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Effect of Light, Nitrogen, and Water Management on Rice (*Oryza sativa*) Tolerance to Fenoxaprop

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Abstract

The effect of light intensity, nitrogen (N), and water management on rice (*Oryza sativa* cv. 'Newbonnet' and 'Lemont') tolerance to fenoxaprop {(±)-2-[4[(6-chloro-2-benzoxazolyl)oxy]phenoxy]propanoic acid} was determined in two field studies at the Rice Research and Extension Center, Stuttgart, AR, in 1988 and 1989. In one study, 'Newbonnet' rice was treated with 0.22 kg ai ha^{-1} fenoxaprop at 0, 1, 3, 5, 7, 10, 14, and 28 days after N application and flooding. Moderate to severe foliar chlorosis, stunting, and stand and yield reductions occurred when fenoxaprop was applied within 7 days after N application and flooding. None to slight injury or yield reduction occurred when fenoxaprop was treated later than 7 days after N application and flooding. In the second study, 'Lemont' rice grown in full or reduced (53%) sunlight and treated with preplant incorporated or preflood N was sprayed with 0.17 kg ai ha^{-1} fenoxaprop 1 week before or after flooding. Injury at early to midseason was greater in plants grown in reduced sunlight than in full sunlight. Also injury was greater when fenoxaprop was applied after flood than when applied before flood. Although rice generally recovered from injury, its tolerance to fenoxaprop was reduced by N application and flooding particularly in reduced sunlight.

Introduction

Barnyardgrass (*Echinochloa crusgalli* (L.) Beauv.] and bearded sprangletop [*Leptochloa fascicularis* (Lam.) Gray] are the most competitive of 70 weed species that infest drill-seeded rice in the U.S. and can reduce rice grain yields by 50 to 79% (Smith, 1968), (Smith, 1988a). Effective herbicides against these two grasses, including propanil [*N*-(3, 4-dichlorophenyl) propanamide], thiobencarb [*S*-[(4chlorophenyl) methyl] diethylcarbamothioate], pendimethalin [*N*-(1-ethylpropyl)-3, 4-dimethyl-2, 6-dinitrobenzenamine], or molinate [*S*-ethyl hexahydro-1*H*-azepine-1-carbothioate] (Smith and Khodayari, 1985; Smith, 1988b; Smith and Hill, 1990) usually require critical timing and appropriate water management for maximum efficacy (Richard and Street, 1984; Smith and Khodayari, 1985; Smith, 1988b; Smith and Hill, 1990). These herbicides usually do not adequately control weeds larger than the four-leaf stage and are not as effective against bearded sprangletop as they are against barnyardgrass (Richard and Street, 1984; Smith 1988b; Smith and Hill, 1990). Over the years their continued use coupled with the introduction of short-statured, short-season cultivars has increased bearded sprangletop infestations because of good barnyardgrass control (Khodayari et al., 1989).

Fenoxaprop is one of few rice herbicides that effectively controls bearded sprangletop and barnyardgrass (Khodayari et al., 1989). It belongs to a group of herbicides called polycyclic alkanoic acids (PCAs) which were introduced in the 1970s (Duke and Kenyon, 1988). Highly active against emerged annual and perennial grasses, PCAs are readily absorbed by roots and shoots and translocated into meristematic tissues where they inhibit fatty acid synthesis (Duke and Kenyon, 1988). At 0.10 to 0.20 kg ha^{-1}, fenoxaprop controls two- to six-leaf (pretillering) barnyardgrass and bearded sprangletop (Snipes and Street, 1987a; Khodayari et al., 1989). It offers more flexibility than other rice herbicides since it can be applied either preflood or postflood and also forms compatible combinations with propanil, thiobencarb or pendimethalin (Snipes and Street, 1987a; Khodayari et al., 1989).

