



*Short Communication*

## **Rice Production and Climate Change: A Case Study of Malaysian Rice**

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### **ABSTRACT**

Rice is the most cultivated and consumed cereal in Malaysia. With the local population rising in number, the yield progress of the crop needs to increase in a sufficient and sustainable manner to meet the increasing demand. However, future productivity is uncertain because of the predicted changes in climate, notably temperature and water availability. Here we highlight the impact of climate change on Malaysian rice production and how it is linked to the current use of nitrogen (N) fertiliser. From literature analysis we propose that the sustainable solution lies in targeting photosynthesis per unit N. Here we show a lower sensitivity of photosynthesis to N deficiency in Malaysian varieties in comparison to other widely grown cultivars, indicating the potential for improvement. This initial study is used to establish baseline measurements for more complex, multi-factor stress analyses.

*Keywords:* Climate change, Malaysia, nitrogen deficiency, rice

### **INTRODUCTION**

Addressing the issue of global food security in the 21<sup>st</sup> century is a major challenge. Rice research will play an important role

as rice is one of the most important crops in terms of human consumption (as opposed to animal feed) and is produced in 95 countries across the world (Maclean *et al.*, 2002). It is the staple food in many countries, accounting for more than 40% of global food production. People in the majority of countries in Asia depend on rice as their main source of nutrition, as well as for income and employment (Maclean *et al.*, 2002; Makino, 2011). The Rice Market

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Monitor by the Food and Agriculture Organisation (FAO) in 2012 stated that the current supply of rice outpaces consumption. Nevertheless, an increase in the supply of this cereal crop would be required to meet the future demands of rice in world population. This demands an estimated 50% increase in the yield of rice in order to sustain the predicted world population of 9.3 billion by 2050 (Sheehy & Mitchell, 2013). This is compounded by the uncertainties of the effect of climate change on crop productivity, which will certainly show regional-specific impacts (Parry *et al.*, 2005; IPCC, 2013) across the world. In this case study we (1) highlight the localised effect of climate change on the production of rice in Malaysia, and (2) argue that photosynthesis per unit N is a critical sustainable trait in light of climate change and abiotic stress. This is required to tackle the current trend for increased use of N fertiliser in Malaysia.

### **YIELD LIMITATIONS IN MALAYSIA**

Rice makes up a particularly high proportion of the total agricultural area in Southeast Asia (Maclean *et al.*, 2002). The climate in this region of the world alternates between the wet and dry seasonal cycle, typical of the tropics. In Malaysia, particularly Peninsular Malaysia, paddy is cultivated as a rainfed or irrigated lowland crop. Rice is currently constrained to eight major granary areas in Peninsular Malaysia. It is mainly grown in states such as Kedah, Perak and Kelantan, which together control more than half of Malaysia's harvested area (FAO, 2002). Dryland cultivation occurs mostly

in Sabah and Sarawak, in the islands of Borneo. In comparison to other countries in Asia, Malaysia produces only a small amount of rice. Out of 656.4 million tonnes of rice produced in Asia, only 2.7 million tonnes is from the peninsula and the Borneo islands – approximately 0.4% of Asia's rice production as reported by the FAO in 2011.

The actual average local rice yield was 30-50% lower than achievable potential in 2007, based on MARDI (Malaysian Agricultural Research and Development Institute) local verification trials (Omar, 2008) in granary areas. Due to the inability to currently meet their goal of being 100% self-sufficient in rice, Malaysia still has to import rice from major suppliers – Thailand and Vietnam. The current average yield has been reported as 4.5-5 t/ha, due mostly to farmers applying more than the recommended rate of 170 kg N/ha (Nori *et al.*, 2008). FAO reported paddy yields slightly lower, between 3.36 and 3.97 t/ha between 2006 and 2012, in comparison with an average for SE Asia over the same period of 3.90-4.23 t/ha, indicating that Malaysian yields are slightly lower than regional yields (www.faostat.org). Rice yields within the country are seeing a rise due to an increase in usage of N fertilisers despite a stagnant harvested area (Fig.1).

