WATER USE EFFICIENCY OF RICE (ORIZA SATIVA) IN RELATION TO IRRIGATION SCHEDULE AND SOWING DATE IN THE SUDAN SAVANNA ECOLOGICAL ZONE OF NIGERIA

B Y

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A Thesis submitted to the Faculty of Agriculture, Ahmadu Bello University, Zaria in Partial fulfilment of the requirements for the Degree of:

Doctor of Philosophy
in
Soil Science

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DECLARATION

I hereby declare that this thesis has been written by me and that it is a record of my own research work. It has not been presented before in any previous application for a higher degree.

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CERTIFICATION

This thesis titled 'WATER USE EFFICIENCY OF RICE IN RELATION TO IRRIGATION SCHEDULE AND SOWING DATE IN THE SUDAN SAVANNA ECOLOGICAL ZONE OF NIGERIA' meets the regulations governing the award of the degree of Doctor of Philosophy (Soil Science) of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

"To the poor and down-trodden of this earth"

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ABSTRACT

A field study was carried out to ascertain the effect of irrigation schedule and sowing date on the water use efficiency (WUE) of rice, Oryza sativa.

The experiment consisted of 3 irrigation schedules (irrigating at 10, 15, and 25 Kpa suctions) 4 sowing dates (mid-Dec, mid-Jan., mid-Feb,, mid-Mar.); two lowland rice varieties (ITA 212, and ITA 123) laid out as a 4 x 3 x 2 RCB factorial with 4 replicates. The experiment was conducted at the Irrigation Research Station, Kadawa (11° 39'N, 08° 02'E and 500m above sea level), for 2 dry seasons from 1989 - 1991.

The main effects of irrigation schedule and sowing date on plant height, number of seeds per unit area, and grain yield were significant ($P < 0.05$). These yield components and yield were highest with the March sowing date, and scheduling irrigation at 10 Kpa soil suction.

The main effect of irrigation schedule on ripening grade (filled-grain percentage x 1000-grain weight) was significant ($P < 0.05$). The highest, ripening grade was obtained with scheduling irrigation at 10 Kpa soil suction. Sowing date had no significant effect on ripening grade.

The effect of interaction between treatments on yield and yield components was not significant ($P < 0.05$). The differences in yield between the sowing dates, are attributable to the prevalent weather conditions during the ripening period, especially the max-min. temperature difference and solar radiation. Filled-grain percentage accounted for the highest variation in grain yield, followed by 1000-grain weight. Max.-min. temperature differences and solar radiation were lower during the ripening period in the March sowing date than the other dates.

The relationship between yield, max-min. temperature difference and solar radiation was well described by the following prediction equation:

$$Y = [31.536 - 0.765t - 0.014S]\ 18.5 \times 10\text{-}^{2}$$

where Y = estimated yield in t ha^{-1}; t = max-min. temperature difference in °C, and S = solar radiation in Cal Cm^{-2}.

Water use pattern was monomodal with the single peak at heading, irrespective of sowing date and irrigation schedule. WUE was highest with the March sowing date, and irrigation scheduled at 10 Kpa. The estimated ETcrop was found to be described by the following prediction equation -

$$ET_{crop} - 5.07 + 0.00272\ Rs$$

where $ET_{Ci\text{-}op}$ = estimated crop evapotranspiration, in mm day^{-1}, and Rs is the solar radiation in Cal Cm^{-2}.

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CHAPTER 1

INTRODUCTION

Rice cultivation in Nigeria began with the introduction in the sixteenth century of the indigenous West African species, Oryza glaberrima Steud, to the inundated flood plains of what is now northern Nigeria, where according to Porteres (1950), it had spread from an original centre of variation in the Central Nigeria Delta. Since almost all the numerous varieties of this 'red' rice now grown in Nigeria possess the floating habit, in contrast to the upland habit which the species evolved elsewhere in Africa possess, it would appear that the northern Nigeria flood plains provided a unique ecological niche and possibly a secondary center of diversity.

The earliest cultivation of 'white' rice, Oryza sativa L., in Nigeria apparently started about 100 years ago when upland varieties were introduced to the high forest zone of western Nigeria. The earliest recorded introductions of white rice are those made by the Department of Agriculture after 1919 (Hardcastle, 1959). Shallow swamp varieties from British Guiana, and Ceylon (now Sri Lanka) were successfully established in the shallow flooding valleys (fadama) of Kaduna, Niger, and Benue Rivers where they rapidly replaced swamp varieties of red rice then extensively cultivated. Today, swamp cultivation of <u>Oryza glaberrima</u> is mostly confined to the far north of Nigeria where it is particularly well adapted to the rapid fluctuations in flood depths that occur.

Four typical zones may be recognized in which rice can be grown in Nigeria. In their present order of importance these are:- naturally inundated land, land provided with supplementary irrigation, land not subject to inundation but receiving sufficient rainfall, and tidal fresh-water mangrove swamp. Throughout northern Nigeria rainfall is inadequate for rice cultivation (Rae, 1944). The mean annual rainfall in northern Nigeria varies between 1250mm to 1500mm in the south and 500mm to 750mm at the northern boundary. About two-thirds of the total rainfall is received between July and September, as rainfall before July and in October is markedly reduced and irregular. For this reason rice cultivation, originating with the introduction of <u>O. glaberrima</u> has been confined to the fadamas where the inundation extends beyond the end of rains into the critical period when rice is heading.

The fadama floods,however, are characterised by a rapid rise and vary from year to year in time of onset, duration and depth. Deep flooding precludes the use of much valuable land and the varieties of white rice so far introduced do not possess the tolerance shown by the indigenous red rice to this environment. In an effort to offset this problem, several small irrigation schemes were initiated in the old Niger and Sokoto Provinces (now Niger and Sokoto States), thus increasing the hectarage of swamp rice receiving supplementary water supplies. These schemes usually consist of diversion weirs on perennial streams and a distributory channel network over the area commanded. No large water storage reservoirs have been included in the schemes, but several include flood protection embarkments.

The construction in the mid '70s of large irrigation schemes - the Kano River and the Bakalori Projects, all in the sudan savanna ecological zone has led to a further increase in hectarage under rice outside the traditional fadama areas. Production in these schemes is largely rainfed with supplementary irrigation. With the ever increasing demand for rice and the pressure to expand production in this semi-arid zone, fully irrigated rice production remains the only viable option to meet this demand.

The bulk of rice produced in the Sudan Savanna ecological zone (a semi-arid belt) of northern Nigeria is presently confined to the rainy season within the large irrigation schemes, with supplementary irrigation. Recent developments, however, have shown an increase in production during the dry season under full irrigation. The trend will continue as pressure to boost domestic production of this crop mounts, and also as the search for a viable substitute crop to irrigated wheat continues in the large irrigation schemes within the Sudan Savanna.

Successful rice production under full or partial irrigation will require an effective irrigation schedule, suitable variety, and optimum sowing date. At the moment experimental data to build a fully or partially irrigated rice culture in the Sudan Savanna ecological zone of northern Nigeria is very limited. There is therefore need for research to generate these data.

It is in the light of the fore-going that the present study was initiated to:

(1) develop an operational irrigation schedule for rice production during the dry season,

(2) study the effect of irrigation schedule and sowing date on the grain yield of rice, and

(3) study the effect of irrigation schedule and sowing date on the water use efficiency of rice.

CHAPTER 2

LITERATURE REVIEW

A number of factors - climate, soil moisture regime, variety, and not the least nutrient supply play important roles in successful cropping systems, irrigated rice cultures inclusive. However this review will concentrate mainly on the influence of climate and soil moisture regime (both closely linked) on rice production.

2.1 Climate

Climate plays a dominant role in agricultural production systems; it tends to define the bounds within which the physiological growth of crops occurs. Consequently, cultural practices are influenced extensively by climatic factors. The physiological effects of climatic factors on crops such as rice may not vary significantly between irrigated and rainfed environments, but cultural aspects of rice production can differ greatly, depending on the hydrologic environment in which the crop is grown.

Where water is not a constraint to the rice crop, and where biological stresses and adverse soil conditions are negligible, yield potential is related to such atmospheric parameters as air temperature and solar radiation (Oldeman et al., 1987).

2.1.1 Temperature

Temperature is one of the major factors affecting rice production. The rice plant is cultivated widely from tropical through temperate climate, though it originated in the tropics. It is cultivated even in some subarctic regions, such as Hokkaido island in northernmost Japan (Nishiyama, 1976).

Nevertheless, rice plants have optimal temperature ranges for their growth and development. Both overly high and overly low temperatures are unfavourable for rice production. Cool weather damage is not only awfully severe in Hokkaido, but also occurs widely in cooler areas of temperate regions and in mountainous areas in lower latitude regions (Nishiyama, 1976).

The effect of temperature on rice production is very divergent and complex. Temperature affects rice plants both directly and indirectly, for example through outbreaks of diseases or changes in soil conditions. The effect of temperature differs among different physiological properties and among different organs of rice plants. Developmental age, variety, cultivation methods, and environmental conditions are also factors which influence the relation between temperature and rice production. Application of sharp scientific scalpels to this complexity will contribute to improvements in rice production.

2.1.1.1. Germination Temperature

Exact estimation of the lower limit of temperature for germination is rather difficult. Germination proceeds very slowly under low temperatures, and the seeds are likely to rot before germination. The temperature at which any seed can germinate seems to be near 0°c (for rice plants of cool-tolerant varieties). Himeda (1973) reported that some varieties can germinate at 5°c (0 to 27 percent for seven varieties). Himeda (1973) has observed the germination of seeds at 2° - 5°c, though the seedlings could not grow at this temperature.

Reported values for the lowest temperature of germination are: lower than 10°c (Chaudhary and Ghildyal, 1969), lower than 9°c (Aleshin and Aprod, 1960), lower than 8° and 13°c for other less cool-tolerant varieties) (Lee and Taguchi, 1969), lower than 12°c (Livingston and Haasis, 1933), lower than 11°c for varieties from Japan, and lower than 13°c for those from tropical areas (Oka, 1954).

Tropical varieties show, in general, higher minimum temperatures than temperate varieties (Matsuda, 1930; Pan, 1936; Wada, 1949; Ormrod and Bunter, 1961a). Oka (1954) reported that insular varieties showed lower minimum temperatures than continental varieties.

Among Japanese varieties, Nakamura (1938) reported that germination at low temperatures was the best in early ones, and decreased in the order of middle ones and late ones; on the other hand, Sasaki (1968a) reported that germination ability was not highly correlated with growth duration; upland rice was usually better than lowland rice (Onodera, 1934; Harashima, 1937, Nakamura, 1938). On the other hand, indica varieties did not seem to show differences among different maturity periods (Pan, 1936; Ormrod and Bunter, 1961b).

Reported values for the upper limit of germination temperature for rice plants are: higher than 42°c (Livingston and Haasis, 1933) and 43°c (Chaudhary and Ghildyal, 1969). A review by Owen (1971) showed that there is agreement that the maximum temperature for germination is in the region of 40° - 45°c.

These data indicate that the temperature range at which rice seeds can germinate is between near 0°c and 45°c. The optimal temperature range, is however much narrower - 18° to 33°c (Nishiyama, 1976).

2.1.1.2 Dormancy

Seeds of japonica varieties have relatively short periods of dormancy. On the other hand, some indica varieties have a very long dormant period. The dormancy of rice seeds can be broken by the application of high temperature to dry seeds (Jennings and de Jesus, 1964). This is the easiest and most effective method of breaking dormancy. The exposure of seeds to 50°c for 4 to 5 days was sufficient for most varieties; from 7 to 10 days was required for exceptionally dormant varieties. Ota (1973) reported that the favourable treatment for breaking dormancy is 1-2 weeks at 40-45°C.

The dessication of seeds did not itself have a dormancy-breaking effect, but it enhanced the breaking of dormancy at high temperatures (Ota and Takemura, 1970). On the other hand the pre-soaking of seeds stimulated the breaking of dormancy at lower temperatures (0° and 20°c, Ota and Takemura (1970)); at 3°c but not at 27°c, Roberts (1962).

The germination of partially dormant seeds has a narrower range of temperature. Roberts (1962) showed that a partially dormant population of seeds germinated at 27°c (about 40 percent in this experiment); the germination notably decreased above 30°c, did not occur at 42°c, and was notably low at 17°c; while a population of seed which had completely broken dormancy showed a high percentage of germination over a range from 17 to 42°c. This result indicates that rice seeds belong to the C type of dormancy in the classification by Vegis (1964); that is, narrowing of the temperature range of germination occurs from both the higher and lower sides.

2.1.1.3 Effect of Ripening Conditions on Germination

Environmental conditions during the ripening of seeds influence the characteristics of seed germination. Ikehashi (1967, 1972) showed that low temperature (20°c) at the early period of ripening (about 10 days after heading) and high temperature (30°c) at later periods induced considerable dormancy. However, high temperature at later periods promoted germination. Lee and Taguchi (1969) showed that high temperature during the early part of seed maturation, combined with low temperature during the late part, promoted germination, and vice versa.

Seed germinability at low temperature was increased with the maturation of seeds (Lee and Taguchi, 1970).

Seeds which were produced in a warmer district grew slowly in a cooler district in the first year; they recovered the growth rate gradually during a few successive years (Yui, 1958).

2.1.1.4 Seedling Establishment in Direct Sowing

The time required for seedling emergence from direct seeding of lowland rice increased linearly from an average air temperature of 17°c to 12°c (12 - 13 days at 17°c and about 30 days at 12°c) (Saito, 1964a). Saito (1965) reported that the time from germination to plumule length of 2 or 3cm increased with decreasing temperature: it was very long below 15°c.

The critical average air temperature for direct seeding of low-land rice was estimated at approximately 13°c at seeding time (Saito, 1964a) and 12°c (which might be lowered to 11°c) (Moriya 1963).

After the paper by Hamada (1937), it has generally come to be accepted that the mesocotyl of paddy rice plants of the japonica type does not elongate to more than 10mm in darkness at 30°c, while that of the indica type elongates 50mm or more. Recently, however, mesocotyl of the japonica type was found to be markedly stimulated by high temperature treatment of seeds before sowing (Anayama and Inouye, 1969; Inouye et al., 1969). This stimulation occurred in both normal and dwarf japonica varieties and also in indica varieties (Inouye et al., 1969).

High temperature treatments ranged from 30° to 95°c (Anayama and Inouye, 1969; Inouye, et al., 1970). The treatment most effective for mesocotyl elongation was application of a temperature of 40°c for 15 days to seeds which had husked and absorbed water for 8-14 hours at 25°c. The whole length of the plumule (mesocotyl and coleoptile), however, was the longest following treatment for 12-13 days at 40°c. The percentage of stimulated seeds decreased at temperatures of 35°c and higher than 50°c, no stimulation was observed at 30°c.

This stimulation of mesocotyl elongation in the japonica type is mainly caused by cell multiplication (Inouye, et al., 1970). Concerning the cultural temperature of seedlings after treatment, mesocotyl length increased with rising temperature from 16° to 34°c (Inouye et al., 1970). Coleoptile elongation was stimulated slightly by the same treatment at temperatures from 18 to 30°c; it was strikingly inhibited at 34°c.

High temperature treatment of seeds before sowing promoted the emergence of rice seedlings, especially when the seeds were deeply sown or covered with compacted soil (Inouye, 1972; Inouye and Hibi, 1972). However this effect was not due to the high temperature treatment per se, but primarily to the seed immersion at 25°c for 20 hours before sowing (Inouye et al., 1973). The growth of the plumules in japonica with high temperature treatment was much slower than in Indica (Inouye et al., 1973). This was due to the difference between them in the rate of mesocotyl elongation.

Inouye and Ayanama (1971) studied the effect of temperature on the strength of plumule elongation. Plumule elongation was vigorous in seedlings which were cultured under warm temperatures from 20° to 30°c; seedlings which were cultivated at 17°c had much lower ability to elongate (about one-fourth as compared with that at 30°c). This may be a primary factor in low emergence ability at low temperature (Inouye et al., 1969). Initial growth of germinated seeds was accelerated by germination to a degree of pigeon-breast shape, then kept at 5-10°c for 10-20 days and dried in air (Yamada et al., 1963).

The temperature of irrigation water into which seeds are sown is sometimes overly high in the tropical region. On the other hand, it is sometimes overly low in temperate and subarctic regions.

Chapman and Peterson (1962) reported that water temperatures between 25°c and 30°c were most favourable for seedling establishment of pregerminated rice sown directly into water. Emergence of shoots from the water was most rapid at 30°c, but the optimal temperature for primary root elongation and penetration of the soil was 20° - 25°c. At 35°c the roots grew mainly in water layer, so that the seedlings floated free or were poorly attached to the soil. The elongation of primary roots was inhibited more strongly at 35°c than at 20°c. Conversely, the elongation of shoots and secondary roots was inhibited more strongly at 20°c than at 35°c. Thus the root is more sensitive to high temperature than the shoot. A water temperature of 40°c was lethal to pre-germinated rice seeds.

Herath and Ormrod (1965) reported that warmer temperatures (24°, 27°, and 32°c) favoured growth of both shoots and roots as compared to a cooler one (16°c) in direct sowing into water. However, the adverse influence of low temperature was much smaller in the roots. Chapman (1969) reported that seedling establishment decreased linearly with increasing mean temperature over the range from 25° to 35°c near the soil-water interface for the first 20 days. The turbidity of water contributed to a decrease in the mean water temperature (Chapman, 1969). However, it generally did not improve seedling establishment, because of some factor such as less firm rooting in the soil.

Ormrod and Bunter (1961a) estimated the cold water tolerance (at 15.5°c) of pregerminated rice seedlings sown directly into water. California varieties generally showed greater tolerance than varieties from southern United States; short-grain varieties were more tolerent than long-grain ones; no definite relation was obtained with maturity groups, except that none of the late varieties was equal in length to Caloro, which was the most tolerant. None of the varieties from Japan and other higher latitude countries was significantly superior to Caloro, but many were considerably poorer.

Tanaka and Yamaguchi (1969) studied the effect of temperature on the early growth of seedlings. The growth rate increased with increasing temperature over a range from 20° to 30°c. However, the growth efficiency (defined as the ratio of produced dry matter to the sum of produced dry matter and respiratory consumption) of rice seedlings germinated in the dark was constant over the same temperature range.

