Journal of Agriculture and Rural Development in the Tropics and Subtropics
Vol. 113 No. 1 (2012) 61–68

urn:nbn:de:hebis:34-2012082241643 ISSN: 1612-9830 – journal online: www.jarts.info

Yield gap analysis and assessment of climate-induced yield trends of irrigated rice in selected provinces of the Philippines

Carlos Angulo [a], Mathias Becker [a,*], Reiner Wassmann [b]

[a] *Institute of Crop Science and Resource Conservation, University of Bonn, Germany*
[b] *International Rice Research Institute, Manila, Philippines, working as integrated expert funded by CIM/GIZ*

Abstract

This study describes a combined empirical/modeling approach to assess the possible impact of climate variability on rice production in the Philippines. We collated climate data of the last two decades (1985–2002) as well as yield statistics of six provinces of the Philippines, selected along a North-South gradient. Data from the climate information system of NASA were used as input parameters of the model ORYZA2000 to determine potential yields and, in the next steps, the yield gap was defined as the difference between potential and actual yields. Both simulated and actual yields of irrigated rice varied strongly between years. However, no climate-driven trends were apparent and the variability in actual yields showed no correlation with climatic parameters. The observed variation in simulated yields was attributable to seasonal variations in climate parameters (mainly radiation and temperature differences between dry and wet season) and to climatic differences between provinces and agro-ecological zones. The actual yield variation between provinces was not related to differences in the climatic yield potential but rather to soil and management factors. The resulting yield gap was largest in remote and infrastructurally disfavored provinces (low external input use) with a high production potential (high solar radiation and day-night temperature differences). In turn, the yield gap was lowest in central provinces with good market access but with a relatively low climatic yield potential. We conclude that neither long-term trends nor the variability of the climate can explain current rice yield trends, and that agroecological, seasonal, and management effects are over-riding any possible climatic variations. On the other hand, the lack of a climate-driven trend in the present situation may be superseded by ongoing climate change in the future.

Keywords: Climate variability, ORYZA2000, *Oryza sativa*, Philippines, Yield gap

1 Introduction

Climatic factors (temperature, solar radiation, and rainfall) affect the major processes involved in rice production such as vegetative growth, phenological development and the formation of storage organs and grain filling (Wassmann *et al.*, 2009). Concerns about global warming have encouraged the scientific community to focus on food production constraints that may occur under conditions of global climate change and the corresponding adaptation strategies to support food security (Tubiello & Fischer, 2007). Rice plays an important role as staple food throughout Asia and parts of Africa and any negative consequences of climate change on rice production would put at risk the fragile food supply stability of these regions (Maclean *et al.*, 2002). Calculated domestic losses of up to 40 million dollars have been attributed to climatic constraints in the last decade (Lansigan *et al.*, 2000). Considering that approximately 67 % of the area under rice cultivation in the Philippines is

* Correspondence:
Institute of Crop Science and Resource Conservation
Karlrobert-Kreiten-Strasse 13
53115 Bonn-Germany
Email: mathias.becker@uni-bonn.de

irrigated, and that this share is increasing (PHILRICE-BAS, 2004), there is a need to focus on the effect of climate change and climate variability in irrigated, non-water limited systems, in which the production potential is mainly determined by temperature and solar radiation. While simulated potential yields are driven by climatic and crop cultivar-specific characteristics, actual yields are further limited by soil and management factors related to the crop's nutritional status as well as to biotic and abiotic stresses (Dawe & Dobermann, 1999).

It is hypothesized that trends in climate variability exist, and that these are reflected in trends of potential yield. The latter can be calculated using the well-established and validated crop growth simulation model ORYZA2000 (Bouman *et al.*, 2001). These simulated yields reflect the climatic conditions, and seasonal as well as inter-annual yield trends are a reflection of climate change or variability. The actual yields and yield gaps allow assessing to what extent rice production is affected by climate or by soil and management factors. To test this hypothesis we applied a combined simulation and yield gap approach to determine the climate-related production trends of irrigated rice in six provinces of the Philippines during the two decades (1985–2002) for which complete data sets were available.

