Paddy Water Environ (2004) 2:217–226
DOI 10.1007/s10333-004-0066-z

ARTICLE

**B. Dong · D. Molden · R. Loeve · Y. H. Li · C. D. Chen ·
J. Z. Wang**

Farm level practices and water productivity in Zhanghe Irrigation System

Received: 1 May 2004 / Accepted: 24 September 2004 / Published online: 10 November 2004

Abstract China, the biggest rice-producing country in the world, has put considerable effort into finding ways to conserve water in rice cultivation. One very promising practice, intermittent submerged irrigation (ISI) was reported to be applied on farmers' fields over a large area in the Zhanghe irrigation system (ZIS), which serves about 160,000 ha of irrigated land, which is intensively cultivated with rice. To better understand the actual farmer practices, the degree to which farmers adopt ISI, the resulting water productivity, and implications for farm and system water management, a water accounting methodology developed by IWMI was applied at farm and a larger meso scale. Two areas were observed: Tuanlin, where ISI was reported to be widespread (with ISI), and Wenjiaxiang, where farmers were reportedly not adopting ISI (without ISI). The field water level measurements demonstrate that farmers at the "with ISI" site follow a practice similar to the theoretical ISI techniques by letting ponding levels drop to the soil surface several times during the cropping season. At the "without" site, farmers keep higher water levels ponded, and do not let water levels drop to the soil surface as often as the "with" site. A major determinant of practice is ease of access to water. At the "with" site, farmers have access to a variety of sources such as ponds and drains. At the "without" site, access to water was primarily from canal water, without the degree of flexibility as areas that had a water source near the field. The process fraction of gross inflow at field scale (rice evapotranspiration divided by irrigation plus rain) ranged between 0.66 and 0.93, remarkably high values showing how effective farmers are in converting water sources to productive evapotranspiration. The on-farm water accounting results show that with ISI, the average values of irrigation water applied over two years 1999–2000 are 22% less than without ISI, and the yields approximately the same. The resulting water productivity values per unit of irrigation water ($WP_{\text{irrigation}}$) are 20% higher under ISI practices, but per unit of evapotranspiration water productivity results are similar. The meso site study yielded surprising insights into overall water management in the area. In the years 1999 and 2000, at the meso sites, the irrigation duty in Tuanlin (with ISI) was 29% and 21% less than in Wenjiaxiang (without ISI), respectively, resulting in $WP_{\text{irrigation}}$ values of 24% and 26% higher at Tuanlin than Wenjiaxiang. But values of process fraction of gross inflow were considerably reduced at the meso scale ranging between 0.12 and 0.29, with considerable drainage outflow observed. Different land uses, trees, roads, villages, and ponds, begin to play an important role in overall water resource management at this scale. Drainage water from fields plus runoff served as supplies to ponds within the meso area as well as downstream reservoirs. Ponds play a very important role as an additional source of water, and in fact facilitate the uptake of ISI practices. This demonstrates that there are multiple strategies at play influencing water savings and productivity beyond ISI in the management of water within the area.

B. Dong (✉)
Department of Irrigation and Drainage Engineering,
Wuhan University,
430072 Wuhan, China
e-mail: dongbinh@public.wh.hb.cn
Fax: +86-27-87888155

D. Molden · R. Loeve
International Water Management Institute (IWMI),
P.O. Box 2075, Colombo, Sri Lanka

R. Loeve
FutureWater,
Eksterstraat 7, 6823 DH Arnhem, The Netherlands

Y. H. Li
National Center of Irrigation and Drainage Development,
Ministry of Water Resources,
100053 Beijing, China

C. D. Chen
Zhanghe Administrative Bureau,
448156 Jingmen, China

J. Z. Wang
Tuanlin Experimental Station,
Zhanghe Administrative Bureau,
448156 Jingmen, China

Keywords Water saving · Water accounting · Paddy field irrigation

Introduction

In China, about 31.7 million hectares are under rice cultivation; 28% of China's area is planted in cereals, with production reaching nearly 200.5 million tons, 39% of the total grain production of the country (MOA 2000). China's rice production is the largest in the world and the area planted to rice is the second largest in the world (FAO 2004). Rice cultivation is known to be a heavy consumer of water. In south China, the major rice area, more than 90% of the total irrigation water is allocated to rice production (Mao 1997). Therefore, in a country like China, where the per-capita fresh water availability is among the lowest in Asia and still declining (FAO 2003), growing more rice with less water is a critical issue, and has a high place on top of the agriculture-water research agenda.

Considerable research has been directed at finding ways to conserve water in rice cultivation, and many water-saving irrigation (WSI) methods and techniques for rice have been developed and tested in China as described in the overview provided by Li (2001). One very promising practice, intermittent submerged irrigation (ISI) (Fig. 1) has been disseminated in South China (Li et al. 1999) and large uptake has been reported.

The key practices of ISI are to have shallow water about 20–40 mm (60 mm after rainfall) for pre- and middle tillering stage, field sun-drying for the late stage of tillering, again shallow water 20–40 mm (80 mm after rainfall) as well as alternate wet and dry fields until the milk ripening stage. The ISI regime allows paddy fields to reach a dry condition, (85–90% of saturated moisture content) before the next irrigation application. Ponding levels are kept low so that rainfall can be more effectively captured and stored. ISI was reported to be widely adopted at Zhanghe Irrigation System (ZIS), which serves about 160,000 ha of irrigated land, intensively cultivated with rice.

Since the 1980s, an irrigation rehabilitation and improvement program has been carried out to improve the agricultural performance of ZIS. In addition to infrastructure, the program included popularization of WSI techniques, canal lining, volumetric charging, drainage water reuse and other management innovations. The objective of this paper is to understand to what degree farmers adopt ISI practices at ZIS, to examine differences in actual farm practices and to calculate the resulting water productivity with and without ISI. The research examined meso scale information to try and understand possible physical factors for adoption or non-adoption of ISI and implications for irrigation water management in the area. The information is used in the companion paper that examines how these practices "scale-up" and whether they lead to real water savings at the irrigation system scale (Loeve et al. 2004).

