Red rice (*Oryza sativa*) competition studies for management decisions

(Key words *Oryza sativa*, red rice, competition, rice, Latin America)

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Abstract

Growth analysis and competition studies involving red rice and rice "Oryzica 1" were conducted at CIAT, Colombia, during 1989 and 1990 In competition red rice (2 biotypes) grew taller than Oryzica 1, but had similar leaf area During the first 60 days after emergence (d a e) Oryzica 1 tillered more than the red rice biotypes, but these continued to tiller after anthesis Competitive effects differed for each red rice biotype In field competition studies (1989) red rice was very competitive with rice 5 and 20 red rice plants/m^2 reduced rice yields by 40 and 60% respectively Twenty red rice plants/m^2 shattered 35 seeds/m^2 before rice harvest, and contaminated harvested rice with about 1100 kg/ha of red rice grain An infestation of 24 red rice plants/m^2 reduced rice yields by 10% if allowed to compete during 40 d a e , and 75% after season-long competition In 1990 red rice competition was stronger, and an experiment combining effects of red rice

density and duration of competition indicated that 50% yield was lost when 24 red rice plants/m^2 competed during 40 d a e with Oryzica 1 Economic analysis using competition data indicated that with current prices in Colombia and given the high red rice competitiveness, herbicide control with glyphosate (2 kg ai/ha) followed by paraquat (0 75kg ia/ha) was economically justified even at very low red rice densities The probability of justifying hand weeding practices was higher among low-yield-farmers, early weeding, and low labour costs

1 Introduction

Red rice (*Oryza sativa* L) is one of the most serious weed problems of rice in Latin America Its name refers to the red pericarp layer in the dehulled grain (Smith, 1981), which lowers commercial rice grain quality Red rice grains tend to be softer than commercial rice grains, and removal of the red pericarp results in high proportions of broken white grains reducing milling yields (Smith 1981) Red rice has several distinct weedy features Its plants are generally taller than commercial rice varieties, and tiller profusely, being thus very competitive with rice (Diarra et al, 1985a, Diarra et al, 1986b, Kwon et al, 1991, and Smith, 1988) Red rice grains readily shatter before rice harvest (Diarra et al, 1985a, 1985b), and its seed can remain viable in the soil for several years (Kwon et al, 1991) For being physiologically similar to commercial rice (Hoagland, 1978) its selective removal is difficult Heavily infested fields are often abandoned

Season-long competition by 3 and 19 red rice plants/m^2 reduced yields of irrigated rice by 10 and 50%, respectively (Smith, 1988) Diarra (1985b) found that red rice densities of 5, 108, and 215 plants/m^2 reduced grain yields of rice by 22, 77, and 82% In Southern Brazil 170 red rice panicles/m^2 (approximately 60 plants/m^2) reduced rice yield by 50% (De Souza, 1986) Little competition was found to occur during the first 50 days after rice and red rice emergence (Kwon et al,1991, Smith, 1988) Diverse red rice biotypes with clear morphological differences are known to occur (Montealegre and Vargas, 1982), but the implications of such differences in their competitiveness are not clear

The widespread use of red rice-contaminated seed by a high proportion of rice farmers in Latin America ensures field reinfestations, forcing farmers to control red rice every season (often two per year) Control is mostly done with herbicides, though other alternatives such as crop rotations, transplanting rice, and the use of pure seed have been successful An integrated approach to manage red rice is essential for the economic and environmentally safe control of this weed Integrated management should seek the optimization of cost/benefit ratios, thus leading to more diversified red rice control strategies Predicting yield and quality losses from red rice infestations would be crucial for selecting cost effective inputs to integrate in managing this weed

Competition experiments with different red rice densities and durations of infestation can provide the information needed for crop loss predictions (Zimdahl, 1980, Smith, 1988) A functional approach is needed to interpret results from such experiments, deriving models for crop loss prediction based on timely assessments of red rice infestations

This work was conducted on flush-irrigated[1] rice, and the objectives were a) to relate growth characteristics of distinct red rice biotypes to differences in their competitiveness with commercial semidwarf rice, b) to establish the effect of early-estimated red rice densities,

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[1] The crop was not flooded, irrigation was provided to keep the soil near field capacity

on rice and red rice grain yields, c) to determine the effects of different periods of red rice interference on rice yields, and d) to illustrate how competition studies can be a key tool for the economic selection of components for integrated red rice management

2 Materials and Methods

2 1 *Growth analysis of rice and red rice biotypes*

Rice cv "Oryzica 1", and two red rice biotypes were grown in monoculture Fourteen-day-old seedlings of either Oryzica 1, or red rice biotype A or B were transplanted to pots (monocultures) At the same time mixtures of Oryzica 1 with each of the red rice biotypes were established by transplanting 14 (7+7) 5-day-old seedlings into pots A total of 5 treatments (three monocultures and two mixtures) were thus obtained, and were arranged in a completely randomized block design with 4 replications Pots were placed in a screenhouse At 5, 10, 15, 20, 30, 45, 60, 80, 110, and 115 days after transplanting one pot of each rice variant in monoculture, and two pots of each of the two mixtures were harvested in each replication Thus at each harvest a total of 14 plants of each rice variant (whether in monoculture or in mixture) were harvested Leaf area, total dry matter, number of tillers, and height were determined for each harvested plant At maturity grain yield per plant was recorded

2 2 *Effects of red rice densities and competition periods on rice grain yield*

2 2 1 Density effects (1990) A field experiment was established in Jamundí, near CIAT (Colombia) The soil was clay in texture, pH 5 4, 2 4% organic carbon, 0 5 ppm P, 5 2 meq/100g Ca, and 6 4 meq/100g Mg Treatments consisted of different red rice densities (20, 40, 80, 160, and 320 seeds/m^2) that were broadcast over dry soil in 4x10 m plots, and then incorporated with a hand rake Red rice seed was collected from nearby infested fields A completely randomized design with 4 replications was used Oryzica 1 rice was then drilled (100 kg/ha) in rows 17 cm apart The field was flush irrigated during the first 40 days and then flooded until 2 weeks before harvest Sixteen days after emergence (d a e) weeds were controlled with propanil + butachlor + bentazon at 1 9 + 2 4 + 1 2 kg ai/ha, respectively, applied with a CO_2 portable sprayer with 8002 nozzles delivering 200 L/ha A total of 160 N, 156 K_2O, and 58 P_2O_5 were applied at 20(60%), 40(20%), and

