AJES ASIAN JOURNAL OF ENVIRONMENTAL SCIENCE
VOLUME 11 | ISSUE 1 | JUNE, 2016 | 111-117
DOI: 10.15740/HAS/AJES/11.1/111-117
e ISSN-0976-8947
Visit us : *www.researchjournal.co.in*

A CASE STUDY

Climate change and rice (*Oryza sativa* L.) production

S. ARUNVENKATESH, R. VINOTH KUMAR AND M. RAJASEKAR

Article Chronicle :
Received :
01.02.2016;
Accepted :
28.05.2016

ABSTRACT : Agriculture is extremely vulnerable to climate change. High temperatures eventually reduce yields of desirable crops while encouraging weed and pest proliferation. The present CO_2 of 380 ppm, projected to double by the end of the century, could benefit the rice crop by increasing photosynthesis and biomass depending on rice cultivar, growth stage and environment (IPCC, 2007). The Inter Governmental Panel on Climate Change defined Climate change as a "change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer". It refers to any change in climate over time, whether due to natural variability or as a result of human activity (IPCC, 2007). The present CO_2 of 380 ppm, projected to double by the end of the century, could benefit the rice crop by increasing photosynthesis and biomass depending on rice cultivar, growth stage and environment (IPCC, 2007). Although elevated CO_2 could enhance photosynthesis, especially in C_3 crop like rice, it is a potential component to trap the short Wave radiations from the earth surface only to be redirected back to increase the global surface mean temperature. Increased biomass production due to elevated CO_2 could potentially increase yield, provided microsporogenesis, flowering, and grain-filling are not disrupted by environmental stresses such as drought or high temperature. The adaptation strategies for changing climate are, Screening of CO_2 - responsiveness and temperature-tolerant varieties, Changing cultivation method, Site-specific adjustment in crop management (shifting planting dates and improved water management), Geographic analysis of vulnerable regions (where the rice crop is already experiencing critical temperature levels), Regional climate modelling to identify future "tilting points" of rice production (temperatures or CO_2 levels above which major yield losses are experienced)

Key Words :
Climate change,
Elevated CO_2,
Temperature

HOW TO CITE THIS ARTICLE : Arunvenkatesh, S., Kumar, R. Vinoth and Rajasekar, M. (2016). Climate change and rice (*Oryza sativa* L.) production. *Asian J. Environ. Sci.,***11**(1): 111-117, **DOI: 10.15740/HAS/AJES/11.1/111-117.**

Author for correspondence :
S. ARUNVENKATESH
Department of Agronomy, Tamil Nadu Agricultural University, COIMBATORE (T.N.) INDIA
Email : venkatesarun@gmail.com

See end of the article for **Coopted authors'**

The cultivation of rice extends from dry lands to wetlands and from the banks of the Amur River at 53° north latitude to central Argentina at 40° south latitude. Rice is also grown in cool climates at altitudes of over 2600 m above mean sea level in the mountains of Nepal, as well as in the hot deserts of Egypt. However, most of the annual rice production comes from tropical climate areas. Rice is the principle staple food crop of Asia and any deterioration of rice production systems through climate change would seriously impair food security in this continent. Because agriculture is so vulnerable to weather and climate changes, a great deal of effort is being put into studies of the influence of weather and climate on crop growth and development. The changes in climatic parameters are being felt globally in the form of changes in temperature and rainfall pattern. The global atmospheric concentration of carbon dioxide, a Green House Gas (GHG) largely responsible for global warming, has increased from a pre-industrial value of about 280 ppm to 387 ppm in 2010. Similarly, the global atmospheric concentration of methane and nitrous oxides and other important GHGs, has also increased considerably resulting in the warming of the global system by 0.74°C between 1906 and 2005 (IPCC, 2007). IPCC also reported that sea levels have risen by between 10 and 20 cm and snow and ice covers have fallen almost worldwide, while the precipitation patterns characterizing land areas of the Northern Hemisphere have progressively changed. In the same report, IPCC estimated that sea levels would rise by an average 0.09 to 0.88 m between 1990 and 2100.

