Effects of simulated acid rain on germination and growth of rice plant

(Kesan simulasi hujan asid terhadap percambahan dan pertumbuhan tanaman padi)

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Key words: simulated acid rain, rice, germination, growth

Abstract

Two separate experiments were conducted in the glasshouse at MARDI, Serdang, to assess the effects of simulated acid rain on germination and growth of rice plant cv MR 84. In the first experiment, rice seeds were exposed to simulated acid rain acidified to pH 3.5, 4.0, 4.5, 5.0 and 5.6 (control) every day for 2 weeks. Percentage of germination was determined from 7 to 19 days after sowing. In the second experiment, rice seedlings were exposed to similar simulated acid rain for every 2 days starting from 7 days after transplanting. The plants received approximately 20 mm of rain for each application. Growth parameters such as plant height, tiller and leaf number were measured from 15 days after transplanting until harvest. The results showed that germination, tiller and leaf number were reduced significantly by simulated acid rain particularly at pH 3.5. Relative to pH 5.6 (control), maximum germination percentage, tiller number and leaf number were reduced about 4, 14 and 10% respectively. Meanwhile, plant height showed no significant reduction at any pH level.

Introduction

Rain water in its natural state is slightly acidic with a pH value ranging from 5.6-7.0 due to the presence of carbon dioxide in the atmosphere which dissolves in the rain as it falls. However inadvertent human interference, such as combustion of fossil fuels and industrial processes, produces oxides of sulphur and nitrogen that are emitted into the natural atmosphere thus enhancing the acidic constituents of the atmosphere. As a result, acid rain has become an important environmental issue (Elsom 1987). Until the end of 1970s, the problem of acid rain was only confined to the European and North American countries. However, increased urbanization and

industrialization in the developing countries such as China (Fan and Wang 2000), Pakistan (Maggs and Ashmore 1998) and Malaysia (Ayers et al. 2002) have provided a base for the occurrence of acid rain.

In Malaysia, monitoring of acid rain was first started by the Malaysian Meteorological Service (MMS) in 1977 in Cameron Highlands and Petaling Jaya (Leong and Lim 1993) and currently the MMS network consists of 22 stations (Anon. 2004). From 1985 to 1992, the mean pH values range from 5.0–5.7 in the sites not close to industrial areas, and from 4.3–5.0 near to the industrial and densely populated areas (Leong and Lim 1993). Rain acidity also showed an upward trend particularly in

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the Klang Valley, Pulau Pinang – Perai and Johor Bahru – Senai areas. It was further shown by Ayers et al. (2002) that annual pH value of rain at Johor Bahru and Klang Valley is in the range of 4.16–4.40.

The effects of acid rain on crop growth and yield have been investigated and reviewed about 20 years ago (Irving 1983; Evans et al. 1986). Based on both glasshouse and field experiments with simulated acid rain on several crops, the potential effects of acid rain include injury to foliage (Back and Huttunen 1992), leaching of nutrients from soil and foliage (Reddy et al. 1991), reduction in seedling emergence and growth (Fan and Wang 2000), reduction in growth, biomass and yield (Hongfa et al. 2000; Singh and Agrawal 2004).

Despite having a strong effect on several crops, there has been no study carried out in Malaysia on the effects of simulated acid rain in particular on the rice plant. However, some efforts have been made to study the effects of dry deposition of NO₂ and SO₂ (which are dominant sources for acid rain) on the rice plant (Ishii et al. 2004). In view of the rapid industrialization and higher prevailing concentrations of SO₂, NO₂ and O₃ in Malaysia (Ayers et al. 2002), the present study was conducted to investigate the effects of simulated acid rain at different levels of acidity on the germination and growth of the rice plant cv MR 84.

Materials and methods Study site and plant material

The study was conducted in the glasshouse at MARDI, Serdang. During the crop growth period, average temperature and relative humidity ranged from 30–35 °C and, 65–75%, respectively. The temperature was maintained at this range by installing a tunnel with suction fans at both ends in the middle of the glasshouse. Rice cultivar MR 84, i.e. the most popular cultivar which accounted for about 80% of production in Peninsular Malaysia (Anon. 2000), was used.

Component	Concentration (ppm)
Na ⁺	0.4733
NH_4^+	0.6567
Ca ²⁺	0.3367
Mg ²⁺	0.0700
NO_3^{-}	0.1533
K ⁺	0.1200
Mn ²⁺	0.0051
Pb ²⁺	0.0057
Zn ²⁺	0.0367
SO ₄ ^{2–}	0.9467

Table	1. Averag	ge rainwate	r composition
(1995	-1997) at	Perai area	

Acid rain solution

Simulated acid rain solution was prepared according to the average chemical composition of rain from three years data in Perai area (Anon. 1998) as shown in *Table 1*. Based on the chemical composition in the rain water, a stock solution was prepared. The stock solution consisted of a mixture of several chemicals prepared in one litre solution. The compositions of each chemical (g) are 0.1023 g NaCl, 0.2049 g NH₄SO₄, 0.1050 g CaCl₂.7H₂O, 0.0603 g MgSO₄.7H₂O, 0.0179 g NaNO₃, 0.0014 g MNSO₄.H₂O, 0.0008 g Pb(NO₃)₂, 0.0125 g Zn(NO₃).4H₂O and 0.0034 g FeSO₄.H₂O.

