WORKING PAPER 56

Strategies for Conserving Water and Effecting Mosquito Vector Control in Rice Ecosystems

A Case Study from Tamil Nadu, India

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International Water Management Institute

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The authors: Dr. S. Krishnaswamy is a Professor of Agronomy at theTamil Nadu Agricultural University in Madurai, India; Dr. F. P. Amerasinghe is a Principal Researcher and Theme Leader, Water, Health and Environment Theme at IWMI; Dr. R. Sakthivadivel is a IWMI Senior Fellow, working as a Consultant to the IWMI-South Asia Regional Office in India; Dr. G. Ravi is an Assistant Professor at the Department of Agronomy of the Tamil Nadu Agricultural University in Madurai, India; Mr. S.C. Tewari is a Senior Technical Officer at the Centre for Research in Medical Entomology in Madurai, India; and Dr. W. van der Hoek is a Medical Doctor, Epidemiologist, and a Consultant to the Water, Health and Environment Theme of IWMI.

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Please send inquiries and comments to: *iwmi@cgiar.org*

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Summary

A small-scale case study on the impacts of water saving irrigation techniques on land and water productivity and mosquito vector breeding was carried out in farmer-managed rice fields under the command of the Andaman Tank in Madurai District, Tamil Nadu State, India, during October 1999 to January 2000. The tank received water from its own catchment as well as from a sluice of the main canal of a nearby major irrigation system.

The tank had three outlets, at which different water management regimes were implemented as follows: outlet-1 for continuous submergence irrigation (CSI); outlet-2 for irrigation to 5 cm depth one day after disappearance of ponded water in fields (alternate wet/dry irrigation—AWDI); and outlet-3 for rotational water supply (RWS), i.e., 4 days "on" and 3 days "off". Five rice fields were selected for detailed data collection under each water management regime. Water accounting was based on measurements at tank outlet, field and drainage levels. Agronomic evaluations included rice plant growth (root length and width, leaf area index [LAI]), yield attributes (no. of panicles/m^2, panicle length, grains/panicle, sterility percentage), fertilizer and pesticide applied, weed density and de-weeding effort. Mosquito immature stages breeding in the rice fields, together with associated arthropod fauna, were sampled.

Rice yield, LAI and percent grain sterility were influenced by rice variety and water regime. When water management regimes were compared for the same rice variety (ASD 19), 6–7 percent higher yields and root length, 4 percent greater panicle length and 29 percent lower grain sterility were recorded under AWDI than CSI. Intermediate values were recorded for RWS. Overall, therefore, AWDI resulted in slightly greater land productivity in rice, compared to CSI and RWS.

Water accounting studies showed that local irrigation efficiency (consumed water /supplied water) and depleted fraction at field and outlet levels were highest, and ground- water level change lowest, under AWDI. This practice locally retained about 22 percent of water compared to CSI, the saving occurring mainly from reduced recharge loss and return flow.

Five *Culex* and five *Anopheles* mosquito species occurred in the rice fields, the dominant species being two vectors of Japanese encephalitis, viz., *Culex tritaeniorhynchus* and *Cx. vishnui*. Statistically equivalent mosquito immature densities occurred under all three water regimes, but both *Anopheles* and *Culex* occurred significantly more frequently in AWDI and RWS than CSI fields. Clearly, the AWDI technique was not effective in suppressing mosquito breeding under the farmer-managed conditions encountered in the field where frequent rainfall and inadequate field leveling confounded the intended drying effects of the AWDI and RWS water management regimes.

Overall, this case study under farmer-managed conditions suggest that alternate wet/dry irrigation saved water locally whilst maintaining yields on par with the other management regimes tested. However, the results on mosquito breeding indicate that caution needs to be exercised in promoting the technique as a method of mosquito vector control.

Introduction

Rice is the staple food for almost half of the world's population, but it is also the most water-intensive crop under large-scale cultivation. However, water is fast becoming a scarce resource: according to Guerra et al. (1998) the per capita availability of water is expected to decline by some 15–54 percent by 2025. Increasing land and water productivity by producing more rice with less water is thus important for maintaining food security in the face of impending water scarcity. One of the techniques of using water efficiently is the alternate wet/dry irrigation method (AWDI) which is practiced in countries such as Japan, China and India. In this method, water is not kept continuously inundating rice fields, but is supplied intermittently so that the fields are alternately wetted and dried.

In recent reviews, van der Hoek et al. (2001) and Keiser et al. (2002) point out that AWDI also has potential health benefits in that the intermittent drying of rice fields could kill immature stages of mosquitoes that transmit diseases such as malaria and Japanese encephalitis. Rice ecosystems have traditionally been associated with these diseases because of the proclivity of the vector mosquitoes to breed abundantly in the rice fields (Lacey and Lacey 1990). Any agricultural water management technique that has the dual benefits of increased land and water productivity and improved health status would make an important contribution to sustainable development, because it would enable healthier farmers to spend more productive time tending their crops (van der Hoek et al. 2001).

There have been many trials of the AWDI technique (reviewed extensively by van der Hoek et al. 2001 and Keiser et al. 2002), but most have been in experimental plots where agronomic aspects (field size and leveling, rice variety, water regime, fertilizer, pesticide, weed control etc.) have been under the control of the experimenters. For a proper evaluation of the multiple benefits of AWDI, trials under farmer managed conditions are necessary. The present report provides information from a small-scale field study done under on-farm conditions, in a rice growing area of Tamil Nadu, India.