Although highly selective to dicotyledonous crops, fenoxaprop usually causes no more than 30% injury to rice with the degree of tolerance varying with rate, cultivar, growth stage, or other conditions at the time of treatment (Snipes et al., 1987; Snipes and Street, 1987b; Khodayari et al., 1989; Griffin and Baker, 1990). The most common visible injury symptoms in the field are chlorosis, stunted growth, and stand reduction (Griffin and Baker, 1990), which are most apparent 5 to 10 days following application as a result of inhibited cell elongation or enlargement (Oosterhuis et al., 1990). Symptoms disappear within 1 to 2 weeks, and rice is usually fully recovered by 4 to 8 weeks after treatment. High rates (0.3 kg ha^{-1}) were observed to reduce grain yields (Snipes et al., 1987), but in most cases injury did not reduce yields at normal use rates (Snipes and Street, 1987b; Khodayari et al., 1989).

In dry-seeded rice, 50 to 65% of the total N is applied to rice 4 to 6 weeks after it has emerged and is at the four- or

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five-leaf to tillering stages of plant development (Anonymous, 1990). Flooding usually follows within 0 to 5 days after N application to prevent N losses, enhance crop growth, suppress weeds, and enhance herbicide activity against weeds (Anonymous, 1990). Fenoxaprop injures very young rice seeedlings, thus it is applied to four- or five-leaf to tillering rice, which coincides with the time of N application and flooding. N application (Oosterhuis et al., 1990) and flooding (Snipes and Street, 1987b; Khodayari et al., 1989; Griffin and Baker, 1990) have been observed to decrease rice tolerance to fenoxaprop. Depending on herbicide rate, an interval of 1 - 10 days between fenoxaprop application and flooding is needed to minimize, if not avoid, rice injury with longer intervals needed at higher rates (Snipes et al., 1987). Decreased tolerance of rice to fenoxaprop following N application has been observed in the greenhouse (Oosterhuis et al., 1990). Sunlight intensity may also affect rice tolerance to fenoxaprop. While the effect of solar radiation on rice (Seshu and Cady, 1984) and the effect of sunlight on herbicide activity in various plants have been studied (Muzik and Mauldin, 1964; Hammerton, 1967; Muzik, 1976; Shaw et al., 1987; Dali-Armelina and Zimdahl, 1988; Regnier et al., 1988), the effect of light intensity on fenoxaprop activity is not fully understood.

This study was conducted to determine the effect of the following factors on rice tolerance to fenoxaprop: a) time of fenoxaprop application in relation to N application and flooding; and b) light intensity, time of N application, and time of fenoxaprop application.

Materials and Methods

General.--The studies were conducted in 1988 and 1989 at the Rice Research and Extension Center, Stuttgart, Arkansas. The soil was Crowley silt loam (Typic Albaqualfs, ph 6.5, 1% organic matter). Land was prepared by tilling the soil with a cultivator and cultipacked before and after seeding rice. Soil levees were constructed to separate replications.

Lemont or Newbonnet rice was drill-seeded at 135 kg ha^{-1} into 6 by 1 m plots consisting of seven rows spaced 18 cm apart at a depth of 2 cm. The plots were flush-irrigated one to two times before permanent flood to provide sufficient moisture for crop growth. Nitrogen as urea was broadcast by hand at rates and times of application required for each cultivar. To keep the plots weed-free, propanil applied sequentially or tank-mixed with either thiobencarb or bentazon [3- (1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide] was used. These treatments control weeds in rice with no adverse effects on rice growth and yield (Smith and Khodayari, 1985; Smith, 1988b; Smith and Hill, 1990).

Herbicide treatments were applied with a Co_2-pressurized backpack sprayer in 190 L ha^{-1}. Rice response to the fenoxaprop treatments was determined by visually rating crop injury on a scale of 0 (no injury) to 100 (plant killed) at various times after treatment (Frans et al., 1986). Morphological symptoms, plant height, and days to 50% heading were also recorded. Grain was harvested from 3 m^2 with a small plot combine, and yield was adjusted to 12% moisture.

Rice injury was analyzed as percentages and transformed percentages (arcsine or square root). Because the transformed analysis was not different from the nontransformed, the actual percentages are reported. A significant year by treatment interaction was obtained for both studies, thus data for both years were analyzed and presented separately.

