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To cite this article: Nurul Amalina Mohd Zain, Mohd Razi Ismail, Adam Puteh, Maziah Mahmood & M. Robiul Islam (2014) Drought Tolerance and Ion Accumulation of Rice Following Application of Additional Potassium Fertilizer, Communications in Soil Science and Plant Analysis, 45:19, 2502-2514, DOI: 10.1080/00103624.2014.932374

To link to this article: http://dx.doi.org/10.1080/00103624.2014.932374

Accepted author version posted online: 30 Jun 2014.
Published online: 25 Sep 2014.

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Drought Tolerance and Ion Accumulation of Rice Following Application of Additional Potassium Fertilizer

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Five levels of water stress cycle (control flooded, control saturated, 5, 10, and 15 days of irrigation interval) and three potassium fertilization levels [80 kg, 120 kg, and kg 160 dipotassium oxide (K2O) ha−1] were exposed to investigate the influence of potassium fertilizer for minimizing water stress effect and maximizing productivity of rice. Different phyto-physiological parameters as well as uptake of major nutrient elements [nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe)] were examined. It was observed that rice yield, harvest index, and other physiological parameters reduces with increasing duration of water stress while application of additional potassium fertilizer has progressive impact on those parameters. From our observation, 10 days of watering cycle with potassium fertilization at 120 kg K2O ha−1 produces highest grain yield and harvest index. Uptake of major nutrient elements was also enhanced by potassium fertilizer. Therefore, it can be stated that additional potassium fertilizer application could be useful to mitigate water stress effect in rice.

Keywords Drought stress, nutrient uptake in rice, potassium fertilization, water stress cycle

Introduction

Rice (Oryza sativa L.) is one of the major cereal crops of the world that provides 20% of the total calories and 15% of protein requirements of the world population (FAO, 2012). Besides being the cheapest source of carbohydrate and protein in Asia, it is also a good

Received 18 September 2013; accepted 25 March 2014.
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source of minerals and fiber. Rice straw and bran are important animal feed in many
countries. About 92% of the world’s rice is produced and consumed in Asia (Huke and
Huke, 1997). A major part of Asian rice is grown under flooded irrigation where water is
the main limiting factor for increased production of rice.

The lower productivity of Asian rice in most of the cases attributed to various abiotic
stresses including drought. Drought stress has now become a severe threat to ensure food
security in the developing world as well as in Malaysia. Most of the high yielding vari-
eties of rice are very much susceptible to drought. Although water is required all over the
growth periods of the rice plant, there are some critical growth stages when drought stress
impacts seriously and create a massive reduction in quantity and quality of yield (Turner
et al. 1986). Drought stress reduces both water and nutrient uptake by the roots and also
transport of those materials by restricting transpiration rates and membrane permeability
(Pervez et al. 2006). On average, rice plants needs 5000 L of water to produce one kilo-
gram of grain (Cabangon et al. 2002). More than half (40 million hectares) of the rain-fed
lowland rice over the world suffers seriously from drought stress in some levels of their
growth stages (Sarkarung et al. 1997). Depending on timing, duration and severity of plant
water deficit, the yield of rice could reduce up to 81% (Pantuwan et al. 2000). Water stress
adversely affects plant establishment, and thereafter growth and development. Different
physiological activities such as cell enlargement, gas exchange and assimilates partition-
ing are also affected by drought stress. Under extreme conditions, it may severely disturb
several metabolic processes, which may result in lower photosynthesis, cell enlargement
and division and finally cell death (Kramer 1983). Water stress at the reproductive stage
is more harmful to plant processes than that at any other growth stages (Karim et al.
2000).

Potassium is reported to improve water relations as well as productivity of different
crops under water stress conditions. Numerous studies have shown that the application of
potassium (K) fertilizer mitigate the adverse effects of drought on plant growth in barley
(Andersen et al. 1992), sunflower (Lindhauer 1985), fava beans (Abd-Alla and Wahab
1995), sugar cane (Sudama et al. 1998), and rice (Tiwari et al. 1998). The larger potassium
requirement of plants under different abiotic stresses appears to be related to the inhibitory
role of potassium against oxidative stress (Cakmak 2005).