The Study Area

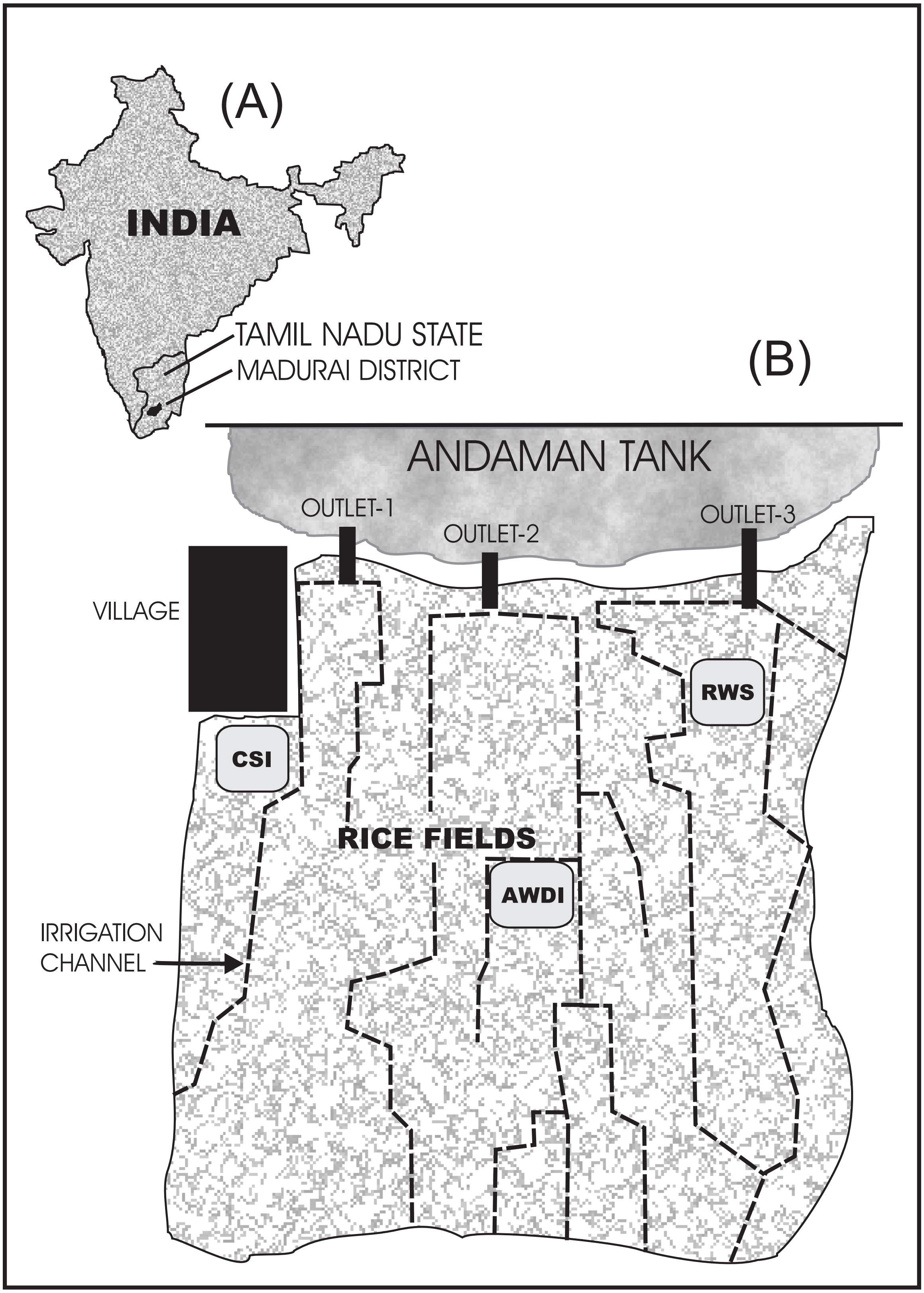
This collaborative study involving TNAU-CRME-IWMI[1] was conducted in a System Tank[2] at Andaman village of Madurai district located in Tamil Nadu, India (latitude $9^{o}54'$ and longitude $70^{0}80'$ E) (figure 1).

The tank was mainly fed by the 27 (R) sluice of the Periyar Main Canal (PMC) of the Periyar-Vaigai system and also received water as drain flow from its own catchment which formed the upper basin areas. The total length of the channel from 27 (R) to the tank was 1,697 m. Of this, 791 m was lined with random rubble masonry and the remaining 906 m length existed as an unlined earthen channel. There were five diversion boxes provided between the 27 (R) sluice and the tank. The diversion boxes were provided with shutters to regulate the supply of water to the direct PMC *ayacut* (= service) area lying upstream of the tank. The system tank was opened for irrigation on 13.8.1999 and closed on 29.1.2000, thereby making available water for 168 days. It had three

[1] Tamil Nadu Agricultural University—Center for Research in Medical Entomology—International Water Management Institute.

[2] A System Tank is one that receives its water supply from its own catchment as well as from an external source such as an irrigation canal or diversion canal from a river.

Figure 1. Map of (A) India showing the State of Tamil Nadu and District of Madurai, and (B) the study area showing the location of the Andaman Tank, village, rice fields, irrigation channels, and study plots.



outlets with a service area of 65.87 ha (402 fields, of varying sizes). Outlet-related details of the number of fields and irrigable area were as follows: outlet-1 (139 fields, 20.06 ha); outlet-2 (168 fields, 28.05 ha); outlet-3 (95 fields, 17.76 ha).

Soils

The soils of the Andaman tank service area are of the sandy clay loam type, low in available nitrogen (N), and medium in available phosphorus (P) and potassium (K). The organic matter content of the soils revolves around 0.50 percent. The soils have a dominance of montmorrillonitic clay minerals with clay content increasing with depth.

Climate

The mean annual rainfall of the study area is 850 mm. During the study period, a total rainfall of 579 mm was received in 31 rainy days. The mean minimum temperature and maximum temperature ranged between 19^0C to 37^0C. The mean relative humidity is 75 percent and during the study period it ranged between 73 to 87 percent. The wind velocity and sunshine hours during the study period ranged from 1.0 to 6.0 km hr^{-1} and 1.0 to 10.7 hrs day^{-1}. Total pan evaporation recorded during the cropping period was 497 mm.

Socioeconomic Aspects

In the study area, the average operational landholding was 9.3, 2.9 and 0.5 ha per large, medium and small sized farms, respectively. Large, medium and small farmers accounted for 38.9, 27.1 and 34.0 percent, respectively, of the total. About 60 percent of the large farm holders, 50 percent of medium farm-holders, 23 percent of small farm-holders and 22 percent of landless are either middle or high school or higher secondary school educated.

Vector-borne Diseases

Malaria, Japanese encephalitis (JE), Bancroftian filariasis, and leishmaniasis are the dominant vector-borne diseases in South India. Of these, the first three are mosquito-borne diseases, the vectors being certain species of *Anopheles* and *Culex*, respectively. Some of these mosquitoes are known to breed in rice fields; indeed rice fields are reported to be important breeding sites of *An. culicifacies* (the main vector of malaria) and of *Cx. tritaeniorhynchus* and *Cx. vishnui* (major vectors of JE) (Rao 1984, Lacey and Lacey 1990). Madurai District is not a highly malaria-endemic area, but it is identified as a problem area for JE, with many cases and several deaths being recorded each year.

Methodology

Water Regimes

The study was conducted both at outlet level and at field level. At the outlet level the following three water management features were tested:

Outlet 1	–	Continuous submergence irrigation (CSI)
Outlet 2	–	Irrigation to 5 cm one day after disappearance of ponded water (alternate wet/dry irrigation - AWDI)
Outlet 3	–	Rotational water supply (RWS) - 4 days “on” and 3 days “off”

In outlet 3, rotational water supply was practiced in canals below the main outlet canal. The water supply was continuously made available in the canal outlet and the rotational system was practiced by farmers in channels taking off from the outlet canal. At the outlet level, flow release from the tank for each outlet was measured daily by installing 15 cm throat-width Parshall Flume water measuring devices and the total outflow for each outlet for the crop period was accounted for. Similarly drainage flow for each outlet was also measured whenever drain flow occurred at the end point of the drainage canal by using the Parshall Flume device.

Five fields were selected in each of the three outlets for detailed data collection. At the field level, the quantity of water given to each field was accounted for whenever irrigation was applied. Details of the outlet field numbers, extent, rice varieties transplanted and dates of transplanting are given in table 1. Only the water regime was under the control of the experimenters; factors such as the rice variety and fertilizer applied were under farmer control. The fields transplanted formed a continuous area and more or less had synchronized transplanting. The rice varieties tested were of medium duration, ranging from 125 to 135 days. The variety ADT 39 was of fine quality type whereas ASD 19 and CO 43 were medium fine quality types.

Table 1. Details of field extent, rice varieties and dates of transplanting of outlets studied.