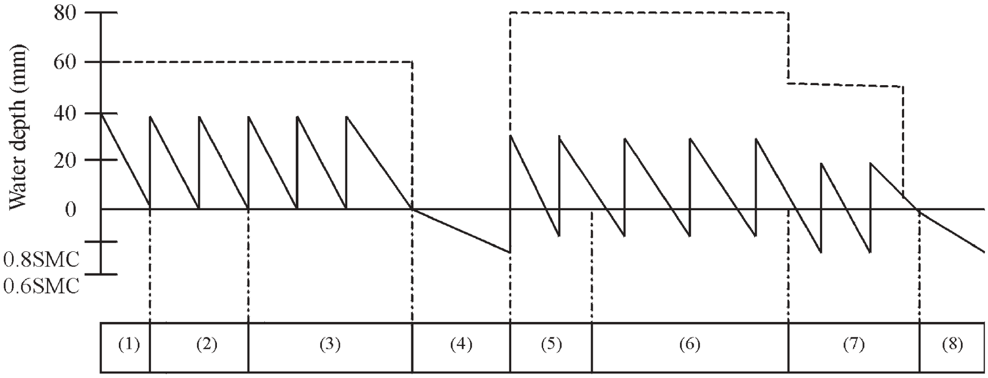
Materials and methods

Study area

The Zhanghe Irrigation District, situated at Hubei Province in central China, North of the Yangtze River (Fig. 2), has a total area of 5,540 km^2 and is one of the most important bases of commodity grain in Hubei Province. The Zhanghe Reservoir, built on a tributary (the Juzhang River) of the Yangtze River, supplies most of the irrigation water in ZIS. The reservoir was designed for multipurpose uses of irrigation, flood control, domestic water supply, industrial use and hydropower generation.

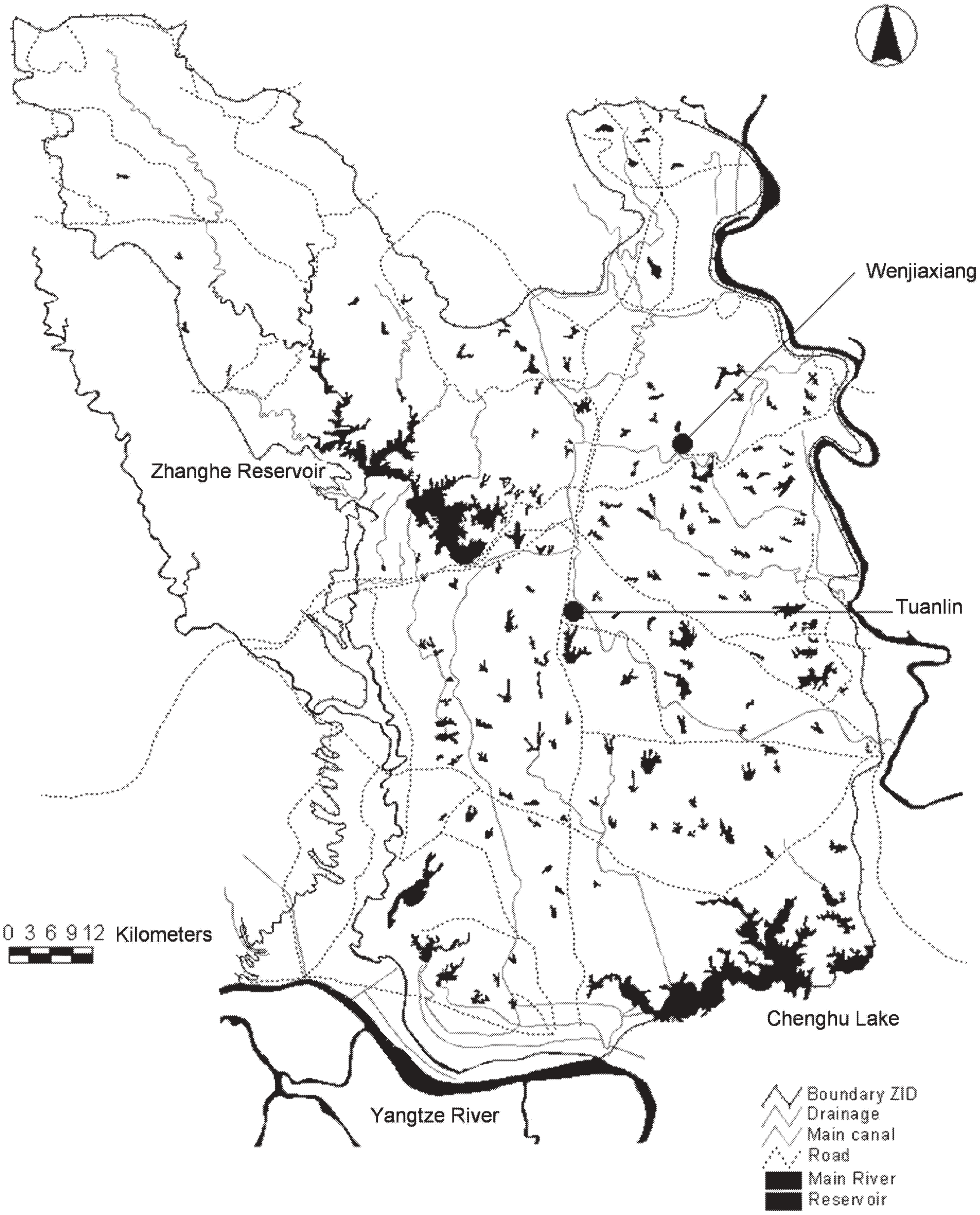
In ZIS, the canal systems include one general main canal, five main canals and a large number of branch and tertiary canals with a total length of more than 7,000 km. An extensive irrigation network including large, medium and small-size reservoirs which store, divert and supply water has been established. The average annual rainfall is 970 mm, but it is unevenly distributed both between years and over the year. The main crops are rice, winter wheat, rapeseed and soybean with paddy fields occupying about 80% of the total irrigation area. Loeve et al. (2001) describe in detail the layout and operation of ZIS.

Fig. 1 Graphical description of the Intermittent Submerged Irrigation regime



(1) Transplanting, (2) Revival of green, (3) Early & middle stages of tillering, (4) Late stage of tillering, (5) Elongating & booting, (6) Heading & flowering, (7) Milk ripening, (8) Yellow ripening (SMC = Saturated Moisture Content)

Fig. 2 The area served by Zhanghe Irrigation System



Methodology

In ZIS, two similar sites (with and without ISI) were selected. One site, Tuanlin, was selected to represent situations where ISI is widely practiced, and another site, Wenjiaxiang, was chosen where ISI is reportedly not so common (see Fig. 2).