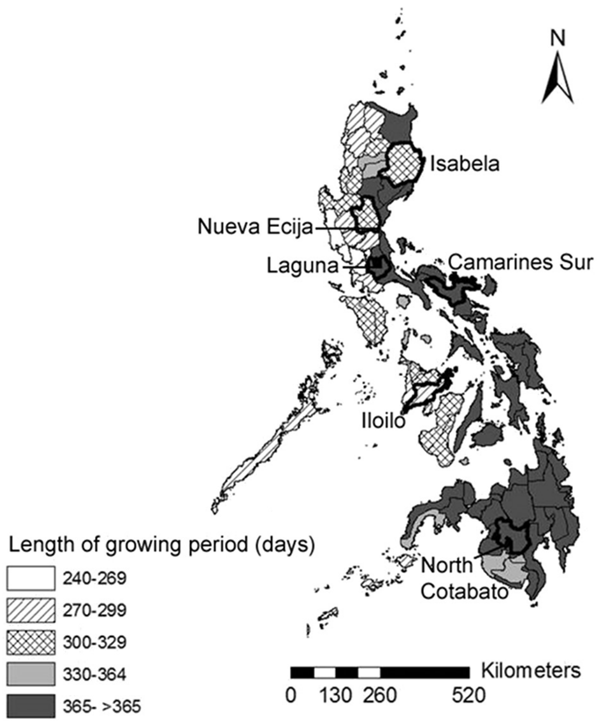

Fig. 1: *Length of growing period (days) in the provinces of Camarines Sur, Iloilo, Isabela, Laguna, North Cotabato and Nueva Ecija in the Philippines (modified form: Global length of growing periods, http://www.fao.org/geonetwork/srv/en/metadata.show?id=73-&curTab=simple).*

2 Materials and Methods

2.1 Actual yield data

The official survey data from the Philippine Rice Statistics Handbook 1970–2002 (PHILRICE-BAS, 2004) were used to generate yield tables and to identify representative rice-producing provinces in the country. The 33-year mean yields and the total irrigated rice production for each province were calculated and categorized. The selection of provinces for the present study was based on the following criteria: (1) rice is the dominant crop with a provincial production of >105 Mg; (2) the share of irrigated rice is >50 % of the respective rice-growing area; and (3) in totality, the provinces cover an agro-ecological gradient from North to South (Figure 1). Based on these criteria, six provinces were selected. Their location, production, biophysical environmental and infrastructure attributes are presented in Table 1.

2.2 Climate data

A set of climate data from six Philippine provinces was compiled to be used as input parameters for the Model ORYZA2000. For all six provinces, climate data (radiation, minimum and maximum temperature at daily time steps) were obtained from the NASA Climatology Resource for Agro climatology Daily Averaged Data (NASA, 2004; http://earth-www.larc.nasa.gov/cgi-bin/cgiwrap/ solar/agro.cgi). For the provinces of Nueva Ecija, Laguna and Iloilo, additional climate data (daily time steps) were obtained from the IRRI Climate Unit (ICU). For these three provinces, weather data were already compiled in Fortran Simulation Environment-FSE format while the NASA data from the other three provinces needed FSE transformations. The climate data used for simulating the non-water or nutrient-limited yield potential consisted of solar radiation (Figure 2), and minimum and maximum temperatures.

