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RICE AND ITS ADAPTATION TO WORLD ENVIRONMENTS

by

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Introduction

May I begin by expressing my deep appreciation to the Farrer Memorial Trustees who have honoured me with the Farrer Medal for 1977. The award came as a complete surprise but is all the more appreciated because it is added to the great satisfaction of having participated in the tremendous development of the rice industry in New South Wales. My career has been so closely interwoven with those of others concerned with rice research in this state, particularly Mr. Ed Boerema, that I must acknowledge his contribution to the achievements you have judged worthy of recognition.

I have chosen to speak about the adaptation of rice because it focuses attention on the interaction between genotype and the environment in which the plants grow. As an evolutionary process it has provided us with untold riches in the form of swarms of varieties and races of every crop species which are genetically closely aligned with the environment in which they evolved. As a necessary consideration in the improvement of crop species the adaptation of high yielding genotypes to new environments presents the breeder with his greatest challenge.

William Farrer, the man we honour today, was a visionary where the adaptation of wheat to the Australian environment was concerned. Looking back from our present place in history it is hard to imagine that scientists of less than 100 years ago were almost totally ignorant of the potential for plant improvement offered by hybridisation and selection. Yet in 1882, the assertion that varieties of wheat could be developed which would resist rust was the subject of controversy between Farrer and "The Australasian" newspaper (Russell, 1949).

Farrer saw clearly that the way to develop high yielding, well adapted wheats for his environment was to find varieties which together possessed the necessary characteristics, cross them and select progeny combining all the desired traits in one individual. He recognised that rust and drought were the most important environmental constraints and his remarkable success as a plant breeder was due in no small measure to recognition of the importance to productivity of adaptive characters such as rust resistance, drought tolerance and early maturity.

In the course of its evolutionary history, rice has become adapted to distinctive environmental niches which make it unique amongst the cultivated cereals. I intend to discuss the adaption of the species to tropical and temperate environments generally, and then to review the process of rice improvement internationally and in Australia with emphasis on the use of characteristics with specific adaptive advantages.

Rice as a World Crop

Rice is the most important food crop in tropical and subtropical regions of the world. About nine tenths of the world's crop is produced and consumed in the Far East (Parthasarathy, 1972). Because of its importance in the tropics, rice is often regarded as a tropical crop but it grows in remarkably diverse ecological and climatic conditions on every continent except Antarctica. It is cultivated at altitudes of 2,400 metres in the Kashmir Valley; as a rainfed hillside crop in Sarawak; in water up to 6 metres deep in the "floating rice" areas of Bangladesh; as far north as Central Czechoslovakia (50^{o}N) and as far south as Uruguay and southern New South Wales in Australia (35^{o}S) (I.R.R.I., 1975).

Origin of Cultivated Species

There are two cultivated species of rice, *Oryza sativa* L., or common rice and *O. glaberrima* Steud., African rice. *O. sativa* is found in both tropical and temperate regions of the world. It probably originated in the area encompassing South Asia, South east Asia and China where wild species were cultivated up to 9000 years ago. Cultivation in Asia may have occurred independently and about the same time in many places along a broad belt extending from the Ganges plains below the eastern foothills of the Himalayas, across northern Burma, northern Thailand, Laos and Vietnam, to southwest and south China (Chang, 1964; Chang, 1976). *O. sativa* appears to have spread from India to Egypt, Europe, Africa, the Americas and Australia, and from China to Korea and Japan. O. glaberrima is indigenous to tropical West Africa and probably originated there about 1500 B.C.

Chang (1976) recently proposed that the genus Oryza originated in Gondwanaland and, with the breakup of the supercontinent, became widely distributed in the humid tropics of Africa, South America, South and Southeast Asia, and Oceania. He has speculated further that the two cultivated species had a common progenitor, O. perennis, in the distant past but arose from parallel, independent evolutionary streams following the sequence of wild perennial to wild annual to cultivated annual. The very extensive differentiation and diversification of annuals in South Asia occurred as a response to dispersal over a range of latitudes or altitudes, human selection and manipulation of the cultural environment. Much less diversification is apparent in African species which evolved later and wild races in South America and Oceania have retained their primitive features mainly due to lack of dispersal or cultivation pressure.

Evolution of Geographical Groups

Rice has been cultivated for thousands of years in widely differing geographic and agroclimatic regions. It is not surprising that, during that time, a great many varieties and ecotypes have evolved. Of considerable importance was the development of three fairly distinct races, indica, japonica and javanica, into which varieties can be grouped on the basis of hybrid sterility, geographical adaptation, morphological characteristics and yield potential. (Chandraratna, 1964; Chang, 1964; Jennings, 1966). Of these the indica and japonica groups comprising most tropical and temperate varieties respectively, are by far the most important in terms of geographical distribution.

Thousands of varieties, mostly indicas, have been cultivated in tropical Asia. They are remarkable for both their genetic diversity and uniform vegetative characteristics. Jennings (1966) asserted that their uniformly vigorous growth, large leaves and culms, photoperiod sensitivity and grain dormancy, was probably the result of natural selection for character associations conferring adaptability to major features of the environment including uncontrolled water supply and deep flooding in later growth stages, weed competition, infertile soils, low light intensity, and alternating wet and dry seasons. Over a long period of time there was little directed improvement by man and agriculture remained rather primitive. The character associations that emerged ensured survival and stable but low yield capacity under cultivation. Yields of these varieties are not dramatically increased by the use of improved management practices including fertilisation, control of weeds and water etc. (Jennings and de Jesus, 1968).

The highly productive temperate varieties (japonicas) are of more recent origin, arising from the introduction of the basic tropical stock into the cooler regions of Indochina and China (Chang, 1976). There it was subjected to intense light, scattered rainfall and a cooler environment, and strong human pressure under an advanced form of agriculture. Soils were more fertile, weeds and water were controlled and crops rotated. Characteristics such as late maturity, photoperiod sensitivity, seed shattering and dormancy were not essential or were undesirable and were lost. Under combined pressures of natural and human selection, temperate types gained potential agronomic worth at the expense of adaptability to, or survival under, primitive conditions (Jennings, 1966).

The different conditions under which the races evolved led to contrasting degrees of competitive ability in the two basic plant types. Tropical varieties are strong competitors whereas, by comparison, the more highly productive temperate plant types are weak competitors. Competition therefore seems to have played a very important negative role in the evolution of tropical varieties by eliminating plant types of greater agronomic worth which undoubtedly arose through mutation or hybridisation (Jennings and Aquino, 1968).

Advent of the Dwarf

One of the most significant events in the history of rice breeding was the development of very high yielding semi-dwarf indica varieties for the tropics. The first such variety, Taichung Native 1, was produced by breeders at the Taichung District Agricultural Improvement Station, Taiwan, in 1956. It was selected from a cross between a semi-dwarf indica mutant Dee-geo-woo-gen and a tall, disease resistant variety Tsai-yuan-chung (Huang, Chang and Chang, 1972). Recognition of the significance of this event by breeders at the International Rice Research Institute (I.R.R.I.) and their subsequent development of widely adapted, "improved plant type" varieties for the tropics led to the green revolution in rice.

I.R.R.I., "a complete plant science research institute devoted exclusively to rice", was established in 1960 under joint sponsorship of the Ford and Rockefeller Foundations to undertake the task of improving the yield and quality of tropical rice (Chander, 1972). It stands out amongst international institutes of its type for its success in solving a wide variety of problems confronting increased productivity.