Malaysia is naturally geographically disadvantaged, as most of Peninsular Malaysia is covered in tropical rainforest with a mountainous interior. Fig.2 is a representation of the major environmental and soil constraints affecting the current and future prospects of rice agriculture. In order

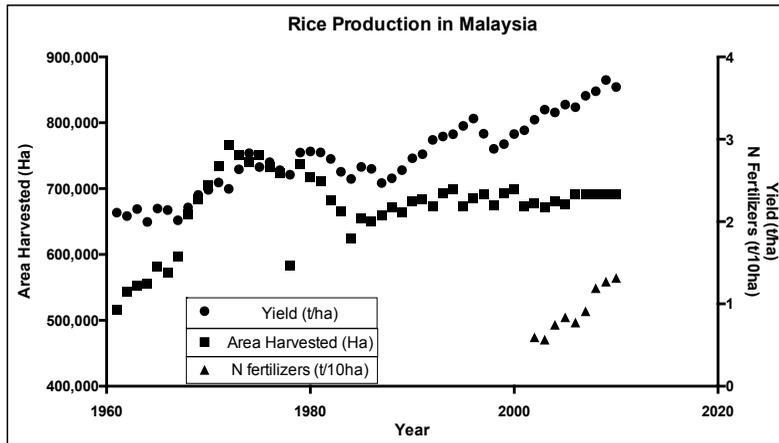


Fig. 1: Patterns of rice production in Malaysia. Increases in yield after 2000 are a result of increasing N fertiliser usage. Data source: FAOSTAT.

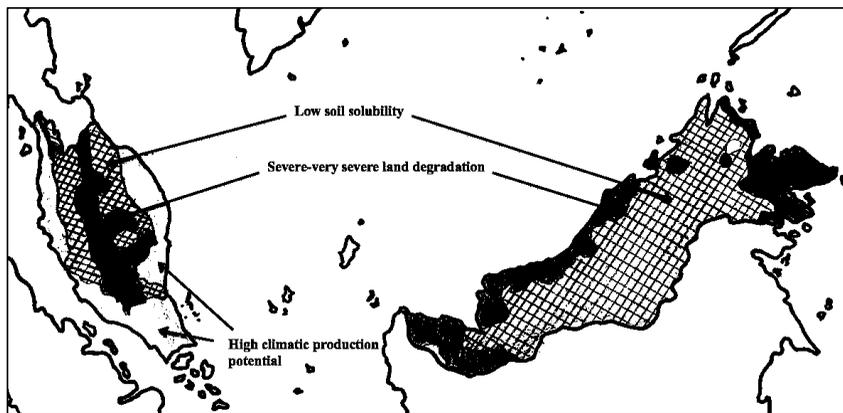


Fig. 2: A schematic of the major environmental constraints in Malaysia. Adapted from Major Environmental Constraints for Agricultural Production Project based on FAOCLIM database, ARTEMIS NDVI imagery and soil and terrain data provided by Soil Resources Management and Conservation Service. FAO-GIS. Prepared using Windisp software by Rene Gomme, Environment and Natural Resources Service, for the SOFI 1999 Report.

to fulfil the demand of a rising population, the country has to be able to sustain rice production and at the same time increase productivity of the crop per unit hectare, without having to expand granary areas (Najim *et al.*, 2007). This increase in rice production will need to be achieved in the face of a climate that will reduce yield, as we shall describe in the next section.

CO<sub>2</sub> concentrations are forecasted to double by the end of the 21st century, and this anthropogenic rise will result in an increase in global temperatures of between 1.5 and 5.8°C (IPCC, 2013). Although higher CO<sub>2</sub> concentrations have shown field improvements in photosynthesis, biomass and yield across species, largely by reducing photorespiration, this will be mitigated

by the rise in temperature, deterioration of water supply and other factors such as disease and pollution (Ainsworth & Long, 2005; Long *et al.*, 2006). Indeed, studies on rice have shown that increased night temperatures are more closely related to yield stagnation across SE Asia than other factors (Peng *et al.*, 2004; Welch *et al.*, 2010). The mechanism behind this is not yet clear but may be associated with temperature-dependent effects on primary metabolic processes such as growth and maintenance respiration. This is independent of sudden temperature spikes that induce spikelet sterility (Wassman *et al.*, 2009). Indeed, temperatures are approaching the upper limit for optimal rice yield and even survival in some regions (Ingram *et al.*, 1995). Using existing crop models, rice production in Malaysia is predicted to decline by 0.69t/ha, and giving rise to an economic loss of RM299m per year with a rise of 2°C and a shift in CO<sub>2</sub> from 383 to 574 parts per million (ppm) (Vaghefi *et al.*, 2011).

