Yield loss prediction for integrated weed management in direct-seeded rice

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Abstract. The critical period of rice-weed competition was studied for the rice varieties Oryzica 1 and CICA 8, in 1989 and 1990. Weed species were: *Eleusine indica, Echinochloa crus-galli, Echinochloa colonum, Cyperus difformis, Cyperus esculentus, Cyperus iria, Leptochloa filiformis,* and *Eclipta alba*. Competition effects were similar for both varieties. Weeds emerging with the crop were the most damaging ones. Rice yields increased with longer weed-free periods up to 70 days after emergence (d.a.e.). No further yield increases resulted from longer weed-free durations. Weed emergence and growth after 70 d.a.e. was suppressed by the crop. Both rice cultivars required a critical height of 44 to 50 cm. to suppress weed growth 70 d.a.e. Though both varieties were equally weed suppressive by 70 d.a.e., leaf area index of CICA 8 was much larger than that of Oryzica 1 when rice grew weed-free after emergence. Economic analysis showed that under heavy

weed infestations, in a system where rice cannot be early and continuously flooded, three postemergent herbicide applications at 9, 18 and 44 d.a.e were justified.

1. Introduction

In Latin America weed control in rice is mostly achieved with herbicides. Herbicide use is costly and often excessive. A survey in Colombia (CIAT, 1991) indicated that farmers could reduce herbicide costs by 25% if inefficiencies in their use were eliminated. Such inefficiencies mainly resulted from excessive dosages and late applications. Estimation of yield losses from competition by existing or predicted weed infestations would allow for the adjustment of weed control costs to the values of the expected losses. Thus, components of integrated weed management programs would be selected on the basis of their cost effectiveness. Therefore, a function describing weed-crop competition effects throughout the growing season is needed, particularly where poor water control forces farmers of irrigated, direct seeded, rice to spray herbicides up to three or four times in the crop's growth cycle. It has been recognized that when direct seeded rice cannot be early and continuously flooded to smother weeds their growth is favored (Bhan, 1983). According to CIAT (1991), in Colombia farmers on the average spray herbicides at 9, 18, and 44 days after crop emergence (d.a.e.). Competition studies and economic analysis can help decide which of these applications are economically justified, and if other weed management techniques could substitute for them. Therefore, this approach has potential for avoiding excessive herbicide use, and also to serve as decision tool in the selection and integration of weed management options in a broad range of situations.

The objectives of this work were to define criteria for selecting and integrating weed management alternatives in rice by:

a) Identifying when, during the crop's growth cycle, weeds have to be removed to avoid yield losses from weed competition in flush-irrigated[1] semidwarf rice.

b) Generating a function describing yield gains with increasing weed-free periods after emergence, and yield losses as the first weed control of the season is delayed.

c) Using the above functions, and survey information of Colombian rice farmers (CIAT, 1991) to perform ex-post

[1] Rice not always flooded, soil kept near field capacity with periodic irrigation flushes.

analysis assessing the economic efficiency of farmers' usual post-emergence herbicide program.

2. Materials and Methods

2.1. *Competition studies*

August 1989, and September 1990 rice-weeds competition experiments were conducted at CIAT, near Cali, Colombia. Soil characteristics in 1989 were: 19% sand, 31% silt, and 51% clay, pH = 7.6, and 3% organic matter; in 1990: 19% sand, 40% silt, and 41% clay, pH = 7.9, and 2% organic matter. Different competition periods were considered: a) The crop grew weedy during 12, 24, 35, 60, 80, and 120 d.a.e. Weeds were seeded with the crop, and at the end of each competition period they were removed. Thereafter, the crop was kept weed-free until harvest. b) The crop was weed- free for 12, 24, 35, 60, 80, d.a.e., and up to harvest. At the end of each period weeds were seeded, incorporated by hand with a rake, and allowed to grow undisturbed with the crop until harvest. Treatments were arranged in split plots within a randomized complete blocks design with four replications. In the main plots two rice varieties were placed: Oryzica 1 and CICA 8, the weed competition periods were in the subplots. Rice was seeded

(120 kg seed/ha) on a dry seedbed in rows 17 cm apart, and fertilized with 120 kg N/ha (40 at 15, 40 at 40, and 40 at 65 d.a.e.), 30 P, 30 K, and 15 Zn. The last three nutrients were applied at seeding time. Plots were 2 x 5 m, and rice was harvested within a 1.7 x 4 m area. The experiments were flush irrigated to near field capacity. Weeds were seeded at a saturating (200-400 seed/m^2) density to express the crop's potential to compete with weeds (Fischer, et al., 1988), and represent the most unfavorable situation. The weed species were: *Eleusine indica*, *Echinochloa crus-galli*, *Echinochloa colonum*, *Cyperus difformis*, *Cyperus esculentus*, *Cyperus iria*, *Leptochloa filiformis*, and *Eclipta alba*. Weed emergence was monitored throughout the season within one 0.09 m^2 quadrat per plot. At each period, rice leaf area of ten average-sized tillers/plot, number of rice tillers/m of row (three samples/plot) weed aboveground dry matter/0.25 m^2 (three samples/plot), and rice height (5 plants/plot) were taken.

Rice yield data were subjected to analysis of variance, and analyzed by regression to derive a <u>yield loss function</u> (treatments weedy after emergence), and a <u>yield gain function</u> (treatments weed-free after emergence).

2.2. *Economic analysis*

Additional income from herbicide applications was estimated, this can vary with: a) The initial yield loss before any weed control is applied, which increases as the first weed control operation is delayed; b) the efficiency of the weed control operations; c) the duration of the critical period of competition: d) the value of rice and the cost of inputs. It was assumed (CIAT, 1991) that an average rice farmer controls his weeds at t_1, t_2, and t_3 d.a.e. It was also assumed that a herbicide applied at t_1 maintains the crop free of weeds until t_2, one applied at t_2 keeps it weed-free until t_3, and after spraying at t_3 the crop remains weed free until harvest. Figure 1 presents hypothetical yield loss and yield gain functions. According to the yield loss function (Figure 1a) a first herbicide application implies that weeds compete with the crop for t_1 days and **p**% of the potential yield is lost, where **p=100-a**. If initial weed control kept the crop weed-free until t_2 **b**% of the maximum yield would be recovered from weed competition (Figure 1b). However, since the first herbicide was applied after certain competition occurred (Figure 1a), the net benefit of the first application would be **c%=b-p** (Figure 1b). If **Y** is the maximum yield in kg/ha, then the additional yield resulting from the first application would be $Y_1=Y \times c$ kg/ha, and the additional income is obtained multiplying by the price per kilogram of rice. Similarly, an application at t_2 would recover e%=d-b-p (Figure 1c), and one at t_3 f%=100-p-d (Figure 1d). The net benefit of the second application is $Y_2=Y \times e$ kg/ha, and that of the third application $Y_3=Y \times f$ kg/ha. From a survey (CIAT, 1991) costs of each of the herbicide applications, and the price of rice to the farmer were obtained.

