

Chapter 13 F

Agrometeorology and Rice Production

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I. IMPORTANCE OF RICE IN VARIOUS CLIMATES

Cultivation of rice has been in vogue in many countries for over 6500 years. Dryland rice culture has preceded the adoption of wetland paddy culture. Two species of the rice genus have been domesticated namely, *Oryza sativa* and *Oryza glaberrima*. The former is widely cultivated and has originated in the foothills of the Himalayas while the latter, limited to Africa, has originated in the Niger River delta. Rice is the most important consumed cereal grain meeting the needs of 50% the world's populace. Some of the agricultural and industrial uses of rice are (i) use of rice straw and bran as cattle-feed and as growing medium for mushrooms (ii) use of rice husks and hull as seed-bed medium (iii) use of bran for extraction of a healthy oil and (iv) use of rice for making rice-beer and rice-based wine. Only 5%, of the total global production of rice enters international trade. Thus, for many countries national self-sufficiency in rice production is the crux of the matter.

Rice is grown from about 50° N to 35° S and from below sea level to above 2000 meters height covering a mean temperature range of 17 to 33 degrees centigrade, growing-season rainfall range of 0 to 5100 mm and solar radiation range of 300 to 600 calories/cm²/day in its growing areas and seasons. Many of the rice areas are served by major rivers and have alternating wet and dry seasons. The varieties used and cultural practices adopted in rice culture vary widely and are influenced by local climatology (rainfall, temperature and solar radiation regimes) and times and certainty of availability of water for main or supplementary surface irrigation. The variations in cultural practices may not, per se, affect the phenological or physiological responses of the crop to weather factors. However, the water, fertilizer and seed requirements of the crop, its field-life duration, extent of realization of potential yields and susceptibility to pests, diseases and weeds are affected by cultural practices. The unraveling of the weather relations of several aspects of growth, development, yield and protection of the rice crop is, therefore, complex.

Country-wise data on production, acreages and per capita consumption of rice for 29 countries that produce more than one million tonnes of rice are set out in Table 1. Of the total 620 million metric tonnes of rice the 29 countries produce about 580 million metric tonnes with an average yield of 3.9 t/ha. The following features emerge from Table 1. Nearly 90% of the rice is produced in Asia. China and India account respectively for 30% and 20% of global production and 20% and 30% of the global area. The South East Asian region extending from Pakistan to Indonesia and comprising of 12 countries account for 60% and 70% respectively of global area and production. In this region rice yield is mostly 3.5 t/ha with Indonesia and Vietnam producing 4.5 t/ha and Cambodia and Thailand producing 2.0 and 2.5 t/ha respectively. The yields in Egypt and Australia are 10.0 and 8.0 t/ha respectively while the yield is 6 to 7 t/ha in China, Italy, Japan and Korean Republic. Thus a poleward increase in rice yields is discernible. The yields in African regions are very low and range from 1.0 to 2.0 t/ha.

It is estimated that rice production must increase by at least 40% in the coming three decades to meet the global requirements. Over most of the regions Rice yields are beginning to decline. Irrigation can push up rice yields. However, because of the substantial non crop-use water losses in irrigated, puddle rice and its very low water use-efficiency, shortage in availability of surface irrigation for catering to even current areas of puddled rice culture is a certainty in future. The immediate need is, therefore, to increase gross rice acreage and outturns by optimal use of existing resources. In this the practice of growing irrigated rice under puddled conditions deserves critical examination.

Table 1. Rice production and consumption statistics worldwide, 2002

Country	Production (000 tonnes)	Area (000 ha)	Yield (t/ ha)	Consumption (kg/Y/ capita)
China	176,342	28,509	6.19	83
India	116,500	40,280	2.89	83
Indonesia	51,490	11,521	4.47	149
Bangladesh	37,593	10,771	3.49	164
Vietnam	34,447	7,504	4.59	169
Thailand	26,057	9,988	2.61	103
Myanmar	21,805	6,381	3.42	205
Philippines	13,271	4,046	3.28	105
Japan	11,111	1,688	6.58	58
Brazil	10,457	3,146	3.32	35
United States	9,569	1,298	7.37	9
Pakistan	6,718	2,225	3.02	18
Korea, Rep. of	6,687	1,053	6.35	83
Egypt	6,105	613	9.97	38
Nepal	4,133	1,545	2.67	102
Cambodia	3,823	1,995	1.92	149
Nigeria	3,192	3,160	1.01	24
Iran, Islamic Rep. of	2,888	611	4.73	37
Sri Lanka	2,859	820	3.49	91
Madagascar	2,604	1,216	2.14	95
Laos	2,417	783	3.09	168
Colombia	2,348	469	5.01	30
Malaysia	2,197	677	3.25	73
Korea, DPR	2,186	583	3.75	70
Peru	2,119	317	6.69	49
Italy	1,379	219	6.31	6
Ecuador	1,285	327	3.93	47
Australia	1,192	150	7.95	10
Côte d'Ivoire	1,080	470	2.30	63
World	577,971	147,633	3.91	57

Yield = Total production / Total area and an average across all rice environments and seasons. Source: FAOSTAT service; <http://faostat.fao.org/faostat/collections>.
Importance of Rice in Tropical Asia

Both Southeast (S.E.) and East Asian regions (i) regularly experience cyclonic storms/typhoons (ii) are subject to riverine floods and (iii) are characterized by heavy rains

of 100mm per week or so over an extended period, Rice is the only suitable crop that can be grown under puddled conditions of soils i.e. with standing water over bunded fields. In fact certain varieties of rice called Floating Rice having the ability to elongate their stems with rise in water level up to 2 meters height and remain alive for a fortnight even when the water level rises to 6 meters are required to be used. The low yield in S.E. and East Asian region is due to preponderance of rainfed areas, which also leads to great inter-annual variability in outturns. The rice areas in tropical Asia abound in populous countries. Puddled rice culture is labour intensive and hence suited to be grown in above areas with low labour costs. Puddled rice is said to be of assistance in mitigating the effects of floods. Problem of weeds is minimal in puddled rice culture. Thus rice emerges as a livelihood crop for millions of small, marginal farmers in tropical Asia who can afford only low cost technologies.

II. AGROCLIMATOLOGY OF THE CROP

II. 1. Rice production ecosystems and main climate-related problems

The main systems of rice culture are Irrigated Lowland, Rainfed Lowland, Rainfed Upland, Irrigated Upland, Seasonally Flooded Wetlands and Tidal Wetlands. On a global scale, rice under flood prone and tidal wetlands, rainfed upland, rainfed lowland and irrigation constitute respectively %, 10%, 25% and 55% of the area. Irrigated rice, rainfed lowland rice, rainfed upland rice and rice from flood prone areas account for 75%, 17%, 4% and 4% respectively of global rice production. For any given region or season, prevalent cropping systems cannot be taken as the ideal ones for optimal crop productivity. Thus, for each of the main rice ecosystems, its climatological necessity and /or soundness, weather vagaries impairing operations and agronomic measures to cope with weather anomalies are now examined.

II.1.1.a Irrigated Lowland Rice Ecosystem

The coleoptile of the germinating rice seeds can elongate under anaerobic conditions (Apli and Beaver,1983) and rice can thrive under these conditions. Rice can, therefore, be raised with standing water over the soil. The system wherein rice fields are bunded to ensure ponding of irrigation water for most of the crop's life from sowing till a little time before its harvest is called the Irrigated Lowland Rice Ecosystem.

In the above system, in tropical Asia, an area equivalent to 1/10th of the main field area is set apart as nursery. Seeds soaked in water for 24 to 36 hours are incubated for about 48 hours in a warm environment to facilitate germination and the pre-germinated seeds are broadcast on the drained seedbeds of the nursery, which is kept wet for 5 days and gradually flooded thereafter. The seedlings after a nursery time, roughly equivalent to 3 and 2 weeks respectively in case of varieties of 4 to 4 ½ months and 3 months duration, are transplanted in the main field. Prior to transplanting, the soil in the main field is puddled i.e. ploughed and harrowed and finally leveled with standing water in the field. Water from the main field is drained only towards harvest of the crop.

The irrigated lowland rice cultivated in the United States and Brazil is quite different from that of Asia. In the United States rice is grown as a single crop per year in

three main areas, namely (i) the semi-arid Sacramento Valley of California with less than 50 mm rainfall during the growing season (ii) the humid sub-tropical areas of the Gulf Coast of Louisiana, Texas and Florida, with a seasonal rainfall range of 700-1,000mm and (iii) Grand Priarie and Mississippi and Missouri river deltas. Dry seeding with a mechanized grain drill is the most common method of planting in the southern United States. In California and southwest Louisiana, pre-germinated seeds are seeded into standing water. In Brazil, the lowland irrigated rice is concentrated in the southern states of Rio Grande do Sul and Santa Catarina. In the former state, in about 80% of the area, 2 years of rice is rotated with 3 years of pastures and only one crop per year is established in which dry seed is broadcast or line-sown in dry soil. In Santa Catarina, irrigated rice areas are planted once a year using pre-germinated seed in puddled soil

Weather Related and other constraints and adaptive measures

Availability of water to raise requisite area of nurseries ahead of the normal dates of availability of surface irrigation is a major constraint in many areas. In places with adequate groundwater availability, community or individual nurseries known as Reduced Area Wet Bed Nursery are raised. In places where groundwater is rather scarce Modified Mat Nurseries are raised. In both the above methods (i) seedlings are ready for transplantation in about 2 weeks of sowing (ii) requirement of nursery area is 1% of the main-field area and (iii) high seed rates to ensure adequate number of sturdy seedlings for transplanting in the main field are used.

Transplantation shock delays phenological development of the crop, especially tillering. Recovery from transplantation shock and potential yield, increase and decrease respectively with increase in age of seedlings. Irrigated lowland rice requires enormous amount of water for field preparation. Thus, to properly time the commencement of nurseries a firm indication of the date of availability of canal water for irrigation must be known in advance. The latter in turn calls for a quantitative and reliable forecast of rains in catchment areas of the irrigation systems about two weeks in advance. Quantitative rainfall forecast with a lead-time of 15 days are not currently available.

To overcome the weather-related constraint, direct wet seeding of rice is being increasingly resorted to. In this, after receipt of canal water, pre-germinated rice seeds of varieties suitable for direct sowing (Yamauchi et al, 1993), namely good germination under anaerobic conditions with good initial seedling vigour, are broadcast or line-sown with drills in drained fields. Random broadcasting leads to great variations in seedling density. Row seeding of germinated seeds is costly but helps in (i) maintaining optimum density of seedlings (ii) controlling weeds and (iii) better crop management. After sowing, the field is intermittently wetted for a week and flooded thereafter. Provided a good vigorous stand of seedlings is established and weeds are kept under check, wet seedings have a higher yield potential than transplanted rice (De Datta and Herdt, 1983).

