarra et al., 1985; Pantone and Baker, 1991).

Fatty acid synthesis inhibitors, the grass-specific aryloxyphenoxypropanoic acid herbicides, offer good control of grasses in dicotyledonous as well within *Poeaceous* crops (Hosaka et el., 1984, Andersen, 1976, Warren et al., 1989, Beardmore and Linscott, 1989; Leys et al., 1989; Street and Snipes, 1987b; Harker and Blackshaw, 1991). They share this property with cyclohexanediones. Fenoxaprop-ethyl, an aryloxyphenoxypropionate, discovered in the laboratories of Hoechst AG Frankfurt, Germany (Bieringer et al., 1982), has emerged as a prominent warm season annual and perennial grass killer (Beringer et al., 1982; Matolcsy et al., 1988; Peters et al., 1989). The crops of economic importance tolerant of fenoxaprop include cotton, soybean, tobacco, ryegrass, and rice (Anon., 1987; Mueller-Warrant and Brewster, 1986; Bieringer et al., 1982, Street and Snipes, 1987, Carter and

[3]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 309 West Clark Street, Champaign, IL 61820.

Kelley, 1987). Economically important, very susceptible weed species include blackgrass *(Alopecurus myosuroides* Huds.*)*, oats *(Avena* spp.*)*, foxtail *(Setaria* spp.*)*, johnsongrass *(Sorghum halepense* (L.) Pers. # SORHA*)*, barnyardgrass *(Echinochloa crus-galli)*, crabgrass *(Digitaria* spp.*)* and red rice (Beringer et el.; 1982, Anon., 1987).

For weed control in rice, propanil, molinate, and acifluorfen have been recommended (Smith, 1974a; Smith and Khodayari, 1985; Hassan et al., 1986; Barker et al., 1986; Wills and Street, 1988). One problem with the aerial applications of propanil and other herbicides is that the adjoining cotton and soybean crops can suffer a setback due to a spray drift. Advantages with the fenoxaprop are that it is selective on all dicotyledonous species, has the potential to selectively control the prevailing grasses in rice, and is effective on the advanced growth stages of weeds (Street and Snipes, 1987; Smith and Khodayari, 1987; Snipes and Street, 1987a; Smith 1988b; Smith 1988c; Griffin and Baker, 1990; Stauber et al., 1991b). However, Minton et al., (1990) recently showed the failure of fenoxaprop to control red rice compared to other grass-killers.

Timing of chemical weed control has an important impact on the efficacy of herbicides. For good economic returns herbicides need to be applied at the most tolerant stage of the crop coupled with the most vulnerable stage of weeds. An increased tolerance to herbicides due to age has been reported in several weed and crop species (Street and Richard, 1983; Kells et al., 1984; Buhler and Burnside, 1984; Warren et al., 1988; Peters et al., 1989). Increased tolerance to fenoxaprop in rice with more advanced growth-stage has been reported by Snipes et al., 1987, and Snipes and Street, 1987a. Snipes and Street (1987a), however, reported reduced yield with fenoxaprop application at booting and heading stages of rice. Smith (1988c) and Salzman et al. (1988) also reported declines in tolerance of rice and red rice at their reproductive stages.

Tolerance in U.S rice to fenoxaprop has already been documented, but the tolerance among the Pakistani rice germplasm to fenoxaprop has never been investigated. Despite the availability of labor, hand weeding is sometimes impracticable due to harsh weather, similarity of grasses in general with rice, and a high degree of morphological mimicry of barnyardgrass with rice. Therefore, studies were undertaken under field conditions at the Agricultural Research Institute Dera Ismail Khan, Pakistan, during summer 1989. The present studies were carried out in the greenhouse at Oregon State University Corvallis, Oregon to verify the field observations, with these objectives: a) determine whether there is any tolerance among the rice germplasm to fenoxaprop, b) to quantify this degree of tolerance, and c) to evaluate potential differential response of the cultivars at different growth-stages.

MATERIALS AND METHODS

Greenhouse Experiments. Seed of six cultivars, viz. Basmati 385, Basmati 370, Basmati 198, JP 5, KS 282, and IR 6, used in the field experiments was imported from Pakistan. The seed of one cultivar previously evaluated as fenoxaprop susceptible (Griffin and Baker, 1990; Smith, 1990, Personal communication) was obtained from the Rice Research and Extension Center, Stuttgart, Arkansas.

Whole Plant Experiment 6. Plants were grown in the greenhouse environment in individual plastic cones (4 cu. in. Pine cell Rayleach "Container"®)[4] filled with pasteurized potting mixture of sand, peat, loam, and pumice in a ratio of 1:1:1:3 by volume and *p*H corrected to 6.5. Ten seeds were planted in each pot on December 15, 1990. Each pot was subsequently thinned to two seedlings, on 10 January, 1990. Some of the extra seedlings were then transplanted into additional pots filled with the same potting mix for subsequent treatment with fenoxaprop at the 4-leaf stage. Due to poor viability, cultivars Basmati 370 and Basmati 198 could not be included in 4-leaf stage studies. The experiment was a completely randomized design consisting of a factorial arrangement of 2- and the 4-leaf growth-stages, seven cultivars (only five cultivars were included in the 4-leaf growth stage), nine fenoxaprop rates (including three checks, one check harvested

[4]Stuewe & Sons, Inc. Corvallis OR, 97330

for recording the initial weight and the other two harvested along with all other treatments), was replicated four times at the 2-leaf stage, but only three times at the 4-leaf stage. Fenoxaprop-ethyl rates included 0, 28, 84, 140, 196, 280, and 448 g ha^{-1}. Temperatures of 26/15 C day/night were maintained throughout the growing period. Natural light was supplemented with artificial irradiance of 400 $\mu mol\ m^{-2}\ s^{-1}$ photosynthetically active radiation for maintaining the 16-h photoperiod. Irrigation water temperature was maintained at 23 C throughout the growing period. Soluble fertilizer (N:P:K at 20:20:20), was applied twice a wk during the growth period. Plants were treated on 15 January, 1991 at the 2-leaf stage with commercially formulated fenoxaprop-ethyl using a pressurized air, bicycle sprayer delivering at 480 L ha^{-1}. For the 4-leaf stage, the treatment was done on 13 February, 1991. Data were recorded on fresh and dry-weights (g) per treatment for each growth-stage about four wk after spraying. Because the initial dry-weight was not recorded for the first growth-stage, the relative dry-weight at the 2-leaf stage refers to the gross dry-weight from sowing till harvesting and not the post-treatment gain. Relative fresh-weight (R. Fwt) and relative dry-weight (R. Dwt) for all other treatments was determined as defined by Morrison and Maurice (1984) as follows:

$$R.\ Fwt = \frac{Fwt_t - Fwt_0}{Fwt_c - Fwt_0} \times 100$$

where:

Fwt_0 = fresh-weight per pot at the time of spraying

Fwt_t = fresh-weight per pot of treatment at final harvest

Fwt_c = fresh-weight per pot of check at final harvest

$$R.\ Dwt = \frac{Dwt_t - Dwt_0}{Dwt_c - Dwt_0} \times 100$$

where:

Dwt_0 = dry-weight per pot at the time of spraying

Dwt_t = dry-weight per pot of treatment at final harvest

Dwt_c = dry-weight per pot of check at final harvest

Per pot data were subjected to ANOVA and significant means were separated by using Duncan's multiple range test by using SAS® computer program (SAS/STAT™, 1989). As only five cultivars were included in the second growth-stage, analysis was run for each growth-stage separately. Cultivar-wise regression analysis were run for both growth-stages for computing GR_{50} values (fenoxaprop g ha^{-1} to reduce the fresh or dry post-treatment weight by 50% as compared to the check mean).