Using Dee-geo-woo-gen and Taichung Native 1 as the source of short, erect plant type, I.R.R.I. breeders produced new dwarf varieties capable of yielding three to five times as much grain as the traditional tropical varieties. Their success was based on the idea that plant type was of paramount importance in determining nitrogen responsiveness and yield (Chandler, 1972a; 1972b). The new varieties as a group were about 90-110 cm tall (compared to 160-180 cm for their taller parents), had short erect leaves, heavy tillering capacity, a harvest index of about 1.0 and were rather insensitive to day length so that they could be planted at any time of the year in the tropics. Each of these characteristics was shown to be important to yield (Tanaka, Kawano and Yamaguchi, 1966; Tanaka et al, 1964).

Up until 1975, selections which proved to be widely adapted in many countries were named by I.R.R.I. The first to be formally released as a variety was IR 8 which became known as "the miracle rice". Other varieties, incorporating similar high yield potential combined with better grain quality and higher levels of disease and insect resistances, quickly followed: IR 5 in 1967; IR 20 and 22 in 1969; IR 24 in 1971; IR 26 in 1973; IR 28, 29 and 30 in 1974; IR 32 and 34 in 1975. Simultaneously, numbers of other I.R.R.I. lines were named and released as varieties in other countries (I.R.R.I., 1974; I.R.R.I., 1975; I.R.R.I., 1976). Enormous numbers of selections combining improved plant type with specific adaptive characters were distributed to national rice breeding programmes throughout the world. Breeding objectives in major rice producing countries such as India were adjusted in recognition of the importance of plant type and new dwarf varieties also began to emerge from national programmes (Pal, 1972).

The idea that plant type was important to yield was not unique. Breeders in Japan and Taiwan had long recognised that nitrogen responsiveness and yield were closely related to specific plant characteristics (Nagai, 1958; Okobe, 1972; Huang, Chang and Chang, 1972). Very high yielding varieties adapted to favourable environmental and agronomic conditions were available in those countries long before 1960. In 1958 Nagai (1958) wrote "In countries like Japan where high yield is aimed at by intensive culture with heavy application of fertilisers, the leading varieties are required to possess heavy tillering ability with short culm and resistance to disease and lodging".

Selections from these Japanese varieties predominated until recently in temperate parts of the world such as Korea, Australia, Taiwan, Mediterranean countries and California U.S.A. where nitrogen responsiveness and yield have been major criteria in selection of varieties (Beachell and Jennings, 1965). However, extensive use of "improved plant type" varieties in national breeding programmes has brought, or promises to bring substantial changes.

The potential impact on yield of temperate varieties of utilising the dramatically expanded gene pool now available through the activities of I.R.R.I. is apparent from recent events in Korea. In 1972, a new high yielding variety named Tongil was distributed to Korean farmers. Tongil was selected in a massive co-operative project between Korean scientists and I.R.R.I. from a Yukara/Taichung Native 1//IR 8 cross and combined the characteristic short, erect plant and strong tillering ability of IR 8 with the cold resistance, early maturity and grain type of Yukara. By 1975 this variety was cultivated on 450,000 ha or 37.3 percent of the total area sown to rice. The average yield was 5.03 t/ha compared to 3.51 t/ha from the japonica varieties commonly grown. Still newer varieties such as Yushin (IR 1317-392-1/Tongil) and several Milyang selections (IR 1317-316/IR 24) combine the high yield potential of Tongil with better quality. By 1980 it is expected that the improved plant type varieties will be cultivated on almost 85 percent of Korea's rice area (Ham, 1976; Anonymous, 1976).

Not only have the I.R.R.I. genotypes contributed greatly improved yield potential to the new Korean varieties but resistance to disease and insect pests has also been enhanced (Ham, 1976).

Improved Plant Type in Retrospect

Why did rice breeders take so long to recognise the potential value of short, erect plant type for the tropics?

The International Rice Commission of F.A.O. held a series of eight Working Parties from 1950 to 1959 for the purpose of fostering international exchange and co-operation in improving rice yield. An indica x japonica hybridisation project was established in 1950 to try and combine the "high fertiliser response of japonica types with the hardiness and adaptation to the tropical conditions characteristic of indicas" (Parthasarathy, 1960). Crosses were made by the Central Rice Research Institute, Cuttack, India, between selected japonica varieties and indica varieties submitted by participating countries. F2 seed was distributed to participants for selection in their own environments. Parthasarathy (1972), looking back on the project, acknowledged that it did not lead to outstanding results because breeders knew little about the type of plant to select. High yielding short statured selections had occasionally been made but were rarely identified as superior genotypes (Parthasarathy, 1972). In fact short stature, even with high grain yield, was considered to be a disadvantage at least by Indian cultivators who used the straw to feed their livestock (Ramiah, 1953).

The failure of breeders of tropical rice to recognise the importance of plant type at an earlier stage seems to be related to two things; the confusion of competitive ability and total plant size with agronomic worth, and the low level of nitrogen fertility under which rice was grown. Short statured plants always disappeared quickly from segregating populations arising from crosses between the large leafy indicas and the smaller, less aggressive japonicas. Even when the smaller phenotypes were tested in pure stands, nitrogen levels were too low to allow them to exhibit their greatly superior yielding ability and they would have been quickly discarded in favour of varieties which competed better with weeds and were perhaps more resistant to diseases and insects.

Jennings and Herrera (1968), and Jennings and de Jesus (1968) showed that dwarfs are at a severe reproductive disadvantage in competition with tall plants. Nitrogen application, close spacing and "wet season" conditions accentuated the disadvantage. Jennings and Herrera (1968) also demonstrated the importance of testing procedures incorrectly assessing the productive potential of dwarf phenotypes. Tall and dwarf bulk populations from a Peta x Taichung Native 1 cross were compared in plots composed of widely spaced, single plant hills at moderate levels of nitrogen. Grain yields of both populations were approximately the same with no fertiliser while the dwarfs were slightly superior when nitrogen was added. The conclusion was that dwarfs were not inferior to tall plants in yielding ability. A completely different picture emerged when 36 F6 dwarf lines were compared with 36 F6 tall lines from the same cross in plots composed of closely spaced 3 plant hills at high nitrogen levels. The mean yield of the dwarfs was 4.7 t/ha compared to 2.7 t/ha for the tall plants. All except five of the dwarf lines outyielded the best tall line. The grain yield of the five best dwarf lines was 5.7 t/ha, or about 1 ton/ha better than Taichung Native 1 and 2 t/ha better than the best five tall lines. The ultimate conclusion - the dwarf plant type has a much greater yielding potential than the tall plant type with the size of the yield advantages being a function of the cultural conditions practised. Furthermore, Jennings and Herrera (1968) asserted that "the superiority of the dwarfs was directly related to their reduced height and lodging resistance compared with the greater height and heavy lodging of tall plants".

There is good evidence that when water and nutrients are not limiting, light is the resource for which rice plants compete (Jennings and Aquino, 1968) Tanaka et al (1966) demonstrated that highly competitive low yielding indica varieties characteristically undergo fast, early vegetative development which is accentuated by addition of nitrogen. This vigorous early growth rate slows and sometimes becomes negative at later developmental stages. Such a pattern of development leads to mutual shading, increased respiration, reduction of effective leaf area and lower rates of photosynthesis during later growth stages when grain is being produced. Lower grain yields inevitably result. In contrast, the weakly competitive, high yielding, short statured, small-leaved varieties grow slowly in the early stages but at an increasing rate towards the end of the vegetative phase. A high rate of dry matter increase is maintained through grain development. Mutual shading, respiration loss and organ deterioration are minimised while light penetration of the canopy is enhanced. Yield is high because of the high rate of dry matter accumulation after flowering.

