6 Climate Change Impacts and Adaptation in Agricultural Water Management in the Philippines

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Abstract

Climate change is now a reality and is expected to have profound impacts on agricultural production systems, thus threatening food security. Local observational evidence of changing climate based on available historical weather data-sets is presented for selected locations in the Philippines. In this study, plausible climate scenarios and downscaled climate projections for representative crop production areas are discussed. Results of downscaling of climate projections for 2020, 2050 and 2080 using a dynamic downscaling procedure and a statistical downscaling method are presented and compared. Impacts of climate change and variability on crop productivity and production systems in selected crop-growing areas in the country are presented. Crop yields using a calibrated crop simulation model for a standard rice variety (IR-64) and a local maize variety (IPB-911) for projected climate were determined. Results indicate a reduction from 8% to 14% in crop yields per 1°C temperature increase depending on season and location. Some adaptation strategies related to agricultural water management to minimize the adverse effects and impacts of climate change are described. These location-specific measures based on best practices include adjusting the planting calendar, improving water use efficiency and irrigation water management, water impoundment, planting stress-tolerant varieties, and weather index-based insurance for crop production.

6.1 Climate Change and Climate Variability in the Philippines

6.1.1 Introduction

Global climate variability influences the local weather systems that exhibit spatial and temporal variation in specific areas. Local weather systems and climate affect the hydrologic regimes in watersheds, agricultural production systems, livelihoods and other socio-economic activities. In recent years, it has been demonstrated that long- and short-term climate variabilities, such as the global El Niño Southern Oscillation (ENSO) episodes, are highly correlated with seasonal climate variability in an area. ENSO events as represented by the sea surface temperature anomaly (SSTA) over the Niño 3.4 Region (i.e. bounded by the 5°N–5°S latitude, and 120°W–170°W longitude), for example, have been associated with the seasonal climate in some countries in Asia such as Indonesia and the Philippines (Naylor *et al*., 2001; SEARCA and FAO, 2010). The degree of relationships of SSTA with rainfall for different locations in the country ranges from weak to moderate during different periods within the year. Nevertheless, the degree of correlation warrants consideration of using climate information for advanced planning of hydrological and agricultural activities.

Since the ENSO signals at the Niño 3.4 Region are highly correlated with the local weather systems prevailing in the Philippines

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3–6 months ahead, advanced climate information can be used to predict the expected seasonal climate in the Philippines. Agricultural crop production in the Philippines is highly correlated with the climate variability as reflected by the high correlation of SSTA with crop production area planted and yield (SEARCA and FAO, 2010). Thus, agricultural production activities such as determining what crops to grow, when and where to best plant the crops, the frequency and timing of irrigation, and also fertilizer application can be planned.

Climate change is now a reality. There is now growing observational evidence at the global, regional and local levels to support that climate has changed (Alcamo *et al*., 2005; IPCC, 2007; Lansigan, 2009; Comiso *et al*., 2014). With climate change are found the shifts not only in the mean but also in the variance of climate variables such as temperature and precipitation as well as in the corresponding magnitudes and occurrences of extreme events such as dry and wet episodes. Climate change and climate variability have profound effects and impacts on food production systems, ecosystem stability and socio-economic activities. Responses to climate change in the context of water management in crop production range from growing stress-tolerant rice varieties, adjusting the planting calendar and adoption of weather insurance. Thus, this chapter presents some local observational evidence of changing climate in the Philippines, describes the effects and impacts of climate change on crop production, and also discusses some climate adaptation measures related to agricultural water management in crop production.

6.1.2 Local observational evidence of changing climate in the Philippines

There is increasing local evidence based on historical weather and climate data that climate change is now occurring in the Philippines. A recent study of PAGASA (2011) analysed the trends in climate data based on historical records in a number of weather gauging stations in the country. Figure 6.1 shows the general trends in extreme daily temperature in a number of locations in the Philippines from 1951 to 2008. Warm nights and hot days are generally increasing. Climate data show that over the span of 60 years the mean temperature in the archipelago has increased by 0.65°C from 1951 to 2010. Climate change has also brought erratic and changing rainfall patterns characterized by more intense extreme rainfall events. Figure 6.2 shows the general observed trends in extreme rainfall intensity in a number of locations based on the amount of rainfall exceeding the highest four rain events in the year. While the increases in frequency as well as in the intensity of extreme rainfall events are already being experienced in many areas, the observed changes are not statistically significant (PAGASA, 2011). In recent years, however, changes in rainfall patterns in many locations, particularly in crop-growing areas, have been observed necessitating the adjustments in planting dates and other farm operations.

Using the historical records of annual maximum daily rainfall in Los Baños, Philippines (for location see Fig. 6.3) for two time periods, 1959–1978 and 1979–2006, the frequency distribution as shown in Fig. 6.4 has changed. During the earlier period (1959–1978) annual extreme daily rainfall events tended to be uniformly distributed. The later period (1979–2006) shows increased frequency of average maximum daily rainfall plus the occurrence of the more recent extreme daily rainfall event (348 mm), which led to floods resulting in loss of lives and damage to property and livelihoods. Historical data also in Los Baños indicated that minimum daily temperature has significantly increased by 1.27°C over the span of 27 years although the maximum daily temperature has not shown a significant trend. The increase in minimum temperature is a significant factor in the reduced rice yields in the area since the photosynthetic activity of the crop will be affected.

Moreover, the analysis of historical climate data available in Legazpi City, Albay Province (for location see Fig. 6.3) also shows that monthly mean minimum

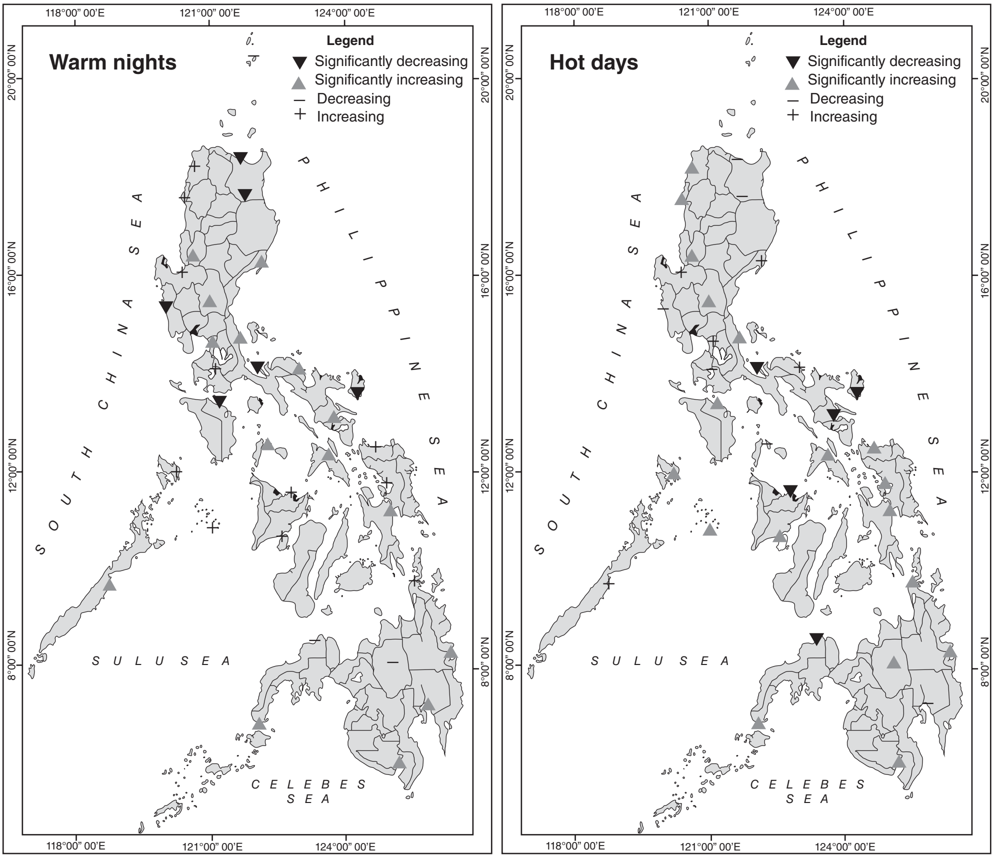


Fig. 6.1. Observed trends in extreme daily temperature in the Philippines based on historical weather records from 1951–2008 (from PAGASA, 2011).

temperature had increased significantly as presented in Fig. 6.5. Similar trends in the analysis of climate variables such as the number of wet days and dry days, the number of days exceeding rainfall threshold levels, the number of hot days and warm nights, etc. have also been observed in other areas in the country with reasonably adequate historical records (Lansigan, 2011a).