Potassium increases the plant’s ability to resistance during drought by control-
ling stomatal regulation, osmoregulation, energy status, ionic balance, protein synthesis,
and homeostasis (Marschner 1995). Potassium also plays a vital role in maintaining
the turgidity (rigidity) of plant cells and to obtain maximum leaf extension and stem
elongation. However, non-judicious application of potassium fertilizers in the field may
create harmful effects on crop productivity as well as environmental problems. In this
study, an attempt was undertaken to elucidate the effects of potassium on the pattern
of dry matter accumulation, nutrient uptake, and productivity of rice under water stress
conditions.

The objective of present study was to identify the best rates of potassium fertilizer
[80, 120, and 160 kg potassium oxide (K_2O) ha^{-1}] at different water stress levels [control
flooding (CF), control saturated (CS), 5, 10, and 15 days of irrigation interval] in rice vari-
ety MR220. The project also aims to investigate the yield, leaf gas exchange, chlorophyll
content, and nutrient uptake of rice under different water stress cycle and potassium fer-
tilization levels. Finally this research will provide knowledge on efficient management of
agronomical inputs (irrigation and nutrient) for better production of rice under drought
stress.
Materials and Methods

Plant Material, Treatments, and Experimental Design

Rice variety MR220 was collected from Gene bank of Malaysian Agricultural Research and Development Institute (MARDI) Research Station, Seberang Perai, Kepala Batas, Pulau Pinang, Malaysia. Seeds were germinated in controlled environment. Seedlings (15 days old) were then transplanted to experimental pot containing 30 kg soil of Bakau Series [electrical conductivity (EC) = 2.83 dS m$^{-1}$; pH = 5.1] in the rain shelter house. Nine (9) healthy seedlings were transplanted in each pot. For proper seedling growth, pots were watered regularly up to 30 Days after transplanting (DAT). Five water stress cycles namely control flooded (CF), control saturated (CS), 5, 10, and 15 days of irrigation cycles and three potassium fertilization levels [80 kg (control recommended by MARDI), 120 kg, and 160 kg K$_2$O ha$^{-1}$] were combined into 15 treatments and those were replicated three times and arranged into a Randomized Complete Block Design (RCBD). For control flooded treatments, the level of water in each pot was maintained at about 10 cm above the soil surface and for control saturated treatment, water was applied just to saturate the soil.

Growth and Yield

Determination of plant growth (plant height, number of tillers, and number of panicles) was carried out on randomly tagged plants. Tillers mortality (TM) was calculated using the following formula:

$$TM(\%) = \left[ \frac{(MT - P)}{MT} \right] \times 100$$ (1)

Where, MT = Maximum number of tillers and P = Number of panicles

Plants were harvested when 70% of rice shown ripening color. Grain yield ha$^{-1}$ was calculated based on Bano et al. (1993), harvest index was calculated based on the ratio between economic yield and total biomass production. Water productivity was determine by following methods of Molden et al. (2003) as yield (kg ha$^{-1}$)/irrigation inflow (L ha$^{-1}$).

Chlorophyll Fluorescence

Chlorophyll fluorescence was measured on fully expanded leaf using a portable chlorophyll fluorescence meter (Handy PEA, Hansatech Instruments Ltd., Norwich, UK). Measurements were undertaken at $>3000\ \mu$mol m$^{-2}$ s$^{-1}$ and data were recorded for 5 seconds. The mean value of three representative plants was used to represent for each sub-plot.

Chlorophyll Content

Chlorophyll a (Chl$_a$), chlorophyll b (Chl$_b$) and total chlorophyll contents of the young expanded leaves were taken at midday and data was calculated following the method of Witham et al. (1986).

Leaf Gas Exchange

The measurement was obtained from a closed infra-red gas analyzer LICOR 6400 Portable Photosynthesis System (IRGA, Licor Inc., Lincoln, NE, USA) from fully expanded young
leaves between 09:00 to 11:00 a.m. Data for net photosynthesis rate (µmol m⁻² s⁻¹), stomata conductance [µmol water (H₂O) m⁻² s⁻¹], transpiration rate (mmol m⁻² s⁻¹), and instantaneous water use efficiency [mmol m⁻² s⁻¹ water transpired mmol⁻¹ m⁻² carbon dioxide (CO₂⁻¹)] assimilated] was collected during the measurement.