3. Results and Discussion

3.1. Competition studies

Most weeds emerged with the crop within the first 12 days. However, since the crop was not kept permanently under flood other flushes of weed emergence occurred later in the season (Figure 2). Yields of weed-free rice in 1989 were 3400 and 4100 kg/ha for Oryzica 1 and CICA 8, respectively. In 1990 yields were 6500 and 7200 kg/ha for Oryzica 1 and CICA 8, respectively. Rice plants suffered of iron deficiency in 1989, which may explain the lower yields this year. When rice yields were expressed as percent of the weed-free yield, the treatment x year interaction was not significant (p>0.05). Therefore, data for each variety were pooled over years, to generate yield loss and yield gain functions (Figure 3).

Weeds emerging with the crop reduced yields the most if left uncontrolled until harvest. Both rice varieties needed to be weed-free for about 70 d.a.e. to avoid significant yield reductions (Figure 3). This is why farmers that cannot establish a permanent flood early, and face heavy weed pressure must weed their crops repeatedly.

In spite of large differences in leaf area indices (LAI) when rice grew weedy after emergence (Figure 4), both varieties had similar competitiveness against weeds during the first 80 d.a.e. (Figure 5). Since height differences between varieties (growing weedy after emergence) (Figure 6) tended to be smaller than LAI differences , height may have been more related to weed suppression than LAI. The poor weed suppression by Oryzica 1 after 80 d.a.e. compared with CICA 8 could be related to its shorter growth cycle (Figure 5). When weed-free rice reached a critical height of 44 to 50 cm in height at about 70 d.a.e. (Figure 7) newly emerged weeds were almost completely suppressed (Figure 8), and rice did not benefit from further weeding (Figure 3). This represents the end of the critical period of competition when the crop's canopy is sufficiently developed to suppress emerging weeds (Dawson, 1977). At this point, a uniform rice stand is important to avoid the establishment of late-emerging weeds in gaps left by irregular seeding. Suppression of weeds emerging after the end of a weed-free period was similar for both varieties (Figure 8), and seemed more related to both rice varieties' reaching the same critical height rather than a certain LAI value for which they differed widely (Figure 9). Crop height has been shown to be relevant to competition in other irrigated systems (Fischer, 1988).

3.2. Economic analysis

Table 1 summarizes the decision matrix for post-emergent weed control with these rice varieties, where maximum yields assumed for Oryzica 1 and CICA 8 were 5600 and 5800 kg/ha, respectively (CIAT, 1991). With such expected maximum yields the cost of each herbicide application was lower than the additional income or the value of the yield losses expected to occur if the herbicides had not been used. Thus the three post-emergent herbicide applications were justified. This agrees with current practices in flush irrigated rice in Colombia (CIAT, 1991). However the heavy yield losses to weed competition in these experiments resulted from the heavy weed infestations imposed in order to observe the critical period of competition under high competitive pressure. The functions thus derived may overestimate the competitiveness of late emerging weeds and the benefits of herbicide applications. Other aspects such as herbicide phytotoxicity to rice from late applications were not considered and deserve to be studied not to overemphasize the benefits of chemical (post-emergent) weed control.

It can be concluded from the information presented in the above two sections that flush irrigation places rice in a serious disadvantage against weeds. Since weeds can not be smothered by flooding, they can emerge throughout the season benefitting from irrigation, establish, and compete with the crop. If weed populations are high, weed control must start at crop's emergence, and will have to be conducted until late in the season, especially with the modern short plant types of rice. Under such conditions, and heavy weed pressure, repeated herbicide use appeared justified. However, the analysis presented here should also be used for the *ex-ante* evaluation of other weed management strategies besides herbicide use, such as land levelling to allow for field flooding and water control (Bhan, 1983), rotation with other dryland crops (Smith, 1983), or high seeding densities (Smith, 1983). The applicability of this methodology resides in competition experiments reflecting well the field conditions of the region where results will be applied. The analysis presented here can also apply to other situations, such as upland rice, where postemergent weed control may also be required more than once during the crop's growth cycle.

Table 1. Decision matrix for post-emergence herbicide applications in rice Oryzica 1 and CICA 8.

	ORYZICA 1			CICA 8		
Herbicide application date (d.a.e.)	9	18	44	9	18	44
Total cost of application[b/] (USD $/ha)	58.37	55.49	58.37	58.37	55.49	58.37
Maximum expected yield (kg/ha)	5600	5600	5600	5800	5800	5800
Yield loss avoided (%)[a/]	59.53	23.33	17.31	53.31	24.77	21.46
Yield loss avoided (kg/ha)	3334	1307	970	3092	1437	1244
Price of rice (USD $/kg)	0.18	0.18	0.18	0.18	0.18	0.18
Additional income per application	590.04	231.27	174.60	547.2	254.26	220.26

a/
Corrected for **p**% loss by weed competition occurring before weeds are sprayed for the first time (9 d.a.e.)

b/
First application (9 d.a.e.): propanil + butachlor + pendimethalin at 2, 1.2, 1.3 kg ai/ha, respectively; second application (18 d.a.e.): thiobencarb + propanil + picloram + 2,4-D (2.2 + 3.3 + 0.09); third application (44 d.a.e.): fenoxaprop-ethyl+bentazon (0.1 + 0.5), paraquat (0.2) in spot applications.

References

BHAN, V. M. 1983. Effects of Hydrology, soil moisture regime, and fertility management on weed populations and their control in rice. Proceedings of the Conference on Weed Control in Rice. International Rice Research and International Weed Science Society. La Laguna, Philippines, pp. 47-56.

CIAT, 1991. Rice Program. Socioeconomics. Annual Report 1991. Cali, Colombia. pp. 202-210.

DAWSON, J. H. 1977. Competition of late-emerging weeds with sugarbeets. Weed Science 25:168-170.

FISCHER, A. J., J. H. DAWSON, and A. A. APPLEBY. 1988. Interference of annual weeds in seedling alfalfa (*Medicago sativa*). Weed Science 36:583-588.

SMITH, R. J., Jr. 1983. Weeds of major economic importance in rice and yield losses due to weed competition. Proceedings of the Conference on Weed Control in Rice. International Rice Research and International Weed Science Society. La Laguna, Philippines, pp. 19-36.

Figure 1. a) Rice yields (as percent of the weed-free yield) for increasingly longer time periods weedy after emergence (TWAE), and yield loss (p) if first herbicide application is made at t_1; b) Yield gains with increasingly longer weed-free periods after emergence, and yield gain (c) if weed control from first application lasts until t_2; c) Yield gain (e) from a second herbicide application at t_2 with residual weed control until t_3; d) yield gain (f) from a third weed control application at t_3.

Figure 2. Sequential emergence of weeds seeded with Oryzica 1 and CICA 8, in two years.

Figure 3. Yield loss (+) and yield gain (■) functions for rice growing weedy or weed-free for different periods after emergence. Data are averages of two years.

Figure 4. Leaf area index of Oyrizica 1 (■) and CICA 8 (o) growing weed free for different periods after emergence, in two years. Vertical bars indicate $\pm$ one standard deviation of the mean.

