Grain Yield Performance of Interspecific Irrigated Rice Genotypes in the Senegal River Valley, as Affected by the Cropping Seasons

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Abstract

Twelve interspecific genotypes, derived from the cross between three *O. sativa* varieties (IR64, IR 1529-680-3–2 and IR 31851-96-2-3-2-1) as recurrent parents and TOG 5681 (*O. glaberrima*) as donor parent, were evaluated for their yield performance. In the wet season period of 2004 and dry season period of 2005, field trials were conducted at Ndiaye (16° 14' N, 16° 14' W) and Fanaye (16° 33' N, 15° 46' W) in the Senegal River Valley to evaluate new interspecific genotypes for intensified double cropping of irrigated rice. The experimental design was a split-split-plot with two replications. The seed quantity from the same source was enough for two replications, two sites and two seasons. Outstanding interspecific genotypes yielding 7–8 t ha^{-1} were identified. WAS 122-IDSA-10-WAS-10-WAB-2-WAS-1 was the highest yielding variety at the two sites (8117 kg ha^{-1}). WAS 191-4-WAB-1-WAS-1 yielded more than 8 t ha^{-1} at Fanaye in each season. Most of the interspecific genotypes matured earlier than the sativa checks. These findings have potential practical value for the double cropping systems in Senegal River Valley and Delta.

Introduction

Rice is the fourth most important grain crop in Africa (DeVries & Toenniessen, 2001) after maize, sorghum and millet. However, in countries like Guinea Bissau, Sierra Leone, La Côte d'Ivoire, Mali, Liberia, Guinea and Senegal, rice is the most important source of carbohydrates. A number of production constraints are encountered in the Sahelian region, particularly the low amount and high variations of rainfall, and low fertility of upland soils. Irrigated crops such as rice are becoming strategic options for increasing agricultural production. A lot of effort and resources have been invested in the development of irrigation schemes to enhance irrigated rice production as a means of promoting food security and tackling rural poverty in Sahelian countries.

In spite of a long tradition of local production, 50% of the rice consumed in Sahelian countries is imported; at a cost of US$ 1.1 billion in 2005 (FAO, 2008). Ironically, the climatic conditions in the Sahelian zone are particularly favourable for high crop yields under irrigated systems (Dingkuhn & Sow, 1995). Once water is available, the high incident radiation and high temperatures of the Sahelian region create a favourable environment for rice production. The yield potential of irrigated rice varieties was estimated at 8–12 t ha^{-1} (Dingkuhn & Sow, 1995). Despite this high yield potential, the average yields observed on farmers' fields are 4–6 t ha^{-1} (Kebbeh & Miezan, 2003).

The yield gap between the potential and farmers' yields is attributed to inefficient farmers' practices, socio-economic constraints and poor agronomic traits of local varieties. For example, farmers in the Senegal River Valley (Senegal and Mauritania) grow only three improved varieties (Sahel 108, Sahel 201, and Sahel 202) selected by the Africa Rice Center (WARDA) 15 years ago. All three are intraspecific *Oryza sativa* varieties that have helped to increase farmers' yields to 7 t ha^{-1}. The development of new improved germplasms can contribute further to improvements in yields of irrigated rice.

Crossing *O. sativa* with *O. glaberrima* was found to be an important option for developing lines adaptable to many ecologies. The procedure makes possible the combination of desirable characteristics of both *O. glaberrima* (drought and disease tolerance) and *O. sativa* (high yielding). Incompatibility between the two species and F_1 sterility were solved using back crossings to the *sativa* parents (Jena & Khush, 1990). These interspecific lines developed by the Africa Rice Center are known as the *Ne*w *Ric*es for *A*frica (NERICA) and have been found to be more suitable to diverse environments in Africa. Screening for biotic and abiotic stresses at different locations confirmed that NERICA 1 and NERICA 5 are resistant to stem borers in La Côte d'Ivoire and Nigeria while others, including NERICA 6, WAB 450-I-B-P-105-HB and WAB-450-25-1-10, are resistant to nematodes in La Côte d'Ivoire and Ghana (Plowright *et al*., 1999).

Four NERICA varieties (NERICAs 1, 2, 3 and 5) are resistant to the blast disease in La Côte d'Ivoire (Séré *et al*., 2004), while another interspecific material (WAB 450-I-B-P-24-HB) is tolerant to iron toxicity (De Dorlodot *et al*., 2005). Good response to phosphorus was found with WAB 450-34-3-2-P-18-HB and Nerica 1 (WARDA, 2005). Studies conducted by Watanabe *et al*. (2006) found that 72% of the interspecific lines had higher protein content than their parents. Although the above results were reported for the upland ecology, interspecific material could also be used to improve rice productivity in irrigated ecologies. As was the case with upland ecologies, the development of new improved and better adapted interspecific materials could help to raise the productivity of rice in the irrigated ecologies.

The irrigated ecologies offer the possibility of growing two crops per year (in the wet and dry seasons). However, double cropping of rice is practiced less and less because of inadequate rice varieties, mainly for the dry season. Varieties adapted to the dry season must have reduced crop duration and tolerance to cold. The ideotype should have stable, not too short crop duration with high potential yield combined with high tolerance to cold. Interspecific varieties with adaptation to the two seasons could reduce seasonal effects due to longer cold period during the dry season in the Senegal River Valley.

Little has been done to exploit the agronomic potential interspecific materials in the irrigated ecology. The study evaluated the performance of the new irrigated interspecific materials in the Senegal River Valley (SRV). The main objective was to identify improved interspecific genotypes, with better adaptation to the two growing seasons in the irrigated rice ecology of the West African Sahel.