Outlet 1

Field No.	Extent (ha)	Rice Variety	Date of Transplanting
28	0.055	ADT 39	29.09.1999
39	0.073	ASD 19	29.09.1999
40	0.088	ASD 19	29.09.1999
41	0.162	CO 43	29.09.1999
42	0.118	CO 43	29.09.1999

Outlet 2

Field No.	Extent (ha)	Rice Variety	Date of Transplanting
25	0.223	ADT 39	30.09.1999
30	0.230	ADT 39	30.09.1999
31	0.165	ADT 39	30.09.1999
32	0.178	ADT 39	30.09.1999
33A	0.228	ASD 19	30.09.1999

Outlet 3

Field No.	Extent (ha)	Rice Variety	Date of Transplanting
24	0.260	ASD 19	29.09.1999
25	0.345	ASD 19	29.09.1999
26	0.205	ASD 19	29.09.1999
27	0.260	ASD 19	29.09.1999
29	0.200	CO 43	29.09.1999

Water Monitoring

Skilled persons working under the supervision of a technical assistant were engaged to regulate the water as per the water management treatment to the study fields after it was drawn from the outlets. The farmers did not regulate the irrigation supply to their fields, but were in control of all other cultivation aspects.

The assigned field number was marked on a 1 m long bamboo stake fixed in the field for easy identification. For controlling the depth of irrigation in each field, 25 cm long bamboo stakes painted red and with a scale marked in white paint were fixed on the four corners of every field approximately 1 m away from the edges. Depending upon the quantity of flow, the water was diverted to a single field or divided into two portions for the purpose of easy regulation. The water level in each field was monitored daily and accounted for.

Effective rain has to be added to the irrigation water applied to the field in order to compute the total water supplied at the field. Since the soils under rice cultivation are always saturated, soil moisture is not a determinant in assessing the proportion of rain that can be considered effective. In rice cultivation, it is the depth of standing water in the field when the rainfall is received that determines the portion that can be considered to be effective. The effective rainfall at field level was computed by using a field water balance approach.

Daily groundwater levels in 13 wells located in the study area were monitored so as to determine the fluctuation in groundwater levels due to water management treatments.

Rice Growth Measurements

Growth in terms of root length, width and leaf area index (LAI) was measured for each water management treatment.

Yield Attributes

Yield attributes, viz. the number of panicles per meter square, panicle length, grains per panicle and sterility percentage were recorded from the samples collected from three different water management treatments and the mean values were arrived at. Rice grain yield in terms of kilograms was recorded for each treatment field and computed to kg/ha.

Weeds

For each treatment, the number of weeds was counted at five randomly selected 0.25 m^2 quadrats, averaged, and expressed as density per m^2. De-weeding effort was computed by accounting for the number of actual laborers required to de-weed each field, converting to the requirement per ha, and calculating the man-hour rate on the basis of 5 working hours per day. Both weed density and de-weeding effort were monitored on the two occasions during the rice growing cycle when farmers actually engaged in de-weeding activities.

Mosquito Sampling

Rice fields were sampled three times per week (Monday, Wednesday and Friday) for mosquito immature stages and associated aquatic fauna. Standard 350 ml. mosquito sampling dippers were used. Twenty dips (five along each margin) taken from each field constituted a sample for that field. Mosquito immatures and associated fauna from the 20 dips were pooled, and placed in a white enamel tray. Mosquito 1st/2nd instars, 3rd/4th instars, and pupae were placed in separate vials, counted and taken to the laboratory for rearing and identification using standard keys for identification (Reuben et al. 1994; Rao 1984). Associated aquatic fauna also were taken to the laboratory for identification. Five fields were sampled on each sampling day for each of the three water management regimes (CSI, RWS and AWDI). Sampling commenced of September 27, 1999, after the land preparation stage had been completed, and continued for 12 weeks until the fields were dried prior to harvest. The relative density of predators and associated arthropod fauna was scored as absent, low (1–20) or high (> 20). Field water levels (measured daily) were scored as low (< 20 mm), medium (20–40 mm) and high (> 40 mm).

Data Analysis

Due to constraints imposed by doing this study in farmers' fields under farmer-managed conditions, balanced sample sizes could not be achieved in respect of rice varieties cultivated in field plots. Thus, data on agronomic factors were subjected only to simple trend analysis, and not to more complex statistical analyses. Data on mosquito relative abundance and on water levels in fields with different water management regimes were examined by analysis of variance (ANOVA). To obtain information on the role of different variables (water regimes, water level, predators, and associated fauna) in explaining the occurrence of *Culex* and *Anopheles* mosquitoes in rice fields, mosquito positive samples were compared with negative samples by means of multiple logistic regression analysis. Results are reported as Odds Ratios (OR) defined in the present context as the odds of a certain factor being present in samples positive for mosquitoes divided by the odds of that factor being present in samples negative for mosquitoes. Confounding by other variables was adjusted by means of the logistic regression.

Trends in mosquito relative abundance in the three water management regimes over the 12-week sampling period are presented as geometric mean abundance per field per sampling day.

Results and Discussion

Water Supply, Agronomy and Yield Attributes

As indicated in the methodology, the three water distribution practices tested were: continuous supply irrigation (CSI), rotational water supply (RWS), and alternate wet/dry irrigation (AWDI). Tables 2, 3 and 4 present salient results obtained in these treatments. However, rice varietal comparisons were constrained by farmer choice: in several instances a rice variety was grown in only one field under a particular water regime (eg., ADT 39 under CSI, ASD 19 under AWDI, CO 43 under RWS).

Three medium duration rice varieties, ADT 39, ASD 19 and CO 43, were planted under CSI. Of these, ADT 39 takes 125 days while the other two varieties extend up to 135 days. Fertilizer applied for these three varieties were more or less similar. The water supplied at the field level for the season was 671 mm for ADT 39, 725 mm for ASD 19 and 723 mm for CO 43; the average for the three varieties was 713 mm.

Table 2. Agronomic details of fields cultivated under continuous submergence irrigation (CSI).

Field No.	Variety	Grain yield (kg/ha)	Root length (cm)	Root width (cm)	LAI	Yield Attributes: Panicles per m^2	Yield Attributes: Panicle length (cm)	Yield Attributes: Grains per panicle	Yield Attributes: Sterility (%)	Weed density per m^2	Man hrs	Fertilizer (N) applied (kg/ha)	Water supplied (mm)
28	ADT 39	5,625	21.80	8.70	5.525	354	19.0	105.2	16.2	80	220	113	671
39	ASD 19	6,075	24.25	11.28	6.000	360	19.6	123.1	18.5	81	210	122	710
40	ASD 19	6,150	24.00	10.98	6.004	361	20.0	124.2	20.2	66	143	125	739
41	CO 43	6,250	24.60	11.47	6.120	366	20.2	129.2	18.5	87	200	113	728
42	CO 43	6,300	24.44	11.56	6.122	364	20.5	127.4	19.2	77	188	113	717
									Mean	78	192	117	713

Note: LAI = Leaf area index

Table 3. Agronomic details of fields cultivated under rotational water supply (RWS).

Field No.	Variety	Grain yield (kg/ha)	Root length (cm)	Root width (cm)	LAI	Yield Attributes: Panicles per m^2	Yield Attributes: Panicle length (cm)	Yield Attributes: Grains per panicle	Yield Attributes: Sterility (%)	Weed density per m^2	Man hrs	Fertilizer (N) applied (kg/ha)	Water supplied (mm)
24	ASD 19	6,275	24.30	11.60	6.000	365	20.0	123.2	17.3	88	212	120	654
25	ASD 19	6,300	23.94	11.42	6.003	362	19.8	126.0	20.5	72	190	120	657
26	ASD 19	6,175	24.32	11.65	6.012	364	19.0	127.4	19.7	70	207	113	662
27	ASD 19	6,225	24.16	11.27	6.002	360	19.4	122.2	18.8	92	222	120	667
29	CO 43	6,600	24.40	11.86	6.125	367	20.8	126.8	19.0	66	196	120	657
								Mean	78	205	119	659	

Note: LAI = Leaf area index

Table 4. Agronomic details of fields cultivated under alternate wet/dry irrigation (AWDI).