The unexpectedly strong negative association of competitive ability with grain yield, coupled with the differential effects of planting density and nitrogen level on competition intensity and on the yielding ability of dwarfs, accounts for much of the difficulty experienced by rice breeders in discerning the importance of plant type for tropical rice varieties at a much earlier stage.

There can be little argument with the contention of Jennings and Aquino, (1968) that strong, competitive ability mitigates against high yield in tall, droopy-leaved, highly photosensitive indica type rice varieties, but this must not be construed to mean that rapid increase in dry weight during early development is always undesirable. In fact, in temperate areas where growth generally is slower than in the tropics, selection for fast growth rate (tillers, not height) in the early stages may be essential for production of high yielding, very early maturing varieties (McDonald and Woodward, 1977). High growth rates during early development of erect, small-leaved strong tillering varieties should not mitigate against high yield provided vegetative development is not allowed to proceed to the point where mutual shading becomes a serious problem. This requires that when sufficient size has been attained to support high yield, the plant should immediately be diverted from vegetative to reproductive development.

Resistance to Diseases and Insects

There can be no adequate discussion of adaptation to any environment without consideration of varietal resistance to diseases and insect pests.

Disease organisms and insects thrive in the tropical climate and cause a great deal of damage to rice. A small number of traditional varieties have proved resistant to one or more diseases or insect pests but are invariably susceptible to others (Khush and Beachell, 1972). Obviously such resistances were important to the survival and popularity of many of these varieties.

Though disease resistance breeding was important in many national programmes there was practically no active international co-operation in this regard until the International Rice Commission of F.A.O. established co-operative nurseries in the mid 1950's to evaluate blast resistance in varieties and hybrid progenies. With only minor exceptions, breeding for resistance to insects had not been seriously attempted (Parthasarathy, 1972).

Six diseases, blast (Piricularia oryzae), sheath blight (Corticium sasakii) bacterial blight (Xanthomonas oryzae), bacterial leaf streak (Xanthomonas transluceno f. sp. oryzicola), tungro (virus) and grassy stunt (virus), and four insect species, stem borers, green leafhoppers, brown planthoppers, and gall midge, attack rice in most ricegrowing countries of tropical Asia (Khush and Beachell, 1972).

Production of resistant varieties is the most practical means by which damage can be reduced over very wide areas and is a major objective of rice breeders in every country. As part of a massive international Genetic Evaluation and Utilisation programme run by I.R.R.I., varieties collected from every part of the ricegrowing world are evaluated for special characteristics including resistance to disease and insect pests. Such resistances are then incorporated in improved plant type varieties for use by breeders all over the world. Many of these improved varieties are resistant to a wide variety of pests and diseases (I.R.R.I., 1974).

The High Yielding Variety Package

Most major ricegrowing countries in Asia have established special programmes to promote the use of high yielding varieties, provide capital for purchase of fertilisers insecticides etc, and educate farmers to adopt improved cultural and management practices. The "Massagana 99" programme in the Philippines (Adriano, 1976) and "BIMAS"/"INMAS" programmes in Indonesia (Siwi, 1976) are typical. They have three basic objectives in common:

(i) through intensified extension programmes to encourage farmers to grow new improved varieties and to adopt improved production techniques including application of fertilisers, use of insecticides and careful water control, and to educate them in improved management techniques.

(ii) to properly distribute and ensure supplies of the necessary inputs.

(iii) to provide credit necessary for farmers to purchase adequate farm supplies.

BIMAS and INMAS programmes have been operating in Indonesia since 1965 and although average yields have been improved there is still a major gap between the yield potential of the high yielding varieties and those obtained by farmers (Siwi, 1976). The Philippine "Massagana 99" programme was set up in 1973. A recent report (Anonymous, 1977b) gives it credit for making the Philippines self sufficient in rice for the first time in June, 1976. However, data on the specific effects of the programme are limited (Adriano, 1976).

A similar programme to expedite the adoption of Tongil rice in Korea was spectacularly successful. Despite severe set-backs in the first two years of the programme (due to floods and cold damage in 1971, and floods and hail in 1972) the new variety was planted on 450,000 hectares or 37.3% of total paddy land by 1975. Concurrently the national average yield rose from 4.7 t/ha between 1967-73 to 5.3 t/ha in 1975 (Anonymous, 1976)

Limitations to the Green Revolution

Despite the greatly expanded yield potential of the new high yielding varieties their very widespread distribution in many of the major ricegrowing countries of the world has had remarkably little effect on national average yields. Efferson (1972) in pointing to this fact emphasised that in Asia, weather was likely to continue to be the most important influence on the production of rice. He asserted that the maximum impact of the improved varieties, added inputs and new methods can only be achieved when more effective water control and irrigation is possible.

It is now recognised that the highly productive short statured, improved plant type varieties are well adapted to only about 25% of the total rice lands of Asia where a good supply of water is available under good control (I.R.R.I., 1976). They are not well adapted under "upland" growing conditions, to deep flooded regions, to problem soils, or to areas subject to low temperatures.

a) *Upland and rainfed rice*

About 67% of Asia's rice area is completely dependent on rainfall to water the crop. On about two thirds of this area, rain water is impounded by bunds or small banks and the soil is puddled in preparation for sowing. This is termed rainfed rice (Athwal, 1972). Under rainfed conditions, good yields can be obtained from the improved dwarf varieties provided there is adequate rainfall and its distribution is satisfactory. Improved technology is directly applicable to these situations where cultivation methods are essentially the same as in irrigated areas. Despite the potential for good yields, the uncertainty of rainfall makes production less assured. The other one third is grown under upland culture without bunding and the soil is not puddled. About 75% of rice in Africa and 65-75% in Latin America is also grown in this fashion (De Datta, 1975). Almost one sixth of the world's total rice area is planted to upland rice and even very small increases in yield would have a very significant impact on total production.

High yields are possible under upland conditions. Experimental yields of 7 t/ha have been recorded in the Philippines, 7.2 t/ha in Peru and 5.4 t/ha in Nigeria. However, farmers yields are generally very low: from 0.5 to 1.5 t/ha in Asia; about 0.5 t/ha in Africa; and from 1 to 4 t/ha in Latin America (De Datta, 1975).

Growing conditions for upland rice are extremely variable. Rainfall varies both in amount and distribution from country to country and location to location, to say nothing of seasonal variation. Soils are as diverse as the climate. Topography ranges from flood liable flat land to high elevation hill-sides. Under these conditions the crop is subjected to many adverse factors that do not affect lowland rice such as water stress, hot and dry conditions, and aerobic soils that have toxic excesses of elements such as manganese or aluminium or deficiencies of vital elements such as iron and phosphorus (Chang and Vergara, 1975). Of these, water stress probably has the most serious effects on production. Drought resistance is therefore the most important single factor needed to increase and stabilise production (De Datta, Chang and Yoshida, 1975). Drought resistance involves the ability to withstand moisture stress and recover quickly from its effects as well as the ability to adjust growth to minimise drought damage.

Traditional upland varieties usually are somewhat drought tolerant and have deep, thick roots which are very important to drought avoidance. Their leaves are rather long and droopy and roll up readily under moisture stress. However, they tiller poorly and produce few panicles per unit area making them inherently low yielding (Chang, Loresto and Tagumpay, 1972).