The study locations were examined at two different scales; a field scale and a larger meso scale. In both sites, all flow components and rice yields were measured to account for water use and productivity at the two different scales.

At field scale, the time period for water accounting started from land preparation in mid May and ended at harvest in August. In the six pilot fields transplanting took about 3 days in the period 22 to 28 May 1999 and in the period 22 to 30 May 2000.

At the meso scale, covering 300 to 600 ha, the time period for water accounting was from land preparation (20 May) up to the end of harvesting (20 September in 1999 and 10 September in 2000).

Measurements

Land use pattern: At the field scale, only rice plots were selected and the area of fields was measured. At the meso scale, the land use pattern was determined using secondary data from the villages in the area. The total area was determined from a map with scale 1:10,000 and remote sensing.

Evapotranspiration (ET): The reference evapotranspiration (ET_o) was calculated with the Penman-Monteith equation (Allen et al. 1998) based on meteorological data from the Tuanlin Irrigation Experimental Station. The meteorological data are manually observed three times per day (at 08:00, 14:00 and 20:00). Daily data was used as input for the ET_o calculations. The actual evapotranspiration of rice and other land cover was calculated by multiplying the ET_o with a crop coefficient (provided by Mao 1992). This method assumes no water stress during the crop growing season, which was verified with field level measurements of standing water on the field and with remote sensing in the meso scale. The evaporation from open water (ponds, canals) was calculated with pan-evaporation data from the Tuanlin Irrigation Experimental Station.

Rainfall: Rainfall measurements were taken daily both in Tuanlin and Wenjiaxiang. This point data was used to calculate rainfall volumes on fields and meso sites.

Surface water inflow and outflow: Inflow and outflow of surface water were measured at the boundaries of the study area (both at the field and at the meso scale) twice a day (at 08:00 and 14:00). The discharge was measured either with broad-crested weirs, some V-notch weirs, trapezoidal weirs or calibrated pipes, depending on site specific conditions. In the main and branch canals, a current meter was used for the discharge measurements. In temporary inflow/outflow points, portable cutthroat flumes were installed. The operation time of several pump stations was recorded for discharge calculation. The volume divided by the area gives the inflow and outflow in millimeters.

Water storage change: This was calculated in 2000 only, for (a) *soil moisture:* before land preparation and after harvesting, the soil moisture content in the top 30 cm was measured by the gravimetric method; (b) *surface storage:* before land preparation and after harvesting, water levels in the selected ponds were measured and multiplied by the total area covered by the ponds; (c) *groundwater:* before land preparation and after harvesting, the water levels in four wells at each site were measured. The groundwater volume was calculated by multiplying the water level with the specific yield of the soil (estimated specific yield 0.10).

Water level measurements in fields: In 1999, the water levels in selected fields were monitored daily and measured with an open-bottom lysimeter and a plastic tube. The plastic tube (40 cm in height and 20 cm in diameter) (with perforated holes 15 cm from the top down to the bottom of the tube) was inserted in the paddy field to a depth of 25 cm. The soil inside the tube was excavated to allow measurement of perched water tables. Additionally, the tubes were used for measuring the standing water depth in the paddy fields. In 2000, the lysimeter was replaced with simple wooden sticks placed in the paddy fields to monitor the standing water depth on the fields.

Paddy yield: For the field scale paddy yield data were obtained from a crop cut of $6\ \mathrm{m}^2$ in the field. For the meso scale, paddy yield data were obtained from a socioeconomic survey, which had a bigger sample size and better spatial distribution over the meso sites than the field scale data (Moya et al. 2001).

Water accounting and indicators

The water accounting procedure developed by IWMI (Molden 1997; Molden and Sakthivadivel 1999), based on a water balance approach, was used to study water savings. The water accounting procedure classifies water balance components according to the outflow and to how the water is used. Water accounting indicators are presented in the form of fractions and in terms of productivity of water.

Water productivity (WP). The water productivity per unit of irrigation water ($\mathrm{WP}_{\mathrm{irrigation}}$) is the rice production divided by the irrigation inflow. The water productivity of per unit of gross inflow ($\mathrm{WP}_{\mathrm{gross}}$) is the rice production divided by the rain plus irrigation inflow. The water productivity per unit of evapotranspiration ($\mathrm{WP}_{\mathrm{ET}}$) is the rice production divided by the rice evapotranspiration.

Depleted fraction (DF). The depleted fraction of gross inflow ($\mathrm{DF}_{\mathrm{gross}}$) is the evaporation and transpiration by all uses divided by rain plus irrigation inflow.

Process fraction (PF). The process fraction of gross inflow ($\mathrm{PF}_{\mathrm{gross}}$) is the rice evapotranspiration divided by rain plus irrigation inflow and indicates the amount of gross inflow that is depleted by $\mathrm{ET}_{\mathrm{rice}}$. The process fraction of depleted water ($\mathrm{PF}_{\mathrm{depleted}}$) is the rice evapotranspiration divided by evapotranspiration from different uses within the boundary, including forestry, grass, and other land cover.

Results

Experimental trials

Table 1 shows the long-term rice yields under experimental conditions at Tuanlin for 10 years under traditional irrigation practices and under WSI. The variation of yield over the years is high for both traditional irrigation and WSI. The yield difference between the two methods is not statistically significant. However when we look at the water productivity per unit of irrigation water it shows us that under WSI the water productivity per unit of irrigation water is much higher (average 27%) compared to the traditional practice, because of reduced applications of irrigation water.