Field No.	Variety	Grain yield (kg/ha)	Root length (cm)	Root width (cm)	LAI	Yield Attributes: Panicles per m^2	Yield Attributes: Panicle length (cm)	Yield Attributes: Grains per panicle	Yield Attributes: Sterility (%)	Weed density per m^2	Man hrs	Fertilizer (N) applied (kg/ha)	Water supplied (mm)
25	ADT 39	5,975	22.84	8.70	5.540	361	19.2	101.2	12.8	104	247	120	562
30	ADT 39	5,850	22.50	8.80	5.543	360	19.4	118.4	13.0	98	225	120	554
31	ADT 39	5,990	22.68	8.70	5.545	358	19.2	110.6	12.1	72	218	120	563
32	ADT 39	6,000	22.82	8.82	5.552	356	20.0	106.4	13.3	70	222	117	584
33A	ASD 19	6,525	25.75	10.64	6.006	363	20.3	123.2	14.0	88	232	147	555
									Mean	86	228	125	563

Note: LAI = Leaf area index

Root length, root width and leaf area index (LAI) were lowest for ADT 39 and highest for CO 43. Among the yield attributes, the number of panicles/m^2, panicle length (cm), grain per panicle and percent sterility were lowest for ADT 39 and highest for CO 43. The variety ADT 39 gave the lowest yield (5,625 kg/ha) and CO 43 the highest yield (6,275 kg/ha) (table 2). From the grain size point of view, ADT 39 is a fine variety that fetches a higher market price compared to the other two, which are coarser.

Two varieties, ASD 19 and CO 43, were planted under RWS. The water and fertilizer supplied over the season for the two varieties were more or less the similar, the average for the season being 659 mm and 119 KgN/ha, respectively. CO 43 gave the higher yield (6,600 kg/ha) and ASD 19 the lower (6,244 kg/ha). The other agronomic and yield attributes parameters followed roughly similar patterns as under CSI.

The varieties ADT 39 and ASD 19 were planted under AWDI. The water supplied over the season for the two varieties were more or less similar, the average for the season being 563 mm. More fertilizer was applied to the ASD 19 field than the ADT 39 fields (table 3). Of the two varieties, ASD 19 gave the higher yield (6,525 kg/ha) and ADT 39 the lower yield (5,954 kg/ha). As before, the pattern of variation of root length, root width, LAI, panicles/m^2, panicle length (cm), grains per panicle and sterility percent corresponded with yield.

It is clear from the above that varietal choice plays an important role in increasing land productivity. Hence, impact of water distribution practices on yield needs to be compared for the same rice variety. From tables 2, 3 and 4 it can be seen that the common variety for all three water distribution practices was ASD 19. Thus, for this variety the agronomic, yield and water supply parameters are listed for all three water distribution practices (table 5).

Table 5 indicates that the land productivity was highest under the AWDI practice (6.73% higher than under CSI). The water saved also was highest under AWDI (21% compared with CSI). Other indicators such as root length, LAI, and panicle length all were higher under AWDI than in the continuous treatment. The most striking factor was that grain sterility was less by 29 percent under AWDI.

Based on these results, we hypothesize that late tillering is effectively prevented in the AWDI treatment. Increase in root length and width allows the plant to extract more nutrients and feed it to effective tillers. Also, better aeration, and oxidation help the roots to absorb more nutrients. This results in marginal increases in the number of panicles/m^2, panicle length and the number of grains per panicle, and a substantial reduction in the sterility of grains. These factors contribute to the increased land productivity under AWDI practices. This hypothesis also has been tested and validated under laboratory conditions by Chinese researchers (Li 2001, Li et al. 1994), but is at variance with the findings of the International Rice Research Institute (IRRI) who claim that AWDI does not lead to increased land productivity (Cabangon et al. 2001a, 2001b).

Water Accounting

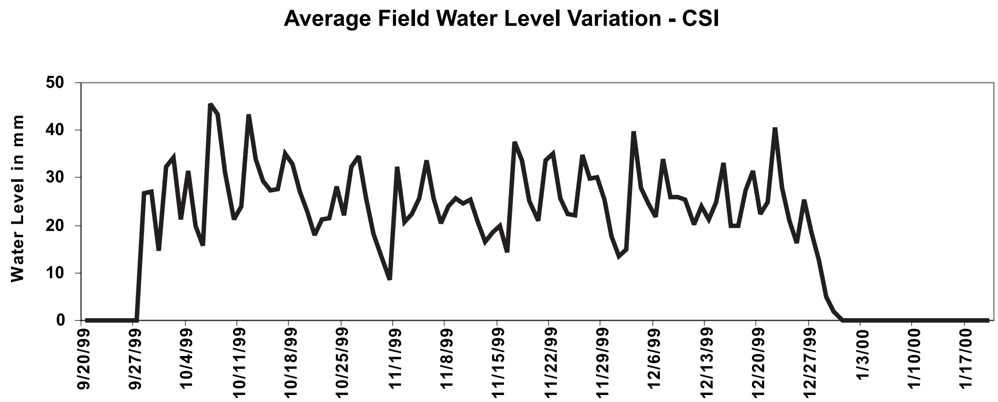
Figure 2 shows the water depth variation over a cropping season in the three treatments adopted. The volume of water stored was highest in CSI followed by RWS and AWDI. Because of the rainfall, it was difficult to maintain a systematic cyclic variation of depth in AWDI treatment; however, it is clear that the volume of water retained in the field was the lowest with AWDI. Water balance analysis carried out for the treatments at field level indicated that effective rainfall varied between 15 percent and 38 percent of total rainfall. The effective rainfall harnessed by AWDI practice was not much different from the other two treatments (table 6).

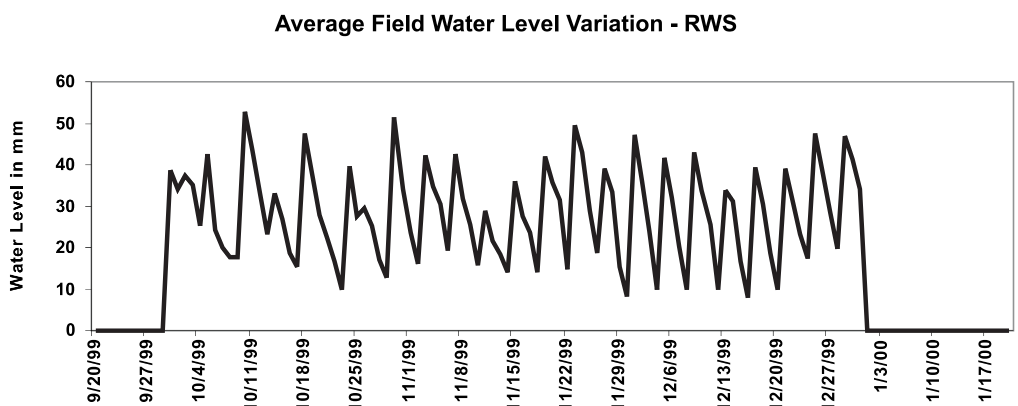
Table 5. A comparison of agronomic and yield attributes of rice variety ASD 19 under different water regimes.