Sasaki (1968a) and his coworkers studied the relationship between germination at low temperature and subsequent early growth of rice seedlings. Correlations between germination coefficient and plant height, leaf length, dry weight, and leaf number at an early stage of growth were statistically highly significant (Sasaki, 1968b). Positive correlation was also obtained between germination at low temperature and root development at an early stage at low temperature (Sasaki and Yamazaki, 1970); and between the germination and seedling establishment (Sasaki and Yamazaki, 1971). These results show that varieties which have high germinability at low temperatures, grow vigorusly at the early stage under low temperatures, and therefore the varieties are favourable to seedling establishment with direct sowing on cool lowland fields.

2.1.1.5 Seedling Establishment in Transplanting

According to Yatsuyanagi (1960), the critical average air temperature for transplanting is 15.0°c - 15.5°c for rice seedlings raised in lowland nursery beds, 14.0° - 45.5°c for seedlings from upland beds. The transplanting period has been advanced about 20-30 days by applying protected upland nursery beds in northern parts of Japan. This difference in temperature sensitivity among seedlings grown differently is considered to be due to the difference in seedling vigour (Yatsuyanagi, 1960). For one thing, upland nursery seedlings have higher starch and protein content, and thus higher rooting ability, than lowland seedlings Yamada and Ota, 1957a, 1957b; Ota and Yamada, 1958).

The rooting of rice seedlings occurs favourably over a range from 19° to 33°c with an optimum at 25-28°c; it is severely inhibited by temperature below 16°c and above 35°c (Nagai and Matsushita, 1963; Matshushima et al., 1968a; Chamura and Honma, 1973). Root number also notably decreased at 9° and 13°c (Chamura and Honma, 1973). Root decay occurred increasingly with rising water temperature (Ueki, 1960; Matsushima et al., 1968b).

2.1.1.6 Top Growth

Top growth of rice plants after the seedling stage is,in general, linearly accelerated by raising average temperature from approximately 18°c to 33°c (Ueki, 1966; Place et al.,1971; Sato 1972a; Chamura and Honma, 1973; Osada, et al., 1973; Yoshida, 1973). Above and below this range, the growth notably decreases. Water temperature is much more significant than air temperature for early growth and development of lowland rice (Matsushima et al., 1964b, 1966, 1968a, 1968b). Sato (1972a) found that dry matter production was the largest under a day-night temperature regime of 30°-25°c for Norin 17, and 25-20°c for IR8; leaf area per plant was the largest at 30-25°c for both varieties; thus, the temperature of 35-30°c was overly high for the growth of either japonica or indica varieties.

Sasaki (1927) reported that the elongation of rice leaves increased with rising temperature from 17° - 31°c; thence it tended to decrease and practically ceased at 45°c. The lower limit of temperature for rice leaf elongation was estimated at 7° - 8°c (Sasaki, 1927), at 10°c (Aimi, 1965) and at 12°c (Tanaka and Munakata, 1974). Oda and Honda (1963) reported that the velocity of leaf emergence was greater at warmer conditions, and this hastened heading accompanying the decrease in leaf number.

Kaneda and Beachell (1974) surveyed the types of cold injury of rice plants in more than 10 countries. For cold injuries at vegetative growth stages, failure in germination and slow seedling growth were observed in almost all countries surveyed; stunting and discoloration of leaves were reported in more than half of them. Seedling discoloration is commonly seen in indica varieties grown under low temperatures. The discoloration is usually various degrees of yellowing of leaves; sometimes white specks on leaves and white bands on sheath, or whitening of entire leaves are observed. At tillering stage, the yellowing occurs on lower leaves. Yellowing of leaves was observed also in japonica varieties grown at 9-13°c (Chamura and Honma, 1973).

2.1.1.7 Tillering

There is disagreement among reported data about the effect of temperature on tillering. First, a number of researchers (Oka, 1955; Takahashi et al., 1955; Hasegawa, 1959; Nagai and Matsushita 1963; Matsushima et al., 1964b; Kakizaki, 1965; Chamura and Honma, 1973; Yoshida, 1973) reported that tillering increased with rising temperature in a range from approximately 15° to 33°c. Among them, Oka (1955) and Takahashi et al., (1955) indicate that tillering period was shortened by the optimal temperatures for tillering differentiation, and thence the final number of tillers decreased with rising temperature. Matsushima et al. (1964b) also indicated that at later periods the number of tillers became larger at 16° and 36°c than at 21° and 31°c.

Second, some researchers found optimal temperatures in the same range: at 25°c day and 20°c night (Sato, 1972a), at an average soil temperature of 26°c (Chaudhary and Ghildyal, 1970), and at an average temperature of 22-24°c (Ueki, 1966).

Third, a number of researchers (Oda and Honda, 1963; Matsushima et al., 1966; Osada et al., 1973) reported that the number of tillers increased with decreasing temperature in the same range as mentioned above. Among them, Matsushima et al., (1966) noted that low temperature is not favourable to the elongation of tillers.

To explain this discrepancy, Yoshida (1973) suggested that tillering of rice plants should be considered in terms of interaction betweeen light intensity, temperature, and carbohydrate metabolism. Oda and Honda (1963) reported that under a short-day duration, the complete suppression of tillering (main culm monopoly) occurred at day-night temperature of 29° - 22°c and 32-25°c in one variety; while under long-day conditions, the sprouting of tillers was not suppressed even under high temperatures. Kaneda and Beachell (1974) reported that tillering in indica varieties was markedly reduced in the first crop Formosa; on the other hand, japonica varieties showed low tillering ability under tropical conditions. These results indicate a possible solution to this controversy.

Oda and Honda (1963) reported that the first tiller appeared earliest under day-night temperature regimes at seeding time of 23° - 16°, 26-19°, and 29° - 22°c; the appearance was delayed at higher (32° - 25°c) and lower (20° - 13° and 17° - 13°c) temperatures.

Temperature above 33°c is not favourable to tillering (Ueki, 1966; Hoshino et al., 1969; Chaudhary and Ghildyal, 1970). The lower critical temperatures reported for tillering were near 9°c (Chamura and Honma, 1973), 13.7°c (Sinitsyna and Chan, 1972), lower than 10° - 15°c (Sato, 1972a), lower than 16°c (Hoshino et al., 1969; Chaudhary and Ghildyal, 1970) and about 16°c for seedlings from low-land nursery beds (Yatsuyanagi, 1960).

2.1.1.8 Leaf and Internode Development

Hoshino et al (1969) and Noguchi (1960) showed that rate of leaf emergence increases with temperature over the range 16° - 36°c. During early growth, Herath and Ormrod (1965), showed that it was water rather than air temperature which was important. Over a similar temperature range, both leaf length and width increased with temperature. Where low temperatures during elongation produced shorter leaves, succeeding leaves were longer if temperatures were then raised. Stomata on leaves formed at 16°c were largest, but there were greater numbers on leaves formed at 32°c. Tajima (1963) showed that leaf respiration increased with temperature up to 44°c, in contrast to leaves of timothy and other grasses, which showed no rise above 38°c. Ormrod and Bunter (1961b) concluded that as photosynthesis in young plants appeared to be relatively insensitive to temperature, its main effects on net CO_2 exchange were the result of its effects on respiration rates and that low temperatures at night, or during periods of low light intensity are probably advantageous. Ormrod and Bunter (1961b) also found that the respiration rates of some long - grained varieties were significantly lower at 23° and 30°c than those of short-grained varieties.

2.1.1.9 Nutrient Uptake

It is clear that any effects of temperature on the uptake of major nutrients are at the same time likely to influence vegetative growth and root growth. Chiu et al., (1960, 1961) found that increases of 3 - 4°c increased absorption of N, P and especially K. Plant height and straw yield were increased, though grain yield did not always increase as well. In some instances increased nutrient uptake were associated with earlier heading. In indica varieties it resulted in increased translocation of nutrients to the grain, but this was not true for japonica varieties. Chaudhary and Ghildyal (1970) obtained similar results with an indica variety, nutrient uptake being greatest at the temperature regime which gave best growth and grain yield. Compared with less favourable regimes, the nutrient concentration was highest in the grain and lowest in the straw, implying an effect of temperature on nutrient transport to the grain.

2.1.1.10 Reproductive Growth

The reproductive growth of a rice plant goes on for a lengthy period of about 60 days from panicle initiation to grain maturity (Munakata, 1976). The rice plant during this period carries on morphological differentiation as well as increasing dry matter.

2.1.1.10.1 Panicle Initiation

The start of floral initiation is marked by the transformation of the apical growing point into floral primordia and by the production of flower initials instead of axillary shoots. In most cereals this change has little apparent effect on growth until previously formed leaves are fully expanded, by which time the leaf area of the plant is near the maximum (Friend 1965). The association between rapid leaf growth and earlier floral induction at high temperatures has been discussed by Japanese workers (Noguchi and Kamata 1959, 1965) and it has been suggested that the number of leaves produced before heading is almost constant for all Japanese early - maturing varieties (Asakuma, 1958; Noguchi and Kamata 1965). The general validity of this suggestion has not, however, been established. Delayed floral initiation at low temperatures has been reported for japonica and indica varieties and the critical minimum temperature is apparently around 15°c. According to Inouye (1964), the optimum range for initiation was 25° - 30°c by day - 20-25°c by night. No initiation occured at a day/night regime of 5°/10° or at a constant regime of 15°c. In 4 varieties (including indica and japonica) tested by Owen (1969), no initiation occurred at 33°/15° but initiation and flowering was satisfactory at 33°/23° (Owen, 1969). Similar effects have been recorded in other field-grown rice crops (Matsuo, 1954; Inoue et al, 1965). Abnormalities caused by temperatures around 14°c have been described and illustrated by Shimuzu and Kuno (1966) and included: reduced numbers of florets; fusion of lodicles, stamens and overies; formation of intermediate or bi-sexual organs; continuation of vegetative-type growth in spikelets without formation of sexual organs, but with abnormally swollen tissue.

Subsequent favourable temperatures are unlikely to overcome the limitations on yield already set by early low temperatures, and this has been emphasised by Matsushima et al. (1964b). Temperature (particularly that of the water) up to panicle - initiation stage can determine the maximum potential yield attainable, and subsequent conditions can influence only the extent to which this potential is realized. As already suggested when considering tillering, the submerssion of the growing point probably accounts for the greater importance of water - than of air-temperature.

2.1.1.10.2 Vernalization

It is doubtful whether true vernalization has been demonstrated in rice, vernalization being defined as a requirement for a period of low temperature as a prerequisite for floral induction or, where this requirement is not absolute, a reduction in the time taken to reach the flowering stage after such a period. Noguchi (1959) discussed the evidence and concluded that no vernalization effects have been shown for Japanese varieties. Sircar and Ghosh (1947) have reported accelerated flowering after high - temperature treatments, but it is debatable whether the term vernalization can properly be applied to this effect.

2.1.1.10.3 Panicle emergence, Anthesis and Pollination

After panicle initiation, the next most sensitive stage is the meiotic stage of the pollen mother cells 10-14 days before heading (Kiyosawa, 1962; Satake et al., 1969). Severe spikelet sterility caused by low temperatures (12°c) for 2-4 days at this time is due to abnormal male characteristics (Hayase et al., 1969; Ito et al., 1970) Development of most of the flower organs, excluding the stamens, is unaffected and pistils of plants subjected to low temperatures can be successfully pollinated with normal pollen from untreated plants. At low temperatures, Nishiyama (1970) reported that anther development ceased, anther respiration fell by 50% and protein content declined; also, there was an apparent correlation between anther protein content and fertility. Moriwaki (1958) found evidence that varieties differences in tolerance to cold water were correlated with successful pollen production.

The effects of abnormal pollen developemt would become apparent at anthesis and thus possibly be confounded with the effects of temperature at that stage. Successful anthesis is dependent upon a favourable combination of atmospheric temperature (in the range 22-40°c, according to Pogendorff (1932), humidity and light intensity. The maximum temperature for pollen germination is 40-50°c and the minimum 7-14°c (Enomoto et al., 1956; Kiyosawa, 1962), but below 16°c the ovary may fail to develop and partially germinated pollen may abort (McDonald, 1966). Varietal differences in minimum and maximum temperatures for successful pollination have been recorded (Enomoto et al., 1956). After fertilization, susceptibility to low-temperature damage may be considerably reduced.

Work in the Philipines (IRRI, 1970) suggests that the variety IR8 does not shed pollen at temperatures of 21°c or less, the optimum temperature being 30°c.

2.1.1.10.4 Ripening

Chandler (Chandler, 1963, 1967) has emphasized the importance of conditions during ripening. Solar radiation is of great importance, and in some circumstances, high radiation levels may be associated with high temperatures. However, where this is not so and where at the same time solar radiation is not limiting, rice yield is negatively correlated with mean daily air temperature during ripening period (Murata, 1966; Tanaka and Vergara, 1967). Translocation of carbohydrates to the developing grain is retarded by low temperatures, but the ripening period is lengthened and the net result is a greater final accumulation of dry matter (Aimi et al., 1959, Tajima et al., 1961). High temperatures during ripening apparently cause capacity of the grain to act as a sink for assimilates to be prematurely reduced (Aimi et al., 1959; Nagato et al., 1961) resulting in chalky-centred kernels and increased thickness of bran and aleurone layers (Ebata, 1961; Nagato and Ebata, 1960, Nagato et al., 1961). Murata (Murata, 1966) provides a general summary of ripening in the yield-determining process.

2.1.1.11 Varietal differences

Systematic testing of varietal differences in temperature response has been mainly concerned with cold-tolerance. It is generally accepted that this trait is heritable, and tolerance testing is done either at the seedling stage (Adair, 1966) or at the reproductive stage (Kondo, 1954), when the criterion is the degree of spikelet sterility. In considering differences in temperature sensitivity during growth, the interaction with photoperiod sensitivity, is clearly recognized. Wada (Wada, 1952; Wada and Nojima, 1954) divides Japanese varieties into two groups:

(i) early varieties of low photo-period and high thermo-sensitivity;

(ii) late varieties of high photoperiod and low thermo-sensitivity.

He relates this grouping to the geographical distribution of the varieties. Other workers in Japan (Asakuma, 1958; Noguchi and Kamata, 1965) have also reported the same relationship between sensitivity to temperature and daylength. There is some evidence that the optimum photoperiod of a variety can be altered by change in temperature regime (Roberts and Carpenter, 1965).

Although the rice crop is commonly subjected to high temperatures at one or other stage of its growth in many regions in which it is grown, resistance or tolerance to high temperatures has not received much attention from plant breeders in the past. Within existing japonica varieties, marked differences in adaptability to high temperatures during ripening have been demonstrated by Nagato et al (1961). Differences in tolerance between indica and japonica varieties have also been shown by Oka (Oka, 1955), who found that the tillering rates of indica varieties, increased more with temperature than in japonica varieties, and there was less shortening of the tillering period so that there is a smaller decrease in final tiller numbers (or even, in some cases, an increase). This implies that indica varieties have a greater capability for vegetative growth under high temperatures. The increasing trend towards multiple cropping and mid-season sowing may enhance the importance of heat tolerance at all stages of growth as a varietal characteristics.

2.1.1.12 Length of Phenological Phases

Higher temperatures accelerate the rate of development at all phenological stages. This implies that the length of a given phenological phase is shorter at higher temperatures.

Van Dobben (1979) collected data on the length of the period from emergence to anthesis for a number of crop species grown at different constant temperatures. The shape of the curvilinear relationship between mean air temperature and days to flowering obtained suggests a constant product of days and temperature (also called heat units, heat sum or degree days). Yoshida (1981) found that the number of days to heading has a curvilinear relationship with temperature within a 21-30°c range.

Traditionally, the flowering to ripening period is considered to be about 30 days. However, Oldeman et al (1987) reported that temperature determines its length.

2.1.2 Solar Radiation

In Japan, the local differences in grain yield of rice when cultured under the latest, recommended management practices, using well-adapted high-yielding varieties, were explained by the following four climatic factors at specific growth stages:

(1) integrated mean daily temperature during the first half of growth period,

(2) daily solar radiation at tillering stage,

(3) mean daily temperature during the panicle development stage; and

(4) daily solar radiation during the 7 weeks before harvest (Murata and Togari, 1972).

In the tropics, where temperature is usually not a limiting factor solar radiation would be the major climatic factor affecting grain yield. Grain yield is positively correlated with solar radiation during the later stages of plant growth (Moomaw et al., 1967; Tanaka and Vergara, 1967; De Datta and Zarate, 1970) Adaptability is partly expressed by the potential to produce relatively high yields even with low solar radiation.

The effect of solar radiation from flowering to harvest time is in filling up the spikelets, the number of filled spikelets, and weight per spikelet. The number of empty spikelets increases with shading or lower solar radiation (Wada et al., 1973). Varietal differences were noted in the degree of sterility as a result of low solar radiation.

During the rainy season or cloudy weather the solar energy is low, but rich in blue and ultraviolet light (Gates, 1965). The low solar energy and high temperature may result in tall plants, as is usual during the wet-season crop. However, this is counterbalanced to a large degree by the blue light, which inhibits plant elongation (Bokura, 1967; Inada, 1973) so that the resulting plant is not unusually tall and spindly. Blue light, however, does not inhibit elongation in some rice varieties (Bokura, 1967).

If the rice leaves can utilize high-frequency radiations, the plant may be able to maintain its photosynthetic efficiency even during cloudy days.

The other extreme is high solar energy per unit of time. In most temperate countries, light intensity during the regular cropping season is higher than in the tropical countries (Moomaw and Vergara, 1965). No bleaching can be seen under field conditions resulting from strong light intensity. Many authors have shown that leaves developed under high light intensity have more cells, more highly organized cells, higher chlorophyl content, and more stomata per unit leaf area than leaves developed under low light intensity (Pearce and Lee, 1969). This is an adaptation for full utilization of the high solar energy available.

Air temperature in the tropics and subtropics is largely a function of the intensity of solar radiation. This linear relationship does not always apply to the tremperate zone, however.

