TEST AND APPLICATION OF THE DSSAT MODEL TO ASSESS RICE PRODUCTIVITY IN THE ACCRA PLAINS OF GHANA

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DEDICATION

This work is dedicated unto the LORD GOD ALMIGHTY, for HIS goodness and abundant mercy unto me. It is also dedicated to all who helped to make this work a success.

DECLARATION

I do hereby declare that, the thesis herein presented for a degree of Master of Philosophy in Soil Science is my work produced from research done under supervision. All references to other authors' works as sources of information are duly acknowledged.

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ABSTRACT

Field studies on the growth and development of the rice variety TOX 3107 were conducted at the Agricultural Research Station (A.R.S,) Kpong with the aim of calibrating and validating the CERES-RICE model of DSSAT (version 3.5). Rice was grown for two seasons namely 1999 minor cropping season (August to December) and 2000 major cropping season (April to August). In the 1999 minor season experiment, rice was grown under rainfall with supplementary irrigation. There were two simultaneous experiments in the 2000 major cropping season. In one experiment, rice was grown under rainfall with supplementary irrigation and in the second, rice was grown under solely rainfed conditions. Three levels of nitrogen fertilization namely 0-, 45- and 90 kg N ha^{-1} were used in all experiments. There was a basal application of 45 kg P ha^{-1} and 35 kg K ha^{-1} in each case. Randomised complete block design was used with four replications.

The growth of the irrigated rice crop in the 2000 major season was better than the irrigated crop in the 1999 minor season. The irrigated rice crop in both seasons performed better than the rice grown under rainfed conditions in the 2000 major season. The durations of the phenological growth stages of rice grown in the minor season were shorter than those in the major season under both irrigated and rainfed conditions.

Crop, soil, weather and field management data from the 1999 minor season experiment were used to calibrate the CERES-RICE model. The calibrated model failed to predict crop growth and development well for the 2000 major season experiment and for an independent data. The goodness of fit for simulations of the calibrated model did not give an indication of a high predictive capability. This constrained its application to assess the output of different nutrient levels, management or weather scenarios.

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CHAPTER 1

1.0 INTRODUCTION

1.1 Background

Rice is one of the most important food crops in the world today. Nearly half of the world's population depend on it for food. Most of the world's population who depend on rice live in developing countries (Purseglove, 1972; Yap, 1997; Hill et al., 1998). In Ghana, the dependence on rice as a major source of carbohydrate is increasing (Oteng, 1997). Rapid population growth, urbanization, improved income levels, ease of cooking and good storage ability are some of the reasons attributed to the increased rate of rice consumption.

The consumption of rice per caput per annum increased from 7.4 kg (milled rice) to 8.0 kg between 1982 and 1990 (WARDA, 1986; Otoo, 1994) and then to 13.3 kg in 1996 (GOG, 1996). By the third quarter of 2000, rice consumption per caput per annum was estimated to be about 18.0 kg (Oteng, personal communication). This means that, with Ghana's current population of 18 million, the total national rice requirement would be 324,000 metric tonnes. The national rice production between 1995 and 2000 averaged 135,000 metric tonnes of milled rice which is just 41.7% of the national requirement. As a result, about US $100 million had been used annually for rice imports to supplement local production between that period (MOFA, 2001). Past production figures indicate that, 135,000 metric tonnes of milled rice is Ghana's best performance in annual local production. For example, in the middle of 1997, annual rice imports totalled 170,000 metric tonnes, contributing to two-thirds of the national requirement (MOFA, 1997). This implies that Ghana produced only one third of her rice needs over that period.

The immediate goal of the government is to reduce rice imports by at least 30% and increase the local production level by 72,000 metric tonnes of milled rice (GOG, 2001). If this goal is achieved, it will raise domestic production levels to 207,000 metric tonnes of milled rice, constituting 63.9% of the total national requirement. Self-sufficiency in rice, which has been the target over the years, can be attained only if sustained efforts are made in both research and production to develop and adopt strategies that will remove production constraints.

1.2 Problem specification

1.2.1 Production constraints

About 90% of the rice production area in Ghana falls under rainfed ecologies (section 2.2). Grain yields of rice under rainfed conditions are generally between 0.9 and 2.2 t paddy ha^{-1} (Otoo, 1994). The low yields are due mainly to the fact that rainfed conditions are characterised by erratic and highly unpredictable rainfall patterns. As a result, farmers are often uncertain of when to sow in order to be assured of adequate moisture for good yields. This poses a major problem that has to be addressed.

In addition to inadequate moisture for rice production in the rainfed ecologies, there are other factors that account for the low production. These include poor soil fertility, hence the need for fertilizer input particularly nitrogen and phosphorus. This will help increase grain yield per hectare and reduce the dependence on increased area of cultivation for higher grain output. Low yielding cultivars and farmers' lack of the requisite knowledge on advanced rice production methods are some of the many other obstacles to expanded production (Oteng, 1994; Otoo, 1994; 2000; Sakyi-Dawson et al., 2000). A limited success has been achieved in attempts at solving these problems. Research efforts therefore need to be intensified to achieve significant increases in rice yields to bring Ghana closer towards self-sufficiency in rice production.

1.2.2 Research needs in rice production

In spite of some positive contributions, agronomic research in Ghana continues to be based on field data collection. The spatial and temporal variability of the weather, particularly rainfall, make research results often location- and season-specific. Thus, extrapolation of such results is often tenuous. Even though multi-location trials may offer some remedy to this constraint, they are labour intensive, costly and time consuming especially where outcomes of alternative strategies need to be considered. Furthermore, research results and any technology developed through the research need to be evaluated over many years to expose any hidden flaws or weaknesses as a result of changing weather patterns. Two or three years of on-farm experiments cannot provide adequate information to assess an innovation's impact on productivity, stability or sustainability (Jintrawet, 1995). Recent advances in systems analysis using crop growth simulation techniques enable alternative strategies and/or different rainfall scenarios to be evaluated in a short period. Many production strategies and improved crop varieties have been introduced through field research to improve rice cultivation in Ghana. However, unlike many developed and some developing countries, the evolving research culture of supplementing field experimental results with systems analysis through simulation models is yet to be established in Ghana. This may be due, among other possible reasons, to (a) lack of awareness and knowledge in simulation models (b) lack of knowledge in the use of computers and (c) difficulty in the acquisition of computers. The only published works in Ghana are those of Adiku et al. (1998) and Naab et al. (2001). There is therefore the need to incorporate system analysis into agricultural research activities in Ghana.

Nearly all the improved rice production technologies were developed under a given ecological setting. In this regard, it will undoubtedly take years of field experimentation to answer questions relating to the (a) effect of a newly developed management strategy on crop performance, (b) effect of changes in weather patterns on crop productivity, (c) performance of a high yielding crop cultivar in a different ecological system and (d) appropriate management strategy needed to exploit the full potentials of rice-growing ecosystems in Ghana. One can continue to ask many related pertinent questions whose solutions may be found through the application of simulation models.

1.3 Project objectives

The objectives of this research are to

1. examine the performance of a lowland rice variety, TOX 3107, under two water treatments (supplementary irrigation and rainfed) at three different nitrogen fertilizer levels (0, 45 and 90 kg N ha^{-1}) during the minor and major cropping seasons;
2. use data from objective (1) to calibrate the CERES-RICE model of DSSAT version 3.5 (Hoogenboom et al., 1999) and
3. validate the calibrated CERES-RICE model by evaluating its simulation performance using independent data sets.

CHAPTER 2

2 LITERATURE REVIEW

2.1 Introduction

The rice plant adapts very well to its environment. It is grown in many different locations and under a variety of climatic conditions throughout the world. Geographically, rice is grown between latitudes as high as 53°N in northeastern China and as low as 35°S in the New South Wales, Australia (Yoshida, 1981). In terms of altitude, the crop is cultivated at or near sea level in many growing areas but it has also been successfully grown at elevations as high as 2000 m above sea level (a.s.l) in Kashmir (India) and Nepal and also below sea level in Kerala, India. In Ghana, rice cultivation is done in all the ten regions of the country. The Accra plains falls under the irrigated rice ecology and currently the main production areas in the plains are Dawhenya, Asutsuare and Ashaiman.

2.2 Rice growing ecologies and rice output in Ghana

The rice plant grows on a wide range of landforms and is thus affected by an equally wide range of moisture conditions in the field. Rice growing ecologies in Ghana have been characterised based on the toposequence concept of Moorman and Van Breeman, (1978). This is the hill to valley continuum (Fig. 2.1) that determines the landscape position of the rice field. In Ghana, the identified ecologies are (a) upland or dryland areas where moisture for production is entirely dependent on rainfall (b) hydromorphic areas where moisture for production is from rainfall and shallow groundwater (c) rainfed lowlands, i.e. inland swamps and valley bottoms where moisture for production is from rainfall, run-off from higher surroundings and flooding by streams and (d) irrigated paddies (Jones, 1993; Oteng, 1994). The first three ecologies account for 90% of the production area in Ghana and the remaining 10% production is done under irrigation (Oteng, 1997).

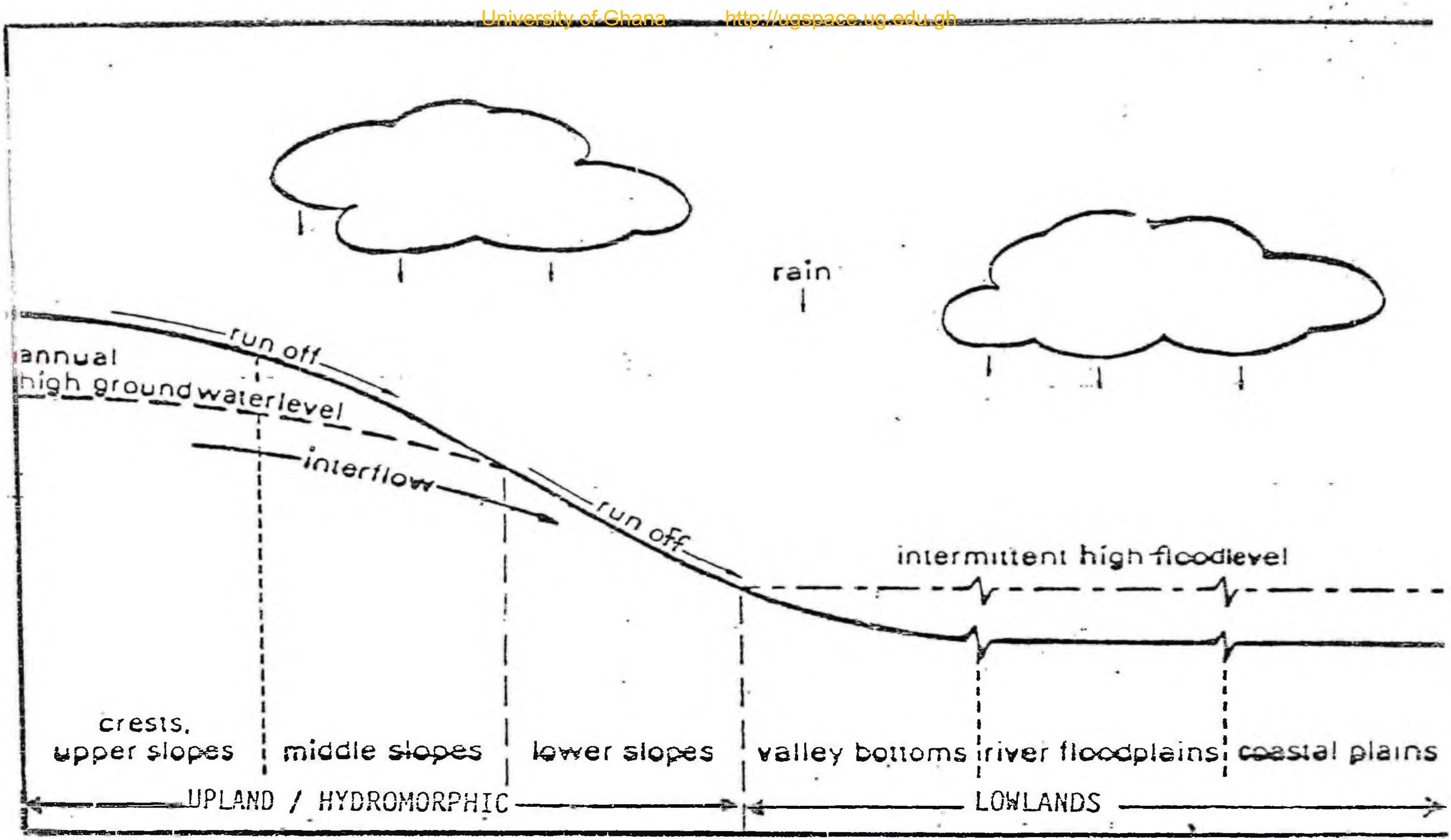

Fig. 2.1 Landscape elements and physio-hydrography along a toposequence (Moorman and Breeman. 1978)

The national average grain yield of rice for Ghana in 1990 was 1.5 t ha^{-1}, increasing slightly to 1.9 t ha^{-1} in 1996. Increases in the total national production have come mainly from increased cultivated area (Vordzorgbe, 1985; Table 2.1).

Table 2.1 Output, area cultivated and yield of rice in Ghana (1987-1996).

Year	Output ('000 metric tonnes paddy)	Area Cultivated ('000 ha)	Yield (t ha^{-1})
1987	81	72	1.1
1988	105	52	2.1
1989	67	72	0.9
1990	81	49	1.7
1991	150.9	94.9	1.6
1992	131.5	79.7	1.6
1993	157.4	77.2	2.0
1994	162.3	80.9	2.0
1995	221.3	99.9	2.2
1996	215.7	105.3	2.0

(Adapted from MOFA, 1991;GOG, 1996).

There is the need to increase grain yield per hectare rather than increasing the area for cultivation. Expansion of the area of irrigated ecologies will undoubtedly lead to substantial increases in paddy rice production. This is however expensive in terms of installation and maintenance of irrigation structure. Significant yield increases of rice must therefore come from the non-irrigated ecologies in order to satisfy the national rice requirement.

Rice yields from hydromorphic and rainfed lowlands are higher than those from uplands because of better soil moisture conditions. However, the water regime in both the hydromorphic and the lowlands fluctuates depending on the seasonal amount and distribution of rainfall. Consequently, these areas could become drought-prone, flood-prone, both drought and submergence-prone or favourable during any given crop growth stage and season. These uncertainties continue to beset rainfed rice production in Ghana.

The yield from the irrigated ecology compares well with the national averages of some of the world's major rice producing countries particularly in Southeast Asia where production is done mainly in paddy fields. For example, between 1988-1990, rice yield of 6.0 t ha^{-1} was reported for China, 4.4 t ha^{-1} for Indonesia and 2.9 t ha^{-1} for India (Yap, 1997).

2.3 Factors Influencing Rice Productivity

Rice productivity is usually assessed by grain yield and this is largely determined by crop variety, environmental factors and cultural management. The growth of the rice plant itself has been divided into three main developmental stages namely; (i) vegetative stage beginning from seed germination to panicle initiation, (ii) reproductive stage (from panicle initiation to the period when 50% of the florets have been pollinated), and (iii) grain filling and ripening stage which begins from the period of pollination and fertilization to maturity. These three stages in turn influence the main components of yield which are the number of spikelets per unit land area, filled spikelet percentage and 1,000-grain weight (i.e. the average weight in grams of 1,000 unmilled grains). The combination of these components determines grain yield (Yoshida, 1981). Any adverse condition or limitation imposed by crop variety, environmental factors or cultural management practice on any of the growth stages will affect crop productivity (Yoshida, 1981; Yoshida and Oka, 1982), as discussed in the following subsections.

2.3.1 Crop Variety

The rice plant belongs to the genus *Oryza*. Among the 22 species found in the genus *Oryza*, only two species are cultivated, namely, *sativa* and *glaberrima*. *Oryza sativa*, sometimes called the common rice by some authors, is the more popular species grown throughout the world. *Oryza sativa* has some subspecies but the most popular cultivated subspecies are the *japonica* and *indica*, each with numerous varieties. The full names of these subspecies are *Oryza sativa* subspecies *japonica* and *Oryza sativa* subspecies *indica*. Most often however, they are simply called japonica rice and indica rice. The japonica rice is better adapted to the temperate climate while the tropical monsoon climate is more favourable for the indica rice (Purseglove, 1972; Yoshida, 1981). The species *Oryza glaberrima* originated from West Africa and is still grown in the sub-region (Sampath and Rao, 1951; Purseglove, 1972). Among these traditional cultivars, the japonica gives the highest grain yields. Until varietal improvement strategies were adopted, average grain yields of the japonica were reported to be between 4.0 and 5.0 t ha^{-1} (milled rice) in some temperate countries such as Australia and Japan. The indica rice varieties are grown mainly in Southeast Asia with average yields varying between 1.0 and 1.5 t ha^{-1} (Purseglove, 1972). Grain yield of *Oryza glaberrima* ranges between 0.7 and 1.0 t ha^{-1} (Bourke, 1965).

Over the years, the genetic yield potential of rice cultivars has been improved significantly through breeding techniques and continue to be improved through more advanced technologies such as biotechnology. Biotechnology programmes emphasize techniques such as molecular markers, anther culture and deoxyribonucleic acid (DNA) fingerprinting to complement conventional breeding techniques. Other techniques are wide hybridization and genetic engineering to further broaden the gene pool that breeders can exploit (FAO, 1997). With these advanced technologies, an endless list of improved varieties has been developed and released to farmers. New improved cultivars continue to be developed as knowledge in the field develops. These new cultivars have the genetic potential for higher yields due to a number of factors such as improved response to applied fertilizers, particularly nitrogen, higher ability to capture solar radiation and thereafter increase in photosynthesis. Other improved attributes included in breeding are resistance to short durations of in-season drought stress, temperature stress, lodging, pest and disease tolerance etc. Yields of some of the new cultivars have been as high as 17.8 t ha^{-1} in India (Suetsugu, 1975), 13.2 t ha^{-1} in Japan (Agricultural Policy Study, 1971), 11.0 t ha^{-1} at the International Rice Research Institute (IRRI), in the Phillipines (IRRI, 1973) and 10.7 t ha^{-1} in Cambodia (Hirano et al., 1968). All these high yields were obtained on experimental fields and are considered potential yields based on the varieties' physiological efficiencies under optimal weather, soil and management conditions. Yields achieved on farmers fields have improved significantly through the adoption of the high yielding varieties (HYVs) yet they still fall below the potential yields. This is due to the inability of farmers to pay for the high cost of the intensive care and the necessary inputs to enable the HYVs to manifest their potential yielding capabilities (Yoshida, 1981; Yoshida and Oka, 1982).