There is also a global trend of an increased frequency of droughts as well as heavy precipitation events over many regions. Cold days, cold nights and frost events have become less frequent, while hot days, hot nights and heat waves have become more frequent. It is also likely that future tropical cyclones will become more intense with larger peak wind speeds and heavier precipitation. The IPCC (2007) projected that temperature increase by the end of this century is expected to be in the range 1.8 to 4.0°C. For the Indian region (South Asia), the IPCC projected 0.5 to 1.2°C rise in temperature by 2020, 0.88 to 3.16°C by 2050 and 1.56 to 5.44°C by 2080, depending on the future development scenario (IPCC, 2007)

Rice cultivation and green house gas emissions :

Rice fields have to be considered as a significant source of greenhouse gases (CH_4 and N_2O) (Bronson *et al.*, 1997). Methane is as an important greenhouse gas which can contribute to global warming. It has the second largest radiative forcing (0.48 Wm^{-2}) after CO_2 (1.66 Wm^{-2}) and contributes some about 16 per cent of the global warming resulting from the increasing concentrations of greenhouse gases in the atmosphere (Nieder and Benbi, 2008). Rice field eco systems account for about 12 per cent of the global annual CH_4 emission (IPCC, 1996). Recent estimates of methane from rice fields range between 39 and 112 Tg CH_4 $year^{-1}$ (Denman *et al.*, 2007). Using region-specific methane emission factors, Yan *et al.* (2003) estimated the global emission of 28.2 Tg CH_4 $year^{-1}$ from rice fields. Asian region accounts for 25.1 Tg CH_4 $year^{-1}$, of which 7.67 Tg CH_4 $year^{-1}$ is emitted from China and 5.88 Tg CH_4 $year^{-1}$ from India.

Effect of climate change on rice production :

Carbon di oxide :

Carbon di oxide is the prime substrate for photosynthesis. Majority of plants, including rice, fix CO_2 via C_3 pathway. At ambient CO_2 levels C_3 pathway is less efficient than C_4 pathway due to the enzyme ‘Rubisco’ which has dual and competing affinity to both O_2 and CO_2. At elevated CO_2, the caboxylation rate increases which will increase photosynthesis of C_3 plants. Studies with rice have indicated that elevated CO_2 generally increases tiller number, photosynthesis, biomass and grain yield as well as plant nitrogen (N) uptake and biological N fixation (Cheng *et al.*, 2001 and Kim *et al.*, 2001).

Elevated CO_2 accelerated rice development, increased leaf photosynthesis by 30–70 per cent, canopy photosynthesis by 30–40 per cent and crop biomass yield by 15–30 per cent, depending on genotype and environment. Elevated CO_2 had a minor effect on rice nitrogen (N) uptake, which appeared to be associated with the relatively insensitive response of leaf area growth to CO_2. Those rice responses to CO_2 resulted in a substantial grain yield increase under elevated CO_2 and nearly optimum temperature conditions. The anticipated changes in temperature and CO_2 have been modeled to have opposite effects on the production. Increasing temperatures shortened the growing season leading to decreased yields, while elevated CO_2 increased the yields (Erda *et al.*, 2005). When C_3 plants, such as rice, are exposed to high CO_2 concentration, the net photosynthesis rate is accelerated due to both enrichment of substrate CO_2 as well as inhibition of photorespiration by high CO_2 concentration (Long *et al.*, 2004).

Reduction of stomatal conductance due to elevated CO_2 has been commonly observed in rice (Ainsworth, 2008). However, the response of stomatal conductance to elevated CO_2 varies considerably in response to various environmental factors (Ainsworth and Rogers, 2007).

