Does reliability of water resources matter in the adoption of water-saving irrigation practices? A case study in the Zhanghe irrigation system, China

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Abstract

The aim of the study was to determine whether the reliability of water sources is important in the adoption of water-saving irrigation practices (WSI). It was hypothesized that access to reliable water sources such as water ponds would increase the likelihood of practicing alternate wetting and drying (AWD) for rice cultivation. While it seems intuitively reasonable to assume that farmer’s ability to access reliable water sources would reduce the risk involved in letting the paddy field dry temporarily, and therefore encourage the adoption of AWD, this study found no solid empirical evidence to support the proposition. However, weaker empirical evidence shows that access to reliable water supply from local ponds positively influences AWD practices. The results show that the adoption of AWD is not driven by farmer’s self choice but rather that they are adopting AWD to mitigate risk in the face of increasing water scarcity. The result suggests that water-saving irrigation training and farm size or land distribution system have an important role in the adoption of AWD practices. The policy implication of this research is that imposing institutional water scarcity could be a way to promote the adoption of water-saving irrigation practices.

Keywords: Adoption; Alternate wetting and drying; Censored Tobit regression; Reliability; Water productivity; Water-saving irrigation practices

1. Introduction

China is not particularly well endowed with water resources. In terms of per capita water resource availability, China ranks among the lowest levels worldwide \cite{Lohmar et al. 2003}. Despite limited water resources, irrigation plays a pivotal role in China’s plans to meet future food demand. China feeds about 22\% of the world population with about 6\% of the fresh water and 9\% of the arable lands in the world.
China also has the largest rice area in the world. Rice production is not only an important factor influencing China’s food security, but it is also a large water consumer and an important element in China’s history and culture (Li & Barker, 2004).

Water remains critical for agricultural and rural development (Hussain & Hanjra, 2003; 2004). However, the volume of water available for irrigation is under threat, largely due to rapidly growing industrial, urban, and new environmental water uses (Rosegrant & Ringler, 1998) as well as a large population with rising incomes (Lohmar et al., 2003). It is expected that, in the near future, less water will be available for agricultural use, especially for rice cultivation (Tuong & Bouman, 2002). Water savings or “producing more rice with less water” are crucial for food security and for the economy of China.

China’s government has already realized the nation’s rising water scarcity as one of the key problems and has attempted to address this issue at nearly all levels, from the national down to the village and farm level (Geng et al., 2001; World Bank, 2002; Lohmar et al., 2003). The Chinese government successfully implemented policies that enabled them to withdraw water from the agricultural sector to fulfill growing demand in the industrial and urban sectors. Water conservation projects were implemented and complemented with the introduction of water-saving irrigation practices, both of which may have caused farmers to voluntarily or forcibly reduce the amount of water used by adopting WSI practices. Farmers also contributed to these efforts by successfully maintaining their agricultural production despite a considerable decrease in water deliveries by relying on local sources, such as ponds, and adopting WSI practices.

Rice has normally been grown under flooded conditions. Increasing water scarcity poses major challenges to rice ecosystems. Scientists have been looking for a methodology for increasing the productivity of irrigated rice by changing the management of water, plants, soil and nutrients (Bouman & Tuong, 2001). The System of Rice Intensification (SRI) is one such approach, which rests on three main tenets: that rice seedlings should be planted quickly when young; that rice plants should be spaced widely apart; and most importantly, the rice fields should be kept moist, not flooded (Surridge, 2004). Careful water management saves water, gives better yield because it supports root growth, increases profitability by reducing the cost of production and reduces risk (Uphoff, 2003 2007; Stoop et al., 2002). This AWD approach should be highly attractive, as the whole world is facing water shortages.

The AWD water-saving irrigation practices refer to any measure that leads to a reduction in irrigation water use without a distinct reduction in crop yield (Li, 2001). Early in the season, the rice crop is irrigated intermittently to keep the moisture sufficient for growth but not for evaporation. These practices allow farmers to achieve relatively dry soil conditions before receiving further water and to store more water after rainfall. In this way, utilization of rainfall is facilitated, need for canal water is eased, and irrigation events are reduced. In addition, percolation and seepage losses from rice fields are controlled (Feng, 1998; Li, 2001). A brief introduction of WSI practices is presented in the next section.

Though these WSI practices, especially alternate wetting and drying, have been promoted since the early 1990s, adoption of WSI remains a big challenge due to either bio-physical or socio-economic constraints (Li & Barker, 2004). By 2002, the AWD irrigation technique had been applied in 40% of the rice production areas (12 million hectares) in China (Li & Barker, 2004). However, there is strong interest to extend WSI practices, which can spare water or increase food production using less water.

The adoption of WSI practices is also influenced by a wide range of economic, social, physical, and technical aspects of farming. Farmers learn and adapt new methods rather than just adopt them, having positive influence on social relations within rice communities. The impact of SRI, structured around AWD, may thus go well beyond the altruistic (Becker & Diallo, 1996) though some controversy continues, as reported in Nature (Hengsdijk & Bindraban, 2004; Satyanarayana, 2004; Surridge, 2004). Uphoff &
Randriamiharisoa (2002) stressed that the challenge in adopting WSI is complicated by the fact that most of the benefits from water savings accrue to individuals who have not directly invested in the effort to achieve the savings, i.e. downstream farmers or other water users for domestic or industrial purposes. Farmer’s incentives to use less water will be limited if there is no appreciable gain from these measures. Others (Burt, 1996; Li, 2001; Loeve et al. 2001) have identified that a reliable water source might be a major factor in the adoption of WSI practices. However, they lack any empirical evidence to support their proposition. They argue that when farmers are confident that their allocation of water is reliable, timely, and according to schedule, they will not only be prepared to adopt WSI practices but they will also make short- and long-term investments in their farming operation. The disappointing adoption dynamics of AWD-led SRI is mainly because the method requires significant additional labor input at a time of the year when liquidity is low and labor effort is already high (Moser & Barrett, 2003), calling into question adoption by small farmers with fixed land plots. Faysse (2002) acknowledged that uncertainty in water supply plays a major role in water management and the subsequent adoption of water saving measures.