6.1.3 Climate change scenarios and projections

General circulation models (GCMs) have been used to project future climate conditions in terms of changes in precipitation and temperature patterns at the global level (IPCC, 2001). Future climates were predicted based on a number of assumptions in terms of the pathways of greenhouse gas (GHG) emissions. These pathways are defined by projected economic development, population growth and human activities. It should be noted that while the Special Report on Emissions Scenarios (SRES) climate scenarios have been widely used, in recent years there has been a new initiative by climate scientists to produce more plausible future climate scenarios based on the so-called Representative Concentration Pathways (RCPs) that determine GHG emissions from human activities (Moss *et al*., 2010). Producing future climate projections involves integrated assessments considering the main features and facets of human systems, climate and Earth-system models, and impact assessments with a focus on adaptation and

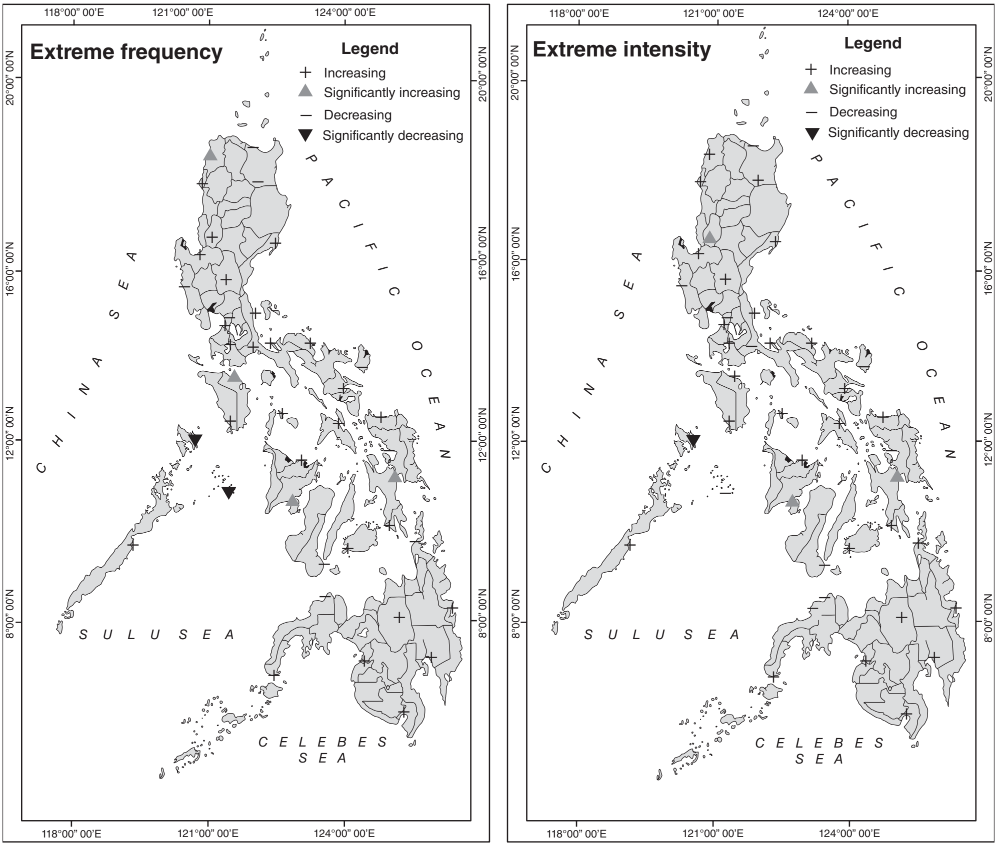


Fig. 6.2. Observed trends in extreme daily rainfall intensity in the Philippines based on historical weather records from 1951–2008 (from PAGASA, 2011).

vulnerability to climate change (Gaffney, 2010). However, there is uncertainty on which model and climate scenario would adequately represent the future climate.

Figure 6.6 shows the observed and the projected climate change in the Philippines in terms of mean temperature for the baseline period (1971–2000), for 2020, 2050 and 2100 for two SRES climate scenarios, namely the medium-range emission scenario (A1B), and the high-range emission scenario (A2) from PAGASA (2011). There is already an observed change of 0.65°C in mean temperature over the span of 60 years from 1951 to 2010. Increase in average temperature is expected to range from 1.0 to 3.1°C and from 0.7°C to 3.4°C for the period 2020 to 2100 under the A1B and A2 scenarios, respectively.

On the other hand, seasonal change in mean rainfall in the Philippines shows wide spatial variability across locations. The dry months are expected to be drier and the wet months wetter. This has important implications in terms of availability and dependability of water from rainfall, particularly for rainfed agriculture.

6.1.4 Downscaled climate projections in the Philippines using PRECIS and SDSM

GCM climate projections, however, are not directly useful for national and local studies such as vulnerability assessments, hydrologic frequency and risks analyses, and impact assessments (IPCC, 2012). The spatial resolution of GCM data is too coarse