The acid rain solution was prepared in a large plastic container by mixing 20 ml of the above stock solution with 170 litres tap water to get the equivalent chemical concentration of acid rain in Perai area. This acid rain solution was then adjusted to the desired pHs using sulphuric acid (H_2SO_4), i.e. 3.5, 4.0, 4.5, 5.0 and 5.6 (control).

Experiment 1: Effects of simulated acid rain on seed germination

Rice seeds were sown at about 1 cm depth and 3 cm apart in plastic trays each measuring (30 cm x 25 cm x 5 cm) containing sand. Three trays (replication) were used for each treatment and each tray contained 100 seeds. The simulated acid rain solutions i.e. with pH 3.5, 4.0, 4.5, 5.0 and 5.6, were sprayed manually everyday to maintain the sand surface in a wet condition. Percentage of germination was determined daily for about 2 weeks. Germination was recorded when the seeds produced plants visible above the sand surface.

Experiment 2: Effects of acid rain on growth

Rice seedlings were raised in plastic trays for 21 days. Each plant was then transplanted into a pot of 20 cm diameter and 25 cm depth. Each treatment consisted of 30 plants. Soil for this study was collected from Tanjung Karang (Bakau Series) which contained 18.6% sand, 44.3% silt and 37.1% clay. The soil also has a pH of 5.7, soluble P (99.7 ppm), cation exchange capacity (32.6 meq/100 g), potassium (0.62 meq/100 g), calcium (12.4 meq/100 g), ferrum (762.2 ppm) and nitrogen (0.4%). The pots were filled with the soil to about 5 cm from the top. The plants were managed throughout the experiment according to the recommended agricultural practices for rice (Alias et al. 2002).

Simulated acid rain treatments were applied simultaneously using a rain simulator. The rain simulator system consisted of a water pump, a pressurized manifold system, polypipes, nozzles and a controller (LOGIC, Philmac, Australia). The simulated acid rain was dispersed from five nozzles (for each replicate) located approximately 1 m above the potted plants. Simulated acid rain was applied once every 2 days (equivalent to the average number of rain days in Perai area) during the growing period, starting at 7 days after transplanting (DAT) until harvest. During each treatment, simulated acid rain was applied for 20 min to achieve the equivalent amount of rainfall in Perai area during each rainy day, i.e. 20 mm. During the spraying treatment, each plot was shielded from its neighbouring plot by using clear plastic sheets.

Throughout the growing period, the plants were assessed for their growth performance at every 15 days until maturity. Plant height, leaf number and tiller number were measured. Three plants were sampled for each treatment, one plant was selected at random for each replicate.

Experimental design and data analysis

The experimental design for both experiments was randomized complete block design with three replications and five treatments of simulated acid rain with pHs 3.5, 4.0, 4.5, 5.0 and 5.6 (control). The data were subjected to analysis of variance, and treatment means were compared using the least significant difference test (p = 0.05).

Results

Effects of acid rain on seed germination In all cases where simulated acid rain of various pH levels was applied, most of the germination occurred between the 7th and 10th days after sowing (DAS) (Figure 1). The percentage of germination decreased as pH level decreased, ranging from 89% to 94%. Germination was remarkably reduced at pH 3.5. Compared to the other treatments, pH 3.5 caused reduction in germination by 3% to 5%. There was no significant effect on germination between pH 4.0, pH 4.5 and pH 5.6 (control) from 7 to 19 DAS, while germination was significantly higher at pH 5.0 compared to the other treatments. Besides, reduced percentage of germination, pH 3.5 also caused a relatively slower germination rate compared to the other treatments. However, all the treatments



Figure 1. Effects of simulated acid rain at various pH levels on percentage of germination. Vertical bars show LSD at p = 0.05

achieved their maximum germination at 10 DAS.

Effects of acid rain on growth

Data showed that simulated acid rain has no adverse effect on plant height. Differences in plant height between treatments were small during the early stage of growth i.e. at 15 DAT and 45 DAT as well as at harvest (*Figure 2*). The result showed that plant height was significantly taller at lower pH



Figure 2. Effects of simulated acid rain at various pH levels on plant height, tiller number and leaf number. Vertical bars indicate LSD at p = 0.05

treatment i.e. pH 3.5 and pH 4.0 throughout the growing period. However, differences between treatments were obvious at 75 DAT when the maximum height was achieved. Plants in other treatments had a maximum height of between 92% and 96% of those at pH 3.5 and pH 4.0 respectively.