The empirical literature on irrigation technology choice has identified a range of factors impacting adoption of WSI. For example in the US mid-west where water scarcity is very high and economic productivity of water is one of the highest in the world, the price of water was an important incentive for the adoption of water-saving irrigation systems because substituting capital for water is more likely when the relative price of water, and hence the marginal value of conservation, is high (Caswell & Zilberman, 1985; Moreno & Sunding, 2005). Nevertheless, such evidence for China does not exist; Liao et al. (2007) empirically argue that water pricing, as a policy tool, is unlikely to succeed in improving irrigation efficiency. In another study, Huffman (2001) stressed the significance of the educational level of farmers in adopting WSI; those who are better educated have a greater ability to acquire and process information as well as being able to critically evaluate the productive characteristics and costs of adopting innovative technologies. An interesting finding of many econometric studies on irrigation technology adoption is the important, even dominant, role of environmental conditions such as land quality (Shrestha & Gopalakrishnan, 1993; Dobermann, 2004).

The aim of this paper is to better understand how reliable water supplies, from main reservoir, smaller reservoirs, and local ponds are important for the adoption of AWD irrigation practices. The statement of Loeve et al. (2001) and Li (2001) was tested as a hypothesis: the reason for the adoption of WSI practices is sound irrigation and reliable supply of water. This hypothesis was tested using farm level data from selected villages in the Zhanghe Irrigation System (ZIS), China. The adoption of AWD at the farm level was modeled as a function of reliability of water sources, namely canal water from ZIS, water from smaller reservoirs and water from local ponds, along with household level socio-economic characteristics, land quality and farm size. The results show that only the reliability of local water ponds had a weakly significant positive effect on AWD practices. Thus, reliable water supply does not necessarily result in the adoption of AWD practices. Hence it seems reasonable to assume that in adopting AWD, farmers are influenced more by their immediate business environment than large-scale concerns about water allocation among competing uses.

2. Water-saving irrigation practices in China

Promoting water-saving irrigation practices have been one of China’s basic national policies. It is generally perceived as a revolutionary measure for sustainable agricultural development (Li, 2001) and
is prompted by the increasing competition between different sectors and impending water shortages. More than 150 research stations, with the collaboration of different professional institutions and universities, have been conducting research on WSI practices for many years (Li, 2001). Water-saving irrigation regimes for rice have been promoted since the 1980s.

Several water-saving irrigation techniques for rice have been reported previously (Bouman & Tuong, 2001; Bouman et al. 2002). AWD is the most widely adopted water-saving practice in China, as well as in the Philippines (Li, 2001; Lampayan et al. 2004).

2.1. Alternate wetting and drying irrigation (AWD)

This method of irrigation is characterized by: a) mid-season drainage during the later tillering stage of the crop and b) periodic soil drying for 2–4 days between irrigation events from panicle initiation to the harvest. In the mid-season drainage, the soil is dried out for 10–15 days, depending on weather conditions, until fine cracks appear in the soil (Cabangon et al. 2001). A graphical description of the AWD irrigation regime is presented in Figure 1.

Wu (1998) has described that the alternative adjustment of “shallowness, wetness and drying” has four advantages. First, soil aeration performance is improved which ensures that sufficient oxygen is supplied. Second, fertility is adjusted and maintained by water, thereby refining the soil environment. Third, the local on-field climate is improved; diseases and pests are thus diminished. Fourth, it is especially favorable for cultivating vast low-productivity farmland in South China, which would otherwise remain unproductive due to intense reduced soil conditions (gley soil) brought about by excessive submergence.

Most of the literature largely concurs that AWD practices improve yield and the microenvironment (Uphoff, 2003) but scientific evidence for China is weaker. The yield benefits of SRI-led AWD over conventional rice management are likely to be small in intensively managed irrigation systems with more favorable soils, as in China (Sheehy et al. 2004). However, according to Bouman et al. (2002), these WSI practices are expected to answer the water crisis and safeguard food security and
alleviate poverty, if diffused among the rice-growing farmers of Asian countries. Hong et al. (2001) reported that, despite a sharp decline (61%) in water for irrigation from the Zhanghe reservoir, crop production has been sustained, which was mainly due to AWD irrigation and improved system management. Water productivity in terms of irrigation water was about 5–35% higher under AWD than in continuous flooding (Lu et al. 2000; Cabangon et al. 2001; Moya et al. 2001; Li & Barker, 2004).

3. Study area, sampling procedure and sample size

The study was conducted in the Zhanghe Irrigation District (ZID), which is located in Hubei Province, in the Yangtze River basin of China. The Zhanghe basin has an area of 7,740 km², including a catchment area of 2,200 km². The Zhanghe Irrigation System (ZIS) accounts for most of the irrigated area in ZID. It is one of the typical large-size irrigation systems in China and is designed to irrigate an area of about 160,000 ha.

