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Agronomic impacts of climate variability on rice production in the Philippines

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Abstract

Climate variability is a threat to food production. Typhoons, floods, and droughts caused 82.4% of the total Philippine rice losses from 1970 to 1990. In 1990 alone, domestic losses due to climatic constraints amounted to US\$ 39.2 million. Weather aberrations, climatic fluctuations such as El Niño, and the growing concern for their effects on agriculture have stimulated academic, public and policy-level interests on the analysis of the impacts of climate variability on agricultural production systems. This paper is presented to discuss the agronomic impacts of climate variability on rice production in the Philippines. Long-term climate variability influences sowing date, crop duration, crop yield, and the management practices adapted in rice production. Short-term weather episodes can also affect yield by inducing changes in temperature, potential evapotranspiration, and moisture availability. The degree of vulnerability of crops to climate variability depends mainly on the development stage of the crops at the time of weather aberration. The vulnerability and risk of crop production due to weather fluctuations and climate variability can be minimized if future weather variation can be adequately predicted and a suitable process-based ecophysiological crop yield forecasting model can be identified to produce real-time yield forecasts. Scientists and farmers must join efforts to further understand crop—climate relationships and formulate viable, locally adapted production technologies that will address critical issues such as climate variability. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Climate variability; Rice production; Philippines; El Niño

1. Introduction

The concern on past, present and future weather aberrations, climate trends, and their effects on agriculture has continued to stimulate research as well as public and policy-level interests on the analysis of climate variability and agricultural productivity (Matthews et al., 1996; IPCC, 1996). It is well recognized that climate variability has a wide range of direct and indirect impacts on crop production. In the

Philippines, typhoons, floods, and droughts caused 82.4% of the total Philippine rice (*Oryza sativa* L.) losses from 1970 to 1990 (PhilRice-BAS, 1994) (Fig. 1). Weather and climate affect plant growth and development, and the fluctuations and occurrences of climatic extremes particularly at critical crop growth stages may reduce yield significantly (Satake and Yoshida, 1978; Peng et al., 1996).

Weather and climate have a direct influence on cropping systems and plant yield. Thus, weather fluctuations and climate variability play a significant role in crop growth and yield. Occurrence of abnormal weather episodes during the growing season or

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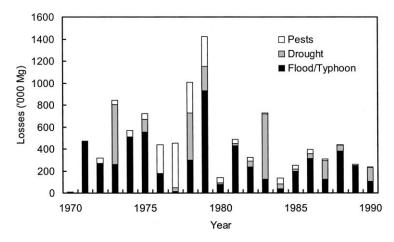


Fig. 1. Annual losses ('000 Mg) in Philippine rice production due to typhoons/floods, droughts, and pests from 1970 to 1990 (adapted from PhilRice-BAS, 1994).

during critical development stages may hamper growth processes resulting in yield reduction. This makes climate variability a threat to food production leading to serious social and economic implications (Geng and Cady, 1991; Hossain, 1997). However, a clear understanding of the vulnerability of food crops as well as the agronomic impacts of climate variability enable one to implement adaptive strategies to mitigate its negative effects.

This paper presents the agronomic impacts of climate variability on rice production systems. These impacts are described based on results of systems-based studies and case examples in the Philippines. Key climate variables and measures of variability are examined. The analysis distinguishes the impacts of long-term weather variability and short-term weather episodes. Some adaptive strategies to climate variability to reduce vulnerability and risk are also presented. Suggestions and recommendations for an efficient and effective analysis of agronomic impacts of climate variability are also discussed.

2. Key climatic variables

The occurrence of weather episodes such as extremes characterized by maximum or minimum temperature, sequences of dry or wet days, and high winds particularly during occurrence of tropical cyclones (typhoons) may significantly affect crop growth and

development which results in reduced crop yield. In the Philippines, monsoon currents, tropical cyclones, and the inter-tropical convergence zone divide the year into wet and dry seasons. Many areas have rain from May to November, the peak amounts falling between August and September. During the dry months (February-April), rainfall is generally deficient and some areas may experience drought. Climate variability can be readily observed from the fluctuations in rainfall, wind speed and direction, and temperature. Fluxes in rainfall volume below or above normal annual values may be experienced in areas affected by the anomaly. Similarly, shifts in temperature regimes in comparison with the temperature range for specific periods of the year and/or across several years also indicate climate variability. Inter-annual variability in wind speed and direction also reflect climate variability.