Generally, the number of tillers produced per plant was greater in the control treatment (pH 5.6) throughout the growing period (Figure 2). In pH 3.5 treatment, the number of tillers per plant was significantly lower than treatments of pH 4.0, 4.5 and 5.6 particularly at 75 DAT, and at harvest but almost similar to pH 5.0. Total number of tillers per plant increased markedly for most of the treatments until 75 DAT except for pH 3.5 and decreased at harvest. Compared to the control, during the period 45 DAT to 75 DAT, the rate of reduction was faster at pH 3.5, thus the number of tillers of this treatment was reduced by 12% and 16% at 75 DAT and at harvest, respectively.

Similar to plant height, leaf number during the early growth stage, at 15 DAT and 45 DAT, was not significantly affected by the simulated acid rain treatment (*Figure 2*). Maximum leaf number was attained in the control treatment at 75 DAT. Maximum leaf number ranged from 99 to 108 per plant. As the plants approached maturity, leaf number declined due to leaf senescence. The difference in leaf number between treatments was also due to the differences in tiller number.

Discussion

The results showed that seed germination, tiller number and leaf number were adversely affected when the rice plant was subjected to the simulated acid rain. However, plant height showed no reduction at any level of pH. Similar results have been reported for wheat (Singh and Agrawal 2004) and a few forest species (Eldhuset et al. 1994; Fan and Wang 2000).

Earlier studies showed that the effects of simulated acid rain on plants are species specific. Some plants showed growth

enhancement (Lee et al. 1981) while others showed growth reduction (Raynal et al. 1982). These findings were supported by Irving (1983), who found that under controlled environment conditions, 34 crops responsed differently to simulated acid rain. Six crops exhibited negative response, eight exhibited positive response, 17 showed no effects and three showed both positive and negative responses.

Positive or negative effects on crops to simulated acid rain could be due to the sulphate content in acid rain itself. Lee and Weber (1979) suggested that stimulation of top growth of any crop exposed to simulated acid rain could occur if sulphate absorbed by the leaves had a fertilizing effect, while inhibition could occur if the sulphate accumulated had reached toxic levels, or if the acid caused direct injury to the leaf.

In the present study, although visible injury was not observed, reduced leaf number could partly be due to injury of the leaves. In rice, although there is no observation of visible injury due to acid rain, a study on the effect of dry deposition of SO_2 (Tripathi and Tripathi 1992) found that rice leaves were severely affected as shown by brownish necrotic lesions on the whole leaf blade.

Apart from being species specific, the detrimental effects of acid rain also greatly depend on the acidity of the rain. Amthor (1984) suggested that rain with acidity greater than pH 3.0 can cause significant damage to plants. This suggestion has been shown by Yu et al. (2002), who reported that the growth of Cucumis sativus L. was significantly inhibited when the plants were exposed to simulated acid rain with pH below 3.5. In the present experiment, rice plants exhibited a significant growth reduction, i.e. germination, tiller number and leaf number, at pH 3.5. A similar finding was also reported by Singh and Agrawal (2004) on wheat, whereby root and shoot growth was significantly reduced at pH 3.0 compared to higher pH levels.

Conclusion

Although the impact of acid rain on growth and yield of rice has been studied across several countries, this study provides the first experimental evidence of acid rain effects on rice plants in Malaysia. The results clearly indicate that simulated acid rain at pH 3.5 can have a significant negative impact on the growth of rice.

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Abstrak

Dua percubaan telah dijalankan di dalam rumah hijau, MARDI, Serdang, bertujuan untuk menilai kesan hujan asid bersimulasi terhadap percambahan dan pertumbuhan tanaman padi cv MR 84. Dalam percubaan pertama, biji benih padi disiram setiap hari selama dua minggu dengan larutan hujan asid yang mempunyai aras keasidan (pH) 3.5, 4.0, 4.5, 5.0 dan 5.6 (kawalan). Peratus percambahan ditentukan pada hari ke-7 selepas disemai hingga hari ke-19. Dalam percubaan kedua, anak benih padi juga disiram dengan larutan hujan asid yang mempunyai aras keasidan yang sama seperti di percubaan pertama. Siraman dilakukan dua hari sekali bermula dari hari ke-7 anak benih dipindahkan dari tapak semaian ke dalam pasu sehingga menuai. Setiap siraman menerima 20 mm hujan. Ketinggian pokok, bilangan anak pokok dan bilangan daun diukur pada 15 hari selepas anak benih dipindahkan ke dalam pasu. Percambahan biji benih, bilangan anak pokok dan bilangan daun didapati berkurangan dengan peningkatan aras keasidan air hujan terutamanya pada pH 3.5. Jika dibandingkan dengan pH 5.6 (kawalan) iaitu paras maksimum, ketiga-tiga parameter telah berkurangan masing-masing sebanyak 4, 14 dan 10%. Sementara itu ketinggian pokok tidak dipengaruhi oleh perubahan aras keasidan air hujan.

Accepted for publication on 14 July 2008