3.1. The Zhanghe irrigation system

The main water source in ZIS is the Zhanghe reservoir. The Zhanghe reservoir was built between 1958–1966 on the Zhanghe River for the purpose of irrigation, flood control, domestic water supply, industrial use and power generation. The annual water supply from the Zhanghe reservoir is about 0.50 billion (10⁹) m³, some 42% of which is allotted to agriculture, 45% to hydropower, and the rest of the water for industry and municipalities. However, the water availability for irrigation is declining over time due to competition from municipal and industrial water use (Figure 2). For instance, water supply from the Zhanghe irrigation reservoir decreased by 61% from the mid 1960s to the end of the 1990s due to increases in population and industry (Hong et al. 2001). Apart from this reservoir, there are thousands of medium- and small-sized reservoirs (ponds) supplying water to the irrigation system. Figure 3 shows the whole ZIS. The small dots represent thousands of small to medium-sized reservoirs.

![Fig. 2. Water allocation for irrigation and other uses, 1963–2003, Zhanghe Reservoir, China.](https://iwaponline.com/wp/article-pdf/11/6/661/406741/661.pdf)
3.2. Water ponds and small reservoirs

The smaller reservoirs and ponds located in the area allow farmers to capture rainfall, store surplus water from the ZIS, and conserve water from other sources (Figure 3). The role of the ponds in rice growing has become important since the reduction in irrigation supplies from the ZIS. Aside from the Zhanghe reservoir, there are about 86,000 ponds and more than 300 medium- and small-sized reservoirs supplying water for irrigation. These ponds and small reservoirs allow the users to obtain water on-demand because of built-in flexibility to store water close to water users (Loeve et al. 2001). They have also proved to be helpful in reducing floods, recharging and providing drainage in high rainfall periods (Anbumozhi et al. 2001). In Hubei Province, China, these ponds and small reservoirs play an

Fig. 3. Area served by the Zhanghe Irrigation System.
important and essential role in agriculture by providing supplemental irrigation. The ZIS obtains one quarter of its water from medium-and small-sized reservoirs to complement the supply from the main Zhanghe reservoir (Moya et al. 2001).

3.3. Data sampling procedure and sample size

A multistage data sampling methodology was used. In the first stage, 36 villages were randomly selected for the purpose of interviewing village heads. Out of the 36 villages, four villages, each with its own small reservoir, were selected purposively for detailed characterization in order to represent different topographies (e.g. hilly, intermediate, flat) in the area. In the second stage, a total of 100 ponds were selected on the basis of stratified random sampling, 25 ponds from each of the four villages. The ponds were categorized on the basis of storage capacity. Small ponds have a storage capacity less then 1,000 m³; medium ponds have a storage capacity between 1,000 and 10,000 m³; and large ponds have a storage capacity of more than 10,000 m³. Finally, 100 households were selected randomly, one farmer from each pond. This was done to capture the variation between the ponds, as there is very little variation among the farmers using a given pond. Therefore, the samples selected through random sampling fairly represented a community at all levels.

4. Models and measurement of variables

Most of the theoretical studies on farmer’s adoption practices use static analysis that relates pertinent factors affecting adoption. These studies investigate the properties of the solution to particular cases of the temporal resource optimization problem of a farmer. One useful approach is to characterize the problem as one where a farmer has to choose between two irrigation practices, continuous flooding or AWD practices, subject to associated costs and benefits. Models following this approach investigate how many farmers are adopting WSI practices and what are the cost-benefit ratios of WSI practices under different circumstances (e.g. Caswell, 1991; Green et al. 1996).

An immediate problem arises in measuring the variable irrigation practices, and tests whether farmers are actually adopting AWD practices or not. Simply asking farmers if they follow AWD practices or not, and developing a binary variable (0, 1) will not give the true picture. Irrigation is a continuous process applied during the entire cropping season. Field experience showed that during different irrigation events farmers sometimes follow AWD practices and, at other times, used continuously flooding irrigation practices. Therefore, to measure AWD adoption a variable, AWDSCORE, was developed and calculated by the following equation:

$$AWDSCORE = \frac{X*1 + Y*0.5 + Z*0}{X + Y + Z}$$

Where $X$ stands for the number of times a farmer irrigates when the soil is dry, $Y$ stands for the number of times a farmer irrigates when the soil is wet or saturated, and $Z$ is the number of times a farmer irrigates when the soil is in standing water. Arbitrary weights of 1, 0.5, and 0 were assigned to dry, wet or saturated, and standing water conditions, respectively, at the time of water application. If, following
AWD practices, a farmer irrigated only when the soil was dry, then he would get a score of 1. On the other hand, a score of 0 implies that the farmer irrigated when there was standing water in the soil, which is the case with continuous irrigation. The AWDScore falls between 0 and 1 if a farmer irrigated at a combination of different soil-water statuses. The score then will indicate if the farmer tends to practice AWD or not, with the higher score indicating a greater adoption of AWD.

4.1. Empirical model

The value of AWDScore ranges from 0 to 1, which implies that the dependent variable is not dichotomous. Test on linearity show that AWDScore is not linear in nature; therefore, a simple OLS regression will give inconsistent results (Pindyck & Rubinfeld, 1991). Because the dependent variable is not binary, binary Logit or Probit models cannot be applied. Therefore, the most appropriate model, where the dependent variable ranges between an upper and lower limit, is the censored Tobit model (Maddala, 1983; Green, 1997).

The LIMDEP-7 econometric package was used to derive the maximum likelihood (MLE) estimates and marginal effects from the Tobit regression analysis. The marginal effect coefficient implies the changes in AWDScore brought about by one unit change in explanatory variable, ceteris paribus. This consists of two effects: (1) the change in the probability of the expected level of those farmers who are already adopting AWD practices, and (2) the change in the elasticity of the probability of being an adopter. The t statistic was used to judge the significance of each explanatory variable. The log-likelihood ratio (LR) test was employed to judge the significance of all parameters associated with the probability of adoption.

