*Proc. Indian natn. Sci. Acad.* B **44**, 49-56 (1978)

**Plant Physiology**

# ASSOCIATION OF PHOTOSYNTHETIC EFFICIENCY WITH VARIOUS GROWTH PARAMETERS AND YIELD IN RICE*

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(*Received* 1 *April* 1978)

The relationship between photosynthesis, growth and yield in rice varieties was investigated from field samples during both wet and dry seasons. The peak activity of $p_0$ (Photosynthetic rate in mg $CO_2$ $dm^{-2}h^{-1}$) reached at 45 DAP whereafter a steady decline was noticed during the wet season only. The growth characters CGR, RGR, NAR, LAI (+ve) and LAR (-ve) were correlated with $p_0$ especially during the dry season. However, the grain yield or growth during ripening period were not related to $p_0$ at flowering. The LAI at flowering was positively correlated with grain yield. The population photosynthesis ($P_N$) had asymptotic relationship with the LAI in wet season whereas in dry season the $P_N$ : LAI relationships were linear. The positive relationship of $p_0$ with growth parameters before flowering and grain yield with LAI, LAD and dry matter increase after flowering strongly suggest the involvement of photosynthesis in the manipulation of yield levels in rice.

## INTRODUCTION

Varietal differences in leaf photosynthetic rates have been established for rice (Murty *et al.*, 1976; Ohno, 1976). However, a correlation between leaf photosynthetic rate and economic yield has not always been found within a species (Asana, 1968 ; Irvine, 1975). In spite of obvious involvement of photosynthesis, little information is available to show its unequivocal relationship with dry matter production (Hanson, 1971). Hence, a knowledge of photosynthesis becomes particularly relevant when multipronged attempts are being made to produce high yields through the use of fertilizers and other improved cultural practices (Tanaka, 1976). Thus, the present studies have been attempted, aiming at a better understanding of photosynthetic manipulation of rice yields.

## MATERIALS AND METHODS

Field studies were conducted during wet season of 1976 *(kharif)* and dry season of 1977 *(rabi)* at Central Rice Research Institute, Cuttack. In the wet season, eight

* The paper was presented at the INSA Inter-disciplinary Symposium on Photosynthesis and Productivity, held at New Delhi, on Feb. 20–22, 1978.

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varieties differing in maturity periods, representing different groups such as early tall *indica (Ptb.* 10*)*, late tall *indica (Mahsuri, T.* 412, *T.* 141*)*, semi-dwarf hybrids, *(Ratna, IR* 8), *Japanica-Indica* hybrid (*JS*-52-102, hereafter designated as *JS*) and gamma-induced mutant of Taiwan type (*Tainan*-3 mutant No. 587-4, hereafter designated as *T.* 3 m) were selected for the study. In dry season, only four early maturing varieties, viz. *Ptb.* 10, *Ratna*, *JS* and *T.* 3 m were chosen. Thirty days old seedlings were transplanted, at 20 × 15 cm spacing, in an adequately fertilized puddled field with 50 kg N, 30 kg $P_2O_5$ and $K_2O$/ha. Both phosphate and potash were added as basal, while N was applied in three splits, one-third each at planting, twenty and forty days after planting (DAP).

Periodical observations were made at an interval of 15 days starting from 30 DAP (from 15 DAP in dry season) till harvest on total dry weight (shoot weight only, TDW), leaf area index (LAI), specific leaf weight (SLW), crop growth rate (CGR), net assimilation rate (NAR), relative growth rate (RGR), leaf area ratio (LAR) and leaf area duration (LAD). Leaf nitrogen content per unit leaf area ($N_{LA}$) and leaf nitrogen content per unit ground area ($N_{GA}$) were computed from nitrogen centent in 0·1 g material following standard procedures.

The photosynthetic rate of leaves was estimated following $^{14}CO_2$ feeding technique. The leaves were excised under water and their area was immediately measured in an automatic Area Meter (Hayashi Denko Limited, Tokyo). They were placed in 20 ml glass tubes containing 3-5 ml water and arranged in a circular fashion in a vacuum desiccator. A petriplate containing 10$\mu$Ci of $Na_2{}^{14}CO_3$ (specific activity 47·6 mCi. $mM^{-1}$) was kept in the centre. $^{14}CO_2$ was liberated by introducing 2 to 3 ml of 0·5N HCl through one of the rubber tubings (connected to a glass tubing inside the chamber) provided on top of the lid. The escape of $^{14}CO_2$ gas was prevented by closing the tube with a pinch cock. The air inside the chamber was thoroughly mixed by constant pumping of an aspirator connected to another rubber tubing. Thirty minutes were allowed for $^{14}CO_2$ fixation. At the end of this period, about 1 ml of 1N KOH was introduced, to trap excess $^{14}CO_2$. The lid was removed, leaf samples taken out and immediately killed and dried in an oven at 80° C. After recording actual dry weights, they were powdered in a grinding machine through 60 mesh. Twenty mg dried leaf samples were uniformly spread in stainless steel planchets and $^{14}C$ activity was measured in a proportional counter (PCS 14C, ECIL, Hyderabad). The cpm values obtained were converted to mg $CO_2$ fixed $dm^{-2}$ $hr^{-1}$ following Naylor and Teare (1975).