The results of the CO_2 sensitivity experiment indicate an increasing trend in the yield with CO_2 concentration increasing from 180 ppm to 1230 ppm (Fig.1). The increase in yield is exponential in the CO_2 incremental range between 180 ppm to 380 ppm, but steady increase thereafter. It appears that at around 800 ppm onwards the fertilization effect of CO_2 in increasing photosynthesis very fast. With a doubling of CO_2 the yield is found to increase by 10 per cent under rainfed cultural practices for cultivation of rice crop in the state.

The response of the model simulated evapotranspiration (ET) to an increase in CO_2 is also presented in Fig. 1. The results indicate a fast decline in the crop ET with increase in ambient CO_2 level. The decline in ET rate is near exponential in the CO_2 incremental range from 180 ppm to 380 ppm and slower thereafter. A lowering in the ET of crop results in a reduced water requirement of the crop, which may be attributed to stomatal regulation by CO_2 concentration in the ambient atmosphere. It is very clear from the published work that elevated CO_2 slows the transpiration rate and contributes to an increase in water use efficiency (WUE). Transpiration is reduced due to lower stomatal conductance, and the stomatal conductance is dependent on the partial closure of guard cells that forms stomata on leaf surface.

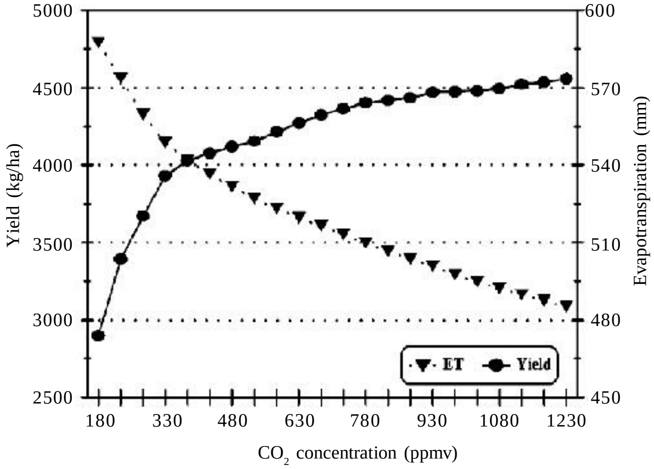

Fig. 1 : **Sensitivity of ET and yield to CO_2 changes in the atmosphere as simulated by the CERES-Rice model (Saseendran *et al.*, 2000)**

Temperature :

Higher temperatures affect rice yields through two fundamentally different processes: (1) gradual changes in metabolism and phenology and (2) spikelet sterility caused by temperatures (heat waves) beyond certain temperature/humidity thresholds. Rice is grown in many regions where current temperatures during grain filling are only slightly below the critical limits for spikelet sterility (Wassmann *et al.*, 2009). Grain yield declined by 10 per cent for each 1°C increase in growing-season minimum temperature in the dry season, whereas the effect of maximum temperature on crop yield was insignificant (Peng *et al.*, 2004).

Extremely high temperatures during vegetative growth reduce tiller number and plant height and negatively affect panicle and pollen development, thereby decreasing rice yield potential (Yoshida, 1981). High temperature is of particular importance during flowering, which typically occurs at mid-morning. Exposure to high temperatures (*i.e.*, >35 °C) can greatly reduce pollen viability and cause irreversible yield loss because of spikelet sterility (Matsui *et al.*, 1997). In a temperature gradient chamber study, rice exposed to 3.6 and 7.0°C higher temperature than ambient, from heading to middle ripening stage, reduced photosynthesis by 11.2–35.6 per cent, respectively (Oh-e *et al.*, 2007).

Biomass yield of a crop can be taken as the product of the rate of biomass accumulation times the duration of growth. The rate of biomass accumulation is determined by the photosynthetic rate minus the respiration rate. The first is primarily governed by the radiation and the latter by ambient air temperature. Higher temperature shortens the rice growth period; consequently reduce the period available to the plant for photosynthetic accumulation. Hence, the biomass accumulation is greatly influenced by the ambient air temperature. Highest potential yield of a particular annual crop is therefore, obtained in regions where the crop duration is characterised by relatively low temperatures unless the radiation levels are also low (Ritchie, 1993). This is due to the fact that, at low temperature levels the crop gets more days to mature, therefore, accumulate more biomass. Hence, there will be a reduction in the grain weight of crop plants with increase in temperature.