60(20%) d a e   Rice density was assessed 35 d a e by counting plants within 1m of row in 3 sites per plot Actual red rice densities were counted 36 d a e within a 0 25 m^2 quadrat placed in 3 sites per plot   Mature, ready to shatter grain was collected daily after red rice began to ripen   At rice maturity, rice and red rice seed were harvested within a 2x9 m area in each plot   Weight of rough rice was recorded   Results were analyzed by regression

2 2 2   Competition periods (1990)   Adjacent to the above experiment, and conducted in the same way, another trial evaluated the effect of a single density of red rice competing for different periods of time with Oryzica 1 One hundred red rice seeds/m^2 (same seed source as in 2 2 1) were broadcast, and incorporated as in 2 2 1 Oryzica 1 was then drilled (100 kg/ha) into dry soil in rows 17 cm apart   Treatments consisted of nine competition periods where red rice competed during 18, 25, 40, 50, 70, and 90 d a e , which approximately corresponded to the following growth stages of Oryzica 1 3-leaf, tillering, maximum tillering, panicle initiation, heading, and anthesis   A weed-free and a weedy check were included Plots were 18x5 m, and treatments were arranged in randomized complete blocks with 4 replications   Red rice was removed by hand at the end of each weedy period At the time of the first red rice removal (18 d a e) rice and red rice densities were assessed as in the previous experiment Rice was harvested at maturity within a 2x6 m area in each plot

2 2 3 Response to densities and periods of red rice infestation (1991) This experiment was conducted in an area adjacent to where experiments 2 2 1 and 2 2 2 had been Oryzica 1 was drilled (100 kg/ha) into dry soil in rows 17 cm apart after 6, 12, 23, and 29 seed/m^2 of locally-collected red rice had been broadcast and incorporated with a hand rake These densities were lower than in experiment 2 2 1, because this field was already infested with red rice seed, and because more data points in a medium to low infestation range were desired The experiment was fertilized with a total of 132 N, 60 P_2O_5 and 60 K_2O applied at 20(60%), 40(20%), and 60(20%) d a e At 10 d a e quinclorac + bentazon + butachlor at 0 75 + 1 2 + 2 4 kg ai/ha, respectively were sprayed Red rice was removed from the plots at 10, 30, 60, and 90 d a e Thus the experiment consisted of a combination of 4 red rice densities and 4 competition periods, a season-long weedy and a weed free check were included Treatments were arranged in randomized complete blocks with 4 replications, plots were 4x10 m Red rice densities were counted 10 d a e (end of first weedy period) within a 0 25 m^2 quadrat placed at 2 sites in each plot the rest of the treatments were counted 30 d a e Rice density was assessed (30 d a e) by counting the number of plants per meter of row, twice per plot The experiment was flush irrigated during the first 20 days, and then flooded until two weeks before harvest At maturity rice grain was harvested in 10 m^2 within each plot Data were analyzed by regression

3 Results and Discussion

3 1 Growth analysis of rice and red rice biotypes in competition

Both red rice biotypes were of similar height, and grew considerably taller than Oryzica 1 (Figure 1c and f) As noted by Diarra et al (1985a) red rice height advantage over rice was associated with red rice's superior competitiveness (Figure 2) Red rice had no clear advantage in leaf area or early tillering over Oryzica 1 (Figure 1a, b, d, and e) As previously reported (Diarra et al, 1985b) red rice tillered continuously throughout the season, but Oryzica 1 tillered more than red rice early in the season, before panicle initiation (Figure 1 b, and e)

The tillering advantage of Oryzica 1 over red rice was smaller when rice competed with red rice biotype A (Figure 1b, and e). This biotype reduced rice height and yields the most (Figure 1c, f and 3), and was the most competitive since it tended to grow better in competition with rice than in monocrop (Figure 2).

It can be concluded from these data that red rice biotypes can differ in their competitive ability with rice. Such differences might increase the site specificity of results from competition experiments. In fostering the competitiveness of rice against red rice, increased seeding rates, and the use of tall and high tillering cultivars, appear justified. The use of high rice densities for weed suppression is a common practice among Latin American rice farmers.

3.2 Density and duration of red rice infestations

3.2.1 Density effects. By 31 d.a.e. about 312 (± 41) rice plants/m^2 were established. Red rice was very competitive, 5 and 20 red rice plants/m^2 resulted in 40%, and 60% grain yield reduction (Figure 4). Red rice competitiveness has already been recognized (Smith, 1988). Montealegre and Vargas (1989) found similar yield reductions with flush-irrigated rice. A curvilinear crop yield response to increasing weed densities results when that the areas of influence of neighboring weeds overlap (11) Therefore, Figure 3 indicates that intraspecific interference in red rice started at low densities, perhaps as a result of its height and strong tillering habit

Red rice shattered only a low proportion of its seed (Figures 5 and 6) However, according to Figure 5, a hypotethical infestation of 20 red rice plants/m^2 would have shattered about 35 seeds/m^2, assuming 1000 red rice grains weigh 25 g Supposing that only 20% of these germinate with the next crop, a yield reduction of about 50% can be expected (Figure 4) Also, the same infestation of 20 red rice plants/m^2 will contaminate the commercial grain harvested with about 1100 kg/ha of red rice grain (Figure 6), reducing its quality and price Red rice can shatter more seed than it did in this experiment, up to 70% was reported by Diaria (1985b) This potential for reinfesting rice fields and lowering rice quality should be considered when information such as that in Figure 4 is used to derive economic thresholds to manage red rice Managing weeds according to economic thresholds implies that infestations below the threshold are not controlled, and their seed can reinfest fields High competitiveness of red rice and the current rice value justified chemical control (2 kg ai glyphosate followed by 0 75 kg/ha paraquat applied to the weed before seeding rice) even at very low red rice densities (Table 1) Chemical control of red rice is common in Latin America, either alone or in combination with other cultural practices (Antigua, 1990, CIAT, 1991)

3 2 2 *Competition duration* Eighteen days after crop emergence 24 (± 10) red rice and 306 (± 76) rice plants/m^2 were established Only 10% of the potential yield was lost if red rice competed with the crop during 40 d a e (Figure 7) Season-long interference reduced rice yields by 75% These findings agree with previous results (Kwon, et al 1991, Smith, 1988) Yield reduction became sharp when red rice competed with rice during flowering and grain filling stages At these stages, when solar radiation is essential for high yields (Yoshida, 1981), red rice was taller than rice and was still producing tillers (Figure 1b, c, e, and f)

With currents costs in Colombia, and under a moderately high red rice infestation, hand weeding offered no economic advantage over pre-plant herbicide use (Table 2)