Significant improvements can be made by breeding varieties with more efficient plant type which are responsive to nitrogen, more drought resistant, broadly resistant to diseases and insect pests, tolerant of toxic soils or nutrient imbalances and widely adapted giving stable yields under a range of adverse conditions (Chang and De Datta, 1975). Very significant progress has been made both in identifying varieties which can contribute one or more of the elite characters required, and in recombining them into individual genotypes which perform well under upland conditions (I.R.R.I., 1975, 1976). The task would be greatly simplified if ways could be found to stabilise water supply and other growing conditions since it is the extreme variability of the environment which creates the greatest problems.

b) Deep water and floating rice

The new short statured rice varieties are not adapted to vast areas of the deltas, estuaries and river valleys of Thailand, Bangladesh, India, Burma, Cambodia, Vietnam and Indonesia, where floodwaters rise every year to depths of 0.5 m to 4 or 5 m or even higher. Three million hectares of deep water rice is grown in Bangladesh alone. There are another 1 million hectares in Thailand and about 1.7 million hectares in India (Jackson et al, 1972; I.R.R.I., 1976).

Most rice varieties are adapted to only very shallow water. Their tolerance of deeper water varies greatly but flooding to depths exceeding one third of plant height usually causes low yields due to reduced panicle number and high sterility (Oka, 1975). Floating varieties are a remarkable exception. They are distinguished by their ability to elongate rapidly under rising flood water and, provided the water does not rise too quickly, may grow to 6.0 m. The rate of elongation normally varies from 2-10 cm/day but rates as high as 25 cm/day have been recorded (Jackson et al., 1972; Tanaka, 1975). Seed is planted in either dry or puddled soil about six weeks before the floods begin to rise. As the stems elongate with the flood, they produce adventitious roots from the upper nodes which allow the plant to absorb nutrients from the water. When the flood waters recede they collapse but characteristically "knee" and produce secondary tillers from the upper nodes. Most varieties are photosensitive and do not initiate reproduction until the daylength is sufficiently short. By the time heads appear the floods have begun to recede and the problems of harvesting in deep water are avoided.

Large numbers of floating varieties exist in Asia, all of them indicas. They represent a specialised ecotype adapted to periodic inundation. Their floating ability and pronounced drought resistance seem to have been derived from the wild progenitor O. perennis. Floating varieties of O. glaberrima are also cultivated in Africa. These exhibit even higher rates of elongation and can tolerate more rapid inundation than O. sativa varieties (Oka, 1975). Yields of floating rice in Asia are surprisingly high and usually above those from traditional non-floating varieties (Tanaka, 1975).

The stem elongation characteristic of floating varieties is only expressed in the "lag" phase between tillering and panicle initiation and only in response to flooding. In the early stages of vegetative development and after panicle initiation, internode elongation is controlled in the same way as in non-floating varieties. If flood waters rise too early the young plants are not able to elongate fast enough and are drowned. Rises in the water level after panicle initiation can also cause severe damage (Oka, 1975).

Unlike the well adapted local varieties, semi-dwarf varieties cannot elongate to keep pace with the rising flood waters. Neither can they tolerate being submerged for long periods. Even when they survive flooding to 0.5 m or so, they mature too early before the flood recedes because they are insensitive to photoperiod. Consequently they are very difficult or impossible to harvest and grain is often of poor quality (I.R.R.I., 1976).

Very significant advances have been made in adapting improved plant type varieties to areas affected by flooding to moderate depth. Rice breeders in Thailand, in co-operation with I.R.R.I. breeders, have selected a range of better adapted lines including semi-dwarf types capable of surviving water depths of 0.5 m to 2.0 m, and intermediate height plants which normally grow to 140-160 cm tall (Prechachat et al, 1975). Perhaps the most exciting aspect of this work from a breeding viewpoint is the transfer of the flood induced elongation response to semi-dwarf varieties. The potential advantages of being able to extend the use of improved plant type varieties to areas subject to moderately deep flooding are obvious, particularly along the fringes of the deep water areas where variation in water depth is great enough to make the performance of semi-dwarfs unpredictable.

One of the greatest challenges facing rice breeders in the tropics is improving the yield potential of the deep water, floating rices. Under the conditions in which they grow, the concept of "improved plant type" has little meaning.

c) Unfavourable soils

The soils in which rice grows are as variable as the climatic conditions to which it is exposed. They range in texture from sand to clay, have pH's from 3 to 10, organic matter contents from 1 to 50 percent, contain salt at levels of 0 to 1 percent and nutrients in greatly deficient to gross surplus amounts (Ponnamperuma and Castro, 1972). It has been estimated that as much as one third of the total area sown to rice may be affected by one or more of these factors. Furthermore about 40 million hectares of land in the tropics, which is otherwise suited to rice, remains uncultivated because of problem soils. In the Philippines alone there are 280,000 ha of saline coastal soils and 400,000 ha of soils deficient in zinc (I.R.R.I., 1976).

The low yield of rice on unflooded soils is usually attributed to moisture stress and weed competition. However, Ponnamperuma and Castro (1972) found that yields were less on aerobic soils even in the absence of water stress. The most common cause was iron deficiency on neutral or alkaline soils and manganese and aluminium toxicity on acid soils. Iron toxicity is also a widespread problem in strongly acid lateritic soils and acid sulphate soils. Phosphorus deficiency limits growth on these same soil types, often in association with iron toxicity. Zinc deficiency is also widespread. In flooded soils, highly soluble manganous and ferrous compounds sometimes cause trouble and accumulated organic breakdown products may poison the rice plant (Ponnamperuma and Castro, 1972).

Varieties resistant to all of these soil conditions have been identified and very significant progress made towards incorporating the resistances into highly improved semi-dwarf varieties which are also resistant to disease and pests and are adapted to a range of other environmental conditions (I.R.R.I., 1975, 1976).

d) Cold tolerance

Rice grown at high elevations in the tropics or at temperate latitudes is frequently affected by low temperature. Damage may occur at any stage of growth. Seed will not germinate and seedlings often establish poorly at low temperatures. Cold at later stages may cause leaf discolouration, seriously retard growth and development, and/or cause very high sterility (Athwal, 1972). Difficulties in establishment are commonly avoided in Asian countries by raising seedlings in "hot" beds and transplanting them when the soil is warmer. The effects of cold during reproduction can be very serious and are much more difficult to avoid in countries where the growing season is very short. The period encompassing reduction-division in the pollen grain mother cells is most sensitive, although severe damage is often caused by cold during panicle differentiation and flowering stages.

Compared to other small grain cereals such as wheat, rice is not highly cold tolerant. Little or no seedling growth occurs in most varieties below $12^{o}C$ and floral organs are damaged by temperatures much below $15^{o}C$. Many tropical indica varieties are affected by temperatures much higher than this.

Japonica varieties generally are regarded as cold tolerant but some are much more tolerant in specific situations than others. Varieties resistant at one location are not necessarily resistant at another site. However there is evidence that resistances to different kinds of cold damage can be combined into a single variety (Athwal, 1972; Okabe, 1972). Some native indica varieties cultivated under low temperature conditions are also quite resistant to cold injury.

New early maturing, cold tolerant indica selections have been made by I.R.R.I. scientists which will allow farmers in some high elevation areas of the Philippines to grow two crops in the season where previously they could only grow one (I.R.R.I., 1976).

The lack of very high levels of cold resistance in rice makes it difficult to envisage great progress beyond the best japonica varieties. However, the use of very early maturing, fast growing indicas to improve the rate of plant development in the warmest part of the growing season could be an important key to significant improvement.

Genetic Evaluation and Utilisation

Progress in plant breeding requires a continuous supply of genes and gene combinations to be used as basic building blocks in the synthesis of new, more highly improved varieties. Individual breeders can only do a limited amount of the necessary searching and to meet their need for a wide array of germplasm large varietal collections must be assembled and systematically screened for specific traits. Genetic vulnerability due to the widespread use of a very few genes is a major hazard and can only be avoided by continually identifying and utilising elite varieties from diverse gene pools.

