Water Saving Technology in Chinese Rice Production – Evidence from Survey Data

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Abstract

Whereas water is an important input in rice production, China faces severe problems with increasing demand for water and limited water resources. In conventional paddy production, one of the most important irrigated crops, a significant amount of irrigation water is lost due to percolation and evaporation. Therefore, it exist a vivid research in water saving rice technologies. This paper analyzes the adoption of one of these water-saving rice production technologies, the so-called Ground Cover Rice Production System (GCRPS), in the Hubei province. Based on farm survey data several factors which affect the adoption decision could be identified. The adoption decision is treated as a binary choice problem and therefore a probit model is used for the econometric analysis. The main determinants of the adoption decision are the number of previous adoptions, the membership in an extension service and the income of the household. Additionally, soil characteristics show a significant impact on the probability of adoption.

Key works: China, technology adoption, water, GCRPS, probit
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1. **Introduction**

China's rising industrialization and increasing wealth of Chinese, mainly urban, households led to an increasing demand for water. In terms of per capita water resource availability, China ranks among the lowest levels worldwide. Agriculture is still the main user of water, but its share on total water consumption is dropping from 97 percent in 1949 to 69 percent in 1998. Some regions, especially in the North, report severe water shortage problems. Probably 34 percent of the population lives there and about half of China's arable land is located in these relatively water scarce regions. Limited water resources will impact China's future agricultural production, especially the mix of irrigated and non-irrigated crops, and trade portfolio. Therefore, distribution and pricing of water is currently one of the main policy topics of the Chinese government (CROOK and DIAO, 2000; p. 25; LOHMAR ET AL., 2003; pp. 3). Around two-third of the agricultural production is derived from irrigated land and rice is one of the main irrigated crops (WANG ET AL., 2002). Due to the high evaporation in traditional paddy production, a loss up to 60 percent of irrigation water is estimated; water use efficiency is relatively low and research for water saving technologies is vivid (see WANG ET AL., 2002; LOHMAR ET AL., 2003). The most common technologies are field levelling, border irrigation, stubble retention, alternating wet and dry as well as plastic sheeting (GCRPS).

The Ground Cover Rice Production System (GCRPS) consists of the covering of the field with a thin plastic film before the rice seedlings' planting. Fields are not irrigated permanently after planting. Water savings under experimental field conditions varying greatly, depending on soil conditions, and ranging between 50 and 90 percent. Water use efficiency is rising up to 1.3 kg rice per m^3 of water compared to less than 0.5 kg rice per m^3 in conventional paddy production (LIN ET AL., 2003; p. 4). Whereas under experimental field conditions the yield of GCRPS fields are typically up to 10 percent lower than under conventional paddy production, farmers in our survey report higher yields. Another reason for farmers to adopt this technology, expressed in the interviews, is a slightly higher soil temperature under the plastic film which gives the possibility to plant the rice seedlings earlier and to harvest the rice 10 to 15 days earlier. Due to the covering of the soil farmers can save herbicides and labour[1]. Compared to other innovations like new seeds or fertilizer, GCRPS can be implemented without any additional input and special training.

A vast number of theoretical and empirical works have been devoted to the analysis of farmer technology adoption behaviour. While the theoretical studies suggest important hypothesizes relating adoption of new technologies to key economic and physical parameters, empirical literature has been investigating the analyses of observed adoption patterns mostly by focusing on the relationship of farm, household, and regional characteristics to adoption behaviour. Although much of the empirical research has been paralleled the progress made in the diffusion cycle of the Green Revolution technologies, summarizing this literature is difficult for two reasons. First, empirical studies have been carried out in many different regions, and economic, social, and political institutions affecting adoption behaviour vary substantially between these regions. Second, the existing literature analyses different types of agricultural innovations, making a comparison of results difficult. However, the (economic) literature provides several key explanatory variables affecting the likelihood or the levels of adoption. Among these variables are the decision unit dimensions (field and farm size), human capital variables such as age, education, and experience, the availability of labour force, (land) tenure arrangements, and input and output prices

FEDER, JUST and ZILBERMAN (1985) as well as FEDER and UMALI (1993) give detailed surveys of this literature with a special focus on developing countries. But most of the studies focus on the introduction of new inputs like High Yielding Varieties (HYV), fertilizer, pesticides or machinery. Only very few studies deal with the introduction of innovations which save on input use or limit unwanted environmental effects of agricultural production. Following them, the main determinants of adoption are the price of the technology, farm size, farmer's human capital, labour availability, membership in an extension service and liquidity constraints. FEDER and UMALI (1993) state that the significance of adoption's determinants can change with the development stage of the innovation. During early phases of the diffusion process the variables farm size, tenure status, education and access to extension services and credit can be more important than in later phases.