2.3 Simulation of potential yield

The model ORYZA2000 was used (Bouman *et al.*, 2001) in this study namely by applying the module for potential production. ORYZA2000 uses solar radiation (photosynthetically usable light) as the determining factor to calculate daily rates of CO_2 assimilation and dry matter accumulation, and temperature data as the basis for calculating the rate of phenological development and respiration losses. Nutrient and water supply are considered to be non-limiting factors. The dry matter partitioning to roots, stems, leaves and panicles was calculated according to genotype-specific coefficients, obtained from field trials. The net daily growth rates were determined as the difference between the requirements for maintenance respiration and the gross assimilation. The physiological and phenological characteristics were taken from the crop data file for the high-yielding semi-dwarf lowland rice cultivar IR64 (Boling *et al.*, 2007). This cultivar was released as a variety in the 1980's by the International Rice Research Institute (IRRI) and is still widely cultivated throughout Asia (Launio *et al.*, 2008). Input data for management parameters involved the crop establishment by transplanting of 20 day-old seedlings (most common rice establishment methods in the Philippines) and the transplanting dates of rice that were adjusted for each province and cropping season based on the Rice-based Farm Household Survey (RBFHS) for the years 1996–1997, 2001–2002, 2006–2007 (PHILRICE-BAS, 2007).

Table 1: *Physical location, rice production attributes, simulated potential and measured actual rice yields, and biophysical and infrastructure attributes of six selected provinces of the Philippines.*

Province	Northern longitude (°)	Agro-ecological zone [1]	Growing period (days) [1]	Province area (km^2) [2]	Cultivated rice area (10^3 ha) [2]	Share of irrigated rice (%) [2]	Solar radiation ($MJ\ m^{-2}\ d^{-1}$)	Rice yield potential ($Mg\ ha^{-1}$)	Actual rice yield ($Mg\ ha^{-1}$) [2]	Soil description [3]	Nitrogen fertilizer use (kg N ha^{-1}) [2]	Distance to Manila (km) [4]	Extension contacts [2]
Isabela	17.6	Moist savanna	190	12.557	250	94	18	7.75	4.20	Gravelly alluvium, medium fertility	49	308	Medium
Laguna	14.6	Moist savanna	235	1.824	27	98	17	6.57	4.28	Young volcanic clay, high fertility	61	83	High
Nueva Ecija	16.1	Moist savanna	240	5.751	253	84	17	7.08	4.39	Young volcanic clay, high fertility	56	36	High
Camarines Sur	14.1	Forest-savanna transition	280	5.380	138	74	16	6.17	3.26	Old alluvial acid clay, low fertility	41	273	Low
Iloilo	11.6	Forest-savanna transition	295	4.829	243	53	19	9.07	3.39	P deficient clay loam, low fertility	36	465	Medium
North Cotabato	7.7	Humid forest	315	9.009	121	71	19	9.88	3.81	Young alluvial clay loam, high fertiliy	32	952	Low

[1] Agroecological zones, FAO (2004)
[2] PhilRice-BAS Rice Statistics (2004)
[3] World Soil Reference Base (FAO, 2006)
[4] Linear distance on map

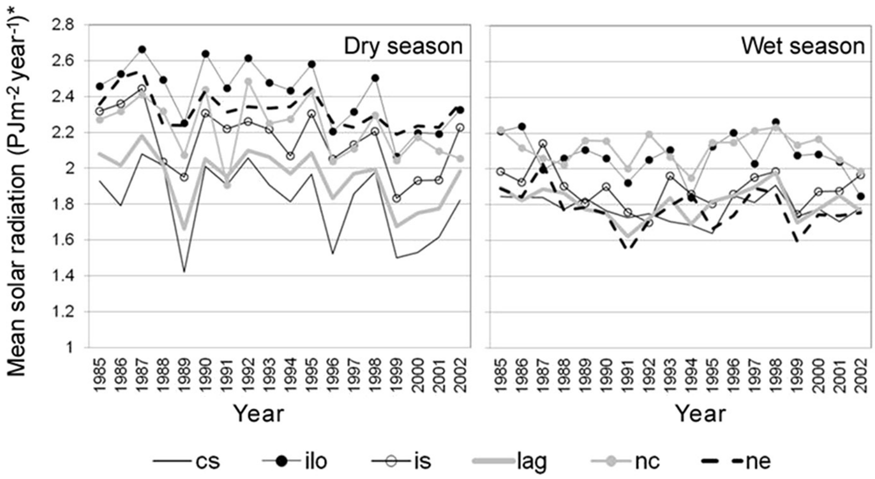

Fig. 2: *Cumulative solar radiation (in* $PJ\,m^{-2}\,year^{-1}$*) for the dry and wet seasons in six selected provinces in the Philippines (cs: Camarines Sur, ilo: Iloilo, is: Isabela, lag: Laguna, nc: North Cotabato, ne: Nueva Ecija). Source: NASA, (2004); Climatology resource for agroclimatology daily averaged data evaluation Version. Available at: http://earth-ww.larc.nasa.gov/cgi-bin/cgiwrap/solar/agro.cgi?email=agroclim@larc.nasa.gov. * PJ = PetaJoule =* 10^{15} *Joule.*