Materials and methods

Site description

The study was undertaken in Senegal on WARDA's research stations at Ndiaye (ND)

(16° 14' N, 16° 14' W) and Fanaye (FN) (16° 33' N, 15° 46' W). Ndiaye is located in the Costal Delta region of Senegal. The climate of the Delta is characterized by a wet season from July to October with approximately 200 mm of rainfall, a cold dry season from November to February and a hot dry season from March to June. The Fanaye site is located in the SRV, has typical semi-arid, hot and dry continental weather, located at 240 km from the sea, whereas Ndiaye is located in the Delta and has more moderate temperature extremes, higher air humidity throughout the year, and stronger winds due to its coastal location.

Minimum and maximum temperatures for the two sites are indicated on Fig. 1. Photoperiod and solar radiation are similar at both sites (Dingkuhn *et al*., 1995). The soil at Ndiaye is a typical Orthithionic Gleysol (FAO, 1998) or a Sulfic Tropaquept, according to the American classification system (Soil Survey Staff, 1992). Soil salinity is generally high due to maritime salt deposits in the subsoil (Raes & Deker, 1993). Fanaye is located in the Middle valley, approxima-tively 240 km inland from the coast. The soil profile represents an Eutric Vertisol (FAO, 1998) or Typic Hyplustert (Soil Survey Staff, 1992). Natural soil salinity is low or absent in the Middle valley (Haefele *et al*., 2002). The planting was done during two cropping seasons: the dry season (DS) and the wet season (WS), i.e. Ndiaye wet season 2004 (NDWS04) and Ndiaye dry season 2005 (NDDS05), and Fanaye wet season 2004 (FNWS04) and Fanaye dry season 2005 (FNDS05).

Plant material

Crosses between *O. sativa* (Asian parents) and *O. glaberrima* (African parents) were made at Ndiaye in Senegal. One *O. glaberrima* parent (TOG 5681) was crossed with different Asian parents: IR 64,

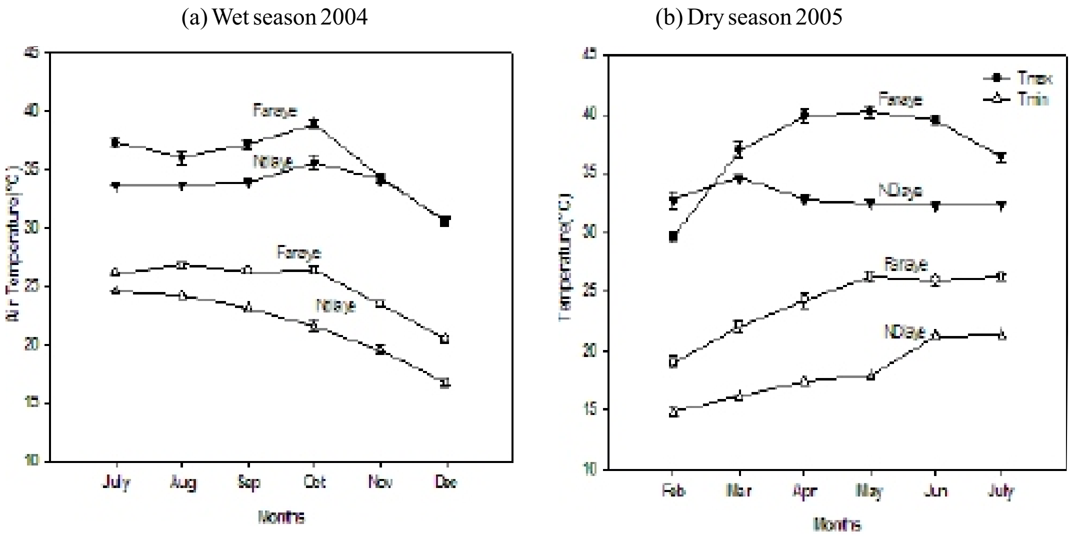

Fig. 1. Minimum and maximum temperatures at Ndiaye and Fanaye during the 2004 wet season (a) and the 2005 dry season (b)

IR 1529-680-3-2 and IR 31851-96-2-3-2-1 (Table 1). The African parent was screened for its resistance to rice yellow mottle virus (RYMV*)*, iron toxicity, and the African rice gall midge (AfRGM*)*. The *sativa* parents have high yield potential, short stature and resistance to lodging and grain shattering. They are not photoperiod-sensitive and are, therefore, suited for double cropping.

The sterility problem was overcome using backcrosses with the *sativa* parents. The names of the parents used for the crosses are presented in Table 1. In this study, 12 interspecific lines in Table 1 were tested along with four checks usually grown by farmers in the region: Sahel 108, Jaya, Sahel 202 and IR 31851-96-2-3-2-1 (Sahel 134).

TABLE 1

Parentage of the different interspecific lines evaluated at ND and FN during the 2004 wet season and the 2005 dry season

Interspecific lines	*African parent* Oryza glaberrima	*Asian parent* Oryza sativa
WAS 122-IDSA-10-WAS-10-WAB-2-WAS-1	TOG 5681	IR64
WAS 187-7-WAB-1-WAS-1	TOG 5681	IR 1529-680-3-2
WAS 191-7-WAB-1-WAS-2	TOG 5681	IR64
WAS 127-IDSA-10-WAS-5-WAB-1-WAS-2	TOG 5681	IR 31851-96-2-3-2-1
WAS 187-2-WAB-1-WAS-1	TOG 5681	IR 1529-680-3-2
WAS 191-7-WAS-1-WAS-1	TOG 5681	IR64
WAS 191-4-WAB-1-WAS-1	TOG 5681	IR64
WAS 191-5-WAB-2-WAS-2	TOG 5681	IR64
WAS 122-IDSA-1-WAS-3-WAB-1-WAS-1	TOG 5681	IR64
WAS 126-WAB-5-WAS-3-WAB-3-WAS-1	TOG 5681	IR64 , IR 31851-96-2-3-2-1
WAS 191-5-WAB-1-WAS-3	TOG 5681	IR64
WAS 187-2-WAB-2-WAS-1	TOG 5681	IR 1529-680-3-2

IR 1529-680-3-2, bred at IRRI, is grown in Senegal and Niger mainly for its high yield performance and good grain quality. Despite the release of higher yielding varieties in the Sahel, IR 1529-680-3-2 is still being grown in the region because of its high grain quality. IR 64, from the International Rice Research Institute (IRRI), is well known for its grain quality, high yield and moderate tolerance to salinity. It has good combinability with the *glaberrima* parent. IR 31851-96-2-3-2-1 was recently released as Sahel 134 in Senegal for its high yield potential and salinity tolerance.