3 2 3 Response surface to densities and periods of competition Rice population in the weed-free checks was 294 (± 49) plant/m^2 The combined response of rice to red rice density and periods of competition showed somewhat more intense competition effects than in 1990 (Figure 8) This could be related to the natural emergence of an additional red rice biotype, different to those seeded With a response surface approach the predictive power of competition studies is strengthened, and farmers' decision making is more realistically represented The feasibility of manual red rice control was studied The economic probability of hand weeding becoming economically justified was higher (larger economic threshold) among farmers in the lower yield bracket, and when hand weeding was done early (red rice can be distinguished from rice usually at about 30-40 d a e), (Table 3) and it also increased at lower labour costs (Table 4)

From the information so far presented one can conclude that competition studies are a powerful tool in rationalizing weed control and reducing its costs, since they allow to predict crop losses and regulate weed management costs accordingly The fact that red rice biotypes can differ in their competitiveness may result in crop loss variation over sites Further studies should attempt to compensate such variations by expressing weed infestations with parameters that closely relate to the outcome of competitive interactions such as relative crop/weed tillering since tillering was so relevant to the outcome of competition Kropff et al (1991) using weed relative leaf area[2] could account for variations in the time weeds emerged with respect to the crop at different sites in different years

Control of emerged red rice in the field leads to herbicide dependence Use of chemicals could be reduced if preventive (pure rice seed, clean farm equipment) or cultural practices (rotations, tillage) are also used Competition studies by helping establish the economic feasibility of such alternatives can stimulate investments to supply clean certified seed to farmers, and persuade these to rotate into other crops when their fields get heavily infested with red rice

[2] Leaf area index of weeds/leaf area index of (weeds + crop)

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Table 1 Economic threshold[a] for chemical control of red rice in rice Oryzica 1

1 Inputs[b]	Value (US dollars/ha)[c]
paraquat (0 75 Kg ai/ha)	14 3
glyphosate (2 kg ai/ha)	39 7
labour	4 1
Cost of red rice control	58 2
2 Threshold losses	
Expected rice yield[c] (weed free) 6222 kg/ha	
Threshold red rice density level 1 plant/13 m^2	
Expected yield loss[d] 340 kg/ha	
Value of loss	58 2

[a] Red rice density for which the cost of control equals the value of the yield loss it avoids

[b] Correspond to farmers' current practice in Colombia (CIAT, 1991)

[c] Current prices in Colombia (CIAT, 1991)

[d] Yield loss (as percent of an expected weed-free yield of 622 kg) = 96-19 LN(X+1), for X = number of red rice plants/m^2 determined within 30 days after rice emergence

Table 2 Comparative returns of chemical and manual control of a 24 plants/m^2 red rice infestation in rice Oryzica 1

	Timing	Yield[b/] recovered	Value of yield recovered	Net value[c/] recovered
	d a e [a/]	(kg/ha)	(US dollars)	(US dollars)
Hand weeding				
	6	6203	1061	998
	10	6129	1048	985
	30	5755	984	921
Chemical control	0	6220	1064	1006

[a]/ Days after emergence

[b]/ From equation Y = 101 5 - 0 3X, where Y is yield as percent of an expected weed free yield of 6222 kg/ha (CIAT, 1991), and X is days weedy after emergence

[c]/ Value of the yield recovered at 0 17 US dollars/kg rice minus the cost of weed control, (estimated at 58 and 63 US dollars for chemical and manual control, respectively)

Table 3 Economic thresholds for handweeding red rice at different rice productivity levels

Rough rice yield	Yield loss	Economic threshold[a]		
		30 d a e	35 d a e	40 d a e [b]
(kg/ha)	(%)	(plants/m^2)		
3630[d]	2 21[c]	1 9	1 4	0 8
6220	1 26	1 6	1 0	0 5
7310	1 06	1 5	0 9	0 4
8330	0 93	1 4	0 8	0 3

[a] Red rice density for which the value of rice yield losses resulting from its competition equals the cost of handweeding Cost of inputs and price of rice as in CIAT, 1991

[b] Time of handweeding in days after emergence (d a e)

[c] Calculated from the equation Y = 12 5+0 31D+2 9P 0 03P2

where

Y = rice yield as percent of weed free yield

D = red rice density (plants/m^2)

P = weedy period after emergence, or time of red rice handweeding in d a e

[d] Different rice yield levels among Colombian farmers (CIAT 1991)

Table 4 Economic thresholds for handweeding red rice at different rice according to rural labour costs

Rough rice yield	Yield loss	Economic threshold[a]		
		30 d a e	35 d a e	40 d a e[b]
(US dollars/hour)	(%)	(plants/m^2)		
1 0	0[c]	1 0	0 5	0
0 74	1 26	1 6	1 0	0 5
0 50	2 51	2 0	1 4	0 9
0 25	3 79	2 4	1 8	1 3
0 0	5 11	2 9	2 4	1 8

[a] Red rice density for which the value of rice yield losses resulting from its competition equals the cost of handweeding Cost of inputs and price of rice as in CIAT, 1991

[b] Time of handweeding in days after emergence (d a e)

[c] Calculated from the equation Y = 12 5+0 31D+2 9P 0 03P2

where

Y = rice yield as percent of weed free yield

D = red rice density (plants/m^2)

P = weedy period after emergence, or time of red rice handweeding

Figure 1 Growth parameters of rice Oryzica 1 (-o-) and red rice biotypes A and B (-) growing in competition

Figure 2 Growth of rice Oryzica 1 (-o-) and red rice (-) biotypes A (a) and B (b) in competition expressed as percentage of their growth in monoculture

Figure 3 Grain yields of Oryzica 1 growing in monoculture or in competition with red rice biotype A or B

Figure 4 Effect of red rice densities on grain yields of rice Oryzica 1 as percent of the weed-free yield