In tropical and subtropical areas, solar radiation is an important factor in affecting yield levels, particularly during the rainy season. Research has shown that grain yield is positively associated with total solar radiation available during booting, flowering, and grain ripening stages (Moomaw et al., 1967; Tanaka and Vergara, 1967; De Datta and Zarate, 1970). A critical light requiring period extending from panicle initiation to 10 days prior to maturation was found to affect rice yields in the Southern States of USA (Stansel, 1975).

For adaptiveness to planting in both the dry and wet seasons, a variety should produce a relatively high level of yield in the wet season as compared to that in the dry season. The differential growth characteristics of different varieties under different levels of solar radiation values and nitrogen were illustrated by Chang and Vergara (1972).

As has been pointed out earlier the yield capacity of rice plants depends on the total number of spikelets per square meter and the average size of individual husks (Murata, 1969). In anlaysing data pooled for 3 years, Murata and Togari (1972) reported that three climatic factors showed comparatively high correlation coefficients with the total number of spikelets. The first was solar radiation during the 6 weeks after transplanting, through its effect on the number of ears per square meter. The second and the third are solar radiation and mean temperature, respectively, during the 6 weeks up to heading, through their effect of increasing the number of spikelets per ear. However, (Kudo, 1975) found that presumably because of the heavy participation of varietal characteristics, the contribution of climatic factors to the whole spikelet number was only about 50%. Thus, it has been found best to use the dry weight at heading, Wo (g/m^2), instead of total spikelet number to represent yield capacity. Introducing the product of Wo and S (average radiation during the 6 weeks after heading in Kcal. sq cm^{-1}), he succeeded in explaining 49% of the total variation in grain yield due to the year, location and variety by the following regression model: Y = 382 + 0.627 Wo.S. It may be considered that Wo represents not only yield capacity but also the average size of photosynthetic organs during the grain-filling period (Murata and Togari, 1972) and to some extent, the amount of carbohydrate reserve accumulated before heading. As earlier discussed, the development of photosynthetic organs depends mainly on temperature combined with the number of days from transplanting to heading, and this can be well represented by Wo. On the other hand, the function of the photosynthetic organ depends mainly on solar radiation, after the middle stage of growth. Needless to say, after the heading stage solar radiation plays the most important role in production of yield content (Soga and Nozaki, 1957; Moomaw et al., 1967; Wada, 1969; Murata and Togari, 1972; Yoshida, 1972).

Murata (1964) demonstrated that differences in rice yields in different localities in Japan could be accounted for by a simple regression using temperature and solar radiation. This was made possible perhaps because in Japan the use of a superior variety is coupled with good soil, ample and timely supply of nutrients as well as water, and with thorough control of pests and disease, climatic or weather factors thus becoming more limiting to grain yield (Murata and Togari, 1972).

A number of studies have indicated that yield per spikelet decreases with increased spikelet number per unit of land (Matsushima, 1957; Munakata, et al., 1967; Murata, 1969; Wada, 1969). This has led many rice scientists, regardless of whether they work in the temperate region or in the tropics, to study ripening as the most critical stage in grain production.

Murata (1964) found a close correlation between grain yield and solar radiation and daily mean temperature. Hanyu et al., (1966) also found a high correlation between grain yield and sunshine hours and daily mean temperature for 40 days of the ripening period. These two studies were made with data collected from different localities where soil conditions as well as climatic conditions differed. Therefore a question still remained whether effects of climatic factors on yield were adequately separated from those of soil factors. Murakami (1973), by growing rice in the same synthetic medium at different localities, also demonstrated a close correlation between grain yield and daily mean temperature and sunshine hours for 40 days of the ripening period. These three authors came up with a similar formula. In spite of different sources of data, the optimum average daily mean temperature was found to be about the same, ranging from 21.4° to 21.8°c.

Munakata et al., (1967) derived a rather complex formula for a relationship between grain yield, solar radiation, temperature, and crop parameters such as grain number and leaf blade weight. These studies indicate that local differences in rice productivity can largely be accounted for by differences in solar radiation and temperature during the ripening period (Murata, 1972).

At IRRI, agronomists showed a high correlation between grain yield and solar radiation during the ripening period (Moomaw et al., 1967) or during the 45 days from 15 days before flowering to harvest (De Datta and Zarate, 1970). In addition, Tanaka et al., (1966) demonstrated a close association between grain yield and dry weight increase after flowering. These results seem to indicate that ripening is the most critical stage in grain production even in the tropics.

Since a major portion of grain carbohydrate comes from current photosynthesis during the ripening period (Yoshida, 1972), it is obvious that active photosynthesis during that period is important. However, whether ripening is more limiting to grain yield than any other stage of growth in a given locality would be a different matter. In rice, sink size of a crop is largely determined by spikelet number per square meter. Spikelets function as sink after pollination. Hence the sink size is determined at and before flowering. Therefore the relative importance of climatic influence before and after flowering depends on whether sink size is limiting to grain yield or not.

Filled-grain percentage appears to be determined by (a) source activity relative to sink size (Spikelet number) (b) ability of grains to accept carbohydrates, and (c) translocation of assimilates from leaves to grains. Solar radiation appears to affect grain filling and hence filled-grain percentage mainly by controlling source activity. Under a given solar radiation, the sink size relative to source activity affects filled-grain percentage. This is shown by increased filled-grain percentage with partial removal of spikelets (Matsushima, 1957; Wada, 1969).

Within a moderate range, temperature appears to affect filled-grain percentage mainly by controlling the capability of grains to accept carbohydrates, or the length of the ripening period. Length of ripening period is inversely correlated with daily mean temperature (Yamakawa, 1962). Thus, persistence of cloudy weather conditions will be more detrimental to grain filling under higher temperature regimes because of a shorter period of ripening. A ripening period shortened by high temperature, combined with cloudy weather conditions, is believed to be a major factor in impaired ripening. Matsushima (1957) demonstrated that a combination of high temperature and low solar radiation seriously impaired ripening.

The relationship between solar energy level and the yield response to nitrogen was studied by Montano and Barker (1974) using results of a 2-year date of planting experiment. They fitted a quadratic response function for each set of monthly planting date, regressing yield on nitrogen. These equations were divided into four groups according to the solar energy level associated with the functions and slope of the functions. Each group covered a specific range of solar energy and contained functions appearing to have similar slopes. Pooled regression was computed for each group. For the highest solar energy, the nitrogen response was linear throughout, indicating that a maximum yield was not reached up to 120kg N/ha (the highest N rate in this experiment).

It is evident from numerous results that nitrogen response in rice varies considerably with the level of solar energy, which in turn varied widely within the year and to a lesser extent from year to year. Experiments at IRRI in fully irrigated fields demonstrated that, for the same amount of N applied, a much higher yield could be expected in the dry season. The major external difference between the two seasons is solar radiation (Bhuiyan and Galang, 1987). De Datta and Zarate, (1970), De Datta, (1973) found that grain yields of irrigated rice closely follow the pattern of solar radiation during the 45 days before harvest.

High solar radiation, particularly during the reproductive stages is considered necessary for high rice yields. Solar radiation in the tropics is generally less in the wet season than in the dry season (Bhuiyan and Galang, 1987). However, extensive cloud cover during the wet season is not considered a significant limiting factor in obtaining grain yield of 5-6t/ha (Yoshida, 1981). The limitation reportedly applies when yields higher than 5-6t/ha are sought. That would require a solar radiation of more than

300cal/cm^2 per day during the reproductive stage (Bhuiyan and Galang, 1987). Yoshida (1981) emphasized that adapted varieties and good soil-water-crop management practices should be the strategies to achieve higher production in areas/seasons where solar radiation is low.

2.1.3 Humidity

Little is known about the influence of humidity on photosynthesis of rice plants. Tsuno and Sato (1971) reported that the photosynthesis of rice leaves attained a maximum at a relative humidity of 50-60% and above this decreased slowly with increasing humidity. When however, half of the roots were cut off, phtosynthesis increased with increasing humidity. Thus, optimum humidity for photosynthesis may vary depending upon interrelationships between water absorption and transpiration.

Factors of the physical environment, such as temperature and relative humidity are often discussed in the literature in relation to the bionomics of insects. Such papers described aspects of the development, survival, reproduction, and behaviour of insects. In rice, examples of field and laboratory work are as follows: for rice gall midge, Fernando (1971), Kovitvadhi and Leaumsang (1971), Praskasa Rao et al. (1971) and Kalode (1974); for stem borers, Areekul and Chamchanya (1973), and Kalode (1974); for leafhoppers and planthoppers, IRRI (1967), Bae and Pathak (1970), Chen (1970), and Ohokubo (1973); and for the rice beetle, Syoji (1972).

Besides the effects of climate on bionomics, numerous authors cite climatic factors as influencing the changes in population size over longer time periods such as several generations (Pathak, 1968). Frequent references have been made to rainfall, relative humidity, and temperature. Pradham (1972a,b) suggested that cooler seasons and cooler regions had higher yields due to fewer pest problems.

Abraham et al (1972), through correlation studies, found that there was a joint influence of rainfall, relative humidity, and mean minimum temperature on stem borer infestation (Tryporyza incertulas). The percentage of white head correlated negatively with relative humidity.

Prakasa et al. (1971) suggested that steady temperatures with the least fluctuations between maximum and minimum, coupled with average high relative humidity, caused outbreaks of the rice hispa (Discladispa armigera Olivier).

Emura and Kojima (1974) found that a relative humidity of less than 60% caused high larval mortality of Naranga aenescens Moore. It has been shown that a population of Nilaparvata lugens reached big levels when plants were transplanted close together (10cm spacing), probably because of the high relative humidity created in the insects habitat (IRRI, 1973). Kim (1969) found a positive correlation between population density of Laodelphax straitellus and relative humidity. Singh and Chandra (1967) were able to find a positive correlation between the peak population of Leptocorpisa acuta (Thunberg) each year and higher relative humidity and higher rainfall at a specific time of year. With regard to the rice whorl maggot, Hydrellia philippina Ferimo, Ferino (1968) found the pest generally more abundant in the rainy season, even though correlation analysis did not show any relationship between population density indices and weather data.

2.1.4 Wind

Gentle wind during the growing period of the rice plant, has been known to improve grain yields as it increases turbulence in the canopy (IRRI, 1976). Photosynthesis of the plant community increases with wind speed; the increase is mainly caused by the decrease in the boundary layer resistance near the leaf surface within the plant community (Yabuki et al., 1972). The increase in turbulence increases the supply of carbon dioxide to the leaf. Extremely slow windspeeds are sufficient, since wind greater than 0.3-0.9m sec^{-1} has no further effect on increasing photosynthesis in different plants (Wadsworth, 1959).

Leaves that can easily move with slightest air movement would certainly have a better mechanism for decreasing the boundary layer resistance (Vegara, 1976). The strong winds contribute to the lodging of plants. In modern varieties, this tendency to lodge has been greatly offset by their short height, an important factor not only in increasing grain yields but in making the varieties better adapted to lowland conditions (Vergara, 1976).

Dry winds have been known to cause dessication of rice leaves. Under upland conditions, the mechanical damage of leaves by wind is more severe than under lowland conditions, probably the result of changes occurring in the leaves when grown under upland condition (Vergara, 1976). It has been shown, however, that some upland varieties are definitely superior in resisting wind damage (Alluri et al., 1973).

Plants grown in low levels of nitrogen were found to have high resistance to wind damages expressed in terms of percentage of ripened grains and the weight and thickness of grains (Matsuzaki et al., 1972). The resistance was ascribed to the accumulation of carbohydrate in plants as a result of low nitrogen level.

Strong winds can be a direct cause of sterility at flowering time by dessicating the plant; they impair grain growth by causing mechanical damage on the grain surface; they cause the crop to lodge (Vergara, 1976). A hot and dry air called foehn is frequently a causative factor of "white heads", particularly when it comes at the panicle exsertion (Hitaka and Ozawa, 1970). Strong winds from the coast often contain brackish water, thus causing severe incidence of sterility (Hitaka and Ozawa, 1970).

Lodging of rice plants is more serious in the rainy season than in the dry season. The impact of raindrops compounded by strong winds, aggravate the lodging susceptibility of tall and week-culmed tropical cultivars. Strong winds cause leaf damage by breakage of blades or shredding of leaf tips. Cultivars differ markedly in their resistance to wind damage (IRRI, 1967, 1970; Alluri et al., 1973). The probable relation of wind resistance to leaf thickness or histological structure needs to be investigated.

It has been observed at IRRI that rice cultivars shatter more in the dry season than in the wet season. Shattering is more serious in an upland planting than in a flooded crop. Perhaps a combination of relative humidity and air movement is involved (Chang and Oka, 1976).

2.1.5 Rainfall and Irrigated Rice Culture

Rainfall and rainfall patterns influence rice cultural practices in irrigated environments through their effects on the availability of water at the irrigation source, the irrigation requirements in the crop field, and the optimum cropping calendar for farmers.

In any irrigation system, the amount of water available for irrigation during a season is determined by the amount of precipitation in its catchment area (Bhuiyan and Galang, 1987). This may be true even for irrigation systems using groundwater; local rainfall can be the primary water source for the annual recharging of a groundwater aquifer. The rice area that can be supported by irrigation depends on the amount of water available during the most water-demanding period of the season, which is dependent on rainfall in the catchment. An irrigation system's design addresses this uncertainty by considering a supply value which long-term records predict has a reasonable probability of being available.

Dela Vina et al. (1986) showed that unexpected reductions in the amount of water available at an irrigation system's source, such as those caused by drastic reductions in rainfall in the catchment caused major cutbacks in the serviceable area of the system as well as severe drought stress in areas that could be only partly supplied with irrigation water. A notable example of such a problem was found recently in the Pantabangan reservoir of the Upper Pampanga River Integrated Irrigation system (UPRIIS) in the Philipines (Dela Vina et al., 1986).

That system was designed to irrigate more than 100,000 ha in the wet season and is expected to serve more than 80,000 ha in the dry season. Low wet season rain for two consecutive years (1982 and 1983) caused water levels in the reservoir to remain well below the expected 210m elevation, which reduced the irrigated hectarage in the subsequent dry seasons to about 83% of a normal year's coverage in 1982 and to 40% in 1983 (Dela Vina et al., 1986). Also, many farmers within the program area for irrigation could be only partially served.

Such incidents are common in irrigation systems. When they happen, many farmers find themselves coping with the difficult problem of the change of their farms from fully irrigated to partially irrigated or rainfed.

A similar example makes the point for pump based irrigation systems (Galang et al., 1984; Bhuiyan and Galang, 1987).

2.2 Ecology and Photoperiodism

Rice is sensitive to photoperiod; long-day treatments can prevent or considerably delay its flowering. Rice cultivars exhibit a wide range of variation in their degree of sensitivity to photoperiod (Enomoto, 1935; Morinaga and Kuriyama, 1954; Liang and Liu, 1983).

Most of the wild species of Oryza and many of the primitive cultivated rices (O. Sativa L.) are photoperiod sensitive and may be classified as short-day plants. Most papers agree on such a classification, and therefore rice is considered as a short-day plant. It is also classified as photoperiod-sensitive and photoperiod-insensitive types, the latter showing a low response or a slight delay in flowering. The present tendency is to select photoperiod-insensitive cultivars so that most of the cultivated rices may eventually become photoperiod-insentisive ones. These improved, early maturing cultivars may fit into the multiple cropping system characteristic of progressive agriculture.

The growth of the rice plant can be divided into three stages:

(1) the vegetative growth phase, from germination to panicle initiation;

(2) the reproductive phase, from panicle initiation to flowering; and

(3) the ripening phase, from flowering to full development of grain.

In the tropics, the reproductive phase is about 35 days while the ripening phase ranges from 30 to 35 days. Both phases are relatively constant, although low temperatures have been known to prolong them and high temperatures to shorten them (Vergara and Chang, 1985). The ripening phase may be prolonged to as much as 60 days. However, it is the vegetative growth phase whose duration generally varies greatly and which largely determines the growth duration of a cultivar, especially in the tropics.

The vegetative growth phase can be further divided into the basic vegetative phase (BVP) and the photoperiod-sensitive phase (PSP), (Vergara and Chang, 1985). The BVP refers to the juvenile growth stage of the plant, which is not affected by photoperiod. It is only after the BVP has been completed that the plant is able to show its response to the photoperiodic stimulus for flowering - this is the PSP of the plant.

Based on the BVP and PSP, varietal response to photoperiod can be classified into four types (Gomosta and Vergara, 1983). Although some tropical cultivars may be classified as the D type having both long BVP and long PSP, most were probably eliminated during domestication since they would have had an unusually long growth period and could be planted only within a narrow range of dates. In classifying cultivars based on BVP, most of those from the low latitudes were found to have long BVP's (Wada, 1952; 1954).

At the early growth stages, the rice plant is photoperiod insensitive (Anema, 1974; Ikeda, 1974; Sakamoto, 1968). Because of this insensitivity to photoperiod, the early growth stage has been termed the basic vegetative phase; it is also referred to as the junvenile growth stage of the insensitive phase of the plant. The range of BVP reported in the literature has varied from 10-85 days (Gomosta and Vergara, 1983; Jagoe, 1952; Pushpavesa, 1980). The indica cultivars generally have longer BVP (Zhang, 1983).

Several experiments showed that short-day treatments of seedlings accelerated heading (Roberts and Carpenter, 1962; Sakamoto, 1968) or delayed it (Asakuma and Kaneda, 1967; Misra and Khan, 1973). The results indicate the possible effect of photoperiod while the plant is in its early growth stage and the possible existence of a very short BVP. On the other hand, long-day treatments of seedlings have been reported to induce earliness in flowering (SenGupta and Ken, 1945, Sen, 1948). These varied and conflicting results may have been caused by nonspecific factors. A good example is seedling vigor, which is known to affect the flowering date, especially in the weakly photoperiod-sensitive cultivars.

The degree of sensitivity of rice plants has been reported to increase with age (Ikeda, 1975; Katayama, 1977; Noguchi et al., 1971). The optimum age of responsiveness is probably the result of growth-limiting factors, such as space and nutrients.