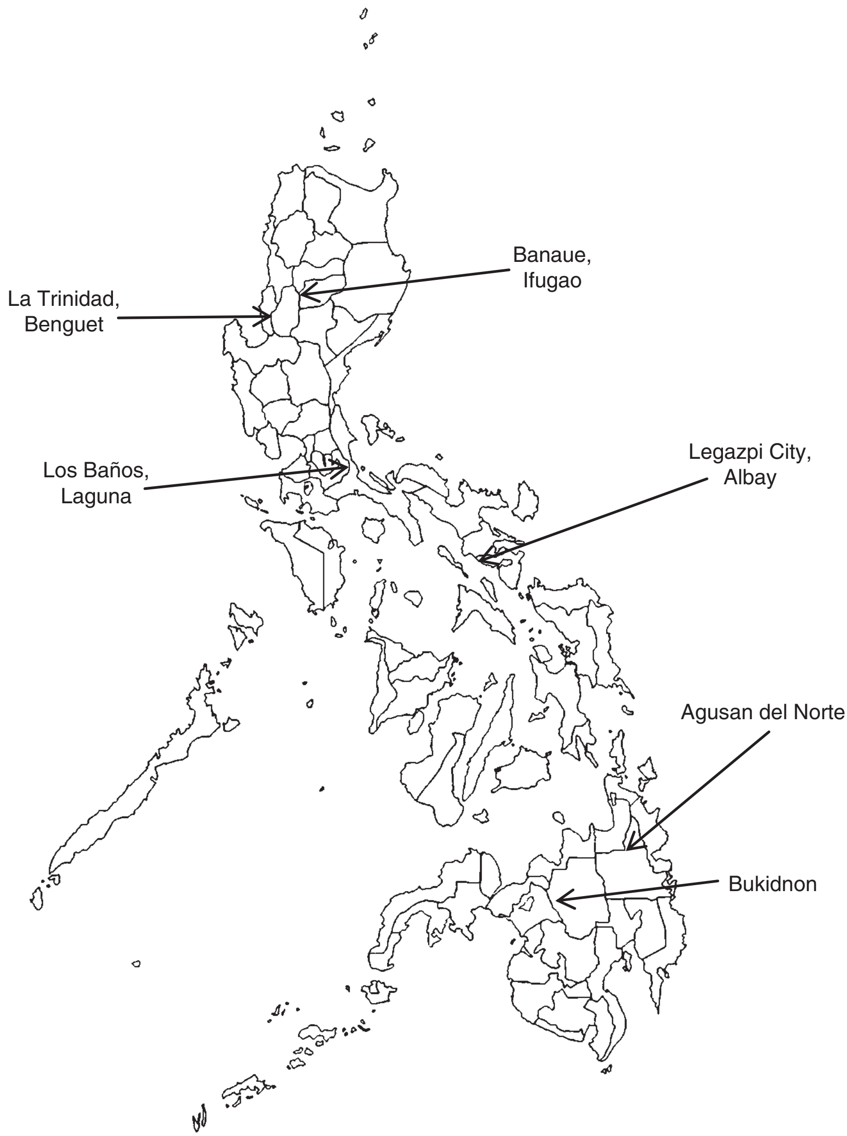


Fig. 6.3. Location map of the different sites in the Philippines considered in the study.

(typically 50,000 km^2) and does not reflect the spatial variability across different locations within the country. While the Philippines has different climatic types, the GCMs considering their coarse resolution, however, provide only one climate projection for the entire country ignoring the local climate variability, i.e. the country is treated as one homogeneous spatial entity.

Thus, downscaling procedures are needed to derive the local-scale surface weather conditions given the regional-scale atmospheric predictor variables used in the global and regional scale models (Wilby and Dawson, 2007). That is, downscaling climate projections is a method used to obtain high-resolution climate information at the scale of 50 km × 50 km or less from the relatively

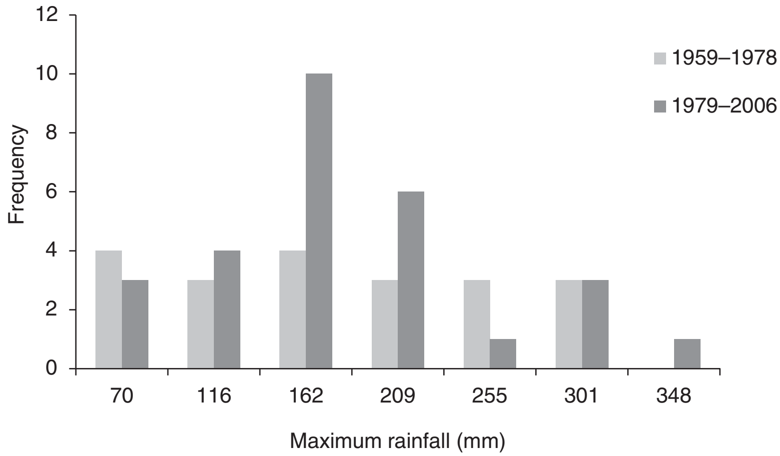


Fig. 6.4. Distribution of annual maximum daily rainfall in Los Baños, Laguna, Philippines during two time periods, 1959–1978 and 1979–2006 (from Lansigan, 2009).

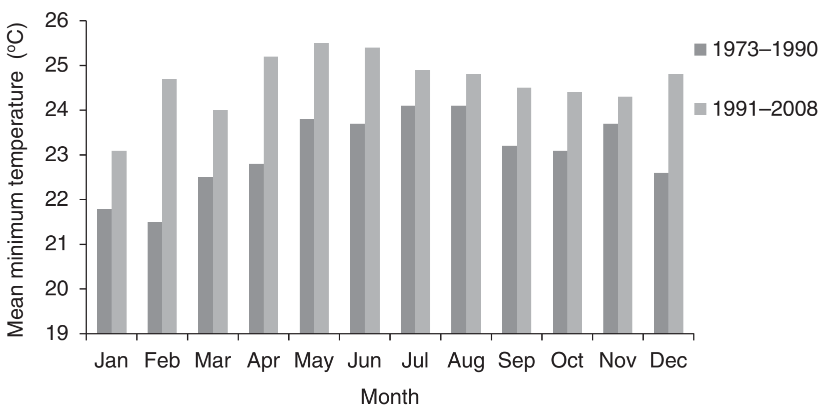
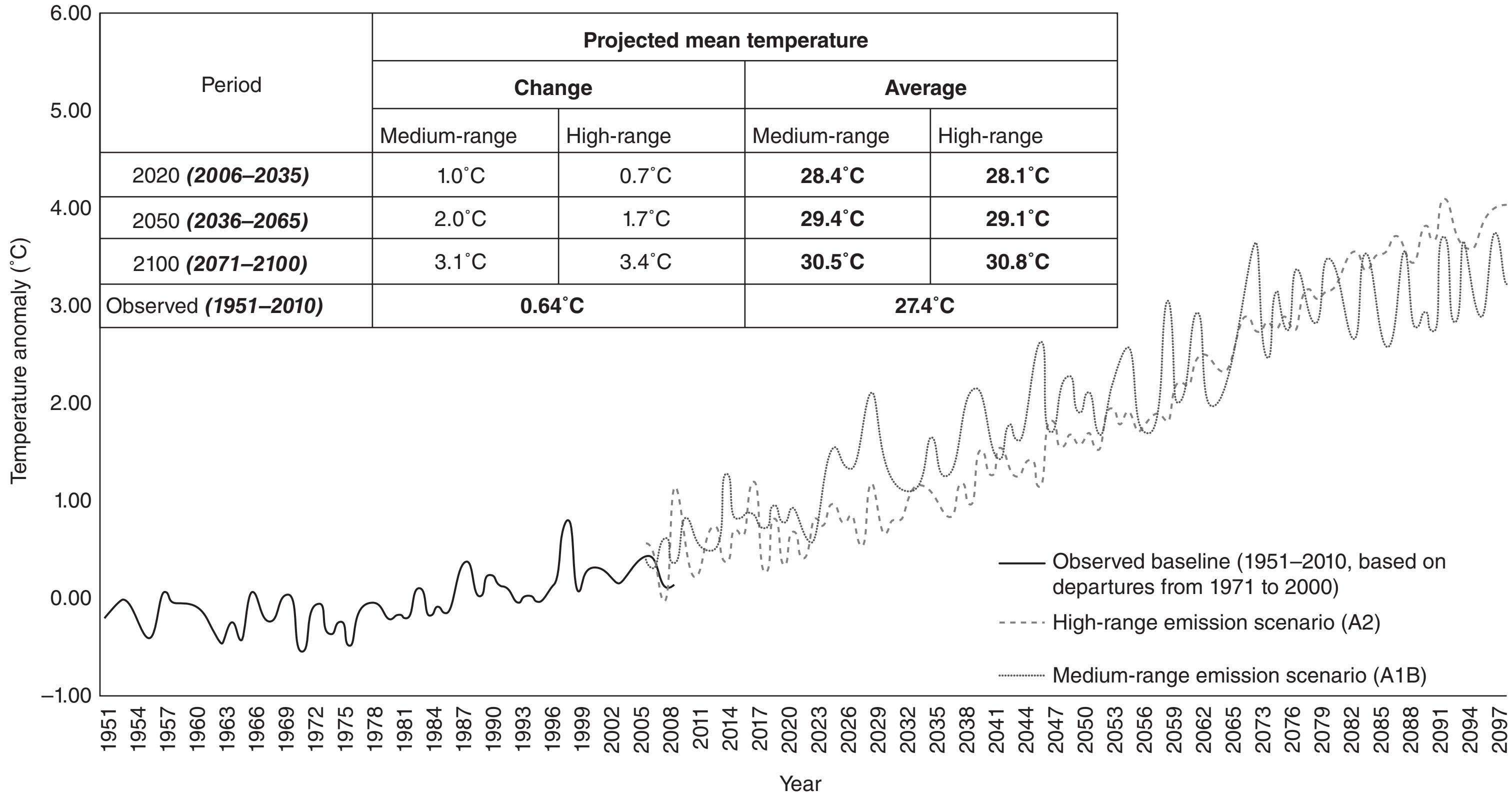


Fig. 6.5. Monthly mean minimum temperature in Legazpi City, Philippines from 1973–1990 and 1991–2008 (from PAGASA, 2011).

coarse-resolution global models such as the GCMs (Anderson, 2008).