Varietal improvement programmes have been in progress for decades now in countries where rice is a priority crop. As far back as 1966, some 75 research institutions were reported to be involved in this work in India alone (Deshaprabhu, 1966). The International Rice Research Institute (IRRI), established in 1962, has become the major international institution that carries out most of the rice improvement research work and has released numerous improved cultivars. In West Africa, the West African Rice Development Association (WARDA) which is now based at Bouaké, in La Côte d'Ivoire, has been conducting some breeding activities since the mid-1980s. This has resulted in the release of some varieties with improved performance under the local sub-regional climatic conditions. Others have been bred for specific ecologies such as the mangroves and uplands in the sub-region (WARDA, 1990). In Ghana there are no on-going rice breeding activities. However, for over four decades, improved varieties obtained from IRRI and WARDA have been screened at the University of Ghana's Agricultural Research Station at Kpong and the Savanna Agricultural Research Institute (SARI). The former screens varieties for the irrigated ecology mainly in the southern half of the country while the latter screens for rainfed upland, rainfed lowland and irrigated ecologies in the northern sector of the country. A number of improved rice varieties have been released to farmers from these two institutions. For example, improved varieties such as Bouaké and TOX 3107 for the irrigated ecologies were released from Kpong. These releases have contributed to the current national average paddy yield of 2.0 t ha^{-1} which is an improvement over that of the past years.

2.3.2 Environmental factors

A plant's environment consists of the aerial atmosphere and the soil. The productive potential of an improved rice variety can be achieved only under favourable climatic conditions, good soil and crop management practices. Soil fertility and water retention characteristics are the main soil factors affecting rice productivity. The climate is characterised by various weather variables of which rainfall, solar radiation, water saturation deficit of the atmosphere temperature and daylength are the major yield determinants (Yoshida and Oka, 1982). These variables are also important inputs in crop modelling.

2.3.2.1 Rainfall

Rainfall is a very important factor especially in rainfed rice production, because it is the major source of water for crop growth. The importance of water in the biochemical and physiological growth processes of plants is well known. Water is one of the two reactants in the process of photosynthesis and the rice plant must absorb about 300 g of water to produce a dry matter of 1g (Yoshida and Oka, 1982). Rainfed upland rice requires a reliable and well distributed rainfall of at least 750 mm over a period of 3-4 months starting from the time of sowing (Purseglove, 1972). For the irrigated and lowland rice, between 180-300 mm water per month is required (Yoshida, 1981). Water stress (drought or excess) at any growth stage may reduce yield and the level of yield reduction will vary with the severity of the stress and the growth stage affected. The crop is most sensitive to water deficit at the period close to heading. Three days of drought occurring 11 days to heading and another at 3 days to heading reduce yield significantly by causing a high percentage of spikelet sterility. Excess water leading to crop submergence could have yield-decreasing effects such as decreased area for photosynthesis and reduced tillering (Yoshida, 1981).

2.3.2.2 Solar radiation

Solar radiation is the primary source of energy for photosynthesis in green plants and hence the level of incident solar radiation determines the amount of dry matter produced as well as yield. In the tropics, solar radiation is higher in the dry than in the wet season. Consequently, under optimum field conditions, the dry season yield is found to be higher than that of the wet season (Yoshida and Parao, 1972; Yoshida, 1981; Cassman et al., 1997). Available long-term weather data for the West African sub-region show that solar radiation values in the wet season are lower than those for the dry season (FAO, 1984). The cloudy weather that characterises the wet season is responsible for the lower solar radiation resulting in lower photosynthetic activity and consequently lower dry matter production and yield. The effect of solar radiation is different at each growth stage of the rice crop, but the greatest effect on grain yield is expressed at the reproductive stage followed by that at the ripening stage and the least effect is at the vegetative stage (Yoshida, 1981).

2.3.2.3 Temperature

The rate of physiological development processes are governed by the plant's biochemical reactions which are influenced by air temperature. Studies by Yoshida (1981) showed that, for the air temperature range of 22-31 °C, the growth rate of the rice plant increases almost linearly with increasing temperatures. The temperature quotient, Q_{10}, has been used to assess temperature effects on growth rates and differentiation (Yoshida, 1981). The temperature quotient is defined as :

$$Q_{10} = \frac{\text{Rate of growth at } (t + 10)\ ^{\circ}C}{\text{Rate at } t\ ^{\circ}C} \qquad 2.1$$

Thus, Q_{10} is the increase in rate of growth when temperature (t) rises by increments of 10 °C. The use of Q_{10} assumes that rates of differentiation and development are expected to obey the Arrhenius relation in which growth increases logarithmically with temperature (Yoshida, 1981). Another temperature function used to describe rice response to temperature is the degree-day also known as heat units or heat sum. This concept generally assumes that at temperatures below a certain minimum value (called base temperature or critical minimum temperature) no plant development occurs and above some optimum temperature (critical high temperature), the plant development decreases drastically.

Between these two defined critical temperatures, the plant development rate is linearly related to temperature. Studies by Lowry (1967) and at IRRI (1975) however showed that, the development processes from germination to maturity include many physiological and biochemical components. Some processes may be insensitive to temperature, others may be linearly dependent on temperature whereas others may be logarithmically related to temperature. Thus, the use of any one particular concept to explain temperature effect on rice growth may be an oversimplification. Depending on the variety, each development stage or growth process responds differently to the same temperature condition. Critical temperatures for the different stages of rice development are summarised in Table 2.1

Table 2.2 Critical temperatures of various development stages of rice.

	Critical Temperature (°C)		
Growth stage	Low	High	Optimum
Germination	10	45	20 45
Seedling emergence and establishment	12 - 13	35	25 - 30
Rooting	16	35	25 28
Leaf elongation	7 12	45	31
Tillering	9 16	33	25 31
Initiation of panicle primordia	15		
Panicle differentiation	15 - 20	38	
Anthesis	22	35	30 - 33
Ripening	12 - 18	30	20 - 25

Source: Yoshida (1977).

Air temperatures exceeding the critical high cause spikelet sterility, reduced tillering, reduced height, reduced spikelet numbers and reduced grain filling depending on the rice variety (Yoshida, 1981). Generally, japonica rice varieties are adapted to low temperatures while indica varieties perform better in high temperature climates.

High temperature is one of the factors responsible for lower rice yields in a tropical climate compared with yields in the temperate climate. High temperatures increase respiratory losses hence the net dry matter production which is the balance between photosynthesis and respiration becomes inevitably lower under higher temperatures (Purseglove, 1972; Yoshida, 1981). Research efforts continue, in order to breed varieties that will adapt well to the tropical weather.

2.3.2.4 Water saturation deficit of the atmosphere

The water saturation deficit of the atmosphere, is the difference between the maximum amount of moisture that the atmospheric air can hold and the actual moisture of the air at any given temperature. Also called the vapour pressure deficit (VPD), it is estimated as:

$$\mathrm{VPD} = e_s - e_a \tag{2.2}$$

where

e_s = saturation (or maximum) vapour pressure of the atmosphere (millibars) at a given air temperature, (^{o}C) and

e_a = actual vapour pressure of the atmosphere (millibars) at a specified temperature (^{o}C).

From the literature, it appears VPD is scarcely mentioned by rice physiologists as an important factor that influences rice productivity. It is normally discussed in connection with the development and spread of fungal and bacterial diseases in rice production. However, studies by a number of scientists established a relationship between VPD and crop productivity. Monteith et al. (1989), observed that the amount of dry matter produced per unit of water transpired is inversely proportional to the mean saturation deficit whether water is limiting or not. This observation became one of the central considerations used by these authors in developing the resource capture model (RESCAP) for sorghum and millet for dry matter production:

$$\frac{Y_{dm}}{T_r} = \frac{k}{e_s - e_a} \qquad 2.3$$

where

Y_{dm} = amount of dry matter produced (kg),

T_r = amount of water transpired in producing Y_{dm} (kg)

k = crop specific constant (determined from both plant and atmospheric parameters)

e_s and e_a are as defined in equation 2.2.

2.3.2.5 Photoperiod

Photoperiodism is the response of the plant to the length of a day defined as the interval between sunrise and sunset (Yoshida, 1981). Rice is basically a short day plant (Purseglove, 1972; Yoshida, 1981). This implies that, it initiates panicle primordia in response to a range of relatively short photoperiods but varietal differences exist. There are varieties that require long photoperiods for flowering while others are day neutral. Day neutral varieties are insensitive to photoperiod. They only require a specific growing time before flowering and maturity. They flower and ripen throughout the year in the tropics provided there is adequate moisture in the root zone.

Daylength varies widely with latitude and with season for a given latitude. At the equator, daylength varies only from 12 hours 6 minutes to 12 hours 8 minutes, a difference of only 2 minutes. Yoshida (1981) notes that at the early stages of research on photoperiodism, small differences in daylength in the tropics were thought to be unimportant in controlling plant behaviour. However, later research work by Chang (1968) demonstrated that, tropical plants might be more sensitive than temperate plants to small differences in daylength. The period from sowing to panicle primordia initiation, sometimes referred to as the basic vegetative phase (BVP), is believed to be insensitive to photoperiod (Purseglove, 1972; Yoshida, 1981). This stage is followed by a photoperiod sensitive phase (PSP), during which floral initiation is triggered by short or long days depending on the photoperiod sensitivity of the crop variety. Photoperiod-insensitive varieties will flower over a wide range of daylengths, hence flowering is not limited by short or long photoperiod. Most of the improved rice varieties that have been released were bred to be photoperiod insensitive making their cultivation at any latitude and time of the year possible.

2.3.2.6 Soil

Rice may be grown on many types of soil provided there is adequate water either from rain or irrigation. For lowland and irrigated rice, heavy clays and heavy alluvial soils of river valleys and deltas are very suitable because of their high water retention capacity. A pH range of 7.0 to 7.2 is considered optimum for paddy rice but the crop also grows on alkaline soils with a pH range of 8 to 9. The growth of the crop is inhibited at soil pH 4 or lower (Purseglove, 1972). Soil fertility and water retention characteristics are usually the most important soil properties affecting rice yield. Soil nitrogen is one of the most important nutrients for rice growth. Generally, rice responds positively to N and trials with lowland rice show that, the response to N fertilizer is usually higher than to either phosphorus (P) or potassium (K) [Yoshida, 1981]. Applied N in doses higher than recommended rates produces excessive vegetative growth, shading, lodging and a negligible increase in panicle number (Purseglove, 1972). Micronutrients such as zinc, iron, manganese, sulphur and silicon are required to maintain a nutrient balance. Zinc deficiency has been reported to reduce rice yield even when N is adequate (Yoshida et al., 1970), emphasising the importance of soil testing to assess the nutrient status. Soil fertility usually declines with cropping intensity and/or poor soil management. Inorganic and sometimes organic fertilizers are often applied to correct poor soil fertility in rice production. Although it may seem expensive, the FAO (1997) has emphasised the need for field–specific fertilizer management, particularly nitrogen. The recommended fertilizer rates for rice on the Vertisols in the Accra plains are 90 kg N ha^{-1}, 45 kg P ha^{-1} and 35 kg K ha^{-1} (Oteng, personal communication).

2.3.3 Cultural management practices

The yield of rice is influenced by management practices. Farmers' yields and consequently national average yields of rice (especially in Ghana) are usually lower than the potential yields in all rice growing regions largely due to poor management practices. Some of the important management practices that affect productivity include irrigation or rain water management, fertilizer application, planting method and crop protection. Although paddy rice (i.e. the rice plant growing under flooded field conditions) will tolerate a wide range of water conditions, the optimum condition appears to be that depth of water which just covers the soil surface. Greater amounts of water beyond a depth of 15.0 cm have no added advantage to rice growth and grain yield and result in waste of water. The optimum depth from a practical point of view is about 5.0 cm (Matsushima, 1962). The problem with water depths shallower than 5.0 cm is the difficulty encountered in maintaining flooded condition particularly during periods of high evaporation with no rains.

The soil fertility status differs from one farmer's field to another. A regional fertilizer rate may not always be useful. Cassman et al, (1997) observed yield reduction in rice in a number of long-term experiments on double- and triple-crop irrigated systems in the Phillipines and India in spite of adhering to all the recommended management practices. The authors observed that, yields could be restored to original levels by increasing the amount of the applied N fertilizer and improving the timing of fertilizer applications. The observation in these experiments was that, the initial N supply of the soil-floodwater system had decreased over time. This was due to the fact that, the crop uptake efficiency of the applied N and the physiological efficiency of the acquired N in producing the grain had not changed. This observation perhaps buttresses the FAO's recommenadation of field-specific fertilizer management. Split N application is generally recommended for lowland rice, half the dosage at transplanting time or a few days after transplanting. In the case of broadcast rice, the first half dosage can be applied just after good crop establishment so that it can enhance high tillering. To achieve optimum growth, the second application, often called top-dressing is usually done at the panicle initiation stage. Under flooded conditions, it is preferred to apply NH_4-N to NO_3-N. Hence ammonium sulphate fertilizer is recommended for wet paddy fields except on very acid or strongly leached soils (Purseglove, 1972). A fertilizer rate of 90 kg N ha^{-1}, 45 kg P ha^{-1} and 35 kg K ha^{-1} is recommended for the irrigated ecology in the Accra plains (Oteng, personal communication). The possibility of using organic fertilizers as N source for rice production has been studied by Cassman et al. (1966) at IRRI with very encouraging results compared with inorganic sources. The practical limitation to the use of organic manures, however, is the huge bulk of material needed to achieve desired results.

The type of planting method and planting density affect rice yields. Transplanted rice is found to give higher yields than broadcast rice. Two to three seedlings per hill, transplanted at 0.02 m x 0.02 m spacing is recommended at a seedling age of 3-4 weeks. Four weeks is more appropriate from practical point of view since the seedlings will be hardier and easy to handle. Transplanted rice gives higher yields because of greater soil area to be exploited for nutrients as against the closely-spaced and clustered plants in broadcast rice. Crop protection measures against weeds, diseases, insect pests, rodents and birds are all very important in ensuring good yields. Caution needs to be taken in the mixing, mode and frequency of application of any agrochemicals, particularly, herbicides since high concentrations could have adverse effect on the growth and yield of the rice crop.

2.4 Crop models in rice research

The growth of rice, like that of any other crop, is the result of the interaction between the plant, its environment (soil and weather) and management practice. Intensive research has been conducted worldwide, with many significant results obtained on the factors affecting the growth of rice, requirements for better growth performance in the field and yield output. As the understanding of soil-plant-atmosphere interaction increased, computer models (or crop models) that simulate the interactive effects of soil, plant, atmosphere and management factors on the growth and yield of crops were developed. Some of the simulation models that have been used in rice research are RICEMOD (McMennany and O'Toole, 1983), MACROS (Herrera-Reyes and Penning de Vries, 1990), RICESYS (Bachelet and Gay, 1993) and CERES-RICE (Hoogenboom et al, 1999). CERES is the acronym for Crop Estimation through Resource and Environment Synthesis.

The CERES-RICE model has been employed quite extensively in rice research in South East Asia and the United States of America. Singh (1992) applied CERES-RICE to identify optimum nitrogen management strategies for different sites in the Phillipines and Malaysia. Pinnschmidt et al. (1996) employed the model to estimate weather and weather plus nitrogen-limited attainable yield levels in some S.E. Asian countries. Jin-Z et al.

(1995), employed the model to study the impact of climate change on cropping systems in Southern China using actual daily weather data for about 30 years from nine sites in seven provinces. Rainfed and irrigated rice production were simulated as well as effects of doubling carbon dioxide concentration. Their results showed, among others, that irrigation did not fully compensate for the effects of increased temperature on crop yields. Carbon dioxide enrichment, however, partially compensated for the yield decrease caused by increased temperature. Yields of rainfed rice were reduced by between 7-78% depending on the level of precipitation. Bachelet and Gay (1993) applied the model in the United States of America to assess the response of rice to temperatures and carbon dioxide concentration. They found that rice sensitivity to changes in temperature and carbon dioxide concentration, as predicted by the model, agreed with experimental data. Buresh and De Datta (1990) studied nitrogen transformations using the CERES-RICE model. The predicted ammonia loss from urea in irrigated lowland rice experiments compared closely with gaseous nitrogen losses determined by the ^{15}N balance technique. Although the model is constantly undergoing evaluation to improve its performance, Singh (1992) noted that it has been validated for a number of sites in the tropics and subtropics with satisfactory results. A review of the available literature shows that, in general, models have not been extensively evaluated and used in rice research in Africa.

Among the major goals of modelling efforts are to (i) facilitate better understanding of the processes that contribute to the growth and yield of crops, and (ii) apply the models to improve crop management (Jones et al., 1990). Model application in a different environment is preceeded by calibration and validation. Calibration is the process of modifying certain model parameters or even coding to reflect local weather and soil conditions on crop growth (Singh and Alagarswamy, 1989). Validation involves a further testing of calibrated model against independent data collected in a different year or location to ensure a wide applicability of a model. There is no further modification of model parameters or code during validation (Hoogenboom et al, 1999). The predictive capability of a calibrated model is often assessed statistically by determining the goodness of fit or agreement between simulated and observed yields. Once the confidence in the calibrated model is established, simulated results from many years of real-time or generated weather can be used to estimate yield variability. Risk under alternative management options and other output variables for different management scenarios can be evaluated.

Boote (1999c), proposed three levels of model testing namely; informational, minimum and maximum or detailed validation. Informational validation requires very minimum data collection whereas detailed validation requires detailed and intensive data collection. Minimum validation was chosen for this work due to budgetary and time constraints. It involves collection of enough in-season data to check model performance for a new region or cultivar. Detailed validation which involves more intensive and extensive data collection is beyond the scope of this study.

Presently, crop models are used for evaluating (i) irrigation and water management options, (ii) effects of soil types, weather and management strategies on the growth and productivity of crops and (iii) responses of different crop cultivars or new crops to the same growing conditions. Other uses of crop models include the evaluation of pest, disease and risk management strategies, economic management strategies and the analysis of crop production systems under different weather scenarios.

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Site Characteristics

3.1.1 Site Location

Experiments were conducted at the University of Ghana's Agricultural Research Station (A.R.S), Kpong. The station is located at latitude 6° 09' North and longitude 0° 04'E, within the Accra plains of the Coastal Savanna agroecological zone. The site is 22 m above mean sea level and 80 km north-east of Accra

3.1.2 Soils at the Experimental Site

The Akuse series [Tropical Black Earth (Brammer, 1962); Typic Calciustert, (Soil Survey Staff, 1998)] is the dominant soil type at the research station. The soil reaction is generally near neutral at the surface (pH = 6.5) and become alkaline with depth (pH = 8.5) because of calcium carbonate accumulation in the subsoil. Cation exchange capacity is generally greater than 30 cmol(+) per kg clay with calcium and magnesium as the dominant bases. Smectites are the major clay minerals which cause the soil to exhibit shrink-swell properties in response to dry-wet cycles. The smectitic clay content of the Vertisol confers characteristics such as high moisture holding capacity, very low water infiltration rate and waterlogging in depressional, flat and bunded basins during seasons of high rainfall. All these characteristics are desirable for rice cultivation. In a season of adequate rainfall, lowland (or irrigated) rice could be successfully grown in bunded basins without any irrigation. Heavy-duty tractors (with horse-power greater than 85) are usually required for land preparation due to the clayey nature of the soils (A.R.S, Kpong, 2000).