Figure 5. Dry matter of weeds growing with Oryzica 1 (■) and CICA 8 (o) for different periods after emergence, in two years. Arrows indicate dates of 50% anthesis. Vertical bars indicate $\pm$ one standard deviation of the mean.

Figure 6. Heights of Oryzica 1 (■) and CICA 8 (o) growing weedy for different periods after emergence, in two years. Vertical bars indicate ± one standard deviation of the mean.

Figure 7. Heights of Oryzica 1 (■) and CICA 8 (o) growing weed-free after emergence, in two years. Vertical bars indicate ± one standard deviation.

Figure 8. Dry matter of weeds at rice harvest when Oryzica 1 (■) and CICA 8 (o) grew weed-free for different periods after emergence, at the end of which weeds were seeded and allowed to grow undisturbed with the crop. Vertical bars indicate ± one standard deviation of the mean, data of two years.

Figure 9. Leaf are index of Oryzica 1 (■) and CICA 8 (o) growing weedy after emergence, in two years. Vertical bars indicate ± one standard deviation of the mean.

FIG 1

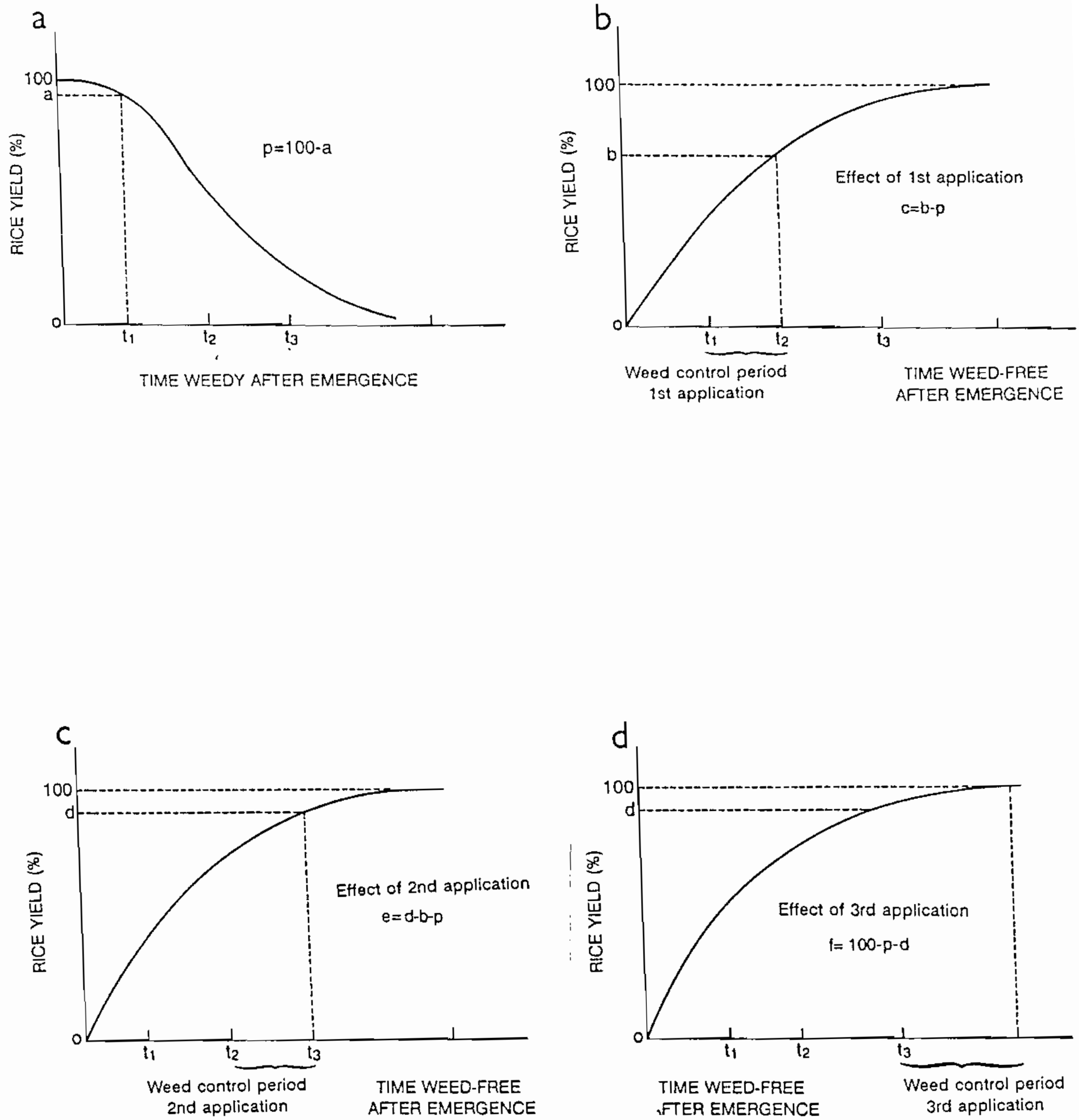

a
100
a
RICE YIELD (%)
p=100-a
0
t1
t2
t3
TIME WEEDY AFTER EMERGENCE
b
100
b
RICE YIELD (%)
Effect of 1st application
c=b-p
0
t1
t2
t3
Weed control period
1st application
TIME WEED-FREE
AFTER EMERGENCE
c
100
d
RICE YIELD (%)
Effect of 2nd application
e=d-b-p
0
t1
t2
t3
Weed control period
2nd application
TIME WEED-FREE
AFTER EMERGENCE
d
100
d
RICE YIELD (%)
Effect of 3rd application
f= 100-p-d
0
t1
t2
t3
TIME WEED-FREE
AFTER EMERGENCE
Weed control period
3rd application