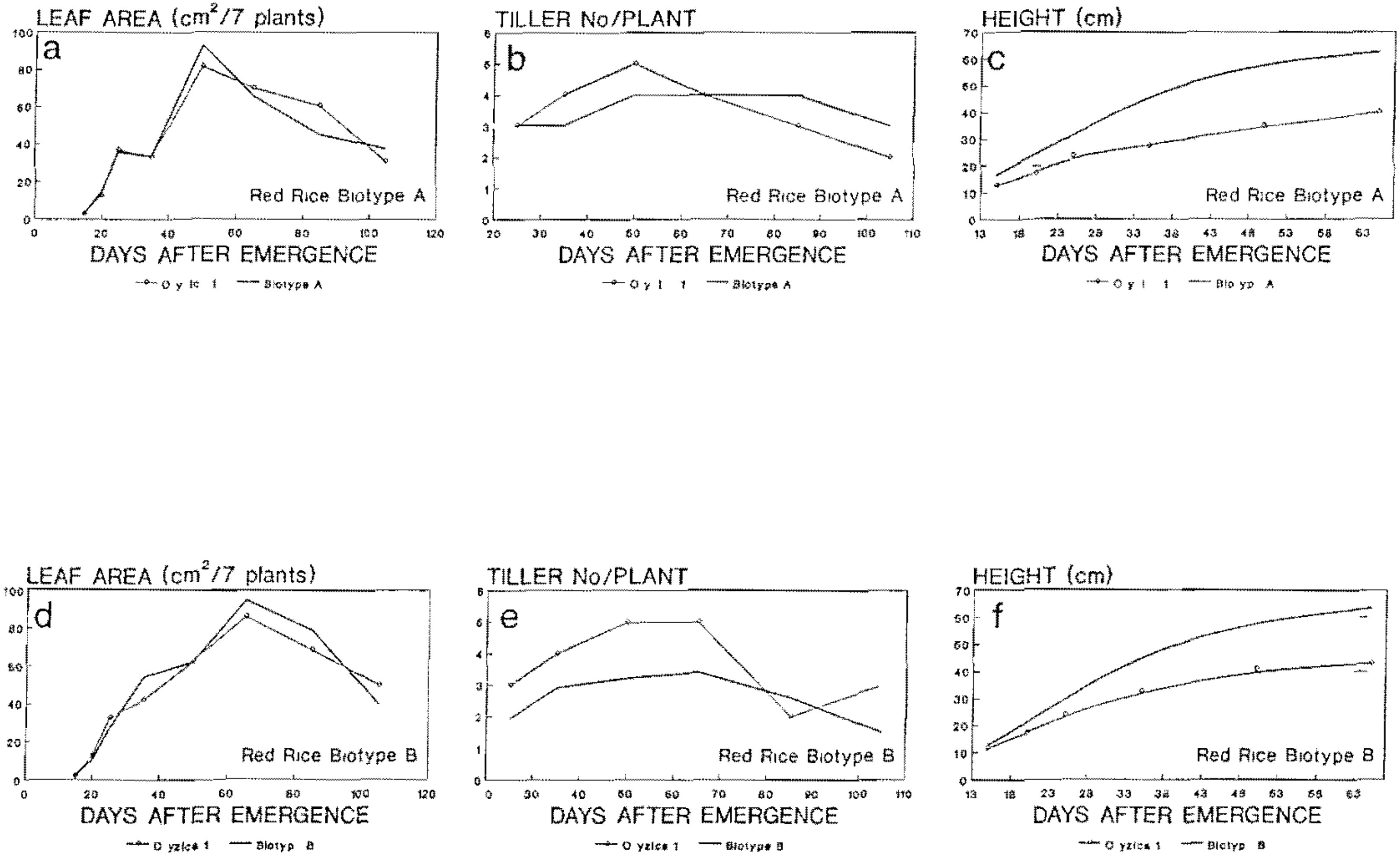
Figure 5 Red rice grains shattered before rice harvest when different red rice densities grew in competition with Oryzica 1

Figure 6 Red rice grains harvested with rice Oryzica 1 that grew in competition with different red rice densities

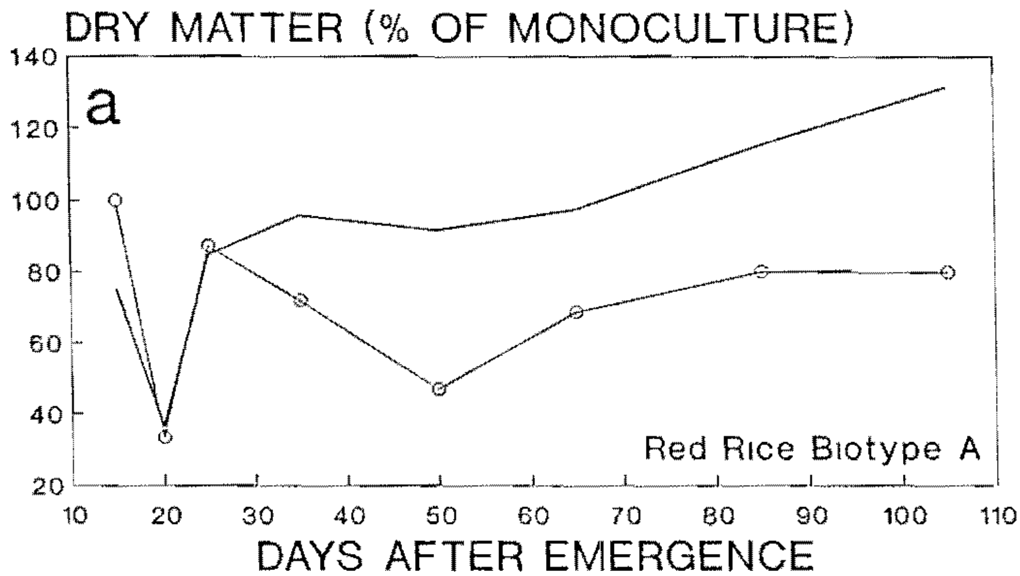
Figure 7 Grain yields of rice Oryzica 1 (as percent of weed-free yields) after competing with red rice during different periods after emergence

Figure 8 Percent yield losses when different red rice densities competed with rice Oryzica 1 during different periods after emergence

FIG 1



LEAF AREA (cm²/7 plants)
a
Red Rice Biotype A
DAYS AFTER EMERGENCE
Biotype A
TILLER No/PLANT
b
Red Rice Biotype A
DAYS AFTER EMERGENCE
Biotype A
HEIGHT (cm)
c
Red Rice Biotype A
DAYS AFTER EMERGENCE
LEAF AREA (cm²/7 plants)
d
Red Rice Biotype B
DAYS AFTER EMERGENCE
TILLER No/PLANT
e
Red Rice Biotype B
DAYS AFTER EMERGENCE
Biotype B
HEIGHT (cm)
f
Red Rice Biotype B
DAYS AFTER EMERGENCE


DRY MATTER (% OF MONOCULTURE)
a
140
120
100
80
60
40
20
Red Rice Biotype A
10
20
30
40
50
60
70
80
90
100
110
DAYS AFTER EMERGENCE

