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Effect of Drought Stress on Photosynthesis and Leaf Gas Exchange of Rice Grown in Nutrient Film Technique (NFT)

K.P. Halder and [1]S.W. Burrage
Farm Management Division, Bangladesh Rice Research Institute, Gazipur-1701, Bangladesh
[1]Imperial College of Science, Technology and Medicine (Wye-Campus), University of London, UK

Abstract: Rice plants grown in nutrient film technique (NFT) to evaluate the effect of intermittent water stress on net photosynthesis rate and leaf gas exchange. Stomatal conductance, net photosynthesis rate and mesophyll conductance decreased with increasing water stress. Internal CO_2 concentration was not affected by water stress. A weak relationship (R^2= 0.60) between net photosynthesis rate and stomatal conductance suggested that non-stomatal limitations to photosynthesis.

Key words: Drought stress, photosynthesis, leaf gas exchange, *Oryza sativa* L., NFT

INTRODUCTION

Drought stress is one of the major problems for affecting crop growth worldwide. It affects almost all of the growth processes but the stress response depends upon the intensity, rate and duration of exposure and the crop growth stages[1,2] . The reduction of growth due to drought is mainly through its influence on leaf expansion reducing this it reduces the potential photosynthetic productivity of the plant[3,4]. The photosynthetic rate in rice leaves is highly susceptible to drought stress. Normally a decrease of photosynthetic rate is parallel to a reduction in stomatal conductivity[5]. Farquhar *et al.*[6], Lu *et al.*[7] reported that a reduction of photosynthetic rate is due to the combined effects of both stomatal and non-stomatal factors. Samuel and Paliwal[8] observed an increased in internal CO_2 concentration in a plant under water stress might be due either to the effect of stress on the CO_2 fixation machinery or to stomatal control through the alteration in the stomatal aperture.

The effects of drought stress have been studied all over the world, but it is difficult to compare results because of differences in timing and degree of drought stress[1]. In the main stress has been applied simply by with holding water from the growing medium. This simple approach is somewhat crude and can lead to variation in response dependant upon the media used, which will influence the supply of water and the aerial environmental factors such as radiation, windspeed, humidity and temperature which will affect the demand for water.

The Nutrient Film Technique (NFT) where plants are grown in a flowing film, introduced by Cooper[9] represents a major advancement in the science of crop production. Many crops have been produced satisfactorily using this technique[10]. The growing of plants in NFT is a return to the true hydroponics principle[11]. NFT culture is the ideal method to optimise both the nutrient supply and the root environment for an efficient uptake of both water and nutrients[12]. Little research has been carried out on rice in NFT. Consequently, there is little information about the effect of intermittent water stress on net photosynthesis rate and leaf gas exchanges of rice.

The purpose of this study was to investigate the net photosynthetic rate and leaf gas exchange characteristics of rice under different level of water stress in relation to solar radiation received by the plants.

MATERIALS AND METHODS

The experiment was carried out in the glasshouse unit of Imperial College at Wye, University of London during May to October 1998. Rice (*Oryza sativa* L. cultivar BR 24) seeds were germinated in an incubator at constant temperature of 30°C for two days. After germination, the individual seeds were placed in small wetted rock wool cubes (2.54 x 2.54 x 3.80 cubic mm). The cubes were placed in trays in a glasshouse at a temperature of 26°C day and night. After 5 days, when the seedlings had reached 3-4 cm height, they were given equal amount of the mixture of 1% stock solution A and 1% stock solution B of Wye nutrient solution[13]. After 10 days when the seedlings had reached 15-16 cm height, they were chosen for uniformity and transferred to larger rock wool cubes

Corresponding Author: Dr. K.P. Halder, SSO, Farm Management Division, Bangladesh Rice Research Institute, Gazipur-1701, Bangladesh E-mail: brrihq@bdonline.com

(10 x 10 x 6.5 cubic mm). Then the plants were transferred to the NFT system.