Population photosynthesis was derived from single leaf photosynthesis, using a simulation model developed for rice (Kuroiwa, 1968; Iwaki, 1975). The ancillary data required for this purpose such as total solar radiation in calories per day, day length in hours, light transmission within the canopy (LTR) and leaf extinction coefficient (*K*) were also collected. The data were subjected to statistical analysis and correlations between photosynthesis and growth parameters were worked out wherever necessary.

## RESULTS

### *Wet Season, 1976*

#### *Single leaf photosynthesis ($p_o$) and its relationship with other characters*

All the varieties showed a maximum activity ($p_o$) at 45 DAP with *Ptb.* 10 having the highest rate (52 mg), and *JS* the least (39 mg). The differences due to varieties, growth stages and their interaction were significant (Table I).

TABLE I

*Photosynthetic rate ($p_o$) of excised leaves at different growth stages, wet season sample*

| Variety | $p_o$ (mg $CO_2dm^{-2}h^{-1}$) | | | | |
|---|---|---|---|---|---|
| | Stage (DAP)* | | | | |
| | 30 | 45 | Flg | M.H. | Mean |
| **Tall** | | | | | |
| *Ptb.* 10 | 46 | 52 | 43 | 20 | 40 |
| *T.* 141 | 44 | 47 | 39 | 14 | 38 |
| *Mahsuri* | 32 | 46 | 34 | 14 | 33 |
| *T.* 412 | 28 | 42 | 39 | 20 | 31 |
| **Semi-dwarf** | | | | | |
| *IR.* 8 | 46 | 44 | 43 | 18 | 40 |
| *Ratna* | 33 | 50 | 48 | 12 | 35 |
| *T.* 3, mu | 35 | 45 | 41 | 11 | 33 |
| *JS.* 52–102 | 35 | 39 | 20 | 12 | 26 |
| Mean | 37 | 46 | 38 | 15 | 34 |
| CD (5%) V | | | | | 3·1 |
| S | | | | | 2·2 |
| V×S | | | | | 4·2 |

**DAP*, Days After Planting, *M.H.*, Mid Harvest

Correlations worked out revealed that $p_o$ had significant positive relationship with both SLW and $N_{LA}$ at all the growth stages studied. However, the association tended to become loose with age, as indicated by decreased '*r*' values (Table IV).

The relationship of growth to $p_o$ was found to vary with age. At early growth stages (30 DAP), CGR, RGR, and NAR had positive, while LAR had negative relationship with the $p_o$. At 45 DAP, none of the growth parameters showed any significant relationship with $p_o$. In contrast at flowering, with the exception of LAR, the other growth traits did show a significant negative relationship with $p_o$. No relationship was found to exist between grain yield and $p_o$ at flowering.

*Population photosynthesis* ($P_N$)

The net photosynthesis of population (g $CH_2O$ $m^{-2}day^{-1}$) increased with the age following LAI rather than inherent $p_o$. Thus at flowering, *Ptb.* 10, *Mahsuri* and *T.* 141 (all talls) had higher rates of around 21·0 g, while all the semi-dwarfs had lower to medium rates (11·5 to 18·6 g) (Table III). A positive correlation between $P_N$ and LAI at flowering was also noticed. However, $P_N$ : *K* relationship was not significant. As with $p_o$, $P_N$ at flowering and grain yield were not significantly related.

*Dry season*, 1977

*$p_o$* : The $p_o$ at early growth stages was low but increased with age and attained a peak at 45 DAP. However, a slight increase was still noticeable even up to flowering in *Ptb.* 10 and *Ratna* (Table II). The $p_o$ at all the growth stages had significant positive relationship with SLW and $N_{LA}$ (Table IV).