The Fig. 2. shows an increase in the trend of simulated rice yield for a 1 to 3°C drop in temperature from present day level and decline thereafter. The yield

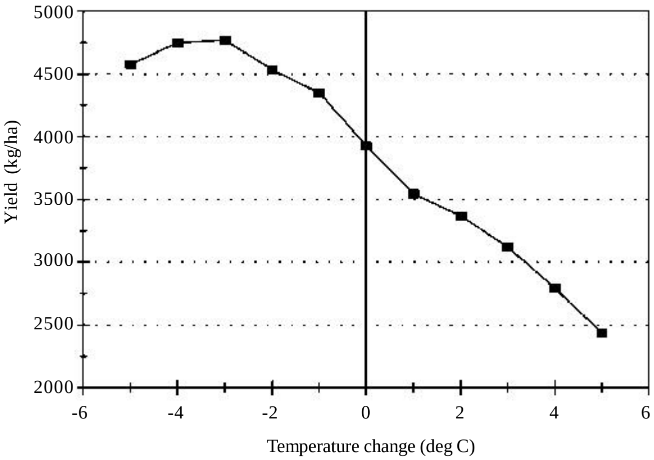

Fig. 2 : **Sensitivity of rice yield to atmospheric temperature changes between -6 °C and +6 °C as simulated by the CERES-Rice model (Saseendran *et al.*, 2000)**

maximum is simulated at a 3°C drop indicating 21 per cent increment over the present level. At 5°C temperature drop the yield remains at 16 per cent from the base (present day) temperature level. For a positive change in temperature upto 5°C, there is a continuous decline in the yield. For one degree increment there is about 6 per cent decline in the simulated yield.

Carbon-di-oxide with temperature :

As atmospheric carbon di oxide continues to rise, there are two consequences with respect to plant biology. CO_2 is the principle source of carbon for photosynthesis, and plants which possess the C_3 photosynthetic pathway (*i.e.,* 95% of all plant species) currently operate at suboptimal carbon dioxide levels. Increasing CO_2 therefore, can directly stimulate photosynthesis and subsequent plant growth (Kimball, 1983). A second, indirect consequence of increasing CO_2 level is related to its ability to trap infra-red radiation in the atmosphere (along with other so-called greenhouse trace gases) with a potential increase in global surface temperature. At present, a 2–4 °C increase in air temperature is predicted with a doubling of current CO_2 levels. Although the actual rise in global temperature is difficult to predict, any increase will affect a number of plant metabolic processes which influence photosynthesis, growth and yield.

With the increase in daily maximum temperature averaged over flowering period above about 36° C, rice yield generally declined because of spikelet sterility induced by high temperatures. Importantly, elevated CO_2 increased spikelet susceptibility to high-temperature damage (Kim *et al.*, 1996). Nearly doubled CO_2 decreased the threshold temperature for high-temperature damage of spikelets by 1–2°C more than the ambient CO_2.

Humidity and temperature :

