Irrigation management effects on yield and water productivity of inbred and aerobic rice varieties in Kaifeng

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Abstract

Kaifeng City and it's surroundings face water scarcity, especially for their rice-growing areas. There is a need to reduce water inputs to rice so that water can be diverted to other users. Aerobic rice is a new way of growing rice: it grows in nonpuddled soil without flooding and can be supplementary irrigated like other crops such as maize. To achieve high yields under aerobic conditions, special "aerobic rice varieties" are being developed. Experiments conducted at two contrasting sites with respect to water table depth (WTD) were carried out in 2001 (WTD approximately 20 cm) and 2002 (WTD > 200 cm) to determine whether aerobic rice can be grown successfully at Kaifeng, and to compare the effects of water-saving irrigation technologies on yield, irrigation water input, and water productivity of aerobic and lowland rice varieties. Water treatments were continuous flooding (CF), alternate wetting and drying (AWD), and flush irrigation (FI). The varieties used were lowland inbred 90247 and aerobic rice HD502. All treatments were established by transplanting.

The aerobic variety yielded significantly less than the lowland variety, especially in water regimes that maintained high soil water potentials. This was probably caused by reduced tillering and a shorter growth duration of the aerobic variety. In 2001, CF had the highest irrigation water inputs, followed by AWD and FI. FI had higher water productivity (per unit irrigation and per unit irrigation + rainwater) than CF and AWD. Among the FI treatments in 2002, water input declined sharply when the threshold soil water potentials (at which irrigation was applied) were reduced from –10 to –70 kPa. Yields of both varieties did not differ significantly among water treatments when the water table was shallow (in 2001). When the water table was deep (2002), yield declined with decreasing threshold soil water potentials, especially with the lowland variety. Treatments with threshold potentials of –10 kPa had significantly lower water productivities than those with lower threshold potentials. The findings showed that the response of yield and water productivity to irrigation regimes depended on the depth of the groundwater and that aerobic rice can be grown successfully in Kaifeng. Suitable crop management practices such as direct seeding and increasing plant density can increase yield. Direct seeding also removes the need for maintaining standing water for about 20 days after transplanting (to overcome transplanting shock), and thus reduces water input and increases water productivity.

Because of continued population growth and economic development, the demand for freshwater to meet industrial and domestic needs has increased rapidly in Kaifeng City and its surroundings. This region faces a severe water scarcity, especially in the rice-growing areas. It is expected that, in the near future, less water will be available for rice cultivation (Tuong and Bouman 2002). Water savings and “producing more rice with less water” are crucial for food security and the economy of Kaifeng and its surroundings.

Several water-saving irrigation (WSI) techniques for rice have been reported previously (Bouman 2001, Bouman and Tuong 2001). The most widely adopted water-saving practice in China is alternate wetting and drying (AWD) (Mao Zhi 1993, Li 2001, Xu Zhifang 1982). The rice field is allowed to dry for a few days in between irrigation events, including a midseason drainage in which the field is allowed to dry for 7–15 days at the end of the tillering stage.

Tabbal et al (2002) reported reduced water inputs and increased water productivity of rice grown under just-saturated soil conditions compared with traditional flooded rice. It has been suggested that rice could be grown aerobically under irrigated conditions just like upland crops, such as wheat or maize (Bouman 2001). The aerobic condition is maintained by using flush irrigation (FI) or sprinklers so that ponding occurs for only short periods of time just after irrigation or rain, if at all. The potential of WSI to reduce water inputs and its effect on yield and water productivity depend on soil type, groundwater table depth, and climate (Bouman and Tuong 2001).

Though the potential for water savings of aerobic cultivation is large, aerobic cultivation using conventional lowland rice varieties almost always leads to a yield reduction (De Datta et al 1973, McCauley 1990, Westcott and Vines 1986). A special type of rice is required to produce high yields under nonflooded conditions in nonpuddled and unsaturated (aerobic) soil. Bouman (2001) named this “aerobic rice”; it is responsive to high inputs, can be rainfed or irrigated, and tolerates occasional flooding. A first generation of high-yielding aerobic rice varieties has been developed successfully over the last 20 years in North China (Wang Huaqi et al, 2002). However, the trade-off between yield reduction and water savings compared with flooded lowland rice is still unknown (Yang Xiaoguang et al, 2002). The potential of the newly developed aerobic rice varieties and the effects of WSI on rice yield and water productivity have not been studied in Kaifeng and in the Yellow River Basin.

This study aimed to test the hypotheses that aerobic rice with high water productivity can be grown successfully in Kaifeng and that the effects of irrigation regimes on water inputs, grain yield, and water productivity vary with different groundwater depths. Experiments in this study were to quantify the effects of different irrigation water management regimes, ranging from rainfed to continuous flooding, on growth, yield, and water productivity of conventional and aerobic rice varieties at two sites with contrasting groundwater depths in Huibei, Kaifeng, China.

Materials and methods

The experiments were conducted near the Huibei Experiment Station, Xin Long Township, Kaifeng County, in Henan Province (from June to October 2001), China. In 2001, the experiment was conducted in Gao Zhao Village, Duliang Township, where rice is generally grown because of shallow groundwater-table conditions. In 2002, the experiment was conducted in Pan Lou Village, Xin Long Township, where upland crops are often grown because of deep water-table conditions. The soil texture was loam in 2001 and sandy loam in 2002.