TABLE II

*Photosynthetic rate ($p_o$) of single leaves, dry season sample*

| Variety | $p_o$ (mg $CO_2 dm^{-2}h^{-1}$) Stage (DAP) | | | | |
|---|---|---|---|---|---|
| | 15 | 30 | 45 | Flg | Mean |
| *Ptb.* 10 | 27·7 | 39·9 | 51·4 | 52·6 | 43·4 |
| *Ratna* | 21·5 | 35·9 | 46·8 | 50·2 | 38·6 |
| *T.* 3 m | 21·4 | 34·5 | 46·7 | 39.6 | 35·5 |
| *JS* 52 | 19·7 | 29·4 | 34·5 | 34·2 | 29·5 |
| Mean | 22·6 | 34·9 | 44·9 | 44·7 | 36·7 |
| CD (5%) V | | 2·5 | | | |
| S | | 2·5 | | | |
| V×S | | 3·2 | | | |

The growth parameters CGR, RGR and NAR were found to have strong positive association, while LAR had negative but significant relationship with $p_o$. However, the relationship between $p_o$ and RGR at initial stages was not significant. Similarly, there was no correlation between $p_o$ at flowering and CGR, RGR, NAR and LAR during ripening period. The $p_o$ : mean LAI relationship at different growth stages was rather inconsistent. At 30 DAP a negative non-significant association was observed, while at 45 DAP and flowering, the negative correlations obtained were significant. It was also recorded that mean LAI during ripening period and $p_o$ at flowering had significant positive association.

TABLE III

*Population photosynthesis ($P_N$) : g $CH_2O.m^{-2}day^{-1}$*

| Varieties/Stage | $P_N$ Season: Wet 45 DAP | Wet Flg | Dry 45 DAP | Dry Flg |
|---|---|---|---|---|
| *Early* | | | | |
| *Ptb.* 10 | 22·7 | 21·4 | 17·8 | 26·3 |
| *Ratna* | 12·6 | 16·9 | 19·4 | 22·9 |
| *T.* 3 M | 10·7 | 14·7 | 12·1 | 21·1 |
| *JS* 52 | 10·1 | 11·5 | 16·9 | 20·4 |
| *Med-late* | | | | |
| *T.* 141 | 20·8 | 20·7 | — | — |
| *Mahsuri* | 11·9 | 21·5 | — | — |
| *T.* 412 | 11·4 | 18·6 | — | — |
| *IR.* 8 | 9·7 | 16·6 | — | — |

*Population photosynthesis*

As in wet season, the $P_N$ followed LAI, increasing with age and reaching peak at flowering. At flowering, *Ptb.* 10 had the highest $P_N$ of 26·3 and *JS* the lowest rate of 20·4 (Table III). A linear relationship (significant at 1%) was obtained between $P_N$ and LAI in different varieties (Fig. 1).

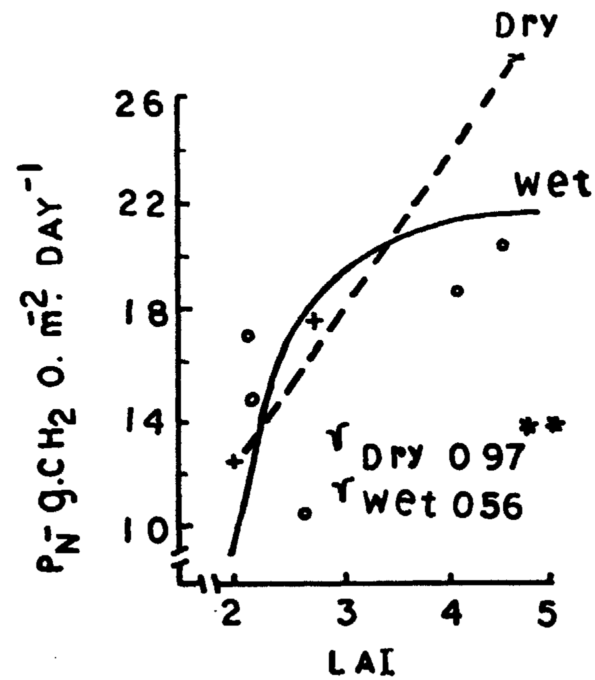


FIG. 1. The relationship between LAI and population in rice during wet photosynthesis and dry seasons.

TABLE IV

*Correlation coefficients of $p_o$ and $P_N$ with different characters (wet and dry season)*

| Character | r values | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Wet (DAP) | | | | Dry (DAP) | | | |
| | 30 | 45 | F | F-H | 30 | 45 | F | F-H |
| $p_o$ *vs* : | | | | | | | | |
| SLW | 0·95** | 0·84** | 0·65** | — | 0·88** | 0·93** | 0·85** | — |
| $N_{LA}$ | 0·87** | 0·77** | 0·61** | — | 0·88** | 0·89** | 0·94** | — |
| CGR | 0·59** | 0·15 | −0·59** | 0·06 | 0·77** | 0·69** | 0·50* | 0·28 |
| RGR | 0·34* | −0·25 | −0·47** | 0·13 | 0·28 | 0·65** | 0·54** | 0·25 |
| NAR | 0·76** | −0·12 | −0·52** | 0·26 | 0·75** | 0·87** | 0·67** | 0·21 |
| LAR | −0·47** | −0·53** | −0·04 | 0·27 | −0·68** | −0·78** | −0·83** | −0·44 |
| LAI | 0·50** | 0·30 | −0·84** | −0·01 | −0·21 | −0·76** | −0·50* | 0·54 |
| Yield | — | — | — | −0·08 | | | −0·09 | |
| $P_N$ *vs* : | | | | | | | | |
| LAI | — | 0·78** | 0·73* | — | 0·55* | 0·44 | 0·39 | — |
| K | — | 0·09 | 0·56 | — | — | — | 0·28 | — |
| CGR | — | — | — | — | — | 0·23 | 0·73** | — |
| Yield | — | — | — | 0·64 | — | — | 0·13 | — |