#### **MITIGATING THE EFFECTS OF CLIMATE CHANGE**

Climate shifts in the next 50 years are also likely to bring about unpredictability in crop production (Sheehy & Mitchell, 2011). More extreme climatic events such as heavier rainfall and drought in certain areas have been attributed to the rise in temperatures. Other production constraints include increased salinity in coastal granary areas from seawater intrusion as well as pests and diseases such as blast and brown plant

hopper. Generally, physiological responses to climate change are complex because of the multiple abiotic factors involved. However, a central process in the response of plants to climate change is photosynthesis. As photosynthesis is intimately linked to climate (temperature and CO<sub>2</sub>) and water, this relationship ultimately determines the success of agricultural systems as a whole across multiple environments (Ainsworth & Long, 2005; Murchie *et al.*, 2009). Photosynthesis is also the largest sink within the plant for nitrogen fertiliser with 50% of leaf nitrogen in the chloroplast. A factor rarely considered is light: it is essential for photosynthesis, but rice grown in the tropics is especially exposed to high and erratic light intensities. In some cases, very high light intensities cause photoinhibition, a process that damages the photosynthetic apparatus through excessive light absorption and photooxidative stress (Murchie & Niyogi, 2011). High light exacerbates other abiotic stress responses.

Farmers are therefore being driven to confront the inevitable prospect of growing under fluctuating and increasingly unfavourable conditions due to the changing patterns of land use due to climate change. With optimisation of other yield components, rice is increasingly dependent on improvements in biomass production, which require increased nitrogen fertiliser application (Peng *et al.*, 2000; Murchie *et al.*, 2009), and this is particularly strong in Malaysia (Fig.1). With the increasing cost of fertiliser and unpredictable climate, there is a convincing argument that the improvement

of crop yield should be achieved from the manipulation of photosynthesis at the leaf level, and this is consistent with available information about rice production in Malaysia. Fig.3 compares the responses of photosynthesis to suboptimal nitrogen in widely grown SE Asian rice cultivars and a variety specific to Malaysia. Low N leads to high light sensitivity as shown in rice (Chen *et al.*, 2003) and spinach (Verhoeven *et al.*, 1997): reduced photosynthetic capacity results in an excess level of absorbed irradiance. Interestingly, MR253 shows higher leaf photosynthesis at suboptimal

conditions, demonstrating a potentially improved nitrogen uptake, allocation or remobilisation dynamics (Foulkes & Murchie, 2011) and potentially lower susceptibility to oxidative stress under high light conditions. Additionally, a higher  $A_{max}$  itself is associated with higher canopy photosynthesis and productivity in cereals (Murchie *et al.*, 2009; Reynolds *et al.*, 2012). The data presented supports a larger study, which will investigate nitrogen–abiotic stress interactions. Table 1 summarises the agronomic traits of the varieties used in this study.

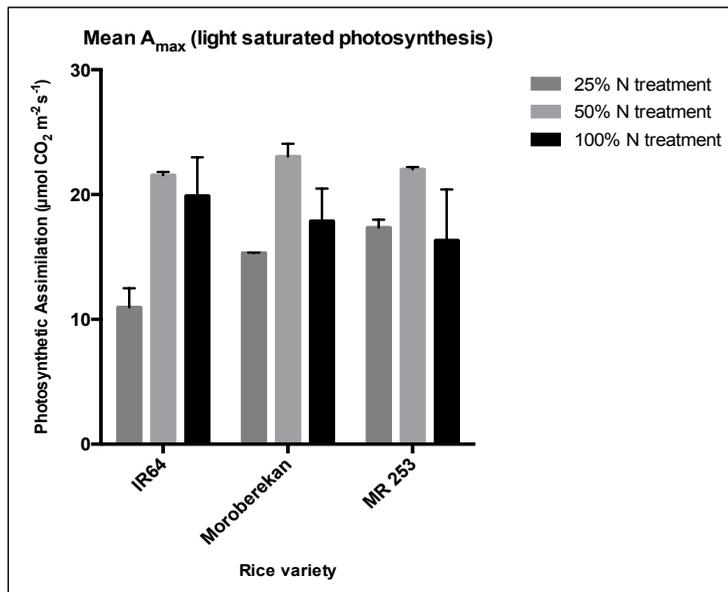


Fig.3: Light saturated rates of  $CO_2$  assimilation in the widely grown IR64, the African cultivar Moroberekan and the Malaysian cultivar MR253. Note the reduced difference in  $A_{max}$  between 50% and 25% for MR253. Means and standard error of the means are shown ( $n=4$ ). These three varieties were grown in hydroponic solution as in Murchie *et al.*, (2005). The experiment was conducted in an environmentally-controlled growth room under three concentrations of  $NH_4NO_3$ : 1.4 mM (100% N), 0.7 mM (50% N) and 0.35 mM (25% N). Measurements were made at leaf 11 for the IR64 and MR 253 varieties and leaf 9 for the Moroberekan variety. The photoperiod was 12 hours, temperature 28°C, an irradiance of  $600\mu mol m^{-2} s^{-1}$  and RH of 40-50%. In-situ light response measurements were made according to Hubbard *et al.* (2012).