**Relative Water Content**

Relative water content (RWC) was estimated by a modification of the method of Turner (1981) as
\[
RWC = 100 \times \frac{FW - DM}{TW - DM}
\]
where FW and DM denote fresh weight (g) and dry weight (g). Turgid weight (TW) was calculated after fully hydrating fresh leaves in darkness at 4 °C for 24 h. Results were expressed as percentages.

**Plant Nutrient Analysis**

The nutrient analysis of nitrogen (N), phosphorus (P), K, calcium (Ca), iron (Fe), and magnesium (Mg) was done using the methods described by Wolf (1982). 0.3 g of leaf tissue was ground (0.5 mm to 1.0 mm) and placed into a digestion tubes with 2 ml of concentrated suluric acid for 12 hours. Two mL of 30% hydrogen peroxide was added in the digestion tube and heated to 350 °C for 30 minutes. This procedure was repeated until solution in digestion tube become clear. Solutions were then filtered and analyzed for N, P, K, Ca, Mg, and Fe elements.

**Statistical Analysis**

Data was analyzed using SAS software version 9.1 (SAS Institute, Cary, NC, USA) and associations among the characters were examined by simple correlation analysis and the significant differences among the treatments were compared using Duncan Multiple Range Test (DMRT) at 5% level of probability.

**Results and Discussion**

**Rice Growth and Yield**

It was observed that rice yield, harvest index, panicle number, and filled spikelet was influenced by interaction effects (p ≤ 0.05) between water stress cycle and potassium fertilization (Figure 1). Rice yield decreased with increasing duration of water stress cycle (Figure 1). The highest grain yield was observed at 10 days of watering cycle with 120 kg K₂O ha⁻¹ potassium fertilization, while lowest grain yield obtained at 15 days of water stress cycle with lowest (80 kg K₂O ha⁻¹) potassium fertilization level. It was also observed that highest potassium fertilization level (160 kg K₂O ha⁻¹) gives the lowest yield under 5 and 10 days of water stress cycle. The similar trend was also observed in harvest index (Figure 1). The results indicated that rice variety MR220 can tolerate water stress cycle from 5 to 10 days, and exceeding this duration (such as 15 days) would reduce yield and harvest index significantly. However, the increased potassium fertilizer rates (120 and 160 kg K₂O ha⁻¹) would reduce water stress effects in rice plant by giving higher yield and HI compared to the control rate (80 kg K₂O ha⁻¹). Application of 120 kg K₂O ha⁻¹ potassium fertilizer would increase the panicle number at all water stress levels (Figure 1). The application of potassium fertilizer at the rate of 120 kg K₂O ha⁻¹ also produces highest 1000-grain weight, total biomass, plant height, and water productivity (Figure 2). Similar
observation was also reported by Singh et al. (2013) and Khan et al. (2012), where application of additional potassium fertilizer was reported to enhance growth and yield of rice. Drought tolerance in rice plant with additional potassium fertilizer might be due increased production of osmolytes (such as glycine, betaine, proline and other amino acids), organic acids, and polyols, which are crucial to sustain cellular functions under water stress. It was observed that rice yield and harvest index have a positive significant correlation with total biomass yield ($r^2 = 0.976$; harvest index; $r^2 = 0.912$ $p \leq 0.05$). The data indicate that the increase in water stress cycle would reduce the production of rice biomass that contribute to the reduction of rice yield and harvest index while application of addition potassium fertilizer increased those parameters significantly. The detrimental effect of water stress on rice was also observed by Wan et al. (2009) and Kandil et al. (2010), where application of high potassium rates have improved the grain yield and yield components in rice.

**Chlorophyll Content**

Total chlorophyll content was influenced significantly by water stress and potassium fertilization (Figure 3). Generally increased water stress cycle significantly reduces total chlorophyll contents in rice and supplementation of potassium fertilizer increased chlorophyll content significantly during water stress. If the rate of potassium increased from 80 to 160 kg K$_2$O ha$^{-1}$, the chlorophyll content become highest at all water stress treatments (5, 10, and 15). The decrease in chlorophyll content with increased
Figure 2. Impact of potassium fertilization on 1000-grain weight (a), total biomass (b) and water productivity in rice. Small bars represent standard error.