Whole Plant Experiment 7. When the rice cultivar evaluation study was repeated in Whole plant Expt. 7, seedling nurseries were raised in flats. Each cultivar was planted on 16 February, 1991 in a separate flat filled with a potting mixture as described earlier. In each flat 40 g garden fertilizer (14:14:14 N:P:K) was added at the planting time of nursery. Transplanting of the nursery into plastic cones filled with potting mix as described in Expt. 6 was done on March 1, 1991. Garden fertilizer (14:14:14 N:P:K) in 1:100 by weight was mixed with the potting mix before filling the cones. All experimental details were the same as in the Expt. 6 except none of the cultivars was missing in any of the growth-stages and a third growth-stage, viz. jointing, was also used. In addition to previously mentioned rates, an additional rate of 840 g ha^{-1} was used for second and the third growth-stages. Data were recorded the same as in whole plant experiment 6. For the analysis of variance, since the 840 g ha^{-1} treatment was lacking at the 2-leaf growth-stage, two separate analyses have been presented. One analysis was run on all rates excluding 840 g ha^{-1} from second and the third growth-stages, whereas the other analysis is run without the 2-leaf growth-stage.

ACCase Assay. Details of laboratory procedures are the same as given in Chapter 3 for Italian ryegrass. Growth-stages for ACCase activity assays were the same for rice as in Italian ryegrass. Rice was grown under the conditions described for the whole plant tolerance studies.

RESULTS AND DISCUSSION

Whole plant Experiment 6. Differences were observed among the cultivars in response to fenoxaprop. Phytotoxicity symptoms were observed beginning two to three days after treatment with fenoxaprop. The symptoms consisted of white chlorotic specs (bands) on older leaves, similar in appearance to a leaf spot disease. Such bands apparently had been in direct contact with the droplets of fenoxaprop spray (Oosterhuis et al., 1990). The plants either recovered within 3 wk from these symptoms or died in case of susceptible plants. Differences were observed ($P \leq 0.05$) among the fenoxaprop rates, cultivars, and their interaction (Table 5.1a) for fresh-weight. Similarly significant differences ($P \leq 0.006$) existed among the rates of fenoxaprop and cultivars for dry-weight, relative dry-weight, and relative fresh-weight (Table 5.1b-5.1d). For the 4-leaf stage the differences among the cultivars and fenoxaprop concentrations were significant ($P \leq 0.04$) for all the traits under reference (Table 5.2a-5.2d). GR_{50} estimates revealed the relative susceptibility of the cultivars Basmati 198, IR 6, and Basmati 370 at the 2-leaf stage (Table 5.3), although all cultivars would have been seriously injured by normal fenoxaprop use rates of 168 g ha^{-1}. The cultivars Basmati 370 and Basmati 198 could not be tested at the 4-leaf stage due to shortage of plants. Among the remaining five cultivars IR 6 most dramatically improved its relative tolerance with age. Although all cultivars showed some increase in tolerance from the 2-leaf to the 4-leaf stage, Mars was the most susceptible cultivar at 4-leaf stage and had the least increase in GR_{50} (Table 5.3). Differential inter- and intraspecific behavior to herbicides has been evaluated for the fatty acid synthesis inhibitors (Andresen, 1976, Beardmore and Linscott, 1989, Chism and Bingham, 1991, Johnson et al., 1991). The susceptibility of Mars to fenoxaprop has already been reported (Griffin and Baker, 1990, Oosterhuis et al., 1990).

Significant differences existed among the main effects of fenoxaprop rate and cultivar (Table 5.4a-5.4b). Averaged over cultivars, almost no growth in fresh-weight occurred after treatment with fenoxaprop at 280 to 448 g ha^{-1} (Table 5.4a). Both fresh and dry-weight as well as the relative fresh and dry-weight show an inverse response to fenoxaprop rate. These same main effects for cultivars (Table 5.4b) rank them similar to the ranking in basically the same order as was done by the GR_{50} estimates.

Averaged over cultivars, increased tolerance was evident (Table 5.5a) at the 4-leaf stage as compared to the 2-leaf stage (Table 5.4a). Even at the highest fenoxaprop application rate, greater than 50% relative fresh and dry-weight growth was observed averaged across all cultivars. This gain in tolerance from the 2-leaf to 4-leaf growth-stage can further be evaluated from GR_{50} estimates on relative fresh-weight main effects (Table 5.4a and Table 5.5a foot notes). These GR_{50} values at 81 and 507 g ha^{-1} represent a more than 6-fold increase in tolerance as the plants advanced to the 4-leaf stage from the 2-leaf stage. The findings are a undoubtedly biased upward because the most susceptible cultivars Basmati 198 and Basmati 370 could not be included in the trial at the 4-leaf stage. However, there has obviously been a very substantial gain in tolerance anyway. These findings corroborate the earlier results of Snipes and Street, 1987a; Smith (1988a); Snipes et al., 1987; for fenoxaprop in rice. Several other workers have documented a proportionate increase in tolerance with age until reproductive phase (Kells et al., 1984; Warren et al., 1989; Peters et al., 1985; Street and Richard, 1983; Smith 1958; Wu and Santelmann, 1976).

Mars is clearly the most susceptible cultivar (Table 5.5b) at the 4-leaf stage. The interaction of cultivar with fenoxaprop rate (Table 5.5c) shows a depression both in the relative fresh and dry-weight for JP 5 at 84 g ha^{-1}. The cause of this unexpected depression is not obvious, but it may be that the transplanted seedlings do not establish by chance well into these cones. The cultivar IR 6 has greatly increased in tolerance compared to the 2-leaf stage. Even the 448 g ha^{-1} application of fenoxaprop is not very inhibitory to the tolerant cultivar KS 282.

Whole Plant Experiment 7. The experiment 6 was repeated in greenhouse for the confirmation of results and to evaluate all the cultivars at all growth-stages. The results of Whole plant Expt. 7 show that, due to better growth conditions, particularly in terms of solar radiation, regardless of growth-stage and cultivar, an overall increase in tolerance occurred as compared to whole plant experiment 6. Our previous results with Italian ryegrass also showed an increased tolerance in summer than the winter experiments (data presented in chapter II).

Differences occurred among rates, cultivars, and growth-stages (Table 5.6a), and almost all of their interactions ($P \leq 0.05$) for the relative fresh-weight. However, only main effects were significant for dry-weight (Table 5.6b). For the relative fresh and dry-weights (Table 5.6c-5.6d) all main effects and 2-way interactions were significant, but the 3-way interaction was of marginal significance, statistically ($P \geq 0.09$). The ANOVA shows the preponderance of variance to be due to rates and growth-stage. The analysis of variance for all 7 rates at the 4-leaf and the jointing growth-stages (Table 5.7a-5.7b) shows much the same response for fresh and dry-weights as the combined analysis of all three growth-stages on common rates. However, one deviation between the two analyses is that growth-stage is non-significant ($P \geq 0.13$) in the second type which only contrasts the 4-leaf and the jointing stage (Table 5.7c-5.7d).