Time of Fenoxaprop Treatment After N Application and Flooding.--Newbonnet rice was drilled on May 2, 1988, and April 17, 1989. Rice emerged 12 days after seeding (DAS) in 1988 and 21 DAS in 1989. Slow emergence in 1989 was due to low temperatures. Nitrogen (83 kg ha^{-1}) was applied 35 DAS (1988) and 49 DAS (1989) (23 and 26 days after emergence) immediately prior to applying permanent flood of 10 cm water to all plots. Fenoxaprop (0.22 kg ai ha^{-1}) was sprayed at 0, 1, 3, 5, 7, 10, and 14 days after flooding in 1988 and at 0, 1, 3, 5, 7, 10, 14, and 28 days after flooding in 1989. At the time of fenoxaprop application, rice was at the four-leaf to mid-tillering stages (20 - 48 cm tall) in 1988 and at early tillering to panicle initiation (25 - 66 cm tall) in 1989.

The first N at 84 kg ha^{-1} was applied before flooding when rice was in the early-tillering growth stage. Two more N applications of 34 kg ha^{-1} each were made; the first at panicle initiation when rice internodes were 1.3 cm and the second about 7 - 14 days after the first midseason application.

Rice injury ratings were taken weekly after each treatment until 31 days after the first fenoxaprop treatment in 1988 and 61 days after the first fenoxaprop treatment in 1989. Grain was harvested 130 DAS in 1988 and 139 DAS in 1989.

Treatments were arranged in a randomized complete block design and replicated three times. Data were subjected to analysis of variance and means separated by Least Significant Difference (LSD) at the 5% level.

Light Intensity, N Timing and Fenoxaprop Timing.--Lemont rice was drilled on April 25, 1988, and April 19, 1989. Rice emerged 18 DAS in 1988 and 22 DAS in 1989. At one week after rice emergence, the plots were subjected to full or reduced (53%) sunlight. Sunlight intensity was reduced to 53% by providing a black shade cloth canopy over and on the sides of plots that required shading. The percent irradiance reduction in µE m² s⁻¹ photosynthetic photon flux density (PPFD) under the canopy was measured compared to full sunlight (considered to be a maximum of 2000 µE m² s⁻¹ PPFD at solar noon on a clear day) and was found to be in agreement with the manufacturer's specified shade level of 47% (Pallas et al., 1971). These plots were kept under the cnaopy for 4 - 5 weeks, and the canopy was removed one week after the last fenoxaprop application.

N was applied either preplant incorporated (PPI) or preflood (PF). PPI treatments were applied at 134 kg ha^{-1} before seeding then incorporated 1.5 cm into the soil with a tooth harrow. PF treatments were applied at 134 kg ha^{-1} 39 DAS (1988) and 51 DAS (1989) when rice was tillering and before the plots were flooded permanently. At midseason, two more N application of 34 kg ha^{-1} each were made; the first midseason N was applied when internodes were 1.3 cm (74 DAS in 1988 and 82 DAS in 1989) and the second midseason N was applied 7 - 14 days later (81 DAS in 1988 and 91 DAS in 1989).

Fenoxaprop (0.17 kg ai ha^{-1}) was applied either at 1 week before flooding to 15-cm rice at the four-leaf stage (32 DAS in 1988; 43 DAS in 1989) or at one week after flooding to tillering rice (30 - 50 cm tall) at 46 DAS in 1988 and 58 DAS in 1989.

Benomyl [methyl 1-(butylcarbamoyl)-2-benzimidazolecarbamate] at 1.1 kg ha^{-1} was applied 97 DAS to protect the crop from rice blast and sheath blight.

Crop injury ratings were made weekly from 7 - 47 days after the first fenoxaprop treatment. Grain was harvested 141 DAS in 1988 and 140 DAS in 1989.

Treatments were arranged in a split-plot design with light intensity as main plot and times of N and fenoxaprop application as subplots arranged as factorial within the split. In full-light and shaded treatments, fenoxaprop untreated rice that received N were included. Treatments were replicated three times, and means were separated by LSD at the 5% level.