3.1.3 Climate

The station has a bi-modal seasonal rainfall distribution pattern. The major season rains begin in March and end in July with the peak in June, followed by a short dry period in August. The minor season rains begin in September and end in November with the peak in October. This is followed by a long dry season which is characterised by dust-laden winds (harmattan) and high evapotranspiration rates. The mean annual rainfall for the station estimated over a 37-year period (1955-1991) is 1.136.4 mm (coefficient of variation = 24% and a standard deviation from the mean = 276 mm). About 60% of the total annual rainfall (about 682 mm) occurs in the major season, and 30% (about 342 mm) falls in the minor season. Thus, the remaining 10% (about 113 mm) occurs during the off season. The dependable annual rainfall (estimated at 75% probability) amounts to only 633 mm (Kranjac-Berisavljevic, 1994).

The mean monthly air temperature is 27.2 °C, minimum temperature of 22.1°C and a maximum temperature of 33.3°C. The relative humidity for the night time to the early hours of the day ranges from 80 to 100% throughout the year. The afternoon relative humidity ranges between 55 and 65 % for most part of the year but decreases to 20-40 % during the harmattan season.

3.2 Field experiments

An improved medium growth duration (120 to 130 days) rice variety TOX 3107, which is photoperiod insensitive and adapted to irrigated conditions, was used in all the field experiments. Rice was grown during the 1999 minor and 2000 major cropping seasons at three levels of N.

3.2.1 1999 minor cropping season

Rice was grown under rainfall with supplementary irrigation, to maintain optimal field moisture conditions during the growth period. The seed rice was nursed and transplanted 28 days after emergence (7th September, 1999) onto field plots at a planting density of 72 plants per square metre. The randomised complete block design (RCBD) was used with 4 replications. Three nitrogen levels (0 kg N ha^{-1}, 45 kg N ha^{-1} and 90 kg N ha^{-1}) were applied with sulphate of ammonia as the N source. All the plots received the same recommended dosage of phosphorus (45 kg P ha^{-1}) and potassium (35 kg K ha^{-1}). Triple superphosphate and muriate of potash were the P and K sources, respectively. The fertilizer was applied two weeks after transplanting the seedlings. The 90 kg N ha^{-1} was applied in two split doses of 45 kg N ha^{-1} two weeks after transplanting the seedlings and the second dose of 45 kg N ha^{-1} given at panicle initiation stage. The P and K were also applied two weeks after transplanting the seedlings. The plot size was 0.013 ha (i.e. 7 m x 18 m).

3.2.2 2000 major cropping season

Rice was grown under solely rainfed and supplementary irrigation conditions. The experimental design was the RCBD with 4 replications. Rice seeds were nursed and the seedlings transplanted 28 days after emergence (2nd May, 2000). Three nitrogen levels (0 kg N ha^{-1}, 45 kg N ha^{-1} and 90 kg N ha^{-1}) were applied. All the plots received the same recommended dose of phosphorus (45 kg P ha^{-1}) and potassium (35 kg K ha^{-1}). The fertilizer was applied two weeks after transplanting the seedlings. The 90 kg N ha^{-1} was applied in two split doses of 45 kg N ha^{-1} two weeks after transplanting the seedlings and 45 kg N ha^{-1} at panicle initiation stage. The P and K were also applied two weeks after transplanting the seedlings. The plot size was 0.0035 ha (i.e. 3.5 m x 10 m) and planting density was 72 plants per square metre.

3.3 The selected rice model

The CERES-RICE model of DSSAT (Decision Support Systems for Agrotechnology Transfer) version 3.5 (Hoogenboom et al., 1999) was used for this study because of its many options for wide applications. It has been widely tested and applied by researchers at the International Rice Research Institute (IRRI), the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) and in many other parts of the world.

The model operates on daily time step and requires daily weather data (maximum and minimum temperatures, solar radiation and precipitation). It computes crop phasic and morphological development using temperature, daylength and genetic characteristics. Biomass production is based on light intercepted by the leaf area index multiplied by a conversion factor. Biomass partitioning into various plant components is based on potential growth of organs and daily amount of growth produced. Soil water and nitrogen balance sub-models provide daily values of supply to demand ratios of water and nitrogen, respectively. These are used to influence growth and development rates.

The CERES-RICE model simulates growth taking into account the following processes:

(1) phenological development, which is affected by genotype, temperature, and daylength. The model simulates the timing of panicle initiation and the duration of each major growth stage;

(2) morphological development and growth of leaves, stems, and roots ;

(3) biomass accumulation and partitioning;

(4) soil water balance including daily soil evaporation, plant transpiration, runoff, percolation and infiltration. Water stress effect on rice growth and development is also simulated.

(5) soil nitrogen transformations such as urea hydrolysis, nitrification, denitrification and ammonia volatilization. The nitrogen sub-model has been modified to simulate nitrogen transformations under flooded, intermittent flooded and upland conditions (Jones et al, 1996).

(6) N use by rice, N deficiency affects on leaf area development, tillering, photosynthesis and senescence of leaves.

(7) N loss through runoff and leaching

The effect of transplanting on growth and development is also simulated by the CERES-RICE model.

3.4 Data collection

Data on soil, weather, crop and irrigation practice were collected in all experiments in the two cropping seasons.

3.4.1 Soil data

Soil samples were taken (using an auger) from 4 layers : 0 to 15 -, 15 to 30 -, 30 to 45 -, and 45 to 75-cm depths (the bedrock was located at a mean depth of 75cm). The following soil physical and soil chemical properties were determined.

3.4.1.1 Soil chemical properties

Soil samples from the experimental plot were air-dried, ground and seived through a 2 mm seive. Subsamples were then taken for the determination of the various chemical properties. Average values of two replications were taken.

3.4.1.1.1 Soil pH

The procedure of Ogoshi et al, (1999) was used. Twenty grams of the air-dried sieved soil sample were placed in a 50-ml beaker and 20 ml of distilled water added. The mixture was stirred with a glass rod for 20 minutes and allowed to stand for one hour. The pH of the suspension was read on an electronic pH meter and recorded as pH in 1:1 soil:water ratio.

3.4.1.1.2 Soil ammonium and nitrate nitrogen

The procedure of Ogoshi et al. (1999) was used. Three grams of the soil sample were placed in a 50-ml plastic tube and 30 ml of 2 N potassium chloride (KCl) added. The tube was capped and shaken for one hour on a mechanical shaker. The mixture was filtered using whatman No. 5 filter paper. A volume of twenty-five millilitres of the filtrate was placed in a 500-ml distillation flask and 1 ml sulfamic acid (NH_2SO_3H) added to digest any nitrite present in the extract. In order to prevent distillation of any nitrate-nitrogen (NO_3-N), 0.2 g of magnesium oxide was added and the flask attached to a distillation unit. The content of the flask was distilled at gentle heat. A 50-ml Erlenmeyer flask containing 5 ml of 2% boric acid (H_2BO_3) and 3 drops of mixed indicator was placed at the end of the distillation unit. Thirty millilitres distillate was collected into the 50-ml Erlenmeyer flask and set aside for ammonium-nitrogen (NH_4-N) determination. The distillation was continued by adding 0.2 g of Devarda alloy (ground to a fine powder; to prevent distillation of any NH_4-N). A 30-ml distillate was collected in another 50-ml Erlenmeyer flask containing 5 ml of 2% H_2BO_3 and 3 drops of mixed indicator placed at the end of the distillation unit. This sample was set aside for NH_4-N determination. During the collection of the two distillates, there were colour changes in the contents of the Erlenmeyer flasks from pink to green. These colour changes occurred before the required distillate volumes were obtained. The two distillates were each titrated with a standardized 0.005 N sulphuric acid (H_2SO_4). Colour change at the end-point in both cases was from green to a permanent faint pink. The amount of NH_4-N and NO_3-N were calculated using the same formula :

Amount of NH_4-N or NO_3-N (μ N g^{-1} soil) =

$$\frac{\text{volume of } 0.005\text{N } H_2SO_4 \text{ used during titration (ml)} \times 70}{\text{mass of soil (g) used for extraction}} \qquad 3.1$$

where:
volume of 0.005N H_2SO_4 used during titration = total volume obtained – volume obtained during blank check.

The nitrogen determinations were preceeded by a blank check in which the above procedure was followed without any soil sample to correct for the presence, if any, of N in the solutions and water used for the determination.

3.4.1.1.3 Soil organic carbon

The Walkley and Black method as modified by Allison (1965) was used to determine organic carbon in the soils. One gram of soil sample was placed in a 500-ml wide neck Erlenmeyer flask and 10 ml of 0.17M potassium dichromate ($K_2Cr_2O_7$) solution was added. The flask was swirled gently to disperse the soil in the solution. Twenty millilitres of H_2SO_4 (97 %) were rapidly added, swirled gently at first then a little more vigorously for about one minute to mix the soil and the reagents. It was left to stand for 30 minutes after which 200 ml of distilled water was added, mixed and allowed to cool. Ten millilitres of 85% phosphoric acid (H_3PO_4) and 3 ml of 0.16% diphenylamine-4-sulphonic acid basalt indicator were added, swirled gently to mix and then titrated with 1M ferrous sulphate ($FeSO_4$) solution to a green colour end-point. The organic carbon determination was preceeded by a blank check in which the same procedure was followed without any soil sample.

The amount of organic carbon was calculated using the formula:

$$\% \text{C} = \frac{(b - s) / (b \times 3)}{W} \times M \times 100 \qquad 3.2$$

where:

b = volume (ml) of $FeSO_4$ used for the titration of the blank.

s = volume (ml) of $FeSO_4$ used for the titration of the sample

factor 3 = equivalent weight of carbon

W = weight (g) of soil

M = moisture correction factor (a ratio of the mass of the moist soil to its oven dry mass at 105 °C). For M estimation, 10 g (any convenient weight can be taken) of the same air-dried soil sample used for the organic carbon determination was taken and oven-dried at 105 °C for 24 hours. The oven-dried weight (say, W_d) was noted.

$$M = \frac{10}{W_d} \qquad 3.3$$

3.4.1.2 Soil physical properties

3.4.1.2.1 Determination of Lower limit (LL), Drained Upper Limit (DUL) and Saturated Upper Limit (SAT) of available soil water

The lower storage limit of soil water is sometimes equated to the moisture content corresponding to moisture potential of –15 bar and it is called the permanent wilting point percentage. While the moisture content corresponding to –15 bar moisture potential may not represent the lowest limit of water available for plant extraction, it is a good approximation in practice. The DUL is estimated as the field capacity which is the volumetric percentage of water remaining in a soil profile 2 or 3 days after having been saturated and after free drainage has practically ceased. The SAT is the moisture content at field saturation (Gardner, 1985). In this study, DUL and SAT were determined by the excavation method of Blake (1965). The Vertisol is very coherent when wet hence slices of the soil of convenient dimensions (e.g. 5 cm length by 5 cm width by 10 cm depth) were excavated from each layer and weighed immediately in the field. The soil moisture contents were determined gravimetrically and multiplied by the dry bulk density of each layer to obtain the volumetric moisture contents. The texture-based empirical equation of Ratliff et al. (1983) and Ritchie and Godwin, (1989) was used to estimate LL. This procedure is contained in the manually-entered soil data software of the DSSAT (Tsuji et al., 1994a). The estimation is based on the following soil properties for which records were available: sand, silt, clay (Asamoa, 1970) and organic carbon contents, moist bulk density (at 1/3 bar). coarse fraction greater than 2 mm as % of whole soil (determined by observation of augured samples), pH in 1:1 soil:water, soil classification, soil horizons, lower and upper depths of each layer, root abundance (observed from augured sample), slope, soil colour, permeability and drainage codes. The DSSAT software provides options that one can select for soil colour, permeability and drainage codes depending on the soil classification. These properties were entered as inputs into the soil data software to generate estimates for the LL of available soil water in cm^3 cm^{-3} for the 4 soil layers considered.

3.4.2 Weather data

The daily weather data for the 1999 and 2000 seasons were compiled from measurements made at the A.R.S. Kpong weather station. The data include rainfall (mm), maximum air temperature (^oC) and minimum air temperature (^oC). Daily solar radiation values (MJ m^{-2} d^{-1}) were obtained from long-term mean daily values for Akuse estimated

Table 3.1 Long term mean daily solar radiation values for selected days in the year at Akuse

Julian day of year (X)	1	15	46	74	105	135	166	196	227	258	288	319	349	365
Solar radiation [kJ m^{-2} d^{-1}], (y)	17987	17836	19427	19552	19134	18589	16077	15407	16287	17082	18924	19469	18171	17998

(Adapted from FAO, 1990)

for some specific days in the year (Table 3.1). Akuse lies about 8 km East of the experimental site in the same eco-climatic zone).

A regression equation (3.1) of the form

$$y = 17.63 + 1.87 \sin(0.0255X + 6.03) \qquad 3.1$$

was used. In equation 3.1, y = daily solar radiation value (kJ m^{-2} d^{-1}) and X = julian day number.

All the necessary daily weather data covering the entire two years 1999 and 2000 are presented in Appendices 1 and 2, respectively.

3.4.3 Crop Data

3.4.3.1 Phenological growth stages

The number of days to germination was determined by conducting a germination test in petri-dishes and the days to emergence determined by observation in the nursery. The days to panicle initiation was determined by cutting through the growing rice plant to observe the developing panicle primordium. The initiation of panicle primordium was generally found to start at about 30 days to heading. This is equivalent to a period starting from 60 days after nursing or direct seeding for a rice variety that takes between 120 to 130 days to mature. This means that, if a 120 to 130-day rice variety (e.g. TOX 3107) was nursed and transplanted at 30 days after nursing, the panicle initiation stage will start from about 30 days after transplanting. A young panicle can be observed with the naked eye or with a magnifying glass when it grows to a length of between 0.5 to 1.0 mm. It is this stage of panicle development that is referred to as panicle initiation. A newly developing panicle appears white in colour, coned in structure and located within the main culm (stem) of the rice plant (Yoshida, 1981; Jones, 1993). Therefore at 30 days after transplanting, two well-developed tillers from each replicated plot of each treatment were cut from the base. The fresh tillers were then cut open lengthwise to observe the newly developing panicle. This procedure was repeated every two days until the young panicle was observed in the majority (50% or more) of the samples.

By convention, days to 50% heading (i.e. panicle exsertion) was taken as days to heading and the day on which 50% flowering was attained was taken as the flowering date. The beginning of grain filling starts about 3 to 4 days after flowering (Yoshida, 1981). Data available did not provide well-defined field indications that will facilitate determination of the beginning of the grain filling. Hence days to 75% flowering was taken as days to the beginning of grain filling. Days to physiological maturity was taken as days to 95% grain ripening (i.e. when spikelets turned yellowish brown) and harvesting was done a day later.

3.4.3.2 Grain yield, leaf area index (LAI), dry matter yield and harvest index

Rice grain samples were harvested from 6 m^2 (6×10^{-4} ha) areas, sun-dried for a few days and the weight, M (kg) as well as the grain moisture content, m.c (%) of each sample taken. The grain yield, Y (kg ha^{-1} paddy) at 14% moisture content was estimated using the general formula (Dekuku, 1993):

$$Y = M \text{ x } \frac{10000 \text{ m}^2}{6 \text{ m}^2} \text{ x } \frac{100 \quad m.c}{86} \qquad 3.4$$

The grain moisture content was measured with an electronic grain moisture meter, the protimeter digital grainmaster (MA-8035-093).

Leaf area index (LAI) is generally defined as:

$$LAI = \frac{\text{sum of the area of all leaves}}{\text{ground area of field where the leaves have been collected}} \qquad 3.5$$

The leaf area index was determined at panicle initiation and beginning of grain filling stages using an electronic leaf area meter. Out of a 1 m^2 area, two well-developed representative tillers of rice were carefully uprooted and kept in water to maintain freshness. All the remaining tillers in the 1 m^2 area were also carefully uprooted, washed to remove any soil lumps and the roots detached. These above-ground portions of the tillers were used to estimate other growth parameters such as biomass and harvest index. The leaves on the two tillers kept in water were individually detached and their total area (A cm^2) determined on an electronic leaf area meter by scanning. The total number (N) of tillers harvested from the 1 m^2 area was noted. By a simple proportion, the LAI was calculated as:

$$\text{LAI} = \frac{\text{A cm}^2 \text{ x N}}{2} \text{ x } \frac{1}{1 \text{ m}^2 \left(10{,}000 \text{ cm}^2\right)} \qquad 3.6$$

All the harvested tillers including the two tillers used for the LAI estimation were oven-dried at 70 °C until a constant weight was attained. At harvest, the sample consisted of the above-ground parts including the grains from the 1 m^2 areas. The oven-dried weights were used to calculate the total biomass in kg ha^{-1}.

The harvest index (H.I.) is defined for a given harvest area by the relationship;

$$\text{H I} = \frac{\text{dry grain yield (kg, paddy)}}{\text{total dry weight (grain + straw) [kg]}} \qquad 3.7$$

The oven-dried weights of grain and above-ground straw from the 1m^2 area were used to calculate the harvest index (H.I) from the relationship given in equation 3.7.

3.4.4 Irrigation

Irrigation data include dates of application, amounts applied per application (mm), total number of applications and total quantity applied in the growing season. Irrigation was by flooding with the dates of application and amounts per application during each experiment presented in Appendix 4.

3.5 Calibration of the CERES-RICE model

The objectives of this study were to calibrate and assess the predictive capability of the CERES-RICE model for the rice variety TOX 3107 under different water treatments and N levels. Model calibration was done using data collected in the 1999 minor cropping season experiment and the calibrated model tested with data collected in the major cropping season experiment as well as an independent data from A.R.S, Kpong.

An important aspect of model calibration is the determination of genetic coefficients (GCs). The authors of the model have already developed two sets of GCs for two groups of rice from trials conducted at the International Rice Research Institute (IRRI), Los Banos, Phillipines. The two groups of rice were designated by the authors as "IRRI originals and IRRI recent" with their assigned GCs as follows:

IRRI Variety	P1* :	P2R :	P5 :	P2O :	G1 :	G2 :	G3 :	G4
Original	880.0	52.0	550.0	12.0	65.0	0.028	1.00	1.00
Recent	450.0	149.0	350.0	11.7	65	0.023	1.00	1.00

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* For the definition of the genetic coefficients, refer to Appendix 3

TOX 3107 originated from IRRI but difficult to classify as IRRI original or recent. Hence, using the IRRI set of GCs one at a time, simulations were run using the field data collected in the 1999 minor season experiment. After a number of trial simulations, the GCs, P1 and P5 had to be adjusted in order to obtain close agreement between simulated and observed values. The set of GCs that gave the best simulated values were:

P1 :	P2R :	P5 :	P2O :	G1 :	G2 :	G3 :	G4
600.0	52.0	300.0	11.7	65	0.023	1.00	1.00

These values were therefore used to calibrate the CERES-RICE model.