There are two types of downscaling procedures, the dynamical downscaling method and the statistical downscaling technique. Dynamic approaches such as regional models (e.g. PRECIS, Providing Regional Climate for Impacts Studies) simulate the interactions between the atmosphere, oceans and land processes at the regional level. It also requires high speed and large memory computing facilities not commonly available in developing countries as well as the need for more intensive training of model users. On the other hand, statistical techniques are based on sound and robust statistical theories and methods that try to capture and mimic the observed relationships between the prediction and the predictors for a given location. Each of these groups of procedures has inherent advantages and limitations with respect to data and information requirements, skills and expertise needed, and facilities to be used.

Dynamic downscaling method uses a limited-area, high-resolution model such as regional climate models (RCMs) driven by boundary conditions from a GCM, to derive



Period	Projected mean temperature			
	Change		Average	
	Medium-range	High-range	Medium-range	High-range
2020 ***(2006–2035)***	1.0°C	0.7°C	**28.4°C**	**28.1°C**
2050 ***(2036–2065)***	2.0°C	1.7°C	**29.4°C**	**29.1°C**
2100 ***(2071–2100)***	3.1°C	3.4°C	**30.5°C**	**30.8°C**
Observed ***(1951–2010)***	**0.64°C**		**27.4°C**	

Fig. 6.6. Historical (observed) and projected annual mean temperature anomalies for the Philippines from 1951 to 2100-based departures from 1971 to 2000 normal values (from PAGASA, 2011).

smaller-scale information. RCMs generally have a domain area of 106 to 107 km^2 and a resolution of 20 to 60 km. An example of a dynamic downscaling approach is the PRECIS (Providing Regional Climates for Impact Studies) model used by PAGASA (2011) to generate climate projections for different provinces in the Philippines. However, regional climate models such as PRECIS are computationally demanding and require intensive training on the use of the model.

Recent studies (e.g. Wilby and Dawson, 2007; Lansigan *et al*., 2013) using a statistical downscaling method to generate finer resolution climate projections for 2020, 2050 and 2080 show that results of statistical downscaling are quite comparable with the downscaled climate projections generated by PAGASA (2011) using the PRECIS model as shown in Fig. 6.7. Statistically downscaled information was used in the Philippines for impact assessments on the hydrology of the watershed (Delfino *et al*., 2012), on the frequency analysis of episodes of wet and dry days, agricultural planning, and on impact assessment on crop productivity (Lansigan and Dating, 2012; Lansigan *et al*., 2013). Results obtained are comparable in terms of average values, variance and extreme events considering the trade-offs in terms of computing facilities needed and training required to apply the dynamic downscaling approach.

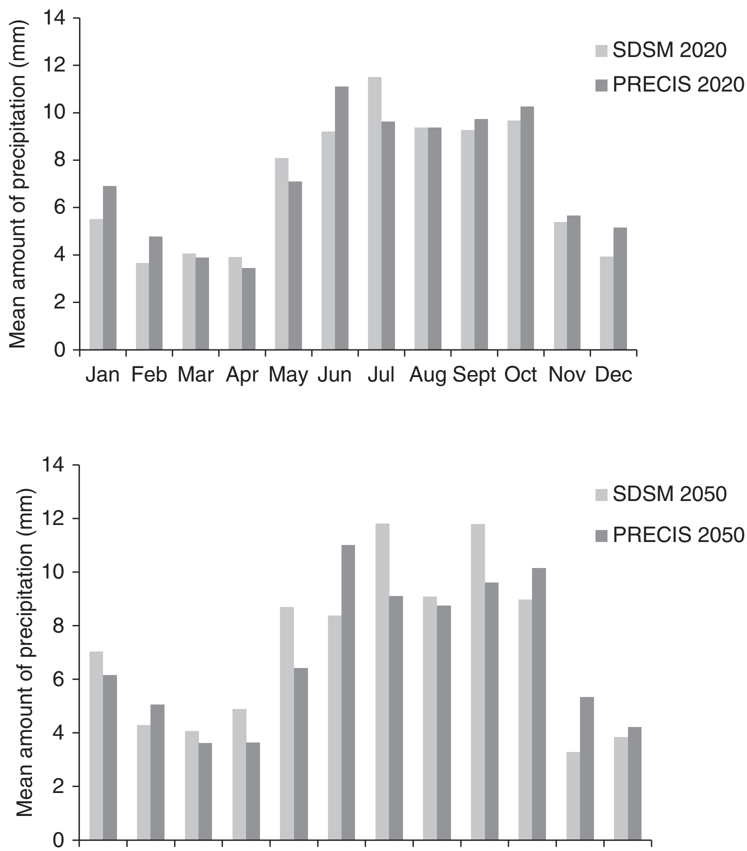


Fig. 6.7. Comparisons of downscaled monthly mean daily rainfall (mm) in Malaybalay, Bukidnon, Philippines for 2020 and 2050 using SDSM and PRECIS (from Lansigan and Dating, 2012).

6.2 Climate Change Effects and Impacts on Agricultural Production

6.2.1 Increased temperature due to global warming

Changes in distributions of climate variables such as rainfall and temperature have profound impacts on agricultural production systems. Climate change affects agricultural crop production through the following processes: (i) increased atmospheric temperature or global warming; (ii) erratic and changing rainfall patterns; (iii) occurrence of extreme events such as more intense rainfall, and typhoons with strong winds; and (iv) sea-level rise.

Temperature gradient tunnel studies, field experiments and crop simulation studies have shown that increased temperature in crop production in the Philippines as well as in many areas in South-east Asia will reduce crop yields. Studies have shown that potential crop yields will be reduced from about 8% to 14% for every 1°C increase in ambient temperature depending on location due to specific climate type. While increased carbon dioxide (CO_2) concentration in the atmosphere will enhance the photosynthetic activity of the plant, and therefore increases crop yields, studies have shown that CO_2 enrichment cannot compensate for the increased maintenance of respiration due to increased temperature, resulting in decreased grain yields.

6.2.2 Erratic and variable rainfall patterns

Changing rainfall distributions have altered the planting calendar in many areas. In certain areas in the country, summer months (March, April, May) have become wetter and wet season (June, July, and August) has become drier. Planting date has to be adjusted considering the variability in rainfall in the area. For example, cropping calendar or planting date may be determined based on rainfall patterns. Optimal planting can be determined using rainfall probabilities, crop yield probabilities determined by crop models, or the use of the modified Penman–Monteith equation considering rainfall distribution and evaporative demand for crop growth. Using the downscaled climate projections for different periods in selected locations, optimal planting dates based on high rainfall probabilities may be derived. Crops have different water requirements for each stage of crop growth and development (Penning de Vries *et al.*, 1989) to give optimal yields. For rainfed crop production systems, water is mainly from rainfall whose availability and temporal variability determine the optimal planting date. Location-specific probabilities are considered, namely: P_w, probability of wet soil ready for planting; P_{200}, probability of at least 200 mm cumulative rainfall during flowering stage; and P_d, probability of a dry period during harvesting (Lansigan, 2010b). Combining these probabilities of meeting the water requirements at different stages of growth by taking their product is the Q probability (i.e. $Q = P_w \times P_{200} \times P_d$) of satisfying the rainfall requirements. Thus the period during which Q probability is high is the best planting date.