*F*, Flowering, *H*, Harvest
*r* values significant at 1% (**) and 5% (*) levels

## DISCUSSION

### *$p_o$ and its relationship with leaf characters and growth*

The $p_o$ increased with age with a peak at 45 DAP in both the seasons. The rates were, however, stable in dry season whereas, in wet season there was a steady decline after 45 DAP. The results, in general, are at variance with those of Dastur and Chinoy (1932), Suzuki (1953) and Osada (1964) who observed two peaks, i.e. at 30 DAP and at flowering. The $p_o$ was strongly associated with SLW and $N_{LA}$ especially during the dry season. The relationship tended to be loose with age presumably due to mutual shading and changes in SLW and $N_{LA}$ with stage of the crop.

The $p_o$ also showed significant correlation with CGR, RGR, NAR (+ve) and LAR (—ve) mostly during the dry season. However, during wet season and at early stage during dry season, these relationships were rather inconsistent. Similar discrepancies were noticed by Osada and Murata (1965). They explained the RGR of varieties was determined by photosynthetic rates through NAR when leaf area was not high and the solar radiation was abundant. The consistent relationship of growth components with $p_o$ during dry season when compared with that in wet season could be attributed to the steady rates observed during the former season. However, the negative association of $p_o$ with all the growth parameters at flowering during wet season might be due to its inverse relationship with leaf area.

The association of LAI, $p_o$ and grain yield appears to be of complex nature. In the present findings neither the $p_o$ between flowering and mid harvest (wet season) nor the $p_o$ at flowering (dry season) showed any significant relationship with any growth parameter or yield, confirming the earlier observations of Puspavesa *et al.* (1974). On the other hand, the post-flowering DMP by CGR, RGR or NAR had significant positive association with yield (Table V). It is of interest to record here that mean LAI values during ripening period (dry season) had highly significant relationship with $p_o$ after flowering indicating the direct involvement of post-flowering photosynthesis in grain yield.

TABLE V

*Correlation of yield with $p_o$, $P_N$ and different growth characters*

| Characters | Season (*r* value) Wet | Dry |
|---|---|---|
| TDW (F) | 0·67** | 0·28 |
| ,, (H) | 0·96** | 0·50 |
| LAI (F) | 0·75** | 0·74** |
| $N_{GA}$ (F) | 0·65** | — |
| $P_O$ (F-H) | −0·08 | −0·09 |
| $P_N$ ,, | 0·64 | 0·13 |
| CGR ,, | 0·51** | 0·87** |
| RGR ,, | 0·48** | 0·78** |
| NAR ,, | 0·53** | 0·68** |
| LAD ,, | 0·72** | 0·87** |
| LAR ,, | −0·46** | 0·13 |
| HI (H) | 0·57** | 0·45 |

*F*, Flowering; *H*, Harvest
** Significant at 1% and * significant at 5% level

It is observed that the population photosynthesis is mainly dependent on leaf area and the relationship tended to be asymptotic during wet season. The net rates remained static beyond 3·5 LAI (Fig. 1) because of lower K (extinction coef) values. The negative association between LAI and K was noticed only in the dry season. The lack of such inverse relationship during the wet season might be attributed to increased leaf length and area and decreased SLW during the low light situations of the wet season.

In general, the observed relationship of $P_N$ at flowering with CGR after flowering during the dry season indicated the possibility of predicting $P_N$ through dry matter increase. The relationship of $p_o$ with growth parameters before flowering and grain yield with DMP during post-flowering periods strongly suggests the scope for manipulation of yield with improvement in photosynthesis. However, besides photosynthesis, integrated studies on sink activity and translocation of photosynthates to developing sink are important to delineate the exact role of photosynthesis in crop productivity (Murty, 1977).

## ACKNOWLEDGEMENTS

The authors are thankful to the Department of Atomic Energy, for financing the project; to the Director, CRRI, for providing facilities; to Prof. Y. Murata, National Institute of Agricultural Sciences, Tokyo, Japan, for help in the calculation of population photosynthesis.

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