The following empirical model (2) was used to analyze the impact of ponds on the adoption of AWD practices:

\[
AWDScore(\dot{Y}_i) = \alpha_0 + \alpha_i W_i + \beta_i X_i + \epsilon_i
\] (2)

where AWDScore(\dot{Y}_i) is the alternate wetting and drying score, W_i are water sources (ZIS canal, pond, and small reservoir water), X_i is the vector of exogenous variables such as farm size, experience of household head, education, training, land quality, wealth status of household, and dummy variable for villages affecting adoption of AWD practices, \(\alpha_0\) is a constant, \(\alpha_i\) is the coefficient of water sources, \(\beta_i\) is a vector of unknown parameters to be estimated, and \(\epsilon_i\) is an error term, which is assumed to be uncorrelated with the explanatory variables.

4.2. Definitions and measurement of the variables

The variables used in the empirical study are defined and explained below and the descriptive statistics of these variables are given in Table 1.

Reliability implies secure, in terms of time and space, availability of water according to the crop schedule. Due to difficulties in measuring reliability of water supply at farm level, the study developed both a “subjective” variable based on farmer’s perceptions and an “objective” variable based on the dependency of different water sources for irrigation.

\textit{RELI}. This refers to the subjective reliability of water supply, based on the farmer’s perception. The questions asked were whether “having access to pond water makes irrigation more reliable”, whether
“irrigation deliveries from ZIS are so reliable that I can let my field go dry for several days without worrying, because I know that water will arrive soon”, and whether “water deliveries from small community reservoirs are reliable because they deliver water in time”. A value of 0, 1, or 2 was arbitrarily given to “strongly agree” “agree” and “strongly disagree” to characterize levels of water source reliability.

**REL2.** This refers to reliability of water supply based on an objective reliability index. A reliability index was developed based on total number of irrigations from each source and on the number of times irrigations were done when their field was dry due to shortages of water. The reliability index was calculated as

\[
REL2_i = \frac{\text{Total number of irrigations}_i - \text{number of times soil was left dry due to lack of water}_i}{\text{Total number of irrigations}_i} \tag{3}
\]
Where $\text{REL2}_i$, the reliability index, indicates the reliability of water source ($i =$ pond, ZIS canal, and small reservoir water). $\text{REL2}_i$ varies between 0 and 1; a higher value of $\text{REL2}$ implies greater reliability and a low value of $\text{REL2}$ implies poor reliability.

$\text{AWDSCORE}$. This refers to the alternate wetting and drying score. The AWDSCORE was calculated on the basis of soil moisture conditions. It ranges from 0 to 1. A score of 0 implies that the respondent’s irrigation practice is continuous flooding, that is, it is irrigated while the field has standing water. On the other hand, a score of 1 implies that the respondent allows the field to dry before irrigation. A score between 0 and 1 indicates that the farmer follows an intermediate practice between continuous flooding and drying of soil before each irrigation.

$\text{DVILLAGEx}$. This refers to a dummy variable for each village. For example, if the observation is from village Shuangbie then $\text{DVILLAGEx} = 1$, otherwise, 0. Specific characteristics of the study site may greatly influence the dependent variable.

$\text{EDUCATIONx}$. This refers to the educational attainment of the household head. Education could increase the farmer’s ability to obtain, process, and use information relevant to the adoption of AWD. Education is thus thought to increase the probability that a farmer will adopt AWD. It was measured in terms of number of years of schooling of the household head.

$\text{PONDACCSx}$. This refers to the number of ponds accessed. An individual respondent may have accessed one or more ponds, depending on the area and the number of ponds in each village. The numbers of ponds accessed is expected to influence AWD adoption decision, area and yield. This was measured in number of ponds.

$\text{WEALTHx}$. This refers to the wealth status of the household, which might influence the adoption of AWD—the wealthier farmers can afford to take more risks. Wealth status was self-reported by the farmers according to their standing in the village as low, middle, or top. A score of 1, 2, and 3 was then assigned to the low, middle, and high level of wealth status, respectively.

$\text{WSITRAINx}$. This refers to water-saving irrigation (WSI) training. It was expected that WSI training would have a significant effect on the adoption of AWD practice. $\text{WSITRAINx}$ is equal to 1 if the respondent has received any AWD training; 0, otherwise, if no training.

$\text{ELEVATIONx}$. This refers to the elevation of the plot. The terrain was divided into three categories—high, medium, and low. Elevation of the plot may affect irrigation management practices: plots at a lower elevation may be harder to keep dry and thus have lower AWD scores. It was defined as $\text{ELEVATIONx} = 1$ if the plot was located at higher elevation, $\text{ELEVATIONx} = 2$ if the plot was located at medium elevation, and $\text{ELEVATIONx} = 3$ if the plot was situated at lower elevation.

Farm size (FARMSIZE), land quality (LNDQUAL), and farming experience (FARMEXP) were also included as control variables. Farm size was defined as the total area of all parcels owned by the farmer, excluding the area that is rented out. Land quality was measured according to a subjective assessment of the farmer, with possible values of good (1.0), average (2.0), or poor (3.0). Farming experience was measured as the number of years spent in farming.

5. Results and discussion

The practice of AWD means that rice fields should not be continuously submerged, but that they should be allowed to dry intermittently beginning 30 days after transplanting. During this period, farmers adopting AWD practices irrigate only when their fields are dry (Moya et al. 2001).
A wide-scale awareness of AWD practices (about 90%) was observed in the study area as AWD practices have been systematically developed since the 1980s. However, only 6% of the respondents received formal training on AWD, which show the high levels of awareness despite low levels of farmer training.