A major objective in the application of crop models is to ensure that simulations correctly or closely predict observed phenomena. In this study, statistical criteria were used to determine the goodness of fit for the output of the calibrated CERES-RICE model. This was done by plotting and performing a regression of simulated versus observed values. For a good prediction by the model, a plot of the predicted versus in-season observed data should be close to or on the 1:1 line. This implies that the plot should give a regression slope of or near 1.0, an intercept of or close to 0.0, a high regression coefficient (r) and a low residual standard error.

3.6 Statistical analysis of data

Two statistical packages Genstat® for Windows™ (NAG, 1996) and Sigma Plot® Version 2.01 (Jandel Scientific, 1986) were used to analyse the experimental data. The Genstat statistical software was used for analysis of variance while the Sigma Plot software was used for graphs and bar charts. Level of significance in this study is reported at a probability, $P = 0.05$.

CHAPTER 4

4.0 RESULTS AND DISCUSSION

4.1 Pre-transplanting soil chemical properties

Separate fields, located in the same area, were used for the 1999 and 2000 experiments. The chemical properties determined on soil samples from the experimental fields before transplanting the test crop are presented in Table 4.1.

From Table 4.1, the observed pH range for the upper 0.3-m soil layer in both experiments was 6.9 to 7.4. This compares closely with the optimum range of 7.0 to 7.2 for paddy rice observed in soils elsewhere (Purseglove, 1972). The field used for Experiment 1 (1999 minor season), had been cropped, with ammonium sulphate fertilizer applications, more frequently than the one used for Experiment 2 (2000 major season). This may be the cause of the higher levels of NH_4-N, NO_3-N and organic carbon observed on the 1999 field compared with that of the 2000 field.

4.2 Pre-transplanting soil physical properties

Tables 4.2 and 4.3 present the soil physical properties determined in this study. These properties varied with season but the differences were not very remarkable. For a vertisol the values did not depart markedly from that observed elsewhere. For example the saturated water content (SAT) for vertisols is normally given in the range of 0.5 to 0.6 cm^3cm^{-3} The values observed in this study for the top 0.3 m fell within or close to this range. The seedlings were transplanted onto saturated field moisture conditions hence the values appear on the table the same as for SAT. The bulk density values reported for Vertisols mostly fall within the range 1.0 and 1.5 Mg m^{-3} (Gardner, 1985). The observed wet bulk density values (Table 4.3) appear quite normal for a Vertisol. Some of the input

Table 4.1 Pre-transplanting soil chemical properties.

Soil Depth	pH		NH_4-N		NO_3-N		Total Inorganic-N		Organic-C	
(cm)			(μg g^{-1} soil)		(μg g^{-1} soil)		(μg g^{-1} soil)		g C kg^{-1}	
	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000
0 - 15	6.9	7.1	5.48	3.03	4.08	1.5	9.56	4.53	7.6	6.3
15 - 30	7.3	7.4	3.87	1.8	2.92	1.4	5.79	3.10	4.8	4.5
30 - 45	7.7	7.7	2.84	1.5	1.75	1.30	4.59	2.90	4.5	3.8
45 - 75	7.8	7.9	1.22	1.3	1.75	1.17	2.97	2.47	3.9	2.8

Table 4.2 Pre-transplanting soil physical properties.

Soil Depth	LL †		DUL ‡		SAT ‡‡		Initial M.C #	
(cm)	cm^3cm^{-3}		cm^3cm^{-3}		cm^3cm^{-3}		cm^3cm^{-3}	
	1999	2000	1999	2000	1999	2000	1999	2000
0 - 15	0.234	0.234	0.410	0.420	0.566	0.552	0.566	0.552
15 - 30	0.253	0.253	0.400	0.370	0.500	0.467	0.500	0.467
30 - 45	0.246	0.245	0.420	0.365	0.440	0.380	0.440	0.380
45 - 75	0.187	0.194	0.290	0.380	0.390	0.390	0.390	0.390

† LL - Lower limit of available water; ‡ DUL - Drained upper limit water content; ‡‡ SAT - Saturation water content;

Initial M.C - Moisture content at planting.

data for the estimation of the Lower Limit (LL) of available soil water are also presented in Table 4.3. Others are organic carbon and pH (Table 4.1). The soil colour was black, the slope was 1%, the permeability was very slow and drainage was very poor. The soil was classified as Typic Calciustert (Soil Survey Staff, 1998),

Table 4.3 Some input data for the estimation of Lower Limit (LL), of available soil water.

Soil Depth (cm)	Clay content † (%)	Silt content † (%)	Coarse-F ‡ (%)	Wet bulk-d ‡‡ (Mg m^{-3}) 1999	Wet bulk-d ‡‡ (Mg m^{-3}) 2000	Roots #
0 15	44.8	18.8	1	1.11	1.15	common
15 - 30	49.1	22.9	1	1.40	1.28	many
30 45	48.0	22.0	10	1.27	1.21	few
45 - 75	37.0	19.2	20	1.27	1.28	very few

† Values adapted from Asamoa (1970).

‡ Coarse-F = coarse fraction i.e. soil fraction greater than 2 mm in diameter (estimated by field observation).

‡‡ Wet bulk density at 1/3 bar

Root abundance (estimated by field observation).

4.3 Weather analysis during the 2000 major cropping season

4.3.1 Rainfall

Figure 4.1 shows the rainfall pattern during the 2000 major cropping season. Total rainfall during the growth period of the rice crop (nursing to harvest) was 517.9 mm. This was not adequate to ensure good growth of the crop under rainfed conditions. As a result, the rainfed rice crop suffered moisture stress for most part of the season.

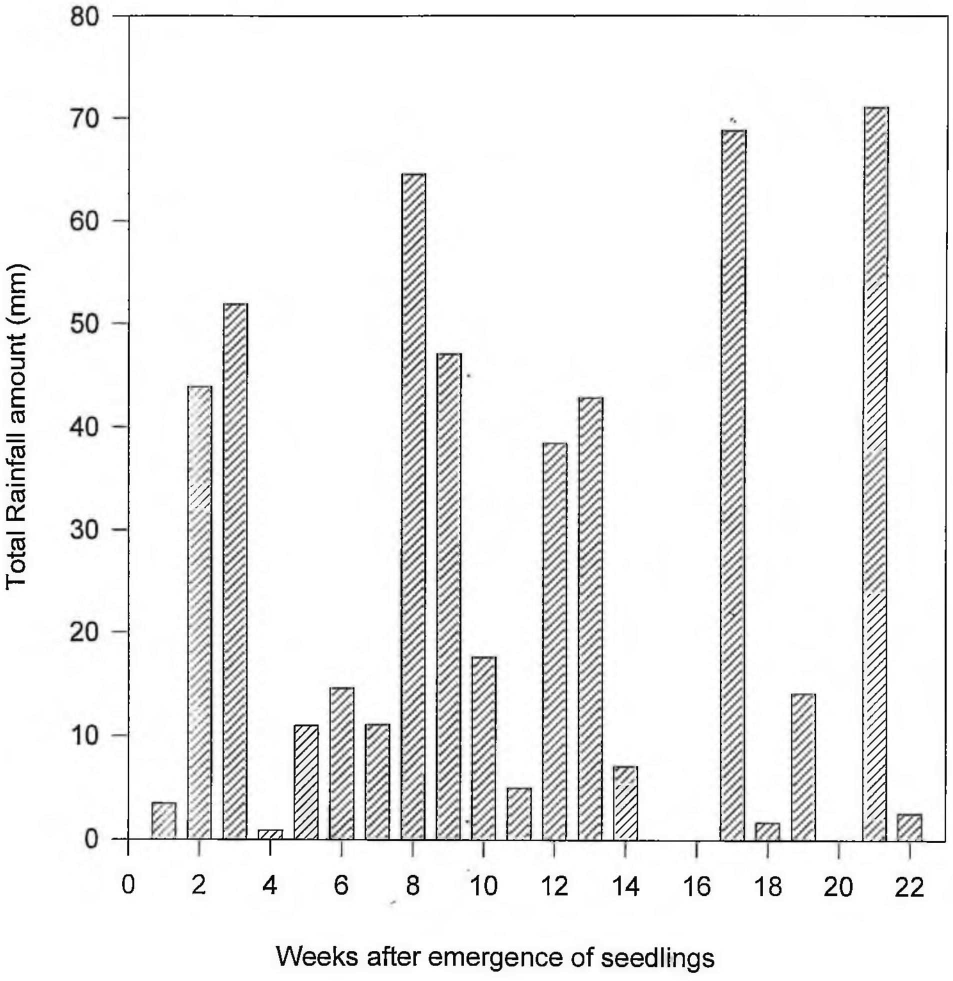


Fig. 4.1 Weekly total rainfall during the 2000 major cropping season.

4.3.2 Solar radiation

Rice productivity is influenced by solar radiation which varies from season to season. Figure 4.2 shows solar radiation trends during the period of the two experiments. Generally, solar radiation values kept rising for a greater part of the minor cropping season but it was the reverse during major cropping season. The minor season is often characterised by clear days with few clouds hence more solar radiation. Cloud cover and more frequent rains characterise the major season leading to lower solar radiation values. These reasons may account for the opposite trends in solar radiation in the 1999 minor and the 2000 major seasons. The trend seems to indicate that rice growth would be different in the two seasons.

4.3.3 Temperature

Temperature trends during the two experiments are presented in Figure 4.3. Temperature values generally increased for a greater part of experiment 1. Clear days and hence higher solar radiation may be the cause of the pattern observed. The temperature decreased steadily during experiment 2, increasing only in weeks 18 to 22 of the cropping period. Cloud cover, lower solar radiation and more frequent rains during the major season may offer some reasons for this pattern.

4.4 Duration of phenological growth stages

The growth duration of a crop variety may be highly location- and season-specific due to varietal sensitivity to photoperiod and temperature. The number of days after emergence taken by the test crop to reach three critical development stages (i.e. panicle initiation, flowering and maturity stages) are given in Table 4.4. The days to panicle initiation was generally the same for all levels of N within a given season.

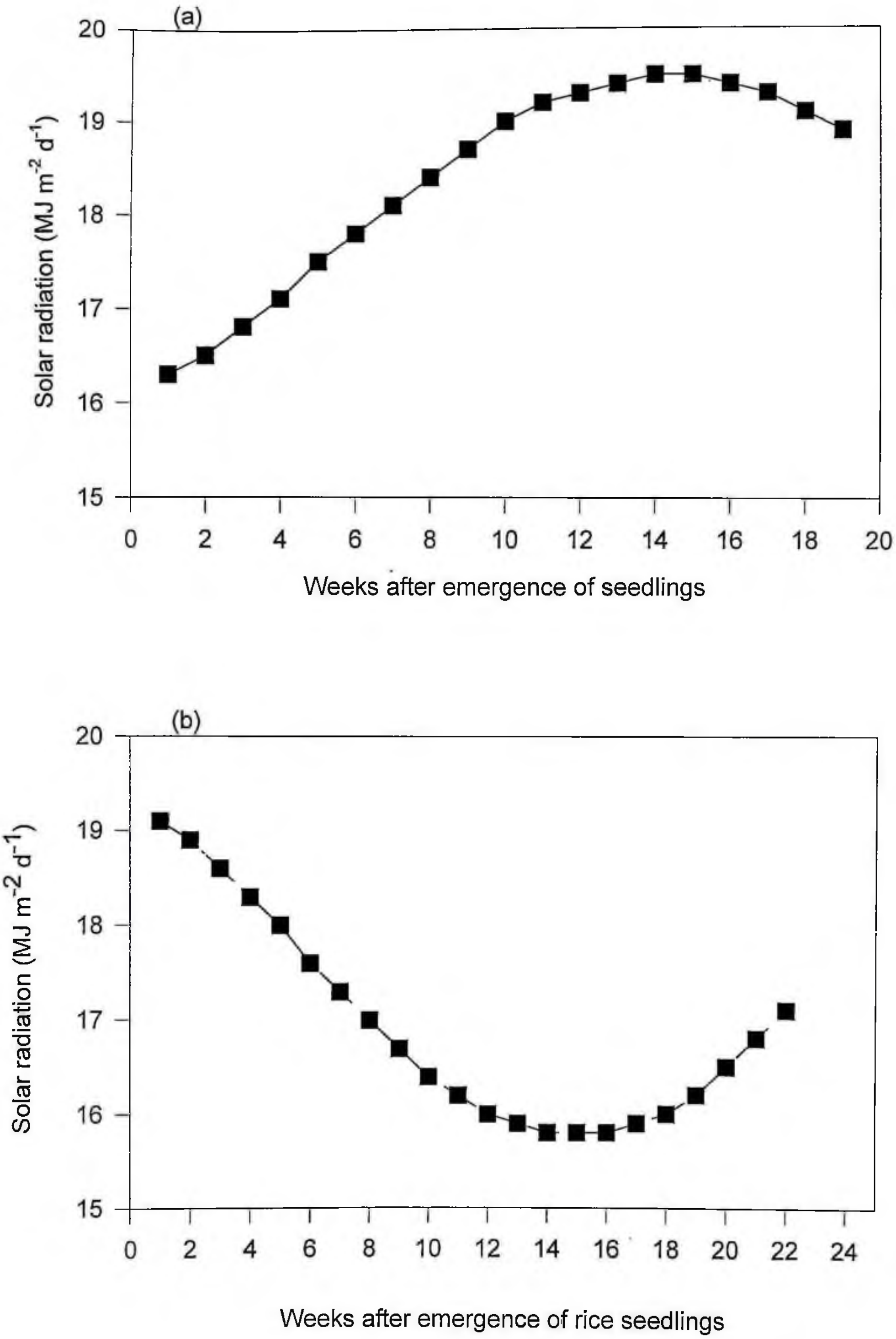
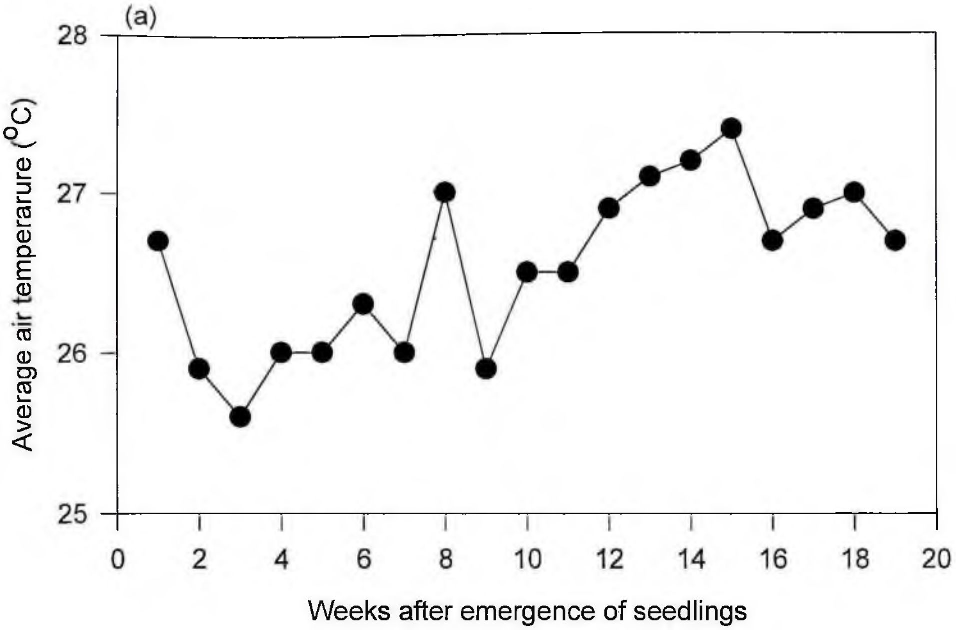


Fig. 4.2 Solar radiation variation during the 1999 minor (a) and 2000 major (b) cropping seasons. Source: FAO (1990) regression model.



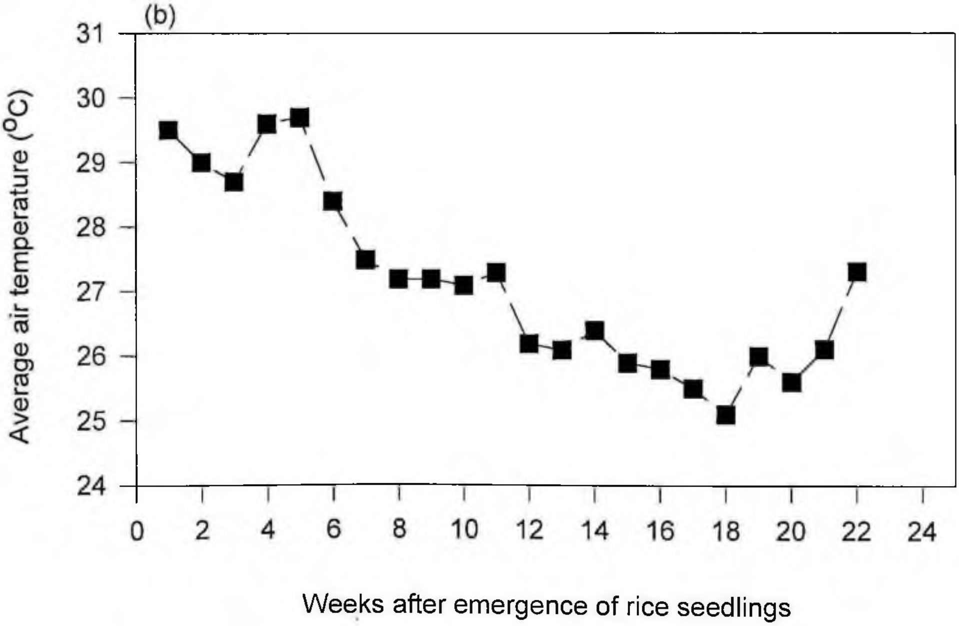


Fig. 4.3 Temperature variation during the 1999 minor (a) and 2000 major (b) seasons.

Table 4. 4 The number of days after emergence taken by the rice variety TOX 3107 to reach three developmental stages in the 1999 minor and 2000 major cropping season experiments.

