SABRAO Journal
of Breeding and Genetics
35(2) 135-143, 2003

CHRONOLOGICAL CHANGE OF YIELD ABILITY AND ITS RELATED TRAITS IN RICE VARIETIES OF HOKKAIDO

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SUMMARY

Hokkaido is one of the regions where rice is cultivated under the coolest climatic conditions. Yielding abilities and plant types of 32 varieties, which had been widely cultivated in Hokkaido during the past 110 years, were compared. The varieties were divided into the following three groups: Group A (indigenous varieties and pure line selections from some of them, viz. nine entries), Group B (12 varieties developed by hybridization and Group C (11 varieties newer than those in Group B). One or two seedlings per hill were transplanted to the paddy field at a spacing of 33 × 15 cm in four years. An increasing trend of panicle weight per hill from the indigenous to newer varieties was noticed in the case of two seedlings per hill, whereas such a trend was not noticed in the case of one seedling per hill. Regarding panicle weight per hill, the three groups were in the order of A < B < C in the case of two seedlings per hill, whereas differences among the groups in the case of one seedling per hill were small. Similar inter-group differences were shown in number of panicles per hill as well as panicle weight per hill. In number of spikelets per panicle, Group C had fewer than Group A or B. Group C was higher than Group A in percentage of panicle weight (% harvest index). The three groups were in the order of A > B > C in culm length and in angle of flagleaf.

Key words: *Oryza sativa*, yield, yield components, plant type, plant breeding

Hokkaido is one of the regions where rice is cultivated under the coolest climatic conditions. However, rice cultivation had been essentially restricted to the southernmost part of Hokkaido before 1891 (Hokkaido National Agricultural Experiment Station, 1967). The earliness and high cold tolerance at the booting stage of the indigenous variety 'Akage' led to the expansion of rice cultivation northward to the Kamikawa district around Asahikawa, which is one of the major rice-producing districts Hokkaido at present. The variety 'Bozu' was selected from 'Akage' by a farmer and the varieties 'Bozu 5' etc. were developed out of pure-line selections from 'Bozu' at a few national agricultural experiment stations in Hokkaido, thus, replacing 'Akage'. In 1913, many varieties such as 'Fukoku', 'Eiko' and 'Yukara' were officially developed after hybridization breeding was initiated. These improved varieties increased yields (Tanaka et al., 1968; Samoto, 1971), being complemented by cultivation techniques, viz. the protected upland nursery and the application of chemical fertilizer. 'Yukara' is characterized by short culm and erect leaves (Samoto, 1971) and was used as a parent of subsequent high-yielding varieties like 'Ishikari' (Ishikari and Shiokari, 1980). 'Ishikari' yielded 6.03 t/ha of brown rice at the high fertilizer level at the agricultural experiment station where it was raised (Wada et al.,

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1986). In 1980, however, the breeding priority shifted from yield to eating quality, resulting in the release of the excellent eating-quality variety, 'Kirara 397' (Sasaki et al., 1990). 'Kirara 397' was planted to 59% of the total rice area of Hokkaido in 2001. Wada et al. (1986) and Sasaki et al. (1990) reported that the yield abilities of 'Kirara 397' and 'Yukihikari', another excellent eating-quality variety, are similar to that of a previous leading variety 'Ishikari'. Hence, it appears that no or little progress in yield ability has been achieved over the last 20 years.

This study compared the yielding abilities and plant types of 32 varieties released before 1980, which had been widely cultivated in Hokkaido during the past 110 years. It aims to clarify genetic progress from old low yielders to high yielders and examined the relationships among yield, yield components, and other traits.

MATERIALS AND METHODS

Thirty-two successively leading varieties widely cultivated in Hokkaido before 1990 were used and were divided into three groups (Table 1). Group A consisted of nine indigenous varieties and pure line selections; Group B consisted of 12 varieties developed by hybridization breeding; and Group C consisted of 'Yukara', 'Ishikari' and nine other varieties. The first variety, 'Fukoku' replaced varieties of Group A.