Figure 2

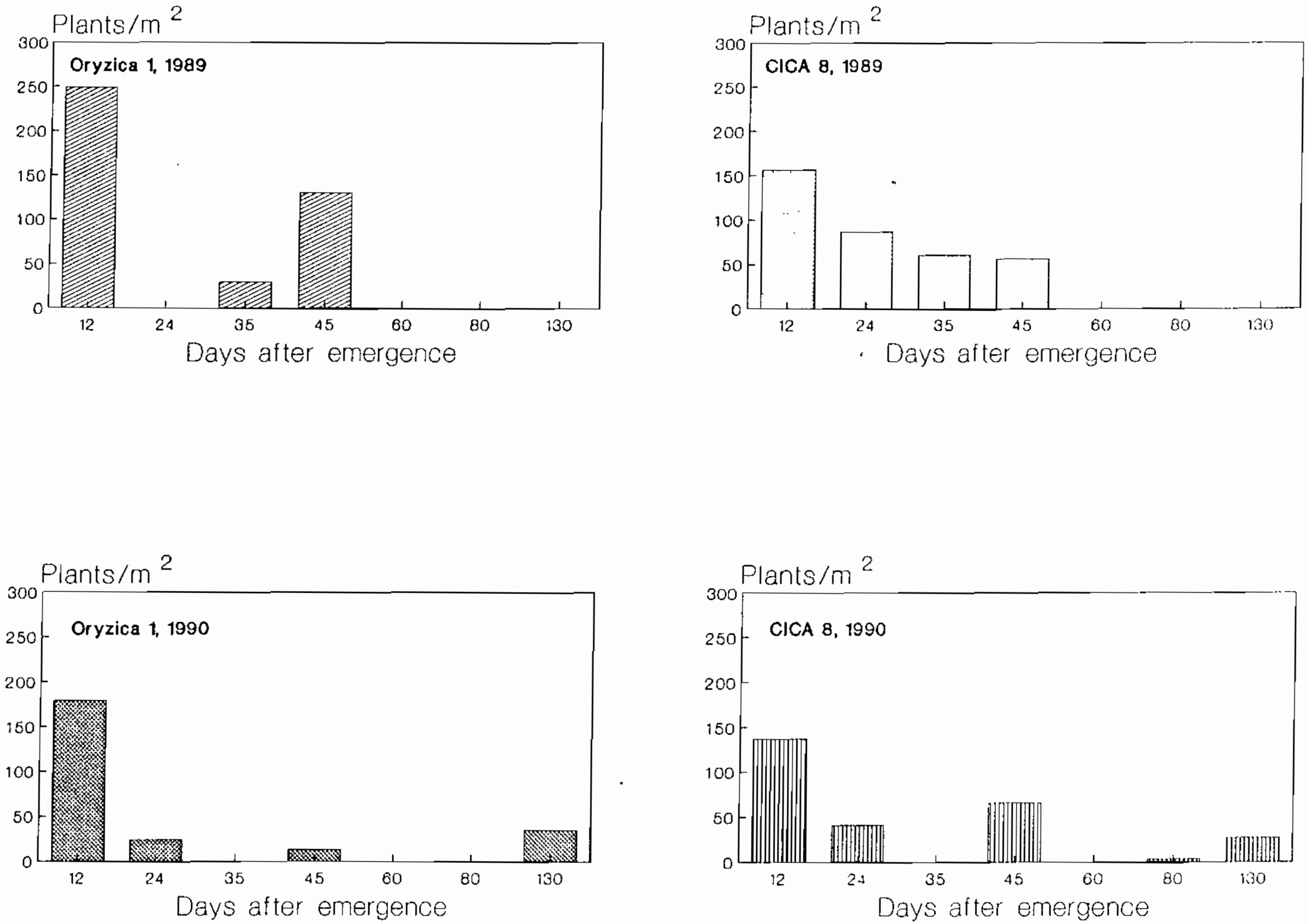
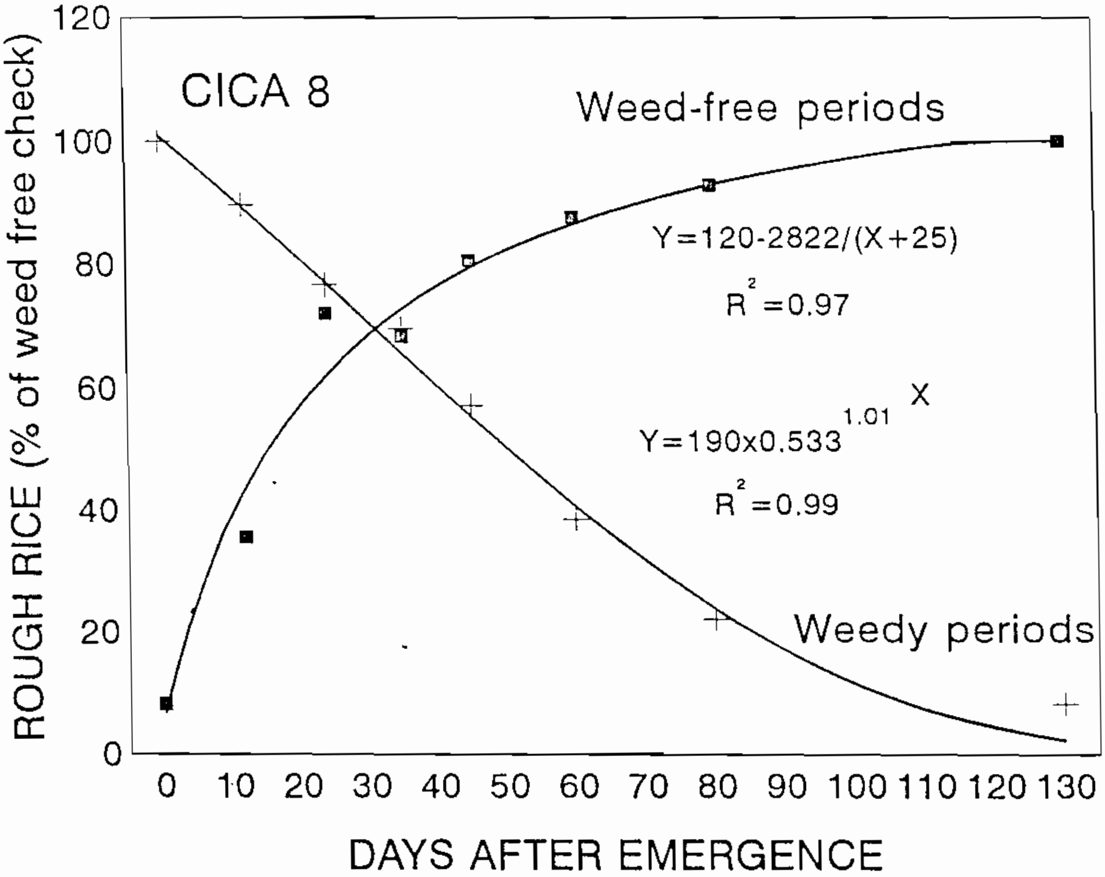
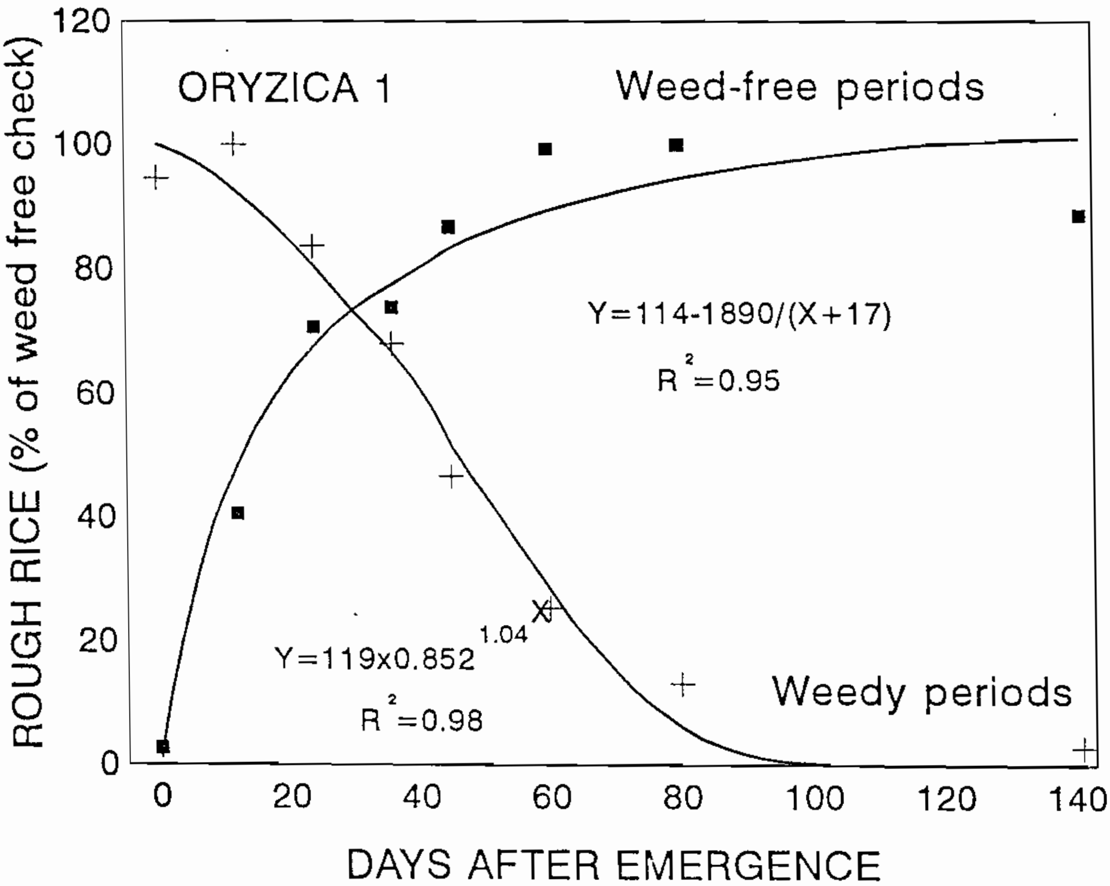