2.4 Yield gap analysis

The data for the simulated yield potential for the period from 1985 to 2002 were compared with actual yields from the same period and the yield gap (difference between potential and actual yield) was determined for each available data pair in each province for both the wet and the dry season. Variations over time and variations within seasons or sites are presented as data means and their standard errors as well as box plots and were prepared using SIGMA-PLOT vers.10.

3 Results

3.1 Variability of potential yields

The variability in simulated potential yield of irrigated rice is a reflection of climatic conditions, particularly of radiation and maximum and minimum temperatures during the crop growth period. In the data set assessed, the potential yields show no apparent trends over the years, suggesting no trends of apparent climate change having occurred during the past 20 years, at least regarding radiation and temperature (Figure 3). On the other hand, the different climate types of the Philippines influence the distinction between the wet and the dry season. In five out of six provinces the yield was higher in the dry than in the wet season, though the extent of these seasonal differences varied between locations (Table 2). Thus, the seasonality of potential yields was much more pronounced in the savanna agro-ecological zones (Isabela, Nueva Ecija) than in the humid forest zone (North Cobatabo, Camarines Sur) (Figure 1).

3.2 Variability of actual yields

Similar to the potential yields, the actual rice yields in the six selected provinces did not show any apparent trend for the study period. However as for the potential yield, different provinces showed distinct yield ratios between wet and dry seasons (Figure 4). In two out of six provinces, (Isabela and North Cotabato) the yields were higher in the dry season than in the wet season.

The mean differences between dry and wet seasons ranged from 0.1 Mg ha^{-1} in Isabela to 1.4 Mg ha^{-1} in North Cotabato with distinct and significant differences between provinces (Table 2). The most productive province for the period from 1985 to 2002 was Nueva Ecija with a dry season yield of 4.4 Mg ha^{-1}. The least productive provinces were Iloilo and Camarines Sur with 2.4 Mg ha^{-1} and 2.9 Mg ha^{-1}, respectively. While the climatic variability between years was clearly reflected in the variability of potential yields, it showed little or no relationship with the actual yields. Only in the province of Nueva Ecija high climatic yield potential in the dry season coincided with increased actual yields.

3.3 Yield gaps

As climatic factors only impacted on the potential yields but had in most cases little effect on the actual yield level, yield gaps tended to be largest in those provinces and seasons with the highest yield potential (i.e., dry and wet seasons in North Cotabato and Iloilo and dry season in Isabela and Nueva Ecija; Figure 4). Largest seasonal differences in the yield gaps were observed in the northern province of Isabela, with a distinct seasonality of the savanna-type climate, while least differences occurred in provinces located in the humid forest agroecological zone (North Cotabato and Camarines Sur). The extent of the yield gap was associated with agronomic parameters such as the rate of urea fertilizer applied and the level of soil fertility (Table 1), but also with the distance to the capital (Manila), which can be taken as a proxy for lacking access to urban markets of the respective province. Thus, remote areas such as Iloilo and North Cotabato with a low mean mineral fertilizer use (32–41 kg N ha^{-1}) and low to medium soil fertility, showed the lowest actual yields and the largest yield gaps. On the other hand, areas with good market access, with relatively fertile soils, and with higher mineral fertilizer application rates (56–61 kg N ha^{-1}), such as Laguna and Nueva Ecija, exhibited the lowest yield gaps during both the dry and the wet seasons (Figure 3).