Water Distribution practices	Grain yield (kg/ha^{-1})	Root length (cm)	Root width (cm)	LAI	Yield Attributes				Fertilizer (N) applied (kg/ha)	Water supplied (mm)
					Panicles per m^2	Panicle length (cm)	Grains per panicle	Sterility (%)		
CSI	6,113	24.12	11.13	6.002	360	19.5	123.6	19.8	123	713
RWS	6,244	24.18	11.49	6.004	362	19.8	126.7	19.0	118	659
	(2.14)	(0.25)	(3.23)	(0.03)	(0.55)	(1.54)	(2.51)	(-4.04)	(-4.07)	(-7.57)
AWDI	6,525	25.75	10.64	6.006	363	20.3	123.2	14.0	147	563
	(6.73)	(6.75)	(-4.40)	(0.07)	(0.83)	(4.10)	(-0.32)	(-29.29)	(19.51)	(-21)

Notes: Values in parentheses indicate percentage difference in comparison with CSI.
CSI = Continuous submergence irrigation RWS = Rotational water supply AWDI = Alternate wet/dry irrigation
LAI = Leaf area index

Figure 2. Temporal variation in average field water levels under continuous submergence irrigation (CSI), rotational water supply (RWS), and alternate wet/dry irrigation (AWDI).





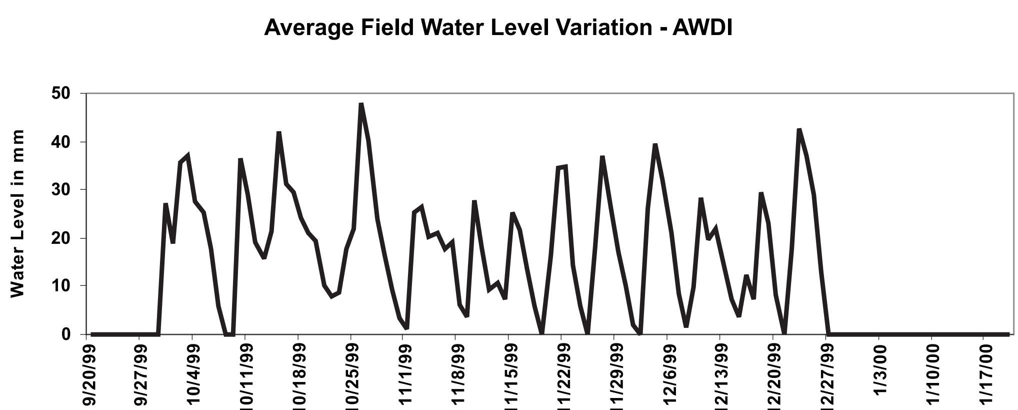


Table 6. Summary of effective rainfall computations under different water regimes.

		Total Rainfall (mm)	Total Irrigation Applied (mm)	Total Water Applied (mm)	Total ETC (mm)	Effective Rainfall (mm)	%
CSI	Replicate 1	579	638	1,217	552	171	30
	Replicate 2	579	678	1,257	552	191	33
	Replicate 3	579	706	1,285	552	144	25
	Replicate 4	579	695	1,274	552	182	31
	Replicate 5	579	684	1,263	552	217	38
RWS	Replicate 1	579	635	1,214	552	150	26
	Replicate 2	579	656	1,235	552	96	17
	Replicate 3	579	647	1,226	552	81	14
	Replicate 4	579	661	1,240	552	87	15
	Replicate 5	579	646	1,225	552	91	16
AWDI	Replicate 1	579	537	1,116	552	141	24
	Replicate 2	579	537	1,116	552	163	28
	Replicate 3	579	532	1,111	552	89	15
	Replicate 4	579	536	1,115	552	84	14
	Replicate 5	579	540	1,119	552	126	22

Note: ETC = Evapotranspiration (computed)

The results of water accounting studies are summarized in figure 3. The following trends were evident:

- Local irrigation efficiency (consumed water divided by water supplied) both at field and outlet levels were highest under AWDI.

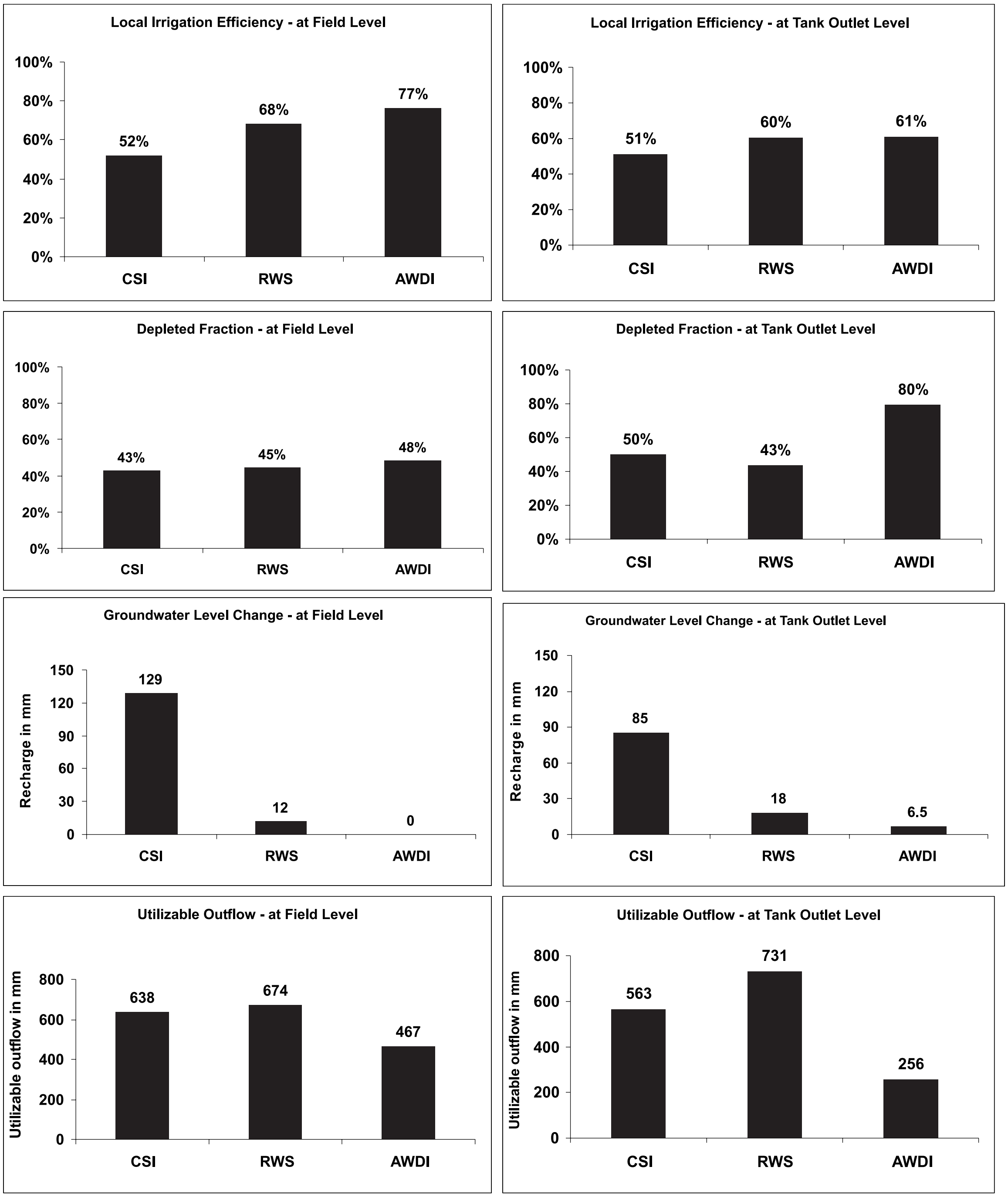
- Depleted fraction both at field and outlet levels were highest in the AWDI practice. Depleted fraction indicates the water depleted (evaporation + water to sinks) with respect to irrigation water supplied + rainfall. The depleted fraction is computed with respect to gross inflow. The 80 percent of depletion at the tank outlet level under AWDI indicates that only 20 percent of remaining water was available for groundwater recharge and return flow. The large difference between field level and tank outlet level depleted fraction is reflected in the higher amount of utilizable outflow getting out from the field compared to the outlet level (figure 3).