Figure 6.8 shows the combined probability Q for Malaybalay, Bukidnon (for location see Fig. 6.3) for different time periods based on the downscaled climate projections using SDSM. The plot shows that the duration of optimal planting date from the baseline period (1971–2000) to 2020 is shifted and shortened. The low probabilities in 2050 indicate the high risk of planting in the periods during which rainfall may not be sufficient to meet the water demand for crop growth. The low probabilities in 2050 may be attributed to the expected large variability of rainfall compared to baseline and 2020. Thus, there is low probability of meeting the water requirements. On the other hand, Fig. 6.9 shows the date and duration of optimal planting for Iloilo, which remain within the same period but the combined probability Q ($P_w \times P_{200} \times P_d$) has increased under the projected climate. The best planting period remains the same but with higher probability of meeting water requirements during different stages of crop growth than for 2020. Thus, the erratic rainfall patterns in many crop-growing areas remain a challenge to farmers in deciding the best time to plant.

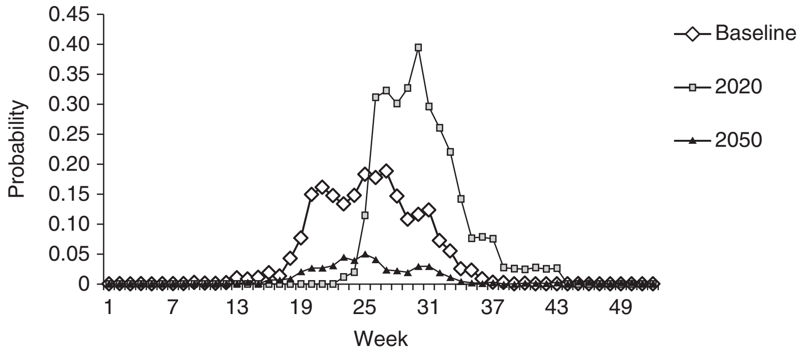


Fig. 6.8. Comparison of the combined probability Q of meeting rainfall requirements for the different crop growth and development stages for the baseline, 2020 and 2050 in Malaybalay, Bukidnon, Philippines.

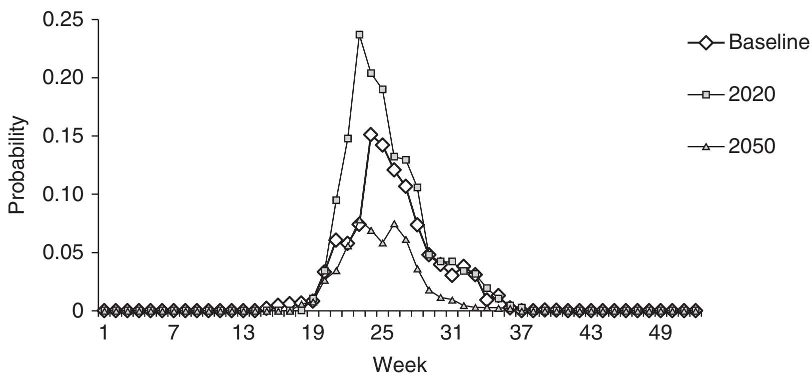


Fig. 6.9. Comparison of the combined probability Q of meeting rainfall requirements for the different crop growth and development stages for the baseline, 2020 and 2050 in Iloilo, Philippines.

6.2.3 More intense extreme climate events

Climate change is expected to result from the disproportionate increase in the mean and variance of climate variables. The percentage change in the mean as well as in the variance of climate variables such as rainfall and temperature are not the same. More intense extreme events, such as more intense rainfall episodes, and hotter days and warmer nights are expected to occur more frequently. However, some downscaled seasonal climate variables do not show significant increase, which may be attributed to the different climate types in the Philippines. Typhoons characterized by more intense and heavy rains and strong winds with shorter recurrence intervals are also expected to occur (IPCC, 2007; PAGASA, 2011; IPCC, 2012). These often lead to floods that result in significant damage to crops and livestock, livelihoods, and even to loss of properties and lives. Damage to crops and livestock, livelihoods and properties exceed 100 million pesos (Php). In recent years, damages and losses have reached more than Php 1.0 bn per occurrence of a strong typhoon.

Historically, an average of 20 typhoons enter the Philippine Area of Responsibility (PAR), although between seven and eight typhoons make landfalls yearly (Yumul *et al*., 2011). Typhoons are observed to have a 27–35% chance of passing through central to northern Philippines and about a 5–7% chance of passing through the southern part of the country. A recent study (Schellnhuber *et al*., 2013) on climate scenarios and impacts reported that more intense typhoons are expected in southern Philippines. Thus, crop losses and damage are expected to be high in areas that will be visited by more intense typhoons. Damaging typhoons are expected to significantly affect the gross domestic product (GDP) of the country, which is estimated to average about 4.7%.

6.2.4 Sea-level rise and saltwater intrusion

As high temperature warms the oceans, the sea level rises, inundating the crop-growing areas in the coastal regions. More intense and heavy rainfall events, in combination with high tides and sea-level rise, enhance saltwater intrusion in coastal areas. Thus, submergence and salinity stresses will affect crop growth and development and will reduce yields. The problem of salinity is expected to become even more significant in coastal and deltaic regions affected by sea-level rise. These areas are more exposed and vulnerable to sea-level rise associated with climate change. Salinity-tolerant crop varieties are needed in these coastal areas, since salinity affects the critical stages of crop growth and development especially during seedling and reproductive stages of the crops.

A vulnerability study of South-east Asian coastal areas (David *et al*., 2008) reported that up to 45,000 ha year^{-1} of land are lost due to submergence, up to 7.7 million people will actually face floods every year by 2100, and there will be a net loss of wetland areas of up to 32,000–435,000 ha due to sea-level rise. In the Philippines, coastal areas account for about 34,000 km^2, covering 804 cities and municipalities and 23,492 *barangays* (political villages). Thus, climate change will not only reduce crop productivity but decrease the areas planted to the crops due to inundation of coastal areas.

6.3 Assessing Impacts of Climate Change on Agricultural Crop Production

6.3.1 Crop model-based evaluation of climate change effects and impacts

The effects and impacts of climate change may be evaluated objectively using eco-physiological or process-based crop simulation models that can estimate crop yields under different climate conditions. These crop models require as inputs the crop genetic coefficients, crop management data and weather data for the specific location. A number of crop models such as DSSAT (Decision Support System for Agrotechnology Transfer) are available, which can be used provided the relevant assumptions are satisfied. The assumptions include the homogeneity of environmental conditions under a specific type of production situation being considered, e.g. potential production, water limited production, nutrient-limited production, etc.

6.3.2 Effects of climate change on major crops

Earlier studies (Matthews *et al*., 1997; Matthews and Stephens, 2002; Lansigan, 2003; Lansigan and Salvacion, 2007; Centeno and Wassmann, 2009) based on the use of crop models quantified the effects of climate change on crop yields. Figure 6.10 shows the changes in crop yields of major crops such as rice, maize, tomato and groundnut for varying temperature regimes in selected locations in the Philippines. The figures also show that reductions in yields vary depending on locations. Some crops such as C3-crops like rice (Lansigan and Salvacion, 2007) are more vulnerable to climate change than others.