The 32 varieties were grown in Takushoku University, Hokkaido Community College at Osamunai in 1977, 1978, 1979, and 1982. Fertilizer application, sowing and transplanting dates, and number of seedlings per hill recorded in the four years are shown in Table 2. The total amount of nitrogen fertilizer applied per year ranged from 153 to 170 kg/ha. The rather heavy fertilizer application was due to the over-percolation of the paddy field. One seedling per hill was transplanted to the paddy field at a spacing of 33 x 15 cm in 1977 and 1978. Two seedlings per hill were transplanted using the same hill spacing in 1979 and 1982. Sixty hills (20 hills x three rows) for each variety were grown during each of the four years and 10 hills per variety were sampled from the central rows at maturity. Data gathered for the four years include panicle number per hill and spikelet number per panicle. Also measured were panicle weight per hill after air drying in 1978, 1979 and 1982; total plant weight per hill without roots was measured after air drying for 1982; length and width of spikelet, and 100-kernel weight for 1977; and the angle between the uppermost part of the main culm and the flag leaf at maturity for1977 and 1978.

No or a few non-productive tillers were observed in each hill of the 32 varieties in the four years. This was due to the absence of an interval between the maximum tiller number stage and the initiation of panicle development owing to their early maturity. Adequate top-dressing was performed (Table 2).

RESULTS AND DISCUSSION

The relationship between panicle weight per hill and the first year of the official recommendation (year of release) in 30 varieties was determined (Fig.1). Two indigenous varieties, namely: 'Akamoro' and 'Iburiwase' were not included because they have not been officially recommended for release. An increasing trend of panicle weight per hill from the indigenous to newer varieties was observed with the use of two seedlings per hill in 1979 and 1982, whereas, no significant increasing tendency was observed with the use of one seedling per hill in 1978 (data not collected in 1977).

The mean values of the three varietal groups in 13 agronomic traits were determined (Table 3). The three groups were in the order of A < B < C for panicle weight per hill in the case of two seedlings per hill during 1979 and 1982, and the increase from Group A to Group B was larger than that from Group B to Group C. On the other hand, differences among the three groups in the case of one seedling per hill in 1978 were small as compared with those in the case of two seedlings per hill. Differences among the three groups in number of panicles per hill were similar to those observed in panicle weight per hill in each year. The increase in this trait from one to two seedlings per hill in Group C was greater than that in Group A. In terms of number of spikelets per panicle, Group C had fewer than Group A or B in each of the three years except 1979. Differences in total weight per hill were similar to those observed in panicle weight per hill. In terms of percentage of panicle weight (% harvest index), Group C was significantly higher than Group A. Differences in mean panicle weight (panicle weight/panicle number) were similar to those in number of spikelets per panicle in each year. Notable decreases in mean straw weight (straw weight/panicle number) from Groups A to C were observed. The difference in this trait between Groups A and C was greater than that in mean panicle weight, resulting in the high percentage of panicle weight for Group C. There were no significant differences among the three groups in 100-kernel weight as well as spikelet width. Regarding spikelet length, Group B was shorter than the other two groups. The three groups were in the order of A > B > C not only in culm length but also in angle of flagleaf.

Tanaka et al. (1968) and Samoto (1971) observed a consistent progress of yield in seven varieties from 'Akage' to 'Yukara', accompanied by an increase in number of panicles. This study indicates that some further progress in yielding ability was gained in varieties released after 'Yukara' (Fig. 1 and Table 3). All varieties of Group C possessed 19 or more panicles in the case of two seedlings per hill (Table 1). Varieties of Hokkaido have the earliest maturity according to the global standard. It is inferred that the greater biomass produced during the limited growth period, resulting from vigorous tillering ability, contributed to the yield increase in Group C (Table 3). On the other hand, Group B included a large variation in plant type: *e.g.* 'Ishikarishiroke' produced 13 panicles per hill but possessed the largest number of spikelets per panicle of all varieties (Table 1). It appears that various plant types had been tried before 'Yukara' was released. The percentage of spikelet setting on the secondary rachis-branches in 'Ishikarishiroke' was higher than that in the varieties of Group C (Murai, 1995). Recent breeders in Hokkaido do not select such panicle type, since secondary-branch spikelets readily contain green-unripened kernels during cool-summer years owing to the first frost before maturity resulting from delay of heading.