Farmers reported several advantages and disadvantages of AWD practices. The advantages include increase in yield, savings in water, improved crop health, and decreased incidence of pests and diseases. Among the disadvantages, the most commonly reported were potential yield losses (if the field is not irrigated on time), increase in weeds, need for reliable water sources to practice AWD, and difficulties in implementing AWD practices.

5.1. The practice of AWD

Filed experience showed that only a few farmers (8%) have been precisely applying the AWD practices to their rice crop. Most of the farmers practiced AWD partially. Therefore, to determine and quantify farmer’s actual irrigation practices and to know whether they were precisely following the AWD system, soil moisture conditions prior to each irrigation were determined. Table 2 presents a summary of soil conditions before each irrigation. The results show that about two-thirds of the time (67%) soil moisture conditions were dry before irrigation. These AWD estimates were closer to ideal AWD conditions, although ideal conditions of AWD demand 100% dry soil moisture conditions before any irrigation event after crop establishment.

Table 2 also shows that farmers in Wuba village were least likely to keep dry soil conditions prior to irrigation (52%) compared with those in other villages, as pond water was the only water source in Wuba. A comparison across water sources show that irrigation with ZIS water (74%) and reservoir water (71%) were more likely to be made on dry soil than irrigation with pond water (65%) (Table 3). This could be due to the occasional availability of surplus water in the ponds that may cause farmers to reduce the irrigation cycle.

5.2. Cause of dry soil conditions

Further inquiry into what causes dry soil moisture conditions yielded some interesting results (Table 4). About three-quarters (77%) of the respondents stated that dry soil moisture conditions were caused mainly by lack of availability of irrigation water. Farmers reported that they had to let their field dry because of water shortages. However, it is not known whether farmers would still dry their field

Table 2. Condition of soil prior to irrigation for rice crop by village, Zhanghe Irrigation System, China (survey data from 2003–2004).

<table>
<thead>
<tr>
<th>Soil moisture conditions</th>
<th>Shuangbie</th>
<th>Wuba</th>
<th>Huangyan</th>
<th>Sundian</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>N</td>
<td>%</td>
<td>N</td>
<td>%</td>
<td>N</td>
</tr>
<tr>
<td>54</td>
<td>61</td>
<td>43</td>
<td>52</td>
<td>68</td>
<td>76</td>
</tr>
<tr>
<td>Wet</td>
<td>23</td>
<td>26</td>
<td>31</td>
<td>37</td>
<td>17</td>
</tr>
<tr>
<td>Standing water</td>
<td>12</td>
<td>13</td>
<td>9</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>Overall</td>
<td>89</td>
<td>100</td>
<td>83</td>
<td>100</td>
<td>90</td>
</tr>
</tbody>
</table>

N = number.
before irrigating if sufficient water were available. About a quarter of the respondents acknowledged that they let their field dry intentionally.

Irrigations made on to dry soil using pond water were more likely to be due to lack of water than were irrigations made on dry soil using ZIS or reservoir water. A likely explanation could be that soil moisture conditions depend mainly on the availability of pond water rather than water-saving irrigation practices; fields were wet when there was surplus water and dry when water was scarce.

5.3. The AWD score

Based on the soil moisture conditions prior to each irrigation, an AWD score was calculated using Equation (1) to find out whether farmers were really following the AWD practices or not. From the overall sample, one farm’s AWD was found to be zero while 28 had a score of 1. Table 5 gives a summary of AWD scores with respect to each village.

The mean AWD score for farmers with ponds was 0.81. The AWD score was highest in Sundian (0.92) while lowest in Wuba (0.72), which was surprising as ponds were the only water sources for Wuba (Table 2). The results were opposite to those that were expected initially: that ponds supply a reliable source of water and should therefore lead to water-saving irrigation practices. One of the reasons is that no water fee was collected on the use of the ponds, except those managed by contractors, implying that the marginal cost of water from the pond was lower when compared with that from the ZIS canal. With the absence of proper pond water use rules, if the pond has surplus water, then it can be expected that farmers would irrigate more frequently, because they will not have any incentive to save water, as their land is fixed and they are not paying water fees.

Table 3. Condition of soil prior to irrigation, by water source, Zhanghe Irrigation System, China (survey data from 2003–2004).

<table>
<thead>
<tr>
<th>Soil moisture conditions</th>
<th>ZIS canal</th>
<th>Ponds</th>
<th>Reservoir</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>N=46</td>
<td>N=186</td>
<td>N=17</td>
<td>N=249</td>
</tr>
<tr>
<td>Wet</td>
<td>N=10</td>
<td>N=80</td>
<td>N=5</td>
<td>N=95</td>
</tr>
<tr>
<td>Standing water</td>
<td>N=6</td>
<td>N=19</td>
<td>N=2</td>
<td>N=27</td>
</tr>
<tr>
<td>Overall</td>
<td>N=62</td>
<td>N=285</td>
<td>N=24</td>
<td>N=371</td>
</tr>
</tbody>
</table>

N = number.

Table 4. Creation of dry soil conditions, Zhanghe Irrigation System, China (survey data from 2003–2004).