4 Discussion

4.1 Variability of potential rice yields

The variability of potential rice yields over the study period (1985–2002) reflects largely the variability in solar radiation and temperatures, excluding other possible yield-limiting factors such as soil water deficit or pests and diseases. Moreover, rainfall variations were not taken into account in the case of irrigated rice, which covers about 70 % of the Philippine rice growing area and which has a steadily increasing share (PHILRICE-BAS, 2004). Many rainfed rice environments have been converted over time due to new irrigation facilities like shallow tube wells (David, 2003). The present study showed neither ascending nor descending trends in potential yields. Thus, for the selected time span and localities, no apparent climate change or effects of climate variability on the potential yield can be concluded. Peng *et al.* (2004) used data from a long-term experiment in Laguna province and observed a trend of decreasing yields for the period 1979–2003. This yield decline was reportedly associated with an increasing nighttime (minimum) temperature. This report was discussed by Sheehy *et al.* (2006) who suggested that although raising minimum temperature could affect rice yield due to higher respiration rates at night, it might

Table 2: *Means across years (1985-2002) of simulated potential and measured actual rice yield and yield gaps in six Philippine provinces for the dry (DS) and wet (WS) seasons.*

Provinces	Potential yield DS		Potential yield WS	Actual yield DS		Actual yield WS	Yield gap DS		Yield gap WS
	(Mg ha^{-1})								
Isabela	9.27	**	6.22	3.74	ns	3.56	5.54	**	2.66
Laguna	7.45	*	5.68	3.98	ns	3.60	3.47	*	2.08
Nueva Ecija	8.33	**	5.82	4.41	**	3.02	3.91	*	2.81
Camarines Sur	6.55	ns	5.79	2.59	ns	2.48	3.96	ns	3.31
Iloilo	9.98	*	8.16	2.86	*	2.39	7.12	*	5.77
North Cotabato	9.64	ns	9.91	3.40	ns	3.26	6.24	ns	6.65
LSD (0.05)	*0.82*		*0.93*	*0.34*		*0.37*	*0.88*		*0.91*

DS: dry season; WS: wet season
ns: not significant; *,** significant at 5 and 1%, respectively
LSD: Least significant difference

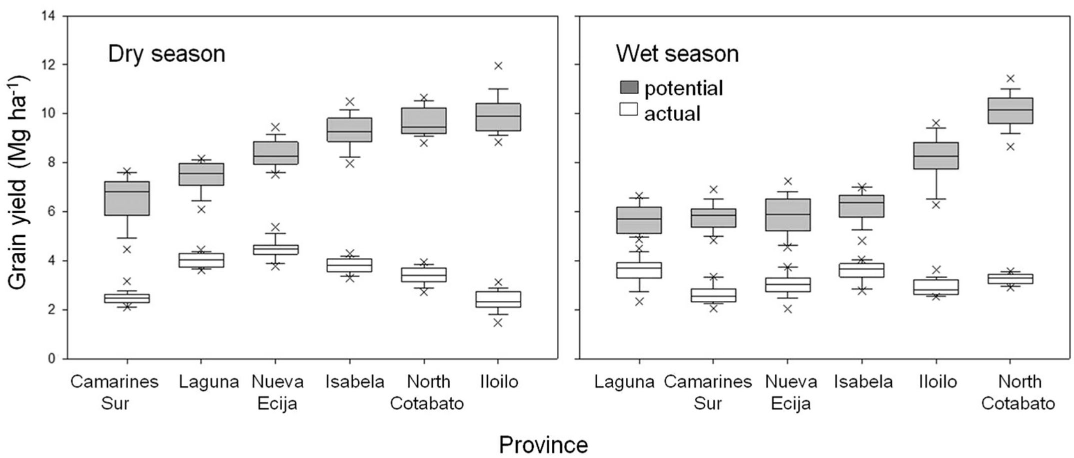

Fig. 3: *Variability of actual (grey boxes) and simulated (white boxes) rice yield (in* Mg ha^{-1}*) between seasons and localities in six Philippine provinces for the period from 1985 to 2002.*

be inadequate to use a simple correlation to detach the effects of minimum temperature from the influence of maximum and mean temperature and solar radiation. Both studies recommend that crop models should consider separately minimum and maximum temperatures to calculate possible yield constrains. Hence, the potential yields in the present study might have been calculated overlooking the effects of minimum temperature because ORYZA2000 aggregates maximum and minimum temperature to calculate phenological development (Bouman *et al.*, 2001).