Storms traverse the deltaic rice belts often leading to flooding and occasionally causing Storm Surges. Avoidance of cyclonic weather is desirable. However, the times, duration, regions and frequencies of occurrences of stormy weather vary amongst the coastal rice belts and the agronomic strategies to deal with them also vary. For example, in India, coastal areas adjoining Bay of Bengal experience cyclones while coastal areas of Arabian Sea are practically free of stormy weather. The Bay of Bengal cyclones, move in a westerly direction, show a southward shift in their origin in the Bay with the progress of the Indian Summer Monsoon and occur over specific short periods of a month's duration. In

such a situation, a short duration rice crop is harvested a little ahead of the cyclone season. Copious rains from cyclones are then used for puddling of soil for nurseries for a second crop and transplanting of the second crop is so done as to ensure that the crop is short during the cyclonic season. For such a crop, arrangements are made for draining away the excess rainwater from storms. In the Philippines, typhoons occur from June to October in the eastern and northern portions and number about 20 per year. Only one of the 4 main rice-climate belts is affected by typhoonic weather. The sub-tropical rice growing region in U.S.A. i.e. Gulf Coast of Louisiana, Texas and Florida encounter violent storms in the period from June to November. Warnings of stormy weather, required to effectively cope with flooding of fields are available and are quite accurate and timely.

II.1.1.b System of Rice Intensification, SRI.

Irrigated lowland rice requires enormous amount of water for field preparation. In this system loss of water through seepage can be reduced. Percolation loss through the soil is unavoidable, is independent of season (Achar and Dastane, 1970) but influenced by soil type, depth of standing water and perimeter of field area (Dastane et al, 1970). Percolating water from rice fields carries risk of pollution of groundwater aquifers through leaching of agrochemicals. Depending on soil types and cultural practices, the percolation and seepage, losses are about 50% of the consumptive (evapotranspiration) requirements of the crop. Thus the water needs of puddled rice are 2 to 3 times of that of an irrigated aerobic crop.

SRI has had an accidental origin due to the observation in 1983 in Madagascar, that transplanting rice seedlings of 8 to 15 days of age gave very high number of tillers compared to the customary transplanting of seedlings of 30 to 35 days' age (Laulane, 1993). The above discovery was followed up to formulate a set of practices that now constitute SRI methodology (Satyanaryana et al, 2007). SRI at present is being used even by small farmers in more than 20 countries.

In the SRI methodology preparation of the main-field is done in the same way as under the lowland irrigated ecosystem. Nurseries raised are similar to the reduced area wetbed or modified mat nurseries. 8 to 12 day old seedlings, with just two leaves and with seed, soil and roots intact, are removed by scooping and transplanted gently in a muddy field within 12 hours of removal from the nursery at a depth of 1 to 2 cm, singly in a square pattern of 25 cm x 25 cm with the roots lying horizontally in the moist beds. Till the roots get established, a thin layer of water is let into the field at night and water is drained away in the morning. Afterwards the soil is kept moist but not saturated by irrigating the crop once in 5 to 6 days or resorting to irrigation when the surface cracks up. Presence of thin depth of water in the reproductive crop phase is not mandatory and alternate wetting and drying can be resorted to. Weeding, by a rotary hoe, is done at 10- day intervals from the 10th day of transplanting till the crop canopy closes. Weeds are incorporated in the soil. Instead of chemical fertilizers farmyard manure or compost is used.

Raising of nurseries in SRI face the same problems as that in the conventional method. Direct wet seeding of rice with pre-germinated seeds in the moist soil as an SRI procedure has been suggested (Rao, 2004). However, SRI yields are dependant on strict adherence to geometry of planting and population density and as the above two features cannot be achieved by direct seeding the same is not advised (Satyanarayana,2005). However, starting of a SRI nursery at the same time as commencement of preparation of the main field will not be as much yield-depressing as in the conventional method on

account of the following. SRI nurseries require only one-third nursery time as conventional nurseries. Minimisation of transplantation shock in SRI methodology further reduces the physiological age gap between conventional and SRI seedlings. Planting young seedlings ensures preservation of tiller production potential of the seedlings. SRI crop also matures ten days earlier than conventional crop.

The SRI practices even when not exclusively used, such as SRI irrigation with conventional planting or SRI planting with conventional irrigation, enhances the yield level of rice (Horie et al, 2005). From a review of water savings and yield increases in SRI rice compared to conventional method in China and tropical Asian countries (Satyanarayana et al, 2007), one could surmise that with the same quantum of water as is being used in the conventional method rice output can be doubled, trebled and quadrupled in areas with present yield levels of over 5t/ha, 3-4t/ha and 2t/ha respectively by SRI methodology.

Plausible reasons for yield increases and variations under SRI.

From the limited experimental material available on rice and the influence of aerobic and anaerobic conditions on soil cum plant processes in other crops, Satyanarayana, (2005) has offered some explanations, as mentioned below, for the observed increases in rice production under SRI vis-à-vis flooded rice.

Young rice seedlings retain their potential for formation of tillers if they are transplanted before the start of the 4th phyllochron (Stoop et al, 1992), i.e. before 15 days of age in tropical conditions. In each phyllochron one or more phytomers i.e. set of tiller, leaf and root are produced from the apical meristem and the number of tillers, leaves and roots will depend on the number of phyllochrons completed before flowering (Satyanarayana, 2005). The latter is more for SRI rice than flooded rice. However, even under SRI, the number of phyllochrons completed in the vegetative phase can vary with variety, season and location. Thus weather factors may significantly account for areal variations noticed in tiller density of rice cultivars under SRI culture.

Wider spacing of plants and daily wetting and drying (i) exposes the soil for better absorption of solar radiation, oxygen and nitrogen (ii) denies the ideal micro-climate needed by many pests and diseases (iii) helps in greater interception of full-intensity of sunlight by the crop canopy and hence of better photosynthesis (iv) leads to greater soil aeration resulting in (a) better and firmer root growth (b) increase in aerobic microbes facilitating increased solubilisation of Phosphorus, mineralization of Nitrogen, availability of main and trace elements from the entire soil column to the crop and suppression of nematodes and rice diseases. Under flooded conditions 30 to 40% of the cortex around the central stele disintegrates to form aerenchyma cells (air pockets) that facilitate oxygen to diffuse to the roots. Thus, a lot of energy is spent in development of air pockets. Under non-saturated soil conditions this energy is diverted to grain production.

Constraints in use of SRI.

Skilled labour is required for more days though for fewer hours per day. As labour cannot be hired on the basis of hours the labour cost becomes substantial. SRI seedlings are highly vulnerable to inundation in the first few weeks of their growth. Lack of drainage facilities in areas where SRI is replacing conventional flooded rice is a handicap. Since current SRI Rice areas have been subject to water logging for long periods, problems of soil amelioration and detection and correction of deficiencies of micro and trace elements,

particularly Iron pose problems. Incorporation of weeds as sole source of biomass addition is inadequate. Organic system of fertilisation to the rice crop is considerably costlier than inorganic fertilization. Heavy incidence of insects like mealy bugs, thrips and stem borer. under SRI has been reported. The measure of micro leveling of field advocated to control thrips and mealy bugs is not felt practicable.

II.1.2. Rainfed Lowland Rice Ecosystem

As the name implies rainfall is the only water source for the Rainfed lowland rice ecosystem. Rainfed lowland rice is raised in places where surface irrigation is not available and there is risk of inundation of fields from rains for significant periods of time in the crop season. In this rice is grown in banded fields with overflow arrangements to ensure that the depth of standing water remains less than 50cms over a period of 10 consecutive days. Rainfed lowland system is characterized by (i) uncertainty in time of start of the crop season and (ii) intermittent ponding, saturation, wetting and drying of the soil in a random manner. Methods for establishment of crops are same as in the irrigated lowland ecosystem. In case of soils where rainwater tends to quickly accumulate on the soil surface, rainfed lowland rice may be established by direct dry-seeding.

On Farm Reservoirs, OFRs.

Due to rainfall vagaries, rice fields in the rainfed lowland system run the danger of drying up frequently during the active growth stage of the rice crop. Digging out a portion of the main rice field to collect surface run-off from rains, called On Farm Reservoir, OFR and using the OFR storages to save the main rice field from drying out and to raise an aerobic crop after harvest of the rice crop have been mooted and are in practice. Use of models for designing OFRs is of recent origin (Srivastava, 2001). For determining the fraction of field to be set apart for OFRs, it is necessary to know, for a given crop (i) the times of start of preparation of main-field for raising the crop and (ii) the temporal march of the quantum of (a) rainfall deficiency vis-à-vis the crop's water need and (b) surface runoff from rains. In the above assessment of daily runoff from for a large number of station-years by standard procedure (USDA 1972) will be a daunting task.

Rainfall Budgeting.

The parameters required for design of an OFR can be assessed through a modification of the daily rainfall budgeting procedure of Pandey et al, (2005) keeping the following in view:

- (i) The water need for land preparation WNLP, depending on soil type, will be 200 plus or minus 50 mm, while the need for raising nursery will be 50mm.
- (ii) The budgeting will involve two phases- the unsaturated phase before ponding of water becomes feasible and the saturated phase with standing water.
- (iii) The Maximum Crop Available Moisture, MCAM will be that between saturation moisture content and permanent wilting point
- (iv) Rainfall for ponding will be available only after saturation of the root zone Percolation (P) and Seepage (S) will occur only with standing water on the field and depending on soil types will range from 2 to 4 mm per day

Methodology.

I. Cumulate on a daily basis differences between rainfall, RR and Potential Evaporation, PE. Take negative values as zero. Set limiting value of such cumulations as equal to Saturated Soil Moisture Content, SSMC.

II. Assign values in excess of SSMC as depths of water available for ponding, DW

III. The time when cumulated DW reaches the value of WNLP is the start of the saturated phase

IV. In the saturated phase, starting with a given depth of water, add daily rainfall to depth of standing water and minus the Potential Evapotranspiration, PET Seepage and percolation losses and assign excess values to runoff, RO.

V. The time when such cumulations lead to nil depth of water is the time of onset of water deficiency and the water need will be equal to the desired depth of water level, D.

VI. Runoff collections in OFR will also be subject to evaporation, percolation and seepage losses. The latter two can be prevented by lining the bottom and sides of the OFR by low-density polythene (LDPE) sheets. In terms of equivalent depth of water evaporation from OFR and evapotranspiration from rice crop can be taken to be the same as the 20% increase due to transpiration of the rice crop will be compensated by an increased free water evaporation on account of shallow depth of water and greater heating by solar radiation. Therefore, minus from values of RO, values of PET on a daily basis to get water depths in OFR on a daily basis in case of LDPE lined reservoirs. In case of unlined reservoirs minus from OFR inflows, the percolation and seepage losses also.

In view of the plethora of terms and methodologies used in meteorological computation of peak crop water needs FAO has prescribed a methodology to compute Reference Evapotranspiration E_{To} as a standard datum. In the above PE will equal E_{To} while PET for crops will be equal to $K_c.E_{To}$ where K_c is a crop coefficient. Evaporation from pan evaporimeters, EP, is an easily available parameter that can be related to E_{To} . Methodology for computation of E_{To} using available data of net radiation components and the variations in time and space of the ratio of E_{To}/EP have been presented by Venkataraman et al, (1984). Procedures for calculating E_{To} from EP recorded with different pans, their settings and surrounding environment and values of K_c for peak water needs of various crops have been given by Allen et al (1998). Values of saturated soil moisture content, seepage, percolation, water needed for land preparation and optimal depth of standing water vary with soil types but are readily available.

