TERMINOLOGY FOR RICE GROWING ENVIRONMENTS

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TERMINOLOGY FOR RICE GROWING ENVIRONMENTS

There is as yet no consensus on the terminology to describe different rice-growing environments. Upland and lowland, and dryland and wetland are widely used, but uplands for rice are often lowlands in more general geomorphic terms, and drylands for rice may be quite wet. Many terminologies are now used, and many rice scientists are uncertain as to which is most appropriate.

In developing an international program to collaborate with the different national organizations, and to produce rice varieties adapted to different environments, it is essential to define basic rice environments and to establish subcategories within them. This is increasingly important as work expands to the diverse environments in which rice is grown without controlled irrigation. Rice varieties must be developed that are adapted to drought and/or flooding, very high or low temperatures, and to salinity and other soil problems.

For several years, IRRI has recognized the need for wide agreement on environmental terminology so that plant type can be better related to the environment. After initial discussions at the 1982 IRRI International Rice Research Conference, it was decided to establish a widely representative International Committee (Table 1) under the chairmanship of Dr. D. J. Greenland, to develop an agreed upon terminology and classification system for rice. The committee has functioned primarily by correspondence, but we believe it has made significant progress. The proposed environmental terminology for rice is summarized in this publication, and related to others on current use. We would appreciate wider discussion and comments on the papers in this volume in the next few years, after which we expect it may be necessary to further refine our definitions and subdivide our terminologies.

Dr. G. S. Khush, head of the IRRI Plant Breeding Department, and Dr. D. P. Garrity, of the International Rice Testing Program, have led much of our thinking in developing the definitions we propose for wide adoption and have authored the two papers in this publication. However, we recognize there have been substantial contributions to these papers from committee members and individuals within and outside IRRI who have contributed their knowledge of the rice producing regions of the world.

M. S. Swaminathan

Table 1. Members of International Committee for Terminology and Classification of the Rice-growing Environments.

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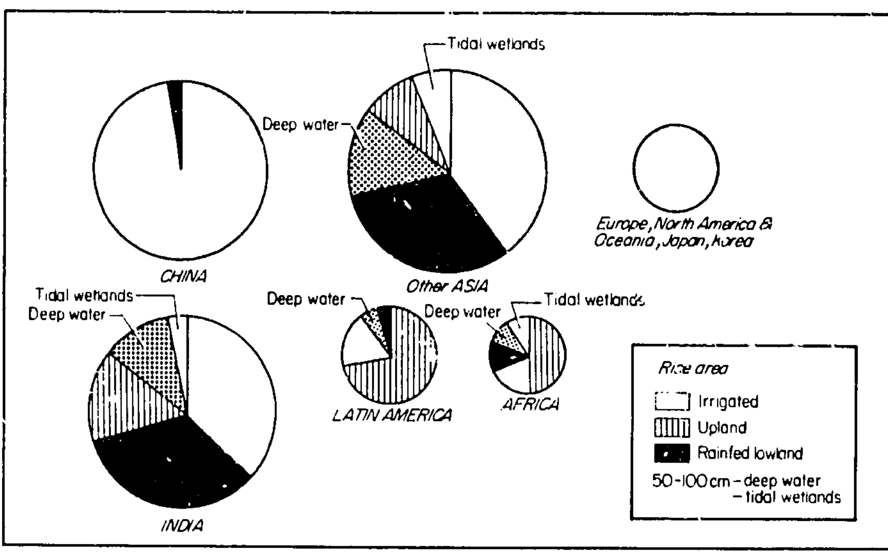
Note: Affiliations or positions indicated are at time of membership.

TERMINOLOGY FOR RICE GROWING ENVIRONMENTS

G. S. KHUSH

The following terminology for rice growing environments recognizes several criteria that affect rice production practices and varietal requirements. Factors considered in naming the environments are water regime (deficit, excess, or optimum), drainage (poor or good), temperature (optimum or low), soils (normal or problem), and topography (flat or undulating). The widely used method of classifying rice environments into five major categories is retained; however, each category is divided into distinct subcategories:



Proportional area of rice grown in different cultural systems.

IRRIGATED

- Irrigated, with favorable temperature
- Irrigated, low-temperature, tropical zone
- Irrigated, low-temperature, temperate zone

RAINFED LOWLAND

- Rainfed shallow, favorable
- Rainfed shallow, drought-prone
- Rainfed shallow, drought- and submergence-prone
- Rainfed shallow, submergence-prone
- Rainfed medium deep, waterlogged

DEEP WATER
- Deep water
- Very deep water

UPLAND
- Favorable upland with long growing season (LF)
- Favorable upland with short growing season (SF)
- Unfavorable upland with long growing season (LU)
- Unfavorable upland with short growing season (SU)

TIDAL WETLANDS
- Tidal wetlands with perennially fresh water
- Tidal wetlands with seasonally or perennially saline water
- Tidal wetlands with acid sulfate soils
- Tidal wetlands with peat soils

Characteristics of rice varieties needed for each subcategory are different and well defined. Production practices for subcategories may differ considerably.

IRRIGATED

About 77 million ha, 53%, of the world rice area is irrigated and has adequate water supply throughout the growing season. In much of this area, rainfall supplements irrigation water. Irrigated areas with good water control are suitable for growing of improved varieties with short stature and lend themselves to improved cultural practices. Perhaps 70 to 75% of world rice production comes from irrigated areas. Varieties with short stature, short growth duration, and multiple disease and insect resistance perform best. Irrigated areas are subdivided into three categories.

Irrigated with favorable temperature
In irrigated areas with favorable temperature, the temperature range is acceptable for normal rice growth throughout the growing period. Most irrigated areas in the tropics and subtropics fall within this category.

Irrigated, low-temperature, tropical zone
In low-temperature irrigated areas within the tropical zone, low temperatures affect crop growth at some stage. The boro crop in India and Bangladesh experiences low temperature at seedling stage. In high-elevation tropical and subtropical areas of India, Nepal, and the Philippines, low temperatures may limit plant growth at seedling stage and cause panicle sterility at maturity. Indica varieties are grown most often. Cold tolerance and blast resistance are the most important characteristics needed.

Irrigated, low-temperature, temperate zone
Rice crops in the temperate zone generally are affected by low temperatures at seedling and flowering stages. Cold-tolerant japonica varieties are grown. Varieties have been improved and selected for cold tolerance, short stature, and

hard threshability to avoid shattering losses. Japonica rices are transplanted in Japan, Korea, and northern China, but are broadcast in standing water or drilled before flooding in Europe, including the USSR, and in Australia and USA (California).

RAINFED LOWLAND

About one-fourth of the world rice area and 40% of the ricelands in South and Southeast Asia are rainfed lowland. Rainfed lowlands have a great diversity of growing conditions that vary by amount and duration of rainfall, depth of standing water, duration of standing water, flooding frequency, time of flooding, soil type, and topography. Varieties with tolerance for varying levels of excess moisture or moisture stress, varying growth duration, and plant height are needed. Management practices vary in the rainfed lowlands. Based on varietal requirements and management practices, rainfed lowland has five categories.

Rainfed shallow, favorable

Rainfall and water control are adequate in areas categorized as rainfed shallow, favorable. Short periods of moisture stress or mild submergence may occur, but are not a serious constraint. Supplementary irrigation may be available. This category comprises perhaps 12-15 million ha of ricelands in Indonesia, Malaysia, the Philippines, Vietnam, Burma, Nepal, India, and Sri Lanka. Varieties developed for irrigated fields are well adapted and widely grown, and management practices are similar to those in irrigated areas. Semidwarf cultivars with disease and insect resistance, 100-140 days growth duration, and photoperiod insensitivity are needed.

Rainfed shallow, drought-prone

Fields in rainfed shallow, drought-prone areas are bunded and growing conditions range from upland to lowland. The rainy period is 90-110 days and moisture stress may occur at any growth stage. There are 6-7 million ha of these lands in north and northeast India (eastern Uttar Pradesh, Bihar, Madhya Pradesh, Orissa, and West Bengal) and Bangladesh (aus crop), and smaller areas in central Burma and northeast Thailand. Rice is generally broadcast but may be transplanted. Soils vary from neutral to alkaline. Photoperiod-insensitive varieties with short growth duration (90-105 days), intermediate stature (120 cm), and drought tolerance at all growth stages are needed.