Results and Discussion

Time of Fenoxaprop Treatment after N Application and Flooding.--In 1988, plants treated with fenoxaprop 0 to 7 days after N application and flooding had initial moderate injury of 40%, and those treated at 10 - 14 days after N application and flooding had initial slight injury of no more than 26% (Table 1). Although plants in all treatments eventually recovered, they yielded 5 - 16% less than untreated plants (Table 1). In 1989, there was a greater degree of injury of plants in all treatments (Table 2) than in 1988. Plants treated with fenoxaprop from 0 to 7 days after N application and flooding had initial moderate to severe injury of 40 - 90%, and those treated later than 7 days had initial slight to moderate injury of 33 - 40%. Recovery of plants treated later than 7 days was faster and more complete than those treated earlier than 7 days after N application and flooding. The 7-day treated plants never recovered from herbicide injury and yielded 83% less than untreated plants. The 0- to 5-day treated plants, which also had slow recovery, yielded 24 - 32% less than untreated plants. Those treated later than 7 days after N application and flooding yielded 1 - 19% lower, but these were not significantly different from untreated rice yields.

Table 1. Injury rating and yield of rice treated with 0.22 kg ha^{-1} fenoxaprop at various times after N application and flooding in 1988.

Time applied[a]	Injury rating at DAT[b] 14	31	Grain yield	Yield reduction
(DAF)	(—— %	——)	(kg ha^{-1})	(%)
0	40	2	6900	8
1	40	0	6530	13
3	40	0	6350	16
5	37	3	6570	13
7	43	3	7140	5
10	26	10	6320	16
14	0	22	6640	12
Untreated	0	0	7510	0
LSD (0.05)	12	7	NS	

[a]DAF = days after flooding

[b]DAT = days after first fenoxaprop treatment

Rice injury from fenoxaprop consisted of foliage desiccation, stunted growth, leaf chlorosis, and stand reduction, which was visible within 7 - 14 days after herbicide application. This agrees with observations in greenhouse studies (Oosterhuis et al., 1990) in which fenoxaprop-treated rice had inhibited leaf elongation within 4 days after treatment and growth and photosynthesis reduction of over 50% within 14 days after treatment. Growth inhibition was attributed to interference of the herbicide with cell division or elongation due to shortage of phospholipids necessary for cell membrane formation (Oosterhuis et al., 1990) as a result of fatty acid synthesis inhibition (Duke and Kenyon, 1988).

Greater plant injury in 1989 could have been caused by unusually high amounts of rain and associated cloudy conditions. During 1989 the total rainfall during the experimental period (April to September) was 73 cm, 38 cm of which occured in 27 days of June and July just before and at the time of fenoxaprop treatments. In 1988, the total rainfall from April to September was 38 cm, 10 cm of which occured in 11 days of June and July just before and during fenoxaprop treatments. Greater activity of sethoxydim [2-[1-(ethoxyimino) butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one] when moisture was high or when there were above normal amounts of rainfall was observed in other studies (Retzinger et al., 1983; Chernicky et al., 1984).

Table 2. Injury rating and yield of rice treated with 0.22 kg ha^{-1} fenoxaprop at various times after N application and flooding in 1989.

Time applied	Injury rating at DAT[b] 10	43	71	Time to 50% heading	Grain yield	Yield reduction
(DAF)[a]	(———	% ———	)	(days)	(kg ha^{-1})	(%)
0	60	27	33	87	6070	30
1	43	30	30	87	6660	24
3	50	40	43	89	5950	32
5	27	40	43	88	6200	29
7	10	90	87	91	1520	83
10	0	37	27	86	7060	19
14	0	33	20	86	8600	1
28	0	40	13	86	7030	19
Untreated	0	0	0	85	8700	0
LSD (0.05)	7	12	10	3	2190	