Each gully contained 12 plants. The end two plants in each gully were considered as guard row plants. Tap water was circulated through the gullies for three days to encourage root growth and development before adding the nutrient solution. The EC of the nutrient solution was 3.0 mS cm^{-1}. The solution pH was maintained at 5.5-6.5 by using 5% acid mixture of nitric and orthophosphoric acid (3:1). The plant spacing was 20 cm within the row and 20 cm between rows. Day and night temperatures were set at 27 and 21°C, respectively. Ventilation of the cubicle was set at 29°C.

During the vegetative phase the nutrient solution was circulated continuously in all treatments. Intermittent water stress treatments were applied from 15 days after panicle initiation (PI) to maturity of the crop. Details of the growth phases at which different water stress treatments were applied are presented in Fig. 1.

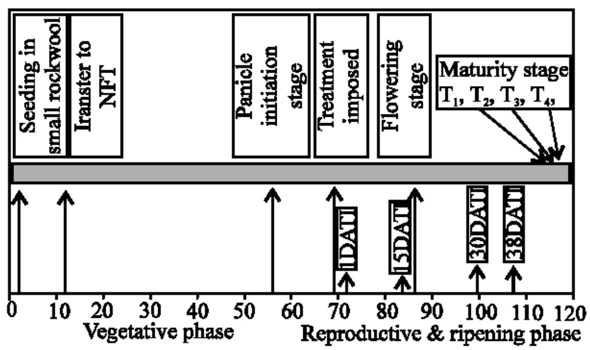

Fig. 1: Growth phases of rice plant at which water stresses were imposed

The water stress treatments were adjusted by controlling the period between recirculation of the nutrient solution by means of a computer connected to a tube radiometer. The total radiation received within the glasshouse was integrated and the pumps were switched on for fifteen minutes after a fixed amount of energy according to the treatment inside the glasshouse had been received. T_1 plants received continuous circulation of nutrient solution during day and night. The other treatments did not receive any circulation of nutrient solution at night. The treatments were laid out in a randomized complete block design with each treatment replicated four times.

Leaf gas exchange characteristics were measured by using a portable carbon dioxide leaf chamber (IRGA), type LCA-3, supplied by the Analytical Development Company (ADC), Hoddesdon, Herts, UK. The unit incorporates a controlled air supply for a Parkinson leaf chamber (PLC),

Table 1: The experimental treatments were imposed

Treatments	From 15 days after PI to particle emergence	From particle emergence to maturity
T_1=minimal stress	Continuous circulation (Control)	Continuous circulation (Control)
T_2=low stress	0.30 MJ m^{-2} solar radiation received then 15 min. nutrient solution circulation.	0.60 MJ m^{-2} solar radiation received then 15 min. nutrient solution circulation.
T_3=medium stress	0.60 MJ m^{-2} solar radiation received then 15 min. nutrient solution circulation.	1.20 MJ m^{-2} solar radiation received then 15 min. nutrient solution circulation.
T_4=high stress	1.20 MJ m^{-2} solar radiation received then 15 min. nutrient solution circulation.	2.40 MJ m^{-2} solar radiation received then 15 min. nutrient solution circulation.

an auto-zeroing, solid state carbon dioxide analyzer and also data processing and storage. Photosynthetically active radiation (PAR) was measured and the net photosynthetic rate (Pn), stomatal conductance (g_s) and intercellular CO_2 concentration (C_i) were also calculated. The mesophyll conductance (g_m) was calculated as the ratio of photosynthesis rate (Pn) and intercellular CO_2 concentration (C_i) following Kubata and Hamid[14].

The second top most fully expanded leaf was measured non-destructively at 5 to 7 days intervals from the initiation of treatment to the maturity of the crop. At least 3 records were taken from one leaf in each treatment in each replication. The measurements were done between 11.30 to 14.00 h.

RESULTS AND DISCUSSION

Stomatal conductance and p_n significantly decreased with increasing water stress, Table 2. The internal CO_2 concentration did not change indicating the decrease in photosynthesis was due the effects of water deficit on the photosynthetic apparatus and or biochemistry of the photosynthesis process. This was indicated by the significant ($P<0.001$) reduction in mesophyll conductance. These results are comparable with the findings of Farquhar *et al.*[6].