The GR_{50} estimates (Table 5.8) support the previous trial's evaluation of the susceptibility of the cultivar Basmati 198 at the 2-leaf stage. Similarly at the 2-leaf stage JP 5 maintained its lead in tolerance as compared to other cultivars. Tolerance improved with age from the 2-leaf to the 4-leaf but it levelled off when the treatment with fenoxaprop was delayed until the jointing stage (Table 5.8). An obvious interaction of cultivars with growth-stage was seen

(Table 5.8). The cultivars KS 282 and IR 6 gained great tolerance with age, while Basmati 370 failed to have any major increase in tolerance as it grew older, and the cultivar Mars had a only a small gain in tolerance from 2- to the 4-leaf stage. These findings are in partial agreement with the work of Linscott and Vaughn (1990), Lefsrud and Hall (1989), and Carlson and Cox (1970), who reported either no gain or decreased tolerance with age. On the other hand these findings support the conclusions of Kells, et al., 1984; Warren et al., 1989; Peters et al., 1985; Street and Richard, 1983 and Neal et al., 1990 who estimated a positive relationship of tolerance with age.

The main effects of fenoxaprop rate (Table 5.9a) show the reciprocal response of all the parameters to fenoxaprop applications. Main effects of cultivars corroborate the tolerance as estimated by GR_{50} (Table 5.8). Evaluated by relative fresh and dry-weight, cultivars KS 282, JP 5, and IR 6, show their superiority in tolerance. The main effect for growth-stag and relative fresh-weight (Table 5.9c) echoes the effects seen in the GR_{50} estimates that tolerance increased from 2- to 4-leaf stage, but no further gain occurred beyond the 4-leaf stage. Two-way interaction (Table 5.10a) shows the stability of tolerant cultivars to increasing rates of fenoxaprop, whereas growth of susceptible cultivars like Basmati 370, Basmati 198, and Mars is inhibited at the four higher concentrations of fenoxaprop.

Cultivar by growth-stage interaction (Table 5.10b) shows that averaged over of fenoxaprop rate, an increase in tolerance was registered for all the cultivars, except Basmati 370 and Mars, as the application of fenoxaprop was delayed from 2- to the 4-leaf stage.

Although non-significant statistically, the 3-way interaction is presented in Table 5.11a-5.11b to preserve the original data. The trend of cultivars and rates as affected by growth-stage has already been discussed in GR_{50} estimates (Table 5.8).

Tables 5.12a-5.12c exhibit the main effects of cultivars at the 4-leaf and jointing stages. The trends are the same as discussed for all three stages excluding 840 g ha^{-1} from 4-leaf and jointing stages. No difference between the growth-stages for relative fresh and dry-weight was recorded (Table 5.12c). The trend in 2-way interactions (Table 2.13a-2.13b) is in accordance with the results of the all three growth-stages combined analysis.

The susceptibility of Mars to fenoxaprop is already posing a problem in controlling weeds in Arkansas. Due to its acceptable agronomic traits growers are eager to plant Mars and there is virtually no other herbicide comparable to fenoxaprop, so they end up with a yield loss due the phytotoxicity of the herbicide to the crop. Unfortunately, the present findings also endorse the susceptibility of Mars. As our findings and previous studies show the existence of genetic tolerance to fenoxaprop in the germplasm, a cultivar alternative to Mars could be evolved either through conventional breeding or genetic engineering. Screening for an alternative herbicide could be another option. For Pakistan, fenoxaprop can successfully be used on the tolerant cultivars which already occupy most of the acreage.

ACCase Inhibition in Rice. Fenoxaprop inhibited the ACCase in rice cultivars at the 2-leaf, 4-leaf, and tillering growth-stages differently (Table 5.14). The cultivars averaged over growth-stages differed among themselves (Table 5.14). The most susceptible cultivar at the whole plant level, viz. Basmati 198, possessed the most tolerant ACCase (Table 5.15). These findings tend to contradict our results on ACCase in Italian ryegrass, as presented in Chapter 3, where the most tolerant cultivar also possessed most tolerant isozyme of ACCase, although the magnitude of the difference at the enzyme level is small.

Table 5.1a. Analysis of variance for net fresh-weight in six exotic and one local rice cultivars at 2-leaf stage (Whole plant expt. 6).

Source	DF	Sum of Squares	Mean Squares	F value	Pr>F
Rate	6	93.0	15.50	90.19	0.0001
Cultivar	6	11.4	1.90	11.06	0.0001
Cultivar*rate	36	9.2	0.26	1.49	0.0497
Error	173	29.7	0.17		

Table 5.1b. Analysis of variance for dry-weight in six exotic and one local rice cultivars at 2-leaf stage (Whole plant Expt. 6).

Source	DF	Sum of Squares	Mean Squares	F value	Pr>F
Rate	6	4.73	0.79	43.82	0.0001
Cultivar	6	3.66	0.61	33.86	0.0001
Cultivar*rate	36	0.78	0.02	1.21	0.2102
Error	173	3.11	0.02		

Table 5.1c. Analysis of variance for relative dry-weight in six exotic and one local rice cultivars at 2-leaf stage (Whole plant Expt. 6).

Source	DF	Sum of Squares	Mean Squares	F value	Pr>F
Rate	6	140404.0	23400.7	41.64	0.0001
Cultivar	6	10494.5	1433.3	3.11	0.0064
Cultivar*rate	36	22264.8	618.5	1.10	0.3339
Error	173	97222.2	562.0		

Table 5.1d. Analysis of variance for relative fresh-weight gain in six exotic and one local rice cultivars at 2-leaf stage (Whole plant Expt. 6).

Source	DF	Sum of Squares	Mean Squares	F value	Pr>F
Rate	6	351416.5	58569.4	85.11	0.0001
Cultivar	6	14281.0	2380.2	3.46	0.0030
Cultivar*rate	36	29699.7	825.0	1.20	0.2212
Error	173	119053.9	688.2		

Table 5.2a. Analysis of variance for net fresh-weight in four exotic and one local rice cultivars at 4-leaf stage (Whole plant Expt. 6).

Source	DF	Sum of Squares	Mean Squares	F value	Pr>F
Rate	6	42.5	7.1	7.45	0.0001
Cultivar	4	60.4	1.9	15.91	0.0001
Cultivar*rate	24	34.2	1.4	1.50	0.0902
Error	84	11.2	0.1		

Table 5.2b. Analysis of variance for net dry-weight in four exotic and one local rice cultivars at 4-leaf stage (Whole plant Expt. 6).

Source	DF	Sum of Squares	Mean Squares	F value	Pr>F
Rate	6	7.1	1.2	8.88	0.0001
Cultivar	4	13.3	3.3	24.98	0.0001
Cultivar*rate	24	2.6	0.1	0.82	0.7005
Error	84	11.1	0.13		

Table 5.2c. Analysis of variance for relative fresh-weight in four exotic and one local rice cultivars at 4-leaf stage (Whole plant Expt. 6).