The experiments were conducted in a split-plot design, with three replicates in 2001 and four replicates in 2002. The main plots were water treatments, in which fields were kept flooded with 2 and 5-cm water depth during the transplanting recovery period, for about 10 and 17 days after transplanting (DAT), followed by water treatments as follows:

In 2001, the three water treatments were

1. *Continuous flooding (CF) in puddled soil*. The field water level was maintained from 2 to 10 cm, with no midseason drainage. This was the farmers' practice in Kaifeng.
2. *Alternate wetting and drying (AWD) in puddled soil*. The field was kept dry for several days after the disappearance of ponded water before irrigation was reapplied, as described in Cabangon et al (2001). This included a period of midseason drainage by withholding irrigation water for 10–15 days around midtillering (no active drainage).
3. *Flush irrigation (FI-50) in nonpuddled, aerobic soil*. Plots were irrigated to cover the field with a layer of 40–80 mm of water, which quickly infiltrated into the soil. Irrigation was reapplied when the soil water potential at 20-cm soil depth reached a threshold value of –50 kPa.

In 2002, the water treatments were three flush irrigation (FI) methods with different threshold soil water potentials: –10 kPa (FI-10), –30 kPa (FI-30), and –70 kPa (FI-70). A fourth treatment of "partially rainfed with survival irrigation" (PRF) was included where irrigation was withheld until the rice crop showed very severe drought symptoms.

The subplots consisted of two varieties: a commonly grown inbred rice, 90247 (V_1), and an aerobic rice, HD502 (V_2) (Wang Huaqi et al, 2002). The establishment method was carefully selected to give the best results for the specific variety, using local experience and expert knowledge (Wang Huaqi, personal communication for aerobic rice). The inbred rice was transplanted using 37-d-old seedlings at 6 plants hill^{-1} in 20 × 20-cm spacing. The transplanted aerobic rice used 27-d-old (2001) and 38-d-old seedlings at 4 plants hill^{-1} in 27 × 13-cm spacing.

The nitrogen (N) fertilizer (180 kg N ha^{-1} in 2001 and 225 kg N ha^{-1} in 2002) was applied in four splits: 30% basal, 30% at 10 DAT, 30% at panicle initiation

(PI), and 10% at heading. In addition, 70 kg P ha^{-1} and 70 kg K ha^{-1} were applied as basal application. Basal fertilizer was broadcast and incorporated into the soil during the last land preparation (harrowing). The topdressings were applied on the soil surface just before irrigation.

Daily meteorological parameters (rainfall, pan evaporation, sunshine hours, temperature—minimum and maximum—and wind speed) were collected from meteorological stations at the Huibei experiment station some 8 km away from the site in 2001 and 1 km from the 2002 site. Irrigation water inputs were monitored using flow meters at each irrigation (in the main plots in 2001 and in all subplots in 2002) and standing water depth was measured daily using meter gauges in all plots in 2001. One PVC percolation ring was installed in each of the AWD and PRF plots in 2001 to quantify the daily percolation rate and groundwater depth was measured in each replicate twice weekly in 2001 and daily in 2002. In 2002, standing water depth and daily percolation rate were not measured because continuous standing water in the field was not expected in flush irrigation treatments. The amount of surface drainage was calculated from the difference in the ponded water depth before and after drainage. The seasonal amount of percolation (in 2001) was computed as the sum of measured daily percolation rates. It was assumed that there was no percolation during days without standing water. The seasonal seepage and percolation, S&P (defined as lateral flow of water through and underneath bunds from one field to another (S) and vertical flow of water through the topsoil (P)), was estimated as the closure term in the water balance over the whole season: S&P = rainfall + irrigation – surface drainage – evapotranspiration. Note that, in this calculation, the computed S&P incorporates the error term and, implicitly, any capillary rise. Further details of the hydrological measurement procedures can be found in Cabangon et al (2001). The aerobic rice variety had a shorter duration than the inbred rice, but, in both years, no irrigation and drainage occurred after harvesting of the aerobic variety, and the above water balance components were the same for both varieties.

In 2001, evapotranspiration (ET) was computed from the weather data using the Penman equations (Allen et al 1998). In 2002, because of the unavailability of weather parameters required in the Penman method, ET was calculated using the pan evaporation method, which uses the crop factor, k_c, of rice for China (Mao Zhi, 1992).

At 15 DAT, PI, flowering, and maturity, 12-hill samples were collected to measure total biomass and biomass components (leaves, stems, panicles), following the procedures described in Cabangon et al (2001). At maturity, we also measured grain yield and yield components (1,000-grain weight, spikelet number, panicle number, filled spikelet number). Water productivity was calculated as the weight of grain per unit of water used (g grain kg^{-1} water). The following values were computed (Cabangon et al, 2001):

- WP_I: yield per unit volume of irrigation water from transplanting to harvest

- WP_{I+R}: yield per unit volume of irrigation and rainfall water from transplanting to harvest

Results and discussion

Climatic and agrohydrological conditions

Rainfall, pan evaporation, and sunshine hours from transplanting to harvest are shown in Table 1. These parameters were different for the two varieties because they had different crop growth durations. Rainfall was lower in 2002 than in 2001. There was hardly any difference in seasonal evaporation between the two years. Sunshine hours were higher in 2002 than in 2001 and higher in V_1 than in V_2 because of its longer crop growth period.