duration of stress was previously been reported by Tuna et al. (2010). The increased chlorophyll content with increased potassium application might also be due to increased uptake of nitrogen from soil (Alam et al. 2011). The positive correlation ($r^2 = 0.92; p \leq 0.05$) between chlorophyll content and nitrogen content are also reported in the present study (Table 1). Naser et al. (2012) reported that application of potassium could minimize the reduction of chlorophyll a, b, and total chlorophyll content during water stress. The increase in chlorophyll content with increased potassium application might be due to increase in nitrate reductase enzyme (Ibrahim et al. 2012).
Figure 3. Impact of water stress cycles (CF = continuously flooding; CS = continuously saturated; 5 = water stress cycle for 5 days; 10 = water stress cycle for 10 days; 15 = water stress cycle for 15 days) and potassium fertilization (80, 120, and 160 kg K$_2$O/ha) on total chlorophyll content, relative water content and maximum efficiency of photosystem II of rice variety MR220. Small bars represent standard error.

**Relative Water Content**

Relative water content (RWC) was also influenced by interaction between water stress cycle and potassium fertilization (Figure 3). Generally the rice RWC decreased with increased duration of stress. The RWC was reduced by 41%, 38%, and 37% for 5, 10, and 15 days of stress cycle, respectively, under normal potassium fertilization (80 kg K$_2$O ha$^{-1}$) compared with CF condition, while RWC increased significantly by 40% for highest potassium rate (160 kg K$_2$O ha$^{-1}$). The increased RWC following additional potassium fertilization might be due to potassium’s role as maintaining the osmotic adjustment and improving the cellular water balance. Fayyaz et al. (2013) reported that synthesis
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*significant at $P \leq 0.05$. Note, HI = harvest index; FS = filed spikelet; 1000gwt = 1000 grain weight; TB = total biomass; WP = water productivity; TCC = total chlorophyll content; RWC = relative water content; Fv/fm = maximum efficiency of photosystem II; PN = net photosynthesis; E = transpiration rate; IWUE = instantaneous water use efficiency.
and accumulation of osmolytes play a major role in osmotic adjustment and also protect the cells by scavenging reactive oxygen species (ROS). In the present study, potassium fertilization at 160 kg ha\(^{-1}\) was effective in remediating the effect of stress in rice.

**Maximum Efficiency of Photosystem II (fv/fm)**

Water stress cycle and potassium fertilization influenced the fv/fm ratio of rice (Figure 3). The maximal efficiency of photosystem II was in ranged between 0.761 and 0.782 in all treatments. The application of potassium fertilizer at 120 kg ha\(^{-1}\) was provides highest fv/fm values at 10 and 15 days of water stress cycle (0.781 and 0.771, respectively). The lowest fv/fm values (0.721) were recorded in control (80 kg ha\(^{-1}\)) potassium fertilization rate with 10 days of irrigation. The present data indicate that application of potassium fertilizer at 120 kg ha\(^{-1}\) would enhance the photochemical quenching of rice and would reduce the occurrence of photo-inhibition under water stress condition. This result was supported by Siringam et al. (2013): where they observed the application of potassium nitrate to rice seedlings have manage to reduce photoinhibition by having high fv/fm values, water use efficiency, and good growth characteristics. Maximum efficiency of photosystem II (fv/fm) was significantly correlated with net photosynthesis rate \(r^2 = 0.923; p \leq 0.05\), which indicate the high fv/fm values under increased potassium fertilization. This might be due to up-regulation of photosynthesis under increased rates of potassium application.

**Leaf Gas Exchange Properties**

The leaf gas exchange was affected by interaction between water stress cycle and potassium fertilizer (Figure 4). Net photosynthesis (\(P_N\)), transpiration rate (E), and instantaneous water use efficiency (IWUE) was influenced by these two factors. Generally, net photosynthesis was reduced with increased days of stress cycle, and application of additional potassium fertilizer increase net photosynthesis rate. The highest \(P_N\) was observed in CF condition at 160 kg K\(_2\)O ha\(^{-1}\) (16.40 \(\mu\)mol m\(^{-2}\) s\(^{-1}\)) and the lowest at 15 days of stress cycle and 80 kg K\(_2\)O ha\(^{-1}\) (10.47 \(\mu\)mol m\(^{-2}\) s\(^{-1}\)). The increase in photosynthesis rate under high potassium fertilization might be due to enhanced ATP production and reduction of respiration rate (Chimenti et al., 2002). The increased application of potassium was also enhance the transpiration rate of rice. However the Transpiration rate was reduced with increased days of stress cycle. Higher potassium fertilization enhanced the stomata opening of plants. Ibrahim et al. (2012) showed that the increased potassium application could increase the leaf gas exchange and simultaneously enhanced the production of secondary metabolites in *Labisia pumila* spp. Additional potassium fertilization would enhance the opening of stomata and enhanced the stomata conductance of plants. The current study showed that addition of potassium would enhance rice tolerance to water stress by having high net photosynthesis, transpiration rate, and water use efficiency.