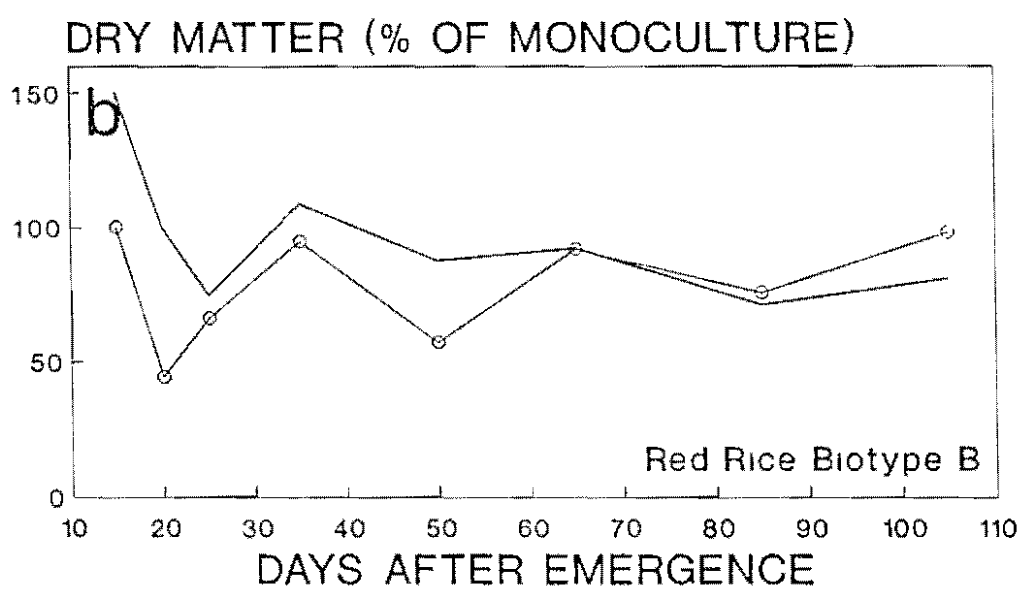

DRY MATTER (% OF MONOCULTURE)
b
150
100
50
0
Red Rice Biotype B
10
20
30
40
50
60
70