Rainfed shallow, drought- and submergence-prone

Rainfed shallow, drought- and submergence-prone areas have periods of heavy rainfall when submergence may result from local rains or from heavy rains that cause rivers and creeks adjacent to the riceland to overflow. The rice crop may be submerged for 10 days. There may be extended periods of no rain and the crop may suffer from moisture stress. There are about 3 million ha of these lands in northeast Thailand and 1 million ha in Laos and Kampuchea. Land is bunded and puddled and rice is transplanted. Soils have light texture and low fertility. Grain quality strongly influences varietal acceptance. Varieties with intermediate height, drought and submergence tolerance, and 100-130 day growth duration are most adaptable. No improved varieties have been developed for this environment.

Rainfed shallow, submergence-prone

Periods of heavy rainfall when sudden floods may submerge the rice crop up to 10 days frequently occur in rainfed shallow, submergence-prone areas. Rainy period is long (5-6 months) and rice is harvested after the rainy season ends. Submergence-prone areas occur in Vietnam, southern Thailand, Burma, and Bangladesh.

Rainfed medium deep, waterlogged

Rainfed medium deep, waterlogged areas are low-lying. Water accumulates and stagnates for 2-5 months because of impeded drainage. Water depth may vary from 25 to 50 cm. Fields may or may not be bunded. Old, tall seedlings are transplanted in puddled soil. Tall, photoperiod-sensitive varieties with tolerance for stagnant water are grown. Rice crops may be submerged for several days during the life cycle, and are harvested after water recedes.

There are about 5-6 million ha of rainfed medium-deep ricelands in India, Bangladesh, Burma, Thailand, Kampuchea, and Vietnam. Photoperiod-insensitive semidwarfs with long growth duration, 110-120 cm height, and tolerance for stagnant water may perform well. In some areas, however, photoperiod sensitivity may be necessary. Submergence tolerance also might be useful in some situations, but elongation ability is unnecessary and may actually be a handicap. Therefore, long-duration semidwarfs with or without photoperiod sensitivity and with submergence and stagnant water tolerance are needed.

DEEP WATER

There are about 9 million ha of low-lying lands on the river deltas of South and Southeast Asia where deep water accumulates during rainy season. Standing water depth varies from 50 cm to more than 3 m; however, flooding occurs only during part of the growing season. Fields are unbunded. Rice is broadcast sown and grows under droughty conditions for 50-60 days before flooding. Some deep water lands are acid sulfate. Two categories are recognized for varietal improvement purposes.

Deep water

Water depth in deep water areas varies from 50 to 100 cm. There are about 6 million ha of deepwater areas in India, Bangladesh, Burma, Thailand, Kampuchea, and Vietnam. Tall varieties with elongation ability are grown in some areas; in others, tall varieties without elongation ability are planted. Improved varieties with elongation ability, semidwarf stature, photoperiod sensitivity, drought tolerance at seedling stage, and tolerance for stagnant water conditions at later growth stages are required.

Very deep water
Very deep water areas have water more than 100 cm deep. There are about 3 million ha of such areas in India, Bangladesh, Thailand, Kampuchea, and Vietnam. Tall, photoperiod-sensitive varieties with drought tolerance at seedling stage and ability to elongate 5-10 cm per day are needed.

UPLAND

Rice grown in rainfed, naturally well-drained soils with bunded or unbunded fields without surface water accumulation is called upland rice. Ricelands that are submerged for a significant part of the growing season are not suitable for upland rice. Some ricelands in West Africa that are classified as hydromorphic are truly upland, especially those areas on higher slopes where there is no water table in the root zone. However, the hydromorphic lands at lower slopes may have the water table in their root zone during a significant part of the growing season, making them more similar to rainfed lowland culture. Varieties suited to upland environments have drought avoidance through deep root systems and drought recovery ability, intermediate stature with moderate tillering and big panicles, blast resistance, and tolerance for iron deficiency and aluminum toxicity. There are four categories of upland rice environments.

Favorable upland with long growing season (LF)
In LF environments the rainy season is long and upland rice is often grown in sequence with other field crops. Growing conditions are favorable. Soils are fertile with good water retention capacity. Yields are relatively high. About 15% of Asian upland rice is in this category. India has 0.6 million ha; Bangladesh, 0.5 million ha; Indonesia, 0.3 million ha; and the Philippines, 0.2 million ha. Colombia, Panama, and Central American countries have similar upland rice areas. There is good potential to develop improved varieties and technology for these environments. Semidwarf varieties may perform well.

Favorable upland with short growing season (SF)
In SF environments the rainy period is short but the growing conditions are favorable. There are about 2.8 million ha of SF uplands in India, 0.5 million ha in Sri Lanka, and 0.2 million ha in Bangladesh. Drought is the overriding constraint because of the extremely short growing season. Varieties with short growth duration, drought avoidance, and drought stress recovery characteristics are needed.

Unfavorable upland with long growing season (LU)
In LU environments rainy season is long but soils are acidic, highly leached, or shallow and are a serious constraint to high productivity and adoption of improved varieties. About 33% of Asian upland rice is LU. It is the most important upland environment in Indonesia (0.8 million ha), Burma (0.6 million ha), Vietnam (0.4 million ha), and Laos (0.4 million ha). India has 0.8 million ha of LU category.

Varieties with adverse soils tolerance, and careful attention to soil management would be necessary to raise the productivity of these areas.

Unfavorable upland with short growing season (SU)
The SU environment is a marginal environment for upland rice. The rainy period is short and soils are infertile. Serious climate and soil constraints may preclude any significant improvements in productivity. SU areas occur in India, Brazil, and West Africa.

TIDAL WETLANDS

Tidal wetlands are near seacoasts and inland estuaries that are directly or indirectly influenced by tides. They are heterogeneous environments and are classified into four categories.

Tidal wetlands with perennially fresh water
Freshwater tidal wetlands occur near inland estuaries some distance from the coast, such as in the Barisal district of Bangladesh. There is little intrusion of saline water. Varieties with tidal submergence tolerance are needed.

Tidal wetlands with seasonally or perennially saline water
Tidal wetlands with saline water occur near seacoasts and mouths of estuaries. There is seawater intrusion either throughout the year or during the dry season. Varieties should have salinity and tidal submergence tolerance.

Tidal wetlands with acid sulfate soils
Vast areas near seacoasts and inland estuaries in Indonesia (Sumatra and Kalimantan) and smaller areas in India, Bangladesh, and Thailand have acid sulfate soils. Salt water intrusion also occurs. Most of these areas are not presently planted to rice. Varieties with acid sulfate soil, salinity, and tidal submergence tolerance are required.

Tidal wetlands with peat soils
Peat soils are found near seacoasts and estuaries in Indonesia and Vietnam and in smaller areas in other countries. Some of the areas may be used for rice production if suitable varieties and appropriate management practices are developed.

RICE ENVIRONMENTAL CLASSIFICATIONS: A COMPARATIVE REVIEW

D. P. GARRITY

Rice is an ancient crop that has evolved along with man's knowledge of land, water, and soils, and is now grown in a multitude of environments. A Vedic seer once said, "That which exists is One, sages call it by various names." Although this ancient statement was not made about rice environments, its essence applies. Sages of rice improvement around the world have developed various systems to classify the rice-growing conditions they have observed. That widely divergent terminologies have evolved is to be expected.

Communication among rice workers should be enhanced by consensus on a common rice environmental terminology. Such a terminology must be sensitive to the worldwide diversity of physical conditions, and to the needs of those whom the system would serve.

A committee was formed at IRRI in 1982 to review riceland terminologies and classification systems at national and international levels, and to recommend a standard international system. Corresponding members from 20 countries and several international organizations participated in the development process (Table 1). Numerous local and regional classification systems were received from Africa, Asia, and Latin America. Many scientists submitted proposals for an internationally acceptable classification, and reacted to other recently proposed international systems.

Table 1. Geographical distribution of corresponding members of the Committee on Terminology and Classification of Rice Environments, IRRI.

Region, country, organization	Scientists (no.)
Africa	
Nigeria	1
Senegal	1
Tanzania	1
Ivory Coast	1
Asia	
Bangladesh	2
Burma	1
China	2
India	3
Indonesia	5
Japan	3
Malaysia	1
Philippines	2
Sri Lanka	1
Thailand	1
Vietnam	2
Latin America	
Brazil	2
Peru	1
Europe & North America	8
International organizations	
FAO	5
CIAT	1
IITA	1
IRAT	2
ISNAR	1
WMO	1
WARDA	1

This paper reviews the various rice environmental classification systems, including the terminology by Khush which has been adopted for use by IRRI. My objectives are to identify the unifying aspects among the systems, account for differences, and elaborate some of the problems inherent in developing a commonly acceptable rice environmental classification.