Plants/m 2
Oryzica 1, 1989
300
250
200
150
100
50
0
12
24
35
45
60
80
130
Days after emergence
Plants/m 2
CICA 8, 1989
Days after emergence
Plants/m 2
Oryzica 1, 1990
Days after emergence
Plants/m 2
CICA 8, 1990
Days after emergence

FIG 3

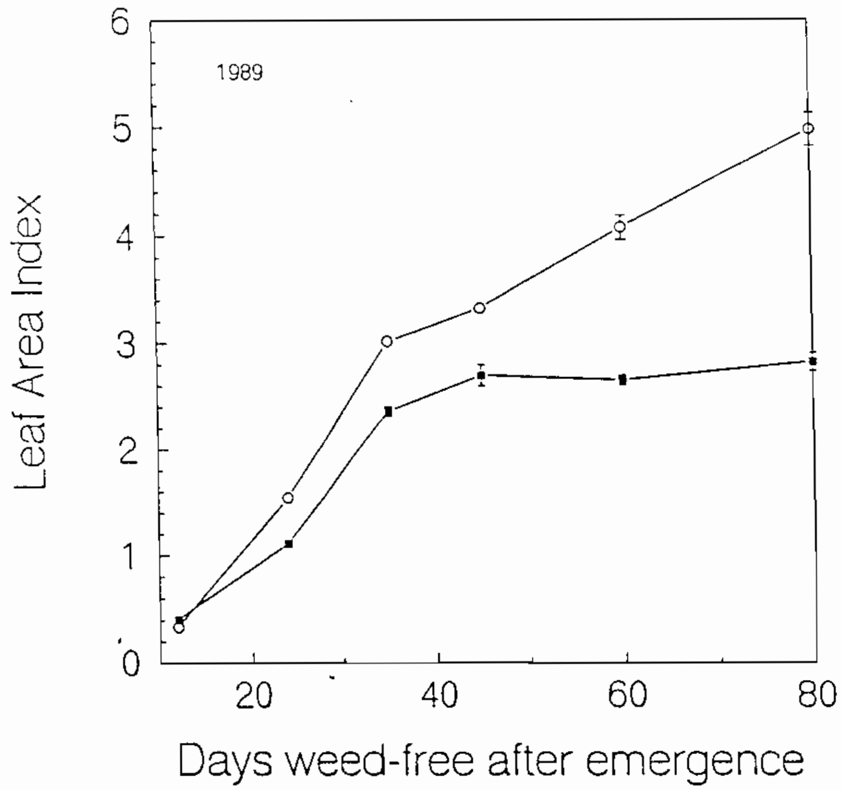


CICA 8
Weed-free periods
Y=120-2822/(X+25)
R²=0.97
Y=190x0.533^1.01 X
R²=0.99
Weedy periods
ROUGH RICE (% of weed free check)
DAYS AFTER EMERGENCE



ORYZICA 1
Weed-free periods
Y=114-1890/(X+17)
R²=0.95
Y=119x0.852^1.04 X
R²=0.98
Weedy periods
ROUGH RICE (% of weed free check)
DAYS AFTER EMERGENCE