Source	DF	Sum of Squares	Mean Square	F value	Pr>F
Rate	6	36785.8	6131.0	6.58	0.0001
Cultivar	4	11795.6	2948.9	3.16	0.0179
Cultivar*rate	24	31225.7	1301.1	1.40	0.1347
Error	84	78299.7	2250.3		

Table 5.2d. Analysis of variance for relative dry-weight in four exotic and one local rice cultivars at 4-leaf stage (Whole plant Expt. 6).

Source	DF	Sum of Squares	Mean Squares	F value	Pr>F
Rate	6	42480.2	7080.0	7.33	0.0001
Cultivar	4	10398.4	2599.6	2.69	0.0364
Cultivar*rate	24	19009.3	792.1	0.82	0.7019
Error	84	81110.1	965.6		

Table 5.3. GR_{50} estimates for relative fresh-weight of seven rice cultivars treated with fenoxaprop at 2-leaf and 4-leaf stages (Whole plant Expt. 6).

Stage	Cultivar	Apparent Max. No Injury Rate	GR_{50} (# Data Points)	R^2
		(g/ha)		
2 Leaf	KS 282	0	88(7)	91.2
2 Leaf	Bas198	0	22(7)	67.7
2 Leaf	Bas370	0	62(7)	93.0
2 Leaf	Bas385	28	107(6)	96.4
2 Leaf	JP5	0	106(7)	75.4
2 Leaf	IR6	0	59(7)	97.0
2 Leaf	Mars	0	121(7)	94.1
4 Leaf	KS 282	28	>448(7)	52.5
4 Leaf	IR6	0	>448(7)	62.8
4 Leaf	Bas385	28	319(6)	92.1
4 Leaf	JP5	0	283(6)	71.5
4 Leaf	Mars	28	256(6)	39.4

Table 5.4a. Main effect of fenoxaprop rate on net fresh-weight, dry-weight, and the relative fresh and dry-weights in six exotic and one local rice cultivars at 2-leaf stage (Whole plant Expt. 6).

Fenoxaprop Rate	Weight Gain		Relative Weight Gain	
	Fresh	Dry	Fresh[a]	Dry
(g/ha)	(g)		(% of check)	
0	1.65a[b]	0.63a	100.0a	100.0a
28	1.40b	0.55b	85.0b	90.4a
84	0.99c	0.44c	56.9c	67.6b
140	0.63d	0.35d	36.6d	54.5c
196	0.23e	0.28de	11.6e	41.7d
280	0.06ef	0.26e	2.8e	38.7d
448	-0.0f	0.28de	-1.1e	38.7d

[a] GR_{50} and R^2 for regression averaged over replications and varieties based on fresh weight are 81 g ha^{-1} and 80.5%, respectively.

[b] Means in the respective column sharing a letter in common do not differ significantly by Duncan's multiple range test (α=0.05).

Table 5.4b. Main effect of cultivar on net fresh-weight, dry-weight, and relative fresh and dry-weight in six exotic and one local rice cultivars at 2-leaf stage (Whole plant Expt. 6).

Cultivar	Weight Gain Fresh	Weight Gain Dry	Relative Weight Gain Fresh	Relative Weight Gain Dry
	(g)		(% of check)	
KS282	0.97ab	0.50ab	54.0a	68.3a
JP5	1.17a	0.54a	58.2a	70.1a
IR6	0.84bc	0.51ab	50.0abc	71.8a
Basmati 385	0.88bc	0.45bc	53.1ab	69.8a
Basmati 198	0.35d	0.14d	39.1bc	55.4b
Mars	0.93b	0.46b	53.0ab	69.5a
Basmati 370	0.68c	0.39c	38.0c	58.5ab

Table 5.4c. Cultivar by fenoxaprop rate interaction for relative fresh and dry-weight in six exotic and one local cultivars at 2-leaf stage of rice (Whole plant Expt. 6).

Cultivar	Fenoxaprop ($g\ ha^{-1}$)[a] 28	84	140	196	280	448
	(% of check)					
KS282	82(85)	64(72)	43(69)	19(45)	11(33)	14(42)
JP5	72(80)	67(78)	42(55)	46(62)	8(41)	30(45)
IR6	71(82)	49(66)	26(56)	18(52)	9(50)	9(69)
Basmati385	109(107)	57(64)	51(71)	11(42)	3(39)	-7(34)
Basmati198	99(110)	18(37)	17(39)	-7(17)	-8(16)	-6(23)
Mars	90(87)	78(80)	59(52)	13(50)	6(50)	-28(57)
Basmati370	73(81)	64(76)	16(40)	-16(25)	-7(35)	-25(10)

[a]Values in parentheses are for relative dry-weight, those outside for relative fresh weight.

Table 5.5a. Main effect of rates of fenoxaprop on net fresh and dry-weight, and relative fresh and dry-weight in four exotic and one local rice cultivars at 4-leaf stage (Whole plant Expt. 6).

Fenoxaprop Rate	Net Weight Gain		Relative Weight Gain	
	Fresh	Dry	Fresh[a]	Dry
(g/ha)	(g)		(% of check)	
0	3.49a[b]	1.39a	100.0a	100.0a
28	3.54a	1.42a	101.1a	101.8a
84	2.52bc	0.95b	70.2b	65.5c
140	2.67b	1.00b	73.9b	68.1b
196	2.53bc	0.98b	71.4b	68.0b
280	2.36bc	0.91b	63.9b	59.7b
448	1.85c	0.78b	53.4b	54.7b

Table 5.5b. Main effect of cultivar on net fresh-weight and dry-weight, and relative fresh and dry-weight in four exotic and one local rice cultivars at 4-leaf stage (Whole plant Expt. 6).

Cultivar	Weight Gain		Relative Weight Gain	
	Fresh	Dry	Fresh	Dry
	(g)		(% of check)	
KS 282	3.32a	1.39a	86.2a	83.0a
JP 5	2.05b	0.92b	65.4b	75.4ab
IR 6	3.11a	1.30a	87.4a	79.6ab
Basmati 385	3.65a	1.38a	84.7a	85.3a
Mars	1.87b	0.51c	72.7ab	62.9b

[a] GR_{50} and R^2 for means over replications and varieties, based on fresh weight are 507 g ha^{-1} and 97.0%, respectively.

[b] Means in the respective column sharing a letter in common do not differ significantly by Duncan's multiple range test (α=0.05).

Table 5.5c. Cultivar by fenoxaprop rate interaction for relative fresh and dry-weight in four exotic and one local cultivars at 4-leaf stage of rice (Whole plant Expt. 6).

	Fenoxaprop (g ha^{-1})[a]					
Cultivar	28	84	140	196	280	448
	(% of check)					
KS 282	79(90)	92(84)	76(64)	82(74)	80(80)	77(70)
JP 5	96(105)	7(31)	91(94)	45(61)	36(56)	48(56)
IR 6	96(95)	81(66)	85(75)	85(75)	91(68)	61(58)
Basmati 385	127(125)	89(86)	87(88)	76(77)	68(63)	30(44)
Mars	107(94)	81(61)	31(19)	68(52)	34(17)	48(44)

Table 5.6a. Analysis of variance for net fresh-weight in six exotic and one local rice cultivars at 2-leaf, 4-leaf, and jointing stages (Whole plant Expt. 7).