THE URGENCY OF RICE ENVIRONMENTAL CLASSIFICATION

Substantial progress has been achieved in developing improved rice varieties and associated management technology and diffusing them to tropical rice farmers. About one-third of the rice area of South and Southeast Asia is now planted to modern varieties (MVs) (Herdt and Capule 1983). Where irrigation exists, or where water usually is available during the growing season, MVs have generally been adopted. There is still some potential for adoption in these areas, but not much.

It was not at first apparent, but it has become clear, that existing MVs are poorly adapted to many important rice environments. MVs are not grown on two-thirds of the world rice area. In Asia alone, this represents more than 53 million ha.

As the difficulties of developing rainfed rice technology became more apparent, the strategy for solving the problem through genetic improvement is being reappraised. Herdt and Barker (1977) asked if rice improvement objectives should be fixed in terms of plant characteristics or in terms of the target environments for rice production. They noted that results of attempts to match desired plant characteristics with particular environmental factors are uncertain and suggested that a preoccupation with plant characteristics, rather than evaluation under specific environments, may slow progress in rice improvement.

Rainfed areas are a great unfulfilled challenge to rice researchers; and one of awesome complexity. The interactions of numerous physical, biological, and human factors reveal a wide and fascinating array of rice-growing ecosystems that require multidimensional approaches to rice improvement. How can research be focused in the face of such complexity?

Environmental classification for rice improvement may be undertaken for two purposes of particular relevance:

- To identify major environments so that research activities can be designed for priority environments, and representative sites for breeding, testing, and crop management research can be more accurately selected.
- To identify areas with analogous environmental conditions, thus forming a basis for extrapolating experience from one location to another. Identification of similar environments would enhance communication, exchange of genetic materials, data interpretation from multilocational trials, and collaboration among rice workers of different regions or nations.

UNITY AND DIVERSITY IN CLASSIFICATION SYSTEMS

We evaluated 23 presently used or proposed rice environmental classification systems (Table 2). The survey was not exhaustive but it included most systems

Table 2. Environmental classification systems, grouped according to basic approach.

I. General surface hydrology		
International	:	Khush (1984) Huke (1982) De Datta (1981) Barker and Herdt (1979)
India	:	Chaudhary (1982) Singh et al (1982) Saran et al (1979) Datta et al (1978)
Vietnam	:	Xuan (1982) Tuan (1982)
West Africa	:	WARDA (1980) Buddenhagen (1978)
Nigeria	:	Hardcastle (1959)
Senegal	:	Toure (1982)
II. Physiographic source of water		
International	:	Dent (1982) Moormann and van Breemen (1978)
Thailand	:	Mancharoen (1982)
III. Landform and soil units		
Philippines	:	Bruce and Morris (1981)
China	:	Hseung and Xu (1982)
India	:	Murthy et al (1982)
IV. Matrix of ecological factors		
International	:	Brammer (1982)
V. Crop season, crop intensity, management practices		
Bangladesh	:	Zaman (1980)
Vietnam	:	Tuan (1982)

that were seriously intended for rice. A few are in widespread use, but most were only recently proposed and may not have been locally accepted. Several systems submitted by corresponding members were developed specifically for the IRRI committee.

The structure of the classification systems varied widely, partly because of different rice-growing conditions in different countries. Intended usage of the system and the disciplinary bias of the classifier also contributed to differences.

Five major classification system approaches were identified. They were based on

- general surface hydrology,
- physiographic source of water,
- landform and soil units,
- matrix of ecological factors, or
- crop season.

Table 2 lists the systems within each group, and Appendix 1 gives an outline and short discussion of the structure of each of the systems that were included in the study.

General surface hydrology

Centuries of natural and human selection have evolved rice genotypes suited to a diverse range of growing conditions. Rice is grown at altitudes below sea level up to 2,000 m, and from latitude 35° S to 53° N. Although a few other cereals, such as maize, are as widely distributed, no other crop but *Oryza sativa* is cultivated over a comparable range of hydrological conditions.

Rice is grown on perennially dry soils on steep slopes and in water depths approaching 6 m. Some ricelands are regularly subjected to drought stress, and some to deep submergence caused by flash flooding during the growing season. Sometimes rice must survive alternating floods and drought. In deep water areas the length of flooding, the rate of inundation, and maximum depth vary.

The important role of water depth in the broad delineation of rice environments is well recognized. In Bangladesh, for example, farmers classify their land according to its level in relation to flooding: high land (*unchu jami*) is above normal flood levels; medium high land normally floods from 0.9 to 1.8 m; low land (*nichu jami*) normally floods to more than 1.8 m, but is dry during part of the dry season; bottomland may have deep or shallow flooding and is wet or flooded throughout most years.

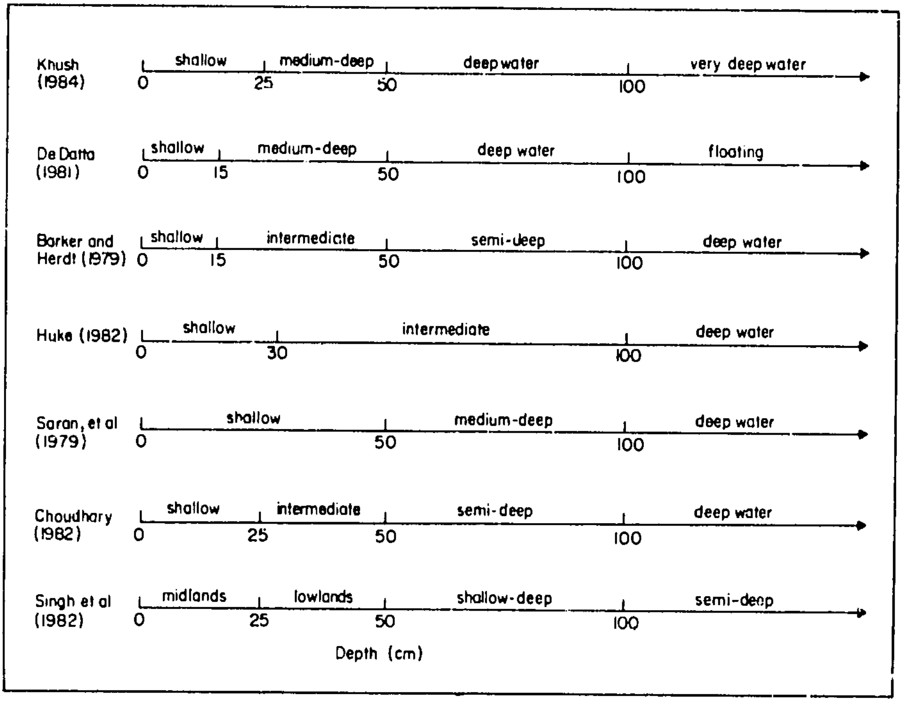
Most environmental classifications for scientific purposes also consider the maximum sustained water depth as the primary criterion. In some systems (e.g. Huke 1982, Datta et al 1978, De Datta 1981, and Saran et al 1979) maximum water depth and the distinction between irrigated and rainfed were the only classification criteria used. In others (e.g. Khush 1984) these distinctions were made, but moisture dependability and soil conditions were also considered.

IRRI first defined water depth classes for rice at the 1978 International Rice Research Conference (IRRI 1979). The first uniform estimates, by country, of the hectarage of riceland planted in different maximum water depths were solicited by D. V. Seshu and subsequently summarized by Barker and Herdt (1979). Revisions in the classes and in terminology were proposed in subsequent years (De Datta 1981, Huke 1982, IRRI 1982, Khush 1984).

In national programs, particularly those of India and Bangladesh, several water depth classifications have been used (e.g. Saran et al 1979, Chaudhary 1982). HilleRisLambers et al (1982) cite others.

Huke (1982) published a thorough analysis of rice area by cultural types for South, Southeast, and East Asia. Maps drawn in six colors to show the spatial distribution of rice by cultural type across the landscape (Huke 1982) have made possible a more detailed macroclassification of rice environments.

Those systems were mainly developed by and for plant breeders, and the water depth boundaries selected were those that are relevant thresholds where major plant characters differ. Most breeders agree on certain water depth boundaries. For example, 50 cm is generally accepted as a threshold because beyond this depth genotypes with semidwarf plant type require elongation ability. Most systems



1. Correlations between recently proposed rice classification systems in water depth boundaries and terminologies.

agree that breaks should occur between 15 to 25 cm, at 50 cm, and at 100 cm.

Most of the disagreement among systems is over the terminology for describing water depth classes. Figure 1 illustrates the confusion presently existing in the terminology for describing water depth classes. Environments with water depths between 50 and 100 cm have been given a bewildering array of names, including deep water, semideep water, medium-deep water, shallow-deep water, and intermediate.