The water productivity per unit evapotranspiration was similar for each treatment and not significantly different. Transpiration between treatments would be very similar, as soil water availability is not limiting. Evaporation

Table 1 Tuanlin irrigation experimental station: yield, water productivity (WP) and process fraction (PF) of traditional irrigation practice and WSI

Year	Rice yield (kg ha−1)		WPirrigation (kg m−3)		WPET (kg m−3)		WPgross (kg m−3)		PFgross	
	Trad.	WSI	Trad.	WSI	Trad.	WSI	Trad.	WSI	Trad.	WSI
1991	6,701	7,751	1.62	1.92	1.54	1.56	0.88	1.03	0.57	0.66
1992	10,200	10,050	2.38	2.45	2.11	1.95	1.13	1.13	0.53	0.58
1993	8,378	10,497	1.59	2.15	1.39	1.66	0.86	1.12	0.62	0.67
1994	7,277	9,756	1.37	1.91	1.22	1.66	0.71	0.97	0.58	0.58
1995	7,689	9,873	1.20	1.59	1.04	1.40	0.77	1.02	0.74	0.73
1996	10,808	10,235	4.28	4.84	2.14	2.20	1.23	1.22	0.57	0.55
1997	9,969	9,455	1.56	1.78	1.41	1.35	0.75	0.77	0.53	0.58
1998	8,561	8,658	2.19	3.33	1.41	1.49	0.85	0.98	0.60	0.66
1999	8,332	8,015	1.81	2.94	1.39	1.34	0.99	1.23	0.71	0.92
2000	7,726	7,496	1.45	1.77	1.24	1.20	0.82	0.85	0.66	0.7
Average	8,564	9,179	1.95	2.47	1.49	1.58	0.90	1.03	0.61	0.66
s.d.	1,349	1,106	0.90	1.00	0.36	0.30	0.17	0.15	0.07	0.11
p-value (t-test, (paired)	0.147		0.001[a]		0.177		0.005		0.033	

[a] The value indicates that the difference of $\mathrm{WP}_{\mathrm{irrigation}}$ between traditional practices and WSI is statistically significant

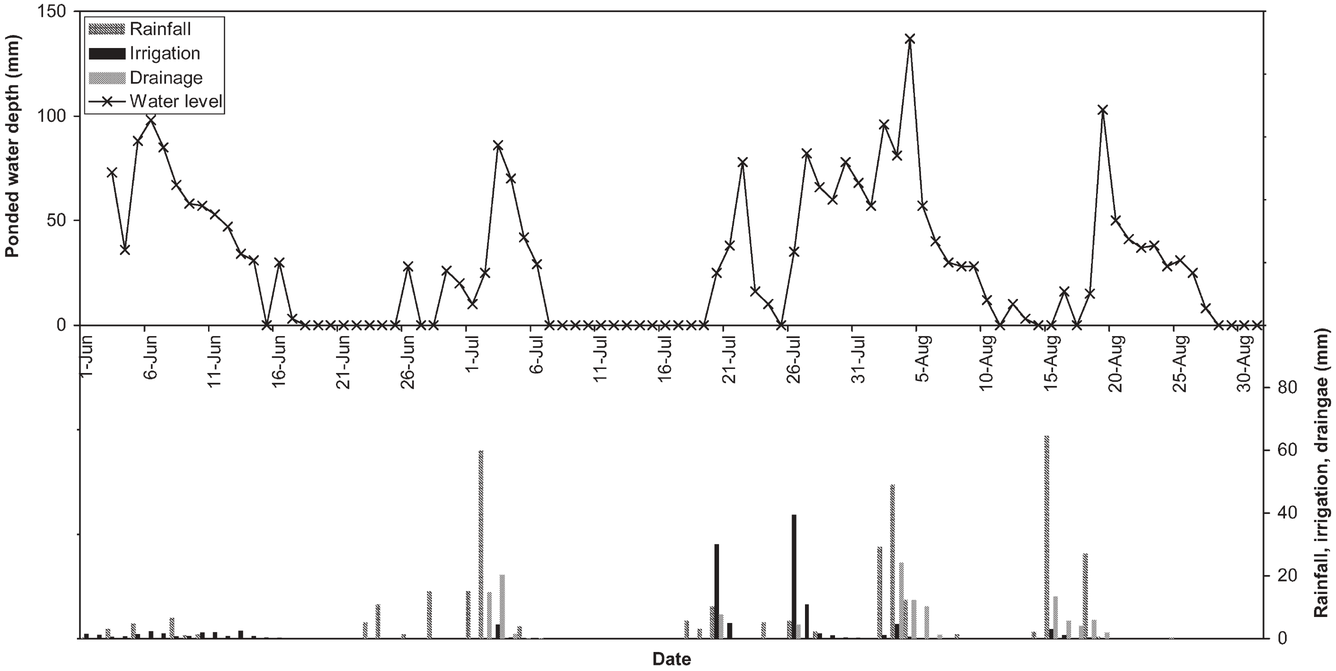


Fig. 3 Water level on selected field in Tuanlin in 2000

could differ, especially in the period between transplanting and establishment of a full crop canopy, or if the field surface is left unponded for a long period of time. Because the soil is very wet through the entire growth period, and differences in evapotranspiration between treatments are very difficult to measure, we assume the same evapotranspiration between treatments. Thus the difference in application between with and without WSI results from seepage and deep percolation.

These are results from the experiment station – what do farmers actually do in practice? Do they reduce applications from standard practices, and what is the significance at large scales, and to overall irrigation water management?

Farmers' practices

The water level measurements in 2000 show that farmers, especially at Tuanlin, do use elements of ISI. As expected, there is high variability in actual practices (see Fig. 3 and 4). Figure 3 shows the field irrigation practice at Tuanlin, in relatively flat terrain, ponding water levels dropped to the soil surface six times, with a period in the middle of the growing season of 2 weeks without standing water, clearly showing a pattern of intermittent submerged irrigation. By contrast, in Wenjiaxiang (Fig. 4) farmers kept standing water in their field. Three times water levels dropped to the soil surface and there was a period of 10 days without standing water in the mid season period. The ponding level was kept quite high in comparison to Tuanlin. One reason given by water managers is that the water supply is less reliable in Wenjiaxiang, thus farmers like to store water on their fields.

But key elements of the ISI techniques exist, and certain patterns emerge. Standing water is not necessary for the entire rice growing season and at the sun drying period at late tillering farmers do not pond water. Farmers let water levels drop to the field surface but do not allow it to remain at this level for periods longer than a few days except during the period of sun drying. In conclusion, Tuanlin farmers show a practice that is close to ISI, while Wenjiaxiang farmers prefer to keep water ponded on their fields, similar to traditional practices.