[1] For a detailed description of the technology and a cost-benefit analysis see GLAUBEN and HERZFELD (2004).

CASWELL (1991) as well as KOUNDOURI ET AL. (2004) analyze the adoption of water saving irrigation technologies in the USA, Israel and Greece, respectively. SALTIEL ET AL. (1994) analyze the adoption of management-intensive and low-input sustainable practices in the USA. In the case of SRI (System of Rice Intensification), a high-yielding, low-external input rice production method, in Mozambique, MOSER and BARRETT (2003) analyze the adoption and disadoption behaviour of agricultural households. Increasing disadoption is mainly due to additional labour demand in times of labour scarcity. The case of non-adoption of slash-and-burn cultivation practice in Nicaragua is analyzed by ABDULAI and BINDER (2005). HUFFMAN (2001) stresses especially the educational level of farmers, those who are better educated posses a greater ability to acquire and process information as well as are more able to critically evaluate the productive characteristics and costs of adopting innovative technologies. In most developing countries, agricultural extension tends to be a major source of information on technological improvements in the agricultural sector. Although the information provided by extension agents may not be totally objective with respect to information on expected performance, it is most likely that they serve as an important source of information on how and when to use a technology.

Following the literature on might hypothesises that bigger farms with more educated farmers tend to adopt a new technology earlier. Further, farmers which are member of an extension service or have more contacts with extension agents might show a higher likelihood to implement the water saving technology. Since farm proprietors may differ regarding their personal attitudes towards technical progress, it seems to be reasonable that the more farmers judge it positive the higher the probability that they adopt GCRPS. Finally, it might be expected that liquidity constraints will reduce the probability of adoption. The present study investigates the choice of adopting a water saving technology in paddy production (GCRPS) using survey data form 2004 for 240 households in the Shi Yan district in the northwest of the Hubei province. Following previous work, we use a probit approach to examine whether specific farm and family characteristics are related to the likelihood of succession within a given observation period. We go beyond the existing literature by controlling for farmers' values and attitudes towards farming and agriculture.

The remainder of this article is organised as follows: A description of the survey region and the data follows in the next section. The results are presented and discussed in chapter 3 and a summary concludes.

2. Description of data

We use data from a survey in the Shi Yan district in the northwest of the Hubei province. The survey took place in May 2004 and covered 240 interviews. The GCRPS is promoted by the Agricultural Bureau in Shi Yan city and is practised since 1990 in this region. The region is very mountainous and monthly rainfall amounts to 70 mm. Yields of the main crops, rice, wheat and corn, are slightly above the official provincial average (513, 197 and 367 kg/ mu[2]). Cultivated area per capita and per household is about 1.05 mu and 4.28 mu, respectively, which is slightly below the provincial average (AGRICULTURAL BUREAU, 2004; NATIONAL BUREAU OF STATISTICS, 2001). The study area is characterised by different soil types: Ranging from a yellow sandy soil with a low water holding capacity to a black soil.

Table 1 presents some descriptive statistics of the villages and households in the sample. Our sample over represents the number of adopters compared to the real rate of adoption. Since no projections are intended this overrepresentation does not limit our analysis.

[2] Mu is the traditional Chinese square measure: 1 mu is equivalent to 0.067 ha.