The occurrence of El Niño-southern oscillation (ENSO) is one of the most remarkable inter-annual climate phenomena in the world. Dry or wet period tends to occur for 12 months or more, and is phase-locked to the annual cycle. El Niño-induced climate variability in the Philippines usually results to: (a) late onset of the rainy season, (b) early termination of the rainy season, (c) weak monsoon events characterized by isolated heavy rainfall events of short-duration, and (d) weak tropical cyclone activity characterized by less intense cyclones and less number of tropical cyclones occurring within Philippine territory

(PAGASA, 1997). Tropical cyclones, usually characterized by strong high winds and heavy rainfall are destructive to annual crops. Damage to crops may range from negligible to total wipeout depending on the intensity and duration of the storm event as well as the prevailing crop growth stage during the occurrence of the cyclone. In 1990 alone, domestic losses due to floods and typhoons were US\$ 11 million. Losses due to drought during the same year resulted in an additional US\$ 28.2 million (PhilRice-BAS, 1994).

Fig. 2 illustrates the differences in the average annual rainfall received during El Niño years compared to normal or non-El Niño years for three selected locations in the Philippines. The average annual precipitation values represent an average of annual rainfall during 1965–1966, 1968–1969, 1972–1973, 1977–1978, 1982–1983 and 1987 years when El Niño were experienced in the three test sites studied. The data used to represent the non-El Niño years were averages of annual precipitation between 1961 and 1990 with the exception of those El Niño years mentioned previously. The average difference among the three sites, between El Niño and non-El Niño years is about 400 mm of rainfall. The three test sites, Los Baños, Laguna in northern Philippines, Daet,

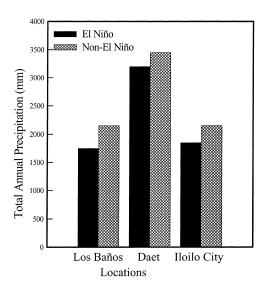


Fig. 2. Average annual precipitation (mm) during El Niño years (1965–1966, 1968–1969, 1972–1973, 1977–1978, 1982–1983 and 1987) and non-El Niño years between 1961 and 1990 at Los Baños, Laguna, Daet, Camarines Norte, and Iloilo City, Iloilo, Philippines.

Camarines Norte, located along the Pacific coast in eastern Philippines, and Iloilo City, Iloilo, in central Philippines represent three varied geographical regions in the country. In other sites in the Philippines, the gap between an El Niño and a non-El Niño year can reach as high as 1000 mm of precipitation.

3. Effects of long-term climate variability

3.1. Sowing date

Climate variability affects timing of initiation of the cropping season which is determined largely by the start of the rainy season particularly in rainfed areas. For rice production in Los Baños, Philippines, land preparation starts as soon as the cumulative amount of rainfall for the last 30 days after April 1 (Julian day 91, historically the driest day in areas with climate characterized by pronounced wet and dry seasons in the Philippines) reaches 200 mm (Yoshida, 1981). It is during this period that the soil accumulates enough moisture to support plant growth. Fig. 3 shows the relative frequency distribution of the mean sowing date for Iloilo City, Philippines (climate characterized by pronounced wet and dry seasons) during non-El Niño years and during El Niño years based on available historical weather data. During non-El Niño years, the relative frequency of the number of times the volume of cumulative rainfall reached 200 mm within 30 consecutive days beyond Julian day 91 is most common on Julian day 173 based on available historical weather data. Except for Julian day 143, the probability of sowing date occurring on Julian day 173 is three times the probability that sowing date will fall on any other date. During an El Niño year, mean planting time may occur as early as mid-May (Julian day 137) or may be delayed to mid-August (Julian day 229) depending on the degree of climate variability. The occurrence of an El Niño event is usually associated with drought in the Philippines, thus, sowing in affected areas is usually delayed.