Figure 1 gives the dynamics of groundwater table depths. In 2001, the groundwater table fluctuated from 0- to 20-cm depth during most of the crop growth period and started to decline some 2 wk before the harvest of V_1 at the time of drainage of the fields (Fig. 1) to about 75 cm at the time of harvest of V_1. At the 2002 site, the groundwater table changed from 200-cm depth at transplanting to about 350-cm depth at harvest.

Figure 2 shows the dynamics of field-water depths in 2001. The number of days with ponded water during the crop season was higher in CF than in AWD and FI-50 (Table 2). The AWD treatment almost always had some floodwater and FI-50 was generally only non-flooded after flowering. Even then, the water table never went deeper than 6 cm and aerobic soil conditions were barely obtained.

In 2002 it was not possible to maintain ponded water in the field, except for a few hours after the flush irrigations. Thus, the number of days with standing water refers also to the number of irrigations. In Table 2, the number of days with standing water during the crop season declined as the threshold soil water potential decreased. Except for the FI-10 treatment, a large portion of days with ponded water occurred during the transplanting recovery period.

Grain yield

In both years, the local inbred variety had significantly higher yields ($P < 0.01$) than the aerobic variety (Fig. 3). This may be attributed to a lower tillering ability (data not shown) and a shorter duration (103-105 d for the aerobic variety versus 115-119 d for the inbred; Table 1) of the aerobic variety.

In 2001, there was no significant difference in yield among the three water treatments in either of the two rice varieties. In 2002, however, differences in grain yield were observed among the water treatments. Yields tended to increase with the number of days with standing water (Fig. 3 and Table 2). In the inbred variety, FI-70 had a significantly lower yield than the F-10 and F-30 treatments but had a significantly higher yield than the PRF treatment. The difference between the highest and lowest yields came to about 46% of the lowest yield. In the aerobic variety, the yield of FI-10 was significantly higher that that of F-70 and PRF. The yield difference between the best and the worst treatments was 17%.

The different response in rice yield to water treatments in two years is probably caused by attributed to different groundwater depths. The lack of a significant difference in 2001 was due to the very high water table (Fig. 1), which supplied water to the rootzone during days without standing water in the AWD, FI-50, and PRF treatments. The deep water table in 2002 allowed different water treatments to impose different stress levels on the rice plants. It should be noted that the inbred variety was more sensitive to water treatment (or water stress levels) than the aerobic variety.

Despite the higher sunshine hours, the inbred variety in the best treatment in 2002 yielded less than in 2001 (7 vs. 8 tons ha^{-1}). The difference between the best-performing treatments in aerobic rice was small (4.8 vs. 5 tons ha^{-1}, Fig. 3a vs. 3b). This confirmed that a slight water stress (soil water potentials sometimes reached –10 kPa in FI-10, 2002) might result in a severe yield penalty in the inbred variety, but not in the aerobic variety.

Water balance

Figure 4 shows the water balance components for the different water treatments from transplanting to harvest in two years. In 2001, water inputs for both varieties were the same since the irrigation input was measured in the main plots. In 2001, the total water input (rainfall + irrigation) ranged from 570 to 930 mm, of which 354 mm was rainfall (Fig. 4a). The differences in irrigation and total water inputs were statistically significant among all three water treatments ($P < 0.01$), with CF having the highest values and FI the lowest. The daily percolation rates ranged from 0.2 to 1.4 mm d^{-1}, averaging 0.7 mm d^{-1}. Summed over the whole season, percolation loss was about 60 mm, with no statistical difference at the 5% level among the water treatments. There was no significant difference in percolation loss between the two varieties (data not shown). The low percolation rates are attributed to the shallow groundwater table. The mean seasonal surface drainage in CF was significantly higher than in AWD and FI-50, which were able to make more effective use of rainfall than CF. Treatment CF had significantly the highest S&P and FI-50 the lowest.

In 2002, the total water input (rainfall + irrigation) ranged from 1,008 to 3,338 mm, of which 267 mm was rainfall. The differences in irrigation water inputs among the treatments were statistically significant ($P < 0.05$). Irrigation water input was highest in FI-10, followed by FI-30, FI-70, and RF. A similar level of significance was found in the S&P values. No drainage occurred in 2002 (Fig. 4b) because rainfall was very low during the crop season (Table 1).

The water inputs in 2002 were much higher than in 2001. This was attributed to a much higher S&P, because of lighter soil and a deeper water table, in 2002 than in 2001 (Fig. 4a vs. Fig. 4b). Most (about 1,300 mm) of the S&P in 2002 occurred during the transplanting recovery period, when irrigation has to be applied daily to keep the field flooded (though only a part of the day) to help plants recover from the transplanting shock. This period was longer in the aerobic rice variety than in the inbred rice variety (17 vs. 10 d, Table 2), indicating that the former suffered more severe transplanting shock than the latter. The irrigation amount supplied during transplanting recovery to the aerobic variety was higher than that supplied to the inbred variety.