Table 1: Descriptive statistic of survey area

Village	No. of Households	Share of adopters (%)	Inter-views	Interviewed adopters	Share of adopters in survey (%)
Huangtu	216	23.1	31	15	48.4
Haokou	512	9.4	9	9	100.0
Tongqinggou	379	30.6	10	9	90.0
Yuanquan	268	73.1	40	35	87.5
Lugoukou	368	29.9	10	10	100.0
Huabao	396	50.5	4	1	25.0
Bailu	485	42.3	25	18	72.0
Heizhangshu	312	32.1	18	12	66.7
Shuangbai	366	32.8	16	2	12.5
Mingyue	358	27.9	7	3	42.9
Xiaoyan	288	25.0	12	8	66.7
Shangba	335	29.3	33	33	100.0
Luojiapo	306	37.6	13	13	100.0
Youcheng	384	43.0	12	12	100.0
Qingcaoping	312	48.1	-	-	-
Total Area	5285	34.9	239	180	75.3

In which aspects farmers who adopted GCRPS differ from farmers who don't adopted? Comparing the means of the groups of adopters and non-adopters shows some differences between these two groups (Table 2). Regarding the productivity of rice and corn production, measured as yield per mu, adopters harvest on average a higher yield, whereas the difference is not statistically significant. But adopters have a significant higher yield of wheat per mu. Adopters are less specialized measured by the Hirschman-Herfindahl-Index, but show a higher probability to be member of an extension service. Adopters of GCRPS adopted significantly more innovations in the last ten years than the group of non-adopters. Asked if they agree to the two statements, 'Our environment is a fragile system and we have to protect it from destruction.', and, 'Technical progress in agriculture is positive.', the group of adopters report a significantly higher degree of consent. Regarding the attitude versus risk both groups show no significant difference. Additionally, adopters judge their personal future in agriculture more positive than non-adopters. Whereas regarding the attitude towards markets and agricultural policy there are no differences between both groups. The same applies to personal characteristics like age, schooling and household size. Households who adopted GCRPS work about 36 and 85 days per year less off-farm, which is statistically significant different from the group of non-adopters. Unfortunately, we have no information about liquidity constraints in our sample. Therefore, we approximate this variable with the reported income. The overwhelming majority of the farm households in our sample are subsistence farms; they consume nearly 100 percent of their production by themselves. Income from off-farm work or transfers from family members are therefore the most important sources of liquidity. However, the positive effect of farmer's non-farm income on liquidity and the likelihood of adoption may be offset by the reduction in time available for producing knowledge and making decisions, as well as the increased opportunity cost of time. As one example, it is referred to the low adoption and relatively high abandonment of a low-input rice technology (SRI) in Madagascar. Adoption requires more labour and calls for reallocation of family labour away from off-farm wage employment, which renders SRI unattractive especially for poor farmers with small plots (BARRETT ET AL., 2004). Hence, the net effect on adoption is ambiguous

Table 2: Comparison of the mean of main variables

Variable	Unit	Mean adopters	Mean non-adopters	t-Value (Significance)
Productivity				
Rice yield	kg per mu	461.71 (10.07)	431.27 (19.04)	-1.41
Wheat yield	kg per mu	226.73 (10.33)	188.42 (15.00)	-2.10 **
Corn yield	kg per mu	340.60 (9.96)	328.55 (14.58)	-0.68
Farm characteristics				
Farm size (*FARM*)	mu	4.98 (0.75)	3.82 (0.32)	-1.42
Paddy size (*PADDY*)	mu	1.69 (0.06)	1.84 (0.14)	0.99
Specialization (*HHI*)		0.49 (0.02)	0.62 (0.03)	3.27 ***
Personal and household characteristics				
Age (*AGE*)	years	46.79 (0.77)	46.05 (1.29)	-0.49
Schooling (*EDU*)	years	5.70 (0.27)	5.75 (0.47)	0.09
Household size (*HHSIZE*)	number	3.79 (0.06)	3.85 (0.12)	0.44
Member in an extension service (*EXTEN*)	1 (yes); 0 (no)	0.60 (0.04)	0.15 (0.05)	-7.54 ***
Adoptions in the last 10 years (*PASTADOPT*)	No.	5.99 (0.27)	3.29 (0.34)	-6.18 ***
Off-farm occupation of household head (*OFFFARMH*)	days/ year	147.63 (10.02)	183.81 (14.28)	2.07 **
Off-farm occupation of household head and spouse (*OFFFARMC*)	days/ year	214.76 (15.24)	300.17 (29.69)	2.56 **
Share of marketed production (*MARKET*)	percent	6.80 (1.21)	8.46 (2.37)	0.62
Reported income (*INC*)	RMB/ year	7535.17 (496.05)	3340.05 (542.85)	-5.38 ***
Farmer's Attitudes				
Statement 1: "Our environment is a fragile system and we have to protect it from destruction." (*STATE1*)	1 (strongly agree); 5 (strongly disagree)	1.69 (0.06)	2 (0.14)	2.02 **
Statement 6: "Technical progress in agriculture is positive." (*STATE6*)	1 (strongly agree); 5 (strongly disagree)	1.40 (0.05)	2.04 (0.15)	4.04 ***
Statement 9: "When selling my products, I prefer financial certainty to financial uncertainty." (*STATE9*)	1 (strongly agree); 5 (strongly disagree)	2.58 (0.09)	2.56 (0.14)	-0.14