Terminologies published by IRRI scientists between 1979 and 1984 have changed several times. Within national programs there also has been a distinct lack of uniformity. Three recent attempts to classify the ricelands of Bihar, India, reveal substantial variation in terminology (Saran et al 1979, Chaudhary 1982, Singh et al 1982).

A standard terminology is essential to reduce misunderstanding. The terminology outlined by Khush in the companion paper in this volume is the culmination of studies of the available systems by the IRRI Committee on Environmental Classification, and includes inputs of the delegates that participated in the 1983 International Rice Research Conference. It has been accepted for general use by the Institute.

The concept of a modal year or a modal flooding regime is key to these classifications. Hydrological conditions vary strongly from year to year not only in maximum sustained flooding depth, but in the flooding duration as well.

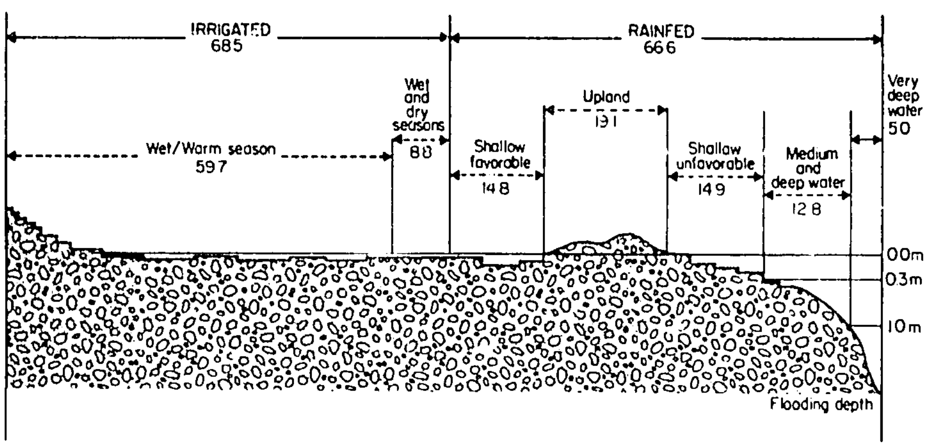
Classification of rice environments by water depth is incomplete in the sense that it oversimplifies the hydrological situation. Shallow rainfed rice is the largest rainfed category, representing about 35% of all riceland in South and Southeast Asia. Many shallow rainfed areas have moisture sufficiency comparable to that of irrigated lands. The zone of adaptation of MVs and related technology may include these areas.

Other rainfed shallow areas are so prone to water stress that they may be comparable to upland areas from the standpoint of rice research. Still others are subject to short-term flooding and require varieties with submergence tolerance similar to that needed in many deepwater environments.

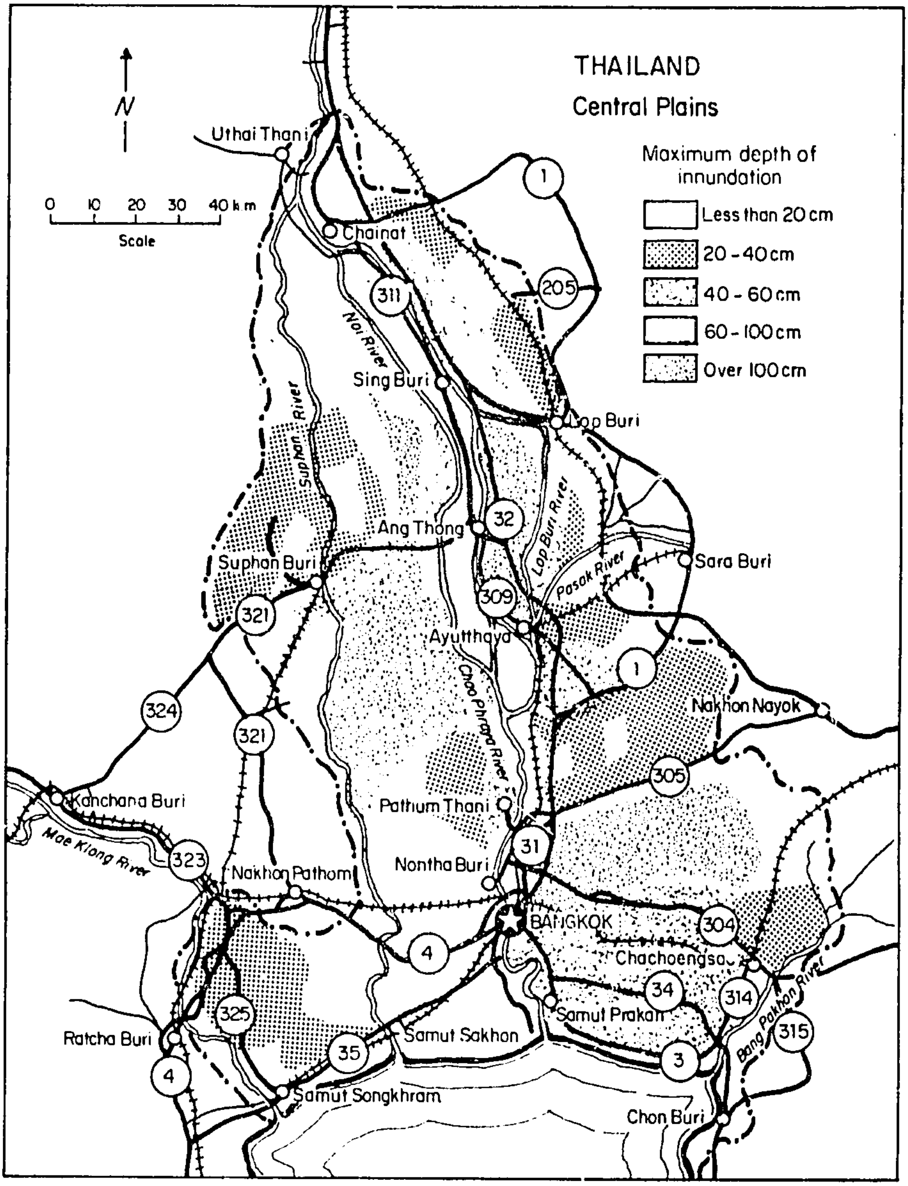
Because of such differences, classification by flooding depth should have fairly broad classes, and should be supplemented with subclasses that delineate variations in moisture sufficiency and flooding pattern.

Figure 2 is a schematic representation of the world's rice area subdivided into major water regimes. In the rainfed category, rainfed lowland (0-50 cm) is allocated about 30 million ha, and is further subdivided into subclasses based on surface hydrology: 1) shallow favorable, 2) shallow drought-prone, 3) shallow drought- and submergence-prone, 4) shallow submergence-prone, and 5) medium deep, waterlogged. The estimated areas of these subclasses are tentative and may be revised substantially as more data become available.

We need to identify the precise locations where the rice in a given water regime is grown, as well as the total hectarage. These will remain unclear until more effort is directed to gathering data and mapping such critical hydrological variables as maximum sustained water depth, rate of increase in water depth, and length of the flooding period. Maps of these variables have been accomplished for the large deep water rice areas of the Chao Phraya River basin in Thailand (Fig. 3) by Kaida (1973). Such information does not exist for most rainfed rice areas of Asia.



2. Relative areas of the world's riceland by water regime (m ha). Horizontal extent of each class is approximately proportional to the area. Terminology follows that of Khush (1984).



3. Maximum depth of inundation on the central plain of Thailand (Kaida 1973).

Upland hydrology

Rice production systems in West Africa are markedly different from those of Asia, not only in terrain, soils, and moisture regimes, but also farmer technology. Rice classification systems for West Africa tend to differentiate major rice cultural types by ecological factors as well as by water depth.