Humidity also plays an important role in rice yield, as higher relative humidity (RH) at the flowering stage under increased temperature affects spikelet fertility negatively (Yan *et al.,* 2010). Field observations in some high-yielding rice areas with a drier climate and high temperatures (e.g. New South Wales and Southern Iran) suggested no significant increase in spikelet sterility even at temperatures >40 °C (Wassmann and Dobermann, 2007). Prior to this, a decrease in the fertility of spikelets at high air temperatures with increased humidity was reported by Matsui *et al.* (1997) who suggested that humidity modified the impact of high temperature on spikelet fertility. An RH of 85–90 per cent at the heading stage induced almost complete grain sterility in rice at a day/ night temperature of 35/30 °C (Abeysiriwardena *et al.,* 2002). Heavy water loss from florets might impede one of the major processes of pollination, such as swelling of the pollen grains (Matsui *et al.,* 1997). Weerakoon *et al.* (2008) reported that spikelet fertility was not always inhibited by high humidity, because at low temperature (> 30 °C) the fertility was C. 0·9. They also observed that with increased RH, pollen shedding on stigma was reduced at high temperature, while no such reduction with increased RH was noted at lower air temperatures. The shedding of pollen on the stigma and the subsequent spikelet sterility are affected by RH along with temperature. Nishiyama and Satake (1981) also showed that the dehiscence of the anther, which plays an important role in the fertility of the spikelet, was promoted by dry air. The temperature inside the spikelet decreases with a reduction in RH, possibly due to the enhancement of transpiration at low RH (Weerakoon *et al.,* 2008). This reduction in temperature inside the spikelet increases the viability of pollen grains. Viable pollen grains absorb moisture and swell at moderate to high RH levels and create the required pressure for the rupture of the septum, which helps in the deposition of pollen on stigma and thus, produces a fertilized spikelet (Weerakoon *et al.,* 2008).

Adaptation and mitigation strategies :

Adaptation involves adjustments to decrease the vulnerability of rice production to climate changes, while mitigation focuses on reducing the emission of greenhouse gases from rice production and minimizing deforestation resulting from upland rice cultivation under slash-and-burn shifting cultivation. There are a range of technological options that are presently available or which can potentially be developed in the near future for enhancing the rice production systems' ability to adapt and mitigate the effects of global climate changes.

Selection of appropriate planting date :

As temperature varies from month to month, it is possible to select the right date for crop establishment in such a way that the reproductive and grain filling phases of rice fall into those months with a relatively low temperature. This would minimize the negative effect of temperature increase on rice yield as reported by Peng *et al.* (2004). Efforts to collect and disseminate the information on month-to-month variation in temperature regimes in major rice-producing tropical areas, therefore, are essential for helping rice production to adapt to climate changes.

Screening of heat-tolerant varieties :

Among the varieties tested, ADT 38, ADT 48, CO 43, ADT 36, ADT 37 and BPT 5204 are highly tolerant to higher temperature and gave higher yields compared to the other varieties. This indicates that these varieties can be recommended for the warmer climatic regions. (Geethalakshmi *et al.,* 2011).

Changing cultivation method :

Under changing climatic conditions, more water scarcity is expected. The results of the field experiment conducted in the farmer's field of the Cauvery basin with different cultivation methods indicated that under the system of rice intensification method, 22 per cent increase in grain yield and 24.5 per cent water saving were noticed compared to transplanted rice. Water productivity was also maximum under SRI method of rice cultivation (0.58 kg/m^3), followed by alternate wetting and drying method, and aerobic rice cultivation. The conventional rice cultivation (0.36 kg/m^3), and direct sown rice produced lower grain yield per unit of water used. SRI method of cultivation will suit better under future warmer climate in terms of economizing water and increasing the productivity (Geethalakshmi *et al.*, 2011).

Reducing the emission of greenhouse gas :

The emission of methane from flooded rice soils has been identified as a contributor to global warming. Water regime, organic matter management, temperature and soil properties, as well as rice plants, are the major factors determining the production and flux of methane (CH_4) in rice fields. Intermittent irrigation or alternating dry-wet irrigation could reduce emissions from rice-fields, while the transfer and adoption of a Rice Integrated Crop Management (RICM) approach would increase the efficiency of nitrogen fertilizer in rice production, thus, reducing nitrous oxide emissions (Nguyen, 2002).

Geographic analysis of vulnerable regions (where the rice crop is already experiencing critical temperature levels).

Regional climate modelling to identify future "tilting points" of rice production (temperatures or CO_2 levels above which major yield losses are experienced).