Water productivity

In 2001, WP_{I+R} ranged from 0.87 for 1.45 kg m^{-3} for inbred rice and from 0.54 to 0.95 kg m^{-3} for aerobic rice (Fig. 5a). Because of the higher yields of inbred rice, WP_{I+R} was higher for the inbred rice than for the aerobic variety in all water treatments. The differences among the water treatments were significant: FI had the highest and CF the lowest WP_{I+R} for both the inbred and aerobic variety. The relative trends and differences in water productivity with respect to irrigation were the same as in water productivity with respect to the total water input.

In 2002, the total water productivity, WP_{I+R} (for hybrid rice), ranged from 0.13 to 0.45 kg m^{-3}, whereas WP_I ranged from 0.14 to 0.53 kg m^{-3} (Fig. 5b). The WP_{I+R} values are relatively low compared with those in the literature (see Bouman and Tuong 2001 for review data) and are explained by the combination of relatively lower yields (of aerobic rice) and extremely high water inputs, especially in the FI-10 treatment (Fig. 4b). Among the four water treatments, FI-10 had the significantly lowest WP_{I+R} and WP_I . The differences among FI-30, FI-70, and RFI were not significant.

Discussion and conclusions

The aerobic rice variety HD502 used in our experiments was primarily bred for, and tested in, temperate zones of China (Wang Huaqi et al, 2002). The relatively high yields (around 5 t ha^{-1}) we obtained in Huibei are an indication that aerobic rice varieties can also be grown in subtropical environments. Aerobic rice has a distinct advantage over the inbred variety in that it is less sensitive to the level of water stress.

The lower yield of the aerobic variety compared with that of the inbred variety was related to its shorter duration and lower tillering capacity. On contrast, a shorter duration may have other advantages compensating for the lower yield, such as allowing earlier establishment of a post-rice crop and thereby increasing its yield, and perhaps increasing total system productivity and/or water productivity. Increasing plant density may compensate for the lower tillering capacity of aerobic rice.

Aerobic rice was bred and selected for direct seeding (Wang Huaqi, personal communication). This could explain the more severe transplanting shock (as reflected by the longer period of transplanting recovery) than with the inbred variety. Transplanting shock can be avoided by establishing the crop by direct-seeding methods. This may further increase the yield of the aerobic rice. More importantly, direct seeding removes the need for maintaining standing water in the field during the transplanting recovery period (of the transplanted rice), which would reduce the amount of irrigation substantially, especially when the soil is permeable and the groundwater is deep. Direct seeding is thus very important for increasing the water productivity of aerobic rice.

Water-saving irrigation, especially flush irrigation and partially rainfed systems, can significantly reduce the amount of irrigation compared with farmers' practices, without affecting rice yield if the soil water potential is not allowed to drop below –30 kPa. This implies that there is a possibility for irrigation system managers to reduce the amount of water diverted to rice at the study sites. These findings and their implications, however, are site-specific and care must be taken in extrapolation. Our results were obtained in relatively small subplots in farmers' fields which allowed us to keep irrigation time short and the irrigation application efficient. In larger fields, the irrigation time is longer, which may result in larger seepage and deep-percolation losses. Our results also confirmed that yield responses to irrigation management are highly dependent on groundwater depth. Data on the effect of irrigation management were useful only when groundwater depth and soil conditions were specified. More study is needed on the interaction between irrigation and groundwater table depths before recommendations for the large-scale application of water-saving irrigation techniques can be made. The shallow groundwater tables at our 2001 experimental site may be the result of continuously ponded water in surrounding rice fields that recharge the groundwater through deep percolation. Furthermore, seepage from unlined irrigation canals in our study areas may also recharge the groundwater. With the wide-scale adoption of water-saving irrigation techniques, the groundwater tables may go down because of less groundwater recharge from the rice fields and the effect of irrigation management on yield may become more prominent. Systems approaches, using models, may be useful in analyzing the complex interactive effect of groundwater, canal, and irrigation management on rice yield and water productivity.

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Table 1. Climatic data and crop duration from transplanting to harvesting at Huibei, 2001 and 2002.

Year	Variety[a]	Rainfall (mm)	Pan evaporation (mm)	Sunshine (h)	Duration (d)
2001	V1	360	437	427	119
2001	V2	354	398	360	103
2002	V1	267	427	532	115
2002	V2	266	393	498	107

[a] V1 = inbred variety, V2 = aerobic variety

Table 2. Number of days with standing water in the field during the crop season and transplanting recovery period in Huibei, Kaifeng, 2001 and 2002. In 2002, the standing water in the field lasted only a few hours after irrigation; the number of days with standing water thus equaled the number of irrigation events.

	Days with standing water			
	Crop season		Transplanting recovery	
Treatment	V1[a]	V2[b]	V1	V2
2001[c]				
Continuous Flooding[a]	93 ± 2	92 ± 0	10 ± 0	10 ± 0
Alternate wetting and drying	71 ± 6	65 ± 9	10 ± 0	10 ± 0
Flush irrigation at -50 kPa	44 ± 15	37 ± 15	10 ± 0	10 ± 0
2002[d]				
Flush irrigation at -10 kPa	44 ± 1	40 ± 1	14 ± 1	17 ± 1
Flush irrigation at -30 kPa	24 ± 1	27 ± 1	13 ± 1	17 ± 1
Flush irrigation at -70 kPa	21 ± 1	22 ± 1	14 ± 1	17 ± 0
Rainfed	16 ± 1	20 ± 1	14 ± 0	17 ± 1

[a] V1 = inbred rice
[b] V2 = aerobic rice
[c] N = 3 (from three replicates)
[d] N = 4 (from four replicates)

Figure captions

Fig. 1. Mean groundwater table depth in Huibei, 2001 and 2002. V1 = inbred rice variety; V2 = aerobic rice variety.