Source	DF	Sum of Squares	Mean Squares	F value	Pr>F
Rate	6	8557.7	1426.3	17.12	0.0001
Cultivar	6	4792.4	798.7	9.59	0.0001
Cultivar*rate	36	6419.3	178.3	2.14	0.0001
Stage	2	83854.1	41927.0	503.18	0.0001
Cultivar*stage	12	3200.8	266.7	3.20	0.0002
Rate*stage	12	2280.7	190.1	2.28	0.0079
Cultivar*stage*rate	72	7784.8	108.1	1.30	0.0598
Error	520	43328.2	800.6		

[a]Values in parentheses are for relative dry-weight, those outside for relative fresh weight.

Table 5.6b. Analysis of variance for net dry-weight gain in six exotic and one local rice cultivars at 2-leaf, 4-leaf, and jointing stages (Whole plant Expt. 7).

Source	DF	Sum of Squares	Mean Squares	F value	Pr>F
Rate	6	441.3	73.5	4.32	0.0003
Cultivar	6	549.6	91.6	5.38	0.0001
Cultivar*rate	36	778.7	21.6	1.27	0.1391
Stage	2	8410.4	4205.2	246.90	0.0001
Cultivar*stage	12	312.0	26.0	1.53	0.1105
Rate*stage	12	142.6	11.9	0.70	0.7544
Cultivar*stage*rate	72	1382.1	19.2	1.13	0.2366
Error	520	8856.5	17.0		

Table 5.6c. Analysis of variance for relative fresh-weight in six exotic and one local rice cultivars at 2-leaf, 4-leaf, and jointing stages (Whole plant Expt. 7).

Source	DF	Sum of Squares	Mean Squares	F value	Pr>F
Rate	6	252697.1	42116.2	32.43	0.0001
Cultivar	6	96926.8	16154.5	12.44	0.0001
Cultivar*rate	36	85320.9	2370.0	1.83	0.0029
Stage	2	61210.1	30605.1	23.57	0.0001
Cultivar*stage	12	54676.7	4556.4	3.51	0.0001
Rate*stage	12	95544.2	7962.0	6.13	0.0001
Cultivar*stage*rate	72	104411.5	1450.2	1.12	0.2504
Error	520	675284.4	1298.6		

Table 5.6d. Analysis of variance for relative dry-weight gain in six exotic and one local rice cultivars at 2-leaf, 4-leaf, and jointing stages (Whole plant Expt. 7).

Source	DF	Sum of Squares	Mean Squares	F value	Pr>F
Rate	6	150079.2	25013.2	14.59	0.0001
Cultivar	6	114324.2	19054.0	11.11	0.0001
Cultivar*rate	36	109555.4	3043.2	1.78	0.0043
Stage	2	26703.9	13352.0	7.79	0.0005
Cultivar*stage	12	103844.3	8653.7	5.05	0.0001
Rate*stage	12	55864.3	4655.4	2.72	0.0014
Cultivar*stage*rate	72	154175.5	2141.3	1.25	0.0919
Error	520	891434.5	1714.3		

Table 5.7a. Analysis of variance for net fresh-weight in six exotic and one local rice cultivars at 4-leaf and jointing stages (Whole plant Expt. 7).

Source	DF	Sum of Squares	Mean Square	F value	Pr>F
Rate	7	13032.3	1861.8	16.01	0.0001
Cultivar	6	4865.8	811.0	6.97	0.0001
Cultivar*rate	42	10336.4	246.1	2.12	0.0001
Stage	1	27958.2	27958.2	240.39	0.0001
Rate*stage	7	1833.1	261.9	2.25	0.0296
Cultivar*stage	6	3473.6	578.9	4.98	0.0001
Cultivar*stage*rate	42	5935.5	141.3	1.22	0.1761
Error	387	45009.4	116.3		

Table 5.7b. Analysis of variance for net dry-weight gain in six exotic and one local rice cultivars in response to seven rates of fenoxaprop at 4-leaf and jointing stages (Whole plant Expt. 7).

Source	DF	Sum of Squares	Mean Squares	F value	Pr>F
Rate	7	607.4	86.8	4.01	0.0001
Cultivar	6	618.5	103.0	4.77	0.0001
Cultivar*rate	42	1389.0	33.1	1.53	0.0220
Stage	1	3612.0	3612.0	166.98	0.0001
Rate*stage	7	90.0	12.9	0.59	0.7608
Cultivar*stage	6	278.9	46.5	2.15	0.0472
Cultivar*stage*rate	42	1544.5	36.8	1.70	0.0056
Error	387	8371.5	21.6		

Table 5.7c. Analysis of variance for relative fresh-weight gain in six exotic and one local rice cultivars at 4-leaf and jointing stages (Whole plant Expt. 7).

Source	DF	Sum of Squares	Mean Squares	F value	Pr>F
Rate	7	148436.0	21205.1	15.84	0.0001
Cultivar	6	126461.6	21076.9	15.74	0.0001
Cultivar*rate	42	90007.8	2143.0	1.60	0.0126
Stage	1	3125.6	3125.6	2.33	0.1273
Rate*stage	7	33608.3	4801.2	3.59	0.0009
Cultivar*stage	6	20714.0	3452.3	2.58	0.0184
Cultivar*stage*rate	42	66445.3	1582.0	1.18	0.2109
Error	387	518104.5	1338.8		

Table 5.7d. Analysis of variance for relative dry-weight gain in six exotic and one local rice cultivars in response to seven rates of fenoxaprop at 4-leaf and jointing stages (Whole plant Expt. 7).

Source	DF	Sum of Squares	Mean Squares	F value	Pr>F
Rate	7	87675.7	12525.1	6.39	0.0001
Cultivar	6	204024.5	34004.1	17.36	0.0001
Cultivar*rate	42	148273.0	3530.3	1.80	0.0023
Stage	1	1832.3	1832.2	0.94	0.3341
Rate*stage	7	19237.0	4176.7	2.13	0.0395
Cultivar*stage	6	54389.5	9064.9	4.63	0.0001
Cul*stage*rate	42	90849.4	2163.1	1.10	0.3092
Error	387	758105.5	5532.1		

Table 5.8. GR_{50} estimates for relative fresh-weight of seven rice cultivars treated with fenoxaprop at 2-leaf, 4-leaf, and jointing stages (Whole plant Expt. 7).

