Four Decades of Breeding for Varietal Improvement of Irrigated Lowland Rice in the International Rice Research Institute

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Abstract: Since the establishment of the International Rice Research Institute (IRRI) in 1960, IRRI’s breeding effort in varietal improvement for irrigated lowland has passed four decades. Breeding of semi-dwarf rice varieties such as IR8 at IRRI during first decade from 1960 to 1969 resulted in quantum leaps in yield potential, which marked the green revolution in Asia. During the second decade from 1970 to 1979, the primary emphasis of rice improvement has been directed towards incorporation of multiple disease and insect resistance and shortening of growth duration. Grain quality was the main target of crop improvement at IRRI during the third decade from 1980 to 1989. The fourth decade from 1990 to 1999 and beyond was focused again on the improvement of yield potential by developing hybrid rice and new plant type. Up to 1999, 46 indica inbred varieties and 2 indica/indica hybrid rice varieties were developed by IRRI and released in the Philippines for the irrigated lowland rice systems. Large-scale adoption of these improved varieties under modern crop management practices has resulted in a dramatic increase in rice production in major rice-growing countries. The hybrid varieties between indicas increased yield potential by 9% under the tropical conditions. New plant type (NPT) breeding has not yet resulted in an increase in yield potential. The second generation NPT developed by crossing tropical japonica with indica has demonstrated some promising results in terms of improvements in yield potential, disease and insect resistance, and grain quality.

Key words: Breeding, Disease resistance, Grain quality, Insect resistance, Irrigated rice, Yield potential.

Rice is the most important food crop in the world. Rice accounts for more than 40% of calorie intake in tropical Asia. Global rice production must reach 800 million tons of paddy rice to meet projected demand in 2030, which is 200 million tons more than the rice production in 2000 (FAOSTAT, 2003). This additional rice must come mainly from irrigated land in Asia because improving rice yields in most rainfed regions is constrained by drought, flooding, and poor soil quality (Cassman, 1999). Moreover, the scope for expansion of irrigated rice area is limited. Irrigated riceland contributes more than 75% of total rice production although it accounts for about 50% of total rice area. Therefore, the average yield of Asia’s irrigated riceland must increase from 5.0 to 8.0 tons per hectare in the 30-year period from 2000 to 2030. Rice varieties with higher yield potential must be developed to enhance the average farm yields.

Yield potential is defined as the yield of a cultivar when grown in environments to which it is adapted; with nutrients and water non-limiting; and with pests, diseases, weeds, lodging, and other stresses effectively controlled (Evans, 1993). Potential yield refers to maximum yield that could be achieved by a crop in given environments (Evans and Fischer, 1999). Crop simulation model estimates potential yield with plausible physiological and agronomic assumptions. Therefore, yield potential is used mainly for measured comparison of varieties while potential yield for comparisons between different crops and environments (Evans and Fischer, 1999).

Since the establishment of the International Rice Research Institute (IRRI) in 1960, IRRI’s breeding effort for improving rice yield potential of irrigated lowland has passed four decades (Table 1). The first decade from 1960 to 1969 emphasized on dwarf breeding by introducing dwarf genes from Taiwanese varieties to tropical tall land races. During the second decade from 1970 to 1979, the primary emphasis of rice improvement has been directed towards incorporation of multiple disease and insect resistance and shortening of growth duration. Grain quality was the main target of crop improvement at IRRI during the third decade from 1980 to 1989. The fourth decade from 1990 to 1999 and beyond was focused again on the improvement of yield potential by developing hybrid rice and new plant type.

In 1966, IRRI released IR8, the first high-yielding variety. Table 1. Breeding objectives in irrigated rice at IRRI during the last four decades.

| Decade | Years    | Breeding objective                        |
|--------|----------|-------------------------------------------|
| 1st    | 1960-1969| Dwarfism                                  |
| 2nd    | 1970-1979| Multiple disease and insect resistance     |
| 3rd    | 1980-1989| Grain quality                             |
| 4th    | 1990-1999| High yield with hybrid and new plant type  |

Table 1. Breeding objectives in irrigated rice at IRRI during the last four decades.