Conclusion :

Rice is the staple food crop of the world population. The world population continues to grow steadily, while land and water resources are on the decline. Studies suggest that temperature increase, rising seas and changes in patterns of rainfall and its distribution under global climate changes might lead to substantial modifications in land and water resources for rice production as well as the productivity of rice crops grown in different parts of the world. The emission of methane and nitrous oxide gases from lowland rice production and the deforestation in upland rice production under slash-and-burn shifting cultivation are contributors to global climate changes. The sustainable increase of rice production for food security will require efforts to enhance the capacity of rice production systems to adapt to global climate change as well as to mitigate the effects of rice production on global warming. Technical options for adaptation and mitigation are available and could be further improved. Policy support to rice research and development to develop and transfer appropriate and efficient technologies, however, will be vital for the realization of such measures for sustainable rice production.

Coopted Authors' :

R. VINOTH KUMAR, Department of Soil and Water Conservation Engineering, Tamil Nadu Agricultural University, COIMBATORE (T.N.) INDIA

M. RAJASEKAR, Department of Agronomy, Tamil Nadu Agricultural University, COIMBATORE (T.N.) INDIA

REFERENCES

Abeysiriwardena, D.S., DE, Z., Ohba, K. and Maruyama, A. (2002). Influence of temperature and relative humidity on grain sterility in rice. *J. National Sci. Foundat. Sri Lanka*, **30**: 33-41.

Ainsworth, A.E. (2008). Rice production in a changing climate: a meta-analysis of responses to elevated carbon dioxide and elevated ozone concentration. *Global Change Biolog.*, **14** : 1642-1650.

Ainsworth, E.A. and Rogers, A. (2007). The response of photosynthesis and stomatal conductance to rising [CO_2]: mechanisms and environmental interactions. *Plant Cell Environ.*, **30** : 258-270.

Bronson, K.F., Neue, H.U., Singh, U. and Abao, Jr. E.B. (1997). Automated chamber measurements of methane and nitrous oxide flux in a flooded rice soil. I. Residue, nitrogen, and water management. *Soil Sci. Soc. American J.*, **61** : 981-987.

Cheng, W.G., Inubushi, K., Yagi, K., Sakai, H. and Kobayashi, K. (2001). Effects of elevated carbon dioxide concentration on biological nitrogen fixation, nitrogen mineralization and carbon decomposition in submerged rice soil. *Biolog. Fertil. & Soils*, **34** : 7-13.

Denman, K.L., Brasseur, G., Chidthaisong, A., Ciais, P., Cox, P.M., Dickinson, R.E., Hauglustaine, D., Heinze, C., Holland, E., Jacob, D., Lohmann, U., Ramachandram, S., da Silva Dias, P.L., Wofsy S.C. and Zhang, X. (2007). Coupling between changes in the climate system and biogeochemistry. In: Climate change 2007: The physical science basis (Eds.: S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller). Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK/New York: Cambridge University Press. 499-587.

Erda, L., Wei, X., Hui, J., Yinlong, X., Yue, L., Liping, B. and Liyong, X. (2005). Climate change impacts on Yield formation of CO_2-enriched inter-subspecific hybrid rice cultivar Liangyoupeijiu under fully open-air field condition in a warm sub-tropical climate crop yield and quality with CO_2 fertilization in China. *Philosoph. Transact. Royal Soc. Biolog.*, **360**: 2149-2154.

Geethalakshmi, V., Lakshmanan, A., Rajalakshmi, D., Jagannathan, R., Gummidi Sridhar, Ramaraj, A. P., Bhuvaneswari, K., Gurusamy, L. and Anbhazhagan, R. (2011). Climate change impact assessment and adaptation strategies to sustain rice production in Cauvery basin of Tamil Nadu. *Curr. Sci.*, **101**(3) : 342-347.

IPCC (2007). Summary for Policymakers. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 7-22.

Kim, H.Y., Horie, T., Nakagawa, H. and Wada, K. (1996). Effects of elevated CO_2 concentration and high temperature on growth and yield of rice. *Japanese J. Crop Sci.*, **65** : 644-651.