Water accounting at field scale

The summary of water accounting at field scale within the two meso sites in 1999 and 2000 is shown in Table 2. Calculation of deep percolation was set to close the water balance. However since we also measured the deep percolation we were able to estimate the error term for the water balance, which varied from 2 to 7%, except for Tuanlin in 1999. Here the closure term, i.e., more outflow than inflow, was almost 23% of the gross inflow. This error can be attributed to lack of storage data and maybe an underestimation of inflow. In the two years rice yields in Wenjiaxiang were slightly higher than in Tuanlin. The amount of diverted irrigation water to the fields was higher in Wenjiaxiang compared to Tuanlin leading to higher average values of the water productivity per unit of irrigation water ($WP_{irrigation}$) for Tuanlin. The values for water productivity per unit of evapotranspiration (WP_{ET})

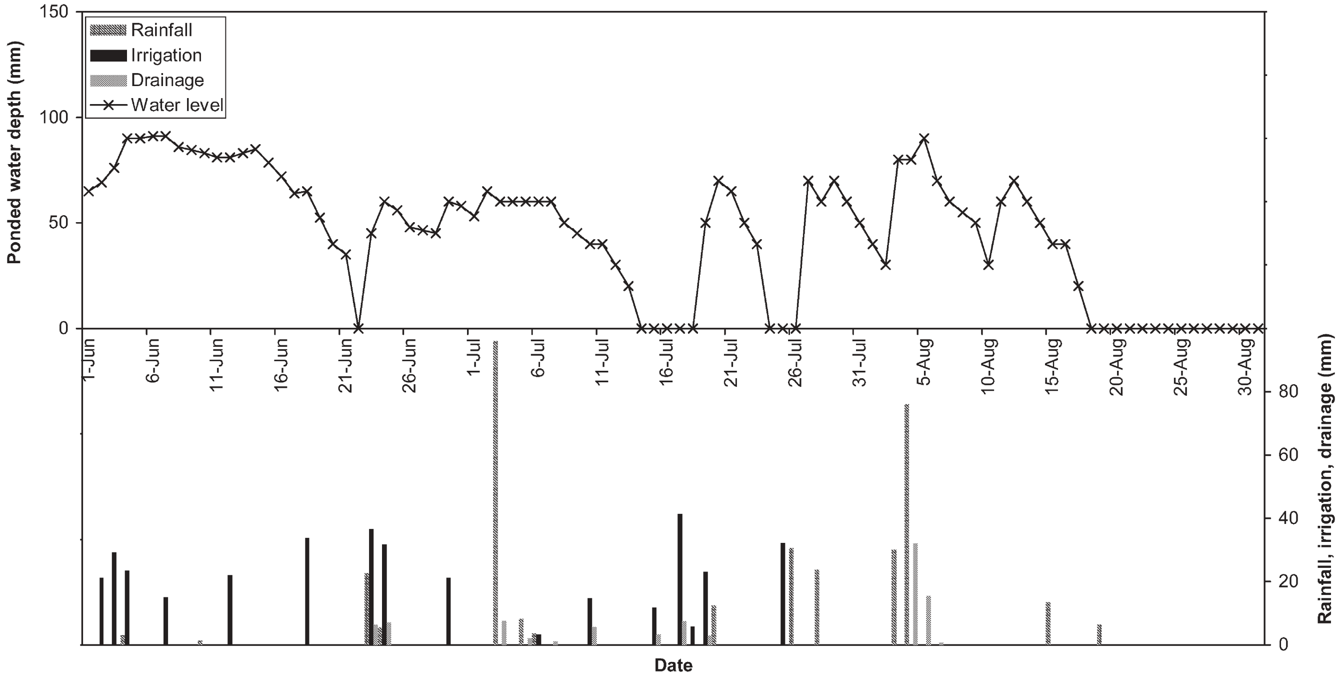


Fig. 4 Water level on selected field in Wenjiaxiang in 2000

Table 2 Water accounting at field scale in Tuanlin (TL) and Wenjiaxiang (WJX) [a]

	Year 1999		Year 2000	
	TL	WJX	TL	WJX
Gross area (m2)b	7,606	7,788	7,606	7,788
Net area (m2)	7,445	7,577	7,445	7,577
Inflow (mm)				
Irrigation	274	438	493	533
Rainfall	377	379	463	412
Gross inflow	651	817	956	945
Storage change	0c	0c	−18	−6
Net inflow	651	817	938	939
Depletion (mm)				
ET(rice)	603	603	623	623
Total depleted	603	603	623	623
Total Outflow (mm)d	48	214	315	316
Paddy yield (kg ha−1)	7,890	8,610	7,430	7,770
Indicators				
Process fraction of gross inflow	0.93	0.74	0.67	0.66
Water productivity per unit (kg m−3)				
of irrigation water	2.90	1.98	1.65	1.48
of ET	1.31	1.43	1.19	1.25

[a] Average value of three fields
[b] Gross area is the net area plus the area occupied by bunds
[c] In 1999 change in storage was not measured, and assumed to be zero
[d] The total outflow includes drainage and deep percolation
Since the deep percolation is estimated as a closure term of the water balance, it also captures errors in measurements. Percolation was also measured and the closure term for the water balance varied from 2 to 7%, except for Tuanlin in 1999. Here the closure term, i.e., more outflow than inflow, was almost 23% of the gross inflow

were similar for both sites in both years because yield is similar, and we assume that ET is the same.

The process fraction of gross inflow (PF_{gross}) indicates the amount of rain and irrigation water that is depleted by rice ET. At the field scale, PF_{gross} ranged from 0.66 to 0.93, meaning that up to 93% of irrigation and rainwater supply goes to rice evapotranspiration—a very high value for paddy cultivation. This high value implies that farmers spend much effort to make full use of both irrigation water and rainfall. Field observations demonstrate that farmers are quite effective in capturing and storing rain

Table 3 Water accounting at meso scale in Tuanlin and Wenjiaxiang

	Year 1999		Year 2000	
	TL	WJX	TL	WJX
Total area (ha)	287	606	287	606
Paddy field area (ha)	117	179	117	167
Inflow (mm)[a] (total area [ha])				
Canal inflow[b]	2,938	1,358	4,543	1,696
Other surface inflow (mm)	33	56	94	22
Rainfall (mm)	385	387	463	408
Gross inflow (mm)	3,356	1,802	5,099	2,125
Storage change (mm)[c]	-	-	−5	−181
Depletion (mm)[a] (total area [ha])				
ET (rice)	254	184	258	175
ET (upland crops)	79	57	78	65
Non-process depletion[d]	139	166	144	174
Total depletion	472	407	480	414
Outflow (mm)[a] (total area [ha])				
Committed canal outflow[e]	2,631	1,045	4,055	1,277
Drainage outflow	415	116	524	103
Total outflow	3,046	1,161	4,579	1,380
Irrigation duty for rice[f] (mm)	755	1,065	1,199	1,522
Paddy yield[g] (kg ha−1)	7,430	8,440	6,330	6,440
Indicators				
Depleted fraction				
of gross inflow	0.14	0.23	0.09	0.19
of available water	0.65	0.54	0.46	0.62
Process (rice) fraction				
of available water	0.35	0.24	0.25	0.26
of depleted water	0.54	0.45	0.54	0.42
Production per unit (kg m−3)				
of irrigation water	0.98	0.79	0.53	0.42
of ET	1.19	1.35	1.00	1.01