Climate change is expected to reduce crop yields such as in rice crops. Figure 6.11 shows the yield probabilities for IR-64 rice variety planted on 8 May in Malaybalay, Bukidnon (for location see Fig. 6.3) for the baseline period and A1B projected

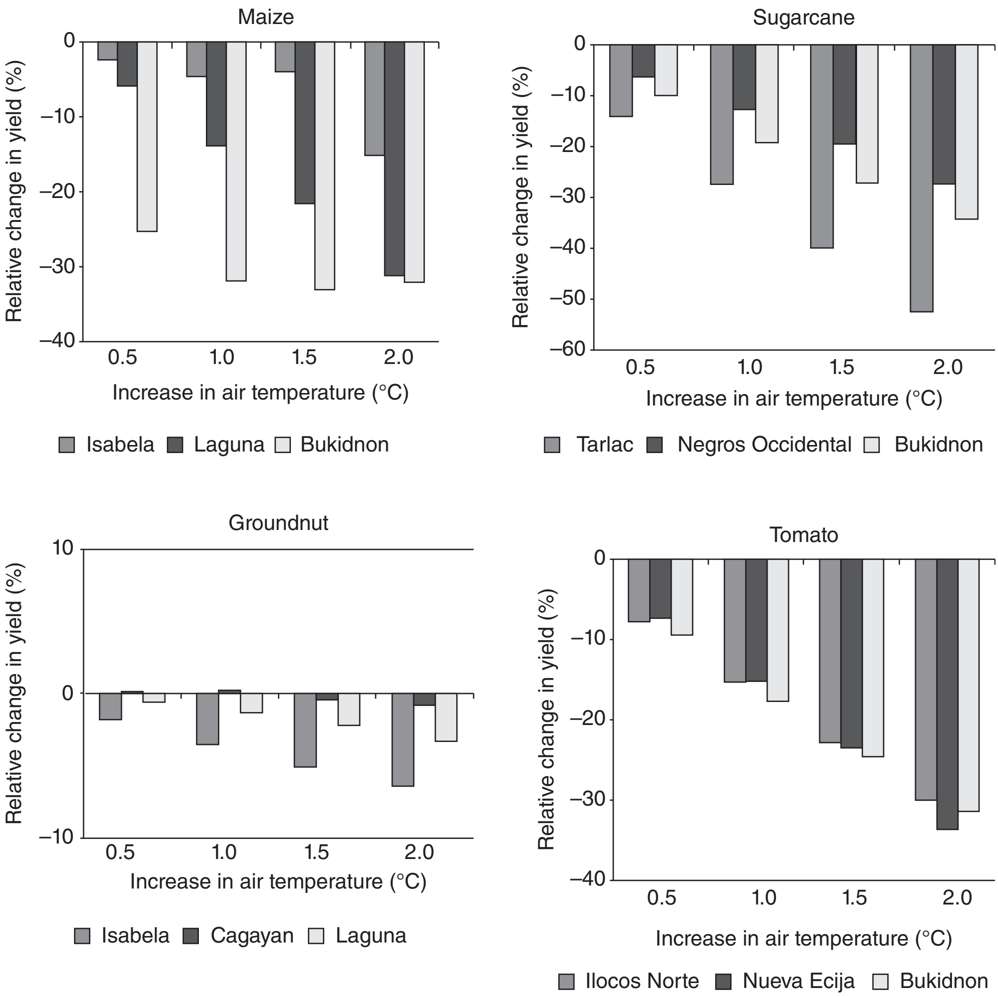


Fig. 6.10. Reduction in simulated crop yields of maize, sugarcane, groundnut and tomato for the projected temperature increase in selected locations in the Philippines (from Lansigan *et al.*, 2008).

temperature and rainfall in 2020 and 2050. The probability of exceeding particular rice yields decreases under projected climate change with the difference being very pronounced in the variety grown on 8 May. This shows the vulnerability of the rice crop to climate change as temperature increases.

Figure 6.12 shows the average rice yields in three locations (Agusan del Norte, Bukidnon and Benguet) in the Philippines (for location see Fig. 6.3) with different climate types and elevation for the baseline period (1971–2000) and under the climate projections for the periods centred on 2020 and 2050 (Lansigan, 2010a). Using the downscaled temperature and rainfall, crop productivity decreases as temperature increases due to climate change except in Benguet Province, which has a higher elevation and therefore a cooler climate. Thus, increase in temperature will benefit rice production in this area.

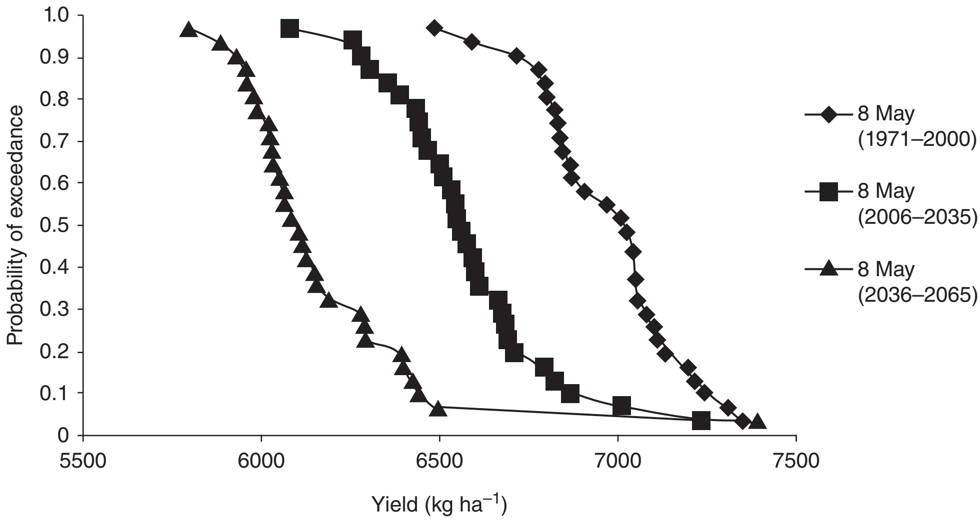


Fig. 6.11. Probabilities of exceedance of rice yields (IR-64 variety) during 8 May planting in Bukidnon, Philippines for the baseline period (1971–2000) and projected climate in 2020 (2006–2035) and 2050 (2036–2065).

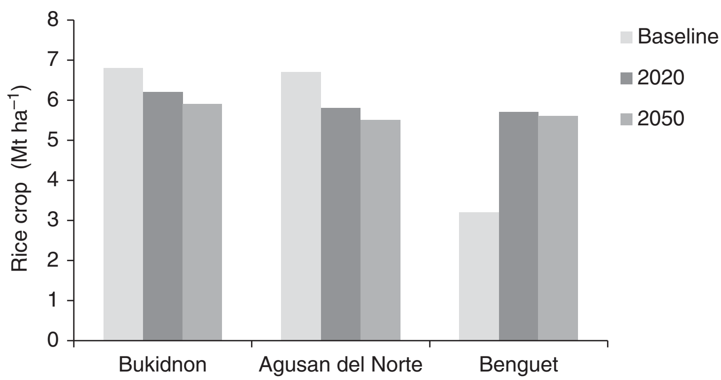


Fig. 6.12. Mean rice crop productivity in three locations in the Philippines (Bukidnon, Agusan del Norte and Benguet) under baseline (1971–2000), 2020 and 2050 projected climate.

6.4 Adaptation Strategies in Agricultural Water Management

There are a number of location-specific adaptation strategies and measures that may be applied to increase climate resilience. These measures are based on best practices in the area, which may be modified to suit local conditions. In crop production, for example, water-related adaptation strategies that may be used to reduce vulnerability to the adverse effects and impacts of changing climate include the following:

- Adjusting cropping calendar based on medium-range weather forecasts and seasonal climate outlook. The best planting window for the major crops may be determined using empirical procedures to estimate yield probabilities, and also frequencies of receiving rainfall threshold values critical in crop growth and development. A dynamic cropping calendar can be developed based on downscaled climate projections. Probabilities of receiving specified cumulative rainfall during the critical stages of crop growth can be determined (see Figs 6.8 and 6.9).