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Abbreviations: CMS, cytoplasmic male sterility; DS, dry season; IRRI, International Rice Research Institute; NPT, new plant type; WS, wet season.
modern rice variety for the irrigated tropical lowlands. Up to 1999, 46 indica inbred varieties and 2 indica/indica hybrid rice varieties were developed by IRRI and released in the Philippines for the irrigated lowland rice systems (Table 2). These varieties were named as "IR" series until 1988, after which they have been designated as Philippine Seed Board Rice (PSBRc) varieties. Agronomic traits of the 48 varieties were summarized in Tables 3 and 4. These varieties and their derivatives have been widely grown in South and Southeast Asia and account for more than 80% of total rice production in this region (Khush, 1990).

The objectives of this review paper are to summarize what has been achieved in breeding for irrigated rice varieties at IRRI during the first three decades and to describe the progress in developing hybrid rice and new plant type at IRRI in the fourth decade for increasing yield potential of irrigated rice crop.

1. First decade: Development of first tropical semi-dwarf variety, IR8

Scientists at IRRI discovered soon after IRRI's founding in 1960 that the main constraint to grain yield was the architecture of the traditional tropical rice varieties, which were tall and lodged easily with fertilizer-N application (Khush et al., 2001). Tall varieties yielded essentially the same as the lodging-resistant varieties if they were supported with bamboo sticks. The supported tall varieties also responded positively to fertilizer-N application. Therefore, lodging was the primary cause of low yield when the traditional tropical rice varieties were subjected to modern crop management practices (Khush et al., 2001). The success in semi-dwarf wheat proving that breeding rice varieties with short stature could solve the lodging problem. Some semi-dwarf rice varieties were available in the subtropical area of Mainland China in the 1950s. Taichung Native 1 (TN 1), a susceptible to major diseases and insects in the tropics, could solve the lodging problem. Some semi-dwarf rice varieties also responded positively to fertilizer-N application in 1960 that the main constraint to grain yield was the architecture of the traditional tropical rice varieties, which were tall and lodged easily with fertilizer-N application (Khush et al., 2001). Tall varieties yielded essentially the same as the lodging-resistant varieties if they were supported with bamboo sticks. The supported tall varieties also responded positively to fertilizer-N application. Therefore, lodging was the primary cause of low yield when the traditional tropical rice varieties were subjected to modern crop management practices (Khush et al., 2001). The success in semi-dwarf wheat proving that breeding rice varieties with short stature could solve the lodging problem. Some semi-dwarf rice varieties were available in the subtropical area of Mainland China in the 1950s. Taichung Native 1 (TN 1), a semi-dwarf variety from Taiwan, was first planted in the tropics in 1960.

The yield potential of irrigated rice crop described the progress in developing hybrid rice and new varieties at IRRI from 1960 to 1990. What has been achieved in breeding for irrigated rice plant type at IRRI and account for more than 80% of total rice production in this region (Khush, 1990). Tables 3 and 4. These varieties and their derivatives have been widely grown in South and Southeast Asia and account for more than 80% of total rice production in this region (Khush, 1990). The objectives of this review paper are to summarize what has been achieved in breeding for irrigated rice varieties at IRRI during the first three decades and to describe the progress in developing hybrid rice and new plant type at IRRI in the fourth decade for increasing yield potential of irrigated rice crop. **1. First decade: Development of first tropical semi-dwarf variety, IR8**

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introducing dwarfing genes from Taiwanese varieties to tropical tall land races. The short statured parents from Taiwan were Deeg-geo-woo-gen (DGWG), TN1, and I-

Table 3. Growth duration and plant height of 46 inbred and 2 hybrid varieties developed by the International Rice Research Institute and released in the Philippines for irrigated lowland in the tropics. Measurements were taken at maturity. All varieties were grown at IRRI farm in the dry season of 2001.