[a]DAF = days after flooding

[b]DAT = days after first fenosaprop treatment

Greatest injury in plants treated at 7 days after N application and flooding was apparently a result of optimum response of the plants to N. At this time, rice plants were about 30 to 40 cm tall and at the early tillering stage, which coincides with the rapid vegetative growth phase (Anonymous, 1990). As a rule, a young plant growing in good nutritional status is most susceptible to herbicides (Aberg, 1964; Hammerton, 1967; Muzik, 1974; Aberg and Stecko, 1976). Increased leaf mortality of greenhouse-grown rice plants treated with fenoxaprop and N fertilizer has been observed (Oosterhuis et al., 1990). Other studies also have reported a direct relationship between herbicide activity and N levels in the soil (Aberg, 1964; Hammerton, 1967; Aberg and Stecko, 1976). Oats (*Avena sativa* L.) treated with glyphosate [*N*-(phosphonomethyl) glycine] or fluazifop [(±)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid] and N showed greater injury of plants with high N treatments which was attributed to greater translocation of either herbicide to young shoots and meristems and to greater leaf area than plants with low N treatments (Dickson et al., 1990). High fertility and adequate water supply, in general, will increase plant susceptibility to herbicides because of increased leaf area, which results in greater herbicide interception or retention than in low fertility or low moisture conditions (Hammerton, 1967).

Fenoxaprop and other PCAs are usually applied as ester formulations. Once absorbed in the leaf, they are metabolized into the acid form, which is the active form and also the form in which they are translocated within the plant (Duke and Kenyon, 1988). Reduced metabolism of fluazifop-butyl ester to the acid form occurred when moisture was low resulting in low herbicide activity (Coupland and Bond, 1988). Thus it is possible that when moisture is high there is greater conversion of the ester to the acid form, which leads to greater herbicide activity than when moisture is low. In growth chamber, greenhouse, and field studies (Dortenzio and Norris, 1980; Grafstrom and Nalewaja, 1988; Kidder and Behrens, 1988; Dickson et al., 1990), decreased toxicity of PCAs, diclofop [(±)-2-[4-(2,4-dichlorophenoxy)phenoxy]propanoic acid], fluazifop, and haloxyfop[2-[4-[[3-chloro-5-(trifluoromenthyl)-2-2pyridinyl]oxy]phenoxy]propanoic acid] when moisture is low has been attributed to either reduced growth rate or to decreased herbicide retention, uptake, or translocation. When moisture is high, it is possible that these processes are enhanced leading to greater herbicide activity and hence greater plant injury than when moisture is low. Some studies (Snipes et al., 1987) observed the need for an interval of more than 1 – 5 days after flooding until applying fenoxaprop to minimize injury to rice. However, how flooding or excessive moisture increases rice susceptibility or fenoxaprop activity is not yet fully understood.

Light Intensity, N Timing, and Fenoxaprop Timing.--Significant interaction between light intensity and fenoxaprop treatments occurred in both years. In 1988, plants grown in reduced sunlight had greater initial injury than plants grown in full sunlight (Fig. 1). Within each light intensity, plants treated with fenoxaprop after flood had greater injury than those treated with fenoxaprop before flood. Thus, greatest injury was observed in plants grown in reduced sunlight and treated with fenoxaprop after flood. Although plants in all treatments eventually recovered within 47 days after treatment (DAT), those treated with fenoxaprop after flood and grown in reduced sunlight recovered slower than those grown in full sunlight or treated with fenoxaprop before flood (Fig. 2). By midseason, all plants had recovered fully so that yields were not different between treated and untreated rice (Table 3).

A similar trend, but with a higher degree of injury, occurred in 1989 (Fig. 3). Injury during this year was double and recovery was slower than in 1988, and plants with reduced sunlight in the after-flood treatments still had slight injury of 30% by 54 DAT. Plants in full sunlight and before-flood treatments had fully recovered or had no more than 13% injury (Fig. 4). Eventually plants in all treatments fully recovered, and although those grown in full sunlight were shorter than those in reduced sunlight, treatments did not affect maturity dates or yields (Table 3). As in the flooding study, the high degree of injury observed in 1989 could have been due to the high amount of rain with associated cloudy conditions that occured this year particularly at the time of fenoxaprop treatments.