A very large collection of germplasm has been assembled at I.R.R.I. It contains 35,000 accessions of Asian cultivars (O. sativa), 900 accessions of African rices (O. glaberrima), and more than 1,100 strains of wild taxa, genetic testers and mutants (Chang, 1975). More than 4,000 of the O. sativa samples are reported to have special features or to have originated from areas where specific stresses exist such as salinity, alkalinity, low temperatures and drought.

A very large collection of the world's available germplasm has been assembled at I.R.R.I. and large sectors of it have been evaluated for characteristics important to the Institute's breeding programmes.

More recently a massive international programme has been launched by I.R.R.I. to facilitate the evaluation of germplasm from all over the world. Twelve international nurseries were set up in 1975: three for yield; two for observation; three for disease; two for insects; and two for adverse soils and environmental stresses. Thirty five percent of entries originated from national programmes, 49% from I.R.R.I.'s breeding programme and 16% from the germplasm collection. The nurseries are grown by co-operating scientists in almost every ricegrowing country of the world thus providing broad international distribution and appraisal of both national and I.R.R.I.-generated breeding material (I.R.R.I., 1975a). Such co-operative testing is an extremely powerful tool in measuring the adaptation of rice varieties to the world's major environments. It will inevitably result in identification and widespread utilisation of a much greater range of germplasm than could be achieved by any individual national programme.

RICE IN AUSTRALIA

Ricegrowing methods used, the rotations practised and the problems confronting rice production are quite different in the three areas where rice is produced in Australia. The industry in New South Wales (N.S.W.) is by far the largest, producing more than 95% of Australia's rice. It is very highly productive, growing both long and short grain varieties of rice in rotation with legume pastures. In Queensland the crop is cultivated in monoculture and only one variety is grown. The Western Australian industry is in its infancy and is confronting problems of varietal adaptation, nutrient deficiencies and high costs of production.

Rice in Northern Australia

Several attempts have been made to grow rice on a large scale in northern Australia. The biggest and best known of these was the "Humpty Doo" project where Territory Rice Ltd planned to develop 200,000 hectares for ricegrowing just south of Darwin. However, the maximum area grown was 2,200 ha in 1959. Insuperable difficulties were experienced with local rainfall distribution, soil characteristics (particularly salinity) topography and hydrological conditions. The varieties grown were traditional indicas which were incapable of responding to nitrogen or improved husbandry. These difficulties, accentuated by management deficiencies, led to eventual abandonment of the project (Basinski - personal communication).

Other attempts were made to grow rice on a commercial scale in the Kimberley region of Western Australia, first at Camballin on the Lower Fitzroy River and later at Kununurra on the Ord River (latitude 17^{o}S). Severe flooding in the wet season and low minimum temperatures at critical periods in the dry season prevented satisfactory production at Camballin (Basinski - personal communication). Attempts to grow the crop commercially have continued at Kununurra but with little success. The project received a major set-back in the mid 1960's with the occurrence of a disorder later identified as zinc deficiency.

The late E.C.B. Langfield was Australia's only breeder of tropical rice. He was located at the C.S.I.R.O. Kimberley Research Station near Kununurra, W.A. from 1947 to 1959 and then at the Coastal Plains Research Station near Darwin, N.T. until his death in 1974. In 1962 he named and released the variety Circna. Originally known as HD 18 Circna was selected from indica x japonica material tested as part of the International Rice Commission's hybridisation project. The parental cross, Zui Huo (japonica) x Mayang Sabotil (indica) was made in India. Circna was grown on about 400 ha on the Ord River "pilot" farms in the mid 1960's and may have been grown briefly at Camballin (Basinski - personal communication).

More recently high yielding I.R.R.I. genotypes were identified and tried on a commercial scale but milling quality was extremely poor. For this reason Bluebonnet 50, which is low yielding but of good quality, was the only variety cultivated last season (McDonald, 1976a, 1976b). The areas cultivated and yields achieved in 1975 and 1976 are recorded in Table 1.

Khush (1977 - unpublished report) has suggested that the milling quality problem in the dry season might be alleviated if earlier maturing, cold tolerant varieties are grown. They would have to be planted early and harvested before the onset of very hot weather with its attendant suncracking problems. It seems likely that, with a sufficiently large testing programme, new varieties can be found which are tolerant to low levels of zinc, tolerant to cold and have short growth duration combined with grain quality similar to Bluebonnet 50.

The resources now available through I.R.R.I. have enormously increased the possibility that suitable varieties adapted to the Ord River environment will be identified.

Rice in Queensland

There is a long history of ricegrowing in Queensland dating back at least to 1869 (Allen, 1969). However, there was no substantial industry until 1966 when a small project was established on the Burdekin River (latitude 19-20°S) where the industry is still concentrated. Small areas are also grown near

Mareeba and, as upland rice without irrigation, in wetter tropical situations around Ingham. The area sown and paddy rice produced since 1969 are recorded in Table 2.

Production methods are similar to the drill sowing techniques used in N.S.W. but two crops per year are possible with plantings in December/early January or June/early July. Low temperature sterility is occasionally a problem with crops sown in June but the risk of cyclone damage increases if sowing is delayed. There is no rotation of rice with other crops (Seton and Greenaway, 1969). Khush (1977 - unpublished report) considered that, with its ideal growing conditions and fertile soils, this area has greater potential for rice cultivation than any other ricegrowing area in Australia provided additional water storages are built as planned.

Bluebonnet 50, a long, slender, high quality variety bred in Texas, U.S.A. is the only variety grown commercially in Queensland. A range of other varieties from I.R.R.I., the U.S.A. and elsewhere have been tested but Bluebonnet 50 has been retained because of its exceptional market acceptability (Seton and Greenaway, 1969). Yields could probably be improved substantially using new I.R.R.I. lines, many of which have similar quality characteristics to Bluebonnet 50 (Khush, 1977 - unpublished report). In addition, the vulnerability of the industry to catastrophic disease outbreak could be substantially reduced.

Rice in New South Wales

The N.S.W. rice industry was founded in 1922 when the first 2.8 hectares of experimental plantings were sown near Leeton (I.R.E.C., 1967). Despite some initial difficultues with water control and weeds, the experiments were successful. Seven commercial crops totalling 74 hectares were planted in 1924 and yields up to 100 bushels per acre (approx. 4.2 t/ha) were obtained. Very rapid expansion followed and in 1929, more than 8000 ha of rice was grown. The recently completed 1977 harvest totalled 518,960 tonnes of paddy from 89,318 hectares, an average of 5.81 t/ha. By world standards it is a small industry but achieves significance because of exceptionally high average yields and the high proportion of product exported (more than 85% in 1976). The area cultivated and production of paddy rice from 1967 to 1977 is recorded in Table 3.

Climate and soils

Ricegrowing in N.S.W. is confined to irrigation areas along the Murrumbidgee, Murray and Edwards rivers (latitude 34-36°S). The climate is typically temperate with high solar radiation, high temperatures and long periods of daylight in the summer. Winters are cool with short days. There is a frost free growing season of about 200 days though temperatures low enough to delay seedling establishment or cause high levels of sterility sometimes occur in spring and autumn respectively. Crops are normally sown from late September to mid-October but individual plantings may be as late as mid-November. Pan evaporation averages 6.5 mm/day over the ricegrowing season. A detailed account of the climate of southern N.S.W. and its influence on the growth and yield of rice has been published by Boerema (1974).

The soils on which rice is grown range from fertile, calcareous, crumbly, self-mulching clays to very infertile soils of poor structure. Extensive experimentation has shown that deficiencies of nutrients other than nitrogen are rare even where rice has been grown continuously for several years.