3.2. Crop duration

Weather and climate variability influence the initiation of the rice cropping season since it is often synchronized with the onset of the rainy season. The

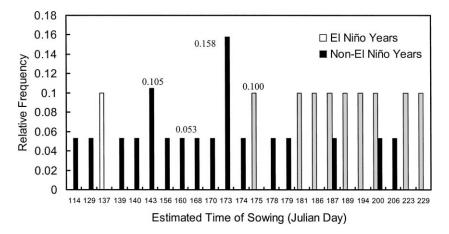


Fig. 3. Relative frequency of sowing dates during El Niño years (1965–1966, 1968–1969, 1972–1973, 1977–1978, 1982–1983 and 1987) and non-El Niño years between 1961 and 1990 at Iloilo City, Philippines.

cropping calendar is often adjusted to coincide with the period with high probability of receiving adequate rainfall to support plant growth requirements. In the Philippines, it is commonly observed that planting period, capable of sustaining effective rice production during the dry season, is narrower for most of the regions in the Philippines compared to the time frame available during the wet season. The narrower dry season planting period seeks to maximize the remaining moisture from the previous wet season rice cropping. Regions with more even year-round distribution of rainfall may also exhibit overlaps in rice planting and harvesting operations.

3.3. Crop yield

Crop yield is directly influenced by climate variability as exhibited in the time series data of Philippine rice yields. Fig. 4 illustrates rainfed rice productivity in the Philippines (1970–1994) as affected by El Niño. It shows how El Niño can negatively influence wet season cropping of rice without any corresponding effect on the dry season cropping. This condition is due to the late onset and early termination of the rainy season. This exposes the wet season cropping to unnecessary water stress resulting in drastically lower yield. The El Niño years of 1973, 1983, and 1990 specified in Fig. 4 accounted for 65, 81 and 52% of all rice losses, respectively, during those years as represented in Fig. 1.

3.4. Cropping systems

Cropping sequence/crop rotation of annual crops can be modified to adapt to climatic variability. This may also result in adjustments in scale of production often resulting in a decrease in area for crop production. The reduction in area cultivated is often a coping mechanism to reduce the impact associated with increased risk and uncertainty. Modification in choice of crops or cultivars to grow especially in areas accustomed to high crop diversification, and even changes

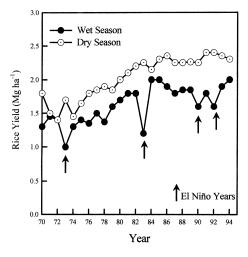


Fig. 4. Effect of El Niño on rainfed rice productivity in the Philippines from 1970 to 1994 (adapted from PhilRice-BAS, 1995).

in agronomic management practices including fertilizer use, irrigation, and control of pests and diseases are other adjustments resorted to in times of climate variability.

4. Impacts of short-term weather episodes

4.1. Changes in temperature

Crops have varying sensitivity to temperature. There are temperature threshold values beyond which crops become vulnerable to sharp temperature shifts. Satake and Yoshida (1978) reported that spikelet sterility in Indica rice varieties was induced when exposed to high temperature immediately before and during anthesis. The same study attributed the major causes of high temperature-induced sterility in rice to disturbance of pollen shedding and decreased viability of pollen grains. This resulted in decreased number of germinated pollen grains on the stigma. Thus, rice yield is expected to decrease during instances of high temperature during flowering. Similar results of induced sterility, reduced kernel quality, and decreased kernel dry weight in rice were reported by Tashiro and Wardlow (1991a,b) when day/night temperature shifts from 27/22 to 36/31°C during the reproductive stage of plant development.

4.2. Crop water requirements

Occurrence of sequences of wet and dry periods can affect crop physiological processes that may prematurely hasten or retard crop growth and development. Prolonged periods of heavy rainfall (which may result in flooding) during initial crop development may abort crop growth, and may lead to significant yield reduction when the heavy rainfall events occur during the critical period of crop growth before harvesting.

Effects of climate variability can also be seen in the difference in crop water requirements. Crop water requirement is estimated by potential evapotranspiration (PET) which can be determined using the modified Penman equation (Schwab et al., 1993). Analysis of spatial and temporal distribution of mean monthly PET values in the island of Mindanao in southern Philippines showed differences in average PET values during El Niño (1990) and non-El Niño (1988) year. Fig. 5 shows spatial differences of mean monthly PET values for January during El Niño and non-El Niño years. These differences determine what type of annual crops to grow or crop rotations to be followed in southern Philippines as well as the timing of the initiation of the cropping season particularly for rainfed cropping systems to take advantage of rainfall needed to sustain crop growth.