- Groundwater level change due to percolation was highest under CSI while it was the lowest under AWDI. On the other hand, utilizable outflow was highest under RWS and the least with AWDI.

Observations on Weeds and Pesticides

The first weeding of fields was done between 13–19 October, and the second weeding between 27 October–8 November 1999. The results are presented in table 7. In both periods the AWDI

Figure 3. Local irrigation efficiency (%), depleted fraction (%), groundwater level change (mm), and utilizable outflow (mm) at field and tank outlet level in the study plots.



Notes: CSI = Continuous submergence irrigation
RWS = Rotational water supply
AWDI = Alternate wet/dry irrigation

Table 7. Weed density and de-weeding effort in rice fields under different water regimes.

Water Regime	First de-weeding		Second de-weeding	
	Weed Density (No. per m^2 ± sd)	De-weeding Effort (Man-hours ± sd)	Weed Density (No. per m^2 ± sd)	De-weeding Effort (Man-hours ± sd)
CSI	102.2 ± 14.4	236.0 ± 45.6	53.4 ± 4.8	150.0 ± 24.7
RWS	105.2 ± 18.3	245.0 ± 16.9	50.0 ± 5.7	168.0 ± 13.0
AWDI	115.6 ± 21.7	273.0 ± 26.8	57.0 ± 8.9	185.0 ± 10.6

Notes: Differences between water regimes are non-significant at the $P < 0.05$ level.
sd = Standard deviation
CSI = Continuous submergence irrigation; RWS = Rotational water supply
AWDI = Alternate wet/dry irrigation

fields had more weeds per square meter and required a greater weeding effort than CSI and RWS fields. The differences, however, were statistically nonsignificant.

The farmers used chemicals for the management of leaf-folder and stem borer pests of rice. Regardless of water regime, all fields received a single application of Monocrotophos 36 wsc at the rate of 1 liter/ha. In the CSI group, one field received an additional 3 kg of Furadon 10G, and in the RWS group, a single field received an application of Malathion 50EC at the rate of 500 ml/ha. In contrast, four of the AWDI fields received an additional treatment with Furadon 10G (adding up to a total of 10 kg of pesticide) approximately 10 days after the Monocrotophos application. It is not known whether this was in response to a perceived pest upsurge or was the customary practice of the particular farmer(s) concerned.

Water Regime and Mosquito Breeding

Five *Culex* and five *Anopheles* species bred in the rice fields, the dominants being two vectors of Japanese encephalitis, viz., *Cx. tritaeniorhynchus* and *Cx. vishnui* (table 8). Seven types of arthropods that prey on mosquito immature stages co-occurred in these fields, the commonest being adult *Notonecta* (water boatmen) and *Dytiscus* (water beetle), and larval stages of dragonflies and damselflies (table 8).

The distribution of different mosquito immature life stages in fields with different water management regimes was fairly similar (table 9). Overall, however, AWDI fields contained 1.9 times more mosquito immature stages than RWS fields, and 1.5 times more larvae than CSI fields. As for pupae (the critical stage from which adults emerge), AWDI fields contained 2.5 times more than RWS, and almost 1.5 times more than CSI fields.

The biophysical characteristics of fields under different water management regimes are summarized in table 10. Mosquitoes, predators and associated other arthropods generally occurred at lower frequency in AWDI than RWS and CSI. Daily field water levels analyzed over the 12-week sampling period showed significantly lower mean levels in AWDI fields than in RWS and CSI fields (ANOVA, $F = 18.9$, $df = 2$, $P<0.001$; followed by Dunnett Multiple Comparison Test, $P<0.001$). Mosquito relative abundance data (ln x+1 transformed mean per sampling day) were not normally distributed, and examined by the Kruskall-Wallis non-parametric ANOVA. The results showed that relative abundance was not significantly different ($P > 0.05$) in the 3 water management regimes. Temporal trends in mosquito abundance in the three water management regimes also were similar (figure 4).

Table 8. Composition of mosquito species and associated predators collected from rice fields.

	Percentage
Mosquitoes (n = 31,938)	
Culex (Culex) tritaeniorhynchus	61.4
Culex (Culex) vishnui	23.3
Culex (Culex) pseudovishnui	5.3
Culex (Culex) infula	4.7
Culex (Lutzia) fuscanus	0.2
Anopheles (Cellia) subpictus	3.9
Anopheles (Cellia) annularis	0.2
Anopheles (Cellia) vagus	0.2
Anopheles (Anopheles) barbirostris	0.5
Anopheles (Anopheles) peditaeniatus	0.3
Total	100.0
Predators (n = 3,372)	
Notonecta sp. (Hemiptera)	35.0
Dytiscus marginalis (Coleoptera)	27.0
Odonata (Anisoptera)	20.9
Odonata (Zygoptera)	13.9
Gerris sp. (Hemiptera)	1.4
Hydrometra stagnorum (Hemiptera)	1.3
Nepa sp. (Hemiptera)	0.5
Total	100.0

Table 9. Distribution (number [%]) of mosquito immature life stages in fields with different water regimes.