| Variety | Growth duration (day) | Plant height (cm) |
|---------|-----------------------|-------------------|
| IR5     | 133                   | 141               |
| IR8     | 133                   | 115               |
| IR20    | 119                   | 105               |
| IR22    | 116                   | 91                |
| IR24    | 125                   | 103               |
| IR26    | 133                   | 118               |
| IR28    | 110                   | 102               |
| IR29    | 116                   | 87                |
| IR30    | 116                   | 84                |
| IR32    | 134                   | 104               |
| IR34    | 126                   | 126               |
| IR36    | 110                   | 84                |
| IR38    | 119                   | 96                |
| IR40    | 116                   | 95                |
| IR42    | 133                   | 109               |
| IR43    | 125                   | 96                |
| IR44    | 133                   | 102               |
| IR45    | 125                   | 109               |
| IR46    | 125                   | 109               |
| IR48    | 126                   | 124               |
| IR50    | 110                   | 94                |
| IR52    | 116                   | 97                |
| IR54    | 119                   | 106               |
| IR56    | 110                   | 89                |
| IR58    | 110                   | 85                |
| IR60    | 110                   | 90                |
| IR62    | 110                   | 89                |
| IR64    | 116                   | 97                |
| IR65    | 116                   | 93                |
| IR66    | 116                   | 92                |
| IR68    | 126                   | 119               |
| IR70    | 133                   | 109               |
| IR72    | 116                   | 88                |
| IR74    | 133                   | 104               |
| PSBRc2  | 133                   | 105               |
| PSBRc4  | 116                   | 97                |
| PSBRc10 | 116                   | 82                |
| PSBRc18 | 120                   | 110               |
| PSBRc20 | 116                   | 97                |
| PSBRc26H| 125                   | 109               |
| PSBRc28 | 116                   | 93                |
| PSBRc30 | 120                   | 96                |
| PSBRc52 | 116                   | 96                |
| PSBRc54 | 116                   | 98                |
| PSBRc64 | 133                   | 112               |
| PSBRc72H| 127                   | 115               |
| PSBRc80 | 116                   | 103               |
| PSBRc82 | 116                   | 102               |

Table 4. Yield components of 46 inbred and 2 hybrid varieties developed by the International Rice Research Institute and released in the Philippines for irrigated lowland in the tropics. Measurements were taken at maturity. All varieties were grown at IRRI farm in the dry season of 2001.

| Variety | Panicles per m² | Spikelets per panicle | Spikelet filling % | 1000-grain weight (g) |
|---------|------------------|-----------------------|--------------------|-----------------------|
| IR8     | 557              | 126                   | 65                 | 21                    |
| IR22    | 322              | 111                   | 63                 | 27                    |
| IR26    | 377              | 117                   | 77                 | 19                    |
| IR28    | 419              | 71                    | 81                 | 22                    |
| IR30    | 312              | 98                    | 77                 | 26                    |
| IR32    | 380              | 106                   | 74                 | 21                    |
| IR34    | 414              | 77                    | 74                 | 23                    |
| IR36    | 469              | 97                    | 78                 | 22                    |
| IR38    | 462              | 66                    | 90                 | 21                    |
| IR40    | 411              | 77                    | 70                 | 22                    |
| IR42    | 308              | 114                   | 66                 | 25                    |
| IR44    | 451              | 75                    | 69                 | 21                    |
| IR46    | 333              | 71                    | 82                 | 24                    |
| IR48    | 475              | 75                    | 86                 | 19                    |
| IR50    | 328              | 83                    | 76                 | 28                    |
| IR52    | 409              | 65                    | 75                 | 25                    |
| IR54    | 348              | 82                    | 79                 | 27                    |
| IR56    | 586              | 93                    | 82                 | 22                    |
| IR58    | 235              | 122                   | 74                 | 27                    |
| IR60    | 483              | 88                    | 70                 | 19                    |
| IR62    | 341              | 77                    | 81                 | 24                    |
| IR64    | 293              | 103                   | 71                 | 24                    |
| IR65    | 508              | 76                    | 81                 | 24                    |
| IR67    | 417              | 70                    | 85                 | 21                    |
| IR69    | 458              | 77                    | 80                 | 20                    |
| IR70    | 453              | 80                    | 80                 | 22                    |
| IR72    | 371              | 78                    | 84                 | 25                    |
| IR74    | 376              | 81                    | 73                 | 23                    |
| IR76    | 384              | 89                    | 79                 | 21                    |
| IR78    | 371              | 112                   | 73                 | 30                    |
| IR8     | 389              | 92                    | 76                 | 20                    |
| IR80    | 290              | 70                    | 75                 | 22                    |
| IR82    | 415              | 93                    | 72                 | 24                    |
| PSBRc2  | 533              | 95                    | 77                 | 24                    |
| PSBRc4  | 394              | 81                    | 83                 | 23                    |
| PSBRc10 | 381              | 92                    | 77                 | 25                    |
| PSBRc18 | 427              | 86                    | 76                 | 22                    |
| PSBRc20 | 394              | 89                    | 74                 | 22                    |
| PSBRc26H| 277              | 128                   | 64                 | 24                    |
| PSBRc28 | 412              | 88                    | 73                 | 22                    |
| PSBRc30 | 369              | 74                    | 69                 | 24                    |
| PSBRc52 | 514              | 83                    | 67                 | 20                    |
| PSBRc54 | 372              | 113                   | 62                 | 21                    |
| PSBRc64 | 347              | 90                    | 76                 | 23                    |
| PSBRc72H| 335              | 114                   | 73                 | 27                    |
| PSBRc80 | 375              | 99                    | 70                 | 23                    |
| PSBRc82 | 420              | 95                    | 74                 | 25                    |