Field trial

The 12 interspecific and four check varieties were evaluated for their agronomic performance in the field during the 2004 wet and 2005 dry seasons at Ndiaye and Fanaye. The trials were laid out in a RCBD design with two replications. The seed quantity from the same source was enough to plant not more than two replications in two seasons and two sites. Each plot measured 4 m × 3 m with 20 rows of 3 m length, and the harvested area was 3.20 m × 2.20 m. Seedlings were transplanted 21 days after nursing at a spacing of 20 cm between plants and 20 cm between rows. Fertilizer was applied at a rate of 120 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 60 kg KCl ha^{-1}. The N was applied in three split applications.

Forty percent of N (48 kg ha^{-1}) was applied at early tillering, 15 days after transplanting, and at panicle initiation, 40 days after transplanting, and 20% (24 kg ha^{-1}) at the booting stage, 60 days after transplanting. Phosphorus (as diammonium phosphate) and potassium (as potassium chloride) were applied after the seedlings were well established. The plots were irrigated during the growth period, with a water level of 10 cm. The planting dates were 6 and 8 August at Fanaye and Ndiaye, respectively, in the wet season of 2004; 14 and 24 February at Ndiaye and Fanaye, respectively, in the dry season of 2005. Days to maturity from sowing to maturity (DAS), plant height (PHGT) and grain yield (GYLD) were measured. Grain yield was recorded at 14% moisture.

Statistical analysis

The software SAS version 9.0 (Statistical Analysis System, 2002) was used. For individual site analysis, each site was analyzed with each season in a RCBD design. For the pooled analysis, the SAS program was used in a split-split-plot, considering sites as main factor, season as sub-plot and varieties as sub-sub plot. To combine the experiments, the Bartlett's test with equal degree of freedom was used for homogeneity of variance.

Results and discussion

ANOVA from the individual analysis showed highly significant differences among varieties for PHGT and DAS at ND and FN. Highly significant differences were found among varieties for GYLD at FN during the WS and the DS. No differences were found among varieties at ND during both seasons for GYLD (Tables 2, 3, 4 and 5).

The Chi-square test for homogeneity of variance (Table 6) showed that the computed chi-squares are less than the chi-square values on table, combining the data for PHGT, DAS and GYLD. The ANOVA (Table 7) for the combined analysis showed the different combination and their significant. Highly significant differences were found for PGHT, apart from site *genotype* season. For DAS and GYLD all the combinations were highly significant.

Plant height (PGHT)

Results from the combined analysis of the two seasons (Table 8) showed that plants were taller in FN compared to ND, and by combining the sites, it was found that no differences were found between the WS04 and the DS05 (Table 9). Data from the combined analysis of sites and seasons (Table 10) showed that WAS 122-IDSA-1-WAS-3-WAB-1-WAS-1 was the tallest interspecific; it had 103 cm. Shortest individuals were WAS 191-5-WAB-2-WAS-2, WAS 187-2-WAB-2-WAS-1 and WAS 187-2-WAB-1-WAS-1, with an average of 78 cm. Results from site × season combination (Table 11) showed that plants were shorter in FNWS04 (80 cm) followed by FNDS05, where plants had 84 cm.

The average plant height in NDWS04 was 99 cm; it was 95 cm in NDDS05. Results from the genotype × season combination (Table 12) showed that the shortest plant was found during the dry

TABLE 2

Individual analysis of variance (RCBD) of the site of ND during the wet season of 2004

Source variation	*df*	*Mean square* *PGHT*	*DAS*	*GYLD*
Rep	1	28.1	4.5	46894.5
Variety	15	130.2 **	47.6**	785624.6 ns
Error	15	36.4	2.3	682423.7
CV%		6.1	1.3	12

**: Significant at 0.01 probability level; ns: Not significant at 0.05 probability level.

TABLE 3

Individual analysis of variance (RCBD) of the site of FN during the wet season of 2004

Source variation	*df*	*Mean square* *PGHT*	*DAS*	*GYLD*
Rep	1	91.1	1.5	376929
Variety	15	49.6**	72.2**	1541391.6**
Error	15	12.1	2.9	121139.2
CV%		4.3	1.4	4.7

**: Significant at 0.01 probability level; ns: Not significant at 0.05 probability level.

TABLE 4

Individual analysis of variance (RCBD) of the site of ND during the dry season of 2005

Source variation	*df*	*Mean square* *PGHT*	*DAS*	*GYLD*
Rep	1	22.8	9	3519204.5
Variety	15	254.9**	58.2**	3570139.7 ns
Error	15	48.8	4.7	1590191.9
CV%		7.3	1.6	15.7

**: Significant at 0.01 probability level; ns: Not significant at 0.05 probability level.

TABLE 5

Individual analysis of variance (RCBD) of the site of FN during the dry season of 2005

Source variation	*df*	*Mean square* *PGHT*	*DAS*	*GYLD*
Rep	1	12.5	4.5	190498.8
Variety	15	207.1 **	82.8 **	2963620.9 **
Error	15	14.6	3.9	285179.8
CV%		4.5	1.5	7.7