Stage	Cultivar	Apparent Max. No Injury Rate	GR_{50} (# Data Points)	R^2
		(g ha^{-1})		
2 Leaf	KS 282	0	188(7)	77.6
2 Leaf	Bas198	0	108(7)	94.4
2 Leaf	Bas370	0	179(7)	95.8
2 Leaf	Bas385	0	137(7)	87.7
2 Leaf	JP5	140	416(4)	98.3
2 Leaf	IR6	84	184(5)	31.1
2 Leaf	Mars	28	243(6)	84.6
4 Leaf	KS 282	280	≫840(3)	73.6
4 Leaf	Bas198	28	381(7)	49.4
4 Leaf	Bas370	0	227(8)	70.2
4 Leaf	Bas385	140	686(5)	26.8
4 Leaf	JP5	140	≫840(5)	-
4 Leaf	IR6	280	>840(3)	48.0
4 Leaf	Mars	0	387(8)	74.2
Jointing	KS282	140	≫840(5)	28.3
Jointing	Basmati 198	280	410(3)	98.7
Jointing	Basmati 370	0	251(8)	59.5
Jointing	Basmati 385	0	681(8)	69.5
Jointing	JP5	280	≫840(3)	81.8
Jointing	IR6	84	≫840	-
Jointing	Mars	0	652(8)	33.0

Table 5.9a. Main effect of rates of fenoxaprop on net fresh-weight, dry-weight, and relative fresh and dry-weight in six exotic and one local rice cultivars at 2-leaf, 4-leaf, and jointing stages (Whole plant Expt. 7).

Fenoxaprop Rate	Weight Gain		Relative Weight Gain	
	Fresh[a]	Dry	Fresh[b]	Dry[c]
(g/ha)	(g)		(% of check)	
0	23.0a	6.1ab	100.0a	100.0bc
28	22.3a	6.9a	101.8a	103.6b
84	20.8ab	6.6a	94.1a	119.0a
140	19.1b	5.6ab	80.5b	92.2bcd
196	16.3c	5.2bc	73.1b	90cd
280	15.9c	5.2bc	61.1c	80.1d
448	12.7d	4.3c	45.5d	65.5e

Table 5.9b. Main effect of cultivar on net fresh-weight, dry-weight, and relative fresh and dry-weight in 6 exotic and one local rice cultivars at 2-leaf, 4-leaf and jointing stages (Whole plant Expt. 7).

Cultivar	Net Weight Gain		Relative Weight Gain	
	Fresh	Dry	Fresh	Dry
	(g)		(% of check)	
KS 282	17.6b	4.7c	97.5a	119.0a
JP 5	23.2a	7.1a	97.7a	98.3b
IR 6	15.9b	4.8c	91.0a	104.0b
Basmati 385	16.5b	5.2bc	74.8b	86.2c
Basmati 198	17.8b	5.5bc	69.3b	85.2c
Mars	22.4a	6.9a	74.0b	82.6c
Basmati 370	20.6a	6.2ab	68.9b	80.3c

[a]Means in the respective column sharing a letter in common do not differ significantly by Duncan's multiple range test (α=0.05).

[b]GR_{50} and R^2 for regression on means over replications, varieties, and growth stages are 398 g ha^{-1} and 97.4%, respectively.

[c]GR_{50} and R^2 for regression on means over replications, cultivars, and growth stages based on dry weight are 824 g ha^{-1} and 71.3%, respectively.

Table 5.9c. Main effect of growth-stage on net fresh-weight, dry-weight, and relative fresh and dry-weight in six exotic and one local rice cultivars (Whole plant Expt. 7).

Growth Stage	Net Weight Gain		Relative Weight Gain	
	Fresh	Dry	Fresh	Dry
	(g)		(% of check)	
2-leaf	6.1a	1.8a	69.0a	85.4a
4-leaf	18.0b	5.0b	85.4b	95.2b
Jointing	33.4c	10.4c	91.6b	100.7b

Table 5.10a. Cultivar by fenoxaprop rate interaction for relative fresh and dry-weight in six exotic and one local cultivars at 2-leaf, 4-leaf, and jointing stages of rice (Whole plant Expt. 7).

Cultivar	Fenoxaprop ($g\ ha^{-1}$)					
	28	84	140	196	280	448
	(% of check)[a]					
KS 282	137(159)	114(136)	89(117)	114(166)	68(102)	58(72)
JP 5	116(107)	100(104)	115(109)	90(95)	91(93)	70(79)
IR 6	101(97)	121(155)	85(98)	92(102)	69(91)	61(89)
Basmati385	76(79)	88(111)	78(89)	56(70)	46(61)	56(80)
Basmati198	106(110)	69(97)	49(67)	53(83)	54(71)	24(53)
Mars	83(81)	91(105)	69(76)	63(80)	51(66)	31(50)
Basmati370	92(90)	74(93)	78(90)	43(63)	49(75)	17(34)

[a]Values in parentheses are for relative dry-weight, those outside are fresh-weight.

Table 5.10b. Cultivar by growth-stage interaction for relative fresh and dry-weight in six exotic and one local rice cultivars at eight fenoxaprop rates (Whole plant Expt. 7).

	Growth-stage					
	Relative Fresh-weight			Relative Dry-weight		
Cultivar	2-Leaf	4-Leaf	Jointing	2-Leaf	4-Leaf	Jointing
	(% of check)					
KS 282	67.2	125.6	99.7	85.1	132.3	139.6
JP 5	91.0	94.4	107.6	87.0	94.7	113.3
IR 6	71.6	114.5	86.9	91.1	135.8	85.0
Basmati 385	61.4	86.4	77.0	77.7	97.7	83.6
Basmati 198	53.4	74.8	80.5	80.2	85.2	90.5
Mars	75.7	75.4	71.0	85.1	80.9	75.3
Basmati 370	62.7	69.3	74.6	85.4	77.2	78.4

Table 5.11a. Growth-stage by cultivar by fenoxaprop rate interaction in six exotic and one local rice cultivars for relative fresh-weight (Whole plant Expt. 7).

Growth Stage	Cultivar	Fenoxaprop (g ha^{-1}) 28	84	140	196	280	448	840†
		(% of check)						
2-Leaf	KS282	86.5	92.3	52.5	86.5	22.8	-2.7	-
2-Leaf	JP5	118.8	84.4	109.9	91.8	79.5	44.3	-
2-Leaf	IR6	95.5	101.9	24.9	93.2	34.0	23.4	-
2-Leaf	BAS385	76.7	88.6	49.3	35.8	20.1	20.8	-
2-Leaf	BAS198	99.1	74.3	32.9	33.8	-7.8	-17.1	-
2-Leaf	MARS	113.8	85.8	69.4	84.1	61.6	-8.7	-
2-Leaf	BAS370	88.6	80.9	75.8	46.7	24.1	-5.4	-
4-Leaf	KS282	147.3	139.7	109.1	162.4	98.7	87.3	87.5
4-Leaf	JP5	156.7	103.7	109.0	57.7	58.9	68.9	74.5
4-Leaf	IR6	140.3	126.0	137.6	110.5	108.7	63.1	66.7
4-Leaf	BAS385	80.6	96.1	111.5	67.4	44.2	86.4	43.6
4-Leaf	BAS198	122.1	58.9	49.7	59.8	64.0	50.1	31.2
4-Leaf	MARS	85.2	87.9	77.2	38.9	56.2	52.3	31.7
4-Leaf	BAS370	97.3	87.4	76.8	28.9	35.8	28.2	24.6
Jointing	KS282	117.5	110.8	105.8	93.1	81.1	89.6	85.5
Jointing	JP5	71.2	110.7	126.3	121.2	135.7	95.6	82.6
Jointing	IR6	65.6	104.1	92.5	72.0	63.5	97.7	77.4
Jointing	BAS385	68.0	80.5	73.1	65.3	73.1	61.5	44.3
Jointing	BAS198	95.8	73.3	65.4	64.5	105.4	39.8	20.0
Jointing	MARS	74.2	99.9	60.0	66.9	36.1	53.7	55.4
Jointing	BAS370	90.5	48.5	81.4	53.9	88.3	27.8	11.7

† Dashes indicate that 840 g ha^{-1} was not used at 2-leaf stage

Table 5.11b. Growth-stage by cultivar by fenoxaprop rate interaction in six exotic and one local rice cultivars for relative dry-weight (Whole plant Expt. 7).