The transition from the BVP to the PSP is not well known; it could be abrupt or it could involve a gradual buildup. Using several cultivars, Best (1961) found that the insensitive phase (BVP) changed to the fully sensitive phase

PSP within a week. Best (1961) gave the following as possible explanations for the existence of the BVP:

(1) the first leaves formed are completely insensitive to photoperiod;

(2) the first leaves formed have very low sensitivity that they do not reach an adequate level of induction to evoke floral initiation before the more sensitive leaves formed at higher nodes have reached this stage,

(3) the first leaves formed do not attain the induced stage before the (early) senescence of these leaves.

(4) the total leaf area reequired before the plant can react by floral initiation to the inductive photoperiod is so large that it is reached only at a relatively late stage of plant development

(5) the growing point of the young plant is unable to react to the floral stimulus or the stimulus cannot reach the growing point.

The PSP or the eliminable phase (Kakizaki, 1938) is the growth stage indicative of the rice plant's sensitivity to photoperiod. In photoperiod-sensitive cultivars, the PSP determines the rice plant's sensitivity.

The PSP of photoperiod-insensitive cultivars ranges from 0-30 days or longer. Under continually long photoperiods, some cultivars have been reported to remain vegetative even after 12 years of growth (Best, 1959). The PSP is usually determined by subtracting the minimum growth duration from the maximum growth duration of a cultivar (Vergara and Chang, 1985). Because many cultivars remain vegetative for a long period if grown under long-day conditions, experiments are usually terminated after 200 days and the PSP of the cultivar is given the value 200+.

A rice cultivar's response to photoperiod may be measured by the length of the PSP, which in turn is determined by both the critical and optimum photoperiods of the cultivar. Because these two terms have been used interchangeably and in many ways, the following definitions have been adopted. Optimum photoperiod is the day length at which the duration from sowing to flowering is at a minimum (Chandraratna, 1952). Critical photoperiod is the longest photoperiod at which the plant will flower or the photoperiod beyond which it cannot flower.

The critical photoperiod determines whether a cultivar will flower when planted at the usual time at a certain latitude while the optimum photoperiod determines whether it will flower within a reasonable time if planted during a period with longer days than would normally occur during the growing season. A cultivar with a longer optimum photoperiod or no critical photoperiod would have wider adaptability - it could be planted at any latitude and in any season, provided it is not too sensitive to temperature.

The optimum photoperiod differs with cultivars although many workers have observed it to be 8-10 hours (Chandraratna, 1961; Ikeda, 1970, 1975). Njoku (1959) did not find any optimum photoperiod in the varieties he studied. The photoperiod he used was as short as 9 hours, well below the range of natural day lengths.

Cultivars with optimum photoperiods longer than 10 hours have also been reported (Best, 1961; Moursi, 1963; Suge, 1972). The less sensitivity to photoperiod the longer is the optimum period (Hara, 1930; Miyabayashi, 1944). However, others found no correlation between the optimum photoperiod and the photoperiod sensitivity of the many cultivars they tested (Yu and Yao, 1967).

A photoperiod longer or shorter than the optimum has been shown to delay flowering, the delay depending upon the cultivar's sensitivity (Miyabashi, 1944; Roberts and Carpenter, 1962; Venkataraman, 1964; Padhy and Khan, 1982).

The term supraoptimum photoperiod has been used when the photoperiod is shorter than the optimum. Panicle initiation in plants receiving a photoperiod as low as 4 hours has been reported (Ikeda, 1974). Plants receiving 8 hours light and varying dark periods from 16 to 64 hours showed inhibited shoot apex conversion (Khan, 1976). This was ascribed to inadequacy of carbon compounds for synthesis of requisite quantity of flowering hormone.

Scripchinsky (1940), reviewing literature on rice, indicated that the rice plants have a "critical length of day for flowering." Later studies showed the presence of a critical photoperiod ranging from 12 to 14 hours (Lamin and Vergara, 1968; Toriyama et al., 1969; Tsuboki, 1980). The critical photoperiods determined under controlled photoperiod rooms were almost the same as the day length from sunrise to sunset at 30 days before flowering under natural conditions (Tsuboki, 1980).

The lower the latitude of origin of a cultivar or strain, the shorter the critical photoperiod (Katayama, 1964). The critical period is influenced by temperature and lengthens as the plant becomes older. The PSP of a cultivar is probably a measure of the combined effect of photoperiod on its optimum photoperiod and critical photoperiod. The shorter the critical photoperiod, the longer is the PSP. Short optimum photoperiod is also associated with long PSP.

Day length changes rythmically within a year and varies depending upon the latitude. The amount of change in day length during the rice cropping season differs from one latitude to another (Vergara and Chang, 1985). Even in locations at the same latitude the day length during the cropping season may differ because the planting dates may differ greatly depending mostly on the rainfall pattern at each location.

At northern latitudes (Sapporo, 43°N, and Konosu, 36°N, both in Japan) day length increases and then decreases during the cropping season (Vergara and Chang, 1985). At lower latitudes (Taipei 25°N - Taiwan, and Los Bonos, 14°N - Philippines) day length increases during the main growing season. Near the equator (Bukit Merah, 5°N) there is little change. These differences in day length during the growing season may account for the wide range of photoperiod response of rice cultivars.

In the northern hemisphere, the longest days are in June and the shortest are in December. Taking these into account, the photoperiod response of the rice cultivars can be tested to a limited extent by planting the cultivars at a certain location at different dates. Maximum differences in growth duration can be obtained in the May and November plantings if temperatures are not too low for growth. If a rice's growth duration changes more than 30 days, agronomists usually consider it photoperiod sensitive or a seasonal cultivar (Vergara and Chang, 1985). This method of testing sensitivity to photoperiod has been followed in Australia (Langfield and Basinski, 1960), China (Zhang, 1983), India (Misra and Khan, 1973, 1977; Khan, 1982), Japan (Yamakawa, 1962), Philippines (Velasco and Manuel, 1955), Senegal (Coly, 1981), Sierra Leone (Craufurd, 1964), United States of America (Jodon, 1953). These experiments confirm the existence of wide cultivar differences in the effect of planting date on flowering date.

Many of the results obtained from this type of testing, however, are not applicable to identical cultivars grown at different latitudes. A cultivar can be insensitive to day length in Malaysia but sensitive in Taiwan. Results of field tests at a certain latitude are, therefore, not always applicable at another latitude. Some published papers on the use of this testing method failed to mention latitude or the place where the tests were conducted.

Under natural conditions very small differences in day length can affect the rice plant. In Malacca (Malaysia), the difference between the maximum and the minimum day lengths is only 14min and yet the cultivar Siam 29 takes 329 days to flower when planted in January and only 161 days when planted in September (Dore, 1976).

Another instance showing the sensitivity of the rice plant to small differences in day length was reported in a date-of-planting experiment in Malaysia (Lamin and Vergara, 1968). There was a difference of as much as 156 days in the growth duration of photoperiod-sensitive cultivars when planted in the same month but in different years. This presumably resulted from differences in weather during the critical periods. Cloudy weather early or late in the day shortens the twilight hour, thus shortening the day length.

Toriyama et al., (1969) tested rice cultivars involving not only monthly planting but also sowing at different latitudes. This gives a better idea of the photoperiodic response of the cultivars but involves much work and cooperation.

Rice can be grown over a wide range of environmental conditions, from the equator to about 4°N latitude, leading to the differentiation and establishment of various ecotypes and forms. The great diversity in photoperiod sensitivity from one latitude to another or within a latitude probably indicates that the rice cultivars predominantly cultivated in each area are those that have been selected on the basis of local adaptability (that is, adaptability to the temperature of the rice-growing season, day length, and duration of the growing season) to assure the full development of the plant and the best possible balance between vegetative and reproductive growth (Zhang, 1983).

A major problem in studying the ecology of the rice plant, especially in reference to photoperiodism, is that cultivars' in farmers' field keep changing. Recent papers, however, generally agree that among the photoperiod-sensitive cultivars, the lower the latitutde of distribution, the higher the sensitivity (Zhang, 1983).

The cultivars in the tropics or lower latitudes are usually late maturing (long growth duration). Many studies show that the late cultivars are more sensitive to photoperiod than the early ones (Lee, 1964; Zhang, 1983). In the tropics, where rice can be grown any time of the year provided there is sufficient water, photoperiod sensitivity presents certain problems. During the off-season, when the day length during the early growth stage is increasing, the sensitive cultivars are uneconomical to use because they take a very long time to produce any grain. For wider adaptability, cultivars should have low photoperiod sensitivity (Dasananda, 1961; Chang and Vergara, 1972) and thus have little differences in growth duration when planted at different times of the year or at varying latitudes.

Insensitive cultivars have been successfully grown at different latitudes where rice is used as a crop (Yu and Yau, 1962; Chang, 1967). This indicates that it should not be difficult to introduce new photoperiod-insensitive cultivars to different rice growing areas or to culture them year-round in the tropics. The plant breeders, as the varieties coming out indicate, are developing more photoperiod-insensitive cultivars.

Extensive testing in various rice-growing areas of the world has established the wide adaptability of photoperiod-insensitive cultivars. In general, the longer the BVP the less the variation in growth duration and the stronger the PSP the greater the variation in growth duration (Zhang, 1983).

Photoperiod sensitivity may work as a safety mechanism when precise planting dates are not followed. Maturation of the crop at the same time, as with photoperiod-sensitive cultivars planted at different dates, may reduce rat and insect damage in any one field. Also harvesting and drying are simplified.

If the soil is not sufficiently fertile, a photoperiod-sensitive cultivar will continue its compelled vegetative growth until the short days come. This would give the plant enough time to reach a reasonable plant weight and accumulate enough carbohydrates before flowering (Vergara, 1976). Thus a photoperiod-sensitive cultivar generally may be more resistant to unfavourable conditions.

Long-growth-duration cultivars (essentially photoperiod sensitive) are least affected by strong soil reduction (Yamakawa, 1965).

Most upland rice cultivars have short growth duration and are photoperiod-insensitive (Alluri and Vergara, 1975). However, in areas where the rainfall pattern is bimodal, the cultivars are of medium growth duration and are photoperiod-sensitive - possibly another indication of the greater specific adaptability of long growth duration cultivars to adverse conditions.

The sensitivity to photoperiod of wild species has also been studied in relation to their ecological distribution. Most of the wild rice materials tested were sensitive (Katayama, 1961, 1964, 1971, 1977). They suggested that this sensitivity favours the wild rice plant and is perhaps essential to their survival.

2.3 Irrigation and Water Management

The basic purpose of irrigation is to supply plants with water as needed to obtain optimum yields and quality of a desired plant constituent. As Taylor (1965) puts it, "Irrigation should take place while the soil water potential is still high enough that the soil can and does supply water fast enough to meet the local atmospheric demands without placing the plants under a stress that would reduce yield or quality of the harvested crop." A number of new approaches and commercially available devices have been developed for scheduling irrigations which permit the irrigation farmer to evaluate the supply of water to crops and, thus, to greatly improve irrigation practices.

Criteria most suitable for scheduling irrigations vary from one situation to another (Haise and Hagan, 1967). Where water is scarce or expensive, irrigations should be scheduled to maximize crop production per unit of applied water; where good land is scarcer than water, irrigations should be scheduled to maximize crop production per unit of planted area. It should be recognized, however, that other considerations may dominate in some situations. For example, irrigation schedules may be modified to minimize irrigation costs, facilitate other farm operations, overcome problems of slow penetration of irrigation water, control groundwater level, accomplish leaching of salts, or accommodate schedule of water delivery to the farm. In all cases, the criteria selected for irrigation should permit favourable crop yields, optimum use of water, and proper attention to other factors involved.

Various soil, plant, and evaporative techniques are used as criteria for establishing irrigation schedules for a given crop and climatic area (Haise and Hagan, 1967). These include soil water indicators (soil appearance and feel, soil water content, soil water suction); plant water indicators (visual indicators of water stress, plant growth indcators of water stress, leaf reflectance and temperature, plant water measurements); and meteorological approaches (evaporative devices).

Plant response to irrigation is better correlated with soil water potential or suction than with soil water content. Thus measurements of soil water potential or suction provide a useful approach for scheduling irrigations (Haise and Hagan, 1967).

The arithmetic integration of soil moisture tension (soil water suction) measured at various depths in the root zone to obtain a single integrated value has been proposed (Taylor, 1952). The number of instruments required and the difficulties in interpretation make this approach of questionable practical value. The use of instruments placed at the depth of maximum root activity seems to be satisfactory. Taylor (1965) computed ranges in values of water potential or suction required for optimum growth of many common crops based on instruments placed at the depth of maximum root activity for crops growing on soils low in salt content and well fertilized. The range of values given for each crop recognizes the effects of high and low evaporative demand and the need to consider weather conditions when selecting the suction values at which irrigation is to be applied.

The tensiometer measures soil water suction and can be used to schedule irrigations without reference to soil water content. The porous cup and vacuum gauge, when filled with water and placed in the soil, registers soil water suction up to 0.8 bar. The vacuum gauge can be read at a glance. One can irrigate when the vacuum gauge registers the prescribed limits, provided the permissible soil water suction for a given crop and the prevailing conditions are known (Haise and Hagan, 1967).

The use of tensiometer not only to schedule irrigation but to indicate the amount of water to apply was suggested by Richards and Marsh (1961). They showed that placement of tensiometers in the active root zone and near the bottom of the root zone provided information which permitted control of deep percolation losses.

Instruments or other approaches for indicating the need for irrigation are most useful in water deficient areas where cost of water is usually high and where high value crops are grown. Crops with established root systems like orchard trees are easier to instrument than annual crops with an expanding root system. Instruments placed in annual crops are normally removed and reinstalled each crop season. Where qualified technical personnel are available, as on large or corporate farms, soil water gauging devices or plant water measurements can be more easily managed and the data better interpreted in terms of scheduling irrigation.

It is not always possible for a farmer to schedule irrigation at the precise time water may be needed by the crop. In some projects, the irrigation regime may be limited by the water delivery system under which the farmer operates. The rotation system, for example allows little choice (Haise and Hagan, 1967). In other projects, the farmer may receive a small stream of water under a continuous delivery system. The continuous delivery system is inefficient, and excessive use of water often contributes to drainage problems.

Maximum flexibility and the greatest opportunity to irrigate on a more scientific basis occurs where irrigation water is available on demand (Haise and Haga, 1967). Water is usually ordered 1 or 2 days in advance where project distribution systems have capacities to satisfy crop needs during periods of peak demand. In spite of the advantages, many farmers misuse the demand delivery system by irrigating a crop much more frequently than needed.

Often irrigation schedules and applications must consider other farming operations. The maintenance of a favourable salt balance may require, in some situations, water applications in excess of the ET requirements of the crop. This seldom requires more than a 10% increase. Deep percolation losses occuring in the operation of many surface irrigation systems frequently provide leaching considerably in excess of salt balance requirements. Rains which fall during a portion of the year may also provide much or all of the required leaching.

In areas where water is plentiful and cheap in comparison to other production costs and crop values, there may be little incentive for a farmer to extend irrigation intervals or to improve efficiency of water application just to conserve water. If the farmer is to prosper in the face of rising production costs including labour, machinery, and other factors contributing to the so-called "cost-price squeeze", he must reduce operation costs, avoid any serious risks to achieving favourable yield, and thus maximize net returns wherever possible even if it means wasting water.

The extension of irrigation intervals does not always save water. Predicting the possibilities for saving water requires analysis of the prevailing conditions including microclimatic factors affecting evaporation and transpiration, the crop (type, stage of growth, coverage of soil surface, root depth, and effect of plant water stress on yield), the soil (profile characteristics, infiltration and internal drainage rates, and water retention capacity), slope and uniformity of grade, the irrigation system, and management practices - particularly the skill of the irrigator. Extending irrigation intervals by using techniques which allow more accurate assessment of actual need for irrigation can reduce the number of irrigations applied in a season. The resultant savings in water will depend on its effects on reducing evaporation losses, reducing nitrogen fertilizer requirements, and improving irrigation efficiencies (Haise and Hagan, 1967).

Extending the irrigation interval can reduce evaporation from the soil surface, but such reductions will achieve little saving after the soil is fully covered (Haise and Hagan, 1967). Extending the irrigation interval sufficiently to reduce transpiration will usually lead to lower yields for most crops with possible exceptions during the maturation stages of crops grown for dry weight of a reproductive organ or for some chemical constituent (Haise and Hagan, 1967). The extent to which irrigation water can be saved by extending the irrigation interval depends largely on opportunities this provides to reduce application losses. These losses depend on root depth of crop, soil factors, slope and uniformity of grade, irrrigation system, and skill of the irrigator. Losses exceeding 50% may occur with each irrigation especially where roots are shallow, infiltration is rapid, fields are not graded to a desirable or uniform slope, poorly adapted irrigation methods are used, and the irrigator employs little skill (Haise and Hagan, 1967). Application losses will also be higher the wetter the soil at time of irrigation because an already relatively wet soil will retain less of the applied water within the root zone.

In many situations, extending irrigation intervals to the extent permitted by the crop, the irrigation system employed, and the schedule for water deliveries to the farm constitutes a desirable irrigation program not only in terms of water saving but also in labour saving, accomodation of other cultural operations, and sometimes improvement of root growth and reduction in root diseases. In such cases, the irrigation interval will depend primarily on the daily ET rate and on the quantities of water which can be applied.

2.3.1 Irrigation practice for rice

Irrigation of field crops is generally practiced solely for the purpose of improving the plants' moisture environment. Secondary effects sometimes are of importance, as with rice where flooding assists in controlling weeds and causes desirable changes in physicochemical soil reactions. Alteration of the soil temperature is a side effect which may be beneficial or detrimental depending on the crop, the season, and the water temperature (Robins et al., 1967).

Except for flooded rice, need for and quantity of water required at irrigation in a particular environment are determined by:

(i) the quantity of usable water stored in the crop root zone; and

(ii) the rate at which this supply is depleted.

Usuable soil water storage in this context encompasses water storage and transmission properties of the soil, the crops effective root depth and proficiency in water absorption, and the ability of the crop to tolerate soil water stress imposed by increasing soil water suction and interacting climatic parameters (Robins et al., 1967). These factors interdependently determine the quantity of water that may be extracted safely before irrigation is needed. Rate of depletion of this supply is determined primarily by climatic parameters with certain limitations imposed by soil and plant factors which interact to control the evapotranspiration and deep percolation rates. In the case of submerged rice culture, water is stored above the soil surface and irrigation water must be supplied to keep the depth of water within certain limits.