- Water impoundment. Storing water for use during periods with less rainfall is a common best practice in many rainfed areas in the Philippines. The impoundment structure can be made up of natural water impounding, or earth materials, or concrete. This is shown in Fig. 6.13 where rainwater during the wet season is harvested and impounded through a series of farm ponds, such as the example shown in Ifugao Province, Philippines. Stored water is used during the dry periods.
- Improving water use efficiency of irrigation and water management at the farm level. This can be achieved through intercropping or multiple cropping, and crop intensification to maximize the use of available soil moisture, and improved small-scale irrigation systems using shallow tube well (STW) technology. In recent years, it has been demonstrated that alternate wetting and drying (AWD) technology in rice production can improve water use efficiency and can also serve as a mitigating measure since it can reduce GHG emissions from the rice farms when fertilizers are applied in the field (Wassmann, 2010).
- Modifying crop management to reduce water use. This can be achieved through modifications of farm activities such as direct seeding, minimum tillage, and even growing an early-maturing variety which will consume less water. This also involves a shorter management period and less labour.
- Planting stress-tolerant crops or varieties. The adverse effects and impacts of climate change and variability can be reduced by planting crops or using varieties tolerant to environmental stresses such as submergence due to flooding, water stress due to droughts, salinity due to saltwater intrusion and heat stress due to temperature extremes. For example, the Sub-1 rice variety developed recently has been demonstrated to be flood- or submergence-tolerant. Likewise, rice varieties with the

Fig. 6.13. Rainwater harvesting and water impoundment through a series of farm ponds for fish and crop production in Lamut and upland areas of Alfonso Lista municipalities of Ifugao Province, Philippines.

Saltol salt-tolerant gene can withstand salinity.

- Terracing in steep and high-elevation areas. Rice terraces have been practised in many areas, particularly in high elevation areas to maximize area for crop production, reduce soil erosion and maximize water storage. Labour availability and environmental impacts are also considered, since these are important factors in the region where the rice terraces are found. Fig. 6.14a and Fig. 6.14b show the terraces for agroforestry and vegetable crops in Kiangan, and rice terraces in Banaue, Ifugao Province.
- Implementation of innovative agri-insurance for crop production. Crop insurance is one risk transfer mechanism that can be used to reduce vulnerability and risk due to climate-related hazards. They have to be made attractive and affordable to crop growers. Weather index-based insurance (WIBI) has been introduced recently. But development of WIBI products for different climate hazards requires the objective estimation of risks associated with different weather variables based on available historical records, which are often very limited and short, and with missing values. Moreover, an optimal network of weather gauging stations is needed for implementation of WIBI products. For example, Fig. 6.15 shows the risk associated with rainfall deficit for the different stages of growth for the 110-day rainfed rice crop variety PSB Rc14 grown in Iloilo, Philippines (Lansigan, 2013). The plot indicates the low risk-period during which the crop may be grown meeting the required cumulative rainfall for crop growth and development. This information can be used as the basis for developing an objective WIBI product, based on rainfall and also in estimation of premium, based on risk.

In practice, a suite of climate adaptation measures (Tibig and Lansigan, 2007; Asia Rice Foundation, 2010; Lansigan, 2011b) is being implemented in many areas in the Philippines to minimize the adverse effects and impacts to agricultural production systems and related activities. The best strategy is to reduce the vulnerability of the biophysical subsystems to climate-change hazards, and also to increase the resilience of the different stakeholders through a combination of adaptation options.

6.5 Concluding Remarks

Climate and weather are important factors in agricultural crop production. Climate change will lead to increased temperature and CO_2 concentration, sea-level rise and more intense extreme events. Climate change is also expected to alter the hydrologic regime affecting the availability of water supply. Thus, climate change reduces crop productivity and threatens food security.

Assessment of effects and impacts of climate change require the use of GCM climate projections, but they have to be downscaled to be useful for impact assessments using either a dynamic approach such as a regional climate model (e.g. PRECIS), or a statistical downscaling method (SDSM) including weather generator, historical analogue, etc. The use of statistical downscaling techniques gave reasonably adequate results compared to the more computationally demanding dynamic downscaling.

The use of a validated crop simulation model facilitates the objective evaluation of effects of climate change on rice crop yields. Crop variety-specific genetic coefficients, soils and weather data and cultural management practices are model inputs. The model can estimate (simulate) crop yields under any climate condition (e.g. projections). Simulation studies in selected locations show that rice yields are expected to decrease in low elevation areas but increase in high elevation (cool) rice-growing areas like Benguet (and Ifugao). Moreover, the magnitudes of rice yield decrease (in low-lying areas) or increase (in high-elevation areas) vary across locations and also with season (i.e. varying planting dates). Thus, the effects are location-specific and time-dependent.

Fig. 6.14. Terracing in a combination of agroforestry (upper level), vegetable (middle level) and rice (lower level) production systems in Kiangan, Ifugao Province, Philippines. (b) Newly transplanted seedlings in rice terraces of Banaue, Ifugao, Philippines.

Differences in effects and magnitude of impacts of climate change on crop productivity suggest that location-specific adaptation measures are needed to reduce the adverse consequences of changing climate. There are a number of climate-change adaptation strategies and measures based on best practices as well as on recent scientific breakthroughs. What is needed is a suite of adaptation measures that are scientifically sound, cost-effective, economically efficient and socially and culturally acceptable.

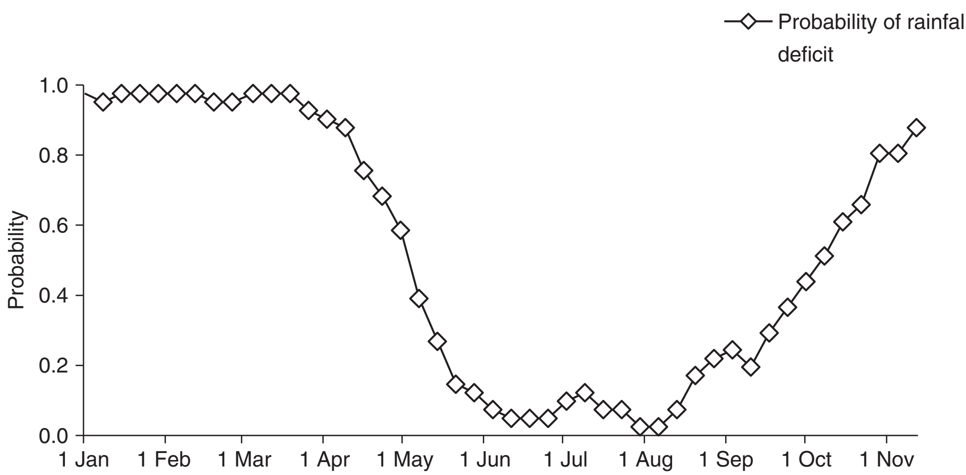


Fig. 6.15. WIBI-based risk of rainfall deficit for different stages of crop growth for rainfed rice production in Iloilo Province, Philippines (from Lansigan, 2013).

References

Alcamo, J., Grassl, H., Hoff, H., Kabat, P., Lansigan, F., Lawford, R. *et al*. (2005) *The global water system project: Science framework and implementation activities*. Earth System Science Partnership (ESSP), Bonn, Germany.

Anderson, C.J. (2008) An overview of downscaling techniques used in climate science. Santa Clara University and Iowa State University, USA. Available at: http://www.colorado.edu/climate_chnage/docs/Anderson_downscaling.pdf (accessed 1 June 2013).

Asia Rice Foundation (2010) *Adaptation to Climate Variability in Rice Production*. Asia Rice Foundation, Los Baños, Laguna, the Philippines, 61 pp.

Centeno, H.G.S. and Wassmann, R. (2009) Regional climate models in predicting Philippine rice production. *Philippine Journal of Crop Science* 25(2), 79–85.