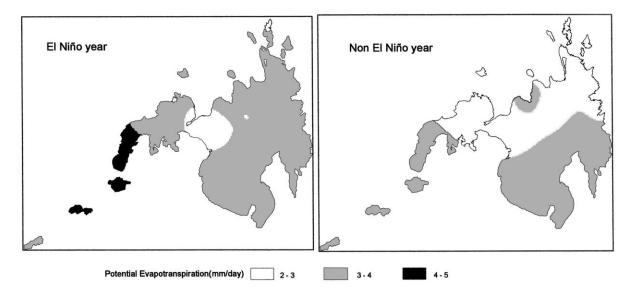


Fig. 5. PET (mm per day) during January of an El Niño (1990) and non-El Niño (1988) year in Mindanao, Philippines.

The El Niño phenomenon which causes fluctuations in temperature and rainfall patterns in the Pacific Basin and beyond is generally associated with drought in the Philippines. Rainfall occurrence during an El Niño year may decrease by 20–50%, and therefore, crops will require more irrigation water than usual. As shown in Fig. 5, during January in southern Philippines, mean monthly PET is higher during an El Niño year than during a normal year. There are differences in the spatial distribution of mean monthly PET values in Mindanao, southern Philippines. Consequently, cropping sequence and schedule can be planned to take advantage of available soil moisture. Alternatively, planting can be delayed or adjusted depending on the sufficiency of accumulated rainfall.

4.3. Water stress

The variability of water supply in crops can cause negative effects to crop production. In rice, water stress at panicle initiation increased the proportion of unfilled grains and decreased 1000-seed weight (Wopereis, 1993; Wopereis et al., 1996). Reduced availability of water at the vegetative stage resulted in reduced morphological and physiological measurements in rice. The affected morphological and physiological features include tiller number, leaf area index, apparent canopy photosynthetic rate, leaf nitrogen, shoot and root biomass, and root length density (Cruz et al., 1986). Varying degrees of water stress at different growth stages can result in a number of plant reactions that can also be variety-specific. In general, water stress during the vegetative stage will delay panicle initiation in rice, mild water stress at reproductive stage will extend panicle development by 10 days and reduce grain number. A severe water deficit during the same development stage will extend panicle development by 18-28 days, and reduce grain and panicle number (Lilley and Fukai, 1994).

5. Weather variability and crop yield forecast

A process-based crop yield forecasting model can be developed which requires as input the historical weather variables (e.g. solar radiation, maximum temperature and minimum temperature, rainfall, etc.) observed up to the time the forecast is made (time of forecast), and the predicted weather variables from the point of forecast up to the time of harvest (Horie et al., 1995; Bouman et al., 1997). Using an adequate ecophysiological crop-forecasting model (based on a scientifically sound dynamic crop simulation model) and a set of reliable predicted weather variables, real-time forecast of crop response and crop yield can be determined. At any given time period during crop development, measurable crop data and observed weather variables plus the predicted weather variables for lead times up to maturity or harvesting of the crop can serve as inputs to crop yield forecasting model. For a rice yield forecasting model, a reliable estimate of crop yield can be determined even at flowering. Reliability of crop yield forecast increases as the time of forecast approaches the time of maturity, i.e. the uncertainty in crop yield estimate decreases as the forecast is made closer to crop maturity. Field data obtained in validating ORYZA 1 model (Kropff et al., 1994) were also utilized to develop a rice yield forecasting model. An adaptive process-based rice yield forecasting model was developed in the Philippines based on the SIMRIW model of Horie (1993). As shown in Fig. 6, real-time forecast can be determined given the observed physiological and weather conditions up to time of forecast (e.g. flowering time) and the forecasted weather conditions up to harvest time. In Fig. 6, the $\pm 15\%$ yield range take into account all possible changes in the conditions affecting the crop such as higher or lower solar radiation or an increase/decrease of leaf area index due to improvement in crop-management techniques. This yield range becomes narrower while the forecasted values converge with the observed values as the time of forecast approaches crop maturity. In the formulation of yield range, the usual method was not applicable since the rice yield forecasting model was non-linear and autoregressive in nature. The alternative was the posteriori approach wherein the proportion of the total number of observations falling within a given interval was determined. About 75% of all observations made fall within the range of forecasted total dry weight.