Fig 4


1989
Leaf Area Index
0
1
2
3
4
5
6
20
40
60
80
Days weed-free after emergence

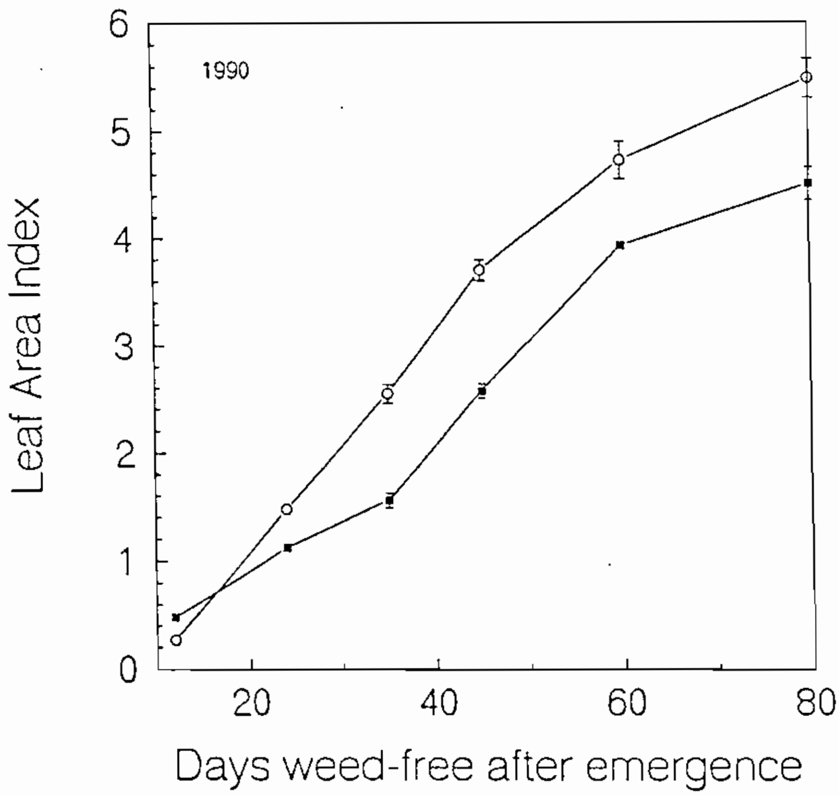
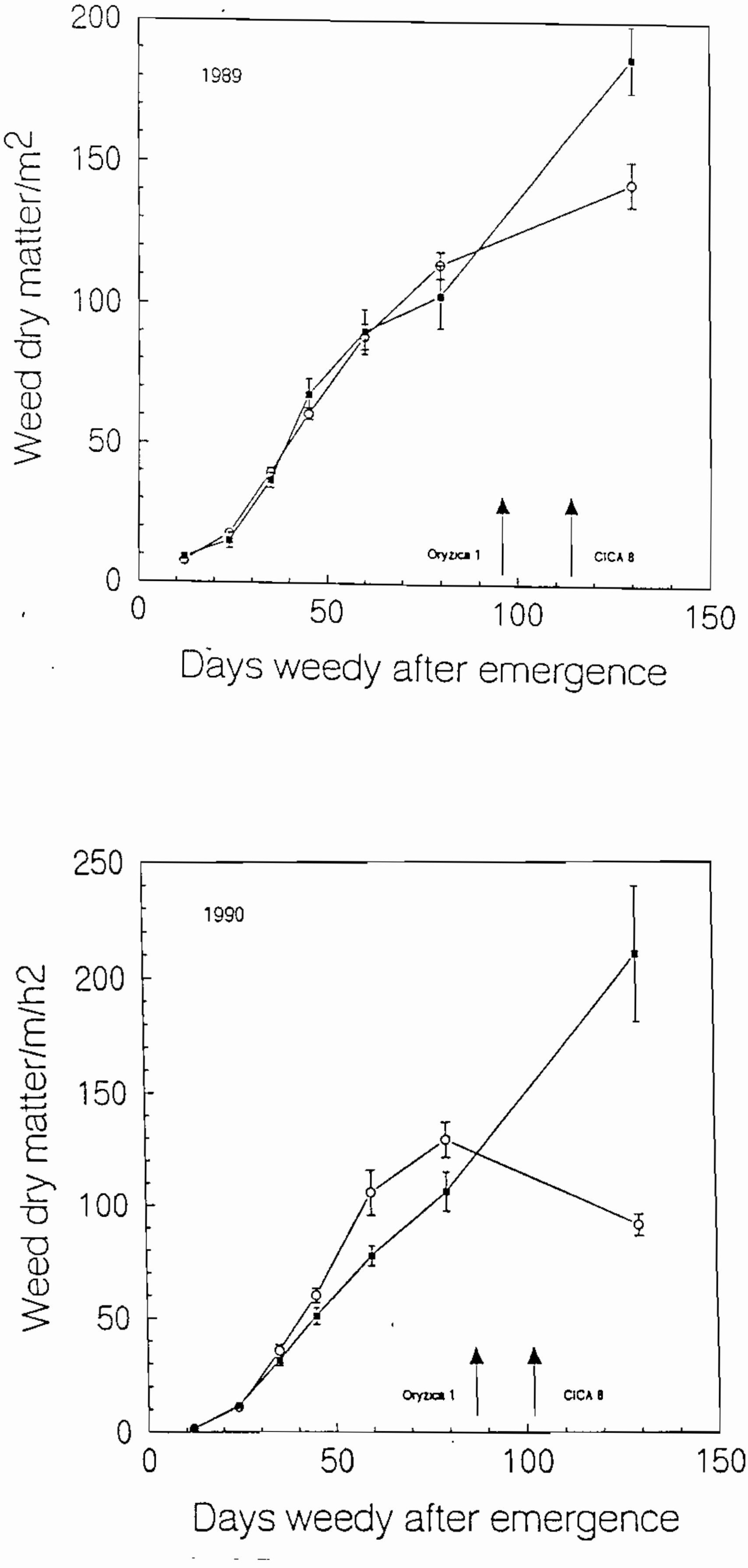

1990
Leaf Area Index
0
1
2
3
4
5
6
20
40
60
80
Days weed-free after emergence

FIG.