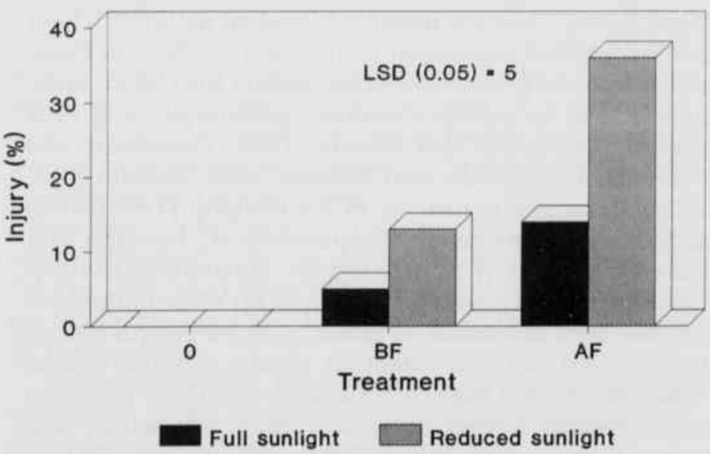

Fig. 1. Rice injury 28 days after treatment with before-flood (BF) or after-flood (AF) fenoxaprop at 0.17 kg ha^{-1} and grown in full or reduced sunlight in 1988.

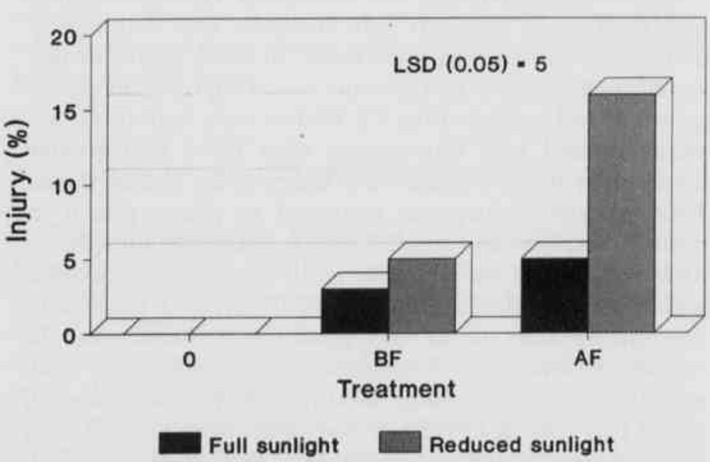

Fig. 2. Rice injury 47 days after treatment with before-flood (BF) or after-flood (AF) fenoxaprop at 0.17 kg ha^{-1} and grown in full or reduced sunlight in 1988.

Table 3. Height, days to heading and grain yield of rice treated with fenoxaprop at different light intensities and times of N application in 1988 and 1989.

Sunlight intensity, N timing, and herbicide[a]	Rate	Herbicide application Time[b]	Height[c]	Time to 50% heading[c]	Grain yield 1988	1989
	(kg ha^{-1})		(cm)	(days)	(kg ha^{-1})	
Reduced (53%)						
N PPI						
Fenoxaprop	0	--	79	84	6780	7950
Fenoxaprop	0.17	BF	85	84	8000	8230
Fenoxaprop	0.17	AF	76	84	7930	7770
N PF						
Fenoxaprop	0	--	79	85	8410	7510
Fenoxaprop	0.17	BF	78	87	8520	7590
Fenoxaprop	0.17	AF	72	86	7850	7590
Full (100%)						
Fenoxaprop	0	--	65	82	7420	8190
Fenoxaprop	0.17	BF	62	82	6830	8330
Fenoxaprop	0.17	AF	62	83	7400	8110
N PF						
Fenoxaprop	0	--	56	81	8230	6940
Fenoxaprop	0.17	BF	65	83	8410	7780
Fenoxaprop	0.17	AF	63	84	8420	8030
LSD (0.05)			11	NS[d]	NS	NS

[a]PPI = preplant incorporated; PF = preflood
[b]BF = before flood; AF = after flood
[c]Rice height and days to 50% heading were recorded only in 1989
[d]NS = not significant