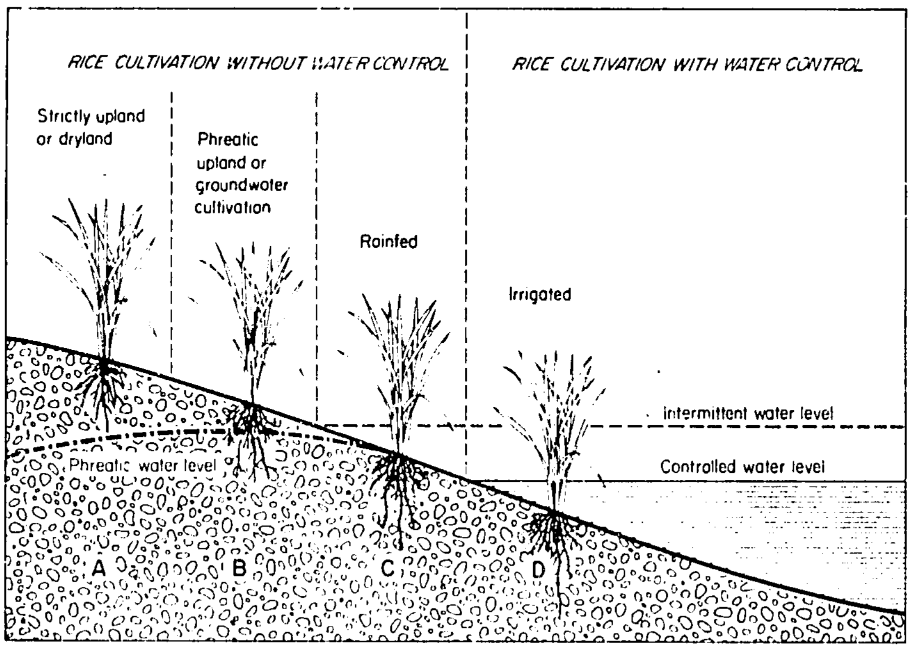
The dominance of upland rice in West Africa is reflected in attempts to more precisely differentiate upland rice cultural regimes. The WARDA (1980), Buddenhagen (1978), and IRAT (Arraudeau pers. comm. 1983) systems divide upland culture into environments with and without a groundwater table present in the root zone (Fig. 4).

The boundary between upland and lowland is less distinct than the boundaries between different maximum sustained flooding depths. In the Khush (1984) system, as well as in the WARDA (1980), Buddenhagen (1978), and IRAT (Arraudeau pers. comm. 1983) systems, upland and lowland rice are differentiated by surface flooding. All ricelands that are flooded for more than 2-3 days during the growing season are considered lowland. Riceland that is not flooded for 2-3 days is considered upland. Bunding is not a criterion. Bunded riceland may be either upland or lowland, depending on surface water accumulation.

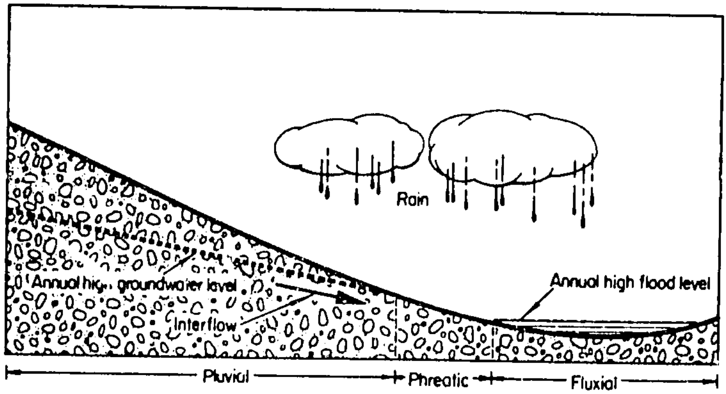
Upland rice is divided into two major classes (WARDA 1980):

- strictly upland, where the groundwater table does not reach the root zone of the crop for most of the growing season, and
- hydromorphic, where the groundwater table is in the root zone for most of the growing period.

The strictly upland class has been further stratified by Garrity (1982) into four ecosystems based on length of the growing season and inherent soil fertility. These are included in the Khush (1984) system.



4. IRAT/West Africa classification of rice environments. A = soils with good drainage, without phreatic water; flooding rarely occurs, and only after very heavy rains. B = soils where phreatic water occurs; flooding rarely occurs; the level of phreatic water may be below rooting depth for short periods. C = soils where flooding frequently occurs for significant periods in the growing season. D = irrigated fields where rice is flooded throughout the growing season.



5. Classes of rice land according to topography and water supply (Moormann and van Breemen 1978).

Physiographic source of water

Moormann and van Breemen (1978) wrote that flooding regimes and depths are extremely variable and difficult to quantify. They proposed a classification of ricelands that emphasized the source of the surface and subsurface water.

They considered unirrigated ricelands to be *pluvial, phreatic,* or *fluxial* (Fig. 5). Ricelands that receive their moisture from rainfall only, whether bunded or not, were called *pluvial* ricelands. *Phreatic* ricelands have the groundwater table near, at, or above the soil surface because of interflow from surrounding higher areas. Rice fields flooded by surface water influx from other areas were called *fluxial.* Moormann and van Breemen also specify 8 flooding regimes which may occur on these three land classes (see the footnote of Table 3).

The Moormann and van Breemen terminology is most popular among soil scientists. The proposals for an improved international rice classification suggested by Mancharoen (1982) and Dent (1982) used this terminology, but revised the secondary and tertiary levels of the system (Appendix 1).

The Moormann and van Breemen approach has not been generally accepted by rice improvement scientists, however, because categorization by water source is generally considered less important than classification by flooding regime. In the Moormann and van Breemen system, pluvial, phreatic, and fluxial ricelands may have the same flooding regimes. Also, a given field may experience pluvial, phreatic, and fluxial conditions within a single growing season, as often happens in Bangladesh (Brammer 1982).

Landform and soils

Murty et al (1982) and Bruce and Morris (1981) used a geomorphological approach in their classifications for India and the Cagayan Valley of the Philippines. Hseung and Xu (1982) used a similar approach although their terminology for the various landforms was unique. In the three classification systems, ricelands first are grouped within broad terrain classes, then subdivided into soil units (Murty et al 1982) or detailed landform units (Bruce and Morris 1981, Hseung and Xu 1982).

Table 3. Tentative correlation among systems representing three general types of rice environmental

I. *General surface hydrology*	Irrigated	Rainfed lowland		
Khush (1984)		Shallow		
		Favorable	Drought prone	Drought and submergence prone
WARDA (1980)	Freshwater cultivation with complete water control	Freshwater cultivation without water control		
II. *Physiographic source of water to the landscape*[a]				
Moormann and van Breemen (1978)	Irrigated (4)	Pluvial (2,3), pt. Phreatic (1,2,3), pt.	Pluvial (1,2), pt. Phreatic (1,7), pt.	Pluvial (1,2), p Phreatic (1), p
III. *Terrain analysis*[b]				
Bruce and Morris (1981)	Alluvial terrace, pt. Interhill mini-plain, pt. Interhill basin, pt.	Alluvial terrace, pt. Interhill Miniplain, pt. Interhill basin	Interhill Miniplain, Alluvial fan	Alluvial terrace, pt.

[a]Numerals indicate the flooding regime: regime 1: shallow, irregular, brief flooding;
regime 2: shallow, irregular, prolonged flooding;
regime 3: shallow, continuous, uncontrolled flooding;
regime 4: shallow, continuous flooding controlled by irrigati
regime 5: shallow to moderately deep seasonal flooding;
regime 6: deep seasonal flooding;
regime 7: moderately deep to shallow flooding after recessio
regime 8: tidal flooding.
[b]Landform units in the alluvial land system, Cagayan River Basin, Philippines.

The Bruce and Morris system recognizes surface hydrology (including the flooding hazard), water availability, and drainage characteristics. It was devised as a procedure for rapid land classification to facilitate extrapolation of rice cropping systems research experience within areas with a reasonably uniform climatic pattern.

Matrix of ecological factors

Flooding depths and other surface hydrological variables are not the only determinants of rice-growing environments, although they are of central importance. A range of other physical, biological, and socioeconomic factors interact with hydrology to define a given rice ecosystem.

Temperatures may vary from perennially high to perennially low with increasing elevation near the equator, or from perennially high to seasonally low with increasing latitude. They may be seasonally very high in arid regions.

Solar radiation during the growing season is <250->600 cal/cm^2 daily (0.1->0.3 kW/m^2). It has a strong effect on rice yields because of a direct effect on photosynthesis and, through associated differences in humidity, on pest and

classifications. Pt. (part) indicates that only a portion of the taxon is included.

		Deep water	Very deep water	Upland	Tidal wetland
Submergence prone	Medium deep				
		Freshwater cultivation without water control	Floating rice	Upland rice	Mangrove rice
uvial (2,3), pt. ıreatic (2,3), pt. uxial (2,3), pt.	Phreatic (5) Fluxial (5)	Phreatic (6), pt. Fluxial (6), pt.	Phreatic (6), pt. Fluxial (6), pt.	Pluvial	Fluxial (8)
ickswamp, pt. luvial terrace,	Backswamp, pt.	Swamp, pt.	Swamp, pt.	Hill-slope	Tidal swamp

ı floods;

disease incidence. High- and low-radiation environments must be distinguished from the main rice-growing environments that have solar radiation between about 300 and 550 cal/cm^2 daily (0.2 to 0.3 kW/m^2).