N level	Panicle Initiation (PI) stage			Flowering stage			Maturity stage		
kg N ha^{-1}	1999	2000		1999	2000		1999	2000	
	Irrigated	Irrigated	Rainfed	Irrigated	Irrigated	Rainfed	Irrigated	Irrigated	Rainfed
0	64	74	74	97	122	119	128	146	144
45	64	74	74	100	123	121	128	146	145
90	64	74	74	105	126	128	130	148	148

The days to flowering and physiological maturity appeared to have been slightly prolonged with increased level of N within each season. This might be due to better N status of the soil.

In spite of the difference between the 90 kg N ha^{-1} and the other two treatments in the number of days taken to reach the flowering stage, the days taken to reach physiological maturity were practically the same in all treatments. In the 2000 major season, the number of days taken to reach the panicle initiation, flowering and physiological maturity stages by the rainfed crop did not vary very much from that of the irrigated crop (Table 4.4). The durations of the various development stages during the 2000 major season were longer than in the 1999 minor season.

Available literature on rice does not clearly explain the effect of N level on rice development. Alagarswamy et al. (1989) noted in their study that the effect of N on crop phenology might not be as large as that of phosphorus (P). This implies that, P rather than N may exert a greater influence on rice phenology. Other studies by Ritchie and Alagarswamy. (1989) and Yoshida, (1981) indicate that temperature and daylength are the major factors that determine development duration.

4.5 Dry matter production

Dry matter (DM) yield is a measure of the photosynthetic performance and crop response to management strategies. About 80-90% of the dry matter of green plants is derived from photosynthesis. The rest, which are minerals, come from the soil (Yoshida, 1981).

The effect of N on DM accumulation of rice under supplementary irrigation conditions during the 1999 minor cropping season is shown with standard error bars in Figure 4.4. At the panicle initiation stage (64 DAE), there was no significant difference in

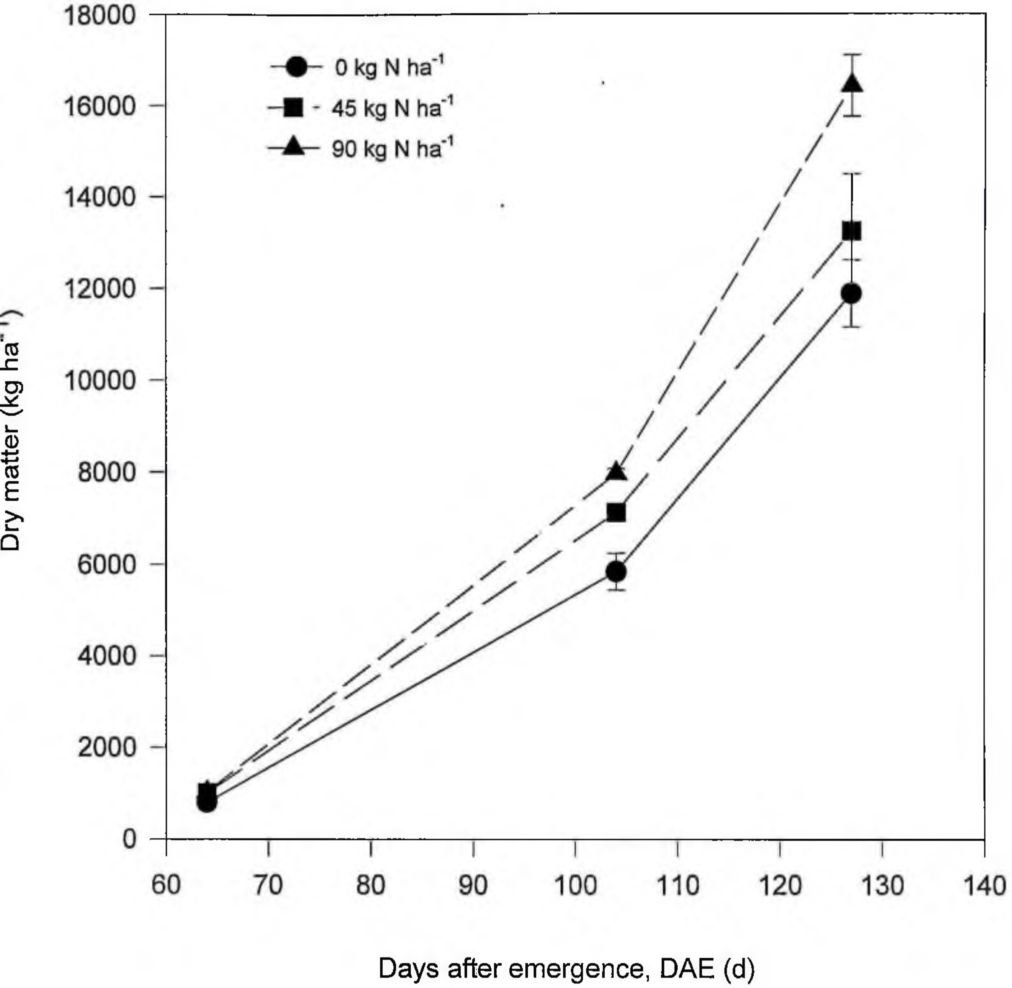


Fig. 4.4 Dry matter yield of the rice variety TOX 3107 under supplementary irrigation conditions in the 1999 minor cropping season. The bars indicate standard errors of the means.

DM yield at different N levels. Differences emerged at the initial grain filling stage (104 DAE), with rice grown under 90 kg N ha^{-1} producing significantly more DM than rice grown under 45 and 0 kg N ha^{-1}. This significant difference in DM was the result of the second split application of N at the panicle initiation stage in the 90 kg N ha^{-1} treatment. At maturity (127 DAE), DM yield of rice under 45 kg N ha^{-1} was higher than but not significantly different from that of rice grown under no N fertilizer. However, the DM yield of rice grown under 90 kg N ha^{-1} was significantly higher than those of rice grown under 45 or 0 kg N ha^{-1}

Figure 4.5 presents the effect of nitrogen on DM accumulation under the supplementary irrigation and rainfed conditions during the 2000 major cropping season. Dry matter production at the panicle initiation stage (74 DAE), was not significantly different among the N treatments in the two water management conditions. At the initial grain filling stage (127 DAE) however, DM accumulation under supplementary irrigation increased and differed significantly at each level of applied N. Results at maturity showed a similar trend. Under rainfed condition, DM yields increased with increasing N at the initial grain filling and maturity stages but these increases were not significant.

A comparison of the total DM at crop maturity between the two irrigated experiments and the rainfed shows the poor performance of the latter (Figure 4.6). This trend was observed for all the other growth parameters and was due to the moisture stress experienced by the rainfed crop. The 2000 major season crop was also better than that of the 1999 minor season due to seasonal effect.

For a good irrigated rice crop, the total DM accumulated at crop maturity was estimated to be between 10 and 20 t ha^{-1} depending on the variety, weather, soil and management practices (Yoshida, 1981). With irrigation, the total DM accumulated at crop maturity, in this study, was within the range of 10 and 20 t ha^{-1} for all levels of N.

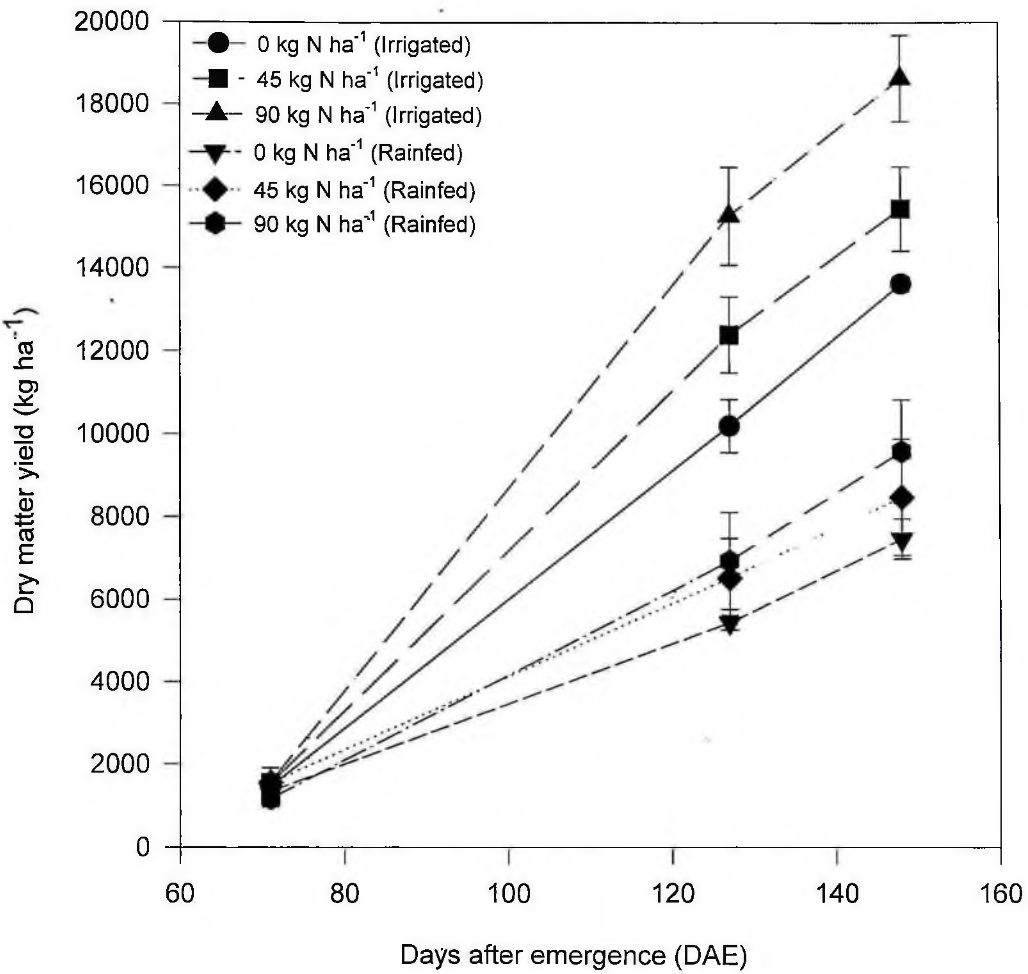


Fig. 4.5 Dry matter yield of the rice variety TOX 3107 under irrigated and rainfed conditions in the 2000 major season experiment. The bars represent standard errors of the means.

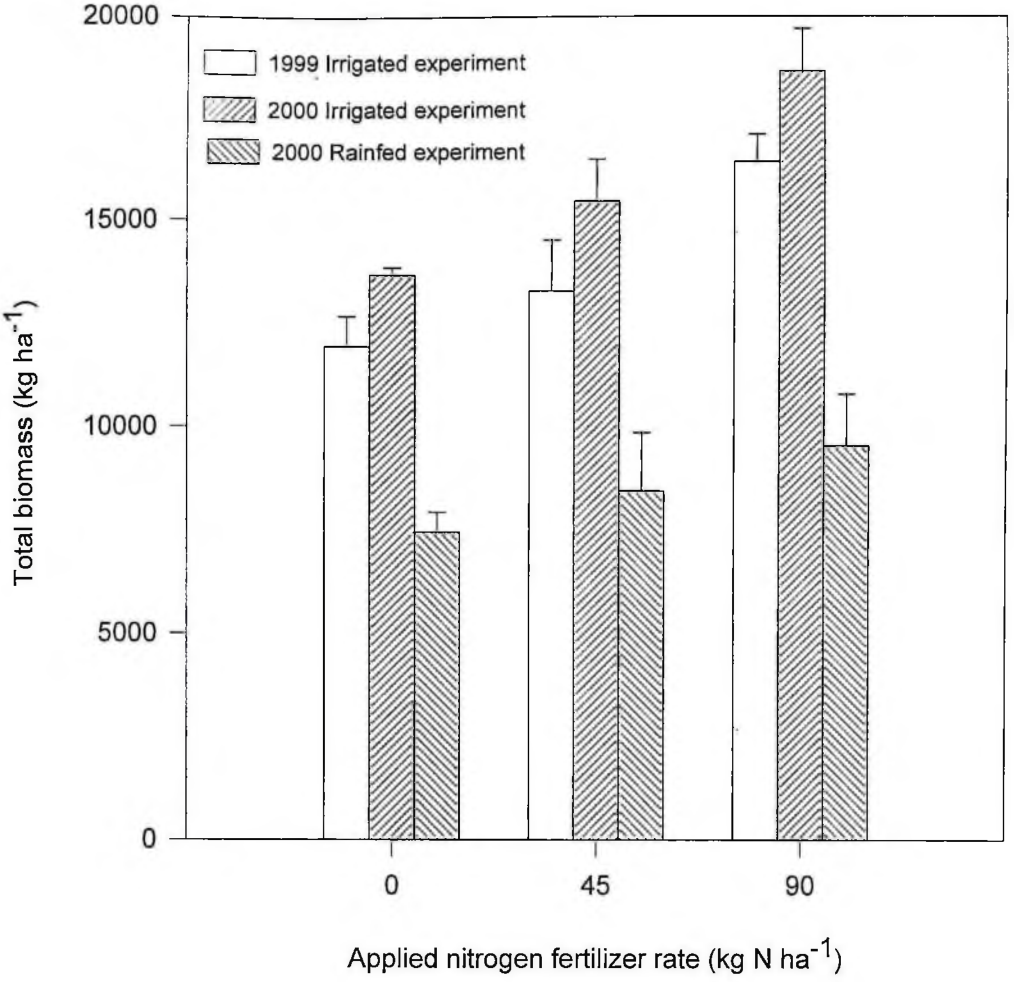


Fig. 4.6 Seasonal above-ground biomass of the rice variety TOX 3107at different N levels under irrigated and rainfed conditions. The bars are standard errors of the means.

However, the DM accumulated under rainfed conditions was lower than 10 t ha^{-1} confirming the useful role of adequate water in minimising drought stress in rice growth.

4.6 Leaf area index (LAI)

Leaf area index is widely used in crop photosynthesis and growth analyses. The LAI values measured at the panicle initiation and initial grain filling stages in both seasons are presented in Table 4.5.

Table 4.5 Nitrogen effect on leaf area index (LAI) at panicle initiation (PI) and initial grain filling (IGF) stages.

N – level †	LAI at PI ‡			LSD_I	LAI at IGF ‡‡			LSD_I
kg N ha^{-1}	1999	2000		(0.05)	1999	2000		
	Irrigated	Irrigated	Rainfed		Irrigated	Irrigated	Rainfed	(0.05)
0	0.86	0.99	NA	0.94	2.63	2.79	NA	1.164
45	0.91	1.29	NA	0.39	3.27	3.99	NA	.97
90	1.24	1.35	1.08	1.76	5.24	6.56	2.08	3.63
LSD(0.05)	0.59	0.51			1.159	2.066		

† N – level = Nitrogen level;

‡ LAI at PI = Leaf area index at panicle initiation stage, 64 days after emergence (DAE) for the 1999 experiment and 74 DAE for the 2000 experiment.

NA = not available.

LSD_I = LSD for the irrigated experiments only.

‡‡ LAI at IGF = Leaf area index at initial grain filling stage, 104 DAE for the 1999 experiment and 127 DAE for the 2000 experiment.

Generally, LAI increased as nitrogen level increased and as growth advanced. In the 1999 experiment, the difference in LAI due to nitrogen was not significant at the panicle initiation stage among the levels of N. However, the LAI observed for the 90 kg N ha^{-1} treatment was significantly higher than that for the other two treatments at the initial grain filling stage. The higher value for the 45 kg N ha^{-1} was not significantly different from that of the 0 kg N ha^{-1} treatment.

During the 2000 major season, no significant difference was observed in LAI among the N levels at PI for the irrigated crop. At the initial grain filling stage, LAI for the 90 kg N ha^{-1} treatment was higher than that of the other two treatments. The higher value for the 45 kg N ha^{-1} showed no significant difference from that of the 0 kg N ha^{-1} treatment. The LAI for the rainfed crop was determined on only the 90 kg N ha^{-1} treatment at PI and IGF stages. In spite of moisture stress, the LAI increased as growth advanced but values for the rainfed condition were lower than those for the irrigated.

Generally, gross photosynthesis and therefore dry matter production have been found to increase curvilinearly with increasing leaf area index (Yoshida, 1981). The amount of dry matter produced largely depends on the leaf area exposed to capture solar energy for photosynthesis. LAI values at maximum crop photosynthesis have been reported to be between 4 and 6 but can be as high as 12 (Tanaka et al., 1966a; Yoshida et al., 1972). Only the LAI values for the 1999 minor and 2000 major season irrigated crops at 90 kg N ha^{-1} at the grain filling stage fell within the reported range (Table 4.5).

4.7 Grain yield

Rice grain (paddy) yields, measured at 14% moisture content, are shown in Table 4.6. The grain yield increased with increased N levels. For the 1999 crop, grain yield for each N level differed significantly from one another showing positive yield response to applied N. In the 2000 irrigated crop, grain yield increase at 90 kg N ha^{-1} was not significantly different from that of 45 kg N ha^{-1} However, grain yield under each of these treatments was higher and differed significantly from that of the 0 kg N ha^{-1} treatment.

Table 4.6 Grain yields (kg ha^{-1}) for 1999 minor and 2000 major season experiments.

Nitrogen level	Grain yield *			LSD(0.05) †
	1999	2000		
(kg N ha^{-1})	Irrigated	Irrigated	Rainfed	
0	4318	4522	2342	295.9
45	4806	6110	2802	1486.3
90	5331	6913	2587	658.5
LSD (0.05)	142.6	1163		

† the LSDs in this column declare significant differences between grain yields of the irrigated treatments only.

* Grain yield was measured at 14% moisture content

Although for all levels of N, grain yields from the 2000 irrigated crop were higher than those from the 1999 minor season irrigated crop, the difference was significant only at the 90 kg N ha^{-1} level. The grain yield from the rainfed experiment (Table 4.6) ranged between 2.3 and 2.8 t ha^{-1} and did not differ very much with increasing N application but compared very poorly with yields from the irrigated plots. Inadequate available water limited the positive impact of applied N on grain yield under the rainfed condition.

4.8 Harvest index (HI)

The harvest index (HI), is considered as the economically useful fraction of the biological yield. It expresses the fraction of total DM that goes into grain production. The harvest index obtained for each treatment in the two experiments are shown in Table 4.7.

Table 4.7 Harvest index values for the 1999 minor and the 2000 major cropping seasons.

Nitrogen level	Harvest index			LSD(0.05) †
	1999	2000		
(kg N ha^{-1})	Irrigated	Irrigated	Rainfed	
0	0.45	0.47	0.38	0.04
45	0.43	0.47	0.38	0.03
90	0.41	0.42	0.30	0.05
LSD (0.05)	0.032	0.051	0.051	

† - LSD values in this column indicate significant differences between HI of the irrigated treatments only.