Donald and Hamblin (1976) recommended the use of harvest index as a criterion for selection in cereal breeding. The percentage of panicle weight (% harvest index) in Group C increased from that in Group A, since the decrease of mean (single) straw weight was greater than that of mean (single) panicle weight (Table 3). In Group C, the decreases of mean (single) straw weight and mean (single) panicle weight were closely related with the reductions of culm length and number of spikelets per panicle, respectively. Thus, the enhancement of harvest index had been achieved during the long process of varietal improvement, even if breeders did not directly select for it

Almost all varieties of Group C possessed short culms and erect leaves (Table 1) that enhance lodging tolerance and lessen mutual shading. Such plant type is also indispensable to tropical high-yielding rice varieties (Tanaka et al., 1966). Tanaka et al. (1968) reported that yields of 'Yukara' and other improved varieties increased with the enhancement of fertilizer level, in contrast to no or small fertilizer response in 'Akage' and other old varieties. In the present study, the yield in Group C increased noticeably from one to two seedlings per hill, whereas Group A showed a small increase in yield with the alteration of seedling number (Table 3). Consequently, improved varieties like those of Group C can exert their high-yielding abilities not only with high fertilizer application but also with the use of two or more seedlings per hill.

Table 1. Agronomic traits in the 32 varieties of Hokkaido.

Group	Name of variety	Year of recommendation	No. of [1] spikelets per hill	No. of [1,5] spikelets per panicle	100 [2] kernel weight (g)	Main [3] culm length (degree)	Angle of [3] flagleaf (degree)	First [4] heading time (in June)
	Akamoro		16.8	96.4	2.01	81.1	91	21
	Iburiwase		10.9	100.6	2.64	80.1	104	19
	Akage	1905	11.6	100.6	2.22	76.3	94	17
	Tokachikuroge	1914	18.8	105.4	2.13	74.9	96	25
A	Igoshiwase	1914	17.4	72.2	2.10	67.9	102	20
	Bozu	1914	11.8	108.8	2.27	82.9	100	—
	Bozu 2	1919	11.3	102.5	2.27	83.8	105	25
	Bozu 5	1919	13.7	85.9	2.24	78.7	106	23
	Kitamiakage	1923	21.1	103.2	2.05	73.4	96	22
	Fukoku	1935	16.0	104.7	2.28	68.9	89	21
	Norin 20	1941	19.0	86.6	1.99	65.1	80	14
	Eiko	1941	19.0	127.6	2.30	69.2	52	26
	Ishikarishiroke	1941	13.0	134.9	2.27	79.8	68	25
	Kamenishiki	1944	27.1	102.3	2.20	71.1	114	29
B	Shinei	1951	21.6	98.9	2.28	69.3	100	28
	Toyohikari	1953	17.6	116.7	2.43	68.7	92	26
	Terunishiki	1953	26.4	108.5	2.28	63.6	82	25
	Shinsetsu	1954	24.7	100.5	2.35	69.1	77	27
	Fukuyuki	1958	26.3	102.1	2.09	65.5	74	25
	Mimasari	1959	27.3	91.3	2.29	56.2	76	26
	Sasahonami	1961	19.4	90.8	2.14	63.9	76	20
	Yukara	1962	23.3	87.2	2.39	54.9	49	27
	Shiokari	1963	19.0	112.0	2.10	68.5	70	22
	Horyu	1964	19.8	103.6	2.34	64.2	82	20
	Uryu	1965	19.7	98.1	2.08	65.6	106	25
	Himehonami	1966	28.9	119.4	2.21	59.1	82	27
C	Sorachi	1967	32.2	88.2	2.23	57.6	71	26
	Narukaze	1970	30.5	60.3	2.20	56.2	30	20
	Matsumae	1970	26.6	105.4	2.38	58.5	48	28
	Ishikari	1971	20.0	85.1	2.49	57.9	47	20
	Yunami	1971	26.7	76.8	2.46	53.5	43	20
	Kitahikari	1975	22.2	91.0	2.29	54.3	58	24

[1] The mean of data in 1979 and 1982 (2 seedlings/hill);
[2] Data in 1977 (1 seedling/hill);
[3] The mean data in 1977 and 1978 (1 seedling/hill);
[4] Data in 1978 (1 seedling/hill); and
[5] The average of the largest three panicle in each hill.

Fig. 1. Relationship between chronology of varieties and panicle weight per hill in 1978, 1979, and 1982. *LSDs of panicle weight per hill at the0.05 probability level were 4.0, 5.2, and 6.6 g in 1978, 1979, and 1982, respectively.