Considerable research effort has been applied to determining optimum irrigation practices and factors related to rice. This research has sufficiently clarified crop characteristics and response to climate, soil and water supply variations to permit outlining irrigation practice recommendations for near-maximum yield under most conditions.

2.3.2 Crop characteristics influencing irrigation practices for rice.

2.3.2.1 Season of growth

Season of growth influences frequency and quantity of required irrigation application because of variations in evapotranspiration with seasonal climatic changes (Penman et al., 1967). Irrigation frequency and quantity for rice, whether produced under upland or lowland environments and whether submerged or not, likewise depend on rate of evapotranspiration. Water depletion is more rapid during hot months than during cooler seasons, other conditions being similar. Under submerged conditions, however, rate at which irrigation water must be supplied is often controled by rate of deep percolation loss and amount of rainfall rather than by evapotranspiration rate (Robins et al., 1967).

Rice is grown over a wide range of latitudes and elevations but grows and yields best under warm temperatures. Short and intermediate season varieties (100 to 150 days) are used in colder climates. Use of long-duration varieties (180 days or more) is limited to tropical latitudes (Robins et al., 1967). Using short or intermediate maturing varietes, two and even three crops a year, can be taken from some tropical lands. Due to the continuous presence of a free water surface under submerged conditions or the very wet conditions usually maintained under intermittent irrigation, evapotranpiration by rice generally approaches the climatic potential throughout its growth cycle (Vacchani, 1953). This is in contrast to other grain and field crops in which incomplete vegetative cover during a portion of the growth period results in evapotranspiration rates considerably below the climatic potential.

2.3.2.2 Rooting Characteristics

Rate and depth of root growth and degree of root proliferation greatly influence irrigation practice, except for submerged rice or where a high water table exists. The plants usable water supply is largely limited to the water storable in that soil volume explored by the crop's root system (Danielson, 1967).

Rice has a very shallow root system. Where grown submerged or on upland areas during periods of very high rainfall, most roots are confined to the top 20 or 30 cm with profuse secondary root development on or near the immediate soil surface and in algal growth on the soil surface (Adair et al., 1962). The root system of rice increases gradually from seeding or tranplanting, reaching a maximum at the time of heading, and decreases after flowering while at maturity most of the roots are dead. Root growth continues under low oxygen concentration in the soil. At the time of head initiation, root growth is horizontal and upward, producing a dense surface mat (Doorenbos et al., 1979).

2.3.2.3 Reaction to soil water conditions

Rice apparently has three critical periods wherein moisture stress reduces grain yield - the seedling establishment, the tillering stage of growth, and a period from about 20 days before to about 5 days after heading (Adair et al., 1962; Matsushima, 1962). Yield reductions during the latter period are due to unfertilized florets. Marked stress near maturity also may cause yield depressions. Stress may develop quite rapidly when submerged rice is drained because of the very shallow root system developed under flooded culture. Thus, care is taken to avoid sudden stress under these conditions.

2.3.3. Rice Irrigation Systems and Practices

Rice irrigation is largely limited to surface flooding systems. With surface systems, rice may be either flooded in basins or irrigated in furrows or rills successfully (Robins et al., 1967; Doorenbos et al., 1979). Rice is not especially sensitive to surface water impoundment so long as ambient temperatures do not raise water temperatures above 40°c.

Rice generally grows and produces best when submerged during most of the growth period with water depth of 5 to 20cm. In some cases, rotation irrigation on a schedule sufficient to keep the soil surface layers at or near saturation has produced yields equal to those under submerged culture and with significant saving of water (Robins et al., 1967; *Doorenbos et al.*, 1979). In other cases, yields comparable to submerged culture were produced by flooding only during seedling establishment and from the early boot stage to maturity (Chow, 1951; Matsuo, 1957; Ten Have, 1959; Aglibut et al., 1960; Adair et al., 1962; Matshushima, 1962).

Need for maintaining flooded conditions for rice production has been attributed to:

(i) difficulties in plant establishment due to shallow root system,
(ii) weed control,
(iii) control of microclimate
(iv) prevention of pollination failure
(v) prevention of high manganese level which upset the growth regulator balance; and
(vi) increase in protein, mineral, and soluble carbohydrate content of the grain.

Detriments from flooding on soils with poor drainage characteristics, low pH and high organic matter include a physiologic disease variously called "Mentak", "Pentek merah", and "browning disease", (Vecht, 1953; Johnson, 1954; Ponnamperuma et al., 1955). Primary visible symptoms is damage to the root system. On soils that are low in iron and where sulfur is present, continuous flooding may result in toxic concentrations of H_2S which cause root damage (Mitsui, 1954). These root-damaging conditions are associated with low soil redox potentials which bring iron, manganese, or H_2S to toxic levels in the soil. Temporary drainage and subsequent aeration as the soil dries help alleviate damage from these "diseases."

As a minimum, water sufficient to maintain the soil at or near saturation during seedling establishment, tillering and the 30 day period from 25 days before to 5 days after heading is essential for maximum production.

Use of irrigation water colder than about 15°c will generally reduce plant growth and ultimate yield. Good water control structures, adequate drainage facilities and land shaping to provide maximum water control during water application and within the field are important if use of irrigation water is to be most efficient. Maximum water control combined with care in scheduling planting can assure meeting the demands of this crop with minimum irrigation water supplies. Vamadevan and Dastanne (1968) showed that about 70% of the water delivered to the rice crop in the submergence practice was lost through deep percolation.

Presently, the orientation of research in water management practices in irrigated rice cultures is directed at water saving methods. Especially in transitional areas (semi-arid tropics like the Sudan Savanna inclusive), and in areas with unstable irrigation systems (Huke, 1976; IRRI, 1989). In these areas, keeping the soil at or near saturation level has been shown to be promising in terms of water saved, without reducing yield. However, few research has been carried out in this aspect of water management in irrigated rice cultures (IRRI, 1989).

CHAPTER 3

MATERIALS AND METHODS

The experiment was conducted for 2 consecutive dry seasons (1989/1990 and 1990/1991) at the Irrigation Research Station, Kadawa (11° 39'N, 08° 02'E and 500 m above sea level). The station is located within the Kano River Project area (one of the largest irrigation schemes in Nigeria). The Kano River Project extends over a large area in the Sudan Savanna ecological zone (a semi-arid belt of northern Nigeria).

The soils of the Research Station have been classified as Eutric Cambisol (FAO/UNESCO) and Typic Ustropept by Ojanuga et al., (1979), who also found the soil parent material to be aeolian sandy drift over ironpan. The soils are moderately to imperfectly drained to a depth of 90 cm because of the perched water table resting on the underlying ironpan at depths varying between 100 and 150cm.

3.1 Physical and Chemical characterisation of Experimental site

A characterisation of the physical and chemical properties of the experimental site was carried out prior to cropping.

3.1.1 Physical Properties

The physical characterisation of the soil profile was carried out for the following soil layers:- 0 - 15, 15-30, 30 - 45, 45 - 60, 60 - 75 cm.

Soil particle size distribution was determined by the hydrometer method of Bouyoucos (1954), modified slightly by Day (1956).

The bulk density was determined by the core method. A hammer-driven core sampler (Lutz, 1947; Schuurman and Goedewaagen, 1971) was used for taking undisturbed soil.

The total porosity was determined from the following relationship:

$S_t = 100\ (1 - D_b/D_p)$ ....(1)

where S_t is total porosity, D_b the bulk density, and D_p the particle density taken as 2.65 g cm^{-3}.

The infiltration characteristics of the soil was determined by the cylinder infiltrometer method (Michael, 1978). The cylinders of 60cm (outer) and 30cm (inner) diameters were installed to a depth of 10cm. The water level in the inner cylinder was read with the field type point gauge at 5 minutes intervals. The water level reading/observations were taken for a total period of 240 minutes.

The saturation capacity (maximum water holding capacity) corresponding to zero water suction (tension), was determined both in the field and laboratory. In the laboratory, it was determined by soaking undisturbed soil cores for 48 hours allowing to drain for one hour, and then oven-dried for about 24 hours at 105°C (Hillel, 1974, 1980). In the field, it was determined by ponding water on the soil surface for three consecutive days. On the third day, the soil was sampled, left to drain for 1 hour on filter papers, and then oven dried at 105°C for about 24 hours (Hillel, 1974). For both field and laboratory methods, the water content was given as

$$O_v = O_g \times D_b \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where O_v is volumetric water content, O_g is the water content on weight basis, and D_b the bulk density of the soil. The depth of water in a given soil layer was obtained by the relation.

$$d = O_v \times D \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where d is the depth of water in centimeters, O_v as defined above, and D is the depth of the soil layer.

The field capacity was also determined in the field and laboratory. In the laboratory, undisturbed soil cores soaked for about 48 hours were subjected to 0.1 bar (10kpa) suction, using the pressure plate technique (Hillel, 1974, 1980). In the field, the field capacity was determined by ponding water on the soil surface ($2m^2$ area), and allowing it to drain for about 24 hours (Hillel, 1974). Evaporation was prevented by spreading polythene sheet over the ponded areea. Soil was sampled, and oven dried at 105°C for about 24 hours. Soil moisture content was given by the relationships in equations (2) and (3).

The wilting point was determined in the laboratory by subjecting undisturbed soil cores soaked for about 48 hours to 15 bar pressure, using the pressure plate technique (Hillel 1974, 1980). Soil cores were then oven-dried at

105°C for about 24 hours (Hillel 1974), and the moisture content determined by the relationship given in equations (2) and (3).

Available water capacity was taken as the water held between field capacity and the wilting point Hillel, 1974, 1980). However, for irrigated rice cultures this is taken as the water held between saturation capacity and wilting point (IRRI, 1970; Doorenbos et al., 1977, 1979).

The soil moisture release (characteristic) curve was determined by subjecting undisturbed soil cores, soaked forabout 48 hours, to different suctions ranging from 0.1 to 15 bars. And then determining the moisture content at these suctions (Hillel, 1974, 1980).

Groundwater table depths were monitored at 14 days intervals by means of piezometers installed in the plots.

3.1.2 Soil Chemical Properties

Composite samples were used for the analyses. Total N was determined by the Macro-Kjeldahl method (Black, 1965); organic carbon content by the Walkley-Black method (Black, 1965); available P by the Bray 1 method (Bray and Kurtz, 1945); Exchangeable K by the ammonium acetate solution/flame photometer method (Jackson, 1965); exchangeable Ca by the ammonium acetate extract with atomic absorption spectrophotometer (Jackson, 1965). Available Fe, Mn, Zn, Cu were determined by the DPTA method (Jackson, 1965).

Soil pH was determined potentiometrically after equilibration with water and INKCl in a 1:2.5 soil to solution ratio, using a glass electrode pH meter.

Electrical conductivity was determined in 1:2 soil-water extract using a conductivity bridge.

3.2 Agrometeorological Data

Because monitoring of the most important weather variables is imperative for rice-weather relation studies, considerable effort was made to collect a set of daily weather data.

The set of daily weather parameters collected are:

Rainfall (mm)
Maximum temperature (°C)
Minimum temperature (°C)
Dry bulb temperature (°C) (2x a day)
Wet bulb temperature (°C) (2x a day)
Radiation (MJ/m^2)
Wind speed (Km/day)
Pan evaporation (mm)

The dry and wet bulb temperatures were used to compute relative humidity (RH - %).

3.3 Crop Data

A set of crop data were collected. The parameters include:

Days from seeding to flowering
Days from flowering to maturity

Dry matter yield (at 14 days interval)

Plant height (at 14 days interval)

Number of grains per m^2 (at harvest) (equivalent to number of spikelets per m^2).

Percent-filled grain (at harvest)

Weight of 1000 grains (at harvest)

Grain yield (at harvest)

Percentage-filled grain was determined by the following procedure:-

1. Some air-dried paddy rice was weighed (x);
2. This was then introduced into 1l measuring cylinder;
3. Some top soil was added to the measuring cylinder which was then filled to the 1l mark with water;
4. The cylinder was then shaken several times and allowed to stand for about 20 secs.
5. The suspension (containing unfilled and partially filled grains) was then decanted.
6. The sediment (consisting of soil particles and filled grains) was washed into a sieve, where the rice grains were washed free of soil.
7. The grains were then air-dried for about 3 days, and weighed ($_y$).

Percent-filled grain was calculated as:

$$\frac{y}{x} \times 100$$

The procedure can be improved upon by drying to a constant weight at 60°C in steps 1 and 7.

3.4 Crop Water Use

Actual evapotranspiration (ETcrop) was determined by a combination of the soil water depletion method (direct sampling), and the method of Vamadevan and Dastane (1968). The method of Vamadevan and Dastane was designed for irrigated rice cultures (submerged and non-submerged). The method estimates quantitively (irrespective of ground water table conditions) percolation losses when the amount of water applied (irrigation or precipitation), the soil texture, and the infiltration rate are known.

Potential evapotranspiration was computed by the radiation and pan evaporation methods, following the proceedure of Doorenbos et al (1979).

3. 5 Treatments

3.5.1 Variety

Two rice varieties: ITA 212 and ITA 123 were used. The selection of the varieties were based on their adaptability to rainfed lowland conditions and irrigation in the Sudan Savanna ecological zone. Both varieties are of the indica type with medium growth duration, but different morphology.

Other factors that influenced the choice of these varieties are their high yield capacity, resistance to blast, and wide acceptance by farmers in the area.

3.5.2 Sowing Dates

The experiment incorporates four (4) sowing dates (December through March) at 4 weeks interval during the dry season (mid-Dec., mid-Jan., mid-Feb., and mid-Mar.).

3.5.3 Irrigation Schedule

Three irrigation schedules were imposed 14 days after seedling emergence by the use of tensiometers. The schedules were irrigating at 10 Kpa (1_1), 15 Kpa (1_2), and 25 Kpa (1_3) suctions (tensions).

Two tensiometers were installed at each station. One at 15cm depth (active root zone of rice in irrigation and lowland cultures); and the other at 30cm depth. The tensiometer installed at the 15cm depth was used to schedule irrigation; while that at 30cm depth was used to monitor percolation.

The schedules (soil suction at which irrigation water was applied) were chosen based on the soil moisture release curve of the soil of the experimental site. 10 Kpa approximates the lower limit of the saturation capacity of the soil (range: 0-10 Kpa); 15 Kpa the mid-point of the field capacity (range: 10-20 Kpa); and 25 Kpa just beyond the field capacity. The root system of rice, with it's uniqueness amongst field crops, was also considered in establishing the irrigation schedules. At each schedule, water was applied to bring the soil to saturation.

3.6 Experimental Design and Cultural Practices

The dry season experiment was laid out as a 4 x 3 x 2 RCB factorial with four replicates. The size of each plot was 5m x 3m. A total of 96 plots were involved.

Rice seeds were broadcast at the rate of 80 kg ha^{-1}; 125 kg N ha^{-1} was applied in two split doses. The first split of N (through calcium ammonium nitrate, CAN) was applied at the beginning of tillering; and the second split as urea at panicle initiation. A basal application of 30 Kg ha^{-1} each of P and K (through single superphosphate, and muriate of potash, respectively) were applied in a single dose during land preparation.

Each plot formed a basin with bunds high enough to check surface run-off (thus retaining all water applied).

Weed control: Ronstar 25 EC (a pre-emergence herbicide) was applied to moist soil three days after seeding. Basagran PL (a post-emergence herbicide) was used up to about 50% groundcover. This was subsequently followed by hand-pulling of weeds.

Control of Rodents: Klerat was used at 7 - 10 days intervals as soon as rodent attack was noticed. The Klerat pellets were placed at the entrance of identified rat holes and on the bunds.

Birds control: Labour was engaged at heading time to scare birds. He came early hours of the morning, and left late in the evening. Birds attack mostly in the mornings and evenings. Scare-crows were not effective in checking bird attack.

CHAPTER 4

RESULTS AND DISCUSSIONS

The results of this study have been categorized into five; in the following order, 1. Preliminary investigations, 2. Sowing date studies, 3. Irrigation schedule, 4. Crop water use, 5. Prediction models. Each data point presented is the mean of the two rice varieties, unless stated otherwise. There was no significant effect of variety on yield components and yield.

4.1 Preliminary Investigations

A preliminary investigation of some of the physico-chemical properties of the soil was carried out. The results of the mechanical analysis, bulk density, and total porosity are presented in Table 1. The soil profile shows a loamy sand top (0-15cm) overlying a sandy loam layer. The bulk density generally increased with depth. The relatively higher bulk density just below the surface (15-30cm) indicates the presence of a plow-pan, probably the result of farm traffic. The total porosity generally decreased with depth, though the 15-30cm layer had a lower porosity than the underlying layers. This can also be attributed to the existence of a plow-pan.

Table 1: Some Soil Physical Properties

Soil Depth (cm)	Clay %	Silt %	Fine sand %	Coarse Sand %	Texture density} (gcm^{-3})}*	Bulk	Total Porosity %
0-15	6.5	14.91	74.00	4.59	Loamy sand	1.56	41.2
15-30	9.82	14.00	72.00	4.18	Sandy loam	1.65	37.7
30-45	10.41	14.00	71.72	3.87	Sandy loam	1.60	39.7
45-60	14.85	11.93	72.00	1.22	Sandy loam	1.62	38.9
60-75	15.02	11.95	71.55	1.48	Sandy loam	1.64	38.2

The soil moisture release curve data (Table 2) shows an increase in soil moisture content with depth at all soil suctions; and decrease with increasing soil suction for all the soil layers. The soil moisture constants (Table 3) indicate an available water of 331.5, and 104.3mm for rice and other crops respectively.