Harvest Index was highest for the non-fertilised crop and decreased with increasing applied N (Table 4.7). Harvest index values of 0.47 and 0.41 were obtained for 0 and 90 kg N ha^{-1} respectively for the same TOX 3107 on the same soil in other trials at A.R.S, Kpong (Nyalemegbe and Oteng, unpublished). At higher N rates, more straw is produced than grain when compared with the non-fertilised treatment (Table 4.7). Harvest index values of 0.5 and 0.3 have been reported for improved and local rice varieties respectively (Yoshida, 1981. The harvest index values from the rainfed experiment were relatively smaller than those from the irrigated experiments.

4.9 Growth and Development of the Rice Variety TOX 3107

4.9.1 Seasonal effects on rice growth

Rice yields in the tropics are higher in the minor seasons than those in the major seasons. This is due to higher solar radiation levels in the minor season which may promote greater photosynthetic activities (Yoshida and Parao, 1972; Yoshida, 1981; Cassman et al., 1997). In this study, however, growth and development parameters [i.e. dry matter (Fig. 4.6), duration of phenological growth stages (Table 4.4), LAI (Table 4.5), grain yields

(Table 4.6) and HI (Table 4.7)] in the major season were higher than those of the minor season. A number of reasons can be given to explain this observation.

The first is the solar radiation factor. Solar radiation values during the 1999 minor season experiment were generally higher than those in the 2000 major season (Fig. 4.2). Leopold and Kriedemann (1975) noted that photosynthetic yield is higher under intermittent than continuous light. Under intermittent light, dark reactions concerned with carbon dioxide assimilation can proceed to completion during the intervening moments of no sunshine. During the same period of no sunshine, the photosynthetic apparatus have some time to get restored to their full efficiency before the start of a new light phase. This allows for a more efficient utilisation of bright light. The days in the major cropping season are characterised by intermittent sunshine due to rain and cloudy conditions. Daily sunshine in the minor season is more continuous due to clear sky conditions.

The second factor is temperature. In the minor cropping season temperatures were lower than those in the 2000 major season between weeks 1 and 11 after the emergence of rice seedlings (Fig. 4.3). After week 11, the minor cropping season temperatures exceeded those in the 2000 major cropping season. For the first 11 weeks of growth, the minor cropping season temperatures increased steadily while those during the major season decreased quite remarkably (Fig. 4.3). The end of the 11 weeks coincided with the period just after panicle initiation in each season. The steady increases in temperature in the minor season might have caused increases in photosynthetic rate but equally caused increases in respiration rates. Hence, net photosynthesis (photosynthetic production minus respiratory losses) was reduced. The steep decrease in temperatures during the 2000 major season might have reduced respiratory losses hence higher net photosynthesis.

Thirdly, Table 4.4 shows that, the major season crop stayed longer in the field by nearly 3 weeks. The longer duration allowed for more nutrient absorption from the soil and more photosynthetic production which possibly led to higher yields. Dry matter production is found to be inversely related to the mean saturation deficit of the atmosphere (equation 2.3). In the minor season, the relative humidity is usually low leading to a high saturation deficit and hence a lower dry matter production. In the major season, the relative humidity is high causing a low saturation deficit and hence a higher dry matter production.

4.9.2 Seasonal effects on rice development

The major season crop took longer period than the minor season crop for each of the three phenological growth stages (Table 4.4). For the air temperature range of 22 to 31 °C, biochemical reactions within the rice plant are known to increase with increasing temperatures (Yoshida, 1981). This might have happened during the minor season where mean daily temperatures increased over the growth period (Figure 4.3). As a result, the crop's growth rate might have increased leading to early maturity. In the major season, temperatures generally decreased, which likely reduced the rate of the crop's physiological growth processes. Thus, a longer time was needed to complete growth processes leading to the longer durations observed for the various phenological growth stages in the 2000 season.

The rice crop grows in phases or stages. Each phase requires a specific amount of accumulated heat units for completion before the next phase begins. Cloud cover coupled with decreasing mean daily temperatures in the major season, resulted in more days being needed to attain the requisite accumulated heat units for completion of the various growth stages thereby leading to longer growth period. The minor season was characterised by clearer days and high temperatures, thus taking a shorter time to attain the necessary accumulated heat units and therefore, shorter growth period.

4.10 Model Calibration

Results of the model calibration using the data for the supplementary irrigation treatments during the 1999 minor cropping season at 0, 45 and 90 kg N ha^{-1} are shown in Table 4.8. Development parameters (panicle initiation, flowering and physiological maturity periods) were closely predicted in all the N treatments. Growth or productivity parameters such as weight per grain, biomass and stalk at harvest as well as harvest index were also closely predicted in all the N treatments. Prediction of panicle number per square metre and biomass at anthesis were fair. However, grain yield and maximum LAI predictions were poor as these parameters were over-predicted at all levels of N.

The results of the goodness of fit test for the 1999 minor season data is shown in Figure 4.8. The plot of the simulated versus the measured grain yield gave a slope of 2.85, a y-intercept of – 6.90 t ha^{-1} and and r^2 of 0.99 (Fig. 4.7a). The plot of simulated versus the measured total biomass at harvest however produced a good fit with a slope = 1.0, y-intercept = -0.52 t ha^{-1} and r^2 = 0.86 (Fig. 4.7b). The plot of the simulated versus the measured biomass accumulation in the 90 kg N ha^{-1} treatment gave a slope = 0.62, y-intercept = 6.51 t ha^{-1} and r^2 = 0.86 (Fig. 4.7c). The calibrated model predicted only the total biomass at harvest well. Its prediction of grain yield and biomass accumulation at 90 kg N ha^{-1} did not agree with measured values of the parameters.

Table 4.8 Comparison of predictions during model calibration and measured parameters for three levels of N during the 1999 minor cropping season irrigated experiment

		0 kg N ha^{-1}		45 kg N ha^{-1}		90 kg N ha^{-1}	
No.	Parameters	Predicted	Measured	Predicted	Measured	Predicted	Measured
1.	Panicle initiation date (dap)	69	64	69	64	69	64
2.	Flowering date (dap)	98	97	101	100	102	105
3.	Physiological maturity (dap)	125	128	127	128	129	130
4.	Grain yield (kg ha^{-1}) at 14% m.c	5408	4318	6839	4806	8300	5331
5.	Weight per grain (g)	0.023	0.026	0.023	0.026	0.023	0.026
6.	Grain number per square metre	20221	22416	25571	23867	31034	28168
7.	Panicle number per square metre	321	250	336	228	351	308
8.	Maximum leaf area index	5.66	2.63	9.29	3.26	10.9	5.24
9.	Biomass (kg ha^{-1}) at anthesis	6973	5846	9408	7133	11021	7976
10.	Biomass (kg ha^{-1}) at harvest	10661	11895	13793	13253	15614	16425
11.	Stalk (kg ha^{-1}) at harvest	6010	6556	7912	7615	8476	9785
12.	Harvest index	0.44	0.45	0.43	0.43	0.46	0.41

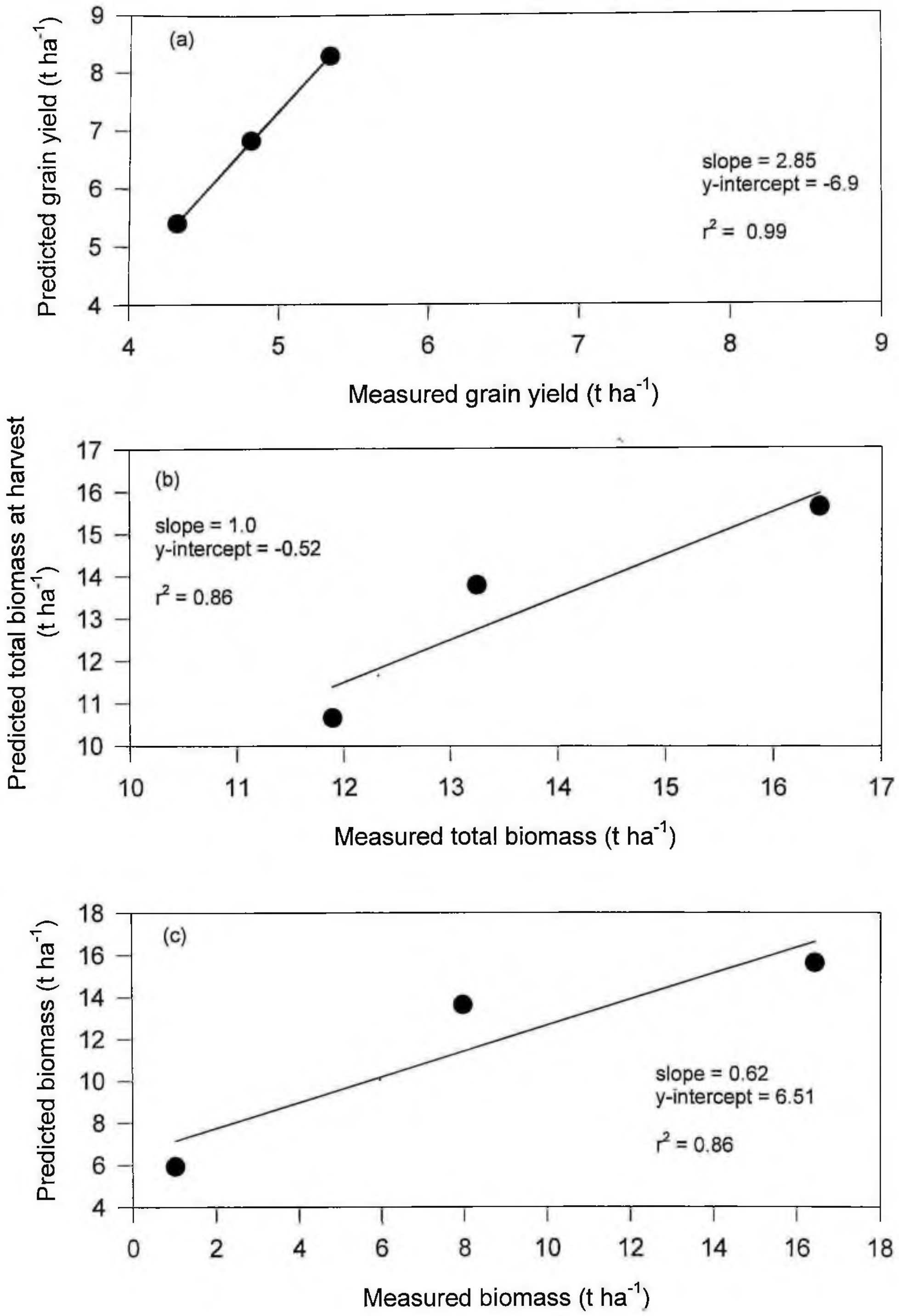


Fig. 4.7 Relationship between predicted and grain yields (a), total biomass at harvest for all levels of N (b) and biomass accumulation in the 90 kg N ha^{-1} treatment (c) during the 1999 minor cropping season.

4.11 Test of the calibrated model

4.11.1 Test of the calibrated model using the 2000 major season data

The 2000 major season data were used to test the performance of the calibrated model. The results of the predicted and measured values for the supplementary irrigation and rainfed treatments are presented in Tables 4.9 and 4.10 respectively. Tables 4.9 and 4.10 show clearly that the calibrated model generally failed to predict reasonably well the development and productivity of rice for both the irrigated and rainfed major season crops. The poor prediction is probably due to seasonal effects on the development and productivity of the rice variety TOX 3107. The crop growth coefficients that gave fairly good predictions during the calibration tests for the year 1999 were based on the prevailing growth conditions. However, TOX3107 performed differently during the minor and major cropping seasons. Hence the apparent inability of the calibrated model to predict reasonably well the development and productivity of the rice variety during the major cropping season. Also, the calibrated model did not respond to the rainfed conditions as predictions of development and growth parameters for both irrigated and rainfed conditions were almost similar. Consequently, more studies may have to be conducted to address these problems.

4.11.2 Test of the calibrated model using an independent data

The testing of the calibrated model was done using limited independent data from experiments in which rice was planted in January 1999 (prior to this study) by a different experimenter. The term "limited data" was used because (i) the experiment was performed at only one nitrogen level, 90 kg N ha^{-1} (ii) the available experimental data lacked some of the necessary input data for simulation studies such as irrigation data. These were reasonably supplemented with some of the field data from this study because the same rice

Table 4.9 Predicted and measured data for three levels of N during 2000 major season irrigated experiment.

		0 kg N ha^{-1}		45 kg N ha^{-1}		90 kg N ha^{-1}	
No.	Parameters/Variables	Predicted	Measured	Predicted	Measured	Predicted	Measured
1.	Panicle initiation date (dap)	46	74	69	74	46	74
2.	Flowering date (dap)	75	122	79	123	79	126
3.	Physiological maturity (dap)	101	146	105	146	105	148
4.	Grain yield (kg ha^{-1}) at 14% m.c	1923	4522	4288	6110	5092	6913
5.	Weight per grain (g)	0.023	0.026	0.023	0.026	0.023	0.026
6.	Grain number per square metre	7190	24471	16032	28144	19040	30096
7.	Panicle number per square metre	318	239	588	315	672	321
8.	Maximum leaf area index	0.99	2.79	3.15	3.99	3.27	6.56
9.	Biomass (kg ha^{-1}) at anthesis	1834	10188	4764	12383	4985	15265
10.	Biomass (kg ha^{-1}) at harvest	3090	13610	7747	15443	8903	18645
11.	Stalk (kg ha^{-1}) at harvest	1436	7270	4060	8125	4523	10820
12.	Harvest index	0.54	0.47	0.48	0.47	0.49	0.42

Table 4.10 Predicted and measured data for three levels of N during 2000 major season rainfed experiment.

		0 kg N ha^{-1}		45 kg N ha^{-1}		90 kg N ha^{-1}	
No.	Parameters/Variables	Predicted	Measured	Predicted	Measured	Predicted	Measured
1.	Panicle initiation date (dap)	46	74	46	74	46	74
2.	Flowering date (dap)	75	119	79	121	79	128
3.	Physiological maturity (dap)	101	144	105	145	105	148
4.	Grain yield (kg ha^{-1}) at 14% m.c	1936	2342	4296	2803	5095	2587
5.	Weight per grain (g)	0.023	0.026	0.023	0.026	0.023	0.026
6.	Grain number per square metre	7241	11038	16065	12538	19053	11240
7.	Panicle number per square metre	319	271	583	276	664	299
8.	Maximum leaf area index	0.99	ND†	3.16	ND†	3.27	2.08
9.	Biomass (kg ha^{-1}) at anthesis	1839	5415	4772	4085	4988	6907
10.	Biomass (kg ha^{-1}) at harvest	3118	7438	7776	8453	8908	9560
11.	Stalk (kg ha^{-1}) at harvest	1453	4568	4081	5192	4526	6638
12.	Harvest index	0.53	0.38	0.47	0.38	0.49	0.30

† ND – Not Determined

variety was grown on the same soil. Field management practices were also similar. The predictions were done for only three parameters because these were the only measured data in that experiment. The results are presented in Table 4.11

Table 4.11 Comparison of predicted and measured parameters for TOX 3107 grown under irrigated conditions in January 1999.

Growth and development parameter	Predicted	Measured
Days after seeding to flowering	91	113
Days after seeding to maturity	117	134
Grain yield (kg ha^{-1}) at 14% m.c	5623	6387

From Table 4.11, days to flowering and maturity were poorly predicted but the prediction for rice grain yield was fairly good. As stated earlier, all the necessary input data for this simulation were not available. Perhaps better predictions would have been obtained if they were available.

4.12 Application of the calibrated model

An inevitable requirement for the application of a calibrated model is a high predictive capability. This is determined from the goodness of fit of its simulations. From section 4.10. the goodness of fit for simulations of the calibrated model, generally, did not give indications of its high predictive capability. This introduced a serious constraint on its application to assess the output of different nutrient levels, field management or weather scenarios.

CHAPTER 5

5.0 CONCLUSION

This study examined the performance of the lowland rice variety, TOX 3107, under two different water treatments and at three different nitrogen fertilizer levels during the 1999 minor and 2000 major cropping seasons. Field data collected during the 1999 minor season experiment were used to calibrate the CERES-RICE model of DSSAT version 3.5. The calibrated model was validated (tested) to evaluate its simulation performance using data from the 2000 major season experiment and an independent data set.

5.1 The performance of TOX 3107 under different water management and different levels of nitrogen fertilizer application

The growth of the test crop, TOX 3107, under supplementary irrigation was better at all nitrogen levels compared with that observed under solely rainfed conditions. While grain yield and dry matter production responded positively to different levels of applied nitrogen under supplementary irrigation, their response to levels of N was poor under the rainfed condition. This was the result of the moisture deficit and its attendant poor nutrient uptake and utilization. It also showed the effect of insufficient field moisture on the productivity of the lowland rice crop.

In spite of the moisture stress under the solely rainfed condition, the number of days taken by the crop to reach the various phenological growth stages was similar for both rainfed and irrigated treatments during the 2000 major season.

With respect to plant development, the levels of applied nitrogen did not result in significant differences in the duration of phenological growth stages.

5.2 Seasonal effects on the performance of the irrigated rice crop

Rice growth and development were affected by a change in cropping season, largely due to weather conditions which are season-specific. The major season crop yielded more dry matter and grain than the minor season crop contrary to observations by Yoshida (1981). This was observed for all levels of applied nitrogen. The number of days taken to reach the various phenological growth stages was also found to be longer for the major season crop. These results further emphasise the importance of the time of planting.

5.3 Calibration of the DSSAT CERES-RICE model

The development of the test crop (i.e. days after emergence to three selected growth stages namely panicle initiation, flowering and physiological maturity) was closely predicted in all the N treatments. While some growth or productivity parameters were closely predicted, others particularly, grain yield and maximum leaf area index were not. Grain yield and leaf area index are important growth parameters hence further study would be useful in order to achieve good prediction of these.

5.4 Test of the calibrated model

The calibrated model did not predict reasonably well the development and productivity of rice when tested with data from both the irrigated and rainfed major season experiment as well as with an independent data. A further study on the model calibration is suggested to consider the issue of seasonal effect and genetic coefficients.

5.5 Application of the calibrated model

Results of the goodness of fit test for predicted versus measured values of the calibrated model did not give indications of good prediction. This made its application to different scenarios impossible. It is necessary to address this situation through further study.