Considering that solar radiation plays a key role as driving factor of potential grain yield in ORYZA2000, the variability of potential yields between years is likely to reflect the variability of solar radiation. In the modeling analysis, however, potential yield and solar radiation can be only partially correlated as in the process of simulation ORYZA2000 aggregates the effects of solar radiation and temperature (Bouman *et al.*, 2001). While no general linear correlation can be established between radiation and yield, two exceptional cases were observed in the years 1988 and 1991 (Figure 2). The observed decline of solar radiation in the dry season of 1988 was associated with unusual high precipitation as a consequence of a La Niña phenomenon (Jose *et al.*, 1996). As a consequence, the calculated yield potential was reduced across all provinces in 1988. A similar yield reduction was observed in 1991. It was again related to reduced solar radiation levels following the eruption of Mount Pinatubo. This affected the simulated yield in both seasons and in all provinces except for Isabela in the wet season (Figure 2).

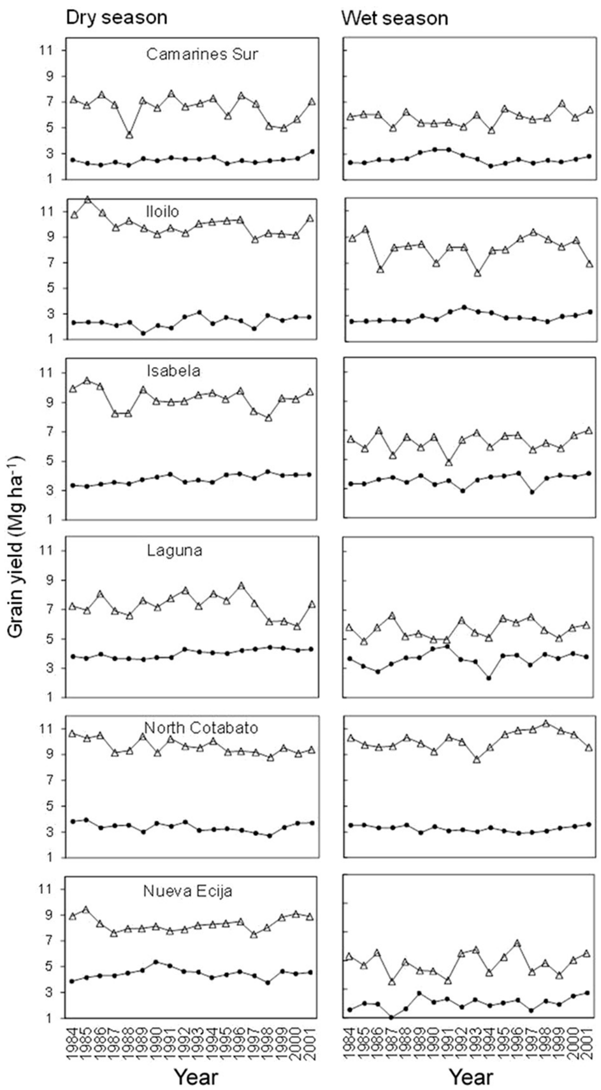

Fig. 4: *Variability of measured (•) and simulated potential (△) yield of irrigated lowland rice in six selected provinces of the Philippines for the dry and the wet season for the period 1985 – 2002.*