Application of the above methodology for a large number of years at a location will give, on a probability basis, the quantum of supplementary irrigation need and the quantum of surface runoff that can be harvested. The two parameters can help in deciding the fraction of main-field that should be set apart for constructing the OFR.

Rice cum Fish Culture

Although FAO had recognized the importance of rice cum fish culture way back in 1948, interest in rice cum fish culture was renewed only in the late 1970s (Ghosh and Saha, 1978). In India, where rice cum fish culture seems to have originated and which has the largest rice acreage, the percentage of rice area under rice cum fish culture is only 0.05 % though the potential for rice cum fish culture is 45% (Mohanty et al, 2002). In China only 4% of the rice area is under rice cum fish culture. Egypt, which has only 10% of the area of India under rice, has 75% of the area under rice cum fish culture. Thailand has the highest (i) area (3 million ha) and (ii) fraction, of total area (32%) under rice cum fish culture

Irrigated lowland Rice areas are suitable for rice cum fish culture. Fish culture would require a greater depth of standing water over the field than rice and will lead to a further reduction in water use-efficiency. In deepwater rice areas and tidal rice wetlands stocked fish may escape from the rice fields due to overflow of bunded fields by floodwaters. Thus, rainfed lowlands emerge as the only suitable system for rice cum fish culture.

When grown together, fish damage the rice crop and chemical control of biological setbacks to rice will harm fish. Again, the requirements of water depth, temperature, pH, oxygen and water-turbidity for fish and rice for optimal performance are quite different. Also water level in the fields cannot be allowed to fall below a specified minimum while fish stocks are present in the rice field. Thus raising of fish concurrently but stocked in OFR is called for. OFRs used as fish-pen, will require a higher depth of standing water. Therefore, a higher fraction of main-field has to be set apart for fish-pen cum OFR and can be agroclimatically calculated (Bhatnagar et al, 1996). However, fish-catch from the fish-pens will be an additional income for the farmer (Pandey et al, 2005) and compensate for yield loss of rice from areas additionally used for fish culture. Lining of bed and sides of the OFR cum fish-pen LDPE sheets will be highly desirable.

II.1.3. Upland, Rainfed Rice Ecosystem

Areas lying above the flood plain constitute the upland, rainfed rice ecosystem, in which the rice crop is raised in unbunded fields. A rainfall regime of 100 mm per month for 4 consecutive months is considered suitable for upland rainfed rice culture, which is mostly found in Asia, Africa and Latin America.

In upland, rainfed rice culture the crop is dry-seeded directly on ploughed land and the seeds are incorporated into the soil by ploughing or harrowing while the soil is still dry. Sometimes rice is dibbled, broadcast or row-sown in soil wetted by rains. In medium and light textured soil a dry nursery equivalent to 5% of the main-field area is raised. In this the seeds are sown dry and the soil is kept moistened and the seedlings transplanted when rains start regularly.

Ideally the completion of the vegetative phase of rice must coincide with the cessation of rains with root zone moisture at field capacity moisture status. The differences in duration amongst rice varieties are due to differences in duration of vegetative phase. The reproductive and ripening phases are of 35 and 30 days for most varieties. Since evaporative power of air is 4.0 to 5.0 mm per day in the rainy season in the rice areas (Cocheme and Franquin, 1967) start of the cropping period for rainfed rice is the one when

rainfall begins and continues to exceed 30 mm per week and vegetative period should end with the week from which rainfall decreases below 20 mm. The duration of variety to be used will be equal to the duration of vegetative phase as delineated above plus two months.

Maintenance of root zone moisture of the rice crop at saturation and not submergence is the need (Venkataraman and Krishnan, 1992). In upland, rainfed rice this is not possible as fields are not bunded. A budgeting of rainfall versus Potential Evapotranspiration of the rice crop, subject to limiting crop available moisture to field capacity moisture content of the rice crop root zone, will give a measure of the climatological risks involved in raising rice as an upland, rainfed crop at a location.

II.1.4. Flood-Prone Rice Ecosystem

There are two types of flood prone areas, namely Deepwater Rice Areas and Tidal Wetlands. The former are found in the lowland, deltaic areas of rivers where water accumulates for 30 days or more to depths of half to three meters in the rainy season. Deepwater rice areas are common in South and Southeast Asia and West Africa. In wetlands, soils remain flooded for several weeks in an year, often for more than 10 consecutive days, with medium (50cm) to very deep flooding (300 cm). Tidal wetlands are in coastal areas subject to risk of seawater intrusion on account of storm surges. Tidal Wetlands are more prevalent in Bangladesh and Eastern India.

In deep water rice culture, varieties known as floating rice are used. The seeds of such varieties are capable of germination even under 15 cm of water. Deepwater rice is directly dry-seeded but the seeds are not incorporated into the soil. The plants growing under non-flooded conditions can elongate their stem at the rate of 15 cm per day with rise in water level up to 2 meters height. However, for the above rate of elongation the plants must at least be 6 weeks old. Deep-water rice can also survive submergence for 15 days.

II.1.5. Irrigated Aerobic Rice Ecosystem

A system of rice production that does not require puddling of soil and of standing water in rice constitutes the Irrigated, Aerobic Rice Ecosystem. Under aerobic conditions, various methods, are adopted for provision of water for crop use, namely:

(i) The soil is ploughed dry and the field is surface- irrigated when the soil moisture tensions in the root zone reaches a tension of –30 to –50 kilopascals.

(ii) Alternate wetting and drying of the field in which the field is allowed to dry out for a few days after the standing water in the field disappears before irrigating.

(iii) Rice is raised in beds divided by furrows. Beds are initially ponded to keep out weeds. Later a shallow depth of water is maintained in the furrows to ensure saturation moisture for rice.

(iv) Rice is raised in beds initially wetted to saturation and water is later supplied to the root zone to replace previous day's loss by crop ET

Non-flooded soil leads to reduction in rice yields. Therefore, the main criterion in the above system is that, vis-à-vis the flooded rice, any reduction in yield should be more than compensated by a saving in irrigation water. This will ensure that with the same amount of water as required for flooded rice more area can be covered under aerobic irrigated rice and more rice crop produced. Ideally, studies on comparison of water used in flooded rice versus aerobic irrigated rice exposed to the same weather should be done during the dry season. Papers detailing comparative water use of aerobic, irrigated rice with flooded rice in the dry season appears extremely limited (Atlin et al, 2006; Bouman et al, 2005; De Dios, et al., 2000). Some interesting features that emerge from such studies are briefly mentioned below.

A 30% reduction in yield in the dry season under aerobic conditions than under flooded conditions has been reported (Bouman et al, 2005). Atlin et al. (2006), however, noted no differences in grain yields in the dry season between flooded and non-flooded treatments. Bouman et al. (2005) report that the savings in water used for aerobic irrigated rice vis-à-vis flooded rice is mostly due to savings in water needed for preparation and seepage and percolation and that reductions on account of evaporation and transpiration are marginal. Water required for puddling of soil in flooded rice culture is a one-time requirement independent of field crop-life duration and season. The percolation cum seepage losses vary with soil but little with season and range from 2 to 4 mm per day (Yoshida, 1981). The total quantum of seepage cum percolation losses is dependant on both soil type and crop field-life. For a rice cultivar of same duration raised on the same soil under flooded and irrigated conditions the quantum of water saved due to non-flooded irrigation will depend upon the quantum of water consumed by the flooded rice, which will be higher in a drier, hotter and brighter environment. Thus, differences in quantum of water saved in raising aerobic irrigated rice without a moisture stress as a fraction of water used for flooded rice, ranging from 25 to 60%, as has been reported, is to be expected. The savings in irrigation water in aerobic rice culture will always be more than the reduction in yield vis-à-vis flooded rice and can be translated into a larger area under rice for the same quantum of water, especially in situations where the farmers do not have access to enough water to grow flooded lowland rice. Thus, from the point of use of efficient use of water in increasing rice production, adoption of aerobic irrigated rice culture is called for.

It is also claimed that aerobic rice varieties, which are upland varieties distinguished by their (i) indica germplasm (ii) higher yield potential, (iii) better response to fertilizer inputs, (iv) improved lodging resistance (v) higher harvest index and (vi) tolerance to occasional flooding can give as high an unit area yield as traditional varieties under flooded conditions and give more rice per unit amount of water used. However, their maturity is reported to be delayed by 10 days. Considerable experimentation needs to be directed for development of (i) varieties for aerobic irrigated culture and (ii) the optimal site-specific crop and water management practices for sustained production of aerobic rice under continuous cropping, before aerobic varieties are widely adopted for upland irrigation.

II.2. INFLUENCE OF CRITICAL CLIMATE AND WEATHER VARIABLES IN GROWTH AND YIELD

Rice Growth Phases

As the weather requirements for optimal development is growth stage dependent, for dealing with weather relations of rice it is necessary to delineate its growth phases and growth stages. The main growth phases of rice are the (a) vegetative phase from emergence

to Panicle Initiation, PI (b) reproductive phase from PI to completion of flowering and (c) the ripening phase from end of flowering to Grain Maturity. The vegetative phase in rice is held to consist of a Basic Vegetative or Juvenile phase and photoperiod sensitive phase from end of Juvenile phase to PI. The photosensitive vegetative phase is of short duration and the additional time due to the photoperiod factor, if and when operative, will make little difference to the total thermal-time requirements of a cultivar (Venkataraman, 2004). Thus vegetative phase of rice can be treated as a single entity.

For rice, considering the postulations of Tanaka et al. (1964), Robertson and De Weille (1973) and Counce et al. (2000), the following growth stages can be delineated, Viz:

Vegetative Phase consisting of (i) seedling stage from primary leaf emergence to 5th leaf stage (ii) transplantation stage- from 5th leaf to recovery from transplantation (iii) tillering stage - from tiller initiation to maximum tillering and (iv) stem elongation stage

Reproductive Phase consisting of Panicle initiation, Booting (appearance of flag leaf), Heading (exsertion of 50% of the panicles) and Flowering (opening and closing of spikelets) stages

Ripening Phase consisting of Milk grain, Dough grain and Mature grain stages.

II.2.1. TEMPERATURE

Critical Temperatures for Rice Growth Stages.

For delineating specific time-periods suitable for maximal production of rice at a given location it is necessary to know the cardinal (high, low and optimal) temperature requirements of various rice growth stages. From the literature cited by Yoshida (1977), Lomaton and Baradas (1983) and Venkataraman, (1987) the low, high and optimal temperatures requirements of important rice growth stages are given below

Growth Stage	Cardinal Temperatures °C		
	Low	High	Optimum
Germination	10	45	20 to 35
Emergence & Establishment	12	35	25 to 30
Transplanting	> 18	-	-
Rooting	16	35	25 to 28
Leaf Emergence & Elongation	7	45	30 to 31
Tillering	16	33	25 to 31
Flower Initiation	15	-	24 to 29
Anthesis	22	35	30 to 33
Ripening	12	30	20 to 25
Fertility	14	38	-

In the above. the Japonica cultivars of rice can tolerate temperatures 5°C lower than that of indica varieties while their maximal values will be 5°C lower than that of indica varieties. However the optimal temperatures will be the same for both Japonica and Indica Varieties

Duration of Vegetative Phase.