geo-tse. The eighth cross that IRRI breeders made in late 1962 was between Peta, a tall, vigorous variety from Indonesia, and DGWG. From that cross, IR8, the first semi-dwarf, high yielding modern rice variety for the irrigated tropical lowlands, was selected (Fig. 1). After the release of IR8, three semi-dwarf varieties, IR5, IR20, and IR22 were developed and released in the Philippines during the first decade from 1960 to 1969.

IR8 has semi-dwarf stature (about 115 cm tall), a profuse tillering growth habit, stiff culm, and erect, moderately sized, dark-green leaves (Chandler, 1969). It is responsive to fertilizer and is photoperiod insensitive compared with many traditional varieties. It has medium growth duration of 130 to 135 d. The birth of IR8 resulted in quantum leaps in yield potential from 6 to 10 tons per hectare in the tropics (Chandler, 1982). The increase in yield potential was due to the improvement in harvest index. Although selections were guided by short stature, and resistance to lodging, breeders were unintentionally selecting for improved canopy architecture, light penetration, and efficient biomass partitioning
1962   \( F_0 \)   Pusa x Dec-gro-wao-gno
   (tall) (dwarf)
   \[ \text{Produced 130 seeds} \]

1963   \( F_1 \)   Selected 298 best plants
   \[ \text{Grew 298 pedigree rows} \]

1964   \( F_2 \)   Selected 288 row and 3rd plant
   and designated as IR8-288-3
   \[ \text{Produced basic seed stock} \]

1965   \( F_3 \)   Produced pure strain for trials

1966 dry season   IR8-288-3 produced 103 t ha\(^{-1}\)

Nov. 14, 1966   IR8-288-3 was named as IR8

Fig. 1. Scheme of breeding procedure for the development of IR8.

proved modern high yielding varieties such as fertilizer application and increased population density, resulted in increased disease and insect damages. In tropical Asia, the most common diseases of the rice crop were blast, bacterial blight, sheath blight, tungro virus and grassy stunt virus; the most common insects were brown planthopper, green leafhopper, stem borer, and gall midge. The main emphasis in the IRRI's breeding program in the 1970s was incorporation of disease and insect resistance and shortening of growth duration (Khush et al., 2001). Large germplasm collections were screened at IRRI to identify donors for resistance to most of the diseases and insects. Varieties with resistance to as many as four diseases and four insects have been bred using these donors.