<table>
<thead>
<tr>
<th>Water source</th>
<th>Intentionally kept dry</th>
<th>Dry due to lack of water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N=19</td>
<td>N=28</td>
</tr>
<tr>
<td>ZIS canal</td>
<td>38</td>
<td>62</td>
</tr>
<tr>
<td>Ponds</td>
<td>19</td>
<td>81</td>
</tr>
<tr>
<td>Reservoir</td>
<td>17</td>
<td>83</td>
</tr>
<tr>
<td>Overall</td>
<td>23</td>
<td>77</td>
</tr>
</tbody>
</table>

N = number.
5.4. Reliability of water sources

The reliability of water sources, as measured by farmer’s subjective assessment (REL1), was higher for water from ponds (1.22) than for water from the ZIS canal water (0.70) and small reservoirs water (0.16). Among villages, Wuba (1.92) expressed greater reliability of pond water, possibly because of reliance on ponds as the major source of irrigation (Table 6).

The water sources reliability, measured in terms of total numbers of irrigations and irrigation made on dry soil conditions indicates that ponds water (0.41) is more reliable than the ZIS canal water (0.25) or water from small reservoirs (0.09). Though Wuba is relying (100%) on ponds water for irrigation, result indicates that pond water is not entirely reliable. However, pond water is more reliable water source in Wuba (0.62) than other villages. Both the reliability indicators show a similar trend, water from ponds being more reliable than from ZIS canal water or water from small reservoirs (Table 7).

5.5. Empirical findings

A censored Tobit model was used to characterize the effect of reliability of water sources on the adoption of AWD practices. This method estimates the likelihood and extent of adoption. The results of the Tobit model (1) using a qualitative reliability index (REL1) are presented in Table 8. The estimates of the variables related to adoption of AWD practices were found to have a priori expected sign, except

Table 5. Alternate wetting and drying scores, Zhanghe Irrigation System, China (survey data from 2003–2004).

<table>
<thead>
<tr>
<th>Village</th>
<th>Percentage distribution of alternate wetting and drying scores</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Shuangbie</td>
<td>25</td>
</tr>
<tr>
<td>Wuba</td>
<td>25</td>
</tr>
<tr>
<td>Huangyan</td>
<td>25</td>
</tr>
<tr>
<td>Sundian</td>
<td>25</td>
</tr>
<tr>
<td>Overall</td>
<td>100</td>
</tr>
</tbody>
</table>

SD = Standard deviation.

Table 6. Reliability of water supply based on farmer’s perception, Zhanghe Irrigation System, China (survey data from 2003–2004).

<table>
<thead>
<tr>
<th>Village</th>
<th>Percentage distribution of farmer’s perception</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ZIS canal</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Shuangbie</td>
<td>0.52</td>
</tr>
<tr>
<td>Wuba</td>
<td>0.08</td>
</tr>
<tr>
<td>Huangyan</td>
<td>1.68</td>
</tr>
<tr>
<td>Sundian</td>
<td>0.52</td>
</tr>
<tr>
<td>Overall</td>
<td>0.70</td>
</tr>
</tbody>
</table>

SD = Standard deviation.

Questions asked were: a) having access to pond water makes irrigation more reliable; b) irrigation deliveries from ZIS are so reliable that I can let my field go dry for several days without worrying, because I know that water will arrive soon; and c) water deliveries from small community reservoirs are reliable because they deliver water in time.
in a few instances. The likelihood ratio (53.58) was highly significant, implying that the independent variables, jointly, influence the adoption of AWD practices. The conditional (predicted) mean of AWD score at the sample mean was found to be 0.66.

The Tobit coefficient of primary index equation, unlike traditional regression coefficients, cannot be interpreted directly as an estimate of the change in the dependent variable as a result of a unit change in the explanatory variable. This implies that it has little interpretative value or is difficult to interpret directly. However, the coefficients of the significant variable are immediately useful in providing the direction of the relationship between the dependent (AWD score) and the independent variables.

Table 8 shows that the size of the farm (FARMSIZE) and land quality (LQUALITY) significantly influence the adoption of AWD practices. The coefficients of reliability, reliability of water supply from local ponds (REL1POND), reliability of water supply from the ZIS canal water (REL1ZIS) and reliable supply of water from smaller reservoirs (REL1RES) were positive but not significant, which implies that access to reliable water supply has positive but not significant impact in the adoption of WSI practices. In addition, the coefficient of dummy variable of Huangyan (DVILLAGE3) and Sundian (DVILLAGE4) was also significant compared with Wuba. The interpretation of the Tobit index coefficient can go this way—for example, the coefficient of farm size \((\beta = 0.007)\) implies that a 1 mu increase in landholding would lead to a decrease in index \((Zi)\) score of AWD by 0.007 units, ceteris paribus. Other non-significant variables, which positively influenced the adoption of AWD practices, included water-saving irrigation training (WSITRAIN), farm experience of household head (FARMEXP), and wealth status of the household (WEALTH).

To evaluate the effect of each independent variable on AWD score, marginal effects and elasticities were estimated. The marginal effects are the partial derivatives of the expected value of the dependent variable (AWD score) \([\partial Ey/\partial x]\) with respect to the vector of characteristics \([F(z)*\beta]\), while elasticity can be computed by multiplying the marginal effect coefficient by the ratio of the mean of the explanatory variables concerned to the mean of the dependent variable.

Among the explanatory variables considered, farm size (FARMSIZE) and land quality (LQUALITY) were significant at the 0.05 levels. Land quality had a negative and significant marginal effect coefficient of 0.051. This may be because of the fact that people still like to follow traditional irrigation methods on the best-quality land. This was confirmed from the statements by the farmers who were forced to adopt AWD practices due to water shortage and dry soil moisture conditions, which were created by the lack of water availability. In this condition, it is plausible to think that, even though farmers follow AWD practices in the best plot, they would still like to add one or two irrigations even when the soil is wet.