[a] Millimeter values for inflow, depletion and outflow are derived from the actual volume measured and divided by the total area. This means that for e.g. the ET_{rice} value is not the actual rice evapotranspiration in mm, but a constructed value to create a water balance term in a uniform format

[b] Supply canal inflow plus some minor irrigation inflow points into the area

[c] Values of storage change in 1999 were not measured

[d] Non-process depletion like trees, non-agricultural land surfaces

[e] At both sites, a supply canal passes through the area serving downstream uses, thus there is a high value for committed outflow

[f] The canal inflow minus canal outflow equals the irrigation water diverted to the meso site. The irrigation duty is the irrigation water divided by the paddy area

[g] Yield data was obtained from a socio-economic survey with sample size of thirty except for Tuanlin in 1999 where the sample size was 22 households (2 outliers were eliminated)

with their field bunds, and keeping field ponding levels low when possible to capture more rain.

In 2000 there was a drought in the early season and farmers responded by applying irrigation. At the end of the season heavy rains resulted in higher rainfall values for 2000 compared to 1999. Yields at both sites were reduced slightly in 2000, possibly due to pests and water stress as reported by farmers.

Water accounting at meso scale

The water accounting components and indicators for the two meso-scale sites in 1999 and 2000 are summarized in Table 3. Though the water balance in Table 3 is not closed, the closure term error is only about 5% of gross inflow except at Wenjiaxiang meso site in 1999 (about 13%). At both sites, a canal conveys water to the meso area, and areas downstream. To obtain the volume of irrigation water delivered to the meso site, we measured canal flow at the inflow and outflow points. The water accounting presents the total canal inflow, and the canal outflow, which is shown as committed outflow for downstream uses. The irrigation duty adjusts for the inflow less the outflow and the depth of irrigation duty is calculated by dividing the irrigation water (inflow minus outflow) by the paddy area, as paddy is the only crop irrigated.

In line with field observations, more water was diverted to the two meso sites in 2000 than in 1999. This is because of a serious rainfall shortage from May to July in 2000, which resulted in a longer duration of canal operation, and more irrigation applications. In 1999 and 2000 the irrigation duty in Tuanlin was 29% and 21% less than in Wenjiaxiang, respectively. As expected from the results at field scale yields at both sites were reduced in 2000.

For the two meso sites, the depleted fraction of gross inflow ranges from 0.09 to 0.23, remarkably lower than the values at the field scale because of the canal conveying water through the area. To adjust for the large volume of water passing through the meso area, we used available water (gross inflow less committed water = irrigation duty plus rain), and found that the depleted fraction of available water ranged from 0.46 to 0.65, still lower than field scale observations. Why is there a difference between scales?

At meso scale, about 41% at Tuanlin and 28% at Wenjiaxiang of the total area is paddy field, making it impossible to capture as much rainfall as on the field scale. Thus rainfall on non-rice land contributes more to runoff and observed drainage outflow than rice land. The average combined ET ranges from 410 to 480 mm, much lower than 600 plus mm of ET on rice lands. In addition, the meso scale observations capture the effect of conveyance spillage and seepage from canals, which are not observed in the farm scale measurements. In Tuanlin and Wenjiaxiang rice evapotranspiration was responsible for about 54 and 43% of the depleted water, respectively, a reflection in coverage by the rice crop. The process fraction of available water (rice ET divided by available water) ranges between 0.24 and 0.35, meaning that very little available water is consumed by rice at the meso scale, and consequently there is high outflow. Again this is a function of the land use. Of the depleted water, between 42 and 54% is from rice fields, again demonstrating the importance of non-rice crops.

Compared to the indicator at field scale, $WP_{\text{irrigation}}$ values at meso scale are lower. The main reason is that much of the irrigation supply into the meso area does not get applied to rice fields, probably due to canal seepage and operational spills.

What happens to the non-depleted water—the outflow? A field investigation at both sites revealed that the outflow was captured and stored in downstream reservoirs that again supplied water to agriculture, cities and industries downstream. For example, the Tongqianshan Reservoir with total capacity of 34.7 million m^3, supplied water to about 3,000 ha paddy downstream. The area of Tuanlin, plus similar areas serve as the catchment area for the reservoirs with most runoff originating from non-rice areas.

The meso site investigations revealed the importance of other factors than ISI that play an important role in overall water resource use and management. Rice farmers are effective at capturing and depleting most of the water that enters their domain. But because the area has so many other land uses, a great deal of runoff is generated, so that both meso areas effectively serve as catchment areas for small ponds within the meso area and downstream reservoirs. The impact of water savings at larger scale depends on the landscape mosaic pattern.

Farmers have constructed small-scale ponds connected to the canal and connected to the drains in both Tuanlin and Wenjiaxiang for storage within the system. The small ponds capturing drainage flows are used quite effectively as storage and a source of water, especially in the Tuanlin area. Through ZIS, there are thousands of small ponds capturing drainage flows and providing another source of water to farmers, providing reliability and flexibility of application within the system. Larger reservoirs are constructed downstream to capture outflow from the meso area and similar meso areas. In effect, a cascading system of use, reuse and internally generated flows using the landscape is important in overall water resource management at ZIS.

The role of ISI, canal operation and ponds

Why is the practice at Wenjiaxiang different from Tuanlin? Are these actions driven by farmers who have an incentive to reduce applications to their fields, and thereby result in reduced releases for agriculture from the Zhanghe reservoir as reported by Loeve et al. (2004b). Or are farmers using ISI as a response to a restriction in supply from ZIS? Figure 5 (Loeve et al. 2001) shows a hydrograph of canal discharge at Tuanlin (above) and Wenjiaxiang (lower). At Tuanlin, the area received two pulses of water from the main reservoir, compared to four at Wenjiaxiang in 2000. This pattern of canal flows in both locations is not one that is in response to farmers' demand. If farmers applied water only at these times, they certainly could not support ISI practices.