Fig. 2. Mean ± SE field-water depths in Huibei, 2001 (N = 6 from two varieties and three replicates). CF = continuous flooding, AWD = alternate wetting and drying, FI-50 = flush irrigation when soil water potential reaches –50 kPa, PI = panicle initiation, V1 = inbred rice variety, and V2 = aerobic rice variety.

Fig. 3. Mean grain yields of inbred and aerobic varieties in 2001 (a) and 2002 (b). CF = continuous flooding, AWD = alternate wetting and drying, PRF = rainfed, FI-10 = flush irrigation at –10 kPa, FI-30 = flush irrigation at –30 kPa, FI-50 = flush irrigation at –50 kPa, and FI-70= flush irrigation at –70 kPa. Columns with the same letters are not significantly different at the 5% level.

Fig. 4. Irrigation (I), total water input (I + R), drainage (D), and seepage and percolation (S&P) during the crop season (from transplanting to harvest) in Huibei, in (a) 2001 (N = 3, from three replicates) and in (b) 2002 (N = 8, from two varieties and four replicates). The lower portion of the bars in (b) represents the amount of water during the transplanting recovery period. CF = continuous flooding, AWD = alternate wetting and drying, PRF = rainfed, FI-10 = flush irrigation at –10 kPa, FI-30 = flush irrigation at –30 kPa, FI-50 = flush irrigation at –50 kPa, and FI-70 = flush irrigation at –70 kPa.

Fig. 5. Water productivities with respect to irrigation (WP_I) and total water input ($WP_{I + R}$) in different water treatments and varieties in Huibei 2001 (a) and Huibei 2002 (b). CF = continuous flooding, AWD = alternate wetting and drying, PRF = rainfed, FI-10 = flush irrigation at –10 kPa, FI-30 = flush irrigation at –30 kPa, FI-50 = flush irrigation at –50 kPa, and FI-70 = flush irrigation at –70 kPa. For each variety, columns with the same letters are not significantly different at the 5% level.

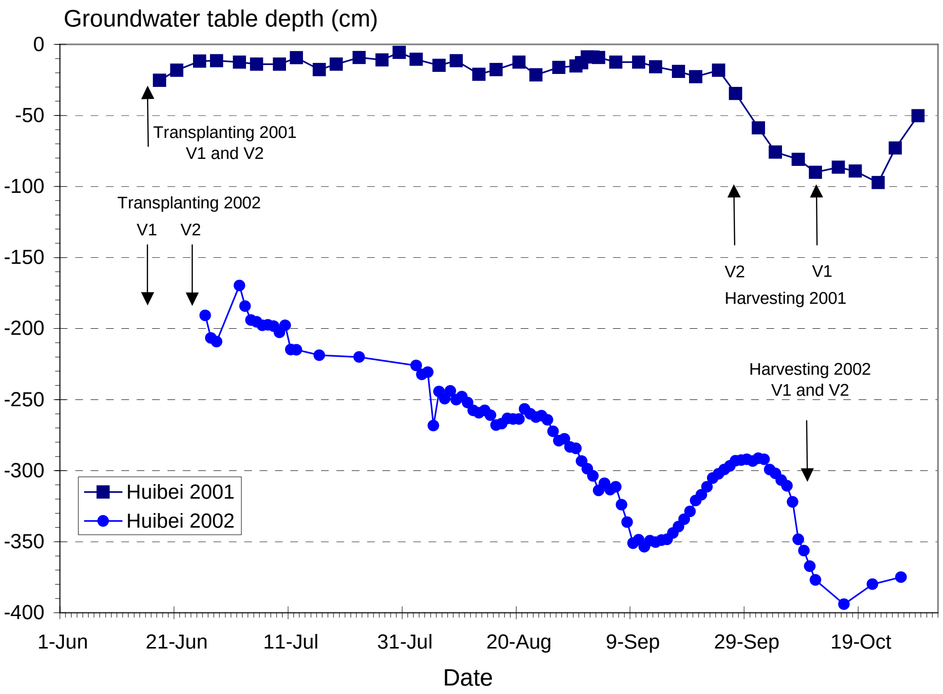

Groundwater table depth (cm)
0
-50
-100
-150
-200
-250
-300
-350
-400
1-Jun
21-Jun
11-Jul
31-Jul
20-Aug
9-Sep
29-Sep
19-Oct
Date
Transplanting 2001
V1 and V2
Transplanting 2002
V1
V2
V2
V1
Harvesting 2001
Harvesting 2002
V1 and V2
Huibei 2001
Huibei 2002

Fig. 1.