Various adverse soil conditions and intensities are common. Soil quality becomes more important as water control diminishes. The biological environment in which the crop grows varies widely, and the complex of pathogens and insect predators changes spatially and is influenced by the physical environment.

The present cropping system is a major determinant of the fitness of a rice genotype. Society also influences the differentiation of rice environments. Technological levels and infrastructure affect the cultivars and management options suited to an area. Local taste preferences also may influence varietal choice.

Brammer (1982) proposed a comprehensive set of factors for the inventory of rice environments. The strength of his system is the range of determinants that are explicitly considered within the major factors of climate, moisture or flooding regime, and soil condition.

In the analysis of flooding regime, Brammer proposes a simple characterization of several critical factors in addition to flooding depth. They include flood duration, inundation pattern, flash flooding hazard, floodwater stagnancy, and floodwater turbidity. Brammer's proposal was not hierarchically defined as were all other systems; however, its categories could become the basis for a hierarchical system.

Crop season

In many countries, traditional classifications are based on the different rice crop seasons, or on the number of crops grown annually. The system used in eastern India and Bangladesh (Zaman 1980) describes three seasons: aus, aman, and boro. These simple classes imply general categorization of surface hydrology, rice varieties, soil conditions, and management practices, but are specific to limited geographical areas. They can be effectively correlated with the elements of a physical characterization of the environment as Brammer (1982) has effectively shown, but they are not useful for international application.

TERMINOLOGY CORRELATION AMONG CLASSIFICATION SYSTEMS

Correlation among the major existing and proposed classification systems can only be attempted on a tentative basis because they differ in terminology and in levels of specificity.

Correlation among systems is least hazardous when the extremes of the hydrological spectrum are considered, i.e. no surface water or very great water depths. Consider, for example, freely drained ricelands that cannot be flooded. In the various systems these would be called dryland (Huke 1982, Buddenhagen 1978), upland (Khush 1984, De Datta 1981, Chaudhary 1982), strictly upland (WARDA 1980), or pluvial (Moormann and van Breemen 1978).

Class distinctions and correlations are less clear for ricelands that are not always freely draining but may have a water table in the root zone and some intermittent flooding. In Africa, these are called hydromorphic ricelands (Buddenhagen 1978) or groundwater cultivation (WARDA 1980). In most Asian classifications, these are transition zones between upland (dryland) and rainfed shallow conditions. The most confusing terminology occurs when water is present at varying depths for varying durations (i.e. the rainfed lowlands) (Fig. 1).

There are pitfalls in correlating classifications, but the information they contain must be made transferable. We noted that several major groups of classifications can be distinguished by differences in their primary factors.

Some systems were selected to represent the major groups, and a correlation among them revealed the pattern of relationships shown in Table 3.

The classes of the Khush system, based primarily on general surface hydrology, were used as a reference. The WARDA (1980) system (from the same group), the Moormann and van Breemen system (based on physiographic water source), and the Bruce and Morris system (landforms and soils) were selected for cross-comparison.

The Moormann and van Breemen (1978) nomenclature has three major categories: pluvial, phreatic, and fluxial. Each rainfed rice cultural type proposed by Khush (rainfed, shallow, medium deep, deep water, and very deep water) is related to one, two, or all three of Moormann and van Breemen's major categories (Table 3) indicating that there can be little direct correlation between these systems. The rainfed shallow classes present the poorest correlation.

The pluvial, phreatic, and fluxial categories tend to correspond to different landscape positions. Many rice production problems are related to landscape position. Therefore, considerable environmental diversity is thus implied within each of the rainfed shallow categories used by Khush (1984).

The terrain analysis of Bruce and Morris (1981) in the Cagayan Valley of the Philippines identifies recurring landforms and their associated hydrological characteristics. Those landform units were correlated with the Khush system in Table 3.

Khush's medium-deep water, deep water, and very deep water rice classes are related to the swamp and backswamp landform units of Bruce and Morris. Alluvial terraces include several rice hydrological environments. The rainfed shallow designation includes the most numerous of the landform units.

The WARDA system has relatively few taxons, and correlates with the Khush system in a straightforward manner. Because water depths or flooding regimes were not specified, the category "freshwater cultivation without water control" spans much of the Khush system (Table 3).

CONCLUSION

The many existing and proposed classifications of rice-growing environments represent a large body of observation by many workers. The present effort to define rice ecosystems is probably unprecedented for any crop species, but in few species would such an effort be as rewarding.

The variation in user needs among specialists is important in determining the structure of a nomenclature and the level of specificity necessary to make such a nomenclature useful. Breeding strategy requires a fairly modest number of subdivisions. Water depth and associated influences on plant type and adaptation are dominant factors. Most systems developed by breeders to target rice improvement have no more than 10-12 categories.

Crop management practices are generally more environment-specific than varieties. Agronomists and soil scientists dealing with these problems need detailed classifications. Cropping systems specialists who study rice cropping pattern potential and extrapolation are particularly concerned about spatial microvariability in hydrology as it affects the number and sequence of crops in a rice-based system. Broad classification has relatively little utility for this work.

Because of the distinctly different needs of plant breeders, soil scientists, and field agronomists, two parallel international nomenclatures may be needed. The foundations for a suitable system for targeting rice breeding are already well-developed in the classifications of Group I, culminating in the classification by Khush (1984).

Developing a comprehensive structure for much greater classification specificity is a different problem. Work on this aspect has only begun. In this review of classification systems the only model encountered that is sufficiently comprehensive to be a basis for substantial specificity was Brammer's. The Committee on Terminology and Classification of Rice Environments also has developed a tentative structure of a comprehensive classification (Morris 1983) for discussion.

Such a classification must include the major biophysical factors that cause crop performance to vary. Therefore, it should incorporate relevant aspects of climate, soils, insect and disease complex, and the human environment. Much more thought and discussion will be needed to construct, quantify, and test an acceptable comprehensive nomenclature for rice environments.

A relevant environmental classification should stimulate action as well as greater understanding. The following are steps in using the information to strengthen research:

- Identify dominant target environments and their locations.
- Characterize present research sites by environment. Decide if they are important or minor environments.
- Select new research sites to represent dominant environments not covered by present sites.
- Develop strong collaboration among researchers in other regions or countries who are working in analogous rice environments.

More precise classifications of rice environments also are needed at the national level. These may define the rice ecosystems within each country better than a broader international system can.

Many countries must achieve most of their rice production increases from rainfed areas over the next two decades (Barker and Herdt 1979), and a modest investment in rainfed rice research may have high returns. However, the complexity of these environments dictates a more focused and coordinated research effort to assure higher productivity in rainfed rice.

In 1978, Moormann and van Breemen wrote:

> "With all the sophisticated and increasingly specialized research on rice and its requirements for optimal production, the diversity of environments in which the farmer produces his crop has received much less attention than it merits."

This situation has improved during the intervening years. The many recent attempts to classify rice environments at local, national, and international levels indicate a widespread felt need to understand and deal with rice environmental diversity.

When workers from disparate ends of the rice-growing world can describe their respective rice environments in precise terms in an internationally accepted nomenclature, a threshold in the efficiency by which experience and innovations in rice science may be transferred will have been crossed.

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APPENDIX 1. RICE ENVIRONMENTAL CLASSIFICATION AROUND THE WORLD

The following is an outline of 23 classification systems that are proposed or adopted for use in various countries and internationally. The focus of the classification is indicated after the author's name and date of publication.

I. Classifications based on general surface hydrology

Khush (1984): international

1. Irrigated
   a. Favorable temperature.
   b. Low temperature, tropical zone.
   c. Low temperature, temperate zone.
2. Rainfed lowland (0-50 cm)
   a. Rainfed shallow, favorable (0-25 cm)
   b. Rainfed shallow, drought prone (0-25 cm)
   c. Rainfed shallow, drought and submergence prone (0-25 cm)
   d. Rainfed shallow, submergence prone (0-25 cm)
   e. Rainfed medium deep, waterlogged (25-50 cm)
3. Deep water
   a. Deep water (50-100 cm)
   b. Very deep water (> 100 cm)
4. Upland
   a. Favorable upland with long growing season (LF)
   b. Favorable upland with short growing season (SF)
   c. Unfavorable upland with long growing season (LU)
   d. Unfavorable upland with short growing season (SU)
5. Tidal wetlands
   a. Tidal wetlands with perennially fresh water
   b. Tidal wetlands with seasonally or perennially fresh water
   c. Tidal wetlands with acid sulfate soils
   d. Tidal wetlands with peat soils

This system has been adopted for rice research at IRRI. It is discussed in greater detail in a companion paper in this volume. Primary classes are based on broad areas of sustained water depth. Secondary classes are based on subdivisions of water depths; the dynamics of the water regime, including the dependability of water supply; and on soil constraints in some cases.