However, it should be emphasized that the accuracy of the crop yield forecast depends heavily on the reliability of the crop yield forecasting model, and on the ability of the weather data generator to predict future weather variability. That is, the crop model

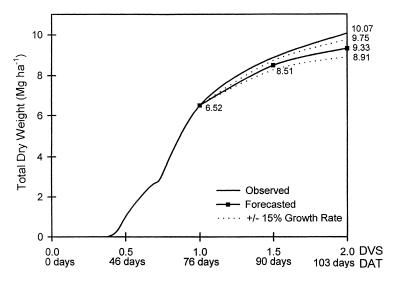


Fig. 6. Observed and forecasted total dry weight (Mg ha⁻¹) of IR 64616 rice variety (time of forecast: development stage, DVS = 1.0) using a modified model based on SIMRIW model (Horie, 1993) and yield range based on $\pm 15\%$ change in forecasted growth rate.

should be based on ecophysiological processes (Penning de Vries et al., 1989; Penning de Vries, 1991), while weather forecasts should represent or mimic the expected weather (Geng et al., 1986; Bouman et al., 1997). Moreover, as additional historical measurements of crop data (e.g., leaf area index and plant height) become available, and updated forecasts of weather variables are made, then crop yield forecast can be adjusted. Such an adaptive crop-forecasting model lends itself well with a crop monitoring system (Bouman et al., 1997).

As mentioned earlier, the vulnerability and risk of crop production due to weather fluctuations and climate variability can be minimized if future weather variation can be adequately predicted. Consequently, adaptive and/or mitigating measures in crop production system can be implemented to minimize risk. At present, however, adequate weather forecasts can only be made for lead times of only a few days to more than a week.

6. Adaptation to climate variability

Climatic averages are poor indicators for adaptation analysis. Farming systems response is more critical with regards to sudden fluctuations in weather and climate rather than to gradual, long-term climatic shifts, and adaptation is geared up more by occurrence of climate extremes (Murdiyarso, 1998). Climatic anomalies may occur with respect to extreme rainfall and/or temperature events, which have potential effects on crop production.

Equally important as the assessment of the agronomic impacts of climate variability is the analysis of adaptation and vulnerability. Adaptation is an important component of an integrated and balanced strategy to climatic variability (MacIver, 1998). A single or combination of adaptive measures as part of farming management adjustments can help to reduce vulnerability to climate variability. However, while adaptation strategies may be effective at reducing vulnerability, these measures may also have some negative impacts or may be inconsistent with other societal goals and objectives. Lebel (1998) has reported that availing crop insurance or changing land use for an area highly vulnerable to climatic flux may not be sustainable in the long run.

Adaptation is an integral component of a balanced strategy to climate variability. Measures as part of adaptive management can actually reduce vulnerability of farmers. Vulnerability here refers to the extent to which climate variability may damage or harm a system (IPCC, 1996). Adaptability is defined as the

degree to which adjustments are possible in practices, processes, or structures of systems to variability of climate (IPCC, 1996; Miles et al., 1998). Adaptation is largely a time-dependent, location-specific learning process (MacIver, 1998). There are a number of production strategies that can be utilized in the face of climatic variability. O'Toole and Chang (1978) recommended the use of early maturing rice varieties as a strategy in unstable production areas. Pantastico and Cardenas (1980) reported possible coping strategies in the face of climatic variability in rice production. These include ratooning for shorter growing periods, planting lodging-resistant, non-shattering, and waterlogged-resistant varieties, establishing windbreaks in strategic areas, developing methods to conserve rainwater to extend the cropping period, and developing simple implements for rapid harvesting and postharvest handling.

7. Concluding remarks

The degree of vulnerability of crops to climate variability depends mainly on the development stage of the crops at the time of weather aberration. Even a slight change in temperature during a critical stage (e.g. flowering) may already result in significant reduction in crop yield (Satake and Yoshida, 1978; Penning de Vries et al., 1989). Climate variability also influences other factors that may hamper crop growth. Incidence of pests and diseases may be hastened by the fluctuations in weather variables, such as temperature and rainfall patterns. Scientists and farmers must join efforts to further understand crop-climate relationships to help them formulate viable, location-specific production technologies that will address critical issues such as climate variability.

Efficient and effective analysis of the agronomic impacts of climate variability requires a good understanding of the systems processes involved in crop growth and development and crop production which allows an objective assessment of the vulnerability of the production systems to exogenous climate variables (Lebel, 1998). The inter-disciplinary, systems-based approach facilitate the understanding of the linkages and feedbacks among the system components.

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