The differences in duration of rice cultivars are due to differences in duration of their vegetative phase (Oldeman et al., 1987). In the phenology component of the *Oryza* and Ceres-rice models a base of 8°C and 9°C mean air temperature is used respectively for computing thermal-time accumulations in rice crop phases. The above models have been reported to account for vegetative phase durations at individual locations. The Ceres-rice model has been found to be superior to the *Oryza* model and accurately account for variations in duration of vegetative phase ranging from 37 to 85 days arising from variations in varieties and locations (Mall and Aggarwal, 2002). The duration of vegetative phase decreases with increase in temperature up to 33°C. and increase in temperature above 33°C has no further decreasing effect (Alocilja and Ritchie, 1991).

Work of Raji Reddy et al. (2004) indicate that vegetative phase durations expressed as Growing Degree Days, GDDs, above a base mean temperature of 10°C will be conservative across seasons. The degree-day requirements for completion of vegetative phase can be expected to vary amongst cultivars. Thus, even limited and random phenological observations on GDDs in the vegetative phase of rice recorded on a few typical short and long duration cultivars, at a few locations and/or seasons, can assist in gauging the vegetative duration of different cultivars in various regions and seasons through temperature links.

Tillering.

Number of tillers per unit area has a great bearing on rice yields (Yoshida and Parao, 1976). The duration of the tillering phase is influenced by temperature (Lalitha et al., 1999). At 23°C the duration is 8 weeks and it is only 5 weeks at temperature of 27°C. The number of tillers per unit area is also influenced by temperature and shows a sharp rise at a temperature of 27°C (Lalitha et al., 2000). The contention (Owen, 1972) that the lower rate of production of tillers at low temperatures will be more than compensated by the increased duration of tillering is not valid (Raji Reddy et al., 2007). Cumulated leaf-area in vegetative phase determines the quantum of intercepted photosynthetically active radiation, which is an yield-determining factor. The optimal Leaf Area Index, LAI for photosynthesis in rice is 4.0 (Murata, 1967). The time in attainment of the LAI of 4.0 from planting depends on tiller population and rate of tiller production, both of which are influenced by temperature. Again, the time between attainment of LAI of 4.0 and end of vegetative phase, becomes crucial and is temperature dependant.

Application of Nitrogenous Fertilisers

At temperatures optimal for tillering, leaf emergence will be little affected but elongation will be slower. However, slower elongation will have little influence on cumulated leaf area. The need for ensuring adequate and timely supply of Nitrogen to the crop for quick and proper leaf growth becomes important. The optimum time for application of nitrogenous fertilizers in rice is when the average internodal length is 6 mm and applications up to 12 mm internodal length have little effect on yield. Downey and Welles (1974) found that the 12 mm internodal length corresponded to value of 200 Effective Heat Units, EHUs, accumulated with lower and upper limits of 21°C and 31°C respectively. Thus, if daily temperature is 20°C, EHU will be zero. Similarly if daily mean

temperature is 33°C the EHU will be 31 only. Thus the concept of EHUs provides an agrometeorological tool for fertilizer applications.

Net Biomass Accumulation

The drymatter accumulated at heading has a significant influence on grain yield of rice (Yogeswara Rao et al., 1999). Most of the drymatter in rice grain comes from post-floral photosynthesis. Part of the photosynthate is used as Growth Respiration i.e. in the formation of plant tissue and the rest is used as Maintenance Respiration in upkeep of existing tissues. Maintenance respiration is a function of both temperature and net biomass. In rice maintenance respiration is 10% of available photosynthates at 25°C (Lal and Aggarwall, 2002) with a Q_{10} of 2.0 (Penning de vries et al, 1989). Thus temperature plays a major role in (i) creation of photosynthetic capacity in the vegetative phase and (ii) the extent of utilization of the photosynthetic opportunity in the reproductive phase.

Reproductive Phase.

Work on the influence of temperature on growth stages and crop attributes in the reproductive phase (Best, 1959; Chang and Oka, 1976; Matsuo et al., 1995 ; Nishiyama, 1984, 1985; Yoshida, 1981)) show that non-optimal, low temperatures, below 15°C for Japonica varieties and below 20°C for indica varieties occurring (i) during panicle initiation lead to reduction in number of florets per panicle and to degeneration of panicle tips, ((ii) after formation of young panicles reduce the size of panicles (iii) during booting cause high sterility of spikelets (iv) in the booting and heading stages delay heading, reduce number and growth of spikelets and lead to incomplete panicle exertion (v) in the flowering stage delays flowering, leads to non-flowering of lower spikelets and incomplete fertilization and (vi) during anthesis reduce (a) pollen maturity and (b) floret fertility due to inhibition of anther dehiscence (Nishiyama, 1984).

Ripening Phase

From international experiments on rice covering many varieties, locations and seasons from 10 to 20°N Oldeman et al. (1987) found that the duration of the ripening phase was conservative and characterized by a GDD of 825 accumulated over a base temperature of zero degrees centigrade. The work of Raji Reddy et al. (2004) show that despite the temperature in the ripening phase varying from 24°C in the rainy season to 31°C, the duration of the phase was constant at about 29 days across varieties and seasons. Optimum night temperature for this phase is held to be 23°C (Ebata and Nagata, 1967) and minimum temperature in the 30-day period following flowering is held to be an important yield-determining factor (Seshu and Caddy, 1984)

II.2.2 SOLAR RADIATION

Vegetative Phase

The drymatter accumulated at heading, which has a significant influence on grain yield of rice (Yogeswara Rao et al.; 1999) is directly proportional to the quantum of intercepted Photosynthetically Active Radiation, PAR. Now PAR is 45% of solar radiation

(Monteith, 1965). Thus, contrary to popular notion solar radiation in vegetative phase is very important and the aim should be to maximize intercepted solar radiation in this phase.

Reproductive and Ripening Phases

Increase in radiation up to 500 calories/cm²/day increases spikelets number (Yoshida and Parao, 1976), which is an important indicator of dry weight at heading (Kudo, 1975). Solar radiation in the range of 300 to 600 cal/cm²/day in the post-flowering period was positively related to number of filled grains per panicle, ranging from 50 to 180 (Oldeman et al., 1987). Solar radiation in the ripening phase influences both the percentage of well-filled grains and weight per grain. For equivalent yields the radiation requirement in the ripening phase is lower than that of the reproductive phase as (i) the dry matter produced in the ripening phase is lesser than that at the start of the ripening phase (ii) substantial portion of photosynthates formed in the reproductive phase is used in grain yield (Yamada, 1963) and (iii) when photosynthesis gets restricted in the ripening phase about 70% of the stored carbohydrates at the start of the phase are translocated to grain (Yoshida, 1972). A cumulative solar radiation of 14000 cal/cm² in the ripening phase (Moomaw and Vergara, 1964) preceded by 6 to 7 hours of bright sunshine per day in the reproductive phase (Sato, 1956) is held to be optimum for rice grain yield.

II.2.3. Rainfall

The type of rains needed for puddling of soil can come only from inland movement of depressions or with heavy rainfall producing systems. In the absence of marine formation and/or inland movement of depressions or heavy rainfall systems, the area under puddled rice goes down. Since the soil surface of a rice field has standing water or is kept saturated, the consumptive-use (evapotranspiration) requirement of an established rice crop will be equal to the Evaporative Power of Air, EPA. The value of EPA in the rainy season is 4.5mm per day (Cocheme and Franquin, 1967). Considering the percolation and consumptive-use needs of puddled rice an amount of 50 mm of rain per week would be needed by an established, rainfed puddled rice. The ideal rainfall interval will be the Saturated Soil Moisture Content, SSMC, of the root zone of the crop divided by 50. In view of the nature of climatology of temporal march of short-period rainfall, collection of run-off from rains in on-farm-reservoirs, OFRs for puddled rice become mandatory to tide over periods of moisture stress for the crop. Thus it is not rainfall requirement but rainfall management that is of utmost importance in rainfed rice culture.

II.2.4. Water Requirement

The physiological make up of a crop plays a vital role in water uptake of the crop during maturity. Limited data recorded with a volumetric lysimeter system (Venkataraman, 1982) shows that varietal variations in physiological control of water needs are likely (Venkataraman et al., 1976). However, as the soil is kept moist till harvest of the crop there will be no reduction in water needs of rice during the maturity period. Thus, the water requirement of irrigated lowland rice will be the same as the rainfall requirement of rainfed lowland rice exposed to the same weather. Limited but critical field trials show that under the aerobic irrigated system savings in water will come from savings in water for field preparation and percolation losses and can range from 30 to 100%.

Water-Sensitive Crop Phases.

For organizing water-saving measures, it is necessary to know the sensitive phases of rice to water stress and to submergence. Moisture stress in the vegetative stage reduces plant height, tiller number and leaf area but the crop can recover without much loss in yield if moisture adequacy is restored before flowering. Rice is most sensitive to moisture stress in the reduction division stage (Panicle initiation through flowering) that leads to high spikelet sterility. The yield reduction due to submergence depends on the duration of submergence and crop stage during submergence and on the muddiness of water. Reduction in yield is two times higher under muddy than clear water. Panicle formation stage and ripening phase are the most and least vulnerable to submergence.

II.2.5. WIND

Only very low wind speeds are required for replenishment of CO₂ supply to the rice plant by turbulence in the crop canopy. Strong winds cause too much fluttering and waving of the crop canopy which (i) interferes with ascent of sap and hence on its mineral nutrition (ii) reduces formation of photosynthates and (iii) poorer retention of assimilation product in ears. Dry winds desiccate ovaries and increase sterility, blow-off the pollen from stigma, especially those with feathery stigma or with a long gap between the opening and closing of lemma and palea (Saran et al, 1972).

II.2.6. RELATIVE HUMIDITY, RH.

RH below 40% inhibit flowering, which is best when RH is 70 to 80% (Angladette, 1966). RH of even 60% lead to faster senescence of leaves (Hirai et al., 1984). Increasing RH increases stomatal aperture and lead to higher photosynthesis irrespective of the solar radiation regime (Hirai et al, 1984). Thus in the dry weather season growing of rice puddled conditions to ensure requisite RH regime would appear necessary. The influence of RH factor has not been widely studied and this lacuna needs to be made good.

III. OTHER BACKGROUND INFORMATION ON RICE.

III.1. Climatic Variability.

Bernard (1992) uses the term “ Climate Fertility ” to stress the direct link between agricultural production potential and climate. Rainfall, temperature and solar radiation, directly or indirectly and singly or in combination, affect the growth, development and yield of rice cultivars. Climatic variability in the above parameters is the major reason for differences in the variations in the yield potential of rice cultivars, observed and inherent, in various regions and seasons. Within the above broad picture several types of climatic variabilities occur and they need to be recognized for micro-scale planning rice agronomy.