TABLE 1  
 Characteristics of Model and Malaysian Rice Cultivars. Wu *et al.*<sup>1</sup> (2005), Haq *et al.*<sup>2</sup> (2009)

Variety	Origin	Agronomic Characteristics
IR64 ( <i>indica</i> ), released in 1984	IRRI, Philippines	High yielding potential, tolerance to multiple diseases and pests, wide adaptability <sup>1</sup>
Moroberekan ( <i>japonica</i> )	Africa	Potential drought resistance <sup>2</sup> (deep-rooted), considerable resistance to rice blast
MR 253 ( <i>indica</i> )	MARDI, Malaysia	Resistant to leaf blast, performs better in marginal soils

## CONCLUSION

We have briefly discussed the future problems of increasing rice production in Malaysia in the face of rising demand of rice and unfavourable climatic conditions and economic uncertainties such as the increase in cost of fertiliser. Yield gains in Malaysia are associated with unsustainable increases in N fertiliser applications. We have focused on sustainable approaches for genetic improvements in productivity that include the optimisation of photosynthesis per unit nitrogen and multi-factor stress analyses in the field. Inefficient applications can result in profoundly catastrophic effects on the climate and important ecosystems. Curtailing the use of N fertiliser and promoting better nutrient management are the more immediate cost-effective options, but it is vital that we realise the need for more sustainable and long-term solutions.

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## REFERENCES

- Ainsworth, E. A., & Long, S. P. (2005). What have we learned from 15 years of free-air CO<sub>2</sub> enrichment (FACE)? A meta-analytic review of the responses of photosynthesis, canopy properties and plant production to rising CO<sub>2</sub>, *New Phytologist*, *165*, 351–371.
- Chen, Y., Murchie, E. H., Hubbart, S., Horton, P., & Peng, S. (2003). Effects of season-dependent irradiance levels and nitrogen-deficiency on photosynthesis and photoinhibition in field-grown rice (*Oryza sativa*), *Physiologia plantarum*, *117*(3), 343–351.
- FAO (2002) Rice in producing countries. In Nguyen, V. N., Tran, D. V. (Eds.). *FAO rice information*. (pp. 126–128) Rome, Italy: FAO
- Foulkes, M. J., & Murchie, E. H. (2011). Optimising canopy physiology traits to improve the nutrient use efficiency in crops. In M. J. Hawkesford, & P. Barraclough, P. (Eds.). *The molecular and physiological basis of nutrient use efficiency in crops*. (pp. 65–83) Chichester: Wiley-Blackwell.
- Haq, T. U., Akhtar, J., Nawaz, S., & Ahmad, R. (2009). Morpho-physiological response of rice