The physical characteristics of soils are extensively modified where pasture is included in the rotation. Organic matter accumulates near the surface, reducing or eliminating problems with crusting as well as providing a source of nitrogen for the rice crop. (Boerema and McDonald, 1965).

Rice varieties and their adaptation to southern N.S.W.

The major features of the southern N.S.W. environment requiring a high degree of adaptation by successful varieties are low temperatures in spring and autumn and soil nitrogen levels ranging from very low to extremely high.

Low temperatures in spring often cause retarded seedling growth. More importantly, if low temperatures occur just before or during flowering, they may induce high levels of sterility in susceptible varieties.

Low levels of soil nitrogen are characteristic of the Riverina soils on which rice is grown. However, after 5 to 10 or even more years under legume pastures, nitrogen levels may be raised to very high levels which can cause over-luxurious growth, severe lodging, high sterility and very low yield in poorly adapted varieties.

a) Japonica varieties:

The N.S.W. rice industry was founded on japonica varieties introduced from California U.S.A. Initially there were three, Caloro, Wataribune and Colusa. Wataribune was discarded because of late maturity, weak straw and heavy awning. Colusa was also withdrawn from cultivation because of increasing problems with "red rice" (Poggendorff, 1937). Caloro became very popular and for a period of about 20 years until 1958 was the only variety cultivated extensively in N.S.W. Selection within the variety by Poggendorff resulted in establishment of two distinct strains. Caloro 2 was a mid-season selection, very high yielding and well adapted to the Murrumbidgee Irrigation Areas. Late Caloro matured 7 - 10 days later than Caloro 2 but under favourable conditions was even higher yielding. However, its late maturity increased the risk from low temperature damage and harvesting conditions were sometimes difficult at the end of the season. A third strain, known as Early Caloro was selected at a later stage. It was about 10 days earlier maturing than Caloro 2 and became very popular in the cooler Murray Valley areas where the later variety was often affected by low temperatures.

Caloro, with its early, mid and late maturing strains, was very well adapted to southern N.S.W. However, it was sometimes severely damaged by cold close to flowering and was prone to severe lodging when grown on highly fertile soils. In addition, a high percentage of the grains contained "chalky" spots, particularly in late maturing crops and those grown after pasture. This characteristic made the variety less attractive on discriminating markets.

Another japonica variety, Calrose, was introduced from California in 1952 and immediately showed promise. It was slightly earlier maturing and more cold tolerant than Caloro 2. Grains were less bold and much less prone to have "chalky" spots when mature. After extensive testing, the first seed was released for commercial increase in 1956. At first the yields obtained from Calrose were lower than those of Caloro 2 and farmers were reluctant to change varieties. However, a single cycle of selection in the new variety produced a strain which consistently outyielded Caloro 2. Seed of the new strain was introduced through the pure seed programme and began to replace the original seed in 1964/65. The average yield and popularity of Calrose increased sharply (Table 4) and within a few years it had completely replaced Caloro 2. Calrose is still grown on about half of the total area sown to rice in N.S.W. and is remarkable for its wide adaptation, consistently high yield and excellent grain quality. It produces high yields at both low and high levels of fertility, responds well to additions of nitrogen and is very tolerant of overfertilisation. However, lodging can be very serious at high fertility, particularly in aerial sown crops.

b) <u>Development of long grain varieties</u>:

The first long grain rices adapted to southern N.S.W. were bred by Walter Poggendorff in the 1930's (Poggendorff, 1937). Though some were high yielding they were not required by the infant industry and were never grown commercially. Rice improvement work was confined to variety testing and there was no hybridisation programme from 1940 when Poggendorff left until my appointment as breeder in 1957. By then most of his breeding lines had been lost or were ungerminable so I began again.

No long slender grained varieties were grown in temperate areas of the world at that time. However, encouraged by Poggendorff and because of a personal fascination, I began to test long grain varieties from the U.S.A. and elsewhere to determine their degree of adaptation. The local industry, impressed by the appearance of these varieties and concerned at the growing imports of foreign long grain rice into Australia, decided to grow the best variety available, Bluebonnet 50. Though very late maturing and low yielding compared to the short grain varieties, it was grown from 1961 to 1966 and enabled the industry to hold the domestic market for long grain rice against the threat of imports.

Beginning in 1958, crosses were made between the late maturing, high quality long grains and adapted short grain varieties. Several lines selected from a Bluebonnet 50 x Calrose cross were much higher yielding than Bluebonnet 50. The best of these was named Kulu and released for commercial production in 1967.

Kulu was well adapted only to the warmer northern portions of the N.S.W. ricegrowing areas but was very responsive to fertiliser and gave high yields when grown on fertile pasture soils. It was much earlier maturing than Bluebonnet 50 and was reasonably tolerant of cool conditions during reproductive phases of development. Though rather soft cooking and lacking distinctive indica quality, Kulu played a key role in establishing the N.S.W. industry as a producer of long grain rice. From 1971 to 1973 it was grown on about 30% of the total area in southern N.S.W. (Table 4). However, poor milling quality in some seasons caused it to fall into disfavour.

The poor milling quality of Kulu, and the demand by industry for a better quality long grain variety to sell on the export market, led to the release of Inga in 1972. Inga yields less paddy than Kulu and is poorly adapted to high fertility. It is also later maturing and even less well adapted than Kulu to cooler parts of the region. However, because of its superior milling quality and exceptionally attractive long grain, it has become very popular and is currently grown on about 50% of the total N.S.W. rice area. (Table 4). The key issue is that Inga competes successfully on the export market with indica varieties from traditional exporters of long grain rice.

From the farmers viewpoint, Inga is both good and bad. Seedling vigour is excellent and growth at high fertility is very fast. These same attractive features, characteristic of traditional indicas, can cause reduced yield due to excessive leafiness and self shading during reproductive stages, leading to high sterility. The combined effects of high plant density and high levels of nitrogen are particularly devastating (McDonald, 1976). However, with good management, average yields of about 5 t/ha are being obtained. Some crops have produced more than 7.5 t/ha. Interestingly, very high yields have been obtained by sod-seeding Inga into pasture. Such crops are characteristically of low density, poorly grown in the early vegetative stages and exceptionally vigorous in later stages of development as nitrogen from pasture residues becomes available.

From a breeders point of view, Inga is an uncomfortable compromise to achieve excellence of quality at the expense of productivity. Only the complete dependence of the N.S.W. industry on retaining high priced export outlets can justify maintaining such a situation for any length of time.

Some improvement is expected with the projected release of a new long grain variety, YR 73, which is in the final stages of testing. Primarily it is seen as a replacement for Kulu which is still grown on high fertility areas where Inga performs poorly. Depending on market acceptability it may also replace Inga to some degree. YR 73 yields less than Kulu but more than Inga, is early maturing, fairly cool tolerant, well adapted to high fertility and has excellent milling and cooking quality. It is the first long grain variety well enough adapted to the cooler Murray Valley ricegrowing areas to be grown there commercially.

The prospects are excellent for breeding long grain varieties combining elite grain quality with very high yield. Promising selections have already been made which go a long way towards this goal. The highly productive, widely adapted genotypes being generated by I.R.R.I. will almost certainly be part of the key to ultimate success.

c) Medium grain and special purpose varieties:

An exceptionally high yielding, medium grain variety, Baru, was released for commercial production in 1972. Baru was earlier maturing than Calrose, was less prone to lodging and yielded more under favourable conditions. However, it never became popular because of an unsuspected sterility problem and the lack of demand for medium grain rice by the industry.