Table 2: continued

Statement 10: "I assess my future outcome in agriculture positive." (*STATE10*)	1 (strongly agree); 5 (strongly disagree)	2.38 (0.08)	2.96 (0.16)	3.29 ***
Statement 13: "When selling my products, a free market is preferable." (*STATE13*)	1 (strongly agree); 5 (strongly disagree)	1.77 (0.07)	1.78 (0.12)	0.05
Statement 14: "Government should protect agriculture more to ensure higher incomes." (*STATE14*)	1 (strongly agree); 5 (strongly disagree)	1.06 (0.02)	1.12 (0.07)	0.87

Note: *, **, and *** indicate that the means are significantly different at the 10%, 5%, and 1% level of confidence (two tailed test); standard deviations in parentheses

Setting up the final model, a set of personal, household and farm characteristics are included as explanatory variables in the vector Z (Equation 2). Village effects should capture the influence of the organisation of irrigation, distance to markets and hydrological conditions. Unfortunately, the village Yuanquan is the only village reporting a monthly rainfall about 80 mm which is 10 mm more than in all other villages and due to the perfect prediction of adoption in villages 2, 5, 12, 13 and 14 dummy variables for these villages could not included in the model. Therefore, only one dummy for the village Yuanquan (village 4) is included in the model.

3. Methodical Framework and Empirical Results

In general, it may be assumed that in deciding whether to adopt GCRPS the farmer weighs up the expected utility of wealth from adoption represented as $U_A^*(\pi)$ and the expected utility of wealth from non-adoption represented as $U_N^*(\pi)$, and adoption occurs if $U_A^*(\pi) > U_N^*(\pi)$. This is under the assumption that farmers are risk neutral and that net farm returns *(π)* represent wealth. The parameters of this decision are usually not observable, but can be represented by a latent variable *U(π)=1* if $U_A^*(\pi) > U_N^*(\pi)$ and *U(π)=0* if $U_A^*(\pi) < U_N^*(\pi)$. Dropping other subscripts for expositional purposes, utility of adoption can be related to a set of explanatory variables, Z as follows:

$$U(\pi) = \delta' Z_i + \varepsilon_i \quad (1)$$

where δ is a vector of parameters and ε is an error term with mean zero and variance σ^2_ε. The error term includes measurement error and factors unobserved by the researcher but known to the farmer. Variables in Z include farm size, education, soil quality, and other socio-economic and resource characteristics of the farm. Policy variables that affect utility or profitability of the innovation may also be included in the vector Z. Equation (1) and $U_i^*(\pi)$ may also be expressed as:

$$\Pr(U = 1) = \Pr(U_A^*(\pi) > U_N^*(\pi)) = \Pr(\varepsilon_i > -\delta' Z_i) = 1 - F(-\delta' Z) \quad (2)$$

where *F* is the cumulative distribution function for ε[3]. Assumptions about the functional form of *F* result in different models. Here we employ the probit model, which assumes a normal distribution and excludes probabilities below 0 and above 1 as well as negative variances (GREENE 2000; pp. 812).