We contend that ISI together with local storage has been an important mechanism for farmers to respond to reduced supplies from the reservoir. A field level response is to capture and deplete as much water as possible from rain and irrigation supplies. Farmers at both Tuanlin and Wenjiaxiang store water on fields using bunds and try to minimize drainage, seepage and deep percolation. At Tuanlin farmers have access to much more local storage than at Wenjiaxiang, and there are several ponds that receive water directly from the canal and are used to supply water when needed. Similarly drainage ponds capturing drainage water are effectively used as storage and supply systems availing farmers more flexibility and precision in their application.

Tuanlin farmers can keep ponding levels low in hope of rain with the knowledge that they can use water from the local storage if needed. Wenjiaxiang is in a hillier terrain, and has much more difficult access to local storage. The on-farm strategy is to store more water on-farm while waiting for the next rain or canal delivery. System managers realize the difficulty of Wenjiaxiang farmers and provide them with more canal supplies.

Conclusions and discussion

Farmers at Tuanlin demonstrate a practice that is fairly close to the theoretical and recommended ISI practice, with ponding water only during part of the season. At Wenjiaxiang, farmers prefer to keep water stored on their fields. In both cases, no ponding water stays on the field after late tillering. In both cases, farmers do not voluntarily drain water at the mid season, but keep ponding

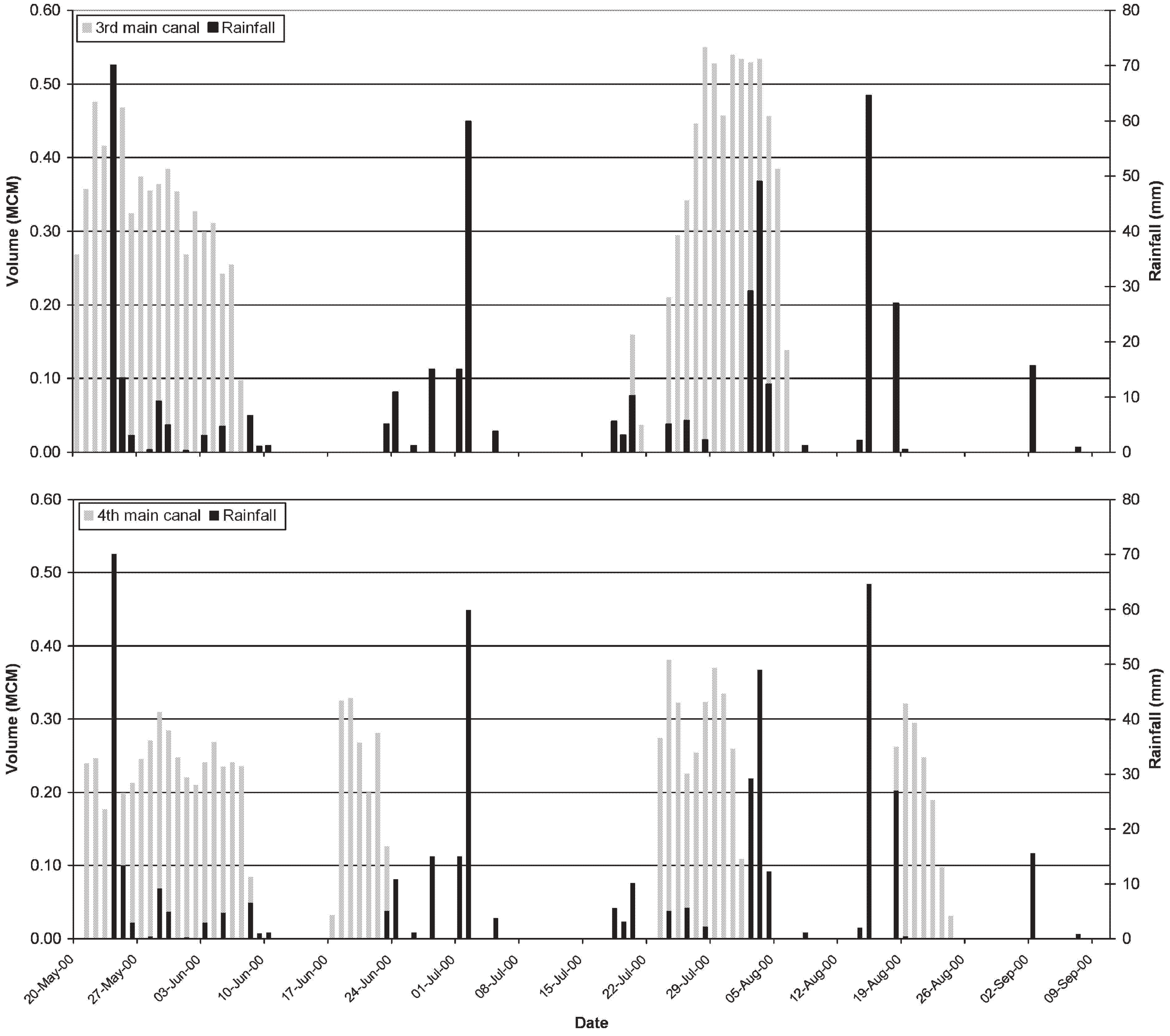


Fig. 5 Hydrograph of canal discharge at Tuanlin (*above*) and Wenjiaxiang (*below*) in 2000

water levels to a minimum at this period by not applying more water.

Tuanlin has a relatively flat topography with several small ponds serving as local storage, compared to Wenjiaxiang, which has a hillier terrain and fewer small storage facilities. A major reason for widespread adoption of ISI at Tuanlin is easier access to water from canals and pond sources at times of water stress. If it does not rain, Tuanlin farmers can access local storage to supply water. Given this, farmers can keep water levels lower which allows for better capture of rainfall.

The water accounting result at field scale shows that the process depletion fraction of gross inflow is commonly more than 0.65, a high value. This implies that the farmers are effectively able to capture rainfall and irrigation water supplied to fields and convert this into productive crop evapotranspiration.

Yields are slightly, but not significantly higher at Wenjiaxiang. Water productivity per unit of evapotranspiration is similar in both cases. Water productivity per unit of irrigation is higher in Tuanlin, where farmers practice ISI, due to reduced irrigation application.