1989
Weed dry matter/m2
Days weedy after emergence
Oryzica 1
CICA 8
0
50
100
150
200
1990
Weed dry matter/m/h2
250

Fig 6

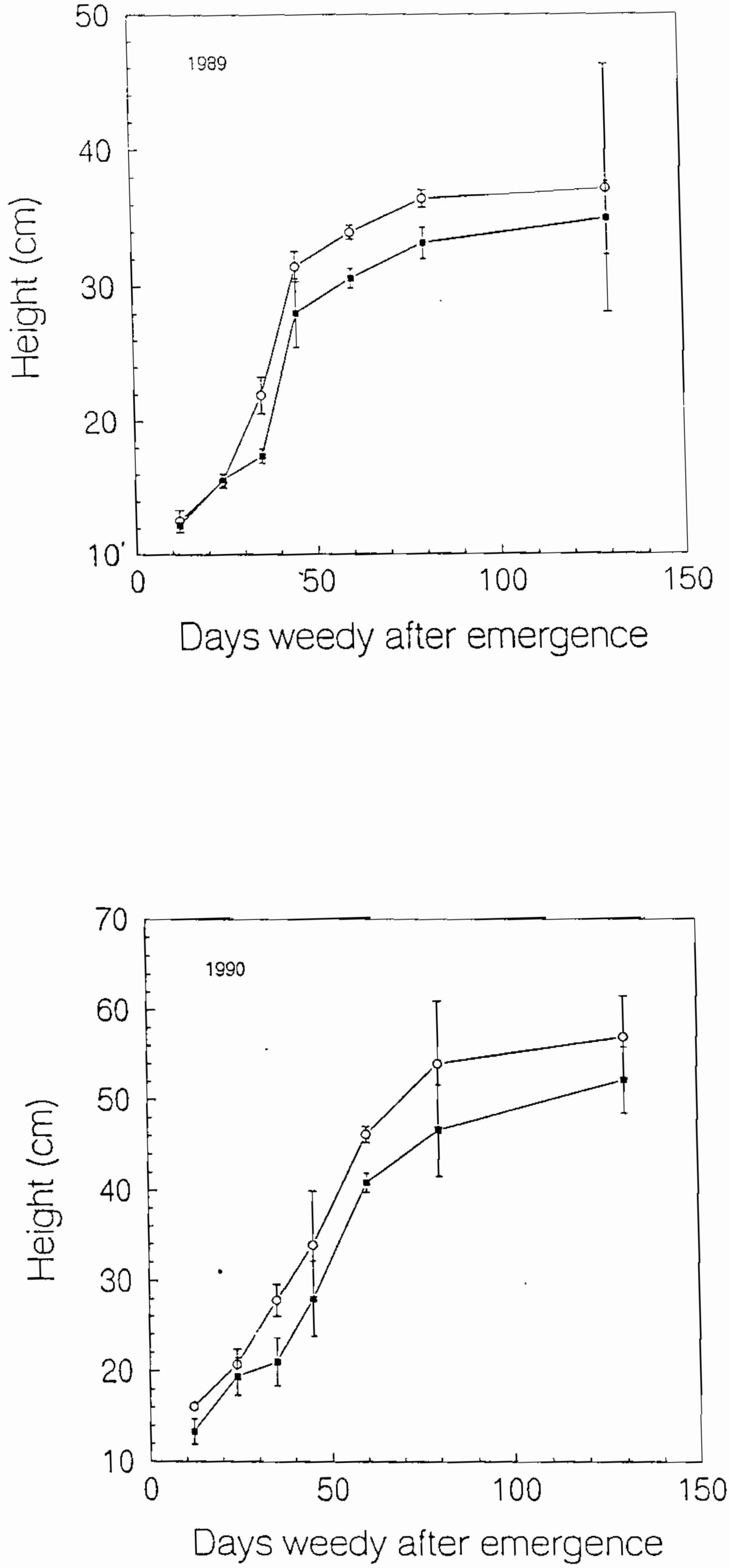
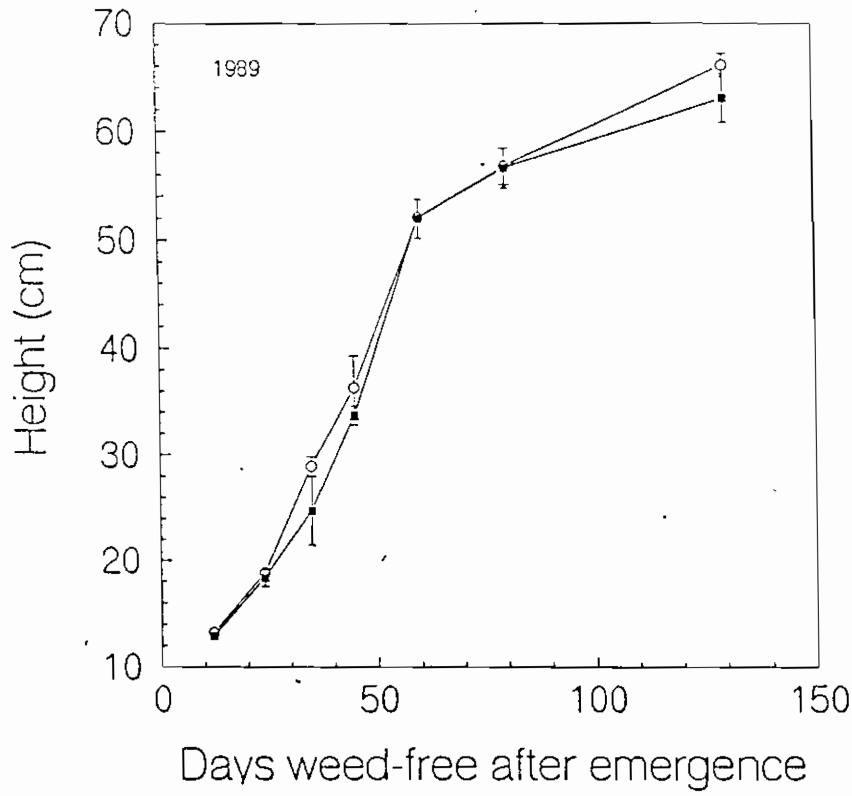

1989
Height (cm)
50
40
30
20
10
0
50
100
150
Days weedy after emergence
1990
Height (cm)
70
60
50
40
30
20
10
0
50
100
150
Days weedy after emergence