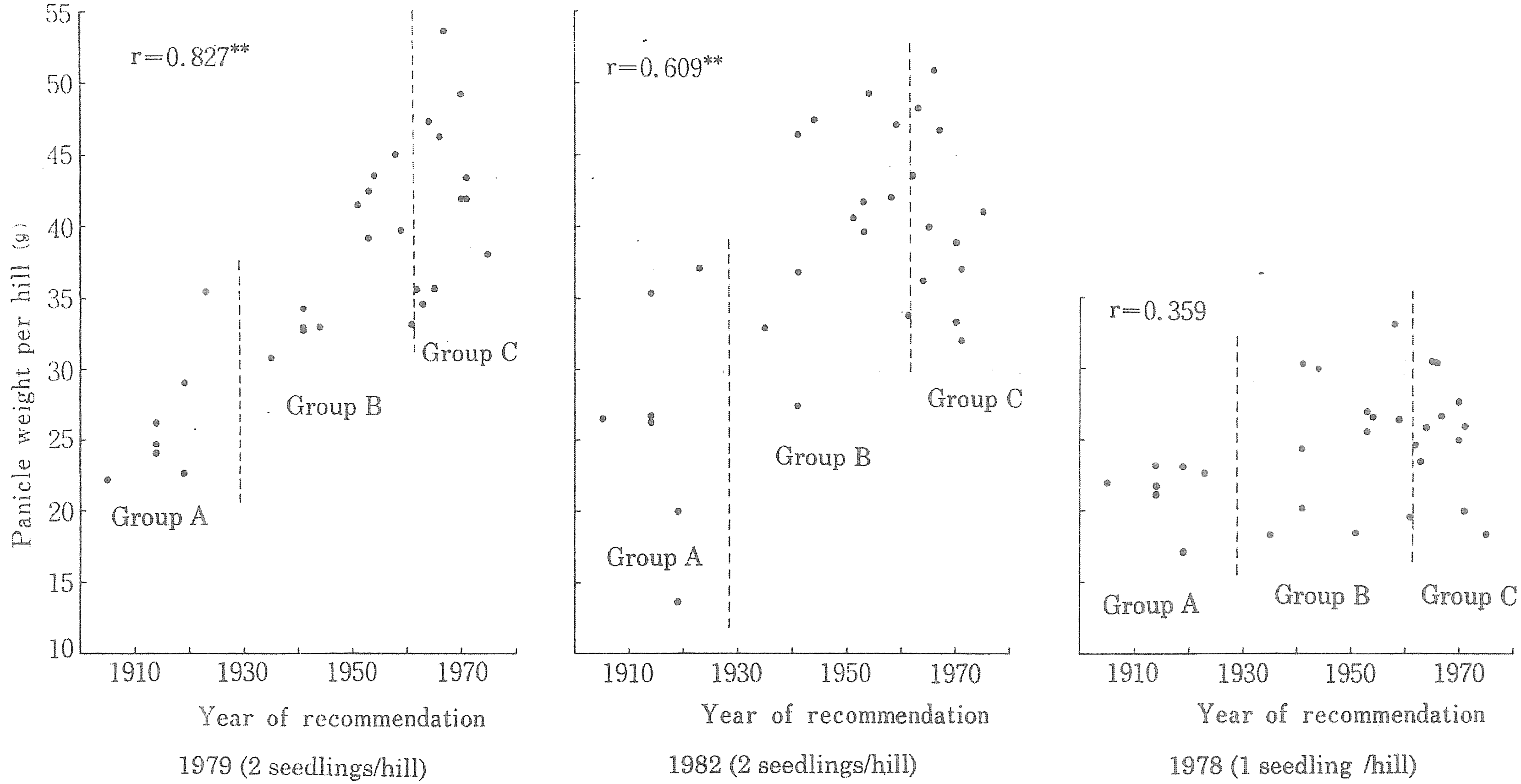

Table 2. Amount of fertilizer applied, dates of sowing and transplanting, and number of seedlings per hill for four years.

Year	Amount of fertilizer applied (kg/10a)			Date of sowing (Date in April)	Date of transplanting (Date in May)	No. of seedlings
	Basal dressing	Top-dressing				
	$N-P_2O_5-K_2O$	N[1]	Date			
1977	14.0-15.5-13.0	3.5	June 27	25	28	1
1978	14.0-15.5-13.0	2.8	June 19	25	26	1
1979	13.1-14.5-12.1	2.3	July 2	23	24	2
1982	13.1-14.5-12.1	2.3	June 28	26	28	2

[1] From urea.