First type of climatic variability is the one associated with regular weather systems that traverse specific regions in specified periods like the monsoons. Even when seasonal total rainfall or seasonal mean temperatures are considered, despite the annual fluctuations, an increasing or decreasing tendency over a period of years is often discernible. This gives

rise to the concept of increasing or decreasing epochs of a weather parameter and constitutes the second type of variability. The third type of variability is associated with non-permanent systems like El Nino or La Nina with varying return periods and times and duration of occurrence and which interact with, add and/or influence the regular systems so as to reinforce or mitigate their variability. For example the tendency for occurrence of drought during the Indian Summer Monsoon in El Nino years was suppressed during epochs of above normal rainfall (Kripalani and Kulkarni, 1997). The fourth type of variability is caused by the differences in the coefficient of variation amongst the weather parameters. As an example, rainfall and evaporative power of air are respectively the most and least variable in time and space. Climatic features over short periods of time like a week or a dekad (10 days) have to be considered for crop planning suited to local climate. The in-situ, inter-year variations over short periods constitute the fifth kind of variability. The above types of climatic variabilities lead to a real and seasonal variations in Climatic Fertility for rice production.

III.2. Climate Change

Puddled rice culture leads to anaerobic decomposition of organic matter and in production of Methane, a key constituent of Green House Gases, GHGs, responsible for global warming and climate change. Under a wet undisturbed soil the Methane from soil does not escape into the air. Cultural practices associated with irrigated lowland rice account for 30% of the soil methane released into the air while aerenchyma cells of the rice plant provide the conduit for 70% of the Methane released into the air. Methane constitutes hardly 2 ppm of air compared to 350ppm of CO₂. However, a Methane molecule is 30 times more efficient in trapping of heat compared to a molecule of CO₂. It has been reported (Reddy et al., 2005) that higher biomass production of rice and higher incorporation of organic matter to puddled fields increase Methane emissions. Lowland rice thus constitutes a significant source of atmospheric Methane (Cicerone et al., 1983).

Climate change is expected to result in increases in (i) rainfall variability (ii) mean and night-time air temperatures (iii) concentration of Carbon Dioxide and (iv) cloudiness all of which will adversely affect growth, development and yield of rice (Peng et al., 1995; Matthews et al., 1996). The magnitude of increases in above factors forecast for the worst climate change scenario occurs even now, both intra-seasonally and inter-seasonally. However, in real-time, aberrations in any weather parameter are limited to short durations and the effects of one period of abnormal weather is often offset by another period of an opposing trend - as in case of rainfall and temperature. However, Climate Change is an uni-directional perturbation that is superimposed on the climatic variabilities.

Impact Assessment.

There is diversity of opinion on the expected rate of increase of the climate change parameters. The parameters change in an inter-dependant manner. For example an increase in CO₂ concentration will be accompanied by a rise in temperature and increased cloudiness. Ambient weather conditions influence the degree of responses of a given crop to a given change of a given parameter. Therefore, in assessing impact of climate change on rice it is necessary to (i) carry out assessments for typical of rice areas and seasons (ii) work in terms of realistic, optimistic and pessimistic future climatic scenario by assigning to each of the above climatic scenario class appropriate and specified increases or decreases of

relevant parameters and (iii) adopt a holistic approach involving assessment of increase or decrease in rice yields due to the specified changes in yield-determining parameters. The above will help assess the net change in rice yield in each scenario class for various areas and seasons of rice culture (Venkataraman,2004).

The dynamic crop-weather models, like Ceres-rice and Oryza, use inputs derived from field and laboratory studies to simulate growth, development, production of net biomass and partitioning of net biomass to rice grain yield. They are useful for assessing relative changes in yield of a rice cultivar due to climate change. However many impact assessment studies using the models are deficient in one or more aspects of the requisite methodology.

Salient Features Relating to Rice

The temperature increase linked to global warming would be more pronounced in night-time temperatures (Karl et al., 1991) leading to higher night minima and a decline in the Diurnal Temperature Range (DTR), which is daily range in temperature expressed as a percentage fraction of the maximum temperature. Rice is sensitive to both minimum temperature (Seshu and Caddy, 1984; Lal et al., 1998) and DTR RTD (Lal et al.,1998). Unlike in other crops elevated CO₂ has little effect on transpiration of rice and the effects of moisture stress for rice will not get mitigated under an elevated CO₂ regime. Reduction in solar radiation will lead to an equivalent reduction in rice yields (Ritchie et al.,1986; Hundal and Kaur,1996; Yogeswara Rao et al., 1999). There is little chance of rice getting CO₂ saturated by the middle of this century (Sinha, 1993; Baker et al, 1990). Maintenance respiration can range from 4 to 16% over the temperature range of 15 to 35°C (Mall and Aggarwal, 2002; Penning de Vries et al., 1989).

Some Observed Features

Some investigations indicate that for some climate change scenario and for some regions/cultivars, the rice yield can either increase or decrease. Long-term field experiments in Japan have shown a decline in rice yields because of increase in spikelet sterility due to higher temperatures (Horie et al., 1996). Historical trends and long-term fertility experiments show a modest decline in rice yields in many districts of N.W. India (Aggarwal et al., 2000) and Indo-Gangetic plains of India (Swarup et al., 1998). Simulation studies help ascribe the above decline to rising temperatures (Matthews et al., 1996; Aggarwal, 2003). Even in an optimistic, future climate scenario, a decrease in rice yields in all parts and seasons of the rice belt in India is held likely (Venkataraman, 2004).

A 10% increase in rice yields for one degree centigrade warming plus 100 mm rain in South China is indicated (Zhang,1989). However, the increase is ascribable to increase in rainfall. With a CO₂ level of 460 ppm and temperature increase of 1 to 1.5 degrees centigrade, rice yields are set to increase by 2 to 5% in India (Rathore et al. 2001). Increase in irrigated rice yields of 4% in N.W. India due to climate change (Lal et al., 1998) has been indicated. Increase in rice yields in all regions of India, both under optimistic and pessimistic scenarios of climate change, leading to evening out of differences in regional rice yields has been made out (Aggarwal and Mall, 2002).

Reasons for Discrepancies

The above diverse results are explainable in light of ecophysiology of rice. The effect of any weather aberration depends on the growth stage of rice during which it occurs. For example high temperatures after heading lead to reduction in grain yield (Tashiro and Wardlaw, 1991) and the decrease in spikelet fertility due to high temperatures is not ameliorated by the associated increase in CO₂ (Allen et al., 1995). In East Java, Indonesia high rice yields are obtained in the wet season due to shorter grain-filling period on account of high temperatures (Daradjat and Fagi, 1991). The ambient conditions during which the weather aberration occurs determines the response of rice. For example while mean temperatures above 33°C do not lead to any further reduction in the vegetative or reproductive phases (Alocilja and Ritchie, 1991), grain filling duration decreases with increase temperature beyond 33°C. The rice crop can use the higher amounts of CO₂ associated with temperatures above 33°C. Thus, in India, southern and western regions currently having lower temperatures are likely to have lesser increases in rice yields than northern and eastern regions in the envisaged climate change (Aggarwal and Mall, 2002),

Crop-weather simulation models show that the level of (i) CO₂ enrichment required to offset the influence of increase in temperatures depends on level of CO₂ and (ii) temperature increase that can nullify the effects of CO₂ enrichment depends on level of temperature increase (Crisanto and Leandro, 1994; Hundal and Kaur, 1996; Mall and Aggarwal, 2002). Thus whether an increase or decrease in rice yield will result from any analyses depends on the level of changes in weather parameters assumed, often arbitrarily, in the climate change model.

Extreme Weather Events

Rice is the only crop that can be grown in tracts subject to storms, and floods. Studies (IPCC, 2007) indicate that an increase in the frequency and intensity of extreme weather events like El Nino, La Nina, Floods, Droughts, Cyclones, Typhoons, heat waves, frosts and high winds will be a feature of the climate change scenario. In the Philippines the declines in production and yield are seen to coincide with the occurrence of El Nino events (Philrice-BAS 2000). The lessening of the return periods of El Nino and La Nina and the recent occurrence of typhoons in the normally typhoon free months of November/December in Philippines is a cause for concern as November and December are months when the rice crop is due for harvest and when the second crop is due to be planted (Lansigan, 2005). In India the largely reduced formation of depressions in Bay of Bengal and/or their subsequent lack of inland movement in recent years are affecting the acreage of puddled rice in some major rice-bowel areas.

Assessment of yield losses of rice under field conditions due to natural calamities is rendered difficult due to the fact that the quantum of reduction in yield is critically dependant on the stage of crop during which the calamities impinge on the crop. For example even a temporary moisture stress for a week centred around the time of heading of the crop can reduce crop yields by 60 to 65% due to a sharp decline in spikelet fertility and slowing down of peduncle elongation (Liu et al., 1978 Liu et al, 1978). Direct sown rice is less prone to drought than the transplanted crop. Droughts are more harmful than flooding in reducing yields of rice. In Philippines in the period 1968-1990 droughts, floods and tropical cyclones and pests and diseases were seen to account for 50%, 40 and 10% of the total rice losses respectively (PhilRice-BAS, 2000; Lansigan et al., 2000).

Regional Variations in Actual and Potential Productivity.

The FAO Expert Consultation on yield Gap and Productivity Decline in Rice (FAO,2004)) has assessed the actual farm yield, potential yield and yield gap of irrigated rice in various countries as under.

Country	Yield(t/ha)		Gap
	Actual	Potential	
North India	4.0	6.8	2.8
Republic of Korea	7.0	7.6	0.6
Phillipines	5.5	7.5	2.0
Viet Nam	6.5	8.5	2.0
Egypt	8.5	10.4	2.1
Madagascar	4.1	6.0	1.9
Italy	6.0	9.0	3.0
Brazil	5.5	8.5	3.0

Since the above figures relate to irrigated rice, moisture stress as a yield-influencing factor can be ruled out. The potential yield is that obtained in experimental stations with no physical, biological or economic constraints and with best-known management practices for a given time and given ecology. Actual yield is the yield on an average farmer's field in the same target area, time and ecology of the research station.

It is seen that the yield gap ranges from 10 to 60%. Except in Republic of Korea the yield gap between the actual and the potential in various Rice regions range from 2.0 to 3.0 tonnes/ha. Rice yields on farmers' fields under SRI are considerably more than that of conventional rice at nearby research station. SRI can easily reduce the yield gap. However, the effects of climatic variability on production potential of SRI rice has been limited. The differences in potential yield amongst countries can be ascribed to differences in climatic regimes of the cropping period. However, higher unit area yields are often attained due to longer field-occupancy by rice. Thus in lower unit area yields more time is available to grow a second crop subject to availability of water. Thus for meaningful comparisons of rice crop productivity (i) yield per day per unit area and (ii) net profit per year per unit area would be required.

IV. MANAGEMENT ASPECTS OF RICE IN VARIOUS ENVIRONMENTS

Rice is grown in diverse hydrologic environments with different cultural and crop management practices in each hydrologic environment. Management of the rainfed crop restricts scope of rice management. Under irrigation, the scope for management of crop to improve unit area and gross yields is better. Cultural practices and features having a bearing on crop production within irrigation systems are linked to major weather features and climatic factors, namely, rainfall, temperature and solar radiation.