At meso scale, a much smaller proportion (less than 10%) of rainfall and irrigation inflow is converted into rice evapotranspiration while the water productivity per unit of irrigation water is reduced compared to the field level. This is explained by the considerable runoff from non-rice land at the two meso sites. However, a large amount of the outflow is not wasted but captured and stored in downstream reservoirs that again supply water to agriculture, cities and industries downstream. The meso scale measurements revealed the role of additional storage in capturing return flows and additional runoff within the entire irrigation system, and its role in water resource management.

The on-farm findings demonstrated that the farmers could reduce irrigation applications and improve water productivity through the adoption of ISI techniques. However, at the meso scale the lower values of indicators suggested that there is no improvement in water productivity as the scale of ISI application increased from field to meso scale. The companion paper (Loeve et al. 2004a) demonstrates that water productivity improves at scales larger than meso scale. This study and the companion study demonstrate that the interaction among the scales of interest is becoming increasingly important in water resources utilization assessment while moving analysis from field to irrigation system to river basin. Several studies have indicated that field level savings may not lead to transferable, or real water savings (Seckler 1996; Solomon and Davidoff 1999).

One difficulty in communicating about water saving is that “water savings” carries different meanings to different people. The meaning is often dependent on the scales of interest. In farm level cases, “water savings” most often refers to a reduction in irrigation water applied to crops (Tuong and Bhuiyan 1999). This is important to farmers who have a limited supply, or who may have to pay for water. Irrigation managers would like to save water from seeping, because after it leaves the canals, they cannot charge for water. They may wish to transfer more water from agriculture to other higher paying sectors and maximize the benefit from the same water quantity which is the case for ZIS.

Interests of society come into play at a basin scale. In many basins of the world, there is a growing demand for good quality water for non-agricultural uses—the environment, cities, and industries. Also, there remains a need to grow more food and support farmers’ livelihoods. In these situations, irrigated rice agriculture is a relatively low-valued use of water; so there is pressure to meet other demands first, and then let agriculture have the remaining water. At the basin scale, a common interest is in reducing the total amount of water depleted by irrigated agriculture whilst maintaining or increasing production. At this scale, we consider the total amount of basin resources and how they are allocated across sectors and uses in time and in space across the basin. If less water is depleted by agriculture, more will be available for other uses.

Acknowledgements This research is part of the two projects “Impact of Water Saving Irrigation Techniques in China” and “Growing more rice with less water” funded by the Australian Center of International Agricultural Research (ACIAR). The research is conducted by a team of scientists and practitioners from Wuhan University, the Zhanghe Irrigation Administration Bureau, the International Rice Research Institute (IRRI) in the Philippines, and the International Water Management Institute (IWMI) in Sri Lanka. IWMI receives its principal funding from 58 governments, private foundations, and international and regional organizations known as the Consultative Group on International Agricultural Research (CGIAR).

References

Allen RG, Pereira LS, Raes D, Smith M (1998) Crop evapotranspiration: guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56. FAO, Rome, Italy, xxvi + 300 pp

FAO (2003) FAO Aquastat. http://www.fao.org

FAO (2004) FAOSTAT Database. 4 February 2004 (FAO last update). FAO, Rome, Italy. http://apps.fao.org

Li YH (2001) Research and practice of water saving irrigation for rice in China. In: Proceedings of International Commission on Irrigation and Drainage, 1st Asian Regional Conference 17–18 September 2001, Seoul, Korea, 10 pp

Li YH, Dong B, Yu F (1999) Improving irrigation management of paddy fields for sustainable increases in water productivity. In Musy A, Pereira LS, Fritsch M (eds) Emerging technologies for sustainable land use and water management: Proceedings of the 2nd Inter-Regional Conference on Environment-Water, 1–3 September 1999, Publ. Presses Polytechniques et Universitaires Romandes, Lausanne, Switzerland, 36 pp

Loeve R, Dong B, Molden D, Li YH, Chen CD, Wang JZ (2004a) Issues of scale in water productivity in Zhanghe Irrigation System: implications for irrigation in the basin context. J Paddy Water Environ (forthcoming)

Loeve R, Dong B, Zhao JH, Zhang SJ, Molden D (2001) Operation of the Zhanghe Irrigation System. In: Barker R, Loeve R, Li YH, Tuong TP (eds) Water-saving irrigation for rice: Proceedings of an International Workshop held in Wuhan, China 23–35 March 2001, International Water Management Institute, Colombo, Sri Lanka, pp 25–53

Loeve R, Hong L, Dong B, Guo Mao, Chen CD, Dawe D, Barker R (2004b) Changes in long-term trends in intersectoral water allocations and crop and agricultural water productivity in Zhanghe, Hubei, China and Kaifeng, Henan, China. J Paddy Water Environ (forthcoming)

Mao Z (1992) Calculation of evaportranspiration of rice. In: Proceedings of International Workshop on Soil and Water Engineering for Paddy Field Management, Bangkok, Thailand, pp 21–34

Mao Z (1997) Water saving irrigation for rice. China Rural Water Hydropower 4:45–47

MOA (Ministry of Agriculture, China) (2000) Almanac of agricultural crop in 2000. Agricultural Publication, Beijing, China

Molden D (1997) Accounting for water use and productivity. SWIM Paper 1. International Water Management Institute, Colombo, Sri Lanka, ix, 16 pp

Molden D, Sakthivadivel R (1999) Water accounting to assess use and productivity of water. Water Resources Development 15(1), pp 55–71, DOI 10.1080/07900629948934

Moya P, Hong L, Dawe D, Chen CD (2001) Comparative assessment of on-farm water-saving irrigation techniques in the Zhanghe Irrigation System. In: Barker R, Loeve R, Li YH, Tuong TP (eds) Water-saving irrigation for rice. Proceedings of an International Workshop held in Wuhan, China 23–35 March 2001, International Water Management Institute, Colombo, Sri Lanka, pp 81–96

Seckler D (1996) The new era of water resources management: from “dry” to “wet” water savings. Research Report 1. International Irrigation Management Institute, Colombo, Sri Lanka, iii, 17 pp

Solomon KH, Davidoff B (1999) Relating unit and subunit irrigation performance. Transactions of the ASAE 42(1):115–122

Tuong TP, Bhuiyan SI (1999) Increasing water-use efficiency in rice production: farm-level perspectives. Agricultural Water Management 40(1):117–122, DOI 10.1016/S0378–3774(98) 00091–2