Table 7. Reliability index of water supply based on the numbers of irrigation, Zhanghe Irrigation System, China (survey data from 2003–2004).

<table>
<thead>
<tr>
<th>Village</th>
<th>ZIS canal</th>
<th>Ponds</th>
<th>Reservoir</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Shuangbie</td>
<td>0.28</td>
<td>0.42</td>
<td>0.43</td>
</tr>
<tr>
<td>Wuba</td>
<td>0.0</td>
<td>0.0</td>
<td>0.62</td>
</tr>
<tr>
<td>Huangyan</td>
<td>0.43</td>
<td>0.47</td>
<td>0.35</td>
</tr>
<tr>
<td>Sundian</td>
<td>0.30</td>
<td>0.45</td>
<td>0.22</td>
</tr>
<tr>
<td>Overall</td>
<td>0.25</td>
<td>0.41</td>
<td>0.41</td>
</tr>
</tbody>
</table>

SD = Standard deviation.
The elasticities presented in Table 8 take into account that a change in an explanatory variable will affect the AWD score. The elasticity of the farm size (\( \beta = 0.10 \)) implies that a 1% increase in farm size would reduce AWD score by 0.10%. The rest of the variables can be interpreted in the same way. The interpretation of the elasticity for binary variables is somewhat different. For example, receiving WSI training will lead to an increase in AWD score by 0.001%.

To make sure that multicollinearity does not exist between the reliability indexes and that their joint effect is not important, likelihood ratio tests were performed based on constrained and unconstrained regressions with the null hypothesis that the three coefficients of reliability indexes are simultaneously equal to zero. The low values of likelihood ratios failed to reject the null hypothesis. Therefore the results drawn were fairly consistent and unbiased.

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The results of the regression model (2) using quantitative reliability index (REL2) are presented in Table 9. The likelihood ratio (67.22) was highly significant, implying that the independent factors, jointly, influence the adoption of AWD practices. The coefficients of reliability, reliability of water supply from ponds (REL1POND), reliability of water supply from the ZIS canal (REL1ZIS) and reliable

Table 8. Tobit estimates of subjective reliability of water sources (REL1) on the adoption of alternate wetting and drying practices, Zhanghe Irrigation System, China (survey data from 2003–2004).

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>Tobit estimate of index function</th>
<th>Tobit estimate of marginal effecta</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>Standard error</td>
</tr>
<tr>
<td>INTERCEPT</td>
<td>0.52***</td>
<td>0.126</td>
</tr>
<tr>
<td>REL1POND</td>
<td>0.007</td>
<td>0.017</td>
</tr>
<tr>
<td>REL1ZIS</td>
<td>0.006</td>
<td>0.020</td>
</tr>
<tr>
<td>REL1RES</td>
<td>0.045</td>
<td>0.027</td>
</tr>
<tr>
<td>FARMSIZE</td>
<td>-0.007***</td>
<td>0.002</td>
</tr>
<tr>
<td>LQUALITY</td>
<td>-0.049***</td>
<td>0.018</td>
</tr>
<tr>
<td>ELEVATON</td>
<td>-0.037</td>
<td>0.023</td>
</tr>
<tr>
<td>WSTRAIN</td>
<td>0.011</td>
<td>0.055</td>
</tr>
<tr>
<td>EDUCATON</td>
<td>-0.002</td>
<td>0.006</td>
</tr>
<tr>
<td>FARMEXP</td>
<td>0.002</td>
<td>0.001</td>
</tr>
<tr>
<td>WEALTH</td>
<td>0.007</td>
<td>0.021</td>
</tr>
<tr>
<td>DVILAGE1</td>
<td>0.020</td>
<td>0.040</td>
</tr>
<tr>
<td>DVILAGE3</td>
<td>0.105**</td>
<td>0.050</td>
</tr>
<tr>
<td>DVILAGE4</td>
<td>0.161***</td>
<td>0.047</td>
</tr>
</tbody>
</table>

Sigma (\( \sigma \)) 0.113***
Log likelihood function (unrestricted) -47.18
Log likelihood function (restricted) -73.87
Likelihood ratio 53.58***
Scale factor for marginal or total effect F(\( z \)) 0.82
Conditional mean of dependent variable at sample point 0.66
Pseudo R² 0.36
Total observations 98