In the ordinary process of rice breeding in Japan, no selection is performed for the F_2 population and F_3 bulk population. The selection for individual plants starts in the F_4 bulk population (grown with one plant per hill). For lines, plant selection is performed in the F_5 lines raised from the selected F_4 plants (grown with one plant per hill). Yield test with two or three seedlings per hill is performed for F_6 lines. Further selection for lines and various tests for yield, eating quality, disease resistance, regional adaptability etc. are repeated until F_{10} generation and one or more elite inbred lines are determined. The selection for F_4 plants regarding plant type and maturity is conducted through field observation. As previously mentioned, the difference in panicle weight per hill between the high-yielding varieties and low-yielding ones was small with the use of one plant per hill. Hence, skillful eyes of an experienced breeder are necessary for adequate plant selection in the F_4 generation or in an earlier generation.

A genetic analysis for five out of the 32 varieties indicated that the variation in culm length is controlled by two or more minor genes (Murai and Kinoshita, 1986); hence, the reduction of culm length in Group C including 'Ishikari' was achieved by the accumulation of minor genes. The current leading variety 'Kirara 397' has similar culm length and plant type with those of 'Ishikari' (Wada et al., 1986; Sasaki et al. 1990). In Southeast Asia and other countries, short-culm and high-yielding rice varieties are widely grown, which carry the dwarfing gene *sd1* originating from the Taiwanese variety 'Dee-geo-woo-gen' (De Datta et al., 1968; Peng et al., 1999). However, the high-yielding ability of such varieties is ascribable to QTL genes with effects on increasing spikelet number per panicle (Yagi et al., 2001; Nagata et al., 2002), although *sd1* itself has a pleiotropic effect in reducing spikelet number per panicle resulting in a smaller sink size (Murai et al., 1982, 1995, and 2002a,b; Murai and Yamamoto, 2001). In fact, an *sd1* isogenic line showed a lower yield by 6% than its recurrent parent 'Shiokari', *viz.* a variety of Group C, resulting from its smaller spikelet number per panicle caused by the pleiotropic effect of *sd1* (Murai et al., 2002a). Furthermore, its culm length was noticeably short (43.4 cm), since *sd1*was shown to reduce that of 'Shiokar' (69.9 cm) by 26.5 cm. On the other hand, *sd1* has a pleiotropic effect on lowering the cool temperature tolerance at the booting stage as well as the flowering stage (Murai et al., 1991 a,b, 1992). Thus, *sd1* would give excessive dwarfness and fragility to cool weather for current Hokkaido varieties such as 'Kirara 397'. Hence, it is not recommended to use *sd1* in developing lodging-tolerant varieties in Hokkaido and other rice-growing areas readily damaged by cool weather.

Table 3. Comparison of the three varietal groups in traits concerning yield.

Trait	1982 (2 seedlings/hill) Group			1979 (2 seedlings/hill) Group			1978 (1 seedling/hill) Group			1977 (1 seedling/hill) Group		
	A	B	C	A	B	C	A	B	C	A	B	C
Panicle weight per hill (g)	27.2**	40.4	40.7(**)	25.6**	37.3*	42.5(**)	21.5*	25.8	25.3(*)			
Total weight per hill (g)	45.8**	63.9	63.1(**)									
Straw weight per hill (g)	18.7**	23.5	22.4(**)									
Percentage of panicle weight	58.6	63.0	64.3(*)									
No. of panicles per hill	14.3**	21.8	22.7(**)	15.3*	21.0*	26.1(**)	10.8	13.2	14.8(**)	11.2*	13.9	15.3(*)
No. of spikelets per panicle[1]	113.5	111.8	98.0	81.1**	99.0	88.7	108.1	106.1*	91.4(*)	94.7	95.7*	77.5(**)
Mean panicle weight (g)	1.93	1.92	1.83	1.75	1.83	1.66	2.12	2.03	1.74			
Mean straw weight (g)	1.34**	1.14**	1.02(**)									
100-kernel weight (g)										2.21	2.24	2.29
Spikelet length (mm)										6.71**	6.36**	6.52
Spikelet width (mm)										3.42	3.48	3.43
Culm length[2] (cm)	84.1*	74.6*	65.9(**)				78.0**	67.9**	61.1(**)	77.4**	67.0**	56.7(**)
Angle of flag leaf[3] (degree)							102.2*	90.2**	60.9(**)	96.1*	72.5	63.1(**)

[1] The panicle of main culm in 1977 and 1978, and the average of the largest three panicles in each hill in 1979 and 1982.
[2] The main culm in 1977 and 1978, and the longest culm in each hill in 1979 and 1982.
[3] At maturity
*, ** Differences between two of the three varietal groups were significant at the 0.05 and 0.01 levels, respectively. The asterisks in parentheses indicate significant differences between groups A and C.