Growth Stage	Cultivar	Fenoxaprop (g ha^{-1}) 28	84	140	196	280	448	840†
		(% of check)						
2-Leaf	KS282	90.9	110.5	100.1	109.1	62.9	32.2	-
2-Leaf	JP5	100.4	87.1	97.1	91.3	70.5	49.8	-
2-Leaf	IR6	100.8	124.4	42.5	111.8	80.3	69.3	-
2-Leaf	BAS385	84.3	107.2	72.3	56.6	43.4	57.8	-
2-Leaf	BAS198	104.1	132.2	67.5	71.7	38.0	23.4	-
2-Leaf	MARS	109.0	107.0	92.0	118.0	85.0	22.0	-
2-Leaf	BAS370	99.5	108.3	103.6	82.1	65.5	36.9	-
4-Leaf	KS282	158.6	196.1	92.5	161.0	97.8	89.9	103.1
4-Leaf	JP5	139.7	107.9	97.2	68.1	64.8	80.3	86.9
4-Leaf	IR6	129.5	138.7	169.2	121.4	124.4	99.0	89.8
4-Leaf	BAS385	69.6	125.2	113.7	86.3	66.5	110.5	75.4
4-Leaf	BAS198	121.7	74.2	64.2	92.6	64.9	68.0	50.4
4-Leaf	MARS	91.2	99.1	74.7	46.9	67.5	63.5	55.5
4-Leaf	BAS370	90.7	102.5	78.3	40.4	57.5	48.8	41.3
Jointing	KS282	166.0	191.5	182.4	136.9	146.1	93.8	155.6
Jointing	JP5	81.9	116.2	131.2	126.8	143.7	106.3	103.5
Jointing	IR6	60.3	96.6	81.6	74.0	69.5	98.4	85.9
Jointing	BAS385	77.4	99.2	82.3	66.2	74.5	73.0	70.5
Jointing	BAS198	104.0	84.8	70.4	85.8	111.4	67.4	51.7
Jointing	MARS	56.6	109.2	60.0	75.9	46.9	67.8	76.8
Jointing	BAS370	87.5	60.8	88.5	66.9	101.5	17.8	36.8

† Dashes indicate the 840 g ha^{-1} was not used at 2-leaf stage

Table 5.12a. Main effect of rates of fenoxaprop on net fresh-weight, dry-weight, and relative fresh and dry-weight in six exotic and one local rice cultivars at 4-leaf and jointing stages (Whole plant Expt. 7).

Fenoxaprop Rate	Weight Gain Fresh	Weight Gain Dry	Relative Weight Gain Fresh[a]	Relative Weight Gain Dry[b]
(g/ha)	(g)		(% of check)	
0	30.3a	8.2abc	100.0a	100.0a
28	29.0ab	9.3a	104.5a	107.3ab
84	27.6ab	8.8ab	97.8a	123.0a
140	26.0bc	7.5abcd	91.1a	99.0bc
196	21.5d	6.8cd	75.9b	89.2cd
280	22.3cd	7.1bcd	75.0b	88.3d
448	18.8de	6.0d	64.6bc	77.7d
840	15.1e	6.1d	52.6c	80.1d

Table 5.12b. Main effect of cultivar on net fresh-weight, dry-weight, and relative fresh and dry-weight in six exotic and one local rice cultivars at 4-leaf and jointing stages (Whole plant Expt. 7).

Cultivar	Net Weight Gain Fresh	Net Weight Gain Dry	Relative Weight Gain Fresh	Relative Weight Gain Dry
	(g)		(% of check)	
JP5	29.4a	9.2a	98.5a	103.0b
KS 282	23.2bc	6.3b	109.8a	135.2a
IR6	21.0c	6.4b	97.5a	110.0b
Basmati 385	21.1c	6.7b	77.2b	88.2c
Basmati 198	22.9bc	7.2b	71.8b	83.7c
Mars	28.4ab	9.0a	70.2b	77.3c
Basmati 370	25.6ab	7.9ab	65.9b	73.5c

[a] GR_{50} and R^2 for regression on means over replications, varieties, and growth stages are 866 g ha^{-1} and 93.6%, respectively.

[b] GR_{50} and R^2 for regression on means are 2.5 kg ha^{-1} and 55.7%, respectively.

Table 5.12c. Main effect of growth-stage on net fresh-weight, dry-weight, and relative fresh and dry-weight in six exotic and one local rice cultivars (Whole plant Expt. 7).

Growth Stage	Net Weight Gain Fresh	Net Weight Gain Dry	Relative Weight Gain Fresh	Relative Weight Gain Dry
	(g)		(% of check)	
4-leaf	17.0a	4.8a	87.0a	97.9a
Jointing	32.0b	10.2b	82.0a	94.1a

Table 5.13a Cultivar by fenoxaprop rate interaction for relative fresh-weight in six exotic and one local cultivars at 4-leaf and jointing stages of rice (Whole plant Expt. 7).

Cultivar	Fenoxaprop ($g\ ha^{-1}$) 28	84	140	196	280	448	840
	(% of check)						
KS282	162.4	125.3	107.5	127.8	89.9	88.4	86.7
JP5	113.9	107.2	117.7	89.4	97.3	82.2	78.5
IR6	103.0	129.9	115.0	91.2	86.0	80.4	72.1
Basmati 385	74.3	88.3	92.3	66.3	58.6	74.0	44.0
Basmati 198	108.9	66.1	57.6	62.2	84.7	45.0	25.6
Mars	71.1	93.9	68.6	52.9	46.2	53.1	43.6
Basmati 370	94.0	70.7	79.1	41.4	62.1	28.0	18.1

Table 5.13b. Cultivar by growth-stage interaction for relative fresh and dry-weight in six exotic and one local rice cultivars at eight fenoxaprop rates (Whole plant Expt. 7).

Cultivar	Growth-stage: Relative Fresh-weight 4-Leaf	Relative Fresh-weight Jointing	Relative Dry-weight 4-Leaf	Relative Dry-weight Jointing
	(% of check)			
KS 282	121.3	129.1	98.2	141.4
JP5	92.2	104.8	93.9	112.2
IR6	109.2	85.9	134.8	85.2
Basmati 385	81.1	73.2	94.1	141.4
Basmati 198	69.8	73.8	81.2	86.2
Mars	70.4	69.9	78.0	76.6
Basmati 370	64.3	67.4	73.3	73.7

Table 5.14. Analysis of variance for inhibition of ACCase by fenoxaprop at 2-leaf, 4-leaf and tillering stages of rice (mean of Lab Expts. 8 to 10).