4.2 *Variability of actual rice yields*

The trends of actual yields showed little relation to the observed year-to-year variability in climatic factors or to the simulated potential yields. However, actual yield statistics reflected a clear inter-seasonal pattern with generally higher yields in the dry than in the wet season. This seasonal aspect can be ascribed to higher solar radiation in the dry season, particularly in the provinces of Nueva Ecija, Laguna and Isabela. North Cotabato, on the other hand, is located in the humid forest agroecological zone with little apparent seasonality and shows only 0.14 Mg ha^{-1} of difference between the dry and the wet season. With the exception of the seasonality, the variability of the climate (and accordingly of the simulated yield potential) between years and provinces was by far higher than that of the actual yields. Hansen & Jones (2000) indicated that climate data in regional or (in our case provincial) level are commonly calculated by averaging and aggregating the climatic factors in a smaller plot to be translated into regional data. The effect of the mentioned aggregation is likely to affect the accuracy of observations of the real climatic effect on a hyper-plot scale. The observed variations in the actual yields could thus not be linked to climate or yield potential and were rather ascribed to differences in the production conditions between provinces related to differences in resource base quality (soil type), markets and infrastructure and access to extension services. Similar observations were made by Herdt & Wickham (1978) in an analysis of yield gaps in Philippine rice production. In general, we observed a tendency of higher production levels in those provinces which are (1) closer to the supply and commercialization centers with good infrastructure and access to extension, and (2) are characterized by more fertile soils (Laguna and Nueva Ecija).

4.3 *Gaps between actual and potential yield*

The yield gap analysis is generally recognized as a tool to prioritize and target research interventions (FAO, 2004). Thus the extent of the gap between the actual and the potential yield can be indicative of farmer's resource base quality and technicity level in a given environment (Becker *et al.*, 2003; Neumann *et al.*, 2010). The accuracy of the yield gap estimates are largely determined by the accuracy of predicting the yield potential. Such predictions are in the case of ORYZA2000 cultivar-specific. In the present case, we used the input parameters of cultivar IR64. While this cultivar is still widely cultivated in parts of Asia (Launio *et al.*, 2008), farmers in the Philippines use mainly more recently released cultivars such as IR72. Hence, it cannot be excluded that the calculated yield gaps present either under- or overestimations. In addition, the climate information for calculating potential yields was obtained from spot data, usually in the centre of each province, thus not reflecting a possibly larger intra-provincial variation.

The lowest yield gaps were found in the provinces of Laguna and Nueva Ecija. Among other factors, the presence of the International Rice Research Institute (IRRI) in Laguna and the Philippine Rice Institue (PHILRice) in Nueva Ecija may provide farmers in these two provinces with more opportunities to access the new cultivars and technology options to overcome non-climatic production constraints. In addition, the soils in these provinces are dominated by young volcanic clay Inceptisols or Mollisols (see Table 1), providing relatively fertile conditions. On the other hand, largest yield gaps occurred in remote areas and were further associated with less favorable soil conditions. We may conclude that the extent of the reported yield gaps could not be attributed to climatic factors, but were rather linked to resource base quality, and to access to inputs and know-how.

5 Conclusions

While climate change phenomena have been reported for the Philippines, these do not appear to have affected the yield of irrigated rice during the past 20 years. The observed trends and the variability in climatic conditions between years, season and provinces could not be linked to long-term trends in the potential yields. The variability of actual yields was much lower than that of simulated potential yields. The extent of the resulting yield gaps was ascribed to soil and management factors rather than to climatic factors.

References

Becker, M., Johnson, D. E., Wopereis, M. S. C. & Sow, A. (2003). Rice yield gaps in irrigated systems along an agro-ecological gradient in West Africa. *Journal of Plant Nutrition and Soil Science*, 166, 61–67.

Boling, A. A., Bouman, B. A. M., Tuong, T. P., Murty, M. V. R. & Jatmiko, S. Y. (2007). Modeling the effect of groundwater depth on yield-increasing interventions in rain fed lowland rice in Central Java, Indonesia. *Agricultural Systems*, 92, 115–139.

Bouman, B. A. M., Kropff, M. J., Tuong, T. P., Wopereis, M. C. S., Ten Berge, H. F. M. & Van Laar, H. H. (2001). *ORYZA2000: Modelling Lowland Rice*. International Rice Research Institute, Los Banos, Philippines.