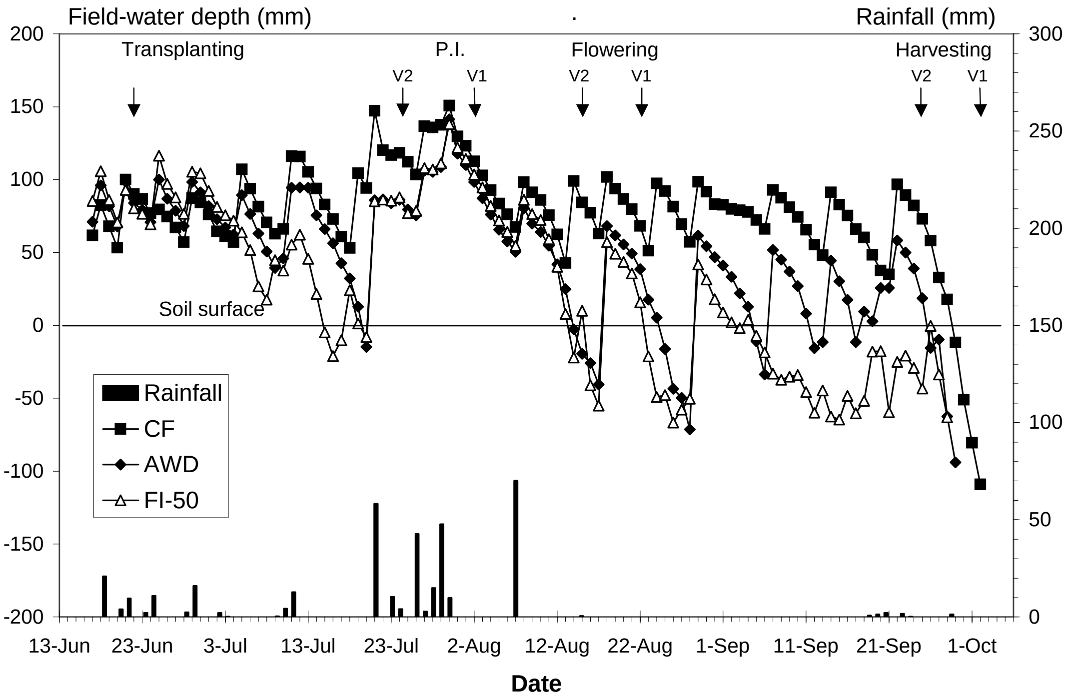

Field-water depth (mm)
Rainfall (mm)
Transplanting
P.I.
Flowering
Harvesting
V2
V1
V2
V1
V2
V1
Soil surface
Rainfall
CF
AWD
FI-50
200
150
100
50
0
-50
-100
-150
-200
300
250
200
150
100
50
0
13-Jun
23-Jun
3-Jul
13-Jul
23-Jul
2-Aug
12-Aug
22-Aug
1-Sep
11-Sep
21-Sep
1-Oct
Date

Fig. 2.