80
90
100
110
DAYS AFTER EMERGENCE

FIG 5

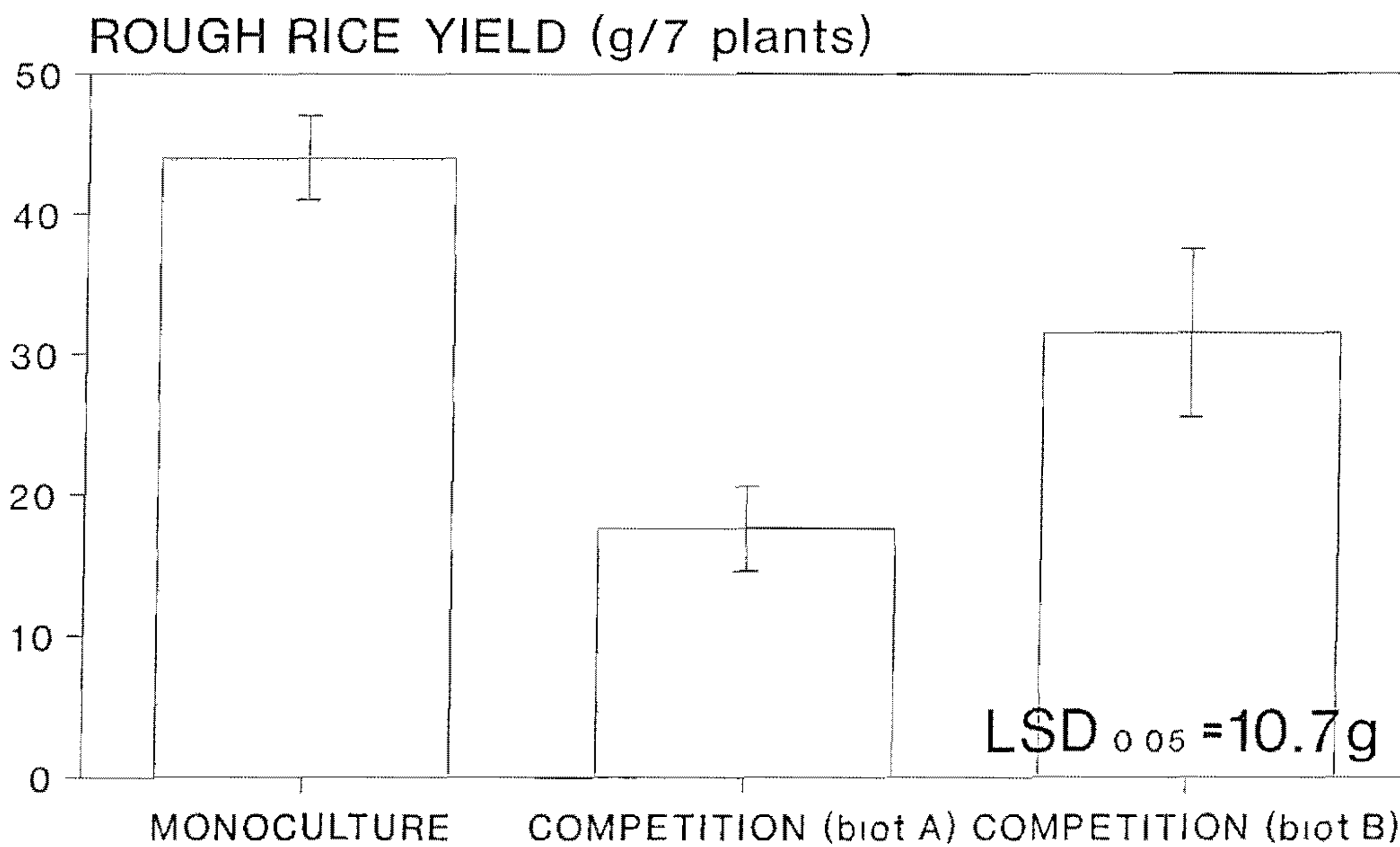
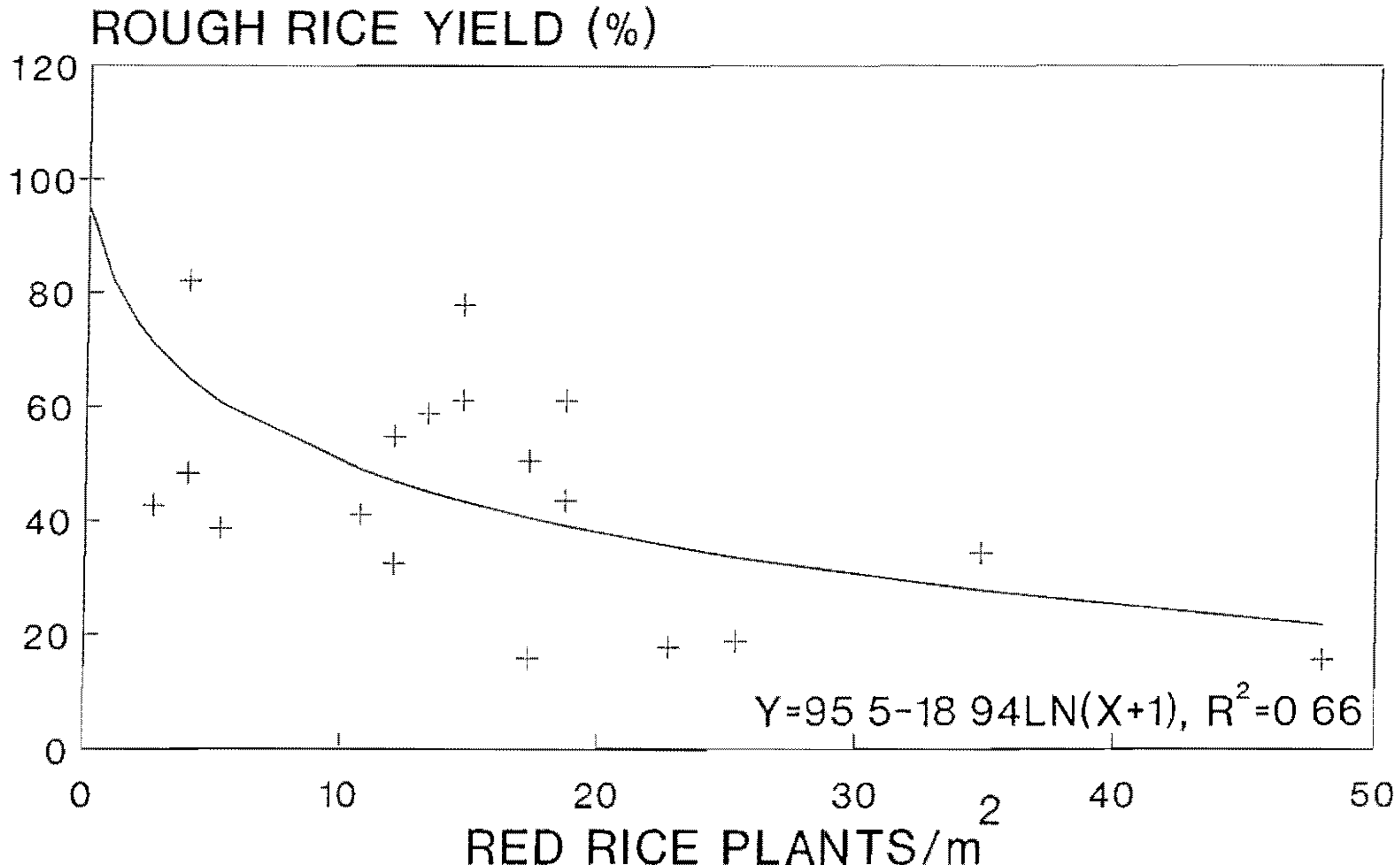