**: Significant at 0.01 probability level; ns: Not significant at 0.05 probability level.

TABLE 6

Chi-square test for homogeneity of variance (Bartlett's test) for equal degrees of freedom

Site-Season	*Error mean square Si²*	*Chi-square computed*	*Chi-square table*
Material			
NDWS04	682423.7	24.52	24.72 at 0.01
FNWS04	121139.2		19.67 at 0.05
NDDS05	1590191.9		
FNDS05	285179.8		
Maturity			
NDWS04	2.3	2.15	
FNWS04	2.9		
NDDS05	4.7		
FNDS05	3.9		
Height			
NDWS04	36.4	9.75	
FNWS04	12.1		
NDDS05	48.8		
FNDS05	14.6		

TABLE 7

Analysis of variance of the effect of site and season on maturity, grain yield and plant height of 16 rice genotypes grown at ND and FN during the wet season 2004 and the dry season 2005

			Mean square	
Source variation	*df*	*PGHT*	*DAS*	*GYLD*
Rep	1	10.695313	18	1288213.13
Site	1	7006.32**	5.28ns	3095383.10*
Rep*site	1	7.50ns	0.78ns	916827.26ns
Season	1	4.13ns	10117.53**	5007425.70**
Site*season	1	548.63**	1012.50**	19861540.95**
Rep*season(site)	2	68.16ns	0.39ns	964243.23ns
Genotypes	15	422.12**	210.15**	2803819.81**
Site*genotypes	15	85.67**	19.43**	2322835.09**
Season*genotypes	15	94.34**	9.84**	2117311.81**
Site*season*genotypes	15	39.68ns	21.51**	1616810.20**

*, **: Significant at 0.05 and 0.01 probability level, respectively; ns: Not significant at 0.05 probability level.

TABLE 8

Overall mean for PGHT, DAS and GYLD for the two combined seasons in ND and FN

	PGHT	*DAS*	*GYLD*
ND	97 a	125.1	7452.0 a
FN	82 b	124.7	7141.0 b

TABLE 9

Overall mean for PGHT, DAS and GYLD for the two combined sites during the wet season 2004 (WS04) and dry season 2005 (DS05)

	PGHT	*DAS*	*GYLD*
WS04	89.3	116 b	7099.0 b
DS05	89.7	134 a	7494.3 a

TABLE 10

Overall mean of PGHT, DAS and GYLD for the two combined sites ND and FN and the two combined seasons WS04 and DS05

Genotypes	*PGHT*	*DAS*	*GYLD*
WAS 122-IDS-1-WAS-3-WAB-1-WAS-1	103 a	132 b	6611 def
WAS-122-IDSA-10-WAS-10-WAB-2-WAS-1	89 d	123 d	8117 ab
WAS 127-IDSA-10-WAS-5-WAB-1-WAS-2	88 d	126 c	7425 abcd
WAS 191-4-WAB-1-WAS-1	88 d	126 c	7489 abcd
WAS 191-5-WAB-1-WAS-3	95 bc	127 c	7034 cdef
WAS 191-5-WAB-2-WAS-2	78 e	123 d	7252 bcde
WAS 191-7-WAS-1-WAS-1	89 d	124 d	7517 abcd
WAS 191-7-WAB-1-WAS-2	92 bcd	127 c	7444 abcd
WAS 187-2-WAB-2-WAS-1	78 e	118 e	6213 f
WAS 187-2-WAB-1-WAS-1	79 e	120 e	6725 efd
WAS 187-7-WAB-1-WAS-1	89 d	127 c	7287 bcd
WAS 126-WAB-5-WAS-3-WAB-3-WAS-1	89 d	123 d	6349 ef
JAYA (Check)	101 a	133 ab	8256 a
SAHEL 202 (Check)	97 ab	135 a	7808 abc
SAHL 108 (Check)	87 d	120 e	7878 abc
IR31851 (Check)	91 cd	118 e	7337 abcd

TABLE 11

Results of the combined analysis site × season for PGHT, DAS and GYLD

Variables	Ndiaye		Fanaye	
	WS 2004	DS 2005	WS 2004	DS 2005
PGHT	99	95	80	84
DAS	113	137	119	131
GYLD	6860	8044	7337	6945

season (WAS 191-5-WAB-2-WAS-2 with 73 cm. WAS 122-IDSA-1-WAS-3-WAB-1-WAS-1 was the tallest entry during the same dry season with 113 cm. Plant height varied from 81 cm to 101 cm, with WAS 187-2-WAB-2-WAS-1 and Jaya check, respectively, during the wet season. By combining genotype and site (Table 13), it was found that plant height varied from 81 cm for WAS 187-2-WAB-2-WAS-1 to 115 cm for Jaya (check) in ND. In FN, WAS-122-IDSA-1-WAS-3-WAB-1-WAS-1 was the tallest plant (100 cm) whilst WAS 191-5-WAB-2-WAS-2 was the shortest with 70 cm.

Results from the combined analysis genotype × site × season (Table 14) showed that the interspecifics had different growth habits when grown during the DS or the WS, and from ND to FN. Therefore, WAS 122-IDSA-1-WAS-3-WAB-1-WAS-1 was taller in both ND and FN during the dry season. The same entry grew shorter during the WS at the same sites. Genotypes which grew taller in ND during both seasons were WAS 191-5-WAB-1-WAS-3 and the checks Jaya and Sahel 202; they were site specific.

In the other hand, WAS 122-IDSA-10-WAS-10-WAB-2-WAS-1 had 104 cm in ND during the WS and 74 cm in FN during the same season. Data also showed that WAS 187-2-WAB-2-WAS-1, WAS-187-2-WAB-1-WAS-1, and Sahel 108 (check) had similar plant height regardless the sites and the seasons. It can be concluded that the interspecifics and the different checks behaved differently. Some were site specific or season specific. Others were more stable across seasons and sites.