**Nutrient Uptake**

Generally the plant nutrient uptake reduced with increased in water stress (Table 2), and uptake of N, P, K, Ca, Fe, and Mg enhanced with potassium application. From the correlation table (Table 1), it was observed that potassium have a significant positive correlation with Nitrogen, \(r^2 = 0.91\), phosphorous, \(r^2 = 0.92\), Calcium, \(r^2 = 0.81\), Iron, \(r^2 = 0.76\) and Magnesium, \(r^2 = 0.83; p \leq 0.05\) accumulation in rice. As the potassium fertilization rates increased from 120 to 160 kg K\(_2\)O ha\(^{-1}\), the uptake of nitrogen increase by 17% and 31%,
respectively, compared to the control (80 kg K2O ha⁻¹). Application of potassium would also increase the uptake of other macro and micronutrient in rice. The increase in rice nutrient uptake with high potassium fertilization might be due to increase in transpiration rate under high potassium. It is generally known that plant nutrient and water uptake in plant is facilitated with transpiration rate in plant xylem (Ge et al. 2012). In the present study, the increase in potassium fertilizer would enhance the transpiration rate, which would enhance the nutrient uptake. Despite that, it was also reported that increased translocation of xylem under sufficient potassium would also enhanced uptake of certain amino acid that is important in plant system (Nawaz et al. 2012). From the present study it could be suggested that additional potassium application is useful to increase the uptake of plant nutrient and reduce water stress effect in rice.
Table 2
Impact of potassium fertilization on nutrient uptake of rice variety MR 220

<table>
<thead>
<tr>
<th>Nutrients</th>
<th>Potassium (kg K₂O/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>80</td>
</tr>
<tr>
<td>Nitrogen (N; mg g⁻¹)</td>
<td>47.21 ± 2.21 c</td>
</tr>
<tr>
<td>Phosphorous (P; mg g⁻¹)</td>
<td>56.21 ± 2.31 c</td>
</tr>
<tr>
<td>Potassium (K; mg g⁻¹)</td>
<td>27.21 ± 10.21 c</td>
</tr>
<tr>
<td>Calcium (Ca; mg kg⁻¹)</td>
<td>211.32 ± 9.23 c</td>
</tr>
<tr>
<td>Magnesium (Mg; mg kg⁻¹)</td>
<td>42.21 ± 8.88 c</td>
</tr>
<tr>
<td>Ferum (Fe; mg kg⁻¹)</td>
<td>13.21 ± 3.44 c</td>
</tr>
</tbody>
</table>

Means not sharing a common letter are significantly different at p ≤ 0.05.

Conclusion
To determine the effectiveness of additional potassium fertilization for minimizing drought stress effect in rice, five levels of water stress cycles (Control flooded, control saturated, 5, 10, and 15 days of irrigation interval) and three potassium fertilization levels [80 kg K₂O ha⁻¹ (control), 120 kg K₂O ha⁻¹, and kg 160 K₂O ha⁻¹] were exposed on Malaysian rice variety MR220. Results have indicated that the use of water stress cycle at 10 days with potassium fertilization at 120 kg K₂O ha⁻¹ is more appropriate for better yield and harvest index in rice variety MR220. This combination is also effective for maximum efficiency of photosystem II (fv/fm), 1000 grain weight, total biomass production as well as uptake of major nutrient elements (N, P, K, Ca, Mg, and Fe) in rice. In the current study, it was suggested that additional potassium fertilizer application is useful to mitigate water stress effect in rice variety MR220.

Funding
The authors thank the Ministry of Higher Education Malaysia, LRGS Food Security Rice Research Grant and the Research Management Centre of UPM for financing this work.

References