They reported that under drought stress conditions accumulation of abscisic acid (ABA) in leaves is very common. If the sole direct effect of ABA were to reduce

Table 2: The effect of intermittent water stress on the stomatal conductance and net photosynthesis rate of rice grown in NFT (n for each treat = I treat X 3 reading X 4 rep X 9 dates = 108). Photosynthetically active radiation (PAR) = (595.3 ± 51.4) µ mol m^{-2} S^{-1}

Treatments	Stomatal conductance (Mol m^{-2} S^{-1})	Pn (µ mol CO_2 m^{-2} S^{-1})	Sub-Stomatal CO_2 concent ration (ml 1^{-1})	Mesophyll conductance (Mol m^{-2} S^{-1})
T_1	0.44a	6.00a	415.00	1.43
T_2	0.37b	5.80a	417.50	1.38
T_3	0.30c	5.10b	426.80	1.18
T_4	0.17d	4.40c	434.40	1.02
LSD (0.05)	0.02	0.66**	NS	0.15***

Number followed by different letters in the same column differs significantly at the 5 % level by LSD test. ns= not significant, **= significant at P <0.01 and ***= significant at P <0.001

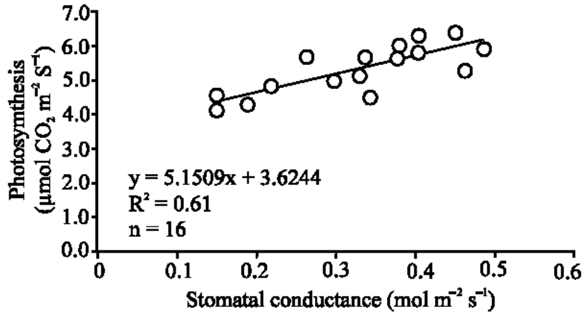

Fig. 2: The relationship between net photosynthesis and stomata conductance of rice grown in NFT

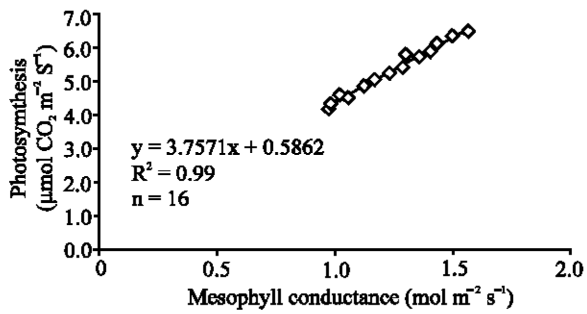

Fig. 3: The relationship between photosynthesis and mesophyll conductance of rice response to intermittent drought stress grown in NFT

stomatal aperture, then assimilation rate would also decrease, because of a lower intercellular pressure of CO_2. But they also postulated from their experimental findings that the intercellular CO_2 concentration was little affected by ABA and that the capacity for CO_2 fixation had actually decreased. With such small changes in sub-stomatal CO_2 concentration and yet large changes in photosynthesis they considered that the bio-chemical capacity for photosynthesis was somehow decreased by water stress[6.15] and might be due to effects on the photosynthetic apparatus[16].

In this experiment this was reflected by the weak relationship (R^2=0.61, P<0.001) between photosynthesis p_n and g_s (Fig. 2) indicating that a reduction of photosynthesis under drought stress conditions could not be attributed purely to the stomatal effects alone as was found by Siddique *et al.*[17].

The mesophyll conductance significantly (R^2=0.99, P<0.001) decreased with increasing water stress and there was a strong relationship between p_n and g_m (Fig. 3) indicating that dominance of mesophyll in reducing pn rate in water stressed plants Siddique *et al.*[17].

In conclusion the significant (P< 0.001) reduction in photosynthesis was not due to stomatal conductance but was more likely due to a change in mesophyll resistance.

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