No statistical differences were found for plant height between seasons. This may be due to a possible escape of the plants to the seasonal cold stress (Dingkuhn & Miezan, 1995) that appears during the DS. The authors found that plants can grow taller if the vegetative growth period coincides with the hot dry season. If there is no constraint due to cold, plants can grow taller during the DS and the WS or either higher during the season as in the case of this study. Moderate temperature in ND with a maximum of 35 °C apparently favoured the plants to grow higher than the hot dry temperature of 40 °C as maximum in FN.

Detailed studies with more physiological parameters might help to explain the different in plant height between the two sites and the two seasons. Agronomically short stature plants with high tillering ability are preferred in the SRV because the system is intensified with high input. Tall plants are susceptible to lodging when high input is applied. Apart from high yielding varieties, short plants with abundant tillers are preferred because rice straw is very important, and farmers in the SRV and Delta use the rice straw for feeding animals. Rice straw is not incorporated into the soil.

Days to maturity (DAS)

The differences among test entries for DAS were statistically significant (Table 9) between the DS and the WS. However, no differences were found between the two sites (Table 8). The overall mean (Table 10) by combining sites and season showed that Sahel 202 matured at 135 days, and the earliest entries were WAS 187-2-WAB-2-WAS-1, Sahel 108 (check) and IR 31851 (check). Date to flower was delayed during the dry season by 18 days. Varieties which delayed less their DAS are needed for Senegal and similar countries to allow double cropping. Results from the site × season analysis (Table 11) showed that

TABLE 12

Results of the combined analysis genotype × season for PGHT, DAS and GYLD

Genotypes	*PGHT*		*DAS*	*GYLD*		
	WS 2004	*DS 2005*	*WS 2004*	*DS 2005*	*WS 2004*	*DS 2005*
WAS 122-IDS-1-WAS-3-WAB-1-WAS-1	92	113	125	140	6544	6679
WAS-122-IDSA-10-WAS-10-WAB-2-WAS-1	89	89	115	131	7893	8342
WAS 127-IDSA-10-WAS-5-WAB-1-WAS-2	88	88	116	136	7002	7847
WAS 191-4-WAB-1-WAS-1	88	89	117	135	7412	7566
WAS 191-5-WAB-1-WAS-3	97	93	116	137	6103	7964
WAS 191-5-WAB-2-WAS-2	82	73	113	132	6559	7946
WAS 191-7-WAS-1-WAS-1	87	92	114	134	7337	7698
WAS 191-7-WAB-1-WAS-2	93	92	119	134	7676	7211
WAS 187-2-WAB-2-WAS-1	81	75	110	126	7030	5397
WAS 187-2-WAB-1-WAS-1	84	75	112	128	6768	6683
WAS 187-7-WAB-1-WAS-1	87	91	119	135	7608	6966
WAS 126-WAB-5-WAS-3-WAB-3-WAS-1	89	88	113	133	6143	6556
JAYA (Check)	101	101	123	144	7564	8949
SAHEL 202 (Check)	95	100	126	144	6541	9076
SAHL 108 (Check)	87	87	111	128	7910	7847
IR31851 (Check)	90	92	109	128	7489	7184

TABLE 13

Results of the combined analysis genotype × site for PGHT, DAS and GYLD

Genotypes	PGHT	DAS	GYLD			
	ND	FN	ND	FN	ND	FN
WAS 122-IDS-1-WAS-3-WAB-1-WAS-1	105	100	132	132	6387	6836
WAS-122-IDSA-10-WAS-10-WAB-2-WAS-1	99	78	125	122	9235	6999
WAS 127-IDSA-10-WAS-5-WAB-1-WAS-2	94	82	126	126	7605	7244
WAS 191-4-WAB-1-WAS-1	92	85	125	127	6555	8423
WAS 191-5-WAB-1-WAS-3	103	87	127	127	7036	7032
WAS 191-5-WAB-2-WAS-2	85	70	125	120	7651	6855
WAS 191-7-WAS-1-WAS-1	97	82	124	124	8053	6981
WAS 191-7-WAB-1-WAS-2	101	83	129	124	8165	6722
WAS 187-2-WAB-2-WAS-1	81	75	117	119	5442	6986
WAS 187-2-WAB-1-WAS-1	88	71	121	119	6959	6492
WAS 187-7-WAB-1-WAS-1	92	86	125	129	7889	6685
WAS 126-WAB-5-WAS-3-WAB-3-WAS-1	100	77	124	121	7038	5661
JAYA (Check)	115	87	130	137	8424	8089
SAHEL 202 (Check)	108	87	134	135	7581	8036
SAHL 108 (Check)	92	82	121	118	7926	7831
IR31851 (Check)	100	82	119	117	7290	7384

TABLE 14

Results of the combined analysis genotype × site × season for PGHT

Genotypes	*Ws04*	*DS05*		
	ND	*FN*	*ND*	*FN*
WAS 122-IDS-1-WAS-3-WAB-1-WAS-1	96	89	115	111
WAS-122-IDSA-10-WAS-10-WAB-2-WAS-1	104	74	95	83
WAS 127-IDSA-10-WAS-5-WAB-1-WAS-2	97	80	91	85
WAS 191-4-WAB-1-WAS-1	96	81	89	89
WAS 191-5-WAB-1-WAS-3	107	88	100	87
WAS 191-5-WAB-2-WAS-2	94	71	77	70
WAS 191-7-WAS-1-WAS-1	95	79	99	85
WAS 191-7-WAB-1-WAS-2	99	86	104	81
WAS 187-2-WAB-2-WAS-1	87	76	75	75
WAS 187-2-WAB-1-WAS-1	94	74	81	69
WAS 187-7-WAB-1-WAS-1	92	82	93	90
WAS 126-WAB-5-WAS-3-WAB-3-WAS-1	101	78	99	77
JAYA (Check)	121	80	109	94
SAHEL 202 (Check)	109	81	107	94
SAHL 108 (Check)	94	80	90	83
IR31851 (Check)	99	82	102	82

plants matured at 137 days after planting during the DS in ND for only 113 days for the same site during the WS.