The time and manner of onset of rains and the seasonal rains in the catchment areas of the source of the irrigation system, determine respectively the time of land preparation

for the first rice crop and the quantum of water available for irrigation. Solar radiation and temperature, as important constituents of the Evaporative Power of Air, EPA, determine the command area that can be irrigated with water available for irrigation and optimal irrigation scheduling of crops in the crop season. The very high water needs for land preparation and meeting of percolation losses give little scope for adopting a seasonally varied command area for rice. The cropping calendar relating to sequencing of rice and its rotational crops and duration of growth periods of such crops vary from place to place on account of (i) variations in the phasic weather requirements of crops (ii) temporal march of radiation and temperature regimes and (iii) the need to ensure that maturity periods of crops are sunny but not warm. Cropping intensity is the number of crops, including rice and its rotational crops that can be raised in an year at a place. The vegetative duration of rice which determines the rice cropping period and the life duration of rotational crops of rice are governed by the temporal march of the temperature regime. Fertiliser applications are timed as per phenological crop stages, which are influenced by temperature. Solar radiation and temperature are important for harvesting and crop processing since sunny and warm weather are required in the pre and post-harvest periods. The above are tabulated schematically in Table 4.1 as per notation of Bhuiyan and Galang,(1987).

Table 4.1. Irrigated rice cultural practices linked to major climatic factors

Rice cultural practices or related activities within irrigation systems	Climatic factors		
	Rainfall	Solar radiation	Temperature
Land preparation and crop establishment	•		
Available water at irrigation system source	•		
Command area	•	•	•
Cropping calendar	•	•	•
Cropping intensity	•		•
Crop Management	•		
Field water management	•	•	•
Fertilizer use and management			•
Irrigation Delivery Schedule	•	•	•
Harvesting and crop processing		•	•

IV.1 ADAPTIVE, PROTECTIVE AND IMPROVEMENT MEASURES.

Adaptation of the rice production systems to weather abnormalities and climate is an integral component of balanced strategy to climate variability. It is a measure of the degree to which adjustments are possible in practices, processes or structures of systems to variability of climate. Adaptations are mostly agronomic. Protection measures relate to avoidance of unfavourable climatic features and mitigation of hazardous weather effects. Improvement measures relate to desirable future developments

Agronomic Adaptation, Commencement of Cropping

Rainfall vagaries result in uncertainty in starting of the rice crop, in both irrigated and rainfed agriculture. This is sought to be overcome by raising of nurseries and

transplanting so as to preserve the physiological age of the crop. The reduced area wet bed nursery and mat nursery are adaptations to overcome water constraints. In case of irrigated rice, low temperatures of less than 15°C prevent raising nurseries in high latitudes. Uncertainty in use of young seedlings for transplanting is overcome by direct seeding. The inability of dry rice seeds to germinate under flooding is overcome by wet seeding with pre-germinated seeds of varieties suitable for direct seeding under anaerobic conditions.

Choice of Cultivars.

The combined duration of the reproductive and ripening phases is 55 plus or minus 5 days. The optimum life duration for rice is 135 plus or minus 5 days (Moomaw and Vergara, 1964; Tanaka, 1964;) So optimal duration of vegetative phase is 80 days. The reproductive and ripening phases must have about 8 hours of bright sunshine with mean temperatures not exceeding 30°C. Agroclimatic analyses can help delineate the best possible growing period for irrigated rice and thus identify cultivars that would perform optimally in a given region and season under early, normal and late start of the season.

The optimal duration for rainfed rice is very often not realisable as rice requires bright sunny weather during the ripening phase and the crop must enter the ripening phase when rains cease, preferably with good root zone moisture storage or with availability of enough water in the OFRs. This calls for use of photosensitive varieties. Under lowland rainfed culture delay in transplanting of photoperiod sensitive varieties due to rainfall hold up has no significant effect on grain yield. It is agroclimatically possible to determine for any given location the time of (i) commencement of the type of rains that will enable start of the lowland rice and (ii) cessation of significant rains. The former will give the last possible date up to which transplanting/seeding of rice can be delayed without a reduction in yield potential while the later will give the photoperiod regime for commencement of flowering and help in choice of cultivars with appropriate photoperiod requirements for flowering.

Optimisation of Population Density

The time from panicle initiation to about 10 days before maturity is the most critical period of solar energy requirement of the rice crop (Stansel, 1975; Stansel, et al., 1975), when temperatures strongly interact with sunlight. Grain yield of rice is highly associated with drymatter at heading (Yogeswara Rao et al., 1999) and increase of dry matter from the early start of panicle initiation to harvest (De Datta et al., 1968). Drymatter production is directly influenced by the amount of solar radiation received and duration of the phases. Both the above parameters are not manipulable. To maximize drymatter accumulation at end of vegetative period, the population density of rice and its nitrogenous fertilisation must be such that the optimal cumulated leaf area index of 4.0 for photosynthesis (Murata, 1967) is reached as early as possible. Under temperatures non-optimal for tillering and/or leaf emergence and expansion, thicker sowings should be resorted to (Venkataraman, 2004). Such maximization of drymatter production in the vegetative phase will also aid the translocation of pre-flowering drymatter to grain dry matter due to non-optimal solar radiation and/or temperature regimes during the grain filling phase (Cock and Yoshida, 1973; Yoshida, 1972). Thus, to make best use of whatever solar radiation is available in the reproductive and ripening crop phase adjustment of population density as per the normal temperature regime at a location needs to be resorted to.

IV.II. PROTECTION MEASURES.

Floods and Droughts.

Growing of puddled rice with standing water is by itself considered a bulwark against flooding. In rainfed lowland rice, risks due to flooding can be minimized by effective techniques for drainage of excess water in the field, such as openings in the field bunds at a level corresponding to the desired depth of standing water in the field, in tune with local aspects of plant and water management under excess moisture. However, this arrangement will result in a large quantum of rainfall becoming ineffective. Collection of runoff from rains in on farm reservoirs, OFRs and introduction of water-saving techniques (Lansigan, 2005) are adaptive measures to mitigate drought situations caused by rainfall anomalies and improve water use efficiency respectively. The On-farm-reservoir system also provides an effective means for combating floods.

High Winds

Strong winds lead to (i) poorer mineral nutrition of the crop and (ii) enhanced spread of many diseases of rice. Establishment of windbreaks in strategic areas can help reduce wind-damage in rice. For this information on Prevailing Wind Direction, PWD, in various months is required to be known, as windbreaks have to be erected perpendicular to PWD. “ Wind Roses ” giving climatic information on a monthly basis of frequency of occurrence of winds from 8 cardinal directions and frequencies of occurrence of specified wind speed classes in each direction are widely available and can be used for proper orientation and structuring of windbreaks.

Pests and Diseases.

During night hours, due to back radiation the rice canopy can cool to a value below the screen level minimum temperature. When relative humidity is high, 75% or more, winds are light or absent and the crop cools to a temperature below the dew point of air, Dew forms and wets the leaves. The times of onset and evaporation of foliar Dew is called Leaf Wetness Duration, LWD, which has a vital bearing on incidence of diseases. LWD can be measured by instruments (Post et al., 1963; Lomas and Shashqua, 1970; Monteith, 1972). The procedure suggested for computation of LWD by Matra et al. (1995) is not practicable for real-time use. The extent to which crop minimum temperatures drops below the screen level minimum varies with seasons and places. Extrapolable data on depression of crop minimum below the screen minimum are available for many areas and seasons. The hourly distribution of temperatures can also be calculated from maximum and minimum temperatures (Venkataraman, 2002). Thus data on maximum, minimum, dewpoint and depression of crop minimum below screen minimum can be used climatologically to avoid disease incidence by crop planning and operationally for effective control operations.

Rice is susceptible to a given pest or disease at a certain growth stage only. The pest or disease organism does damage at a certain development stage only. The pre-disposing weather conditions for incidence and spread of many important pests and diseases of rice are also available (Venkataraman and Krishnan, 1992). Such information can be used to agroclimatically demarcate susceptible areas and periods for many major pests and diseases of rice. The above along with the pheno-meteorological relationships of rice can be used to avoid pests and diseases through a proper choice of sowing date or variety or both.

Temperatures

Cold temperatures can arise from advection or local radiational cooling with standing rice crop. Temperatures below 20°C and above 35°C for Indica varieties and below 15°C and above 30°C for Japonica varieties are potentially harmful. The extent of damage depends on crop growth stage, variety, temperature duration, diurnal range and physiological status of the plant. Cool weather hazards to Rice are often encountered in high latitude regions. Low temperature incidence in hilly areas in the tropics and subtropics is a critical factor in rice production. Some types of cool weather damage to plants in typical growth stages of rice are indicated in Table 4.2 below

Table 4.2: Cool weather damage to rice (Nishiyama, 1985 cited by Matsuo et al., 1995).

Growth stage	Types of cool weather damage to rice plant
Before nursery	Retarded cultivation
Nursery stage	Inferior germination and growth; withering, and seedling rot; Delay in transplanting due to freezing immediately after removing a cover on the protected nursery
Early stage :Transplanting, Tillering , Panicle formation	Delay in transplanting; poor rooting; discoloration of leaves; decrease in tiller number; delay in growth and formation of young panicles; reduction in size of panicles
Panicle Initiation to Booting	Degeneration of rachis-branches, decrease of spikelets; cessation of spikelet growth; Delay of heading; non-heading; browning of leaf sheath;
Heading stage	Delay of heading
Flowering stage	Delay of flowering, unfertilization, and non-flowering, of lower spikelets
Ripening stage	Incomplete ripening; discoloration of unhulled rice grains; Cessation of ripening due to early frost

In North Japan, to overcome delays in start of rice nurseries due to chilly winters, the nursery beds are covered by oil paper or vinyl films and the nurseries are drained and re-flooded frequently to maintain equable warm day and night temperatures (Matsuo, 1954). The protected seedbed method helps in extending the rice season from early spring to late autumn (Inoue et al., 1965). In Northern China seedlings are raised in plastic-protected nurseries when the air temperature is around 10°C and transplanted to the main field when the temperature rises to 20°C. In Katmandu valley of Nepal seedlings are raised in unprotected nurseries when the temperature is about 20°C, transplanted to the main field and harvested before the temperature decreases to 13°C (Yoshida, 1978) and causes high sterility of spikelets. Similar approaches have been reported for some areas of Japan (Robertson, 1975). The following measures (Barfield and Gerber, 1979), singly or in combination, can be used to cope with risks to rice on account of cold weather namely heating or mixing of the air layers in the crop canopy, sprinkler or flood irrigation, artificial fogging and insulation with suitable material.

Usually heat wave conditions arise from advection associated with en masse movements of warm weather systems. Local heating of surface leading to high air temperatures occur during summer and generally after the harvest of the rice crop. High

temperatures in the vegetative phase reduce duration of tillering but enhances tiller production with the result that total number of tillers is little affected. Reduced tillering period will help the crop in maturing in less than normal temperatures. However, high temperature during heading is detrimental and during the ripening phase reduce the grain-filling period. Protection against high temperatures has received considerably less attention than cold temperatures. This is because rice can tolerate in the vegetative phase temperatures of 44 – 45° C (Abrol and Gadgil 1990). Unlike low temperatures high temperatures allow rice to be grown though with reduced yields. Heat stress can be minimized by irrigation, which exerts a cooling effect by converting sensible heat to latent heat and is the most promising and suitable measure (Marva and Vandenbrink, 1979).