Life Stage	CSI		RWS		AWDI		Total
Culex							
I/II instars	5,990	(69.2)	4,023	(63.4)	8,859	(68.2)	18,872
III/IV instars	2,252	(26.0)	2,101	(33.1)	3,513	(27.1)	7,866
Pupae	408	(4.7)	224	(3.5)	615	(4.7)	1,247
Subtotal	8,650	(100.0)	6,348	(100.0)	12,987	(100.0)	27,985
Anopheles							
I/II instars	588	(69.1)	894	(65.9)	1,289	(73.9)	2,771
III/IV instars	230	(27.0)	427	(31.5)	416	(23.8)	1,073
Pupae	33	(3.9)	36	(2.7)	40	(2.3)	109
Subtotal	851	(100.0)	1,357	(100.0)	1,745	(100.0)	3,953
Grand Total (100.0)	9,501	(29.8)	7,705	(24.1)	14,732	(46.1)	31,938

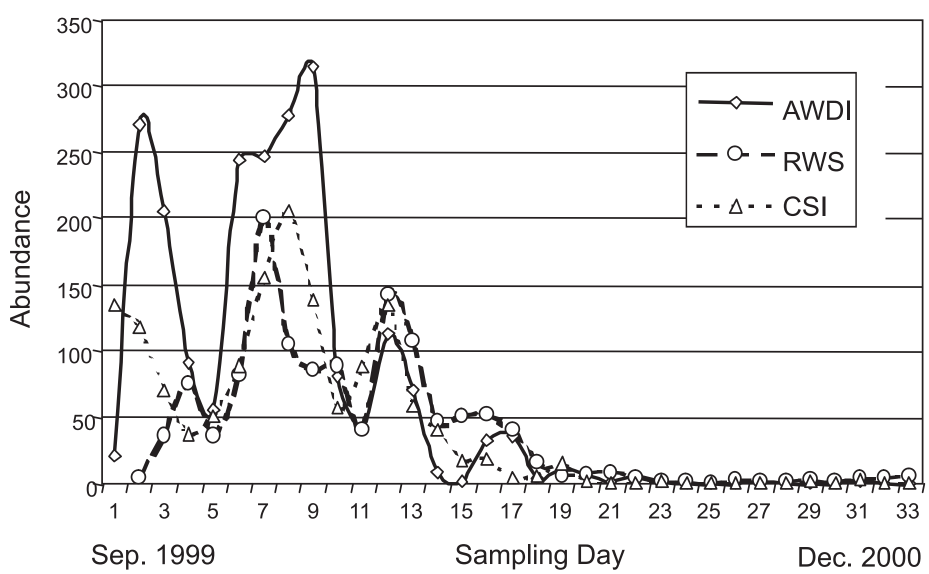
Notes: CSI = Continuous submergence irrigation
RWS = Rotational water supply
AWDI = Alternate wet/dry irrigation

Table 10. Biophysical characteristics of rice fields with different water management regimes.

Field characteristic	CSI	RWS	AWDI
Culex species (%)			
Absent	39.4	21.9	43.0
Present	60.6	78.1	57.0
Anopheles Species (%)			
Absent	38.8	21.9	44.8
Present	61.2	78.1	55..2
Arthropod Predators (%)			
Absent	20.6	11.9	44.8
Low	67.6	85.0	48.5
High	11.8	3.1	6.7
Other Arthropods (%)			
Absent	22.9	13.8	48.5
Low	55.9	66.8	30.3
High	21.2	19.4	21.2
Water level (%)			
Low	34.7	26.3	60.0
Medium	48.2	56.2	32.5
High	17.1	17.5	7.5

Notes: CSI = Continuous irrigation
RWS = Rotational water supply
AWDI = Alternate wet/dry irrigation

Figure 4. Trends in the abundance (geometric mean number per 20 dips) of mosquito immature stages breeding in rice fields under continuous submergence irrigation (CSI), rotational water supply (RWS), and alternate wet/dry irrigation (AWDI).



The results of multivariate analyses for total *Culex* and total *Anopheles* in fields are presented in tables 11 and 12. The variables used explained 80 percent of the distribution of these mosquitoes. *Culex* occurrences were significantly more associated with AWDI and RWS fields than CSI, and also were associated with the presence of predators. *Anopheles* occurrences were associated significantly more with AWDI and RWS fields than CSI, and with both predators and non-predatory arthropods. Water level was not a significant descriptor of mosquito occurrence. More detailed analyses (data not provided) showed that *Culex* I/II instars were significantly and positively associated with AWDI and RWS fields, medium water levels, and predators, and not significantly associated with other fauna. *Culex* III/IV instars were associated with AWDI but not RWS fields, non-associated with water level, and associated with both predators and other fauna. *Culex* pupae were nonassociated with all parameters tested. For *Anopheles*, I/II instars were associated with AWDI and RWS fields, nonassociated with water level, and associated with both predators and other fauna. Higher instars (III/IV) also were associated with AWDI and RWS fields and nonassociated with water level, but were significantly associated only with predators and not with other fauna. Anopheles pupae were associated with AWDI fields and non-associated with all other parameters. Positive associations between mosquito immatures and predatory arthropods indicate an ecologically significant predator-prey relationship between the two (Southwood 1966). In general, all larval stages of *Culex* and *Anopheles*, and the pupal stage of *Anopheles*, occurred significantly and more frequently in AWDI than other fields.

Table 11. Importance of biophysical parameters in relation to the occurrence of Culex *mosquitoes (all immature stages).*

Variable	No. of Samples (490)	No. of *Culex* Positive Samples	Odds Ratio	95% CI
Water Regime				
CSI	170	103	1	
RWS	160	125	2.03	1.18-3.49
AWDI	160	94	1.99	1.12-3.56
In-field water depth				
< 20 mm	197	111	1	
20-40 mm	224	158	0.82	0.43-1.67
> 40 mm	69	50	1.03	0.52-2.04
Predators				
Absent	123	30	1	
Present	367	292	11.78	6.71-20.67
Other Fauna				
Absent	136	59	1	
Present	354	263	1.66	0.97-2.85

Notes: CSI = Continuous submergence irrigation
RWS = Rotational water supply
AWDI = Alternate wet/dry; CI = Confidence interval

Table 12. Importance of biophysical parameters in relation to the occurrence of Anopheles *mosquitoes (all immature stages).*

Variable	No. of Samples (490)	No. of *Anopheles* Positive Samples	Odds Ratio	95% CI
Water Regime				
CSI	170	104	1	
RWS	160	125	2.19	1.18-4.08
AWDI	160	91	1.95	1.12-3.42
In-field water depth				
< 20 mm	197	112	1	
20-40 mm	224	161	1.39	0.69-2.85
> 40 mm	69	46	1.75	0.89-3.46
Predators				
Absent	123	23	1	
Present	367	297	15.61	8.65-28.19
Other Fauna				
Absent	136	50	1	
Present	354	270	2.64	1.52-4.57

Notes: CSI = Continuous submergence irrigation
RWS = Rotational water supply
AWDI = Alternate wet/dry irrigation
CI = Confidence interval

It is clear from the results that alternate wet/dry irrigation as practiced in the present study was not effective in controlling mosquito breeding. On the contrary, AWDI fields generated more mosquito immatures than fields with rotational water supply or continuous submergence irrigation. There are several reasons for these results. One is the leveling of the AWDI fields, which if improperly done would have allowed pools to form as the water drained out. Another is that the period of drying of the AWDI fields (1 day, which was all that the farmers would accept) was probably insufficient to kill substantial numbers of mosquito immatures, which could still have survived in the wet mud in-between inundations. These are, however, practical difficulties that will be encountered in implementing AWDI under farmer-managed conditions. A third reason was rainfall, especially in the critical period 4–6 weeks between transplanting and canopy closure that is known to be the most productive in terms of mosquito generation in South India. In the present instance, the initial 5 weeks of sampling contained 30 rainy days (only 5 dry days) during which a total of 451.9 mm of rain was deposited in the area. This would have compounded the problems caused by uneven field surface and the short frequency of drying of the AWDI fields. These can be regarded as flaws in the present study that render it almost a “worst case scenario”; yet, they represent the realities of implementing the technique under farmer-controlled field conditions, in contrast to well-controlled experimental plot studies.