A waxy variety Tarra 140 was also released for very limited production in 1974. It performed poorly in its first season and this coupled with the lack of demand for waxy rice, prevented further cultivation. Greatly improved waxy lines have since been developed and it should not be too difficult to develop varieties yielding as well as Calrose.

Quality of rice in N.S.W.

Quality is of crucial importance to the strongly export oriented N.S.W. rice industry. High milling yields must be maintained to preserve profitability and cooking quality must be satisfactory to the markets supplied.

a) Milling quality:

Rice milling involves dehusking, whitening and polishing. The object is to complete the process with a maximum percentage of unbroken, high polished grains. The husk is easily removed and kernels are not usually damaged in the process. Whitening, or removal of the bran layers, is much more difficult and is usually achieved through the combined effects of abrasion of the kernels against a metal screen and attrition of kernel upon kernel in the whiteners.

If rice is left to mature and dry down to low moisture contents in the field, transverse cracks often develop in the kernel which cause severe grain breakage during milling and low yields of whole kernels. This problem, known as "suncracking" or "checking", has been a difficulty with some varieties since the inception of the industry (Poggendorff, 1937). The vulnerability of rice to suncracking increases sharply as the moisture content falls below about 21%. Varieties vary in their susceptibility to damage. Resistance appears to be fairly simply inherited and is easily recovered from crosses between resistant and susceptible genotypes (McDonald, 1967, 1968).

Calrose, Inga and YR 73 are resistant to suncracking and give high milling yields even when dried in the field to low moisture contents. Kulu is susceptible and this, together with a tendency to chalkiness in some seasons, severely reduces its milling quality. Another long grain selection, otherwise very well adapted to the cooler Murray Valley areas, is very susceptible and gives very low milling yields unless harvested early.

The worst effects of suncracking are avoided by harvesting at high moisture contents and drying artificially (McDonald, 1967). Most drying is done with unheated air in N.S.W. but the necessity to provide aerated storage for the entire crop is an enormous cost to the industry.

The problem is not as severe in N.S.W. as in northern Australia, but it is essential that all future varieties be highly resistant to suncracking and capable of giving high milling returns even under adverse conditions. The importance of resistance will be greatly accentuated in earlier maturing varieties which will be subjected to higher temperatures and will dry much faster than existing varieties.

b) Cooking quality:

Most Australians are unsophisticated in their rice eating habits and have been educated to use rather soft cooking varieties. However, rice importing countries of Asia, the Middle East and Europe are often very discriminating. Some prefer the soft cooking, sticky japonicas. Others like very dry cooking indicas but often insist that the cooked grain remain tender when cooled and stored for a period (Juliano, 1972). Scented and highly flavoured rices are also favoured in some areas.

The degree of stickyness in cooked rice is largely dependent on the amount of amylose in the starch. High percentage amylose produces very dry cooking but usually results in the grain being hard after cooling. Some indica varieties are of this type and are preferred in various countries. Low amylose produces sticky cooking but the grains remain tender (Juliano, 1972). A delicate compromise is required for the long grain markets in which Australia is interested. Amylose content must be high enough to produce dry cooking, but low enough to avoid a very hard cooked product. In southern N.S.W. the appropriate level appears to be 25 - 26% amylose which is 1 - 2% higher than the levels sought after in the tropics. The higher level is necessary to achieve dry cooking characteristics under cool ripening conditions. Positive selection for tenderness at amylose contents within this range is also essential.

There is essentially no problem with cooking quality of japonica varieties grown in N.S.W. but there is a well defined requirement for drier cooking long grain varieties for both domestic and export markets.

Outstanding breeding problems in N.S.W.

a) Yield and quality of long grains:

The need to develop high quality long grain varieties which are better adapted to high fertility and the cool temperatures of southern N.S.W., and which will yield as well as the adapted japonicas, has already been discussed. This is probably the most important breeding problem to be resolved.

b) Early maturity and cold tolerance:

The japonica varieties cultivated in N.S.W. are amongst the most tolerant in the world to low temperature during reproduction. Varieties from Japan, Romania and Hungary are equally cold tolerant but are poorly adapted from other points of view and give low yields in the N.S.W. environment.

Cold hardiness is much more difficult to find in long grain varieties. Kulu has proved comparatively cold tolerant in tests conducted by I.R.R.I. but is far less hardy than Calrose. Both Inga and Kulu mature too late under cool temperatures in the Murray Valley and are usually highly sterile. YR 73 has performed satisfactorily in that region because of its earlier maturity but is not more cold hardy than Kulu. However, one long grain selection last season proved almost as hardy as Calrose in tests under very high nitrogen at Deniliquin and this gives hope of substantial progress in the future.

The prospects for greatly improving the absolute level of cold tolerance of varieties are unknown. New sources of resistance identified in I.R.R.I.'s Genetic

Evaluation and Utilisation programme may be useful. However, I am convinced that the ultimate solution will be to develop early maturing varieties that will not be subject to very low temperature.

c) Lodging resistance:

Lodging is sometimes a serious problem especially with japonica varieties and under aerial sown conditions. About 80% of all rice grown in the Murray Valley is aerial sown to avoid difficulties with low soil temperature and surface crusting. Aerial sown crops also need about 14 days less time to mature than drill sown ones and thus flower and set grain with less risk of low temperature damage. However, lodging is often severe, particularly with japonica varieties.

Semi-dwarf varieties offer great advantages in situations where lodging is a problem. Lewin, ricebreeder at Yanco Research Centre, made a series of crosses between adapted varieties and dwarf genotypes from Taiwan and I.R.R.I. in an attempt to develop highly lodging resistant lines. Quality has been particularly difficult to recover in these lines despite up to five backcrosses to the adapted parent. However, some dwarf and semi-dwarf lines have given very high yields and will be used for further crossing.

d) Straighthead resistance:

"Straighthead" is a form of severe sterility accompanied by distortion or malformation of florets which results in the panicles standing erect when mature, rather than drooping with the weight of grain. Similar problems occur in Japan (Sakai, 1975), the U.S.A. (Hollis, 1967) and Italy (DeCarolis, 1974). The disorder is caused by breakdown product from anaerobic decomposition of organic matter. Mid-season draining is often effective in avoiding problems.

Rice varieties vary greatly in their sensitivity to straighthead and the logical solution to the problems encountered in N.S.W. is to ensure that all future varieties are highly resistant. Of the existing varieties Inga is most susceptible, Kulu moderately susceptible and Calrose most resistant. YR 73 is also susceptible. Tests of breeding material in two locations last year indicate that high levels of resistance are available in advanced selections of both long and short grain varieties.

e) Vulnerability to diseases and insects:

Southern N.S.W. is completely free from serious diseases of rice and is almost equally fortunate with respect to insects. Bloodworms, the larvae of a midge (Chironomis spp.), are the only major pest and they can be readily controlled.

Diseases and insects are serious problems in some other temperate rice-growing countries of the world. Until now, strict quarantine and good fortune have kept southern N.S.W. free from their ravages. However, it is too much to hope that this situation can be preserved indefinitely. No commercial variety is resistant to blast, bacterial blight or the virus diseases common in other parts of the world. Neither do they have any resistance to insects such as the brown planthopper which carries "grassy stunt" virus and causes severe damage to rice in Asia.

Help is being sought from I.R.R.I. to identify breeding lines with useful resistance to diseases and pests. Wider use of highly resistant, improved plant type varieties as parents in the breeding programme will increase the probability that future varieties will be resistant.