FIG 7


1989
Height (cm)
Days weed-free after emergence

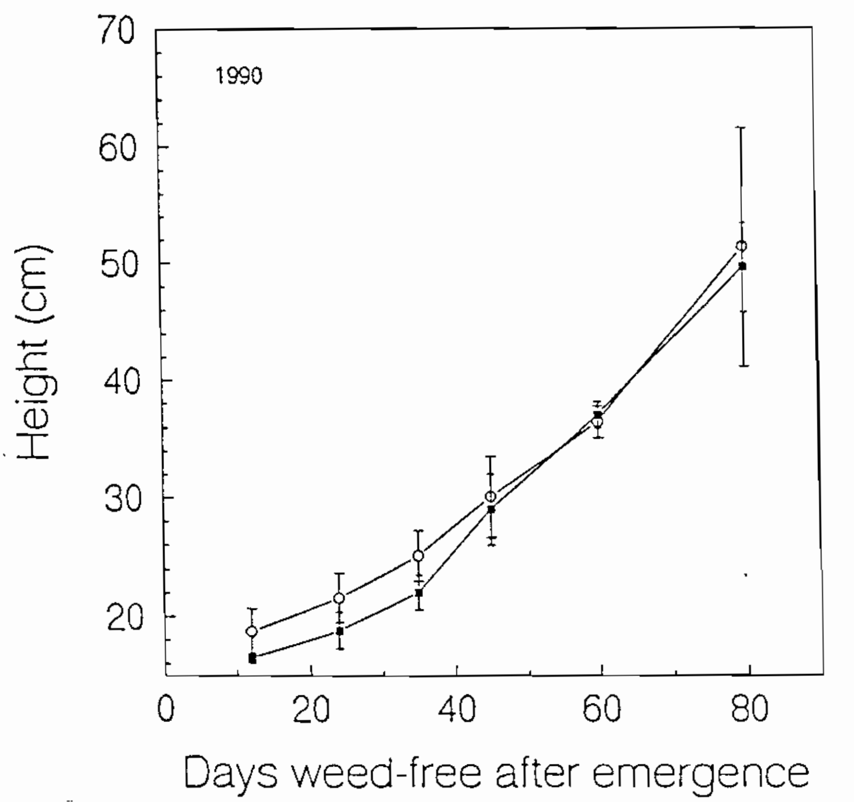
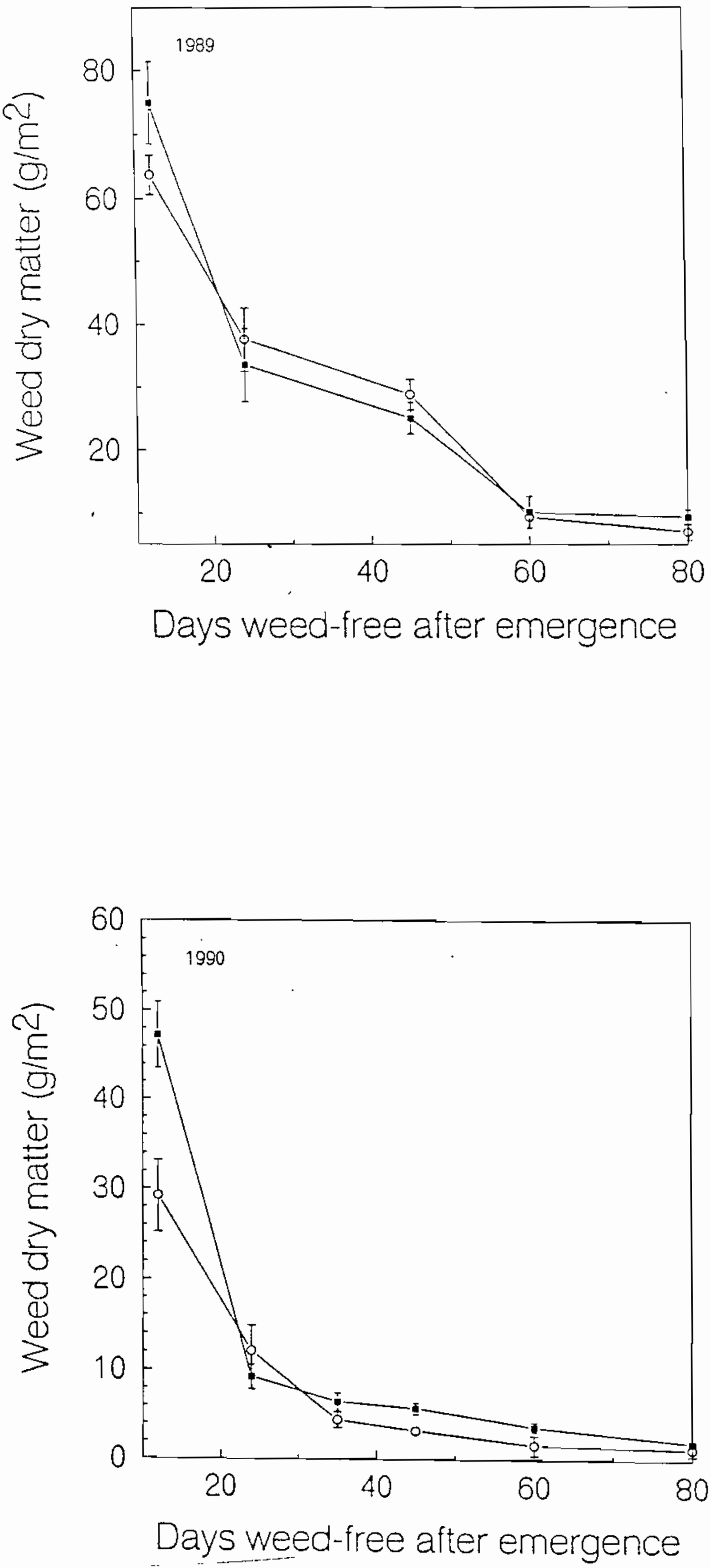
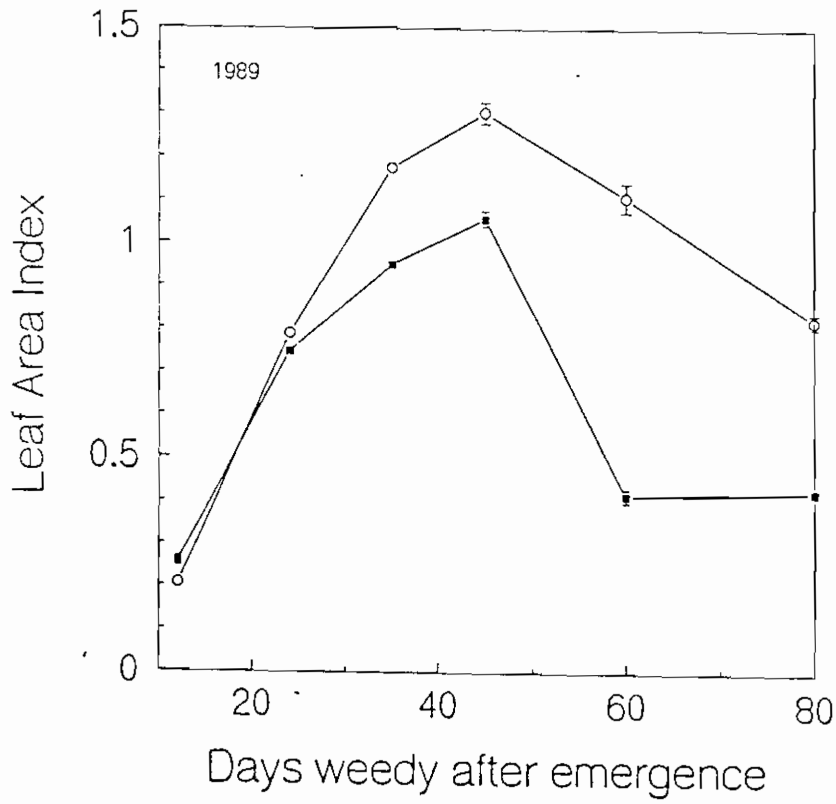

1990
Height (cm)
Days weed-free after emergence

FIG. 5

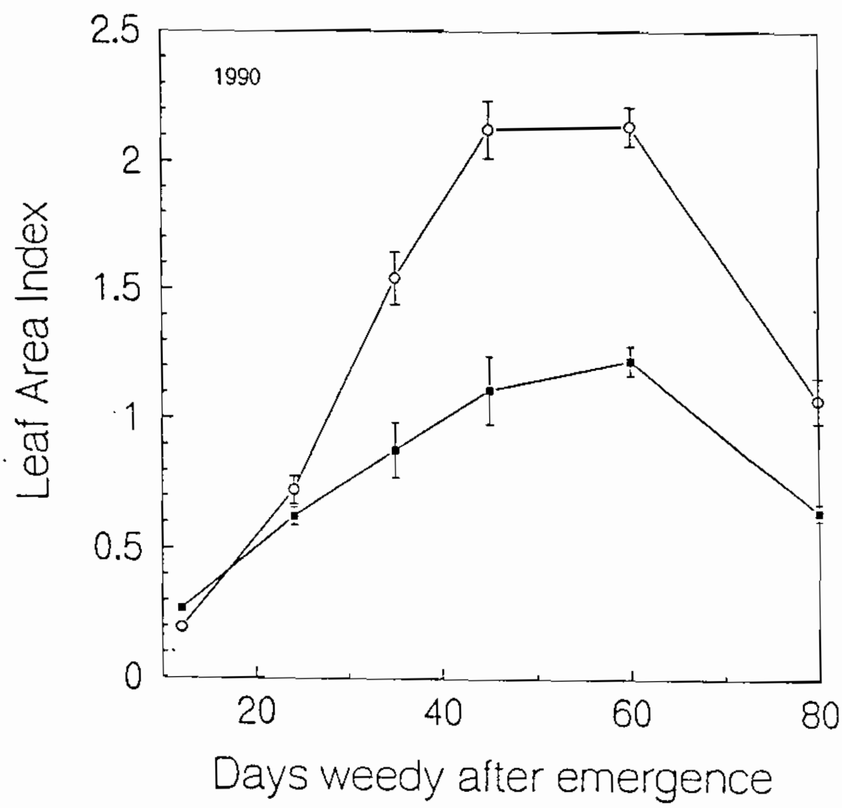


1989
Weed dry matter (g/m2)
80
60
40
20
20
40
60
80
Days weed-free after emergence
1990
Weed dry matter (g/m2)
60
50
40
30
20
10
0
20
40
60
80
Days weed-free after emergence

FIG 7



1989
1.5
1
0.5
0
20
40
60
80
Leaf Area Index
Days weedy after emergence



1990
2.5
2
1.5
1
0.5
0
20
40
60
80
Leaf Area Index
Days weedy after emergence