In previous trials done in South India too, difficulties in water management were encountered in 1990 due to a shortage of irrigation water, but successful implementation of the AWDI technique was achieved in 1991. In the latter instance, a significant reduction in mosquito pupal abundance was achieved by AWDI (Rajendran et al. 1995). As in the present experiments, the AWDI fields were re-irrigated as soon as they had dried out. Another series of experiments in South India where neem-based insecticidal products were tested in conjunction with water management also provided evidence that AWDI was effective in depressing mosquito abundance (Rao et al. 1995). The results of the present study parallel those from a recent study in Kenya that also showed the ineffectiveness of the AWDI technique in controlling mosquito generation in experimental rice fields (Mutero et al. 2000). Although the experimental technique was slightly different in the Kenyan study (i.e., fields were actively drained, rather than being allowed to dry as in the present study), there too, AWDI fields generated as many mosquito immatures as continuously flooded fields, in a situation where rain was not a confounding factor.

Conclusions

The study results suggest that AWDI practice leads to slightly higher land (6-7%) and water (21%) productivity of rice compared to continuous flooding irrigation practice, but the limited number of observations and the presence of several uncontrolled variables do not allow definitive conclusions. The increased land productivity is in congruence with Chinese controlled experimental results (Li 2001, Li et al. 1994) but at variance with IRRI review of research results from various countries (Bouman and Tuong 2000). Also, AWDI practice locally retains about 22 percent of water in comparison with continuous flooding irrigation practice (CSI). The saving of water occurs mainly from reducing percolation (recharge loss) and the drainage (return flow). Also, less water is supplied to the field under AWDI practices, most of which is depleted. Thus, AWDI practice allows the retention of water locally, for instance in reservoirs, which can be diverted for other purposes such as drinking or industrial use or increasing irrigated area. However, this will have implications for the water use at the basin level.

In basins where groundwater recharge and return flow is effectively used on the downstream side of the basin, practicing AWDI in the upstream side will have an adverse impact, especially if the basin is closing or closed. On the other hand, if the underlying water in the command is saline, or if the command lies in the closure zone or the command area is having a rising water table with waterlogging conditions, then the AWDI practice will lead to water saving.

The present study and several previous ones (cited above) show that there are limitations to the application of the AWDI technique for mosquito control. First, it is likely to be ineffective under conditions where rainfall can compromise the drying effects of AWDI. Second, the leveling of the fields is crucial to effective drying and kill-off of mosquito larvae. Third, the water regime is of critical importance: a longer drying period of the fields than the 1-day drying as practiced by farmers in the present study would be needed to kill the mosquito immature stages. The second and third factors are heavily dependent upon farmer practices, and considerable effort would be needed to implement changed practices on a large scale in farmer-managed systems. Several successful studies have shown the potential of AWDI for rice field mosquito control (reviewed most recently in Keiser et al. 2002), but it is important that the limitations of its practical application in the field also are defined.

Overall, the present study provides evidence that under farmer-managed conditions, alternate wet/dry irrigation is effective in saving water locally whilst maintaining yield levels on par with those obtained with the other water management techniques tested. This result provides the major impetus for promoting the AWDI technique among farmers. The present and some previous studies suggest that the benefits with regard to mosquito control could be expected only under conditions where factors such as rainfall, field leveling, and the duration of drying in-between spells of inundation are optimal.

Literature Cited

Bouman, B. A. M.; Tuong, T. P. 2000. Field water management and increase in productivity in irrigated rice. *Agricultural Water Management* (Forthcoming).

Cabangon, R. J.; Castillo, E. G.; Luc, G.; Cui, Y. L.; Tuong, T. P.; Bouman, B. A. M.; Li, Y.; Chen, C.; Wang, J.; Liu, X. 2001a. Impact of alternate wetting and drying irrigation on rice growth and resource-use efficiency: I. In Tuanlin, Hubei, China. Pp.31–52. In: *International Workshop on Water Saving Irrigation for Paddy Rice*. Published by China Rural Water and Hydropower.

Cabangon, R. J.; Castillo, E. G.; Bao, L. X.; Wang, G. H.; Tuong, T. P.; Bouman, B. A. M. 2001b. Impact of alternate wetting and drying irrigation on rice growth and resource-use efficiency: II. In Jinhua, Zheijang, China. Pp.53–74. In: *International Workshop on Water Saving Irrigation for Paddy Rice*. Published by China Rural Water and Hydropower.

Guerra, L. C.; Bhuiyan, S. I.; Tuong, T. P.; Barker, R. 1998. *Producing more rice with less water from irrigated systems.* SWIM Paper 5. Sri Lanka, Colombo: International Irrigation Management Institute.

Keiser, J.; Utzinger, J.; Singer, B. H. 2002. The potential of intermittent irrigation for increasing rice yields, lowering water consumption, reducing methane emissions, and controlling malaria in African rice fields. *Journal of the American Mosquito Control Association* 18: 329–340.

Lacey, L. A.; Lacey, C. M. (1990). The medical importance of riceland mosquitoes and their control using alternatives to chemical insecticides. *Journal of the American Mosquito Control Association* 6, Suppl. #2: 1–93.

Li, Y. H. 2001. Research and practice of water saving irrigation for rice in China. Pp.135–144. In: *International Workshop on Water Saving Irrigation for Paddy Rice*. Published by China Rural Water and Hydropower.

Li, Y. H.; Cui, Y. L.; Xie, L. G.; Zhao, C. M. 1994. Experiment study of water saving irrigation model for rice. *Irrigation and Drainage and Small Hydropower Station*, 12: 5–9.

Mutero, C. M.; Blank, H.; Konradsen, F.; van der Hoek, W. 2000. Water management for controlling the breeding of *Anopheles* mosquitoes in rice irrigation schemes in Kenya. *Acta Tropica* 76: 253–263.

Rajendran, R.; Reuben, R.; Purushothaman, S.; Veerapatran, R. 1995. Prospects and problems of intermittent irrigation for control of vector breeding in rice fields in southern India. *Annals of Tropical Medicine and Parasitology* 89: 541–549.

Rao, T. R. 1984. *The Anophelines of India.* Indian Council of Medical Research, New Delhi. 518 pp.

Rao, D. R.; Reuben, R.; Nagasampagi, B. A. 1995. Development of combined use of neem (*Azadirachta indica*) and water management for the control of culicine mosquitoes in rice fields. *Medical and Veterinary Entomology* 9: 25-33.

Reuben, R.; Tewari, S. C.; Hiryan, J.; Akiyama, J. 1994. Illustrated keys to species of *Culex (Culex)* associated with Japanese encephalitis in Southeast Asia (Diptera: Culicidae). *Mosquito Systematics* 26: 75-96.

Southwood, T. R. E. 1966. *Ecological Methods, with Particular Reference to the Study of Insect Populations.* Methuen, London. xvii + 391 pp.

van der Hoek, W.; Sakthivadivel, R.; Renshaw, M.; Silver, J. B.; Birley, M. H.; Konradsen, F. 2001. *Alternate wet/dry irrigation in rice cultivation; a practical way to save water and control malaria and Japanese encephalitis?* Research Report 47. Sri Lanka, Colombo: International Water Management Institute.

Postal Address
P O Box 2075
Colombo
Sri Lanka

Location
127, Sunil Mawatha
Pelawatta
Battaramulla
Sri Lanka

Telephone
94-1-787404, 784080

Fax
94-1-786854

E-mail
iwmi@cgiar.org

Website
www.iwmi.org

International Water Management Institute

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