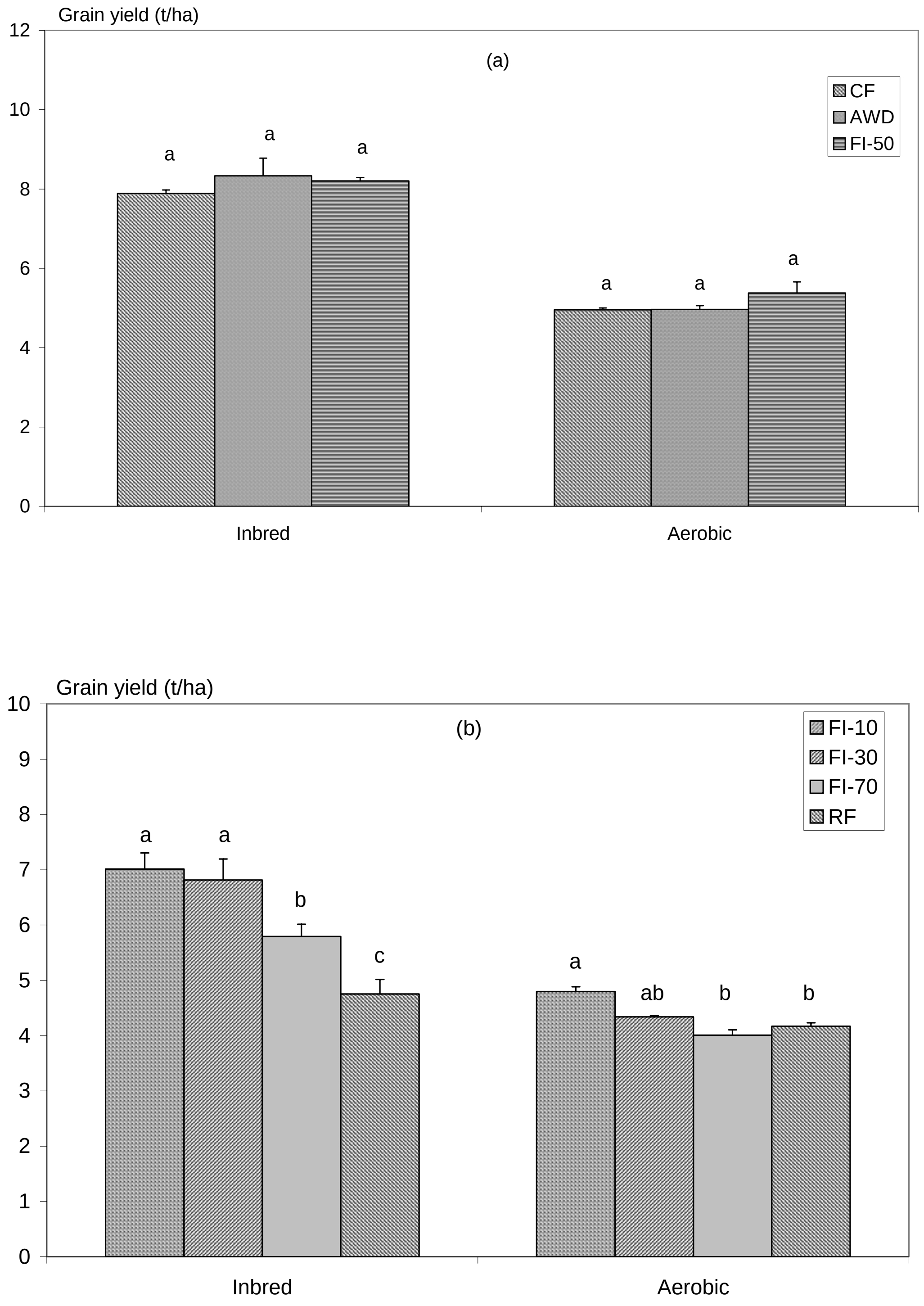

Grain yield (t/ha)
(a)
CF
AWD
FI-50
12
10
8
6
4
2
0
a
a
a
a
a
a
Inbred
Aerobic
Grain yield (t/ha)
(b)
FI-10
FI-30
FI-70
RF
10
9
8
7
6
5
4
3
2
1
0
a
a
b
c
a
ab
b
b
Inbred
Aerobic

Fig. 3.