*** and ** refer to significance at the 1% and 5% level, respectively.

a Marginal effect (\( \partial \bar{y}/\partial x \)) refers to the partial derivatives of the expected value with respect to the vector of characteristics. They were computed at the mean of the independent variable.
b Elasticity equals marginal effect coefficient multiplied by the ratio the mean of the relevant explanatory variables to the mean of the dependent variable.
Dependent variable: AWD score.
Table 9. Tobit estimates of objective reliability of water sources (REL2) on the adoption of alternate wetting and drying practices, Zhanghe Irrigation System, China (survey data from 2003–2004).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Tobit estimate of index function</th>
<th>Tobit estimate of marginal effect&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Elasticity&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient (intercept)</td>
<td>Standard error</td>
<td>P value</td>
</tr>
<tr>
<td>INTERCEPT</td>
<td>0.730***</td>
<td>0.097</td>
<td>0.000</td>
</tr>
<tr>
<td>REL2POND</td>
<td>0.108***</td>
<td>0.035</td>
<td>0.090</td>
</tr>
<tr>
<td>REL2ZIS</td>
<td>0.061</td>
<td>0.031</td>
<td>0.152</td>
</tr>
<tr>
<td>REL2RES</td>
<td>0.020</td>
<td>0.051</td>
<td>0.699</td>
</tr>
<tr>
<td>FARM.getSize</td>
<td>-0.006***</td>
<td>0.002</td>
<td>0.007</td>
</tr>
<tr>
<td>LQUALITY</td>
<td>-0.035***</td>
<td>0.018</td>
<td>0.054</td>
</tr>
<tr>
<td>ELEVATION</td>
<td>-0.048**</td>
<td>0.022</td>
<td>0.030</td>
</tr>
<tr>
<td>WSITRAIN</td>
<td>0.014</td>
<td>0.051</td>
<td>0.790</td>
</tr>
<tr>
<td>EDUCATION</td>
<td>-0.003</td>
<td>0.006</td>
<td>0.654</td>
</tr>
<tr>
<td>FARMEXP</td>
<td>0.001</td>
<td>0.001</td>
<td>0.450</td>
</tr>
<tr>
<td>WEALTH</td>
<td>-0.005</td>
<td>0.020</td>
<td>0.805</td>
</tr>
<tr>
<td>DVILAGE1</td>
<td>0.027</td>
<td>0.036</td>
<td>0.452</td>
</tr>
<tr>
<td>DVILAGE3</td>
<td>0.093**</td>
<td>0.040</td>
<td>0.020</td>
</tr>
<tr>
<td>DVILAGE4</td>
<td>0.124***</td>
<td>0.036</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Sigma (σ) 0.106***
Log likelihood function (unrestricted) -47.16
Log likelihood function (restricted) -80.79
Likelihood ratio 67.22***
Scale factor for marginal or total effect F(z) 0.89
Conditional mean of dependent variable at sample point 0.73
Pseudo R<sup>2</sup> 0.42
Total observations 98

***, **, and * refer to significance at the 1%, 5%, and 10% level, respectively.

<sup>a</sup>Marginal effect ( Ey/̂x) refers to the partial derivatives of the expected value with respect to the vector of characteristics. They were computed at the mean of the independent variable.

<sup>b</sup>Elasticity equals marginal effect coefficient multiplied by the ratio of the mean of the relevant explanatory variables to the mean of the dependent variable. Dependent variable: AWD score.

The supply of water from small reservoirs (REL1RES), have same signs as in the regression with REL1. However, coefficient of reliability of water from the ponds (RELIPOND) was the only significant factor (at P < 0.10) affecting AWD, which implies that pond water positively influenced the adoption of AWD irrigation practices.

The positive and significant marginal effects of reliability of pond water (0.108) imply that a 1 point increase in the reliability index of ponds would increase the AWD adoption score by 0.108 points. This may be because the access to pond provides greater flexibility to use water and due to this reasons almost 75% of the respondents were using pond water. Similarly, the elasticity of the reliability of pond (0.068) implied that a 1% increase in the reliability of pond water would increase AWD score by 0.068%.

6. Summary and conclusions

Water saving irrigation practices refer to any measure that leads to a reduction in the use of irrigation water or increases water productivity without a distinct reduction in crop yield. Intuitively, the key factor...
for the adoption of water saving irrigation is the availability of a dependable and timely water supply. Lack of reliable water sources or uncertainty in water supply can play a major role in water management and the subsequent adoption of water-saving measures.

Based on soil moisture conditions, both qualitative and quantitative scores of alternative wetting and drying were computed to assess the level of adoption by Chinese farmers in the Zhanghe Irrigation System following a significant reduction in canal water supplies. The results show that some forms of AWD practices were widely adapted in the area, albeit not to the full theoretical description. The AWD score did not show ideal AWD practices but current irrigation practices were found to be close to AWD practices. The result showed that AWD is not driven by farmer’s choice; increased water scarcity was perhaps the most important factor for the adoption of AWD practices, which could be seen in terms of creation of dry soil conditions, which, in most cases, were due to water shortages. Thus it seems reasonable to assume that, in adopting AWD, farmers are influenced more by their immediate business environment than large-scale concerns about allocation among competing uses. Other factors come into play but do not impact the adoption of AWD practices in a significant way.

To measure the reliability of water sources, two reliability indicators were developed: first based on the total numbers of irrigations and irrigation made on dry soil conditions, and then in terms of farmer’s subjective assessment on the reliability of water resources. Both the reliability indicators show a similar trend: water from ponds was more reliable than from ZIS canal water and water from small community reservoir.

Two censored Tobit model were used to assess the impact of the reliability of water sources and other parameters on the adoption of AWD. The results indicated that farm size and land quality have a significant but negative influence on the adoption of AWD practices. The reliability of supply of water from ZIS canal water and small reservoirs influenced positively but not significantly the adoption of WSI practices. Reliability of water ponds however had a weakly significant positive effect on AWD practices. Thus reliable water supply does not necessarily result in the adoption of AWD practices. The effect of water-saving irrigation training and the farm experience of the household head were positive but insignificant.

Other authors have hypothesized that access to reliable water sources such as water ponds would increase the likelihood of practicing AWD. While it seems reasonable that the ability to access reliable water would reduce the risk involved in letting the paddy fields dry temporarily, and thus encourage adoption of AWD, this study found no solid empirical evidence to support the proposition. There is somewhat weaker empirical evidence that access to reliable water supply from ponds influenced AWD positively. The results also provide some support that an AWD training program would have a positive impact on the adoption of AWD practices in the future. The results concerning farm size suggest that the land distribution system has an important role in the adoption of AWD practices. Limiting water supply by creating institutional water scarcity backed by agricultural research and development may lead to the adoption of water-saving irrigation practices. Appropriate education, training, AWD extension, and water policy programs are required.

References


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