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APPENDIX 1

1999 DAILY WEATHER DATA FOR AGRICULTURAL RESEARCH STATION, KPONG †

JULIAN DATE	SOLAR RAD. MJ/m^2/d	MAX. TEMP. °C	MIN. TEMP. °C	RAINFALL mm
99001	17.2	33.9	24.4	0.0
99002	17.2	34.0	23.1	0.0
99003	17.3	34.3	23.9	0.0
99004	17.3	35.0	24.1	0.0
99005	17.4	33.6	24.4	2.0
99006	17.4	29.6	22.8	0.0
99007	17.5	32.5	22.2	0.0
99008	17.5	32.6	21.6	0.0
99009	17.6	32.3	21.6	0.0
99010	17.6	32.2	22.7	0.0
99011	17.7	32.0	22.5	0.0
99012	17.7	32.7	22.2	0.0
99013	17.8	34.5	22.8	0.0
99014	17.8	33.7	23.5	0.0
99015	17.9	33.4	23.7	0.0
99016	17.9	32.8	23.7	0.0
99017	18.0	34.2	23.7	0.0
99018	18.0	35.6	23.4	0.0
99019	18.1	33.9	25.4	0.0
99020	18.1	33.7	24.3	0.0
99021	18.1	34.1	23.4	0.0
99022	18.2	34.5	23.1	0.0
99023	18.2	34.4	24.1	0.9
99024	18.3	34.0	21.8	0.0
99025	18.3	33.1	22.7	0.0
99026	18.4	33.5	21.9	0.0
99027	18.4	34.0	22.2	0.0
99028	18.5	35.2	21.1	0.0
99029	18.5	34.5	22.8	0.0
99030	18.5	34.3	23.5	0.0
99031	18.6	35.2	21.7	0.0
99032	18.6	35.0	24.1	4.7
99033	18.7	34.7	22.4	0.0
99034	18.7	35.0	22.8	0.6
99035	18.7	32.5	22.4	0.0
99036	18.8	34.2	19.6	0.0
99037	18.8	33.2	19.4	0.0
99038	18.9	31.7	17.7	0.0
99039	18.9	34.6	15.2	0.0
99040	18.9	36.2	17.8	0.0
99041	19.0	35.0	21.1	0.0
99042	19.0	34.5	22.4	0.0
99043	19.0	35.0	23.6	0.0
99044	19.1	36.0	23.6	0.0
99045	19.1	36.2	23.9	0.0
99046	19.1	34.9	25.1	2.5
99047	19.1	30.6	21.1	9.0
99048	19.2	34.7	21.2	0.7
99049	19.2	33.2	22.8	0.0
99050	19.2	33.5	22.9	0.0
99051	19.2	34.3	23.9	0.0
99052	19.3	34.9	21.8	0.0
99053	19.3	35.3	22.2	0.0
99054	19.3	32.0	21.1	0.0
99055	19.3	36.0	23.4	0.0
99056	19.3	34.9	25.0	0.0
99057	19.4	35.5	25.0	0.0
99058	19.4	36.0	25.1	8.3
99059	19.4	32.6	20.4	0.0
99060	19.4	35.6	22.2	0.0
99061	19.4	34.9	21.9	0.0
99062	19.4	37.2	24.4	0.0
99063	19.5	36.4	22.9	1.4
99064	19.5	32.4	22.4	0.0
99065	19.5	36.5	23.3	0.0
99066	19.5	35.7	25.0	3.2
99067	19.5	35.5	23.6	0.0
99068	19.5	34.0	24.0	0.0
99069	19.5	36.3	24.9	0.1
99070	19.5	34.5	22.2	0.0
99071	19.5	34.9	23.9	1.6
99072	19.5	33.5	20.8	18.7
99073	19.5	33.5	20.3	0.0
99074	19.5	35.1	22.4	0.0
99075	19.5	36.0	20.6	7.1
99076	19.5	34.9	20.6	0.0
99077	19.5	35.3	20.2	17.7
99078	19.5	34.2	20.7	0.0
99079	19.5	34.5	23.6	0.0
99080	19.5	34.6	24.6	0.0
99081	19.4	34.9	24.4	3.2
99082	19.4	34.9	24.6	0.0
99083	19.4	34.9	23.4	0.0
99084	19.4	36.0	24.4	4.8
99085	19.4	35.0	23.8	0.0
99086	19.4	35.1	24.2	0.0

99087	19.4	36.5	24.4	0.0
99088	19.3	36.8	24.2	0.0
99089	19.3	37.3	22.9	0.0
99090	19.3	36.7	24.4	0.0
99091	19.3	36.1	23.5	14.1
99092	19.2	31.8	20.8	0.0
99093	19.2	35.0	21.8	0.0
99094	19.2	34.7	24.0	0.0
99095	19.2	35.5	26.6	0.0
99096	19.1	35.8	22.8	8.4
99097	19.1	32.5	22.2	0.0
99098	19.1	31.5	23.7	0.0
99099	19.1	35.5	22.6	0.0
99100	19.0	35.0	23.9	0.0
99101	19.0	37.0	24.4	0.0
99102	19.0	36.3	25.2	0.0
99103	18.9	36.6	23.9	0.0
99104	18.9	36.0	24.7	0.0
99105	18.9	33.2	24.4	0.0
99106	18.8	36.8	24.2	0.0
99107	18.8	30.2	21.2	19.4
99108	18.7	34.0	20.1	0.0
99109	18.7	35.5	23.1	0.0
99110	18.7	35.1	25.3	0.0
99111	18.6	35.1	20.7	15.9
99112	18.6	31.5	20.6	6.9
99113	18.5	35.0	21.7	0.0
99114	18.5	34.4	21.7	0.0
99115	18.5	34.5	22.2	0.0
99116	18.4	35.8	22.6	0.0
99117	18.4	32.0	22.2	0.0
99118	18.3	34.3	21.8	18.4
99119	18.3	34.3	21.8	18.4
99120	18.3	33.2	21.7	0.0
99121	18.2	33.2	24.9	0.0
99122	18.2	34.8	22.1	0.0
99123	18.2	35.6	24.8	0.0
99124	18.1	35.4	25.0	0.0
99125	18.1	35.2	23.3	0.0
99126	18.0	35.4	23.2	0.0
99127	18.0	35.5	25.0	0.0
99128	17.9	35.4	24.1	0.0
99129	17.9	35.0	24.1	0.0
99130	17.8	34.2	23.6	6.5
99131	17.8	29.5	20.7	0.0
99132	17.7	34.0	21.3	0.0
99133	17.7	33.7	23.4	0.0
99134	17.6	34.2	22.2	1.9
99135	17.6	33.0	22.1	3.8
99136	17.5	31.7	23.2	2.2
99137	17.5	32.9	22.7	0.0
99138	17.4	35.0	22.5	0.0
99139	17.4	35.2	23.6	0.0
99140	17.4	33.1	22.6	23.5
99141	17.3	26.5	21.2	2.7
99142	17.3	31.9	20.7	0.0
99143	17.2	34.1	21.4	0.0
99144	17.2	34.3	22.8	0.0
99145	17.1	34.1	22.8	0.3
99146	17.1	33.8	22.5	9.1
99147	17.0	33.7	22.5	0.0
99148	17.0	32.4	23.3	4.4
99149	16.9	32.6	22.8	0.7
99150	16.9	33.0	23.8	2.4
99151	16.9	30.8	23.2	7.1
99152	16.8	32.9	22.2	0.0
99153	16.8	34.0	22.2	0.0
99154	16.7	34.7	23.8	86.6
99155	16.7	27.1	21.0	13.7
99156	16.6	31.0	21.2	30.0
99157	16.6	31.0	21.7	0.0
99158	16.6	32.5	22.8	0.0
99159	16.5	32.8	22.4	0.0
99160	16.5	33.9	22.9	0.0
99161	16.4	33.4	21.7	11.5
99162	16.4	32.5	21.7	0.0
99163	16.4	33.1	21.3	34.5
99164	16.3	30.5	21.3	2.7
99165	16.3	32.5	21.5	0.0
99166	16.3	33.5	23.4	0.0
99167	16.2	33.5	20.6	34.4
99168	16.2	31.9	20.6	0.0
99169	16.2	32.6	20.1	36.1
99170	16.1	29.7	20.1	0.0
99171	16.1	28.6	22.8	0.1
99172	16.1	30.6	22.2	0.2
99173	16.1	32.6	21.6	0.0
99174	16.0	32.3	23.8	16.5
99175	16.0	30.0	23.3	0.1
99176	16.0	27.8	22.9	11.4
99177	16.0	30.2	21.3	0.1
99178	15.9	31.8	21.8	0.2
99179	15.9	29.6	21.6	37.7
99180	15.9	29.9	21.6	0.0
99181	15.9	31.7	22.2	9.7
99182	15.9	30.7	22.1	0.2
99183	15.9	31.5	22.3	0.0
99184	15.8	26.7	22.8	1.6
99185	15.8	31.3	21.4	0.0
99186	15.8	33.0	21.8	0.0
99187	15.8	25.5	20.4	13.5
99188	15.8	30.3	20.2	0.0

99189	15.8	33.0	21.2	27.0
99190	15.8	31.5	20.5	1.5
99191	15.8	31.7	21.6	0.2
99192	15.8	30.7	22.4	0.4
99193	15.8	30.2	21.4	0.0
99194	15.8	30.2	22.2	5.6
99195	15.8	28.8	22.2	0.0
99196	15.8	30.6	22.3	0.0
99197	15.8	29.6	22.8	2.5
99198	15.8	29.2	22.0	0.0
99199	15.8	28.4	22.3	2.2
99200	15.8	28.6	22.0	0.6
99201	15.8	29.7	21.8	19.2
99202	15.8	29.1	22.6	0.0
99203	15.8	30.2	21.1	0.0
99204	15.8	30.9	22.2	0.0
99205	15.8	31.0	23.0	0.0
99206	15.8	30.0	23.3	0.0
99207	15.8	30.4	23.0	0.0
99208	15.8	30.1	22.1	0.0
99209	15.9	31.6	22.3	0.0
99210	15.9	31.5	22.8	0.0
99211	15.9	29.5	22.6	0.0
99212	15.9	28.9	22.5	0.0
99213	15.9	30.5	22.7	0.0
99214	16.0	31.8	22.2	0.0
99215	16.0	31.5	21.8	0.0
99216	16.0	32.0	21.8	0.0
99217	16.0	30.5	20.8	0.0
99218	16.0	31.4	19.6	0.0
99219	16.1	32.5	21.1	0.0
99220	16.1	30.7	21.6	0.0
99221	16.1	31.0	21.4	0.0
99222	16.2	33.3	21.6	0.0
99223	16.2	32.9	21.6	6.0
99224	16.2	30.5	22.2	1.6
99225	16.2	31.9	22.3	0.0
99226	16.3	32.1	21.7	0.0
99227	16.3	31.0	21.1	0.0
99228	16.3	31.8	20.5	0.0
99229	16.4	32.4	21.3	0.0
99230	16.4	29.5	22.8	1.6
99231	16.5	30.4	22.8	6.1
99232	16.5	29.5	22.2	13.0
99233	16.5	30.6	22.2	0.5
99234	16.6	30.5	22.4	6.0
99235	16.6	26.6	21.7	13.4
99236	16.6	29.2	21.7	0.0
99237	16.7	31.0	21.1	0.0
99238	16.7	29.5	22.3	0.6
99239	16.8	29.6	22.8	0.7
99240	16.8	27.5	21.5	7.7
99241	16.9	30.0	20.7	0.0
99242	16.9	31.0	19.4	0.0
99243	16.9	32.0	20.2	23.0
99244	17.0	31.8	21.3	0.0
99245	17.0	31.7	22.2	0.0
99246	17.1	30.3	22.5	2.1
99247	17.1	29.0	21.9	0.0
99248	17.2	30.1	21.2	0.0
99249	17.2	31.0	20.5	0.0
99250	17.3	31.0	19.7	2.0
99251	17.3	29.1	20.7	0.2
99252	17.4	29.5	22.1	0.0
99253	17.4	30.1	21.7	0.0
99254	17.5	30.2	22.4	1.6
99255	17.5	30.0	21.9	0.0
99256	17.6	32.0	20.6	0.0
99257	17.6	31.7	21.8	7.6
99258	17.6	31.2	21.9	0.8
99259	17.7	31.7	21.2	42.6
99260	17.7	30.9	22.2	0.0
99261	17.8	31.5	21.9	30.0
99262	17.8	31.3	20.1	1.1
99263	17.9	31.7	21.0	0.0
99264	17.9	31.2	20.6	22.8
99265	18.0	27.3	20.6	0.0
99266	18.0	32.5	22.1	0.0
99267	18.1	32.0	22.3	0.0
99268	18.1	32.8	21.1	0.0
99269	18.2	32.6	22.3	0.0
99270	18.2	30.5	22.5	0.7
99271	18.3	31.6	22.4	0.0
99272	18.3	31.2	21.6	11.3
99273	18.3	31.2	21.6	0.0
99274	18.4	33.0	22.1	0.0
99275	18.4	31.5	23.0	0.0
99276	18.5	32.5	22.7	0.0
99277	18.5	32.0	22.4	4.7
99278	18.6	30.5	22.8	10.9
99279	18.6	28.7	20.3	0.0
99280	18.6	31.0	21.1	3.2
99281	18.7	29.6	22.2	7.3
99282	18.7	31.3	20.7	0.0
99283	18.8	31.4	20.5	8.0
99284	18.8	30.7	21.1	0.0
99285	18.8	32.2	22.4	1.9
99286	18.9	32.0	22.2	0.0
99287	18.9	32.2	21.2	0.0
99288	18.9	31.1	21.8	0.0
99289	19.0	32.2	21.3	0.0
99290	19.0	31.1	21.3	32.8

99291	19.0	31.6	20.6	5.2
99292	19.2	31.8	21.0	0.2
99293	19.1	31.2	22.0	2.8
99294	19.1	31.5	21.0	0.0
99295	19.1	33.4	20.6	0.0
99296	19.2	32.0	21.7	0.1
99297	19.2	31.8	21.7	21.0
99298	19.2	31.0	19.7	0.0
99299	19.3	31.8	21.9	0.3
99300	19.3	30.5	21.3	0.5
99301	19.3	32.6	21.8	0.0
99302	19.3	32.5	22.4	18.9
99303	19.3	32.5	21.9	1.2
99304	19.4	32.6	21.2	0.0
99305	19.4	31.2	22.7	0.0
99306	19.4	32.5	20.7	0.2
99307	19.4	32.7	21.1	0.6
99308	19.4	31.5	22.1	0.0
99309	19.4	32.8	22.0	0.3
99310	19.4	32.6	21.7	1.4
99311	19.5	32.7	21.1	31.2
99312	19.5	33.0	20.7	0.0
99313	19.5	33.0	22.2	0.0
99314	19.5	33.0	22.1	3.1
99315	19.5	33.0	22.4	0.0
99316	19.5	32.2	21.3	11.1
99317	19.5	33.5	20.8	35.2
99318	19.5	32.6	21.6	0.0
99319	19.5	33.0	20.1	0.0
99320	19.5	32.8	22.2	0.0
99321	19.5	32.7	21.7	0.0
99322	19.5	32.6	21.7	0.5
99323	19.5	32.0	21.9	0.0
99324	19.5	33.1	22.4	0.0
99325	19.5	33.0	21.9	0.0
99326	19.5	33.0	22.7	1.2
99327	19.5	32.5	22.1	3.3
99328	19.4	32.5	20.2	0.0
99329	19.4	33.0	22.2	15.3
99330	19.4	32.1	21.7	6.1
99331	19.4	31.2	20.3	0.0
99332	19.4	31.5	22.6	0.0
99333	19.4	32.8	20.6	0.0
99334	19.4	32.6	19.9	0.0
99335	19.3	31.8	21.0	0.0
99336	19.3	32.5	21.1	0.0
99337	19.3	33.7	21.5	0.0
99338	19.3	33.4	22.1	0.0
99339	19.3	32.0	21.6	0.0
99340	19.2	32.5	21.6	0.0
99341	19.2	32.6	19.8	0.0
99342	19.2	32.6	22.2	4.1
99343	19.2	33.6	21.7	0.0
99344	19.1	33.0	20.2	0.0
99345	19.1	33.0	21.1	0.0
99346	19.1	33.5	21.0	0.0
99347	19.0	32.5	22.2	0.0
99348	19.0	32.4	19.3	0.0
99349	19.0	32.3	18.9	0.0
99350	18.9	32.5	18.1	0.0
99351	18.9	32.5	20.5	0.0
99352	18.9	32.5	21.1	0.0
99353	18.8	33.1	22.4	0.0
99354	18.8	33.4	22.2	0.0
99355	18.8	31.9	22.1	0.0
99356	18.7	32.1	20.0	0.0
99357	18.7	33.5	18.9	0.0
99358	18.7	33.6	20.8	0.0
99359	18.6	33.0	22.5	0.0
99360	18.6	32.5	22.1	0.0
99361	18.5	32.5	21.6	0.0
99362	18.5	31.6	20.6	0.0
99363	18.4	31.5	19.4	0.0
99364	18.4	32.7	19.6	0.0
99365	18.3	31.9	22.8	0.0

Note : 99001 = January 1, 1999

99365 = December 31, 1999

See Appendix 5 for the relationship between the Julian date and normal dates for both ordinary and leap years.