In FN, maturity varied from 119 days to 131 days, respectively, for the WS and the DS. Combining genotype × season (Table 12), the results showed that Sahel 108 (check) had a difference of 13 days between WS and DS to flower. It had the minimum difference. Sahel 108 had 111 days to mature during the WS and 123 days during the DS (Table 12). Similar tendencies were found with WAS 187-2-WAB-2 -WAS-1 and WAS 187-2-WAB-1-WAS-1, with 110 and 112 days during the WS and 126 and 128 days during the DS. WAS 122-IDSA-10-WAS-10-WAB-2-WAS-1, with 115 days to mature during the WS and 131 days during the DS, respectively, is a potential variety for double-culture in the SRV.

The delaying of maturity dates corroborates the report by Dingkuhn (1992) that temperatures between 8 °C and 16 °C during crop establishment in the dry season can delay maturity by up to 60 days. With the combined analysis genotype × site, results showed that the entries matured with a difference of 7 days with Jaya (check) and from 0 to 5 days for the remaining (Table 13). Results from genotype × site × season analysis (Table 15) showed that the maturity varied from 106 days in NDWS04 for Ir31851 (check) to 122 days for WAS-122-IDSA-1-WAS-3-WAB-1-WAS-1. It had 129 days in FNWS04 and 136 days in FNDS05. The earlier interspecifics in FNWS04 were WAS 187-2-WAB-2-WAS-1 and WAS 187-2-WAB-1-WAS-1; they both had 111 days to mature.

In NDDS05, the earliest entry was WAS 187-2-WAB-2-WAS-1 (124 days) and the latest was Sahel 202 (check) with 144 days. In FNDS05, two checks, Sahel 108 and

TABLE 15

Results of the combined analysis genotype x site x season for DAS

Genotypes	*WS04*	*DS05*		
	ND	*FN*	*ND*	*FN*
WAS 122-IDS-1-WAS-3-WAB-1-WAS-1	122	129	143	136
WAS-122-IDSA-10-WAS-10-WAB-2-WAS-1	113	118	137	126
WAS 127-IDSA-10-WAS-5-WAB-1-WAS-2	112	120	140	132
WAS 191-4-WAB-1-WAS-1	112	122	138	132
WAS 191-5-WAB-1-WAS-3	112	121	142	133
WAS 191-5-WAB-2-WAS-2	114	113	137	127
WAS 191-7-WAS-1-WAS-1	112	116	136	131
WAS 191-7-WAB-1-WAS-2	118	120	139	129
WAS 187-2-WAB-2-WAS-1	110	111	124	128
WAS 187-2-WAB-1-WAS-1	113	111	129	127
WAS 187-7-WAB-1-WAS-1	114	125	136	134
WAS 126-WAB-5-WAS-3-WAB-3-WAS-1	109	117	139	126
JAYA (Check)	117	128	143	145
SAHEL 202 (Check)	125	126	144	144
SAHL 108 (Check)	109	113	133	123
IR31851 (Check)	106	112	132	123

IR31851, matured earlier with 123 days. Early maturing varieties with high and stable yields, such as Sahel 108, are needed in the Delta and SRV. Early maturing varieties, e.g. I Kong Pao from Taiwan, Tatsumi Mochi from Japan, and AIWU and China-998 from China were introduced in Senegal, Unfortunately, these materials are *japonica* types with undesirable grain quality (Randolph, 1994). The taste was not suitable to consumer's preference. Early maturing interspecific lines with good grain quality may solve this problem.

Grain yield (GYLD)

GYLD performances of the interspecifics and the checks at different locations and growing seasons were different. The average GYLD was higher in ND with 7452 kg ha^{-1} compared to FN 7141 kg ha^{-1} (Table 8). Combining the two sites, the yield average was higher during the DS. Yield varied from 7494 kg ha^{-1} during the DS to 7099 kg ha^{-1} for the WS (Table 9). The overall mean for GYLD across sites and seasons was higher with Jaya (check) with 8256 kg ha^{-1} (Table 10). Jaya was followed by the interspecific WAS-122-IDSA-10-WAS-10-WAB-2-WAS-1 with 8117 kg ha^{-1}. The least yielding variety based on the overall mean was WAS 187-2-WAB-2-WAS-1 with 6213 kg ha^{-1}. The combined analysis site × season (Table 11) showed that the highest yield was recorded in FNDS05 while the least was found in NDWS04.

Combining genotype × season, it was found that the highest yield was recorded with Jaya (check) with 9076 kg ha^{-1} during the dry season. During the same season WAS 187-2-WAB-2-WAS-1 yielded only 5397 kg ha^{-1}. During the wet season, yield varied from 6103 kg ha-1 for WAS 191-5-WAB-1-WAS-3 to 7910 kg ha^{-1} for Sahel 108 (check). By combining genotype and site (Table 13), it was concluded that the lowest yield was recorded in Fanaye with WAS 126-WAB-5-WAS-3-WAB-3-WAS-1 (5661 kg ha^{-1}). The highest yield was found in Ndiaye WAS 122-IDSA-10-WAS-10-WAB-2-WAS-1 (9235 kg ha^{-1}). Results from the combined analysis genotype × site × season for GYLD (Table 16) showed that the highest yield was recorded in ND during the DS05 with WAS-122-IDSA-10-WAS-10-WAB-2-WAS-1 (10604 kg ha^{-1}).