Sowing of pre-germinated seeds is routinely practiced in rice culture. High pre-sowing treatment temperatures induce early flowering, as short as 60 days in some varieties (Parija, 1943). Therefore, in incubating rice seeds to induce early germination for sowing in warm weather, care should be taken to cool the temperatures of germination rooms to wet bulb temperature by injection of moisture from wet mats

Mitigation Measures, Crop Insurance.

Covering of risks in rice crop production by crop insurance will be a mitigating measure. However, the fraction of farmers in developing countries having cover of crop-insurance is very low. For example in India only 14% of the farmers are covered by crop insurance. In Philippines crop insurance covers only land preparation and establishment. To be meaningful crop insurance for rice must cover all farmers and all the risks from preparation of nursery to harvest of rice. Insurance premia will have to be higher for areas with unstable crop production. Higher crop insurance premia would be an unbearable burden for farmers in areas of low yields of rice with high inter-annual variability. Therefore, if higher premia are charged by crop-insurance companies, the crop insurance premia or the differences in premia compared to the lowest one will have to be borne by the governments. Such payments on behalf of farmers by governments does not attract the charge of subsidization of uneconomic crop production under the WTO regulations.

Agroclimatic analyses using past series of meteorological data can help assess for any given area, season and crop, the extent of inter-annual variability in rice crop production on a relative basis. The above approach is justifiable on the ground that differences between rice cultivars to weather parameters are one of degree rather than that of type. Use of satellite-imageries for crop monitoring, calibrated against agrometeorologically-analysed ground-truth, has the potential to provide an independent check to crop insurance firms on claims of yield losses of crops. Thus agroclimatic analyses have a role to play in (i) fixation of rational insurance premia for rice and (ii) in providing unbiased picture relating to crop losses in rice on a region-wise and season-wise basis.

Weather Forecasting

Even with careful agronomic planning for rice, through micro scale agroclimatic analyses to suit local climate, the start of the rice season is vitiated due to variability of regular weather systems, like monsoons and irregular weather phenomenon like El Nino and La Nina. Standing rice crops are subjected to weather vagaries on a year-to year-basis. Technologies to cope with climatic variabilities and weather anomalies are available. Weather-vulnerability of rice production can be considerably minimised if expected

weather situations can be accurately forecasted on a long-range basis and the same conveyed to farmers. The Long-range weather forecast, LRWF, will give the rice farmers sufficient time to organise and implement appropriate contingency cropping measures, at the start of the season, in tune with the expected weather. Due to lack of sufficient data to validate its accuracy LRWF technology is far from suitable for operational adoption in pre-seasonal planning of rice culture. Again, at present LRWFs only forecast what the anomaly of a weather situation will be at the end of the forecast period and gives no indication of the temporal distribution by which the forecast anomaly will be realised. So they are of no operational use except for indications relating to early, normal or late onset of the season. Once the rice crop is planted, the production resources and technology get committed to a particular course of action. However, medium range weather forecasts, properly interpreted for its likely agronomic consequences in light of actual stage and state of a standing crop and quickly transmitted in real-time, will help rice farmers to (i) cope with and/or counteract the impacts of unfavourable weather and (ii) take advantage of favourable weather situations.

Improvement Measures

Developing simple implements for intercultural operations especially weeding, rapid harvesting and post-harvest handling (Pantastico and Cardenas, 1980) is a much needed improvement measure. Biological improvement measures include breeding varieties (i) for enhanced drought, heat and cold tolerance (ii) with increased resistance to lodging (iii) with morphological adaptations for better interception of solar radiation (iv) physiological improvements for betterment of efficiency in use of CO₂ and solar radiation in photosynthesis and (v) resistance to specific pests and diseases.

V. USER REQUIREMENTS FOR AGROMETEOROLOGICAL INFORMATION ON RICE

Due to complex combinations of climate regimes and cultural systems of rice, the needs for agrometeorological information of the rice farmer might be more specific in some aspects. At present, agricultural weather forecasts and advisories based on the same are being provided on the basis of the existing agronomic scenario of rice. The tacit assumption in the above approach that the existing scenario is either optimal or non-alterable needs to be examined. Rice-climate classification is the starting point to maximise and minimise respectively the positive features and hazards of local climate (Lomoton and Baradas, 1983).

Rice-Climate Zones

Rice climate classification involves delineation of zones with inter-zonal homogeneity and intra-regional differences in times and duration of rice cropping period and potential yield levels under irrigated and rainfed conditions. Water, air temperature and solar radiation are the principal factors governing irrigated rice culture. The water factor is controllable. The other two are not. Thus the potential for irrigated rice, grown without any constraints and stresses should first be established in various regions. Such a potential constitutes Climatic Fertility (Bernard, 1992) of rice, whose reduction due to water constraint must then be assessed. Such Rice-climate zonations will help in (i) quantitative assessment of the climatic risk due to late sowings (ii) prescription of cultivar-specific safe first and last dates of sowing (iii) assessment of probability of occurrence of critical climatic

variables, like minimum temperatures less than 15°C for early, normal and late sowings (iv) drawing up of contingency plans for late starting of the crop season and (v) assessing requirements for real-time agrometeorological information that will aid the farmers on a region-wise and period-wise basis.

Irrigated Lowland Rice

The methodology for rice climate classification has been enunciated by Venkataraman (1987) is reiterated. The requirements for maximal yields of rice grown without any moisture constraints are (i) a crop-life duration of 135 with a vegetative phase of 80 days, a mean air temperature remains in the range of 15 to 30°C and about 8 hours of bright sunshine in the last two months. Isoquant plots giving curves of equal predicted yields for combinations of minimum temperature and solar radiation during ripening period (30 Days after flowering) have been given by Seshu and Caddy (1984). Solar radiation is linearly related to bright hours of sunshine (Thus from climatic data of actual or derived radiation and minimum temperature, yield potential of rice can be assessed on a monthly basis. The month preceding the optimal ripening month can be assigned to the reproductive phase if it has 7 to 8 hours of bright sunshine. The 80-day period preceding the reproductive month can be assigned to the vegetative phase. By repeating the above process for all months one can arrive at times and duration of rice crop periods for various levels of productivity. There may be overlapping periods for same level of productivity. In carrying out the above exercise one should bear in mind that for irrigated rice the start of the season is dictated by date of release of water for first irrigation. The local traditional practice will give a real-time picture of availability of water for start of the rice season. So commencement of vegetative phase cannot be earlier than the traditional first date of irrigation. Delineation of times and duration of rice crop period for various levels of productivity at a net work of stations can help in demarcation of climate zones for irrigated rice.

Rainfed Lowland Rice

For rainfed rice-climate zonation, rainfall over weekly or Dekadal (10 days) periods has to be considered. Over the above periods, the inter-annual variation of rainfall is such that one has to work in terms of probabilities and consider minimum assured rainfall amounts at various percentage probabilities. 50% probability is an acceptable risk leveling rainfed farming. Thus, first of all at the 50% probability level. the commencement can be taken as the week/dekad in which cumulation of rainfall minus evaporative power of air reaches the water requirement for field preparation. The end will be the week/dekad when rainfall sharply declines below evaporative power of air. It is possible that such delineated periods may be more or less than the optimal vegetative life duration of rice crop of 80 days. In the former case agronomic technologies to ensure sowing and harvest of more than one rice crop or a rice crop cum rotational aerobic crop have to be addressed. In the latter case the choice of cultivars and/or sowing dates must be such to ensure that the rice crop enters the reproductive phase when rains cease.

For a standing rice crop, considering the magnitude of evaporative power of air in the rainfed lowland rice areas and the rainfall requirements to meet the transpirational need of the crop from transplanting/sowing to harvest, a weekly rainfall amount 50 to 70 mm and a Dekadal rainfall of 70 to 100 mm, depending on soil types would be required. Agroclimatic, rainfall-budgeting exercises of temporal distribution of rainfall in the

delineated period can help assess the (i) period(s) of moisture stress and excesses (ii) feasibility of rainfall harvest and adequacy of the harvested amounts to (a) meet the water needs of the standing crop during droughts and (b) raise another crop in the post-rainy season. The results from such agroclimatic analyses at a network of stations can be used to demarcate homogenous climate zones for rainfed lowland rice.

Biotic Risks and Weather Hazards.

For irrigated and rainfed rice, in each of the rice-climate zones, periods endemic and/or susceptible to pests and diseases and weather hazards (storms, high winds, cold and heat waves etc) can be delineated for suitable, remedial, agronomic and other measures.

Weather-Forecast Based Advisories for Farming Operations in Rice.

Seasonal outlooks are usually expressed as expected deviations from normal conditions and give no indication of the temporal distribution by which the forecast anomaly would come to be realized. Long-range weather forecasting is still in the research and experimental stage and is far from suitable for operational adoption due to insufficient data about its accuracy. It would be prudent to advise potential users of the tentative nature of monthly and seasonal outlooks (WMO, 1981). Only medium range weather forecasts, MRWFs, offer scope for timely scheduling farm operations to cope with expected weather.

The main weather-sensitive rice farming operations, WMO (1983) are: a) nursery activities; b) land preparation; c) seedling/transplanting; d) irrigation and drainage; e) fertilisation; f) crop protection; (g) application of agrochemicals (h) harvesting; (i) threshing and (j) sun drying and cleaning. The weather situation, which is usually a combination of threshold values of weather parameters, that affect farm operations vary from place to place and from season to season. The current state of knowledge and evaluation of the response of the rice crop to weather variables is adequate enough to lay down the threshold values of weather components such as rainfall, temperature, wind, and cloudiness in relation to all activities of rice production.

Based on the combination of the several categories of sky condition, soil moisture status, leaf wetness duration, temperatures and wind speed, WMO (1983) has indicated 72 weather features to cover all farming operations. Inclusion of too many threshold values for each weather element increases the number of weather forecast categories. However, the same agronomic advisory can be given for many combinations of weather elements (Lomoton and Baradas, 1983). Again, the effects of a given weather situation is critically dependant on the rice crop stage. Implementation of any recommended farm operation takes time to be organized. While weather can change on a daily basis changes in crop state and stage will be gradual. Thus, agrometeorological advisories based on medium range weather forecasts and state and stage of crops are issued by the agrometeorologist in consultation with and specialists such as pathologists, entomologists and agronomists once a week and updated if necessitated by perception of a change in forecasted weather. Issue of agromet advisories on a rice-climate zone basis can help in better real-time use of such advisories.

Agrometeorological forecasting

Agrometeorological forecasting is concerned with the assessment of current and expected crop performance, including crop-development stages (especially maturity) and yields (quantity and quality), and other factors affecting production patterns (WMO, 1981). For the rice crop, two of the most important kinds of agrometeorological forecasting are phenological and yield forecasts. Phenological forecasts are important as the effects of any given weather situation is crucially dependant on the rice crop stage during which it occurs. This in turn decides the type of advisory to be issued and the yield ultimately achieved. Yield forecasts sufficiently ahead of the harvest in conjunction with an advance assessment of acreage planted to rice under various ecosystems are crucial for timely and effective management of the rice food economy.