Table 2: Soil Moisture Release Curve Data

Soil moisture suction (Kpa)	Soil depth (cm) 0-15	15-30	30-45	45-60	60-75
	Soil moisture content ($cm^3\ cm^{-3}$)				
0	0.506	0.550	0.570	0.575	0.575
10	0.240	0.248	0.256	0.259	0.259
15	0.166	0.190	0.230	0.242	0.242
20	0.160	0.179	0.220	0.231	0.231
25	0.153	0.161	0.182	0.210	0.210
30	0.146	0.155	0.174	0.201	0.201
100	0.140	0.148	0.163	0.170	0.170
300	0.120	0.123	0.132	0.162	0.162
500	0.120	0.121	0.124	0.150	0.150
1500	0.106	0.109	0.115	0.118	0.118

Table 3: Soil Moisture Constants

Soil depth (cm)	Saturation Capacity	Field Capacity	Wilting Percentage	Available Water (for rice)	Available Water (for other crops
	cm^3cm^{-3}	cm^3cm^{-3}	cm^3cm^{-3}	mm	mm
0-15	0.506	0.240	0.106	60.0	20.0
15-30	0.550	0.248	0.109	66.1	20.8
30-45	0.570	0.256	0.115	68.2	21.1
45-60	0.575	0.259	0.118	68.6	21.2
60-75	0.575	0.259	0.118	68.6	21.2

The intake characteristics of the soil is shown in Figure 1. The intake rate (final or equilibrium) is 2 $cmhr^{-1}$, and is considered as medium in value (Gairon, 1973).

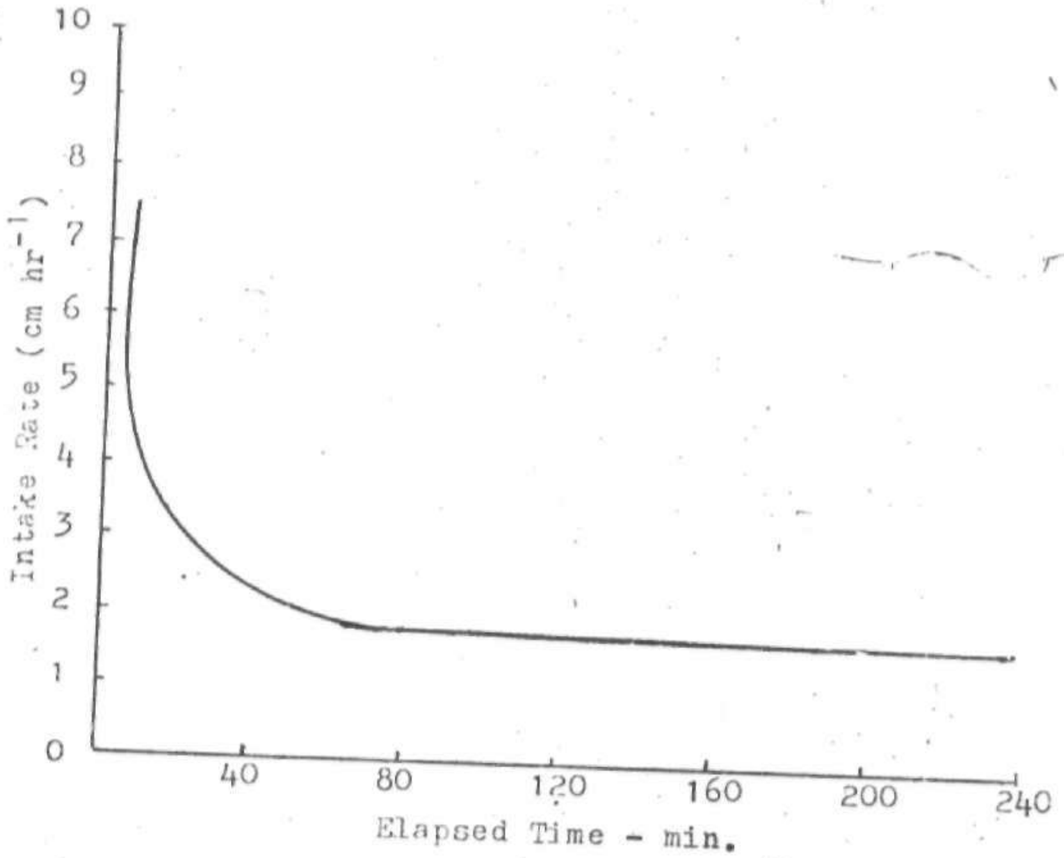

Figure 1. Soil intake rate.

The chemical properties of the soil are given in Table 4. The data indicate medium fertility, a common characteristic of the soils of the semi-arid savanna.

Table 4: Some chemical properties of the soil before cropping

Parameters	1989/90	1990/91
pH	5.30	5.50
Organic carbon-g Kg^{-1}	3.86	4.00
Total N-g Kg^{-1}	0.46	0.48
Available P-mg Kg^{-1}	12.37	12.22
Exchangeable K cmol Kg^{-1}	0.51	0.38
" Ca "	3.75	4.10
" Mg "	1.07	1.05
" Na "	0.13	0.16
Micronutrients		
Cu -mgKg^{-1}	1.13	1.09
Fe "	11.73	14.28
Mn "	19.54	17.79
Zn "	1.01	0.97
EC 1:5 - mmhos	0.03	0.05

4.2 Sowing Date Studies

Under field conditions, the effect of weather variables on yield and yield components as well as length of phenological phases, is usually studied by time of sowing (sowing date) experiments. Where water is not a constraint, and where biological stresses and adverse soil conditions are negligible, yield potential is related to such atmospheric parameters as air temperature and solar radiation. Real-time temperature and solar radiation during crop growth duration are given in Table 5.

Table 5(a).10-day Temp., Rad., RH, Windspeed, Evaporation, Rainfall means:1989/90 Dry Season

Month	Decade	Max. temp. °C	Min. temp. °C	Max-Min temp. °C	Rad. Cal cm^{-2}	RH %	Windspeed Km d^{-1}	Evap mm	Rainfall mm
Dec.	1	29.0	13.9	15.1	460.8	40.5	149.67	7.16	0
	2	29.8	12.1	17.7	451.2	57.8	150.78	6.40	0
	3	28.5	13.1	15.4	441.6	50.1	142.10	6.30	0
Jan.	1	28.5	13.5	15.0	427.2	41.0	138.54	6.66	0
	2	29.4	13.8	15.6	492.0	44.0	152.71	5.87	0
	3	28.2	21.1	7.1	424.8	45.5	139.98	5.50	0
Feb.	1	26.8	12.8	14.0	504.0	39.5	129.03	6.00	0
	2	28.9	14.6	14.3	532.8	41.0	131.73	6.03	0
	3	28.1	11.8	16.3	532.8	44.5	149.30	6.57	0
Mar.	1	31.1	14.7	16.4	508.8	46.5	139.10	6.22	0
	2	30.7	15.3	15.4	528.9	37.0	164.10	7.98	0
	3	30.1	15.4	14.7	600.0	35.5	132.14	7.70	0
Apri.	1	38.2	18.8	19.4	609.6	38.5	117.21	8.20	0
	2	38.2	26.1	12.1	564.0	42.5	177.35	9.54	0
	3	37.1	24.5	12.6	535.2	47.5	159.15	7.20	0
May	1	37.9	22.8	15.1	528.0	53.5	196.12	8.65	3.55
	2	34.5	23.7	10.8	535.2	61.5	192.28	6.12	1.40
	3	37.0	24.7	12.3	549.6	54.0	199.11	9.18	0.15
June	1	35.8	24.5	11.3	568.8	52.5	204.26	8.93	0.20
	2	36.6	25.9	10.7	552.0	55.0	223.49	10.44	1.91
	3	33.6	22.9	10.7	496.8	60.0	248.08	6.67	1.60
July	1	33.6	22.5	10.5	549.6	65.5	191.83	6.72	7.15
	2	30.7	22.0	8.7	458.4	67.0	170.98	5.67	8.86
	3	32.0	21.5	10.5	511.2	61.0	139.83	6.59	6.34

Table 5(b) 10-day Temp., Rad., RH, Windspeed, Evaporation, Rainfall means: 1990/91 Dry Season

Month	Decade	Max.temp. °C	Min.Temp. °C	Max-Min temp. °C	Rad Cal Cm^{-2}	RH %	Windspeed Km d^{-1}	Evap mm	Rainfall mm
Dec.	1	34.4	17.2	17.2	477.6	43.0	103.74	6.15	0
	2	35.3	16.9	18.4	451.2	43.5	122.43	6.48	0
	3	34.1	14.9	19.2	434.4	37.0	136.63	6.70	0
Jan.	1	27.1	13.8	13.3	432.0	36.0	197.41	6.56	0
	2	26.9	13.8	13.1	451.0	40.5	142.93	6.07	0
	3	28.8	15.4	13.4	508.8	42.5	150.38	7.63	0
Feb.	1	31.5	15.5	16.0	508.2	41.0	126.30	7.07	0
	2	34.4	16.5	17.9	552.0	37.5	123.47	7.33	0
	3	35.1	18.7	16.4	547.6	36.0	110.75	7.34	0
Mar.	1	31.3	18.2	13.1	528.0	42.0	116.82	7.92	0
	2	33.1	20.9	12.2	511.2	50.0	119.69	10.71	3.5
	3	34.8	20.0	14.8	602.4	36.5	108.42	7.64	0
Apr	1	36.9	24.0	12.9	571.2	47.5	161.73	8.04	0
	2	37.4	23.7	13.7	518.4	38.5	142.96	7.52	0
	3	37.9	23.5	14.4	525.6	50.0	170.38	8.13	1.86
May	1	37.5	24.0	12.9	571.2	47.5	172.42	5.73	1.35
	2	31.7	22.3	9.4	470.4	64.0	165.38	5.58	4.22
	3	33.5	22.5	11.0	444.0	70.5	131.99	6.00	7.42
June	1	36.0	23.5	12.5	516.0	59.5	170.98	6.90	2.53
	2	36.0	20.9	15.1	484.8	61.0	181.47	5.66	6.41
	3	33.7	22.1	11.5	532.8	71.5	145.95	4.90	1.11
July	1	30.6	22.1	8.5	456.0	59.5	149.64	5.27	11.55
	2	30.6	21.6	9.0	480.0	59.0	138.90	7.71	10.46
	3	30.0	21.0	9.1	432.0	64.0	122.83	7.31	15.44

Table 5(c) Real time temperatures and solar radiation at different crop growth stages (1989/90 dry season)

Sowing date	Max. temp. (°C)	Min. temp (°C)	Mean temp. (°C)	Max-Min temp (°C)	Solar radiation Cal cm^{-2}
	Seeding to panicle initiation				
D1	29.1	14.4	21.7	14.7	536.24
D2	29.2	14.9	22.1	14.2	558.6
D3	32.2	16.7	24.4	15.2	600.5
D4	35.4	20.5	27.9	15.0	608.3
	Panicle initiation to heading				
D1	37.8	23.1	30.5	14.7	617.1
D2	37.8	23.1	30.5	14.7	617.1
D3	36.5	23.7	30.1	12.8	577.2
D4	36.0	24.7	30.3	11.3	597.2
	Heading to maturity				
D1	36.3	23.9	30.1	12.4	590.85
D2	36.3	24.9	30.6	11.4	581.85
D3	36.5	26.5	31.5	10.0	576.00
D4	34.2	25.2	29.7	9.0	568.00

D1 = Dec., D2 = Jan., D3 = Feb., D4 = Mar.

Table 5(d) Real time temperatures and solar radiation at different crop growth stages (1990/91 dry season)

Sowing date	Max. temp (°C)	Min. temp (°C)	Mean temp (°C)	Max-min temp (°C)	Solar radiation (cal cm^{-2})
	Seeding to panicle initiation				
D1	32.1	16.8	24.4	15.3	544.6
D2	32.0	17.4	24.7	14.6	570.4
D3	34.7	18.9	27.5	14.4	593.2
D4	36.3	22.8	29.5	13.5	586.7
	Panicle initiation to heading				
D1	37.4	23.7	30.6	13.7	583.3
D2	37.4	23.7	30.6	13.7	583.3
D3	35.7	23.4	29.6	12.3	547.7
D4	34.3	20.9	28.3	12.0	518.7
	Heading to maturity				
D1	34.7	23.2	28.9	11.7	528.5
D2	34.7	23.2	28.9	11.7	528.5
D3	34.8	24.8	29.8	10.0	515.6
D4	34.6	26.5	30.6	8.1	508.2

D1 = Dec., D2 = Jan., D3 = Feb., D4 = Mar.

4.2.1 Plant Height

The effect of sowing date on plant height at three stages of growth (28 days after emergence (DAE), maximum tillering, and maturity) is presented in Table 6. Each data point represent the mean of the two rice varieties used in this experiment. Data analysis was based on the format of the pooled analysis of variance for measurements over time. The result show a highly significant effect of sowing dates.

Plant heights were significantly higher with February and March sowing dates than the December and January dates. The difference in plant height between the sowing dates are attributable to the differences in temperature and solar radiation during the vegetative period (Table 5c and d). Plant heights became higher as the mean air temperature and solar radiation increased during the vegetative period as the sowing moved from December through March. This observation is similar to an earlier one made by Oldeman et al., (1987), that in general, reduced temperatures and/or solar radiation during the vegetative period reduced plant height.

4.2.2 Number of seeds per square meter

In rice, the sink size of a crop is largely determined by spikelet number per square meter, since this translate into number of seeds per square meter (Yoshida and Parao, 1976). Spikelets function as sink after pollination. Hence the sink size is determined at and before flowering. Therefore the relative importance of climatic influence before or after flowering depends on whether sink size is limiting to grain yield or not.

The effect of sowing date on number of seeds per square meter is given in Table 7. The result shows a significant effect of sowing date on number of seeds.

Table 6: Effect of sowing date on plant height (cm)

Sowing date	1989/90	1990/91
	28 DAE	
D1	6.53	6.62
D2	6.52	6.60
D3	13.37	14.01
D4	16.63	17.16
LSD 0.05	0.41	0.25
	At maximum tillering	
D1	25.38	25.73
D2	26.89	27.41
D3	34.79	35.02
D4	35.70	35.65
LSD 0.05	0.86	0.69
	At maturity	
D1	65.08	62.93
D2	65.31	72.45
D3	70.83	74.05
D4	72.85	75.99
LSD 0.05	1.83	1.32

DAE = Days after emergence; D1 = Dec., D2 = Jan., D3 = Feb., D4 = Mar.

Table 7: Effect of sowing date on number of seeds (x10^3 per square meter

Sowing date	1989/90	1990/91
D1	12.43	16.13
D2	14.98	18.68
D3	15.57	20.27
D4	17.04	20.74
LSD 0.05	0.73	0.73

The number of seeds increased from December through March. The difference in number of seeds between the sowing dates could be linked to the solar radiation level during the reproductive stage (panicle initiation to flowering), as well as the temperature. A combination of high solar radiation and high max. temperature at the reproductive stage have been indicated to reduce the number of seeds (Yoshida and Parao, 1976). Solar radiation from panicle initiation to flowering (heading) was highest within the December and January sowing dates than with the February and March sowing dates (Table 5c and d). This coupled with the high max. temperature could have resulted in the lower number of seeds obtained with the December and January sowing dates relative to the February and March sowing dates.

4.2.3 Filled-grain Percentage

Many factors such as climate, soil, variety, fertilizer application, disease and insect attack appear to affect filled-grain percentage or sterility percentage. In many agronomic papers sterility percentage refers to percentage of infertile grains plus partially filled grains. Hence the term sterility is not being strictly used.

Data presented in Table 8 show no significant effect of sowing date on filled-grain percentage. Data in Table 5 (c and d) indicate that mean air temperatures and solar radiation during the ripening period (heading to maturity) for all sowing dates (December through March) were close in value. Similar levels of solar radiation and temperature at the ripening stage for the four dry season sowing dates could account for the non-significant difference in filled-grain percentage between the December through March sowing dates. Yoshida (1981) indicated that environmental factors (such as high or low temperature during ripening) and cultural practices (protection against pests) determine filled grain percentage. Nakayama (1969) stated that high temperatures (>33°C daily maximum) during the ripening period is believed to be a major factor in impaired ripening, and thus lowered filled-grain percentage. Real-time weather variables at Kadawa during the ripening period (Table 5c and d) for the December through March sowing dates indicate daily maximum temperature greater than 33°c.

Table 8: Effect of sowing date on filled-grain percentage

Sowing date	1989/90	1990/91
D1	64.39	67.95
D2	63.94	68.16
D3	63.93	68.25
D4	63.43	67.95
LSD 0.05	NS	NS

4.2.4 1000-grain weight

Data presented in Table 9 did not indicate any significant effect on 1000-grain weight due to sowing dates during the dry season. The same reasons adduced for the non-significant effect of sowing date on filled-grain percentge hold true for the 1000-grain weight. Because this yield component is related to other yield components, it's relationship with environmental parameters is more difficult to establish. A higher number of seeds and a high number of filled grains might lead to lower 1000-grain weight. According to Oldeman et al., (1987), a long postflowering period or high radiation intensity during postflowering might influence 1000-grain weight.

Table 9: Effect of sowing date on 1000-grain weight (g)

Sowing date	1989/90	1990/91
D1	20.27	22.83
D2	20.67	23.17
D3	20.70	23.20
D4	20.63	23.13
LSD 0.05	NS	NS

4.2.5 Ripening Grade

Ripening grade is the product of filled-grain percentage and 1000-grain weight. It is considered a good indication of degree of ripening. Data presented in Table 10 do not indicate any significant effect of sowing date on ripening grade. The relationship between ripening grade and climatic factors (solar radiation and temperature) could be deduced from the previous discussion on filled-grain percentage and 1000-grain weight.

Table 10: Effect of sowing date on ripening grade

Sowing date	1989/90	1990/91
D1	13.15	15.57
D2	13.28	15.81
D3	13.30	15.90
D4	13.07	15.76
LSD 0.05	**NS**	**NS**

4.2.6 Dry Matter Yield

Solar radiation, temperature, and the productive structure of the plant population are the most important factors which determine its dry matter production. The effect of sowing date on dry matter yield of rice is presented in Table 11.