Kim, H.Y., Lieffering, M., Miura, S., Kobayashi, K. and Okada, M. (2001). Growth and nitrogen uptake of CO_2- enriched rice under field conditions. *New Phytolol.*, **150** : 223-229.

Kimball, B.A. (1983). Carbon dioxide and agricultural yield: an assemblage and analysis of 430 prior observations. *Agronomy J.*, **75** : 779-788.

Long, S.P., Ainsworth, E.A., Rogers, A. and Ort, D.R. (2004). Rising atmospheric carbon dioxide: plants FACE the futhre. *Ann. Rev. Pl. Biol.*, **55** : 591-628.

Matsui, T., Omasa, K. and Horie, T. (1997). High temperature-induced spikelet sterility of japonica rice at flowering in relation to air temperature, humidity and wind velocity condition. *Japanese J. Crop Sci.*, **66** : 449-455.

Nguyen, V.N. (2002). Productive and environmentally friendly rice integrated crop management systems. *IRC News letter*, **51** : 25-32.

Nieder, R. and Benbi, D.K. (2008). Carbon and nitrogen in the terrestrial environment. *Springer Sci.*, 430.

Nishiyama, I. and Satake, T. (1981). High temperature damage in the rice plant. *Japanese J. Tropical Agric.*, **26** : 19-25.

Oh-e, I., Saitoh, K. and Kuroda, T. (2007). Effects of high temperature on growth, yield and dry-matter production of rice grown in the paddy field. *Pl. Prod. Sci.*, **10** : 412-422.

Peng, S., Huang, J., Sheehy, J.E., Laza, R.C., Visperas, R.M., Zhong, X., Centeno, G.S., Khush, G.S. and Cassman, K.G. (2004). Rice yields decline with higher night temperature from global warming. *PNAS*, **101**(27) : 9971–9975.

Ritchie, J.T. (1993). *Genetic specific data for crop modelling*. in Penning de Vries, F. W. T., Teng, P., and Metselaar, K. (eds.), Systems Approaches for Agricultural Development, Kluwer Academic Publishers, Dordrecht, 77–93.

Saseendran, S., Singh, A.K.K., Rathore, L.S., Singh, S.V. and Sinha, S.K. (2000). Effects of climate change on rice production in the Tropical humid climate of Kerala, India. *Climatic Change*, **44** : 495-514.

Wassmann, R., Jagadish, S.V.K., Heuer, S., Ismail, A., Redoña, E., Serraj, R., Singh, R.K., Howell, G., Pathak, H. and Sumfleth, K. (2009). Climate change affecting rice production: the physiological and agronomic basis for possible adaptation strategies. *Adv. Agron.*, **101** : 59-122.

Weerakoon, W.M.W., Maruyama, A. and OHBA, K. (2008). Impact of humidity on temperature-induced grain sterility in rice (*Oryza sativa* L). *J, Agron. & Crop Sci.*, **194** : 135-140.

Yan, C., Ding, Y., Wang, Q., Liu, Z., Li, G., Muhammad, I. and Wang, S. (2010). The impact of relative humidity, genotypes and fertilizer application rates on panicle, leaf temperature, fertility and seed setting of rice. *J. Agril. Sci., Cambridge* **148**: 329-339.

Yan, X., Ohara, T. and Akimoto, H. (2003). Development of region-specific emission factors and estimation of methane emission from rice fields in the East, Southeast and South Asian countries. *Global Change Biol.*, **9** : 237-254.

Yoshida, S. (1981). Fundamentals of Rice Crop Science (International Rice Research Institute, Los Banos, Philippines).

WEBLIOGRAPHY

Wassmann, R. and Dobermann, A. (2007). Climate change adaptation through rice production in regions with high poverty levels. Ejournal of SAT Agricultural Research 4. Available from *http://www.icrisat.org/journal/Special Project/sp8.pdf*