WAB-2-WAS-1, already mentioned, and WAS-191-7-WAB-1-WAS-2 (7693 kg ha^{-1}). In FNWS04, the out-yielding check was Sahel 108 with 8932 kg ha^{-1}. No interspecifics performed as well as Sahel 108. In NDDS05, Jaya (check) performed better than any other check with 9343 kg ha^{-1}. WAS-122-IDSA-10-WAS-10-WAB-2-WAS-1 with 10604 kg ha^{-1} was better than Jaya (check) during the same season in Ndiaye. In FNDS05, Sahel 202 (check) yielded better than the other entries with 9456 kg ha^{-1}. It was followed by WAS-191-4-WAB-1-WAS-1 (8719 kg ha^{-1}).

Table 16

Results of the combined analysis genotype × site × season for GYLD

Genotypes	WS04		DS05	
	ND	FN	ND	FN
WAS 122-IDS-1-WAS-3-WAB-1-WAS-1	6328	6761	6446	6911
WAS-122-IDSA-10-WAS-10-WAB-2-WAS-1	7866	7920	10604	6080
WAS 127-IDSA-10-WAS-5-WAB-1-WAS-2	7074	6931	8136	7558
WAS 191-4-WAB-1-WAS-1	6697	8128	6413	8719
WAS 191-5-WAB-1-WAS-3	6253	5954	7818	8111
WAS 191-5-WAB-2-WAS-2	6454	6665	8847	7045
WAS 191-7-WAS-1-WAS-1	6919	7754	9188	6209
WAS 191-7-WAB-1-WAS-2	7693	7659	8638	5785
WAS 187-2-WAB-2-WAS-1	5693	8368	5191	5604
WAS 187-2-WAB-1-WAS-1	7068	6469	6850	6515
WAS 187-7-WAB-1-WAS-1	7836	7381	7941	5989
WAS 126-WAB-5-WAS-3-WAB-3-WAS-1	6263	6023	7814	5298
JAYA (Check)	7505	7624	9343	8555
SAHEL 202 (Check)	6466	6617	8696	9456
SAHL 108 (Check)	6887	8932	8965	6730
IR31851 (Check)	6767	8212	7813	6556

The same variety out-performed in ND and FN during the WS04 with 7866 and 7920 kg ha^{-1}, respectively. Compared to the high yielding check Jaya (7505 kg ha^{-1}) in NDWS04, the following interspecifics were better: WAS-122-IDSA-10-WAS-10-

The average yield usually obtained by farmers in the SRV and the Delta is 4–6 t ha^{-1} (Haefele *et al.*, 2002) compared with over 10 t ha^{-1} attainable on research stations. The yield gap may be due to factors such as poor weed control, late sowing, low fertilizer rates, late application of fertilizer, poor drainage, and late harvest. The degree of resource endowment plays an important role when farmers are able to adopt new technologies (Kebbeh & Miezan, 2003). Irrigated rice crop yield is reduced if new technologies, comprising high yielding varieties and inputs, are not properly applied.

The higher crop yields in the dry season at Ndiaye may be the result of higher solar radiation as reported by Dingkuhn & Sow (1995). In the Sahel, rainfall was reported to be of less importance to crop maturation and yield (Jamin, 1986) than extreme temperatures because active photosynthetic activity enables plants to produce more grain if extreme temperatures do not hamper yield and yield components. This was probably the case at Fanaye (Fig. 1), which is drier than Ndiaye during the 2005 hot season. A high temperature of 42 °C and beyond, and a low temperature of 16 °C may cause 100% sterility (Dingkuhn, 1995). Complete sterility was not observed at Fanaye, but yield was reduced compared to Ndiaye.

Conclusion

The rice genotypes comprising interspecifics and intraspecifics used as checks studied showed differences in yield performance with respect to location and growing season. Based on the average yields of 4–6 t ha^{-1} in farmers' fields in Senegal, the following interspecifics which yielded more than 7 t ha^{-1} could be recommended for cultivation at Ndiaye and Fanaye or similar locations and seasons: WAS 122-IDSA-10-WAS-10-WAB-2-WAS-1, WAS 191-7-WAS-1-WAS-1 ,WAS 191-4-WAB-1-WAS-1, WAS 191-7-WAB-1-WAS-2, WAS 127-IDSA-10-WAS-5-WAB-1-WAS-2, WAS 187-7-WAB-1-WAS-1,WAS 191-5-WAB-2-WAS-2 and WAS 191-5-WAB-1-WAS-3. For the wet season at Ndiaye, the following could be cultivated: WAS 122-IDSA-10-WAS-10-WAB-2-WAS-1, WAS 187-7-WAB-1-WAS-1, WAS 191-7-WAB-1-WAS-2, WAS 127-IDSA-10-WAS-5-WAB-1-WAS-2 and WAS 187-2-WAB-1-WAS-1. For the wet season at Fanaye, the recommended genotypes are WAS 187-2-WAB-2-WAS-1, WAS 191-4-WAB-1-WAS-1, WAS 122-IDSA-10-WAS-10-WAB-2-WAS-1, WAS 191-7-WAB-1-WAS-2, and WAS 187-7-WAB-1-WAS-1.

Interspecifics that gave high yields at Ndiaye in the dry season and, therefore, recommendable for similar zones are WAS 122-IDSA-10-WAS-10-WAB-2-WAS-1, WAS 191-7-WAS-1-WAS-1, WAS 191-7-WAB-1WAS-2, WAS 191-5-WAB-2-WAS-2, WAS 187-7-WAB-1-WAS-1, WAS 191-5-WAB-1-WAS-3 and WAS 126-WAB-5-WAS-3-WAB-3-WAS-1. Genotypes that yielded more than 7 t ha^{-1} at Fanaye during the dry season and, therefore, recommended are WAS 191-4-WAB-1-WAS-1, WAS 191-5-WAB-1-WAS-3, WAS 127-IDSA-10-WAS-5-WAB-1-WAS-2 and WAS 191-5-WAB-2-WAS-2.