Table 11: Effect of sowing date on dry matter yield (gm^{-1} row)

Sowing date	1989/90	1990/91
	28 DAE	
D1	34.96	47.83
D2	36.85	54.29
D3	51.89	60.63
D4	54.76	60.35
LSD 0.05	0.90	1.68
	At maximum tillering	
D1	111.30	133.90
D2	136.60	162.70
D3	144.4	169.00
D4	145.9	171.70
LSD 0.05	12.36	13.77
	At panicle initiation	
D1	138.10	162.20
D2	164.70	188.00
D3	172.50	194.30
D4	174.00	195.50
LSD 0.05	12.38	12.78
	At 50% flowering	
D1	204.30	233.90
D2	230.90	262.70
D3	238.70	269.00
D4	240.40	271.70
LSD 0.05	13.50	13.77

Table 11 continued

Sowing Date	1989/90	1990/91
At ripening		
D1	277.80	304.00
D2	299.80	334.20
D3	308.00	340.50
D4	309.70	342.00
LSD 0.05	13.50	13.32
	At maturity	
D1	318.70	371.30
D2	346.20	396.50
D3	353.30	403.60
D4	354.70	405.00
LSD 0.05	12.48	12.54

Data analysis was based on the format of the pooled analysis of variance for measurements over time.

The data indicate a significant effect of sowing date at each growth stage. At maturity, there was no significant difference between the January, February and March sowing dates. However these were significantly different from the December sowing date. The deviation of the December sowing date from the mean of the January, February and March sowing dates was not large. The mean air temperature and solar radiation during the early growth stages ofthe December and January sowing dates were lower than the mean temperature and radiation for the same period during the February and March sowing dates, (Table 5c and d). This resulted in a lower rate of dry matter accumulation at the early growth stages in the December and January sowing dates. This is in contrast to the vigorous growth exhibited by the February and March sowing dates. However at the later stages of growth, the rate of dry matter accumulation in the December and January sowing dates appeared to have caught up with the February and March dates. This observation is in agreement with an earlier study by Tanaka and Vergara (1967). The study by Tanaka and Vergara indicated that a vigorous increase in dry matter, consequently too fast an increase of leaf area index, at early growth stages is frequently associated with a low crop growth rate during later growth stages; whereas a rather slow growth at early stages is associated with a high crop growth rate during later growth stages.

The results from the study at Kadawa indicate that low temperature not only impaired the development of the crop at the early growth stages but also reduced the ability to produce dry matter. This may be through it's influence on the development of photosynthetic activity at this early growth stage.The main effect of the relatively lower solar radiation level at this early stage in December and January relative to the February and March sowing dates appears to be mainly through it's direct effect on the photosynthetic rate and partly through leaf area development by the supply of photosynthates and the regulation of specific leaf area.

4.2.7 Grain Yield

Where water is not limiting, and where other stresses (biological or soil) are negligible, the yield potential of rice is related mainly to air temperature and solar radiation. The effect of sowing date on grain yield was significant (Table 12).

Table 12: Effect of sowing date on grain yield (t ha^{-1})

Sowing date	1989/90	1990/91
D1	2.95	4.52
D2	3.65	5.21
D3	3.75	5.32
D4	4.43	6.00
LSD 0.05	0.27	0.27

A close look at Tables 5 (c and d) and 12 show that yield increased as solar radiation and max-min. temp. difference decreased during the postflowering period as sowing moved from December through March. At Kadawa maximum-min. temperature during the postflowering period appears to have a stronger influence on yield than other temperature parameters.

4.2.8 Length of Phenological Phases

Two characteristic times were examined: sowing to flowering, flowering to maturity. The length of each period is given in Table 13. Growth phase duration from seeding to flowering ranged from 92 days (March sowing date) for ITA 123; to 160 days (December sowing date) for ITA 212 (1989/90).

The main effect of temperature during the first 30 days of growth was reduced growth at low mean temperature as evidenced in the dry matter accumulation and plant height of December and January sowing dates relative to the February and March sowing dates. Yoshida (1981, 1983) indicated that seedlings are sensitive to temperature from the first week of post-germination growth. Growth rate increases linearly with temperatures between 22 and 31°C but declines sharply above 35°C. Nishiyama (1976) considered approximately 13°C the critical mean air temperature for sowing rice.

Table 13: Effect of sowing date on length of phenological phases (days)

Sowing date	1989/90		1990/91	
	ITA 212	ITA 123	ITA 212	ITA 123
	Seeding to flowering			
D1	160	151	155	145
D2	134	120	131	118
D3	120	109	106	96
D4	106	92	102	92
	Flowering to maturity			
D1	28	28	28	28
D2	28	28	28	28
D3	30	30	30	30
D4	32	32	32	32

The overall effect of low mean temperatures at Kadawa was prolonged growth duration (seeding to flowering) in the December, January and February sowing dates. It is apparent from Tables 5 (c and d) and 13 that higher temperatures accelerated the rate of development. This implies that the length of the phase is shorter at higher temperatures.

Traditionally, the flowering to maturity period is considered to be about 30 days for rice (Oldeman et al., 1987). But the result of this study at Kadawa indicate that temperature also affects its length. There was little difference between the two varieties. Tables 5 (c and d) and 13 indicate that the higher the mean temperature from flowering to maturity, the shorter the duration.

4.3 Irrigation Schedule

Crop response to irrigation is better correlated with soil water potential or suction than with soil water content. Thus measurements of soil water potential or suction provide a useful approach to scheduling irrigations. In this section results of the effect of irrigation schedule (based on soil suction) on yield components and yield are presented and discussed. It was observed in this study that scheduling irrigation at 10, 15, and 25 Kpa suctions approximated to irrigating at 2, 3, and 4 days intervals, respectively.

4.3.1 Plant Height

The effect of irrigation schedule on plant height is presented in Table 14. Data analysis was based on the format of the pooled analysis of variance for measurements over time. The result shows a significant effect of irrigation schedule. At each crop growth stage studied, plant height was highest with irrigation scheduled at 10 Kpa, and least at 25 Kpa.

The results indicate that maintaining the soil at or near saturation resulted in taller plants than those grown in under unsaturated soil conditions. The rice plant is adapted to anaerobic soil conditions, having air canals from leaves to roots. Katayama (1961) showed that the development of these intercellular spaces in rice is influenced by the air content of the soil, being three times as great in non-aerated soil as in aerated soil. Larger intercellular spaces result in increased plant size (height). Other studies (IRRI 1975; Yoshida, 1978) have also indicated that morphologically, moisture stress in rice results in reduced plant height, reduced leaf area, number of tillers, and in severe cases rolling of leaves.

Table 14: Effect of irrigation schedule on plant height (cm)

Irrigation Schedule	1989/90	1990/91
	28 DAE	
I_1	12.18	12.76
I_2	11.11	11.28
I_3	8.98	9.25
LSD 0.05	0.71	0.21
	At maximum tillering	
I_1	33.09	33.57
I_2	31.44	31.65
I_3	27.54	27.63
LSD 0.05	0.75	0.59
	At maturity	
I_1	70.95	75.78
I_2	69.35	70.98
I_3	62.26	62.31
LSD 0.05	1.57	1.15

I_1 = 10Kpa; I_2 = 15Kpa; I_3 = 25Kpa.

4.3.2 Number of seeds per square meter

The effect of irrigation schedule on the number of seeds per square meter is presented in Table 15. The effect of irrigation schedule was significant. Irrigating at 10 Kpa produced significantly greater number of seeds per square meter, while irrigating at 25 Kpa gave the lowest number of seeds.

Table 15: Effect of irrigation schedule on number of seeds ($x10^3$) per square meter

Irrigation Schedule	1989/90	1990/91
I_1	17.03	20.73
I_2	15.22	18.92
I_3	13.51	17.21
LSD 0.05	0.63	0.63

Rice apparently has three critical periods wherein moisture stress reduces grain yield - the seedling establishment period, the tillering stage of growth, and a period from about 20 days before to about 5 days after heading (Adair et al., 1962; Matsushima, 1962). Yield reduction in the latter period are mostly due to reduced number of spikelets (translated to number of seeds) - the sink size (Reyes and Wickham, 1973; Yoshida, 1981). It is apparent from the results at Kadawa that maintaining the soil moisture regime at saturation is required for increased number of seeds. This observation is similar to those earlier made by Yoshida (1981).

4.3.3 Filled-grain Percentage

Data on filled-grain percentage is presented in Table 16. Irrigation Schedule had a significant effect on filled-grain percentage. Filled grain percentage was highest with irrigation scheduled at 10 Kpa, and lowest at 25 Kpa.

Filled-grain percentage is an important yield component and usually affected by conditions during the ripening period. Other than temperature and solar radiation, soil moisture regime is the next important factor affecting filled-grain percentage (Yoshida, 1981). Stress near maturity is known to cause yield reductions mainly through its effect on filled-grain percentage

Table 16: Effect of irrigation schedule on filled-grain percentage

Irrigation schedule	1989/90	1990/91
I_1	71.24	74.82
I_2	63.24	67.73
I_3	56.82	61.68
LSD 0.05	0.38	0.31

(Robins et al., 1967). Robins et al. (1967), indicated that stress may develop quite rapidly because of the very shallow root system developed in irrigated rice cultures when soil moisture regimes are below saturation from heading to maturity. The below saturation regimes at 15 and 25 Kpa in this experiment at Kadawa, could explain the lower percentage of filled grains relative to the 10 Kpa (saturation regime).

4.3.4 1000-grain weight

Irrigation schedule had a significant effect on 1000-grain weight (Table 17). 1000-grain weight was significantly higher at 10 Kpa than at other suctions studied. As discussed earlier, 1000-grain weight is determined during the ripening period. The result indicate that maintaining the soil moisture regime at saturation (10 Kpa) is needed for high 1000-grain weight.

Table 17: Effect of irrigation schedule on 1000-grain weight (g)

Irrigation schedule	1989/90	1990/91
I_1	22.33	24.84
I_2	20.98	23.51
I_3	18.39	20.90
LSD 0.05	0.28	0.28

1000-grain weight is an important yield component and contributes significantly to the final yield. In 'water saving' irrigation schedules practiced in some parts of the world, the soil is supplied with water to keep the water content in the effective root zone at not less than 75 per cent of full saturation throughout the total growing period (Doorenbos et al., 1979). Yield obtained with this method compared favourably and in many instances were higher than those obtained with continuous submersion. This they attributed to higher grain weight obtained with the 'water saving' irrigation schedule. Similar logic holds true for the differences in 1000-grain weight between the three moisture regimes in this experiment.

4.3.5 Ripening Grade

The effect of irrigation schedule on ripening grade is presented in Table 18.

Table 18: Effect of irrigation schedule on ripening grade

Irrigation Schedule	1989/90	1990/91
I_1	14.98	17.59
I_2	14.23	16.80
I_3	10.39	12.89
LSD 0.05	0.24	0.23

Ripening grade was significantly higher at 10 Kpa irrigation schedule than the other soil moisture suctions.

Ripening grade, defined as the product of filled-grain percentage and 1000-grain weight has been reported to relate more to yield than either filled-grain % or 1000-grain weight (Yoshida and Parao, 1976). The same factors that affect filled-grain percentage and 1000-grain weight also affect ripening grade. Thus the reasons adduced for the differences between the three irrigation schedules in terms of filled-grain percentage and 1000-grain weight also hold true for the ripening grade.

4.3.6 Grain Yield

Data on yield is presented in Table 19.

Table 19: Effect of irrigation Schedule on grain yield (t ha^{-1})

Irrigation Schedule	1989/90	1990/91
I_1	5.05	6.62
I_2	3.48	5.04
I_3	2.56	4.13
LSD 0.05	0.23	0.23

The effect of irrigation schedule on yield was significant. Grain yield was significantly higher at the 10 Kpa schedule, and lowest at the 25 Kpa schedule. It has been reported by earlier works (Doorenbos et al., 1979) that rotational irrigation on a schedule sufficient to keep the surface soil layers at or near saturation has produced yields equal to those under submergence culture, and with significant saving of water. Robins et al., (1967) indicated that as a minimum, water sufficient to maintain the soil at or near saturation during seedling stage, tillering and the 30-day period from 25 days before to 5 days after heading is essential for maximum production.

In this experiment at Kadawa, the conditions indicated by Robins et al., (1967) were met by scheduling irrrigation at 10 Kpa soil suction, and hence the higher yield at this suction than at 15 Kpa suction.

4.3.7 Dry Matter Yield

Dry matter production is closely related to grain yield, and in most cases the response pattern to irrigation is similar to that of yield. Table 20 shows the effect of irrigation schedule on dry matter yield. Data analysis was based on the format of the pooled analysis of variance for measurements over time. The data indicate significant effect of irrigation schedule on dry matter. Dry matter yield was only significantly different between the three irrigation schedules at the early seedling growth stage (28 DAE). At the other growth stages the 10 and 15 kpa schedules were not significantly different, but were however different from the 25 Kpa schedule. The same conditions necessary for high grain yields in rice are also required for high dry matter yield, and factors that affect it are also relevant to dry matter yield.

Table 20: Effect of irrigation schedule on dry matter yield (g m^{-1} row)

Irrigation schedule	1989/90	1990/91
	28 DAE	
I_1	50.33	61.50
I_2	45.30	57.63
I_3	38.21	48.19
LSD 0.05	0.78	1.45
	At maximum tillering	
I_1	148.40	172.80
I_2	139.40	164.30
I_3	118.80	140.90
LSD 0.05	10.72	11.91
	At panicle initiation	
I_1	176.50	197.50
I_2	167.50	191.90
I_3	142.90	165.90
LSD 0.05	10.72	11.07
	At 50% flowering	
I_1	242.80	272.80
I_2	233.80	264.30
I_3	209.20	240.90
LSD 0.05	10.72	11.91

Table 20 contd.

Irrigation schedule	*1989/90*	*1990/91*
	At ripening	
I_1	312.10	344.40
I_2	306.00	333.80
I_3	278.40	312.40
LSD 0.05	11.70	11.54
	At maturity	
I_1	357.20	407.50
I_2	348.80	399.40
I_3	323.70	375.40
LSD 0.05	10.81	10.85

4.3.8 **Length of Phenological phases**

Irrigation schedule had no effect on length of phenological phases. *This is similar to observations* made *by other workers* (Robins *et* al., 1967).

4.3.9 **Interaction between Treatments**

Of all crop growth parameters and yield, the interaction between sowing date and irrigation schedule had a significant effect only on dry matter yield at the early stage of growth - 28 DAE (Table 21). Thus the results indicate that the main effects of sowing date and irrigation schedule were more important factors affecting yield and yield components than their interaction. There was also no significant interaction between irrigation schedule and variety; sowing date and variety; irrigation schedule, sowing date and variety.

Table 21: Effect of interaction between sowing date and irrigation schedule on dry matter yield (g m^{-1} row) 28 DAE

Sowing Date	Irrigation schedule 1989/90				1990/91			
	I_1	I_2	I_3	Mean (D)	I_1	I_2	I_3	Mean(D)
D1	41.66	34.50	28.71	34.96	54.99	48.73	39.76	47.83
D2	37.17	40.26	33.10	36.85	55.80	58.46	48.60	54.29
D3	60.00	51.36	44.30	51.89	68.22	61.54	52.14	60.63
D4	62.49	55.06	46.72	54.76	67.00	61.79	52.28	60.35
Mean (I)	50.33	45.30	38.21		61.50	57.63	48.19	

LSD 0.05

1989/90	1990/91
I = 0.78	I = 1.45
D = 0.90	D = 1.68
IxD = 1.55	IxD = 2.06

4.4 Crop Water Use

Data on the total amount of water supplied to crop (through irrigation and rainfall); percolation loss; ETcrop for the crop growth duration are presented in Table 22. At each irrigation schedule, seasonal ETcrop decreased from the December sowing date through March i.e Dec. > Jan. > Feb > Mar. The decrease of the seasonal ETcrop from Dec. through March is primarily due to the shorter growth duration as sowing moved from December through March. At each sowing date, seasonal ETcrop increased as the soil suction at which irrigation was scheduled decreased i.e ETcrop 10 Kpa > ETcrop 15 Kpa > ETcrop 25 Kpa. Loss due to percolation accounted for about 70% of the total water supplied to the crop.

Table 22: Crop water use data

Irrigation Schedule		Sowing date			
		D1	D2	D3	D4
			1989/90		
I_1	ETcrop (mm)	938	814	776	650
	Applied water (mm)	3085	2672	2516	2032
	Rainfall (mm)	41	41	70	134
	Percolation (mm)	2188	1899	1810	1516
I_2	ETcrop (mm)	915	794	673	564
	Applied water (mm)	3009	2605	2173	1746
	Rainfall (mm)	41	41	70	134
	Percolation	2135	1852	1570	1316
I_3	ETcrop (mm)	903	796	664	556
	Applied water (mm)	2969	2612	2143	1719
	Rainfall (mm)	41	41	70	134
	Percolation (mm)	2107	1857	1549	1297
			1990/91		
I_1	ETcrop (mm)	985	830	730	638
	Applied water (mm)	3052	2535	2131	1708
	Rainfall (mm)	231	231	302	418
	Percolation (mm)	2298	1936	1703	1488
I_2	ETcrop (mm)	959	825	686	582
	Applied water (mm)	2965	2519	1984	1522
	Rainfall (mm)	231	231	302	418
	Percolation (mm)	2237	1925	1600	1358

Table 22 contd

	Irrigation schedule	Sowing date			
		D1	D2	D3	D4
I_3	ETcrop (mm)	900	766	662	569
	Applied water (mm)	2769	2322	1904	1478
	Rainfall (mm)	231	231	302	418
	Percolation (mm)	2100	1787	1544	1327

The pattern of water use during the season is given in appendix 1 and 2 for 1989-90, and 1990-91 respectively. At each sowing date and irrigation schedule, the ETcrop increased from sowing, peaked at heading and then declined towards maturity. The data indicate that the time around heading is the time for peak water demand for all the sowing dates.

Potential evapotranspiration (ETp) during the crop growth stage was calculated by both the pan method, and the radiation method following the procedure of Doorenbos et al., (1979). ETp values by both methods (appendix 3 and 4) were close to each other, and the ETcrop values.

The pattern of water use observed in this study indicate a monomodal pattern (Tables 23 and 24) with the single peak at heading. Studies in other parts of the world indicate that whether the pattern of water use is monomodal or bimodal is location specific (Murakami, 1966; Pande and Mitra, 1971; Sugimoto, 1971; Nishio, 1972).