Rice tolerance to fenoxaprop was decreased in reduced sunlight during the first 40 – 50 days after treatment. Increased toxicity of diphenamid (*N, N*-dimethyl-α-phenyl benzeneacetamide) and monuron [*N'*-(4-chlorophenyl)-*N, N*-dimethylurea] under reduced sunlight has been observed in other studies, apparently due to etiolated plant growth, which leads to plant susceptibility to herbicide injury (Minshall, 1957; Muzik and Mauldin, 1964; Minshall, 1969; Lynch and Sweet, 1971). Also, leaves grown in full sunlight are usually smaller with thicker cuticles and greater wax content than those grown in reduced sunlight, which would lead to reduced herbicide retention or uptake and less herbicide injury (Muzik and Mauldin, 1964). Other studies have observed fast herbicide degradation to non-toxic compounds in tomato (*Lycopersicon esculentum* Mill.) and red best (*Beta vulgaris* L.) grown under high light intensity (Lynch and Sweet, 1971; Stephenson et al., 1971). In our study, greatest injury in plants grown in reduced sunlight and treated with fenoxaprop after flood may have been due to cumulative enhancing effects of increased uptake and reduced degradation on fenoxaprop activity, thus decreasing rice tolerance.

Our studies indicate that rice tolerance to fenoxaprop was reduced by N application, flooding, and reduced sunlight during the frist 50 days after herbicide treatment, but rice generally recovered from the injury. Fenoxaprop injury may thus be avoided or minimized by applying fenoxaprop before N application and flooding, or if it has to be applied after flooding, an interval of not less than 7 days between N application and flooding and fenoxaprop treatment should be allowed. This is much more critical during cloudy days or when there is an unusually high amount of rainfall.

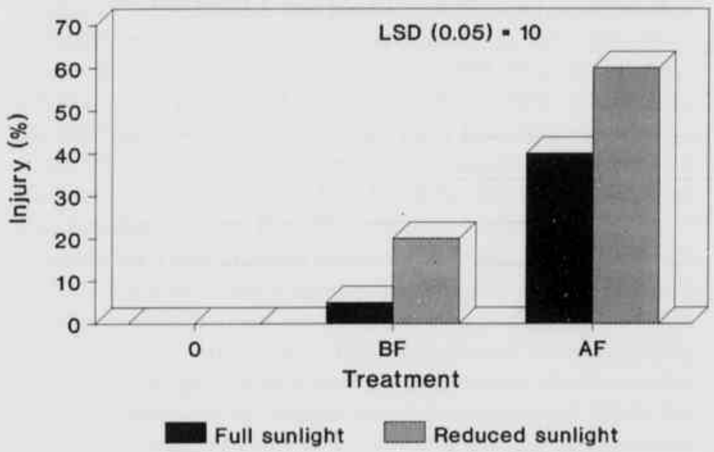

Fig. 3. Rice injury 27 days after treatment with before-flood (BF) or after-flood (AF) fenoxaprop at 0.17 kg ha^{-1} and grown in full or reduced sunlight in 1989.

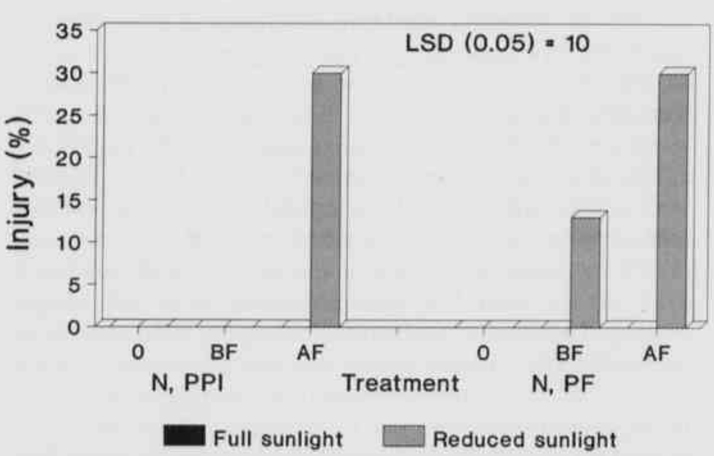

Fig. 4. Rice injury 54 days after treatment with before-flood (BF) or after-flood (AF) fenoxaprop at 0.17 kg ha^{-1} and grown at various light intensities with N applied preplant incorporated (PPI) or preflood (PF) in 1989.

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