Source	DF	Sum of Squares	Mean Squares	F Value	Pr > F
Rep.	2	135.5	67.7	1.89	0.1666
Stage	2	736.6	368.3	10.27	0.0003
Cultivar	6	763.0	127.2	3.55	0.0078
Stage*Cultivar	12	1813.2	151.1	4.22	0.0005

Table 5.15. Main effect of cultivar of rice on inhibition of ACCase averaged over growth-stages (mean of Lab Expts. 8 to 10).

Cultivar	I_{50}
	(mmol)
Basmati 198	3.07a
Basmati 385	3.04a
JP 5	2.74ab
Mars	2.58abc
IR 6	2.39bc
KS 282	2.18bc
Basmati 370	2.10c

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APPENDIX

APPENDIX

Computer Program Used for Computing GR_{50}'s in Whole plant Experiments:

```
10 REM PROGRAM CALCULATES ASYMPTOTIC CURVES
11 REM DESTROY ALL @ DELAY .5
12 PRINT"Program THRUANY running to regress data to asymptotic
   curve"
20 REM FIRST READ IN DATA THEN CALCULATE REGRESSIONS THEN
   ESTIMATE NEW ASYMPTOTE
21 DIM E(3)
22 INPUT "HOW MANY RATES? ",D$
23 D=VAL(D$)
24 DIM A(D),B(D),P(D)
25 INPUT "ENTER VARIETY # ";V9$
30 REM D=DIM OF FUNCTION
45 Q$="N" : V1=0 :D1=1 :V3=0 : Q7$="N"
50 GOSUB 200 : REM NUMENT to enter rates and yields
60 GOSUB 300 : REM ASYM1 to estimate first asymptote
70 GOSUB 400 : REM CALREG calculate regression based on
   asymptote
80 GOSUB 500 : REM TELLME output of search process
90 IF Q$="N" THEN GOSUB 600
100 IF Q$="N" THEN GOTO 70
110 REM DISPLAY IS :PRINTER @ REM OUTPUT RESULTS OF INTEREST
115 LPRINT "VARIETY # ";V9$ : LPRINT "MEAN YIELD=";Y1;
116 LPRINT" AT RATE=";X1
120 LPRINT"ASYMPTOTE(C)=";C
130 LPRINT"B1=";B1:LPRINT"B0=";B0
135 LPRINT"%Y=C+E^(B1X+B0)"
136 LPRINT "R^2=";R2
140 INPUT "GROWTH REDUCTION % VALUE ";H0
150 G=(LOG(100-H0-C)-B0)/B1
160 LPRINT"GR";H0;"=";G
171 PRINT "VARIETY # ";V9 : LPRINT "MEAN YIELD=";Y1;
172 PRINT" AT RATE=";X1
173 PRINT"ASYMPTOTE(C)=";C
174 PRINT"B1=";B1: PRINT"B0="B0
175 PRINT"%Y=C+E^(B1X+B0)"
180 PRINT"GR";H0;"=";G
190 IF H0<>0 THEN 140
194 INPUT "To continue same rates, enter R";R$
196 IF R$="R" OR R$="r" THEN 25
199 STOP
200 'NUMENT':
205 IF R$="R" OR R$="r" THEN 265
210 PRINT"ENTER";D;" RATES 1st"
220 X1=0
230 PRINT"CORRESPOND YIELD 2nd"
240 FOR J=8-D TO 7
250 PRINT J+D-7;" RATE =";: INPUT A(J+D-7)
```

```
255 X1=X1+(A(J+D-7))/D : REM X1 = mean rate used
260 NEXT J
265 Y0=100 : REM Y0 WILL HOLD MINIMUM REAL YIELD IN % OF CHECK
266 Y1=0 : REM Y1 = mean of raw yield data
270 FOR J=1 TO D
280 PRINT J;" YIELD= "; : INPUT B(J)
285 IF Y0>B(J) THEN Y0=B(J)
286 Y1=Y1+(B(J))/D
290 NEXT J
299 RETURN
300 'ASYM1':
305 LPRINT: LPRINT: LPRINT
310 C=.5*Y0 : REM ARBITRARY FIRST VALUE FOR ASYMPTOTE
315 D0=0:REM d0 will hold sstotal corrected for mean
320 IF Y0<0 THEN C=C+Y0
325 B9=0 :REM B9 = mean of transformed yields
330 FOR J=1 TO D
340 B9=B9+(LOG(B(J)-C))/D
350 D0=D0+(B(J)-Y1)^2
360 LPRINT "Yield=";B(J);" at rate=";A(J)
390 NEXT J
399 RETURN
400 'CALCREG':
410 REM CLSTAT
415 E(2)=0
425 F1=0 : F2=0
430 FOR J=1 TO D
440 E(2)=E(2)+LOG(B(J)-C)
444 F1=F1+(A(J)-X1)*(A(J)-X1)  : REM SUM x^2
445 F2=F2+(A(J)-X1)*(LOG(B(J)-C)-B9)  : REM SUM xy
450 NEXT J
455 B1=F2/F1 : REM REGRESS THRU ANY VALUE
460 B0=B9-B1*X1
470 FOR J=1 TO D
475 P(J)=C+EXP(B1*A(J)+B0)
480 NEXT J
490 REM R1=CORR(1,2) @ R2=R1*R1
499 RETURN
500 'TELLME':
515 V0=V3 : V1=0 : V2=0 : V3=0
520 FOR J=1 TO D
525 V1=V1+(A(J)-X1)*(B(J)-P(J))
530 V2=V2+(A(J)-X1)*(B(J)-Y1)
531 V3=V3+(B(J)-P(J))^2
535 NEXT J
540 PRINT "Asymptote= ";C;" ";
545 R2=100*(1-V3/D0)
546 PRINT "R^2 = ";R2;"%"
550 IF (V0<>0) AND (ABS(V3-V0)<ABS(.01*V3)) THEN Q7$="Y" : REM
    prepare to STOP FRUITLESS SEARCH CASES
560 IF Q7$="Y" THEN PRINT "hi there from line 560"
565 IF D1=-1 AND V3>V0 THEN Q7$="Y" : REM prepare to stop if
```

```
    passed maximum R-squared
570 IF V0=0 OR D1=-1 THEN 599
575 IF V3>V0 THEN D1=-1 ELSE D1=1
599 RETURN
600 'ASYMNEW':
610 C0=C
620 C=C0-.5*D1*V1*(Y0-C0)/ABS(V2)
630 IF C>=Y0 THEN C=Y0-.05
640 B9=0 :REM B9 = mean of transformed yields
650 FOR J=1 TO D
660 B9=B9+(LOG(B(J)-C))/D
670 NEXT J
675 IF Q7$="Y" THEN 685
680 IF ABS(C0-C)>.05 THEN GOTO 699
685 Q$="Y"
689 PRINT C,C0
690 PRINT "FOUND ASYMPTOTE=";C0 : C=C0
695 REM FOR J=1 TO D @ DISP P(J); @ NEXT J
699 RETURN
```