Data on water use efficiency (WUE) is given in Table 23. Water use efficiency is defined here as the ratio of economic yield (grain yield) to season ETcrop. WUE efficiency was highest with the 10Kpa schedule. Also WUE increased as sowing date moved from December through March.

The higher WUE at 10Kpa despite the higher season ETcrop indicate that it's higher yield relative to that obtained at the other schedules led to increased WUE. The shortening of the crop growth duration from December through March also reduced the seasonal ETcrop, and thus increased the WUE.

Table 23: Water use efficiency (WUE) as affected by irrigation schedule, and sowing date

		1989/90			1990/91	
Irrigation Schedule	ETcrop (mm)	Yield (Kgha^{-1})	WUE (Kgha^{-1}mm^{-1})	ETcrop (mm)	Yield (Kgha^{-1})	WUE (Kgha^{-1}mm^{-1})
I$_1$	794.5	5050	6.36	795.8	6620	8.32
I$_2$	736.5	3480	4.73	763.0	5040	6.61
I$_3$	729.8	2560	3.51	724.3	4130	5.70
Sowing date						
D$_1$	918	2950	3.21	948.0	4520	4.77
D$_2$	801.3	3650	4.54	807.0	5210	6.46
D$_3$	704.3	3750	5.32	692.7	5320	7.68
D$_4$	590.0	4430	7.51	596.3	6000	10.06

4.5 Prediction Models

4.5.1 Yield Model

Weather has been widely studied as one of the major environmental factors influencing rice production. But in many rice growing areas of the world,no long-term weather data are available. Recently, the rice weather program has introduced standardized data collection procedures (Oldeman and Sheshu, 1983). Local weather combined with crop data obtained at the same site, can be used to quantify environmental effects on growth. Two basically different methods can be used: a statistical or correlation approach or an analytical or simulation approach. The first approach (which has been used in this study) uses empirical data and statistical methods to quantify the observed relationship between environmental and crop variables.

To examine the relative importance of each yield component to grain yield, the percent contribution was computed by means of correlation coefficient and multiple regression based on log scale. As shown in Table 24, filled-grain percentage explained about 60% of yield variation; 1000-grain weight about 53%, number of seeds per square meter 32%; while the combination of all the yield components accounted for 71% of yield variation. Thus filled-grain percentage and 1000-grain weight were clearly the most important yield components limiting yield in this experiment. With this conclusion, it seemed more logical to examine climatic influence on filled-grain percentage and 1000 grain weight rather than yield itself.

Table 24. Contribution of yield components to grain yield

Variable	Contribution to total variation in grain yield (%)		
	1989/90	1990/91	1989/90&1990/91 (Combined analysis)
Number of seed m^{-2} (N)	14.9	20.0	32
1000-grain weight (W)	40.0	36.6	53.4
Filled-grain % (F)	54.2	58.3	60.2
N + W	23.3	23.9	39.1
N + F	3.4	6.6	11.9
F + W	31.9	34.8	41.2
N + W + F	62.8	66.4	71.0

To examine the influence of climatic factors during the ripening period on yield, a regression analysis was computed for ripening grade (filled-grain percentage x 1000-grain weight), temperature, and solar radiation during the ripening period. To select the appropriate temperature parameter to be used in the regression analysis, correlation coefficients were computed for ripening grade and maximum temperature, minimum temperature, maximum-minimum temperature difference, and mean temperature. Ripening grade correlated more strongly with max-min temperature difference than the other temperature parameters. Hence only average daily max-min temperature difference and average daily solar radiation during the last 30 days after heading were considered in developing the prediction equation.

A multiple linear regression analysis between ripening grade, max-min temperature difference and solar radiation was carried out. The following regression equations were obtained:

for 1989/90 dry season

$$Rg = 35.863 - 0.782t - 0.022S \quad \text{.......(4)}$$

$$(R^2 = 0.995^*)$$

for 1990/91

$$Rg = 43.215 - 0.594t - 0.037S \quad \text{.......(5)}$$

$$(R^2 = 0.957^*)$$

for 1989/90 and 1990/91 combined

$$Rg = 31.536 - 0.765t - 0.014S \quad \text{.......(6)}$$

$$(R^2 = 0.988^*)$$

where Rg = ripening grade, t = average daily max-min temperature in °C, S = average daily solar radiation in cal cm^{-2}.

These equations imply that at Kadawa ripening grade is negatively correlated with max-min temperature difference and solar radiation during the ripening period. The procedure used here is similar to that of Yoshida and Parao (1976). The difference is that while Yoshida and Parao examined climatic influence on number of seeds, here it is on ripening grade.

Using 18.5 x 10^3 for number of seeds per square meter (the mean value for the 8 crops in 1989/90 and 1990/91 dry seasons), the grain yield can be estimated at different times during the dry season from the following relationship, between ripening grade (equation b), no. of seeds, and yield:

$$Y = [31.536 - 0.765t - 0.014S]\ 18.5 \times 10^3 \times 10^{-5}$$

$$= [31.536 - 0.765t - 0.014S]\ 18.5 \times 10^{-2} \quad \text{.......... (7)}$$

where Y = estimated yield in t ha^{-1}, and t and S as already defined.

The yield computed by the prediction model (equation 7) correlated with measured yield:

$$Y = 4.508 + 0.348\ X \quad \text{..................(8)}$$

$$(r = 0.931^*)$$

where Y = estimated yield, X = measured yield.

4.5.2 Evapotranspiration (ET) Model

Irrigation systems were in use in ancient times. But an appreciation of the relationship between ET and crop productivity and the start of research on that fundamental process are recent. The estimation of actual and potential ET has wide utility and has been the subject of extensive research. However, it is recognized that available methods for measuring ET differ in short-and long-term accuracy and in convenience and cost. Thus the choice of method depends on application.

The energy balance equation can be used to derive precise estimates of ET. The Research Group of Evapotranspiration (RGE, 1967) reported that for the whole rice season, measured values of open pan evaporation (EP) are equivalent to net radiation.

$$EP = Rn/_{L} = 0.017\ Rn\ (mmt^{-1})\ \ldots\ldots\ldots\ldots(9)$$

where Rn is the net radiation in cal cm^{-2}, L is the latent heat of vaporization of water (580 cal g^{-1} at 30°C), and t is the unit time for which Rn is considered. Continuous measurements of Rn of a paddy during the whole rice-growing period indicate that the ratio of Rn to total incoming solar radiation (Rs) varies from 0.7 at the early stage of growth to 0.55 at the rippening period, with a mean value of 0.62 (RGE, 1967).

$$Rn = 0.62Rs\ \ldots\ldots\ldots\ldots\ldots(10)$$

Thus from equations 9 and 10 and Rs in units of cal cm^{-2} over a period t

$$EP = 0.017 \times 0.62Rs = 0.01054\ Rs\ (mmt^{-1})\ldots\ldots\ldots\ldots(11)$$

From equation 11 and the relationship between ET and EP, approximations of ET can be made.

4.5.2.1 Simple ET Prediction Model

Evaporation pans provide a measurement that integrates the effect of solar radiation, wind, temperature, and humidity on evaporation from a specific open-water surface. The procedure followed in developing this model is based on one of the guidelines recommended by the Research Group of Evapotranspiration (RGE, 1967).

From data collected and analysed (already presented and discussed in preceeding sections), scheduling irrigation at 10 Kpa provided the most suitable soil moisture regime (saturation) for high yield. Weighted averages of actual evaporation (EP) from open pan data, and measured ET at 10Kpa for the four sowing dates (December through March) in the 1989/90 and 1990/91 dry seasons, for the entire crop season were regressed. The following relationship was obtained between ET and EP:

$$ET = 5.07 + 0.258\ EP \quad \text{..........(12)}$$

As discussed earlier, equation 11 can be used to estimate EP. Combining equations 11 and 12, the following relationship was obtained.

$$ET = 5.07 + 0.258\ [0.01054Rs) = 5.07 + 0.00272\ Rs\ \text{mm day}^{-1} \text{....(13)}$$

Equation 13 can serve as a model to estimate average ET values at the Kadawa area for a given rice crop season or crop growth stage from Rs data alone. For example for an average value of 500 cal cm^{-2} per day of solar radiation (calculated from 1989-1991 data for the four dry season sowing dates), the mean ET rate will be 6.4 mm day^{-1} using this model. The seasonal average value of measured ET (5.2 mm day^{-1}) is close to this estimated value of ET over a crop season.

Accurate estimates of rice ET by more sophisticated methods require numerous data imput that are not available in most rice growing regions. The model outlined in this study requires only an estimate of solar radiation.

CHAPTER 5

SUMMARY AND CONCLUSION

The water use effiency of rice (Oryza sativa L.) in relation to irrigation schedule and sowing date in the sudan savanna ecological zone (a semi-arid region) in Nigeria was investigated.

The treatments consisted of 3 irrigation schedules (iirigating at soil moisture suctions of 10, 15, and 25 Kpa respectively); and 4 sowing dates (mid-Dec. through mid-Mar. at 28 days interval). Two rice varieties (ITA 212, and ITA 123) were direct-seeded by broadcasting. The experiment was laid out as an RCB factorial (4 x 3 x 2) with 4 replicates.

The results were as follows:-

1 Irrigation schedule and sowing date had a significant effect on plant height. Plant height was greatest with the March sowing date, and irrigation scheduled at 10 Kpa.

2 The effect of irrigation schedule and sowing date on the number of seeds per unit area (the sink size of the crop) were significant. Number of seeds were greatest with the March sowing date, and irrigation scheduled at 10 Kpa soil suction.

3 Irrigation schedule had a significant effect on ripening grade (filled-grain per centage x 1000-grain weight). Scheduling irrigation at 10 Kpa soil suction gave the highest ripening grade. Sowing date had no significant effect on ripening grade.

4 Irrigation schedule and sowing date had a significant effect on grain yield. Sowing in March and with irrigation scheduled at 10 Kpa gave the highest grain yield.

5 The effect of interaction between treatments on yield and yield components was not significant.

6 Max-min temperature difference and solar radiation during the ripening period was a major factor affecting the yield of rice.

7 The growth duration of the crop was affected by the sowing date. Crops sown in March had the shortest growth duration, while the December sowing date had the longest growth duration.

8 The pattern of water use was monomodal, with the single peak at heading.

9 WUE efficiency was highest in March and with irrigation scheduled at 10 Kpa soil suction.

It is apparent from this study that scheduling irrigation at 10 Kpa soil suction (i.e irrigating at 2 days interval) provided the most favourable soil moisture regime for the growth and yield of dry season rice in the Kadawa area. At this soil moisture regime, climatic conditions, especially temperature and solar radiation during the ripening period was the main factor affecting the yield of rice. Air temperatures and solar radiation during the ripening period accounted for the differences in yield. Air temperatures and solar radiation in the February and March sowing dates were more favourable for grain ripening and thus higher grain yield, than obtained with the December, January and February sowing dates.

The study indicates that for dry season rice, in the sudan savanna, sowing in mid-March, with irrigation scheduled at 10 Kpa soil suction (i.e irrigating at every 2 days) not only gave higher grain yield, but also resulted in high WUE.

There is need for research into N-fertilizer use and dynamics in irrigated (dry season) rice in this ecological zone. This study did not address this.

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Appendix 1: Actual ETcrop - mmd^{-1} (1989-90) Dry season

	Dec			Jan			Feb			Mar			Apr			May			June			Jul
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1 Decade
I_1 D1	5.0	5.0	5.0	**5.0**	5.0	5.0	5.0	5.0	5.0	5.8	5.8	5.8	6.0	6.0	7.0	7.0	4.0	4.0				
D2					5.0	5.0	5.0	5.0	5.0	5.0	6.0	6.0	6.0	6.0	6.0	7.0	7.0	4.0	4.0			
D3								5.0	5.0	5.0	5.0	5.0	6.0	6.0	6.0	7.0	7.0	7.0	4.0	4.0	3.0	
D4											5.0	5.0	5.0	5.0	5.0	5.0	6.5	6.5	7.0	7.0	4.0	**3.0**
I_2 D1		**4.8**	**4.8**	**4.8**	4.8	4.8	4.8	4.8	4.8	4.8	5.8	5.8	5.8	6.0	6.0	6.5	6.5	3.0	3.0			
D2					4.8	4.8	4.8	4.8	4.8	4.8	5.8	6.0	6.0	6.0	6.0	6.5	6.5	3.0	3.0			
D3							4.8	4.8	4.8	4.8	4.8	4.8	5.0	6.0	6.5	6.5	6.5	3.0	3.0	3.0		
D4										4.8	4.8	4.8	4.8	4.8	4.8	6.5	6.5	6.5	3.0	3.0	3.0	
I_3 D1		4.6	**4.6**	**4.6**	4.6	4.6	4.6	4.6	4.6	4.6	5.5	5.8	5.8	5.8	6.3	6.3	4.0	4.0				
D2					4.6	4.6	4.6	4.6	4.6	4.6	5.8	5.8	5.8	6.3	6.3	6.3	4.0	4.0				
D3								4.6	4.6	4.6	4.6	4.6	5.4	5.4	5.4	6.2	6.2	6.2	3.0	3.0	3.0	
D4										4.6	4.6	4.6	4.6	4.6	6.0	6.2	6.2	4.2	4.0	3.0	3.0	

Appendix 2: Actual ETcrop - mmd^{-1} (1990-91) Dry season

	Dec			Jan			Feb			Mar			Apr			May			June			Jul
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1 Decade
I_1 D1		5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.5	6.0	6.0	6.0	6.0	6.0	7.0	7.0	6.0	4.0			
D2					5.0	5.0	5.0	5.0	5.0	5.0	6.0	6.0	6.0	6.0	6.0	7.0	7.0	5.0	4.0			
D3								5.0	5.0	5.0	5.0	5.0	6.0	6.0	6.0	7.0	7.0	7.0	4.0	3.0	2.0	
D4											5.0	5.0	5.0	5.0	5.0	6.5	6.8	7.0	5.0	5.0	4.5	4.0
I_2 D1		4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	5.0	6.0	6.0	6.0	6.0	6.0	7.0	7.0	4.5	4.0			
D2					4.8	4.8	4.8	4.8	4.8	4.8	6.2	6.0	6.0	6.0	6.0	6.5	6.5	6.5	4.0			
D3								4.8	4.8	4.8	4.8	4.8	4.8	6.0	6.0	6.5	6.5	6.5	3.5	2.8	2.0	
D4											4.8	4.8	4.8	4.8	4.8	5.5	6.7	6.5	6.5	4.0	3.0	2.0
I_3 D1		4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	5.8	5.8	5.8	5.8	5.8	6.2	6.3	4.0	4.0			
D2					4.5	4.5	4.5	4.5	4.5	4.5	5.8	5.8	5.8	5.8	5.8	6.3	6.3	4.0	2.0			
D3								4.5	4.5	4.5	4.5	4.5	5.0	5.5	5.5	6.2	6.3	6.2	4.0	3.0	2.0	
D4											4.5	4.5	4.5	4.5	4.5	6.0	6.2	6.2	4.5	4.0	4.0	3.5

Appendix 3: Potential evapotranspiration (mmd^{-1}) calculated by Pan Method for decades (1, 2, 3) during months of December through January, 1989/90 and 1990/91

1989-90 Dry season

	Dec			Jan			Feb			Mar			Apr			May			June			Jul
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1 Decade
D1	5.1	5.0	5.3	4.7	4.4	4.2	4.8	5.3	5.0	5.6	5.4	5.7	7.2	5.8	6.5	4.6	6.9	6.7				
D2					4.7	4.4	4.2	4.8	5.3	5.0	5.6	5.4	5.7	7.2	5.8	6.5	4.6	6.9	6.7			
D3								4.8	5.3	5.0	5.6	5.4	5.7	7.2	5.8	6.5	4.6	6.9	6.7	7.8	5.0	
D4											5.6	5.4	5.7	7.2	5.8	6.5	4.6	6.9	6.7	7.8	5.0	5.0

1990/91 Dry season

	Dec			Jan			Feb			Mar			Apr			May			June			Jul
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1 Decade
D1		5.2	4.7	4.3	4.9	6.1	5.7	5.1	5.1	6.3	8.6	5.3	6.4	5.3	6.5	4.6	4.5	5.1	5.5			
D2					4.9	6.1	5.7	5.1	5.1	6.3	8.6	5.3	6.4	5.3	6.5	4.6	4.5	5.1	5.5			
D3								5.1	5.1	6.3	8.6	5.3	6.4	5.3	6.5	4.6	4.5	5.1	5.5	4.2	4.2	
D4											8.6	5.3	6.4	5.3	6.5	4.6	4.5	5.1	5.5	4.2	4.2	4.2

Appendix 4: Potential evapotranspiration (mmd^{-1}) calculated by Radiation Method for decades (1, 2, 3) during months of December through January, 1989/90 and 1990/91

1989/90 Dry season

	Dec			Jan			Feb.			Mar.			Apr.			May			June			July		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	Decade
D1		4.2	4.4	4.4	4.8	4.3	4.5	5.8	5.6	5.6	6.0	6.9	7.3	6.0	6.3	6.2	6.2	6.3	6.7					
D2					4.8	4.3	4.5	5.8	5.6	5.6	6.0	6.9	7.3	6.0	6.3	6.2	6.2	6.3	6.9					
D3								5.8	5.6	5.6	6.0	6.9	7.3	6.0	6.3	6.2	6.2	6.3	6.9	6.5	4.9			
D4											6.0	6.9	7.3	6.0	6.3	6.2	6.2	6.3	6.9	6.5	4.9	5.6		

1990/91 Dry season

	Dec.			Jan			Feb			Mar			Apr			May			June			July	
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	Decade
D1		5.0	5.2	4.7	4.5	5.4	5.5	6.5	6.5	6.0	6.0	7.3	6.8	6.2	6.2	5.5	4.8	4.0	5.4				
D2					4.5	5.4	5.5	6.5	6.5	6.0	6.0	7.3	6.8	6.2	6.2	5.5	4.8	4.0	5.4				
D3								6.5	6.5	6.0	6.0	7.3	6.8	6.2	6.2	5.5	4.8	4.0	5.4	5.0	4.8		
D4											6.0	7.3	6.8	6.2	6.2	5.5	4.8	4.0	5.4	5.0	4.8	4.0	