During the second decade from 1970 to 1979, 17 rice varieties were developed and released in the Philippines for tropical lowlands. Most notable was IR36. IR36 was bred using 12 varieties and one wild species from six countries (Khush et al., 2001). In 1971, IR1561 was crossed with a plant from the \textit{Oryza nivara}/IR24 backcross. This \( F_2 \) was topcrossed with a third parent (CR94-13). In 1972, \( F_3 \) population was grown. In December 1972, 937 plants were grown in a pedigree nursery as \( F_4 \) rows. In 1973 and 1974, \( F_4 \) and \( F_5 \) progenies were evaluated. IR2071-62S-1-2S2 was selected among these progenies and was named as IR36 by the Philippine Seed Board in 1976. IR36 was the first IRRI improved variety with multiple disease and insect resistance (bacterial blight, blast, tungro, grassy stunt, brown planthopper, green leafhopper, stem borer, and gall midge). It had other desirable agronomic traits such as short growth duration of 110 days, good grain quality (long, slender and translucent grains), and tolerance to abiotic stresses. Its yield potential was evaluated at IRRI, in Philippine Seed Board trials conducted at 10 sites, and in the International Rice Testing Program nurseries. It outyielded the IR30 check during both the dry and wet seasons. Because of the desirable combination of these adaptive traits, IR36 was accepted widely and became the most widely planted rice variety in the 1980s, grown on about 11 million hectares annually from 1980 to 1989 (Khush et al., 2001). IR36 was gradually replaced by IR64 but is still planted in Indonesia, India, and the Philippines. Until today, IR36 is still the variety of rice or any other food crop species that is planted on largest accumulated area in the world.

3. Third decade: Development of variety with high grain quality, IR64

The earliest IRRI varieties such as IR5 and IR8 had poor grain quality with bold and chalky grains that were easily broken during milling (Khush and Virk, 2002). All the varieties released after IR5 and IR8 had improved milling quality with slender and translucent grains and good milling recovery. However, improvement in cooking quality was slow because the donors for
4. Fourth decade: Development of hybrid rice and new plant type

Annual rice production increased at the rate of 2.8% between 1975 and 1985 through the use of fertilizer-responsive improved varieties. However, signs of slower growth were evident in the late 1980s when the growth in grain production fell below that of population. In the late 1980s, IRRI's strategic plan focused again on the improvement of yield potential by developing hybrid rice and new plant type (IRRI, 1989). During the fourth decade from 1990 to 1999, 12 varieties were developed for irrigated tropical lowlands and released in the Philippines. Among the 12 varieties, two were indica hybrids developed using the three-line system.

1) Development of hybrid rice

Hybrid rice have been grown in China since 1976 and today more than 50% of China's rice area is now planted to rice hybrids (Yuan et al., 1994). In the late 1970s, these Chinese rice hybrids were evaluated in tropical lowland environments of Southeast Asia. They were poorly adapted and were susceptible to diseases and insects (Virmani et al., 1982). In 1978, IRRI began to develop hybrids for the tropical lowlands (Khush, 1995). Cytoplasmic male sterility (CMS) and the fertility restoration system are the most common tools used for breeding rice hybrids for the tropics. During the third and fourth decades from 1979 to 1999, IRRI has bred many CMS, maintainer, and restorer lines. Two IRRI CMS lines, IR38023A and IR62829A, are the most popular parents for development of rice hybrids in the tropics. In 1994, the Philippine government released PSBRc26H, the first hybrid combination for cultivation in irrigated lowlands in the Philippines. This rice hybrid used IR62829A as the sterile parent. In 1997, Philippine government released another hybrid combination, PSBRc72H, whose sterile parent was IR38025A. Both combinations are hybrid varieties between indica parents and were developed by IRRI using the three-line system. Some hybrid rice developed at IRRI have shown a yield advantage of about 15% compared to the best inbred varieties when grown in farmers' fields (Virmani, 2001). Farmers usually produce 1 to 1.5 t/ha additional yield by growing hybrid rice. Peng et al. (1999) compared the yield potential of hybrids and indica inbred varieties grown in several field experiments. The results suggest an increase in yield potential of indica hybrids of about 9% compared with the best indica inbred varieties under tropical conditions. The higher yield potential of indica hybrids compared with indica inbred varieties was attributed to the greater biomass production rather than harvest index.

Commercialization of hybrid rice has been initiated in Vietnam (1992), India (1994), the Philippines (1998), and Bangladesh (1999) (Virmani, 2001). Currently, about 280,000, 150,000, 5,000, and 250,000 ha were planted with hybrids in these countries, respectively. However, the area planted to hybrid rice is still quite small in the tropical countries. Major limitations to the large-scale adoption of hybrid rice technology in the tropics are: inadequate level of standard heterosis for grain yield, poor agronomic management of hybrid rice, low yield of hybrid seed production, high seed cost, and poor grain quality. Once these limitations are eliminated by extensive research, area planted to hybrid rice should increase in the tropics.