- (*Oryza sativa* L.) varieties to salinity stress. *Pakistan Journal of Botany*, 41(6), 2943–2956.
- Hubbart S., Ajigboye O. O., Horton P., Murchie E. H. (2012). The photoprotective protein PsbS exerts control over CO<sub>2</sub> assimilation rate in fluctuating light in rice. *Plant Journal*, 71(3), 402–412.
- IPCC (2013). Summary for policymakers. In *Climate change 2013: The physical science basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, USA: Cambridge University Press.
- Lin, B. B., Burgess, A. J., & Murchie, E. H. (2014). Adaptation for climate sensitive crops using agroforestry: Case studies for coffee and rice. In C. Black, & C. Ong (Eds.): *Tree-crop interactions in agroforestry systems under a changing climate*, (2nd ed.) Wallingford, Oxfordshire, UK: CABI (in press).
- Long, S. P., Ainsworth, E. A., Leakey, A. D., Nösberger, J., & Ort, D. R. (2006). Food for thought: Lower-than-expected crop yield stimulation with rising CO<sub>2</sub> concentrations. *Science*, 312(5782), 1918–1921.
- Maclean, J. L., Dawe, D. C., Hardy, B. & Hettel, G. P. (2002). *Rice almanac source book for the most important economic activity on earth*. Published by CABI (Oxon, UK) for IRRI (Manila) WARDA (Cote d'Ivoire), CIAT (Colombia) and FAO (Rome, Italy).
- Makino, A. (2011). Photosynthesis, grain yield, and nitrogen utilization in rice and wheat. *Plant Physiology*, 155(1), 125–129.
- Murchie, E. H., Hubbart, S., Peng, S., & Horton, P. (2005). Acclimation of photosynthesis to high irradiance in rice: Gene expression and interactions with leaf development. *Journal of Experimental Botany*, 56(411), 449–460.
- Murchie, E. H., & Niyogi, K. K. (2011). Manipulation of photoprotection to improve plant photosynthesis. *Plant physiology*, 155(1), 86–92.
- Murchie, E. H., Pinto, M., & Horton, P. (2009). Agriculture and the new challenges for photosynthesis research. *New Phytologist*, 181(3), 532–552.
- Najim, M. M. M., Lee T. S., Haque, M. A., & Esham, M. (2007). Sustainability of rice production: A Malaysian perspective. *Journal of Agricultural Sciences*, 3(1).
- Nori, H., Abdul Halim, R., & Ramlan, M. F. (2008). Effects of nitrogen fertilization management practice on the yield and straw nutritional quality of commercial rice varieties. *Malaysian Journal of Mathematical Sciences*, 2(2), 61–71.
- Omar, O. (2008). Rice production and potential for hybrid rice in Malaysia. Paper presented at International Plantation Industry Conference & Exhibition (IPiCEX), Nov. 2008. Available at web address (<http://ipicex.com/docs/oral/Session%201A%20Othman.pdf>)
- Parry, M., Rosenweig, C., & Livermore, M. (2005). Climate change, global food supply and risk of hunger. *Philosophical Transactions of the Royal Society*, 360(1463), 2125–2138.
- Peng, S., Huang, J., Sheehy, J. E., Laza, R. C., Visperas, R. M., Zhong, X., Centeno, G. S., Khush, G. S., & Cassman, K. G. (2004). *Rice yields decline with higher night temperature from global warming*. Washington, DC: PNAS.
- Peng, S., Laza, R. C., Visperas, R. M., Sanico, A. L., Cassman, K. G., & Khush, G. S. (2000). Grain yield of rice cultivars and lines developed in the Philippines since 1966. *Crop Science*. 40(2), 307–314.
- Reynolds, M., Foulkes, J., Furbank, R., Griffiths, S., King, J., Murchie, E. H. (2012). Achieving yield gains in wheat. *Plant Cell and Environment*, 35, 1799–1823.

- Sheehy, J. E., & Mitchell, P. L. (2011). Rice and global food security: The race between scientific discovery and catastrophe. *ACCESS NOT EXCESS—the search for better nutrition*. (p. 81–90) Cambridgeshire, United Kingdom: Smith-Gordon.
- Sheehy, J. E., & Mitchell, P. L. (2013). *Designing rice for the 21st century: The three laws of maximum yield*. Discussion Paper Series 48, International Rice Research Institute, Los Baños, Philippines.
- Vaghefi N., Shamsudin M. N., Makmom A., & Bagheri M. (2011). The economic impacts of climate change on the rice production in Malaysia. *International Journal of Agricultural Research*, 6(1), 67–74.
- Verhoeven, A. S., Demmig-Adams, B., Adams III, W. W. (1997). Enhanced employment of the xanthophyll cycle and thermal energy dissipation in spinach exposed to high light and N stress. *Plant Physiology*, 113(3), 817–824.
- Wassmann, R., Jagadish, S. V. K., Peng, S. B., Sumfleth, K., Hosen, Y., & Sander, B. O. (2009) *rice production and global climate change: scope for adaptation and mitigation activities*. International Rice Research Institute, Los Banos, Laguna, Philippines.
- Welch, J. R., Vincent, J. R., Auffhammer, M., Moya, P. F., Dobermann, A., & Dawe, D. (2010). Rice yields in tropical/subtropical Asia exhibit large but opposing sensitivities to minimum and maximum temperatures. *Proceedings of the National Academy of Sciences*, 107(33), 14562–14567.
- Wu, J. L., Wu, C., Lei, C., Baraoidan, M., Bordeos, A., Madamba, M., & Leung, H. (2005). Chemical- and irradiation-induced mutants of indica rice IR64 for forward and reverse genetics. *Plant molecular biology*, 59(1), 85–97.