David, W. (2003). *Averting the water crisis in Agriculture; Policy and Program Framework for Irrigation Development in the Philippines*. University of the Philippines Press, Diliman, Quezon City, The Philippines.

Dawe, D. & Dobermann, A. (1999). *Defining productivity and yield*. International Rice Research Institute, Manila, The Philippines.

FAO (2004). Rice and narrowing the yield gap. Food and Agriculture Organization of the United Nations - FAO. URL `http://www.fao.org/rice2004/en/f-sheet/factsheet5.pdf`.

Hansen, J. W. & Jones, J. W. (2000). Scaling-up crop models for climate variability applications. *Agricultural Systems*, 65, 43–72.

Herdt, R. W. & Wickham, T. H. (1978). Exploring the gap between Potential and Actual Rice Yields in the Philippines. In International Rice Research Institute (Ed.), *Economic Consequences of the New Rice Technology* (pp. 3–24). IRRI, Los Baños, The Philippines.

Jose, A. M., Francisco, R. V. & Cruz, N. A. (1996). A study on impact of climate variability/change on water resources in the Philippines. *Chemosphere*, 33, 1687–1704.

Lansigan, F. P., de los Santos, W. L. & Coladilla, J. L. O. (2000). Agronomic impacts of climate variability on rice production in the Philippines. *Agricultural Ecosystems and Environment*, 82, 129–137.

Launio, C. C., Redondo, G. O., Beltran, J. C. & Morooka, Y. (2008). Adoption and Spatial Diversity of Later Generation Modern Rice Varieties in the Philippines. *Agronomy Journal*, 100, 1380–1389.

Maclean, J. L., Dawe, D. C., Hardy, B. & Hettel, G. P. (2002). *Rice almanac*. CABI Publishing, Wallingford, UK.

NASA (2004). Climatology Resource for Agroclimatology; Daily Averaged Data Evaluation Version. National Aeronautics and Space Administration - NASA. URL `http://earth-www.larc.nasa.gov/cgi-bin/cgiwrap/solar/agro.cgi`.

Neumann, K., Verburg, P., Stehfest, E. & Müller, C. (2010). The yield gap of global grain production: A spatial analysis. *Agricultural Systems*, 103, 316–326.

Peng, S. B., Huang, J. L., Sheehy, J. E., Laza, R. C., Visperas, R. M., Zhong, X. H., Centeno, G. S., Khush, G. S. & Cassman, K. G. (2004). Rice yields decline with higher night temperature from global warming. *PNAS - Proceedings of the National Academy of Sciences of the United States of America*, 101 (27), 9971–9975. URL `http://www.pnas.org/content/101/27/9971`.

PHILRICE-BAS (2004). PRS-Philippine Rice Statistics 1970-2002. Philippine Rice Research Institute, PHILRICE and Bureau of Agricultural Statistics BAS, Manila, The Philippines.

PHILRICE-BAS (2007). Rice-based Farm House Halt Survey (RBFHS) for dry and rainy season in the years 1996-1997, 2001-2002, 2006-2007. Philippine Rice Institute and Bureau of Agricultural Statistics of the Philippines, Manila, The Philippines.

Sheehy, J. E., Mitchell, P. L. & Ferrer, A. B. (2006). Decline in rice grain yields with temperature: Models and correlations can give different estimates. *Field Crops Research*, 98, 151–156.

Tubiello, F. N. & Fischer, G. (2007). Reducing Climate Change Impacts on Agriculture: Global and Regional Effects of Mitigation 2000 to 2080. *Technological Forecasting and Social Change*, 74, 1030–1056.

Wassmann, R., Jagadish, S. V. K., Heuer, S., Ismail, A., Redona, E., Serraj, R., Singh, R. K., Howell, G., Pathak, H. & Sumfleth, K. (2009). Climate Change Affecting Rice Production: The Physiological and Agronomic Basis for Possible Adaptation Strategies. *Advances in Agronomy*, 101, 59–122.