2) Development of new plant type

Development of semi-dwarf rice varieties in the 1960s is the most striking example of a successful improvement in plant type. In the late 1980s, it was postulated that the stagnant yield potential of semi-dwarf indica inbred rice varieties might be the result of the plant type common to all of this germplasm. They produce a large number of unproductive tillers and have excessive leaf area which may cause mutual shading and a reduction in canopy photosynthesis and sink size, especially when grown under direct-seeded conditions (Dingkuhn et al., 1991). Most of these varieties have high tillering capacity and small panicles. A large number of unproductive tillers, limited sink size and lodging susceptibility were identified as the major constraints to yield improvement in these varieties. Simulation models predicted that a 25% increase in yield potential was possible by modification of the following traits of the current plant type (Dingkuhn et al., 1991): (1) enhanced leaf growth combined with reduced tillering during early vegetative growth, (2) reduced leaf growth and greater foliar N concentration during late vegetative and reproductive
growth, (3) a steeper slope of the vertical N concentration gradient in the leaf canopy with a greater proportion of total leaf N in the upper leaves, (4) increased carbohydrate storage capacity in stems, and (5) a greater reproductive sink capacity and an extended grain-filling period.

To break the yield potential barrier, IRRI scientists proposed modifications to the high-yielding indica plant type in the late 1980s and early 1990s. The proposed new plant type (NPT) has low tillering capacity (3 to 4 tillers when direct seeded), few unproductive tillers, 200 to 250 grains per panicle, a plant height of 90 to 100 cm, thick and sturdy stems, leaves that were thick, dark green, and erect, a vigorous root system, 100 to 130 days growth duration, and increased harvest index.

Breeding work began in 1989 when about 2,000 entries from the IRRI germplasm bank were grown during the dry (DS) and wet (WS) seasons to identify donors for the desired traits (Khush, 1995). Donors for low tillering trait, large panicles, thick stems, vigorous root system, and short stature were identified in the "bulu" or javanica germplasm mainly from Indonesia. This germplasm is now referred to as the tropical japonica (Khush, 1995). Hybridization was initiated in the 1990 DS. The F1 progenies were grown in the 1990 WS, F2 progenies in the 1991 DS, and the first pedigree nursery in the 1991 WS. Since then, more than 2,000 crosses were made, 100,000 pedigree lines were produced, breeding lines with the desired morphological ideotype traits were selected, and about 500 NPT lines have been evaluated in observational yield trials.

The NPT lines based on tropical japonicas were developed in less than 5 years. They were grown in a replicated observational trial for the first time in late 1993. As intended, the NPT lines had large panicles, few unproductive tillers, and lodging resistance. Grain yield was disappointing, however, because of low biomass production and poor grain filling. Reduced tillering capacity might contribute to low biomass production because the crop growth rate during vegetative stage of NPT lines was lower than the indica varieties. Less biomass production was also associated with poor grain filling, but the cause-and-effect relationship has not been established. The poor grain filling of NPT lines was probably due to lack of apical dominance within a panicle (Yamagishi et al., 1996), compact arrangement of spikelets on the panicle (Khush and Peng, 1996), a limited number of large vascular bundles for assimilate transport (S. Akita, personal comm.), and source limitation due to early leaf senescence (Ladha et al., 1998). The NPT lines are also susceptible to diseases and insects and have poor grain quality.

In 1995, development of second-generation NPT lines was initiated by crossing tropical japonica NPT lines with elite indica parents. Multiple site-year comparisons of NPT lines with highest yielding indica varieties have shown that the original NPT design did not have sufficient tillering capacity. An increase in tillering capacity is needed to increase biomass production and to improve compensation when tillers are lost to insect damage or other causes during the vegetative stage. A slightly smaller panicle size without change in panicle length also appeared to be advantageous to reduce the compact arrangement of spikelets. Some second generation NPT lines (F2 generation) with the above refinements have then been selected and were planted in a replicated observation trial for the first time in the 1998 WS. These second-generation NPT lines have been tested in breeder's replicated yield trial in the 2001 DS (Table 5) and in a replicated agronomic trial in the 2002 DS (Fig. 2) and results are promising. In the 2001 DS, yield components were measured from small plots and based on 12-hill samples (0.5 m2 harvest area). We could see relative difference in grain yield and its attributes among first generation NPT, second generation NPT and indica checks from this study. It was not reliable to determine the yield potential of second-generation NPT lines from Table 5 because of small plots and small harvest areas. In the replicated agronomic trial conducted in the 2002 DS, plot size was 25 m2 and grain yield was measured from 5 m2 harvest area. Yield potential of second generation NPT lines, hybrid varieties, and indica inbred