Phenological forecasts

The most important phenological forecast is the days taken to flowering from sowing. This can vary with varieties. For any given varietal class, successful forecasting of rice crop phenology under field conditions has been reported. The DD50 computerized rice management program uses the concept and computation of degree-days as a tool to (a) predict phenological events with an accuracy of plus or minus two days (Slaton et al., 1996) and (b) assist rice farmers with 28 growth stage based management decisions including herbicide application, scouting for insects and diseases, timing of application of nitrogenous fertilizers etc. ” The described degree of accuracy is quite high; probably it could be quite different in different crop areas and yearly conditions.. Mall and Aggarwall (2002) had reported that ceres-rice accurately predicted vegetative phase durations ranging from 37 to 85 days on account of variations in varieties and locations in India. However, since the predictions are based on variety-specific genetic coefficients derived from observed field data, such findings do not address the problem of real-time prediction of rice phenology.

Yield forecasts

The agrometeorological forecasts of crop yields are unit area yields. They constitute a very important tool to estimate the production of that crop in a certain region or country by knowing the area planted. There are three approaches to modeling the impact of weather and on crop yields (WMO, (1981), namely, (a) The empirical-statistical approach (b) crop-weather analysis models and (c) crop-growth simulation models.

The empirical Statistical Approach.

In this the crop yield is related to levels of weather parameters, either singly or in combination, in selected calendar periods. Due to rainfall and/or temperature vagaries the selected calendar periods would relate to different rice crop phases in various years. Often there is no physiological significance between the selected periods and rice yields. In case of rice, drastic reductions even with normal vegetative growth can occur due to weather vagaries in the reproductive and ripening phases. Assessment of weather aberrations should be growth-phase based and not calendar dates based. The empirical statistical approach will give highly misleading results in almost all years.

Crop-Weather Analysis Models

In this type of analyses (i) crop itself is sought to be used as a weather integrator and (ii) use is made of crop responses to selected agrometeorological variables at various growth stages. Such studies help (i) identify crop growth attributes, which can be used as a measure of the likely yield and (ii) assess the influence of growth stages of a crop in the extent of reduction in potential crop yields due to weather anomalies and soil moisture stresses. While they cannot per se give any yield estimates, they provide valuable inputs for designing sub-routines in the crop growth simulation models for (i) use of quantified crop attributes in yield-assessment and (ii) assessing effects of crop-phase based environmental stresses on extent of reduction in yield vis-à-vis a non-stressed crop.

Crop-Weather Simulation

The dynamic crop-weather models simulate plant physiological processes like photosynthesis, transpiration, respiration, biomass partitioning, nutrient uptake and water use in daily time steps in a manner similar to the processes as they are visualized in the rice crop (Uchida, 1985) for conversion of seeds, water and fertilizers into rice grain and straw. Phenological stages are simulated in the models from considerations of thermal and photoperiod regimes. In crop yield forecasting projects feed back information from fields on the observed stage and state of crops are received. So only the part of the model relating to prediction of rice yield becomes relevant in real-time. For purpose of prediction of rice yields the models require individual calibration for the varieties used. The models constitute valuable research tools for studying the performance of rice cultivars under different environmental, soil and management conditions through meteorological links when weather is the only operating variable. The models, however, require cultivar-specific genetic coefficients for many parameters and development rates. The problem posed by varietal variations in vogue in rice culture can be overcome through the following considerations of phenological and physiological responses of rice to weather.

The drymatter accumulated in the vegetative phase is related to the final grain yield. The ratios in the quantum of dry matter available at the start of the reproductive phase amongst cultivars can reasonably be assumed to be in the ratios of duration of their vegetative phases. The percentage change in the duration of vegetative phase due to weather influences will be the same for all cultivars under the same weather regime. So the ratios will be conservative across yearly weather situations. The durations of the reproductive and ripening phases are nearly the same for all cultivars. The agronomic planning is to ensure that all the cultivars be exposed to the same weather in the maturity phase. The actual quantum of dry matter produced in the reproductive phase can vary amongst cultivars. However, there will be no change in the ratios of production of drymatter in the maturity phase amongst cultivars. The change in duration of vegetative phase at a location due to the temperature factor is never drastic. Thus, the percentage change in yield from the potential due to weather variations will be the same for different cultivars across locations and years. Thus, validation of the models at a few locations and few cultivars can be used for assessment of yields of different cultivar across seasons and locations under irrigated and non-limiting nutritional conditions. The models assume that (a) diseases and pests are absent (b) there are no adverse soil conditions and (c) extreme weather events such as typhoons etc do not occur. Reductions in yield of rice often arise from biotic stresses and hazardous weather. So the final yield estimates have to be adjusted for losses due to biotic and abiotic stresses.

Biometeorological Models.

A combination of the crop weather analysis approach involving the use of yield determining attributes, like spikelet number at heading and Dynamic simulation models for assessing total drymatter accumulation may be necessary for predicting rice yields.

Field-Level Data Series.

For both rainfed and irrigated rice, yield prediction models must be validated at the level of technology the farmer uses, which generally keeps on increasing. Thus, for rice yield forecasting, availability of data, in the recent past years, on yields of typical cultivars recorded on fields of farmers by properly designed crop cutting experiments and archival of such data for ready retrieval and use are necessary. In case of rainfed rice the yield level will depend on the availability or absence of facilities for collection and re-use of runoff from rainfall. So yield data for purely rainfed conditions and conditions of rainfall harvest and re-use have to be recorded separately

Use of Forecasted Weather Data

Rice yield forecasts are required to be issued preferably two months in advance of harvest of the crop and definitely at least a month in advance. Therefore, for use in the models, forecast levels of various parameters have to be provided on a weekly basis for a month or two ahead. As in weather forecasting values of analogous years or climatic normals or forecast values can be used. It is very difficult to find an year, which is completely analogous to the year under consideration. Instead of using climatic normals it better to use forecast probabilities of parameters, principally, temperatures and sunshine/solar radiation.

VI. AGROMETEOROLOGICAL SERVICES RELATED TO RICE.

The national weather services have the mandate to meet the climatic data needs for crop planning and the weather forecast requirements for agricultural operations. The forecast service is a matter of great daily urgency for farmers. However, weather forecasts cannot be issued only for or even with special reference to rice. So agrometeorological services for rice farmers involve the questions of (a) who provides what information where? (b) who receives and interprets the routine flow of various types of forecasts with reference to available rice crop information and issues agronomic advisories? (c) how do farmers access these information? The answers to the above questions lie in rice farmers forming their own associations to appoint agents and/or seek advice from agrometeorological consultants, who understand weather relations of farm operations, pests and diseases etc. relating to all crops and hence can interpret the forecasts in terms of rice and issues rice-specific advisories. .

Agrometeorological Extension for rice farmers

Medium range weather forecasts, MRWFs, by themselves can be used in scheduling farm work in rice. Updated MRWFs can also be taken advantage of by the rice farmers. However, rice farmers in developing countries are ill equipped to take action on daily

weather forecasts or updated MRWFs on their own. Thus, it would be ideal to have (i) working arrangements for cooperation between the meteorological centers and agricultural cooperatives and/or agricultural extension services and (ii) local “Extension Agrometeorologists” well-trained to translate the forecasts in terms of farm operations for rice in a language understood by the farmers. The majority of rice farmers, located in tropical areas are too poor to form associations and not literate enough to benefit from information conveyed through print media, websites or SMS. The governments should, therefore, enable the rice farmers to form cooperatives and facilitate conveyance of agromet advisories through community radios and TV channels. In organising such a set-up the experience of rice farmers of a few countries in organizing self-help set-ups to derive benefit from weather-based precision rice farming should be of help and are mentioned below.

Brazil

Three months’ weather outlook is issued by a team of meteorologists, agrometeorologists and agronomists to help rice farmers to take several planning decisions in the Southern region of Brazil (Berlato & Fontana, (2003). The web page of the Laboratory of Agrometeorology (in Portuguese) (<http://www.cpact.embrapa.br/agromet>) offers some agroclimatological products for the irrigated rice in the State of Rio Grande do Sul like: (a) Agroclimatic zoning for “potential productivity” and “climatic risk” according to the sowing period (b) probability of minimum air temperature harmful to rice (c) three-months weather forecast (d) management techniques to minimize the impact of the forecast weather and (e) application of the degree-days method to help farmers to apply nitrogenous fertilisers at panicle differentiation (PD). Maps (in Portuguese) indicating the climatologically estimated dates of PD for groups of short and medium cycle varieties, for every 10 day emerging dates. Detailed information can also be found in a publication (Steinmetz et al., 2004) available as a PDF file (in Portuguese) in above address.

U.S.A.

The computerized rice management programme, called DD 50, caters to rice farmers in USA, principally in the states of Arkansas, Louisiana and Texas. The above programme is open to individual rice farmers, farmers’ agents and consultants. More than 2,000 Arkansas rice growers on more than 60 percent of the state’s rice area (Slaton et al., 1996) use the programme. To participate in the program, farmers submit the variety, area sowed, and emergence date of each rice field to their local county extension office. Agents automatically receive a copy of all reports (via e-mail) generated for their county, regardless of who initiated the report (producer, agent or consultant). It provides decision management aids based on planting date, variety and weather information.

The main input is the weather information provided by the National Weather Service and updated daily to the University of Arkansas Cooperative Extension Service Weather web site. This program utilizes the concept of degree-days (DD) or heat units to estimate when a certain stage of the rice crop will occur. The basic data used are: 1. the emergence date(s) and the variety (ies) used by the farmer; 2. the thermal units required to reach the main development stages of the most important varieties, which are determined in the research stations; 3. long series (30 years) of past daily maximum and minimum air temperature data and current year’s data for the crop season. In general, the events predicted by DD50 are held to be accurate within plus or minus two days (Slaton et al., 1996). Nowadays, this program assists farmers with 28 management decisions based on

growth stage, including herbicide application, critical times to scout for insects and diseases, and N application. For example, the ability to predict growth stage, specifically internode elongation (IE), reduced physical labor required to sample fields to determine the accurate time for mid-season application of nitrogenous fertilisers

At the beginning of the season, the DD50 operates using the 30-year temperature averages. Then, it is continually updated with the current year's temperature data to improve accuracy. Updated DD50 printouts are provided to farmers when temperature-based phenological dates are expected to deviate from the 30-year average by three or more days. In all the above three states only registered users can avail the benefits of DD 50 programme.

Japan

In the Tohoku region of Japan, yield fluctuations of rice are strongly influenced by the fluctuations of the summer mean temperatures (Hayashi and Jung, 2000). An example of the use of crop model and meteorological data in monitoring the rice development and cool-summer damage, in the Tohoku district of Japan has been given by (Yajima, (1996). The results obtained by combining the models on development stages and on spikelet sterility with the crop, meteorological and geographical data, emphasize the importance of the use of crop model for the monitoring and forecasting of rice development stages and spikelet sterility at the regional level or in areas affected by cool temperature damage. The method could be easily used by extension staff to provide information on the possible occurrence of spikelet sterility in particular areas that may enable the farmers to take the necessary measures to minimize the yield reduction due to cool temperature. An early warning system against cool summer damage in Northern Japan is in operation (Yajima, 2003).

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