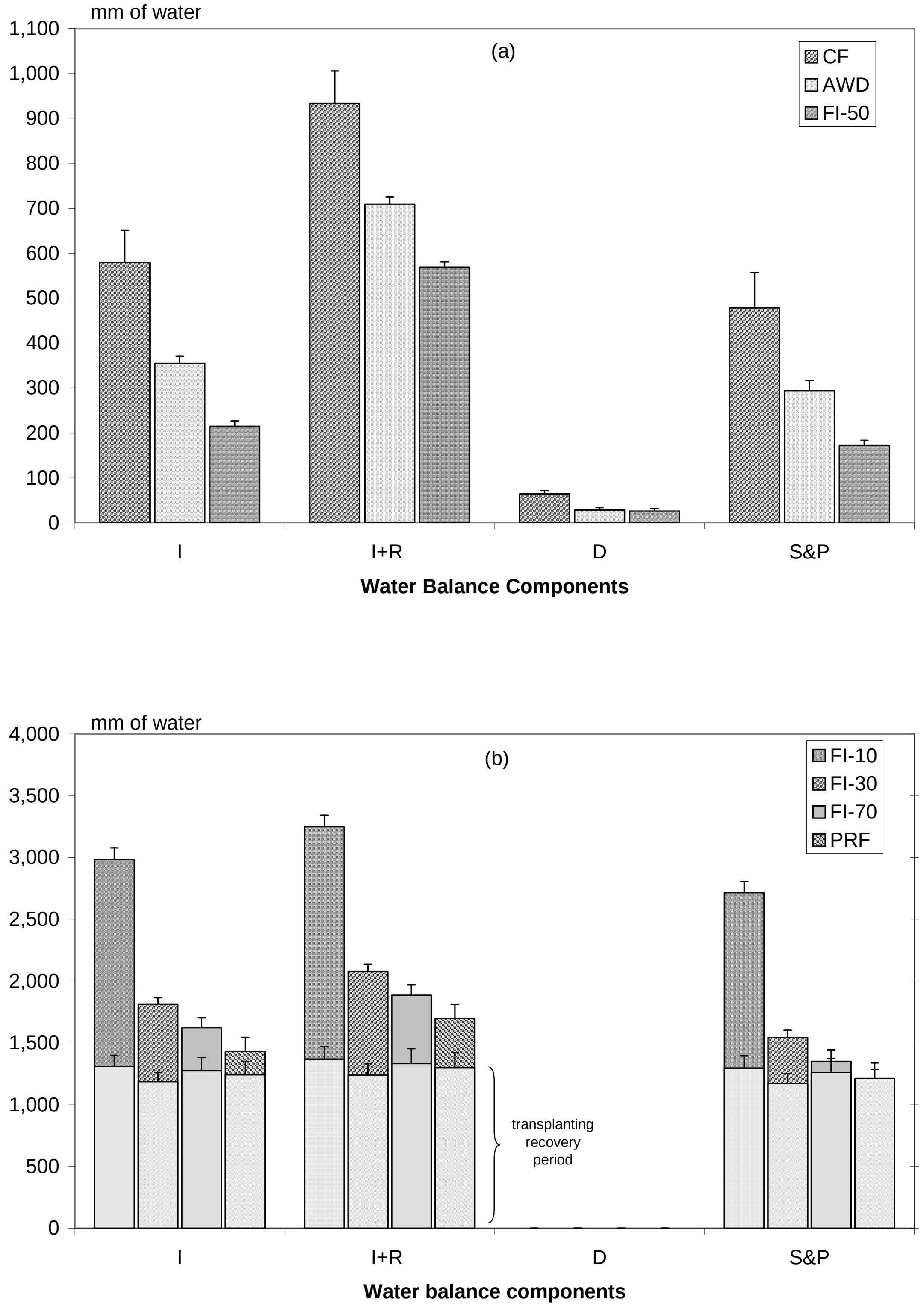
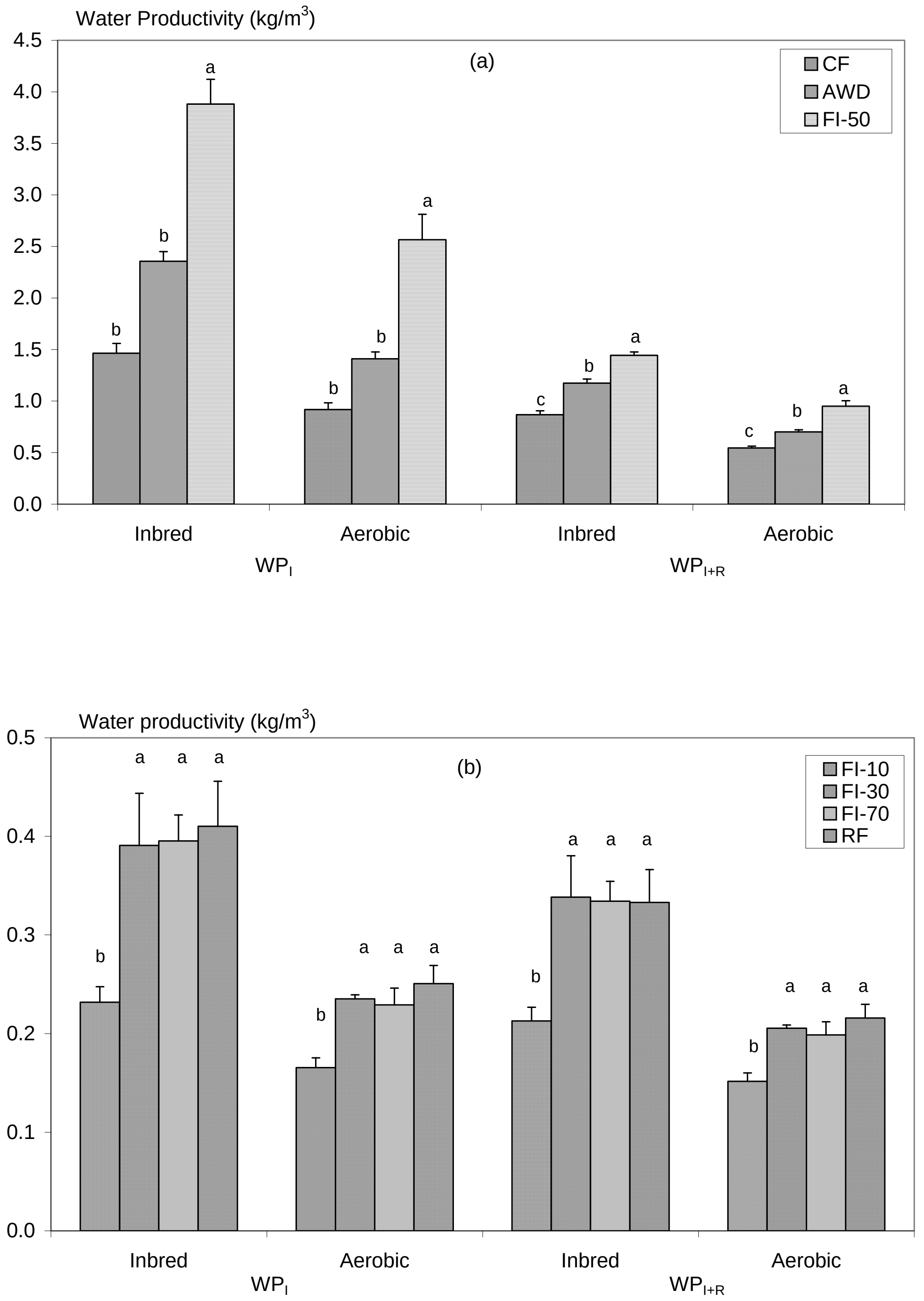

mm of water
(a)
CF
AWD
FI-50
1,100
1,000
900
800
700
600
500
400
300
200
100
0
I
I+R
D
S&P
Water Balance Components
mm of water
(b)
FI-10
FI-30
FI-70
PRF
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
transplanting
recovery
period
I
I+R
D
S&P
Water balance components

Fig. 4.



Water Productivity (kg/m3)
(a)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
CF
AWD
FI-50
b
b
a
b
b
a
c
b
a
c
b
a
Inbred
Aerobic
Inbred
Aerobic
WPI
WPI+R
Water productivity (kg/m3)
(b)
0.5
0.4
0.3
0.2
0.1
0.0
FI-10
FI-30
FI-70
RF
b
a
a
a
b
a
a
a
b
a
a
a
b
a
a
a
Inbred
Aerobic
Inbred
Aerobic
WPI
WPI+R

Fig. 5.