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Table 5. Yield and yield components of second and first generation new plant type lines and indica checks grown at IRRI farm in the dry season of 2001.

| Genotype | Grain yield (t ha⁻¹) | Panicles m⁻² | Spikelet Panicle | Grain filling (%) | Grain wt (mg) |
|----------|----------------------|---------------|-----------------|------------------|--------------|
| **Second generation new plant type lines** | | | | | |
| IR72158-16-3-3 | 10.3 | 345 | 144 | 70 | 26.9 |
| IR72158-16-3-1 | 10.1 | 308 | 151 | 72 | 27.0 |
| IR73459-120-2-2-3 | 10.0 | 360 | 126 | 78 | 25.5 |
| IR73697-12-2-3 | 9.8 | 300 | 138 | 75 | 28.4 |
| IR7385-65-3-1 | 9.4 | 391 | 115 | 79 | 24.2 |
| IR73707-45-3-2-3 | 9.3 | 306 | 140 | 77 | 25.3 |
| **First generation new plant type lines** | | | | | |
| IR68552-100-1-2-2 | 9.2 | 220 | 179 | 79 | 25.9 |
| IR65504-44-2-3 | 6.6 | 217 | 181 | 60 | 25.3 |
| **Indica checks** | | | | | |
| IR72 | 6.7 | 453 | 82 | 76 | 21.5 |
| PSRC18 | 7.1 | 372 | 102 | 73 | 23.1 |
check can be compared from this study. Although second generation NPT lines did not break the yield barrier of 10 t/ha as did by some hybrid varieties, they produced significantly higher yield than indica check variety (Fig. 2). It was observed that some second generation NPT lines produced more biomass than indica inbred varieties due to their taller stature and larger leaf area. They also had larger panicles (more spikelets per panicle) as compared with indica inbred varieties. The simulated climatic yield potential for the 2001 DS is 7.9 t ha⁻¹, but 10 t ha⁻¹ for the 2002 DS. The yield attributes of second generation NPT for achieving 11.0 t ha⁻¹ are listed in Table 6.

Indica germplasm also helped improve other NPT attributes such as grain quality and disease and insect resistance. As the effort of breeding for second generation NPT continuous, it is expected that more elite second generation NPT lines with improved yield potential, disease and insect resistance, and grain quality will be developed at IRRI. These elite second generation NPT lines should increase the yield potential of irrigated lowland rice by about 10% in the tropics.

5. Conclusion

Breeding of semi-dwarf rice varieties at IRRI during first decade from 1960 to 1969 resulted in quantum leaps in yield potential, which marked green revolution in Asia. During the second and third decades, IRRI breeders improved disease and insect resistances, grain quality and shortened growth duration while maintaining the yield potential. Large-scale adoption of these improved varieties under modern crop management practices has resulted in a dramatic increase in rice production in major rice growing countries. During the fourth decade, IRRI developed hybrid rice and new plant type for the tropical environments. The hybrid varieties between indicas increased yield potential by 9%. New plant type breeding has not yet resulted in an increase in yield potential. The second generation NPT developed by crossing tropical japonica NPT lines with elite indica parents is expected to improve yield potential, disease and insect resistance, and grain quality. Further increase in yield potential is possible through inter-subspecific hybrid (indica x tropical japonica NPT) and biotechnology.

Table 6. Yield attributes of second generation new plant type lines.

| Traits                             | Values |
|------------------------------------|--------|
| Panicles per m²                   | 330    |
| Spikelets per panicle              | 150    |
| Grain filling                      | 80%    |
| Grain weight (oven dry weight)     | 25 mg  |
| Aboveground total biomass (at 14% moisture content) | 22 t ha⁻¹ |
| Harvest index                      | 50%    |
| Grain yield (at 14% moisture content) | 11.0 t ha⁻¹ |

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