Comiso, J.C., Blanche, C., Espaldon, M.V., Sarigumba, T. and Lansigan, F.P. (eds) (2014) *Changing Philippine Climate: impacts on agriculture and natural resources*. UP Press, Diliman, Quezon City, the Philippines.

David, L.T., Maneja, R.H., Goh, B., Lansigan, F.P., Sereywath, P. *et al*. (2008) Sea level rise vulnerability of Southeast Asia coasts. *LOICZ InPrint* December, 3–6.

Delfino, R.J., Herath, S., Lansigan, F.P., Pulhin, J.M. and Lasco, R.D. (2012) Assessing the impacts of climate change on water resources and rice production in Pantabangan-Carranglan Watershed, Philippines. Paper presented at the National Climate Research Conference, 27 2012. Manila, the Philippines.

Gaffney, O. (2010) One planet, four futures. *IGBP Global Change* 75, 12–15.

IPCC (2001) *Special Report on Emission Scenarios*. Intergovernmental Panel on Climate Change, Geneva, Switzerland.

IPCC (2007) Climate change 2007: The physical basis. Summary for policy makers. *IPCC Fourth Assessment Report*. Intergovernmental Panel on Climate Change, Geneva, Switzerland.

IPCC (2012) Special report on managing the risks of extreme events and disasters to advance climate change adaptation (SREX). Intergovernmental Panel on Climate Change. Available at: http://ipcc-wg2.gov/SREX/report (accessed 4 October 2012).

Lansigan, F.P. (2003) Assessing impacts of climate variability on crop production, and developing coping strategies in rainfed agriculture. *UN ESCAP CGPRT Center Monograph No. 43*. Bogor, Indonesia, pp. 21–36.

Lansigan, F.P. (2009) Frequency analysis of extreme hydrologic events and assessment of water stress in a changing climate in the Philippines. In: Taniguchi, M., Burnett, W.C., Fukushima, Y., Haigh, M. and Umezawa, Y. (eds) *From Headwaters to the Ocean: Hydrological Changes and Watershed Management*. CRC Press, Taylor & Francis, Leiden, the Netherlands, pp. 497–501.

Lansigan, F.P. (2010a) Determining the seasonal climate-based optimal planting dates for rainfed rice in selected locations in the Philippines. *National Convention on Statistics, 4–5 October 2010*, Mandaluyong City, the Philippines.

Lansigan, F.P. (2010b) Managing climate risk to enhance crop productivity for food security: dynamic cropping calendar for farm operations. *University of the Philippines in Los Banos Centennial Professorial Chair Lecture Paper, 11 August 2010*. University of the Philippines in Los Baños, Laguna, the Philippines, 30 pp.

Lansigan, F.P. (2011a) Adaptation to changing climate in rice production in the Philippines. In: *Asia Rice Foundation, Adaptation to Climate Variability in Rice Production, 2011*. Asia Rice Foundation, Los Baños, Laguna, the Philippines.

Lansigan, F.P. (2011b) Responding to changing climate on rice production in the Philippines. In: *Adaptation to Climate Variability in Rice Production*. Asia Rice Foundation , Los Baños, Laguna, the Philippines, pp. 32–46.

Lansigan, F.P. (2013) Climate risk for weather index-based insurance for crop production in the Philippines. *Proceedings, 12th National Convention on Statistics*, Mandaluyong City, the Philippines.

Lansigan, F.P. and Dating, M.J. (2012) Statistical downscaling of climate projections and assessment of impacts on crop productivity in the Philippines. Paper presented at the National Academy of Science and Technology (NAST) Conference on Climate Change and Variability, 27 September 2012, Manila, the Philippines.

Lansigan, F.P. and Salvacion, A.R. (2007) Assessing the effect of climate change in rice and corn yield in selected provinces in the Philippines. *Proceedings, 10th National Convention on Statistics*, Mandaluyong City, the Philippines.

Lansigan, F.P., Salavacion, A.R. and Garcia, A.G. (2008) SEARCA Seed Fund for Research and Training (SFRT). Southeast Asian Regional Center for Research and Agriculture (SEARCA), Los Baños, Laguna, the Philippines.

Lansigan, F.P., Dating, M.J.P. and Guiam, E.G.A. (2013) Comparison of statistical downscaling methods of climate projections in selected locations in the Philippines. *National Convention on Statistics.* October 1–2, 2013, Mandaluyong City, the Philippines.

Matthews, R.B. and Stephens, W. (2002) *Crop-Soil Simulation Models: Applications in Developing Countries.* CAB International, Wallingford, UK.

Matthews, R.B., Kropff, M.J., Horie, T. and Bachelet, D. (1997) Simulating the impact of climate change on rice production in Asia and evaluating options for adaptation. *Agricultural Systems* 54(3), 399–425.

Moss, R.H., Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose, S.K., van Vuuren, D.P., Carter, T.R., Emori, S., Kainuma, M., Kram, T., Meehl, G.A., Mitchell, J.F.B., Nakicenovic, N., Riahi, K., Smith, S.J., Stouffer, R.J., Thomson, A.M., Weyant, J.P. and Wilbanks, T.J. (2010) The next generation of scenarios for climate change research and assessment. *Nature* 463, 747–756.

Naylor, R.L., Falcon, W.P., Rochberg, D. and Wada, N. (2001) Using El Niño/Southern oscillation climate data to predict rice production in Indonesia. *Climatic Change* 50(3), 255–265.

PAGASA (2011) *Climate change in the Philippines*. Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), Department of Science and Technology (DOST). Millennium Development Goal-Fund (MDGF) and DOST, June 2011, Quezon City, the Philippines, 86 pp.

Penning de Vries, F.W.T., Jansen, D.M., ten Berge, H.F.M. and Bakema, A. (1989) *Simulation of Ecophysiological Processes of Growth in Several Annual Crops*. Simulation Monograph. PUDOC, Wageningen, the Netherlands and International Rice Research Institute, Los Baños, Laguna, the Philippines, 271 pp.

Schellnhuber, H.J., Hare, B., Serdeczny, O., Adams, S., Baarsch, F., Schwan, S., Coumou, D., Robinson, A., Schaeffer, M., Vieweg, M., Piontek, F., Donner, R., Runge, J., Rehfeld, K., Rogelji, J., Menon, A., Perrette, M., Schleussner, C.-F., Bondeau, A., Svirejeva-Hopkins, A., Schewe, J., Frieler, K. and Warszawski, L. (2013) *Turn Down the Heat II: global hotspots and regional cases*. World Bank, Washington, DC, 236 pp.

SEARCA and FAO (2010) *The Impacts of El Niño Southern Oscillation (ENSO) Events in Cereal Production, Area and Yield in Asia. Project Report*. Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA) and Food and Agriculture Organization of the United Nations (FAO), Los Baños, Laguna, the Philippines.

Tibig, L.V. and Lansigan, F.P. (2007) Coping strategies to agro-meteorological risks and uncertainties in crop yields. In: Sivakumar, M.V.K. and Motha, R.P. (eds) *Managing Weather and Climate Risks in Agriculture*. Springer-Verlag, Berlin, pp. 209–235.

Wassmann, R. (ed.) (2010) *Advanced Technologies of Rice Production from Coping with Climate Change: ‘no regret’ options for adaptation and mitigation and their potential update*. International Rice Research Institute (IRRI), the Philippines, 76 pp.

Wilby, R.L. and Dawson, C.W. (2007) SDSM 4.2 – A decision support tool for the assessment of regional climate change impacts. Available at: http://co-public.lboro.ac.uk/cocwd/SDSM (accessed 5 October 2012).

Yumul, G.P., Cruz, N.A., Servando, N.T. and Dimalanta, C.B. (2011) Extreme weather events and related disasters in the Philippines, 2004–2008: a sign of what climate change will mean? *Disasters* 35(2), 362–382.