APPENDIX 2

2000 DAILY WEATHER DATA FOR AGRICULTURAL RESEARCH STATION, KPONG

JULIAN DATE	SOLAR RAD. MJ/m²/d	MAX. TEMP. °C	MIN. TEMP. °C	RAINFALL mm	JULIAN DATE	SOLAR RAD. MJ/m²/d	MAX. TEMP. °C	MIN. TEMP. °C	RAINFALL mm
20001	17.2	33.7	21.8	0.0	20044	19.1	35.5	18.1	0.0
20002	17.2	31.8	23.3	0.0	20045	19.1	34.9	18.9	0.0
20003	17.3	33.2	22.2	0.0	20046	19.1	35.4	21.8	0.0
20004	17.3	33.4	20.0	0.0	20047	19.1	35.6	23.0	0.0
20005	17.4	33.5	20.8	0.0	20048	19.2	35.6	22.9	0.0
20006	17.4	33.0	20.0	0.0	20049	19.2	36.1	24.4	0.0
20007	17.5	33.0	19.2	0.0	20050	19.2	35.9	23.4	0.0
20008	17.5	32.6	21.3	0.0	20051	19.2	36.2	22.7	0.0
20009	17.6	33.3	21.1	0.0	20052	19.3	36.0	24.9	0.0
20010	17.6	34.2	19.9	0.0	20053	19.3	36.5	24.4	0.0
20011	17.7	33.7	20.6	0.0	20054	19.3	36.6	25.0	0.0
20012	17.7	33.7	22.4	0.0	20055	19.3	36.3	25.1	3.9
20013	17.8	34.6	23.1	2.5	20056	19.3	35.3	24.1	0.4
20014	17.8	33.3	23.5	24.0	20057	19.4	35.0	22.7	3.8
20015	17.9	33.1	20.8	0.5	20058	19.4	35.5	22.2	0.0
20016	17.9	33.5	22.6	0.0	20059	19.4	35.0	23.2	0.0
20017	18.0	35.2	22.9	0.0	20060	19.4	34.9	22.7	0.0
20018	18.0	34.0	24.6	0.0	20061	19.4	34.9	23.5	0.0
20019	18.1	32.5	24.7	3.0	20062	19.4	35.5	23.2	0.0
20020	18.1	33.5	21.8	0.0	20063	19.5	35.5	24.7	0.0
20021	18.1	33.3	21.2	0.0	20064	19.5	36.8	24.3	0.0
20022	18.2	34.0	22.2	0.0	20065	19.5	36.5	25.3	0.0
20023	18.2	34.1	23.4	0.0	20066	19.5	36.6	24.4	0.0
20024	18.3	34.0	23.3	0.0	20067	19.5	37.0	24.3	0.0
20025	18.3	34.7	22.2	0.0	20068	19.5	37.0	23.9	0.0
20026	18.4	31.2	22.1	0.0	20069	19.5	36.5	24.2	0.0
20027	18.4	34.8	20.0	0.0	20070	19.5	36.3	24.1	0.0
20028	18.5	35.0	22.2	0.0	20071	19.5	36.3	25.0	0.0
20029	18.5	35.0	23.3	0.0	20072	19.5	36.5	23.9	0.0
20030	18.5	35.0	22.7	0.0	20073	19.5	37.5	25.1	0.0
20031	18.6	34.5	22.1	0.0	20074	19.5	36.8	24.9	0.0
20032	18.6	33.9	21.6	0.0	20075	19.5	36.9	25.7	0.0
20033	18.7	33.5	16.6	0.0	20076	19.5	36.5	25.8	0.0
20034	18.7	33.8	16.9	0.0	20077	19.5	36.9	24.8	0.0
20035	18.7	34.7	17.7	0.0	20078	19.5	36.7	25.4	0.0
20036	18.8	34.0	18.2	0.0	20079	19.5	36.3	25.3	0.3
20037	18.8	35.2	19.8	0.0	20080	19.5	27.6	21.3	0.0
20038	18.9	36.2	18.6	0.0	20081	19.4	35.2	22.0	0.0
20039	18.9	35.2	16.5	0.0	20082	19.4	37.2	24.2	0.0
20040	18.9	34.7	18.1	0.0	20083	19.4	35.5	25.0	35.0
20041	19.0	35.6	16.6	0.0	20084	19.4	36.0	18.9	0.0
20042	19.0	34.8	19.6	0.0	20085	19.4	35.0	24.9	0.0
20043	19.0	36.0	20.5	0.0	20086	19.4	35.0	24.4	6.8

20087	19.4	31.2	21.3	0.0
20088	19.3	35.1	22.3	0.0
20089	19.3	35.2	23.4	0.0
20090	19.3	35.5	24.4	0.0
20091	19.3	35.3	25.0	0.0
20092	19.2	37.0	25.0	17.3
20093	19.2	34.3	22.2	0.0
20094	19.2	35.1	24.2	0.0
20095	19.2	35.5	25.2	3.2
20096	19.1	34.3	22.6	0.0
20097	19.1	35.0	24.3	0.0
20098	19.1	35.7	24.0	0.0
20099	19.1	35.7	24.4	0.0
20100	19.0	35.5	24.1	0.3
20101	19.0	34.9	22.2	0.0
20102	19.0	33.2	23.6	0.0
20103	18.9	35.5	22.7	0.0
20104	18.9	36.5	24.2	0.0
20105	18.9	36.2	24.6	0.0
20106	18.8	30.7	25.0	24.9
20107	18.8	34.3	20.6	0.0
20108	18.7	34.3	24.7	19.0
20109	18.7	34.0	24.7	0.0
20110	18.7	35.1	24.3	7.3
20111	18.6	35.0	22.7	1.5
20112	18.6	32.1	24.4	0.0
20113	18.5	33.0	24.0	43.1
20114	18.5	33.5	20.7	0.0
20115	18.5	34.5	23.3	0.0
20116	18.4	33.8	23.5	0.0
20117	18.4	34.5	23.9	0.0
20118	18.3	35.3	24.3	0.0
20119	18.3	35.5	25.2	0.2
20120	18.2	34.3	24.9	0.0
20121	18.2	34.6	23.9	0.0
20122	18.2	38.5	23.9	0.7
20123	18.1	35.0	20.7	0.0
20124	18.1	36.1	24.1	0.0
20125	18.0	35.7	24.4	0.0
20126	18.0	36.2	25.0	0.0
20127	17.9	35.5	24.0	0.0
20128	17.9	35.0	24.5	11.0
20129	17.8	34.6	24.9	0.0
20130	17.8	25.8	25.2	3.9
20131	17.7	31.9	23.2	0.0
20132	17.7	34.9	22.8	0.0
20133	17.6	34.5	24.6	5.4
20134	17.6	35.2	22.9	0.0
20135	17.5	35.0	24.3	0.0
20136	17.5	34.0	23.3	5.3
20137	17.4	33.7	23.4	2.3
20138	17.4	30.3	22.8	0.4
20139	17.4	33.5	20.3	0.0
20140	17.3	33.2	23.3	0.7
20141	17.3	30.7	22.9	0.0
20142	17.2	33.5	22.0	7.7
20143	17.2	32.7	22.4	0.0
20144	17.1	33.0	23.1	6.9
20145	17.1	30.6	21.1	0.0
20146	17.0	33.0	22.8	2.4
20147	17.0	32.8	22.7	14.1
20148	16.9	30.8	20.7	0.1
20149	16.9	32.6	21.7	0.0
20150	16.9	33.2	22.6	41.0
20151	16.8	32.4	22.2	0.0
20152	16.8	32.4	23.3	5.0
20153	16.7	30.2	23.2	14.4
20154	16.7	31.0	20.6	0.0
20155	16.6	32.4	22.4	0.0
20156	16.6	33.0	22.4	0.0
20157	16.6	31.9	23.6	27.7
20158	16.5	30.5	22.4	0.4
20159	16.5	30.6	22.7	0.0
20160	16.4	33.1	21.7	0.0
20161	16.4	33.0	21.4	0.0
20162	16.4	32.5	22.5	0.0
20163	16.3	31.6	22.2	16.5
20164	16.3	32.2	22.8	0.7
20165	16.3	33.0	21.6	0.0
20166	16.2	33.7	22.7	0.0
20167	16.2	32.0	22.6	0.0
20168	16.2	31.7	23.2	1.2
20169	16.1	29.5	22.8	0.0
20170	16.1	32.4	23.3	3.6
20171	16.1	32.6	21.2	0.2
20172	16.1	30.7	23.3	0.0
20173	16.0	32.5	22.4	16.5
20174	16.0	29.5	22.5	3.2
20175	16.0	27.3	21.8	0.0
20176	16.0	29.2	21.4	0.0
20177	15.9	31.5	22.2	18.8
20178	15.9	30.8	21.7	0.0
20179	15.9	32.0	21.2	0.0
20180	15.9	32.5	21.1	0.0
20181	15.9	32.5	22.2	0.0
20182	15.9	26.2	22.7	18.5
20183	15.8	29.3	20.0	0.0
20184	15.8	31.6	21.7	24.4
20185	15.8	29.8	21.9	0.0
20186	15.8	30.7	21.7	0.0
20187	15.8	30.6	21.1	0.0
20188	15.8	30.7	22.1	0.0

20189	15.8	32.0	22.8	0.0
20190	15.8	32.7	21.7	7.1
20191	15.8	30.9	19.4	0.0
20192	15.8	30.5	22.2	0.0
20193	15.8	30.6	21.7	0.0
20194	15.8	31.5	21.7	0.0
20195	15.8	30.5	21.7	0.0
20196	15.8	28.7	21.7	0.0
20197	15.8	30.5	22.2	0.0
20198	15.8	30.7	20.6	0.0
20199	15.8	29.5	20.5	0.0
20200	15.8	30.0	21.2	0.0
20201	15.8	30.6	22.2	0.0
20202	15.8	31.2	21.8	0.0
20203	15.8	31.0	20.2	0.0
20204	15.8	30.9	21.7	0.0
20205	15.8	31.4	20.3	0.0
20206	15.8	29.4	19.9	0.0
20207	15.8	30.3	20.4	0.0
20208	15.9	31.4	19.2	0.0
20209	15.9	32.6	19.5	0.0
20210	15.9	31.6	21.3	2.5
20211	15.9	25.5	22.2	14.5
20212	15.9	30.5	20.7	0.0
20213	16.0	31.6	19.8	51.8
20214	16.0	28.5	19.7	0.4
20215	16.0	29.0	21.1	0.0
20216	16.0	28.5	20.7	0.6
20217	16.0	27.0	21.7	0.7
20218	16.1	29.6	23.2	0.0
20219	16.1	28.8	21.3	0.0
20220	16.1	30.4	21.6	0.0
20221	16.2	32.1	21.5	13.6
20222	16.2	29.5	20.5	0.0
20223	16.2	29.9	21.1	0.0
20224	16.2	31.4	20.9	0.0
20225	16.3	31.7	21.7	0.0
20226	16.3	30.6	21.1	0.0
20227	16.3	30.0	21.9	0.5
20228	16.4	31.7	21.8	0.0
20229	16.4	30.2	22.1	0.0
20230	16.5	28.0	22.6	0.0
20231	16.5	28.8	21.9	0.0
20232	16.5	30.4	19.2	0.0
20233	16.6	31.3	18.3	0.0
20234	16.6	31.0	20.6	0.0
20235	16.6	32.5	21.0	71.1
20236	16.7	29.0	21.4	0.0
20237	16.7	29.0	22.2	0.0
20238	16.8	30.0	22.2	0.0
20239	16.8	31.0	21.7	0.0
20240	16.9	30.0	22.3	0.0
20241	16.9	30.8	22.0	0.0
20242	16.9	30.5	21.9	0.0
20243	17.0	33.0	22.1	2.6
20244	17.0	32.5	22.4	0.0
20245	17.1	32.5	22.2	0.0
20246	17.1	32.7	22.3	0.0
20247	17.2	32.1	22.4	0.0
20248	17.2	33.0	22.3	0.0
20249	17.3	31.4	22.5	0.0
20250	17.3	30.9	22.7	0.2
20251	17.4	29.5	22.7	3.0
20252	17.4	31.8	21.1	0.0
20253	17.5	32.5	21.2	0.4
20254	17.5	27.0	22.7	0.0
20255	17.6	31.1	20.0	0.0
20256	17.6	28.8	22.4	6.2
20257	17.6	29.5	20.8	0.0
20258	17.7	32.8	21.0	6.5
20259	17.7	31.4	21.2	16.5
20260	17.8	31.2	21.6	5.6
20261	17.8	30.2	21.3	5.0
20262	17.9	30.7	21.6	19.2
20263	17.9	31.8	21.7	0.0
20264	18.0	32.0	21.7	36.8
20265	18.0	32.0	21.2	0.9
20266	18.1	33.0	22.2	0.8
20267	18.1	31.5	22.0	11.1
20268	18.2	31.9	22.2	0.0
20269	18.2	31.9	22.2	0.0
20270	18.3	32.0	22.4	0.0
20271	18.3	32.0	21.8	21.9
20272	18.3	31.7	21.1	0.0
20273	18.4	31.5	21.7	0.0
20274	18.4	32.0	20.7	0.0
20275	18.5	30.0	21.7	0.4
20276	18.5	32.9	21.7	2.8
20277	18.6	32.4	20.6	0.0
20278	18.6	32.5	21.7	8.0
20279	18.6	32.6	21.7	2.4
20280	18.7	32.1	21.8	5.0
20281	18.7	31.0	22.2	3.3
20282	18.8	32.0	21.1	8.0
20283	18.8	32.0	21.9	0.0
20284	18.8	31.5	22.3	0.0
20285	18.9	32.0	20.7	0.0
20286	18.9	32.3	21.3	0.0
20287	18.9	33.5	20.7	0.0
20288	19.0	32.9	21.7	1.5
20289	19.0	33.0	22.2	0.2
20290	19.0	33.0	21.7	0.0

20291	19.2	33.7	20.8	0.0
20292	19.1	32.5	21.8	0.0
20293	19.1	32.8	22.2	0.0
20294	19.1	33.3	21.1	0.0
20295	19.2	33.9	21.1	0.0
20296	19.2	33.0	20.8	0.0
20297	19.2	32.9	20.6	0.0
20298	19.3	32.7	22.2	7.1
20299	19.3	32.0	21.1	0.0
20300	19.3	33.6	20.8	0.0
20301	19.3	32.3	22.9	7.0
20302	19.4	31.5	21.7	28.8
20303	19.4	29.2	20.0	0.1
20304	19.4	32.0	21.2	0.0
20305	19.4	32.5	21.2	2.6
20306	19.4	32.0	21.1	1.1
20307	19.4	32.2	21.7	0.0
20308	19.4	33.0	21.3	1.0
20309	19.5	32.8	22.8	4.1
20310	19.5	33.0	20.6	7.0
20311	19.5	32.3	21.1	0.0
20312	19.5	33.5	21.7	0.0
20313	19.5	33.0	21.4	0.0
20314	19.5	32.7	21.8	19.0
20315	19.5	33.0	21.1	0.0
20316	19.5	33.0	23.9	0.0
20317	19.5	32.4	22.4	0.0
20318	19.5	33.5	22.8	0.0
20319	19.5	33.5	24.1	0.0
20320	19.5	33.5	22.8	0.0
20321	19.5	33.4	22.4	0.0
20322	19.5	32.7	21.9	0.9
20323	19.5	33.3	23.6	0.0
20324	19.5	33.2	23.3	0.0
20325	19.5	32.4	22.7	0.0
20326	19.4	33.5	23.9	0.0
20327	19.4	33.2	23.2	17.1
20328	19.4	33.2	22.4	0.0
20329	19.4	33.5	23.7	0.0
20330	19.4	32.7	21.2	0.0
20331	19.4	33.2	21.7	0.0
20332	19.4	34.1	22.5	0.0
20333	19.3	33.5	22.5	0.0
20334	19.3	33.5	22.3	0.0
20335	19.3	33.4	21.8	0.0
20336	19.3	33.0	22.2	0.0
20337	19.3	33.5	22.2	0.0
20338	19.2	32.8	22.2	0.0
20339	19.2	33.1	22.2	0.0
20340	19.2	33.4	22.4	0.0
20341	19.2	33.1	21.6	0.0
20342	19.1	33.0	22.4	0.0
20343	19.1	32.0	21.8	0.0
20344	19.1	33.0	21.3	0.0
20345	19.0	32.5	22.3	0.0
20346	19.0	31.3	24.5	0.0
20347	19.0	32.9	20.8	0.0
20348	18.9	32.0	21.2	0.0
20349	18.9	32.5	20.8	0.0
20350	18.9	32.5	21.4	0.0
20351	18.8	32.5	18.8	0.0
20352	18.8	32.7	18.6	0.0
20353	18.8	33.4	21.6	0.0
20354	18.7	34.3	23.7	0.0
20355	18.7	33.7	25.3	0.0
20356	18.7	33.8	25.3	0.0
20357	18.6	33.5	23.8	0.0
20358	18.6	33.6	23.4	4.0
20359	18.5	33.4	21.0	0.0
20360	18.5	33.3	21.9	0.0
20361	18.4	33.8	22.7	0.0
20362	18.4	34.5	23.6	0.0
20363	18.4	34.0	23.6	0.0
20364	18.3	34.0	24.4	0.0
20365	18.3	34.0	24.3	0.0
20366	18.3	33.7	21.7	0.0

APPENDIX 3

CROP GENETIC COEFFICIENTS

Crop genetic coefficients account for the way in which crop genotypes differ either in the duration of their developmental phases, response to specific environmental factors or in morphological characteristics (Hunt et al., 1990). The definition of the genetic coefficients used in this study are given by Tsuji et al. (1994b) as follows:

P1 : Time period expressed in growing degree-days (GDD) from seedling emergence to panicle primordia initiation. The GDD (Copeland, 1924; Asakuma, 1958; Nagai, 1962; Yoshida, 1981) is a summation of daily mean air temperatures in °C above a base temperature of 9 °C, over a certain period of growth or development. It is computed from the formula;

$$GDD = \Sigma \text{ (daily mean air temperature – base temperature)} \qquad 3.8$$

P2O : Critical photoperiod or the longest day length (in hours) at which crop development occurs at a maximum rate. At values higher than P2O, developmental rate is slowed, hence there is a delay due to longer day lengths.

P2R : The extent to which phasic development leading to panicle initiation is delayed (expressed as GDD) for each hour increase in photoperiod above P2O.

P5 : Time period in GDD from the beginning of grain filling (3 to 4 days after flowering) to physiological maturity with a base temperature of 9 °C.

G1 : Potential spikelet number coefficient as estimated from the number of spikelets per gram of main culm dry weight (minus lead blades and sheaths plus spikes) at anthesis. A typical value is 55.

G2 : Single grain weight (g) under ideal growth conditions i.e. non-limiting light, water, nutrients, absence of pests and/or diseases.

G3 : Tillering coefficient (scaler value) relative to IR64 cultivar (determined by model developers) under ideal conditions. A higher tillering cultivar would have coefficient greater than 1

G4 : Temperature tolerance coefficient. A value of 1.0 is usually used for varieties grown under normal environmental conditions. The value changes when varieties are not grown in their normal environments. For example, G4 for an *indica* type of rice grown in very cool environments or season would be less than 1.0 and greater than 1.0 for a *japonica* type of rice grown in a warmer environment.

APPENDIX 4

Dates and amounts of irrigation water delivered (measured with a 90° V-notch weir) during the 1999 minor and 2000 major season experiments.

1999 Minor Season		2000 Major Season	
Date	Amount (mm)	Date	Amount (mm)
23 / 9 / 99	4	6 / 5 / 2000	140
24 / 9 / 99	40	14 / 5 / 2000	51
30 / 9 / 99	39	20 / 5 / 2000	82
11 / 10 / 99	53	26 / 5 / 2000	62
15 / 10 / 99	62	10 / 6 / 2000	82
21 / 10 / 99	70	13 / 6 / 2000	19
28 / 10 / 99	50	15 / 6 / 2000	10
3 / 11 / 99	54	21 / 6 / 2000	75
6 / 11 / 99	50	25 / 6 / 2000	47
16 / 11 / 99	46	7 / 7 / 2000	63
20 / 11 / 99	14	12 / 7 / 2000	66
22 / 11 / 99	36	19 / 7 / 2000	58
29 / 11 / 99	42	23 / 7 / 2000	76
		28 / 7 / 2000	64
		17 / 8 / 2000	12
Total	560 mm		907 mm

APPENDIX 5

JULIAN DAY CALENDAR

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
F B	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60*		
MAR	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
APR	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	
MAY	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151
JUN	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	
JUL	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212
AUG	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243
SEP	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	
OCT	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304
NOV	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	
DEC	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365

NB : ADD 1 TO UNSHADED VALUES DURING LEAP YEARS

60* - LEAP YEAR VALUE