ROUGH RICE YIELD (g/7 plants)
50
40
30
20
10
0
LSD 0.05 =10.7g
MONOCULTURE
COMPETITION (biot A)
COMPETITION (biot B)

FIG 4



ROUGH RICE YIELD (%)
120
100
80
60
40
20
0
0
10
20
30
40
50
RED RICE PLANTS/m^2
Y=95 5-18 94LN(X+1), R^2=0 66

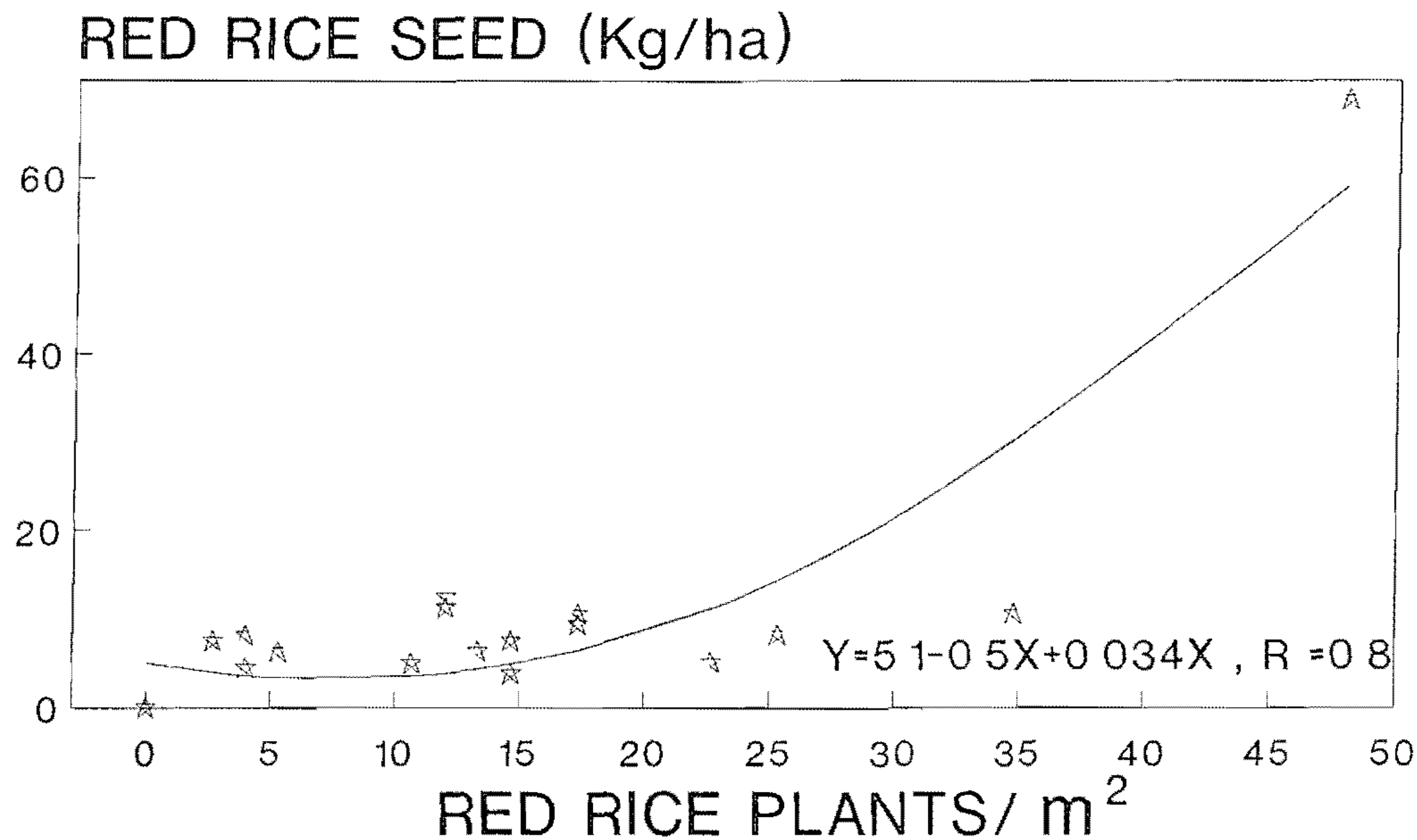
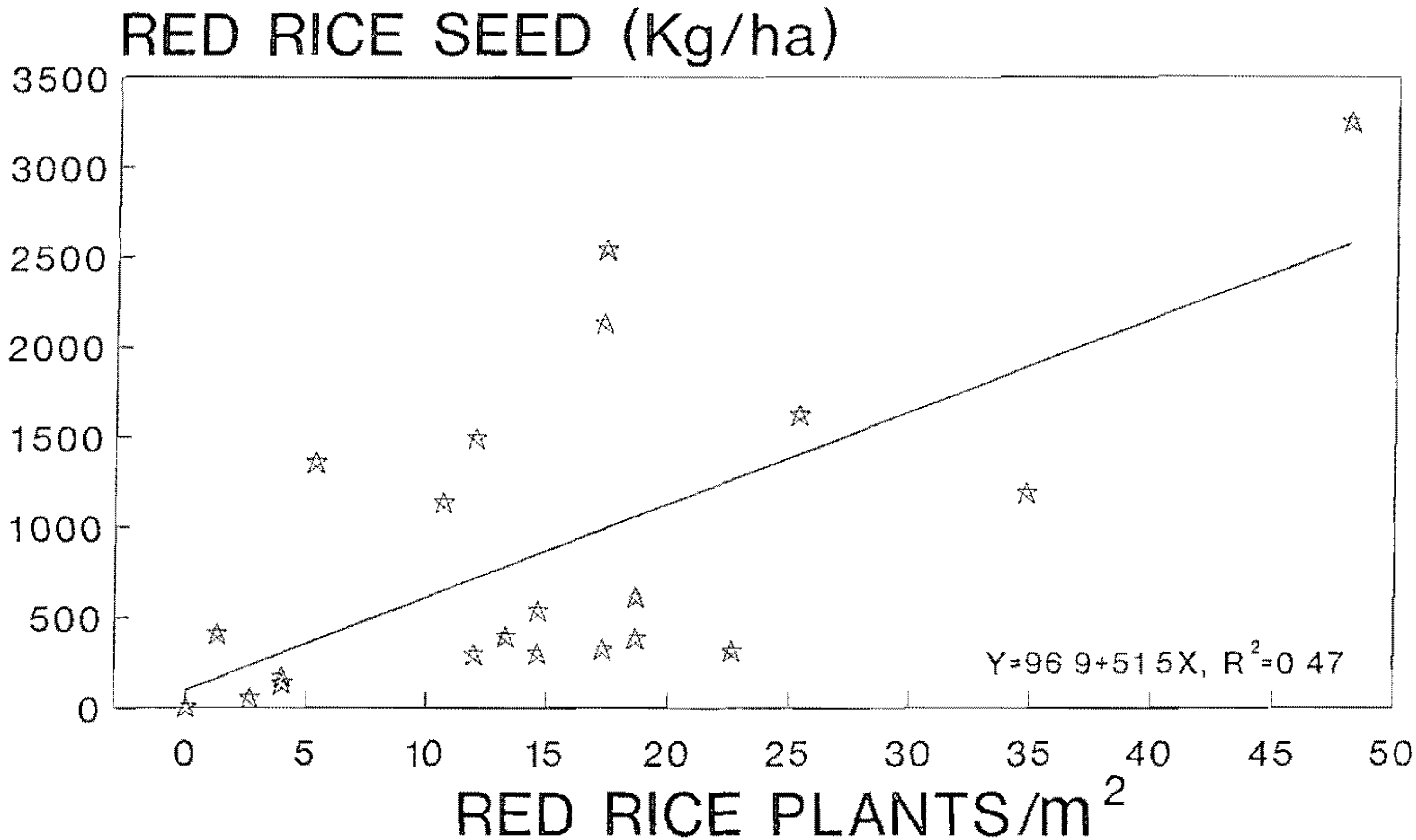

RED RICE SEED (Kg/ha)
60
40
20
0
Y=5 1-0 5X+0 034X , R =0 8
0
5
10
15
20
25
30
35
40
45
50
RED RICE PLANTS/ m 2

FIG 6



RED RICE SEED (Kg/ha)
3500
3000
2500
2000
1500
1000
500
0
0
5
10
15
20
25
30
35
40
45
50
RED RICE PLANTS/m 2
Y=96 9+51 5X, R 2=0 47