De Datta (1981): international

1. Irrigated rice (5-15 cm)
2. Rainfed lowland rice (0-50 cm)
   a. Shallow (5-15 cm)
   b. Medium deep (16-50 cm)
3. Deepwater rice (51-100 cm)
4. Floating (101-600 cm)
5. Upland rice (no standing water)

De Datta emphasized the distinction between rice grown where maximum water depths exceeded 50 cm and rice grown where water depths are less than 50 cm. The latter was considered rainfed lowland rice and the former as deepwater rice, noting that rainfed lowland rice is usually transplanted while deepwater rice and floating rice usually are broadcast on dry soil.

Huke (1982): international

1. Irrigated
   a. Wet season
   b. Dry season
2. Rainfed
   a. Shallow (0-30 cm)
   b. Intermediate (30-100 cm)
3. Deep water (>1 m)
4. Dryland.

This classification was used to map rice cultural types by area planted for South and Southeast Asia. Dot maps showing rice distribution geographically in each of the six categories were constructed.

Barker and Herdt (1979): international

1. Irrigated
2. Shallow rainfed (5-15 cm)
3. Medium-deep rainfed (16-100 cm)
4. Deep water (100 cm)
5. Upland
6. Arid high temperature
7. Long days, low temperature

This system was used to compile the first comparable statistics on rice area in each of the major cultural types in Asian countries.

Datta et al (1978): India

	Field water level (cm)	
	Vegetative phase	Reproductive phase
1. Shallow water	10- 60	45-15
2. Knee-deep water (transplanting)	20- 90	60-15
3. Knee-deep water (direct sowing/transplanting)	20-110	90-25
4. Semi-deep water (direct sowing/transplanting)	20-120	110-25
5. Semideep (direct sowing)	30-160	110-25
6. Deep water (direct sowing)	160	

This system considers the water depths at vegetative and reproductive stages of crop growth and the interaction with planting method.

Saran et al (1979): Bihar, India

1. Deep water (100 cm)
2. Medium deepwater (50-100 cm)
3. Shallow (25-50 cm)
4. Areas prone to flash floods

The above classes were used to distinguish the growing conditions in the areas of Bihar, India, where excess water constrains rice performance.

Chaudhary (1982): Bihar, India

1. Irrigated (5-40 cm). May encounter flash floods of up to 10 d in certain years, bunded fields.
2. Rainfed upland. No standing water, frequent drought stress, unbunded fields.

3. Rainfed lowland.
   a. Shallow (5-25 cm). May be drought or flood prone, bunded fields.
   b. Intermediate (25-50 cm). Drought and flood prone, bunded fields.
   c. Semideep (50-100 cm). Flooding regular, water stagnation, unbunded fields.
   d. Deep (100-400 cm). Continuous stagnant water, unbunded fields.

Each category is associated in this paper with specific topographic situations, soil types, rice cultural practices, cropping systems, and rice plant ideotype.

Singh et al (1982): Bihar, India
1. Uplands. Little water accumulation. Photoperiod-insensitive cultivars, transplanted.
2. Midlands. Up to 25 cm water depth. Photoperiod-sensitive cultivars, transplanted.
3. Lowlands. Up to 50 cm water depth. Photoperiod-sensitive cultivars, transplanted.
4. Shallow-deep. Up to 100 cm water depth. Photoperiod-sensitive cultivars, direct-seeded.
5. Semideep. 100-200 cm. Photoperiod-sensitive cultivars, direct-seeded.
6. Typical deep. Above 200 cm. Photoperiod-sensitive cultivars, direct-seeded and transplanted.

Xuan (1982): Vietnam
1. Irrigated rice.
2. Dryland rice. Water not impounded.
3. Upper wetland rice. Rainwater can be impounded, but the soil dries when rains are erratic. Fields at higher elevations.
4. Direct-seeded lower wetland rice. Water depths up to 1 m. May be drought and/or submergence prone.
5. Transplanted semi-deepwater. Water depths reach 50-80 cm. Depressed areas of landscape.
6. Direct-seeded floating rice and deepwater rice. Water depths in excess of 50 cm.
7. Rainfed lower wetland spring rice. Waterlogged areas. Rice transplanted when water depth declines to 10-30 cm. Spring season.
8. Rainfed medium-deep, tidal swamp rice. Coastal wetlands.

Rice cultural types in Vietnam are determined primarily by hydrological conditions, temperature, and day length.

Tuan (1982): Vietnam
1. Irrigated area
   a. Shallow
      1) Good water supply
      2) Drought-affected
   b. Intermediate
      1) Regular flooding
      2) Sudden floating
   c. Deep water
      1) Semi-floating rice
      2) True floating rice
2. Rainfed area
   a. Shallow
      1) Regular rainfall
      2) Drought-affected in early period
      3) Drought-affected in late period

b. Intermediate
  1) Regular flood. Double transplanting
  2) Sudden flood
c. Deep water
  1) Semi-floating rice
  2) True floating rice

This classification emphasizes the heterogeneity of irrigated areas in Vietnam. Irrigated areas may be affected by drought during critical periods or by flooding of varying depths and durations. In deep water areas with irrigation, rice is also grown during the season when floodwaters have declined.

WARDA (1980): West Africa

1. Upland rice cultivation
   a. Strictly upland cultivation. Rainfed, well-drained soils, not subject to flooding.
      1) Hill rice. Steep slopes, high rainfall, shifting cultivation.
      2) Flatland rice. Gently sloping land, shifting cultivation dominant. Intercropping common.
   b. Groundwater cultivation with rains. Shallow groundwater table which may infrequently reach soil surface.
   c. Groundwater table without rains. Water supply entirely from groundwater table on lake beds with receding water level in dry season.
2. Lowland rice cultivation. Soil is submerged during much of the crop cycle.
   a. Mangrove rice cultivation. Acid sulfate soils and salinity problems.
      1) Without tidal control.
      2) With tidal control. Protection against the tide by diking.
   b. Fresh cultivation.
      1) Without water control. Rainwater or river flooding, variable water depth. Includes floating rice cultivation.
      2) Partial water control. Irrigation but poor water depth control.
      3) Complete water control. Continuous water supply, controlled water depth, drainage.

This classification emphasizes the interaction of diverse physical conditions and management levels characterizing West African rice ecosystems.

Buddenhagen (1978): West Africa

1. Upland
   a. Dryland. Free-draining
   b. Hydromorphic shallow groundwater table
2. Irrigated
3. Inland swamp
   a. Nontoxic
   b. Toxic
4. Flooded
   a. Riverine shallow
   b. Riverine deep
   c. Bolliland. Poorly drained depressions flooded 3-6 months to depths up to 1.5 m
   d. Mangrove

This system is the breakdown of rice ecosystems identified in the research program of The International Institute of Tropical Agriculture.

Hardcastle (1959): Nigeria
1. Naturally inundated land
   a. Periodically flooded river valleys (fadama)
   b. Rainfed inland swamps of eastern Nigeria
2. Land provided with supplementary irrigation
3. Land not subject to inundation but receiving sufficient rainfall (upland)
4. Tidal freshwater mangrove swamps
   a. Tidal mangrove freshwater swamp rice
   b. Deep flooded nontidal swamp rice. Water depth remains nearly constant for 3-4 months

This is the terminology presently adopted to describe rice culture in Nigeria.

Toure (1982): Senegal
1. Upland rice cultivation
   a. Strictly upland cultivation
      1) Flatland rice
      2) Hill rice
   b. Groundwater cultivation
2. Lowland (aquatic) rice
   a. Flooding rice
      1) Shallow flooding (0-30 cm)
         a) Inland valley
         b) Riverine shallow/mangrove
      2) Deep flooding (30-120 cm)
         a) Inland valley
         b) Riverine deep
         c) Mangrove
      3) Very deep flooding (>120 cm)
         a) Inland valley
         b) Riverine very deep
   b. Irrigated rice
      1) With partial water control
      2) With total water control

II. Classifications based on physiographic source of water

Moormann and van Breemen (1978): international

Terminology	*Characteristics*
1. Pluvial riceland	Unbunded, no flooding
a. Pluvial anthraquic	Bunded, flooding regime 1, 2, or 3
2. Phreatic riceland	Unbunded, no flooding
a. Phreatic anthraquic	Bunded, flooding regime 1, 2, or 3
3. Fluxial riceland	With or without bunds, flooding regimes 2, 3, 5, 6, 7, 8
4. Irrigated riceland	Bunded, flooding regime 4

Differentiation at the highest level is based on the source of water to the rice field: rainfall (pluvial), groundwater (phreatic), or surface flow (fluxial). Secondary classes are related to the presence or absence of bunds. Anthraquic denotes bunded riceland. Tertiary classes are flooding regimes varying in depth and duration. For a description of the flooding regimes refer to Table 3 in the paper.