Sahel 108 was the only suitable variety for the short dry season in the SRV and the Delta over the last decade. Sahel 134 was released in 2007. Both varieties are intraspecifics. No single interspecific variety was ready to be released in the region. There is a need for early maturing interspecific varieties. WAS 122-IDSA-10-WAB-2-WAS-1, which matures only 4 days later than Sahel 108 but gives higher yield, could be a promising genotype for the region. Short stature and short growth duration genotypes are needed for intensification of rice production. High input can be applied to short stature genotypes and short growth duration types are suitable for double cropping.

The *O. glaberrima* parent (TOG 5681) was found to be suitable for the development of improved interspecific genotypes for irrigated rice in the Sahel. Other *O. glaberrima* parents can be explored for new crosses with *sativa* parents in order to diversify the parents.

References

De Dorlodot S., Lutts S. S. and **Bertin P.** (2005). Effects of ferrous iron toxicity on the growth and mineral composition of an interspecific rice. *J. Pl. Nut*. **28**:1–20.

DeVries J. D. and **Toenniessen G.** (2001). Rices. In *Securing the harvest biotechnology breeding and seed systems for African crops.* CABI Publishing. Wallingford, Oxon, UK. pp. 131–138.

Dingkuhn M. (1992). Physiological and ecological basis of varietal rice crop duration in the Sahel. *West Africa Rice Development Association Annual Report 1991*. Bouaké, La Côte d'Ivoire. pp. 12–22.

Dingkuhn, M. (1995). Characterizing irrigated rice environments using the rice phenology model RIDEV. In *Irrigated rice in the Sahel: Prospects for sustainable development. (*K. M. Miézan, M. C. S. Wopereis, M. Dingkuhn and T. F. Randolph, ed.), pp. 342–360. WARDA, Bouaké.

Dingkuhn M. and **Miézan K. M.** (1995). Photothermal adaptations of rice genotypes in the Sahel In *Irrigated rice in the Sahel: Prospects for sustainable development.* (K. M. Miézan, M. C. S. Wopereis, M. Dingkuhn and T. F. Randolph, ed.), pp. 327–341. WARDA, Bouaké.

Dingkuhn M. and **Sow A.** (1995). Potential yields of irrigated rice in the Sahel. In *Irrigated rice in the Sahel: Prospects for sustainable development.* (K. M. Miézan, M. C. S. Wopereis, M. Dingkuhn and T. F. Randolph, ed.), pp. 361–379. WARDA, Bouaké.

Dingkuhn M., Sow A., Samb A., Diack S. and **Asch, F.** (1995). Climatic determinants of irrigated rice performance in the Sahel. I. Photothermal and micro-climatic responses of flowering. *Agric. Syst*. **48**: 435–456.

FAO (2008). *FAOSTAT-Agriculture* http://faostat.fao;org/.

FAO (1998). World Reference Base for Soil Resources. *World Soil Resources Report 84,* ISSN 0532–0488. FAO, Rome. Italy. pp. 88.

Haefele S. M., Wopereis M. C. S. and **Donovan C.** (2002). Farmer's perceptions, practices and performance in a Sahelian irrigated rice scheme. *J. exp. Agric.* **38**: 197–210.

Jamin J. Y. (1986). La double culture du riz dans la vallée du fleuve Sénégal: mythe ou réalité? *Cahiers de la recherche Développement* **12**.

Jena K. K. and **Khush G. S. (**1990). Introgression of genes from *Oryza officinalis* ex Wtt. To cultivated rice, *O.sativa* L. *Theor. Appl. Genet.* **80**(6): 737–745.

Kebbeh M. and **Miézan K. M.** (2003). Ex-ante evaluation of integrated crop management options for irrigated rice production in the Senegal River Valley. *Fld Crops Res.* **81**: 87–94.

Plowright R. A., Coyne D. L., Nash P. and **Jones M. P.** (1999). Resistance to the rice nematodes *Heterodera sacchari, Meloidogyne graminicola* and *M. incognita* in *Oryza glaberrima* and *O.glaberrima x O. sativa* interspecific hybrids. *Nematology* **1** (7-8): 745–751.

Raes D. and **Deker J.** (1993). Les sols du delta du fleuve Sénégal. Propriétés physiques et chimiques. *Bull. Techniques* **8**, *Projet Gestion de l'Eau*, KULeuven-SAED, Saint Louis, Sénégal. 84 pp.

Randolph T. (1994). *The comparative advantage of irrigated rice production systems in the Sahel.* West Africa Rice Development Association, 01 BP 2551 Bouaké, Côte d'Ivoire.

Statistical Analysis System SAS Institute (2002). *SAS/SAT users guide, Version 9.* SAS Publishing, Cary, NC.

Séré Y., Sy A. A., Akator S. K., Onasanya A. and **Zai K.** (2004). Screening strategy for durable resistance *to* rice blast disease at WARDA. In *West Africa characterization of pathogen diversity, key screening sites and host resistance.* (Séré, Sreenivasaprasad and Nutsugah, ed.), pp. 38–42.

Soil Survey Staff (1992). *Keys to Soil Taxonomy by the Soil Survey Staff,* 5th edn. SMSS Technical Monograph No. 19. United States Department of Agriculture, Pocahontas Press, Inc., Virginia, USA., 306 pp.

WARDA (West Africa Rice Development Association) (2005). Annual report, 2005. www.warda.org/warda1/main/publications/pulications.htm).

Watanabe H., Futakuchi K., Jones M. P. and **Sobambo B. A.** (2006). Grain protein content of interspecific progenies derived from the crosses of African rice (*Oryza glaberrima* Steud.) and Asian rice (*Oryza sativa* L.). *Pl. Prod. Sci.* **9**(3): 287–293.