Perspectives for the future

Apart from the breeding problems already discussed, I believe that there are three major areas in which breeders can make substantial contributions to the future of the rice industry in N.S.W. In each case, it will be necessary to draw heavily on the international genepool for sources of variation.

a) Varieties capable of germinating at low oxygen levels:

Rice varieties now grown will not germinate satisfactorily in anaerobic conditions. Consequently, seed must be pre-germinated for aerial sowing into water to ensure satisfactory establishment. When crops are drill sown they must be flooded and then drained at least twice to promote germination and seedling emergence. Valuable water is wasted, surface crusting problems are often encountered and substantial losses of nitrogen occur as a result of this practice.

Some varieties of rice will germinate in highly anaerobic conditions. Transfer of this capability into N.S.W. varieties would confer several advantages:

- Dry seed could be sown by air directly into water without the need for pre-germination. This is being practised in California, U.S.A. with Calrose but experiments using their techniques at Yanco Research Centre have not been successful.

- Seed could be drilled into the soil and the permanent flood established immediately without the need for "flushing" to promote germination. Exploratory experiments have shown that nitrogen losses are reduced, juvenile growth rate is increased and earlier maturity induced by very early flooding.

b) Specialty varieties:

The N.S.W. rice industry is one of the most compact, highly organised industries of its kind in the world. A high degree of control is exercised over the area planted and the varieties used. Because of the very highly developed, centralised pure seed scheme, new varieties can be introduced and unwanted ones withdrawn as required. A system of premium payments is used to equalise average returns to growers of the various varieties. In this way, the optimum mix of long and short grain varieties can be achieved.

Such an industry is in a unique position to capitalise on lucrative markets for a few specialty rice varieties. Scented varieties with elite cooking characteristics could be sold in small quantity but at high prices on both domestic and export markets. Development of scent is accentuated in cool growing conditions

(Khush - personal communication), and the industry may well find a special place as an exporter of such types. Work has already begun on the development of suitably adapted varieties, the objective being to reproduce the grain elongation and scented characteristics of Basmati, which is one of the most sought after varieties in the world. Newly synthesised germplasm in which these characteristics have been developed separately in semi-dwarf varieties, has been obtained from I.R.R.I. for use as parent material.

Waxy varieties may also be a useful specialty provided yields can be raised to very high levels. Interest has been expressed by food processors in Australia and by certain foreign importers of Australian rice. It is unfortunate that the industry's first experience of trying to grow waxy varieties was not more successful. There is no doubt that suitable high yielding varieties can be produced if required.

The idea of being a producer of specialty lines is not attractive to industry, particularly as it concerns waxy varieties, because of the exceptionally difficult problems of segregating such rices from mainstream varieties. However, I am convinced that, if really productive varieties of these types can be synthesised, specialty rices could become a very important part of the N.S.W. industry of the future. All of the necessary controls and administrative machinery are there to make such operations feasible.

c) <u>Very early maturing varieties</u>:

The major constraint to further expansion of the rice industry along the Murrumbidgee and Murray Rivers in southern N.S.W. is the availability of water. Already there are heavy restrictions on the total quantity of water available to irrigators in the Murray Valley and it is only a matter of time until similar restrictions are imposed on water drawn from the Murrumbidgee system. Even with existing areas, a prolonged severe drought in the mountain catchment could make it impossible to supply enough water for the crop.

Rice is a heavy user of water requiring a minimum of about 1.1 m to grow the crop. Frequently, higher quantities of 1.5 to 1.7 m are used where soils are more permeable or when care is not taken to avoid unnecessary overflow.

While the need for continuous inundation is a factor in the high water use of rice, the long growing season of the crop has by far the greatest effect on total water use. With present varieties crops are normally irrigated over a period of five months and continuous flood is maintained for more than four months.

The most practical way to reduce the amount of water required by rice and make more available, either for expansion of the ricegrowing area or for growing other crops, would be to greatly reduce the growing period of the crop. A determined attempt has already been made to breed high yielding varieties maturing 3 - 4 weeks earlier but with little success. The major problem is to achieve adequate vegetative development in the shorter time available.

Very early maturing indica varieties from China and elsewhere have been obtained with the help of I.R.R.I. breeders. Provided temperatures are not low, these varieties are said to be capable of extremely rapid growth and tillering. They are prevented from becoming too large by their very early maturity. We hope that they will provide the key to developing very early maturing long and short grain varieties for southern N.S.W. If successful, this programme could mean a saving of up to 10% in the water required to grow the crop.

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Table 1. AREA SOWN, PRODUCTION OF PADDY AND AVERAGE YIELDS OF RICE VARIETIES IN WESTERN AUSTRALIA, 1975 - 1976*

Year	Season	Variety	Area (ha)	Production (t)	Av. Yield (t/ha)
1975	dry	IR.22 and Bluebonnet 50	283	884	3.70
1976	wet	IR.22	85	340	3.98
		Bluebonnet 50	139	475	3.66
1976	dry	Bluebonnet 50	300		

* Swan - personal communication

Table 2. AREA SOWN, PRODUCTION OF PADDY AND AVERAGE YIELDS OF RICE IN QUEENSLAND 1969 - 1976*

Year	Area (ha)	Production (t)	Yield (t/ha)
1969	1212	4872	4.02
1970	2094	10898	5.20
1971	3872	15296	3.95
1972	3546	12437	3.51
1973	3787	12002	3.17
1974	1875	9023	4.81
1975	2397	9921	4.14
1976	2269	10963	4.83

* Kidston - personal communication

Table 3. AREA SOWN, PRODUCTION OF PADDY AND AVERAGE YIELDS OF RICE IN NEW SOUTH WALES, 1967 - 1977

Year	Area (ha)	Production of Paddy (t)	Average Yield (t/ha)
1967	29814	214314	7.19
1968	30631	220825	7.21
1969	33473	255124	7.62
1970	39033	243366	6.23
1971	38574	288426	7.48
1972	36737	237171	6.46
1973	40673	292274	7.19
1974	64868	403438	6.21
1975	72316	374577	5.18
1976	71634	408267	5.70
1977	89318	518960	5.81

Table 4.

AREA SOWN, TOTAL PRODUCTION AND AVERAGE YIELD OF MAJOR VARIETIES OF RICE IN NEW SOUTH WALES, 1967 - 1976

Year	Caloro			Calrose			Kulu			Baru			Inga		
	% P*	% A*	Y* (kg/ha)	% P	% A	Y (kg/ha)	% P	% A	Y (kg/ha)	% P	% A	Y (kg/ha)	% P	% A	Y (kg/ha)
1967	48.1	47.6	7.22	48.3	47.3	7.30	1.4	1.4	6.92						
1968	21.9	22.2	6.97	70.7	69.8	7.22	7.3	7.1	7.47						
1969	11.1	11.9	6.97	76.9	75.5	7.65	11.9	12.1	7.47						
1970	6.3	6.6	5.97	78.8	75.9	6.47	14.9	17.7	5.22						
1971	11.4	12.0	6.97	62.7	59.4	7.72	25.8	28.8	6.67						
1972	7.6	7.8	6.35	59.7	56.6	6.81	32.6	34.9	6.03						
1973	3.7	4.2	6.39	62.1	61.3	7.28	29.5	30.4	6.98	2.0	2.1	6.93	2.6	3.1	5.99
1974	2.6	3.3	4.87	68.6	69.7	6.12	9.1	9.1	6.21	9.5	8.2	7.23	10.1	11.3	5.59
1975	2.8	3.3	4.37	55.6	54.3	5.30	9.2	9.2	5.20	10.9	10.1	5.56	21.4	25.5	4.35
1976	3.5	3.5	5.70	52.4	47.3	6.31	6.0	5.7	5.98	1.0	1.1	5.35	36.6	43.1	4.84

* %P = % total production

%A = % total area (approximate only)

Y = Average yield (kg/ha)