Dent (1982): international

1. Pluvial riceland. Rainfall dependent; flat, terraced and sloping land; not leveled; never flooded.
2. Pluvial-anthraquic riceland. Rainfall dependent; flat, terraced and sloping land; leveled and bunded to impound standing water. Three subdivisions are recognized according to flooding regime:
   a. Shallow, irregular, and brief flooding.
   b. Shallow, irregular, and prolonged flooding.
   c. Shallow and continuous uncontrolled flooding.
3. Phreatic riceland. Rainfall and groundwater dependent, water availability being influenced by high groundwater during at least part of the growing season; flat, terraced, and sloping land; neither leveled nor bunded to impound standing water, never flooded.
4. Phreatic-anthraquic riceland. Rainfall and groundwater dependent, water availability is influenced by high groundwater during at least part of the growing season; flat, terraced, and sloping land; leveled and bunded to impound standing water.
   a. Shallow, irregular, and brief flooding.
   b. Shallow, irregular, and prolonged flooding.
   c. Shallow and continuous uncontrolled flooding.
5. Fluxial riceland. Periodically naturally submerged flatland; with and without leveling and bunding.
   a. Shallow, irregular, and prolonged flooding.
   b. Shallow and continuous uncontrolled flooding.
   c. Shallow to moderately deep flooding.
   d. Deep seasonal flooding.
   e. Shallow flooding following deep seasonal flooding.
   f. Flooding to variable depth due to diurnal or semi-diurnal tides.
6. Irrigated riceland. Irrigation may supplement rainwater or may be the only water source.
   a. Irrigated pluvial-anthraquic riceland.
   b. Irrigated phreatic-anthraquic riceland.
   c. Irrigated fluxial riceland.

This proposed international system is a combination of the Khush (1984) and the Moormann and van Breemen (1978) systems. Duration and regularity of flooding are emphasized in addition to maximum water depths, which are not specified.

Mancharoen (1982): international

1. Pluvial
   a. Ustic
   b. Ustic anthraquic
   c. Udic
   d. Udic anthraquic
2. Phreatic
   a. Ustic
   b. Ustic anthraquic
   c. Udic
   d. Udic anthraquic
3. Fluxial
4. Irrigated

This system was proposed as a modification of Moormann and van Breemen's (1978) system. Primary categories are identical with that system. Secondary categories are differentiated on the basis of the period of time that the soil is too dry for crop growth. Ustic denotes a period of at least 3 months a year when the soil water potential in the root zone is lower than −15 bars. Udic denotes a period of less than 3 months with dry soil conditions.

III. Classification based on landform and soil units

Bruce and Morris (1981): Philippines

The three hierarchical levels of the classification are

1. Land system (alluvial, plain, hill, plateau-mountain)
2. Land subsystem (4-9 categories depending on the land system)
3. Landform unit (numerous)

This system was developed and applied to classify ricelands in the Cagayan Valley, Luzon, Philippines.

Hseung and Xu (1982): China

1. Depression fields. Low relief, waterlogging or excessive water is common, with frequent threat of flooding.
   a. Polder fields. Areas of low relief behind river embankments and in natural depressions.
   b. Swampy fields. Marshy areas of high organic matter soils reclaimed from lake perimeters.
   c. Sandbar fields. Reclaimed river bed areas protected by dikes. Flood-prone, sandy soils.
   d. Tidal fields. Coastal wetlands with tidal fluctuations, frequently with acid sulfate soils and/or salinity influence.
   e. Cold muddy fields. Perennially submerged areas in upper reaches of river valleys. Cool water and soil temperatures.
2. Plain fields. Wide, flat rice areas with good irrigation and drainage.
   a. Flat fields. Deltas and broad valleys at lower elevations.
   b. Basin fields. Valleys in mountainous and hilly areas.
3. Terraced fields. Rainfed or partially irrigated rice areas on sloping land.
   a. Mound and mound-slope fields. Fields on the slopes and summit of valleys, knolls and hills. Drought-prone.
   b. Intermound fields. Fields on the floor of narrow valleys. Generally favorable hydrology and soil fertility for rice.
   c. Valley fields. Fields in the broader valleys of rivers in hills and low mountain areas. Generally favorable water resources and soil fertility.

This classification is based on a geomorphological differentiation of ricelands and the general hydrological and soil characteristics associated with the terrain units. Elevation, as it relates to drainage and irrigation accessibility, is a major consideration at the secondary and tertiary levels of the system.

Murty et al (1982): India

1. Himalayan mountains
   a. Intermontane basin
   b. Low mountain terraced slope
2. Indo-Gangetic plain and the Brahmaputra valley
   a. Piedmont alluvial plain
   b. Interfluves
   c. Floodplain
3. Peninsular India
   a. Plateau

  b. Interplateau basin
  c. Interplateau valley bottom
  d. Interhilly valley bottom
  e. Alluvial plain
  f. Floodplain
4. Coastal plain
  a. Deltaic plain
  b. Coastal plain

This system is a categorization of the major landforms on which rice is grown in India. The rice soils of India have been mapped at the great group level.

IV. Classifications based on a matrix of ecological factors

Brammer (1982): international

1. Climate
  a. Seasonality
    1) Tropical (no temperature limitation)
    2) Subtropical (winter temperature limitation)
    3) Temperate
  b. Insolation
    1) Mainly cloudy
    2) Mainly sunny
    3) Mixed
  c. Photoperiod sensitivity
2. Moisture/flooding regime
  a. Moisture source
    1) Irrigated
    2) Rainfed
  b. Rainfall reliability
    1) Reliable
    2) Variable
    3) Inadequate
  c. Flooding characteristics
    1) Nonflooded
    2) Flood depth
      a) Shallow (< 30 cm)
      b) Moderately deep (30-150 cm)
      c) Deep water (150 cm)
      d) Very deep (300 cm)
    3) Flooding type
      a) Ponded water (usually clear)
      b) River water (usually silty)
      c) Tidal water (silty or clear)
    4) Flood duration
      a) 0.5-3 months
      b) 3-6 months
      c) 6-9 months
      d) 9-12 months
    5) Stagnation
      a) Flowing
      b) Stagnant

c) Flowing followed by stagnant
d) Seepage/upwelling

3. Soil conditions
   a. Permeability
      1) Permeable
      2) Impermeable
   b. Bearing capacity
      1) Firm
      2) Soft
   c. Toxicity/deficiency
      1) Nontoxic, not deficient
      2) Saline
      3) Acid sulfate
      4) Phosphate fixing
      5) Others
   d. Reaction
      1) Normal (pH 5.5-7.5)
      2) Calcareous
      3) Alkali
      4) Strongly acid (pH $<$ 5.5)
   e. Organic matter status
      1) Low ($<$ 2% O.M.)
      2) Normal (2-5%)
      3) High (5-12%)
      4) Peaty (12%) - firm
      5) Mucky (12%) - soft

The above is a listing of the elements to be considered in a comprehensive classification of rice environments. The determinants fall into three nonhierarchical groups.

V. Classifications based on crop season, crop intensity, management practices

Zaman (1980): Bangladesh

1. Aus (early wet season crop harvested Aug-Sep)
2. Aman (main wet season crop harvested Sep-Jan)
   a. Transplant (planted May-Jul)
   b. Broadcast (planted Mar-May)
3. Boro (cool season crop harvested Apr)

This is the classification of ricelands traditionally used in Bangladesh and eastern India.

Tuan (1982): Northern Vietnam

1. Winter rice hazardous. Early flooding may occur at end of dry season.
2. Winter rice sure. No flooding problem.
3. Winter rice sure, summer rice hazardous. Rainy season flooding problems.
4. Winter rice sure, summer rice sure.
5. Winter rice hazardous, summer rice sure. Drought problem in dry years.
6. Summer rice sure. Higher elevation, supplementary irrigation.
7. Summer rice hazardous. Higher elevation, light-textured soil, frequent drought.
8. Upland rice. In hilly areas.

This is the traditional classification of ricelands in northern Vietnam.