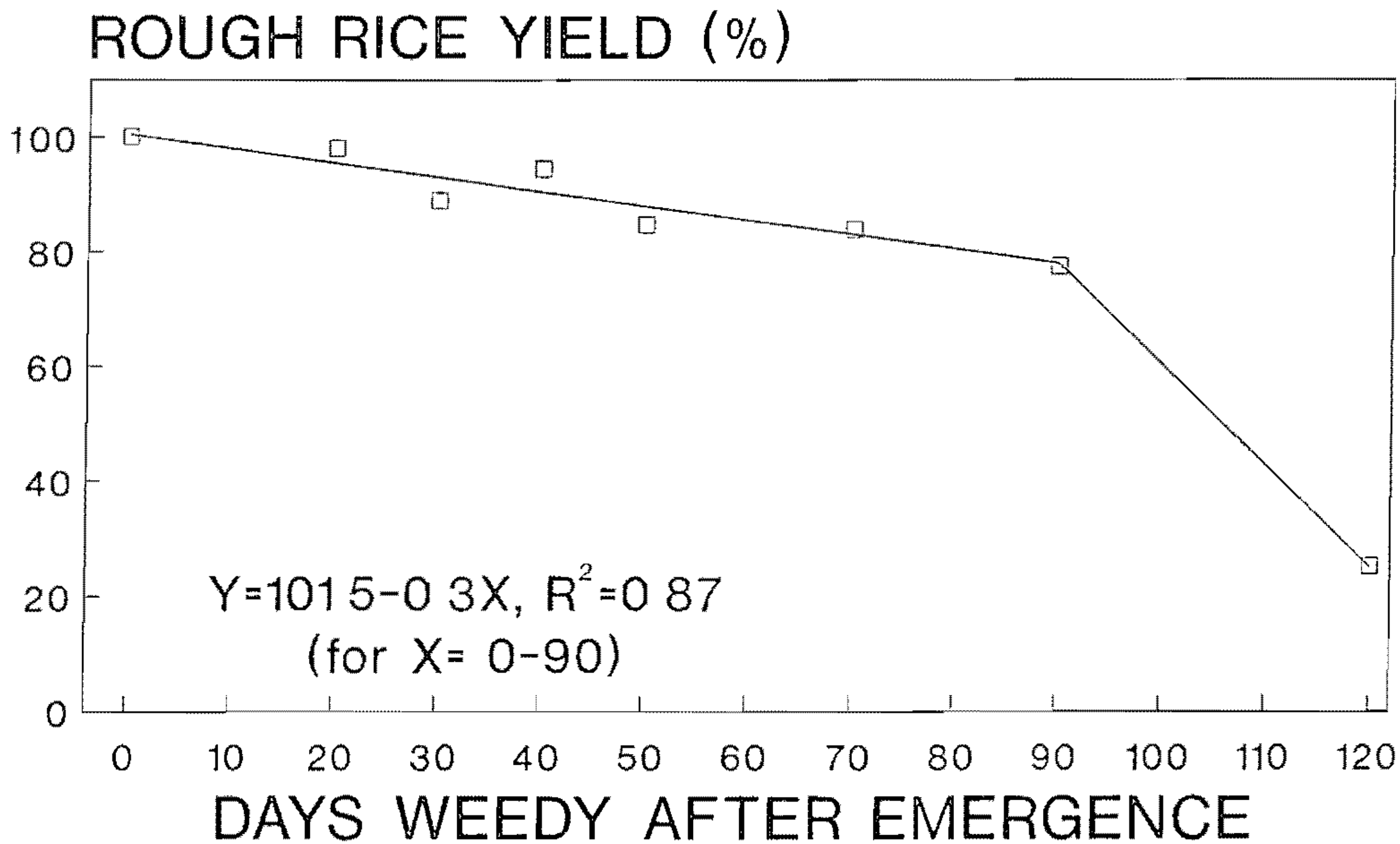
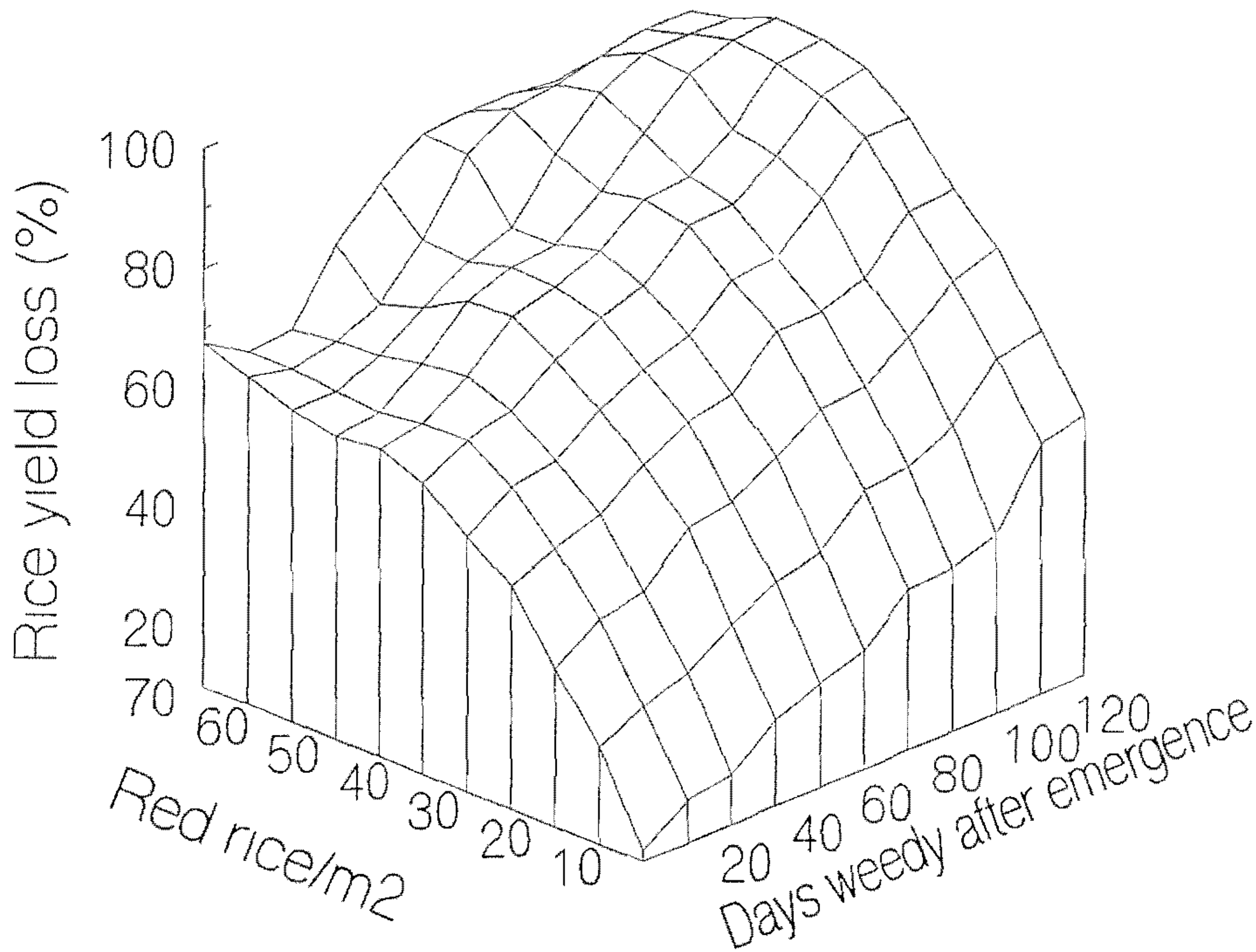

ROUGH RICE YIELD (%)
100
80
60
40
20
0
Y=101 5-0 3X, R²=0 87
(for X= 0-90)
0
10
20
30
40
50
60
70
80
90
100
110
120
DAYS WEEDY AFTER EMERGENCE

FIG-8



$Y = -12.5 + 0.31D + 2.9Rr - 0.03Rr^2$, $R^2 = 0.83$, $p < 0.0009$