In the Heilungkiang (the northernmost) province of China, a breeding line developed in Hokkaido more than ten years ago is widely grown as a leading variety owing to its high yielding ability, while Chinese breeders are developing newer varieties (personal communication from Dr. Akihito Kusutani, Professor of Kagawa University). The development process from old low yielders to high yielders in Hokkaido as examined in the present study may be helpful for rice breeding in other cool-weather rice-growing regions of the world.

ACKNOWLEDGEMENT

We are indebted to Prof. S. Ishimura, Takushoku University, Hokkaido Community College for her cooperation in carrying out the experiments.

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CONFERENCES

1. The **2004 Maize Genetics Conference** is scheduled on March 11-14, 2004 at the Camino Real México, in Mexico City, Mexico. The meeting will begin with the evening meal on Thursday, March 11 and continue until 11:00 AM on Sunday, March 14, 2004. Details concerning meeting and hotel registration, travel directions, and visa information are available at http://www.maizegdb.org/maize_meeting/2004. Registration deadline is on January 10, 2004. There are two separate registration forms, one for lodging reservations and one for meeting registration. There are also two forms for financial aid and can be accessed at the meeting's website.

2. On June 7-11, 2004, the **10th International Symposium on Pre-harvest Sprouting in Cereals** will be held at The Links Country Park Hotel & Golf Club, West Runton, Norfolk, U.K. This will be the tenth in a series of symposia, started in 1976, providing a forum for research into pre-harvest sprouting - the phenomenon of germination of cereal grains in the ear, usually during wet conditions shortly before harvest. The symposium will enable the discussion of latest developments over a wide scientific spectrum. Presentations will cover recent advances in the impacts of sprouting on product quality, the physiology and molecular biology of seed germination and dormancy, as well as genetics and plant breeding for resistance to sprouting damage. For more information, contact the local organizers Jenny English and Helen Freeman of John Innes Centre at the Norwich Research Park, Norfolk NR4 7UH, U.K., Tel: +1603 450794, Fax: +1603 450045, Email: conferencecentre.jic@bbsrc.ac.uk.

3. The **4th International Crop Science Congress (4ICSC)** in conjunction with the 5th Asian Crop Science Conference (5ASC) and the 12th Australian Agronomy Conference is set on September 26 - October 1, 2004 at Brisbane Convention and Exhibition Centre, Queensland, Australia. With the theme, "New directions for a diverse planet", 4ICSC will review and harness the best science in all disciplines that underpin sustainable development in the great cropping systems that feed the world. Interested participants can submit their posters until February 27, 2004. For more information, visit their site at: http://www.cropscience2004.com or email the Congress Managers at 4icsc@im.com.au.

BOOK NOTICE

Recent publications of the International Rice Research Institute (IRRI) are:

Water-wise rice production. B.A.M. Bouman, H. Hengsdijk, B. Hardy, P.S. Bindraban, T.P. Tuong, and J.K. Ladha. 2003. ISBN 971-22-0182-1, 356 pages, product ID: 9789712201820, price: HDC US$27.00; LDC US$9.00; PhP 485.00, postage and handling: foreign orders US$12.00local orders PhP 100.00. This book contains 28 papers presented at the workshop on topics of intermittent irrigation, System of Rice Intensification (SRI), aerobic rice, rice-wheat, physiology and breeding, and irrigation systems. As a special feature of this book, one additional chapter, Technology Transfer for Water Savings in the Philippines, is included on a CD as a 22-minute movie in mpeg format.

Graindell. Rene Villanueva and Redge Abos. 2003. ISBN 9712201767, 32 pages, product ID: 9789712201769, price: HDC US$12.00; LDC US$4.00; PhP 125.00, postage and handling: foreign orders US$15.95, local orders PhP 90.00. *Graindell* is the first children's book published by IRRI. This book is about the friendship and adventures of two boys, Abu