The model correctly classifies 82%, using the model 2, up to 86% of the sample, using model 4. Following the log-likelihood the hypothesis that the independent variables are jointly not significantly

[3] This approach is criticized by FEDER, JUST and ZILBERMAN (1985). They argue that a dichotomous variable contains no information about the degree of adoption at each farm. In our sample adopters apply GCRPS on almost all paddy fields (mean: 97.05 percent). This variable shows not enough variation and we have to constrain our analysis on a discrete choice approach as presented here.

different from zero can be rejected. The results of four different specifications are presented in Table 3. Model 2 contains only statistically significant variables as a result of a stepwise regression. Additionally, it displays the lowest Akaike Information Criterion of all four specifications. Furthermore, it has the advantage to cover the broadest sample. Model 1 and 3 differs in respect of using total farm size and size of paddy fields. Finally, model 4 uses a dummy for off-farm occupation of either household head or spouse instead of only regarding household head in model 1. All specifications give similar results. Therefore, they are discussed jointly in the following.

Table 3: Estimated Probit Models

Variable	Model 1	Model 2	Model 3	Model 4
AGE	-0.005		0.006	-0.0001
	(-0.30)		(0.31)	(-0.01)
EDU	-0.056		-0.033	-0.062
	(-1.30)		(-0.72)	(-1.61)
FARM	0.019			0.001
	(0.36)			(0.01)
PADDY			-0.072	
			(-0.44)	
HHSIZE	0.005		0.206	0.014
	(0.03)		(1.08)	(0.09)
HHI	0.880		0.678	0.779
	(1.34)		(1.01)	(1.26)
OFFFARMH	-0.001		-0.0001	
	(-0.59)		(-0.09)	
OFFFARMC				-0.0004
				(-0.60)
STATE6	-0.358 **		-0.318 *	-0.193
	(-2.00)		(-1.70)	(-1.24)
PASTADOPT	0.134 **	0.096 **	0.096	0.125 **
	(2.02)	(2.27)	(1.33)	(2.16)
EXTEN	1.129 ***	1.176 ***	1.274 ***	1.225 ***
	(3.75)	(4.59)	(3.79)	(4.34)
DYELLOW	-0.852 **	-0.919 ***	-0.837 **	-0.854 **
	(-2.35)	(-3.73)	(-2.07)	(-2.49)
DVILLAGE4	-0.586		-0.114	-0.039
	(-1.07)		(-0.19)	(-0.08)
INC/1000	0.061 **	0.073 ***	0.193 ***	0.081 ***
	(2.04)	(2.84)	(2.68)	(2.79)
Constant	0.680	0.069	-0.890	0.208
	(0.52)	(0.24)	(-0.55)	(0.17)
N	166	225	163	213
McFadden's pseudo-R^2	0.38	0.35	0.44	0.39
LR chi^2	71.32 ***	84.992 ***	80.25 ***	85.58 ***

Note: *, **, and *** indicate that the estimated coefficients are significant at the 10%, 5%, and 1% level; z-values in parentheses

The results of the econometric analysis are shown in table 3. Surprisingly, usual explanatory variables of adoption decisions such as age (*AGE*), education (*EDU*) and farm size (*FARM*) do not significantly contribute to the explanation of the use of water saving technology. That is, age and educational level of farmers, as well as the number of land units under cultivation do not influence the likelihood of practicing GCRPS. This contradicts results of several studies in the area as for example ABDULAI and BINDER (2005) and ABDULAI ET AL. (2004) where education has a significant impact on adoption. One explanation is the relatively easy implementation of GCRPS, where a higher education, ceteris paribus, does not lead to further improvements and higher profits. Papers analyzing the adoption behaviour of minimum tillage practice, like NORRIS and BATIE (1987), find a significant negative coefficient of farmer's age. GCRPS, albeit having an indirect effect on soil conservation, seems to have no long-term impact on soil fertility during farmers' decision process.

Similarly, the variables household size (*HHSIZE*), production's specialization (*HHI*) and off-farm occupation (*OFFFARMH*) have no statistically significant on the dependent variable. Adoption of GCRPS, therefore, does not conflict with off-farm participation. Comparing GCRPS with other water-saving rice production practices, like SRI, this characteristic seems to be a relatively important comparative advantage, especially in countries with small farms and a high importance of additional off-farm employment.

The most important driving factor of adoption is the membership in an extension service (*EXTEN*). This is consistent with results in several studies including ABDULAI and BINDER (2005) and MOSER and BARRETT (2003). Membership raises the adoption probability by 18 to 24 percent. This result is very robust in several specifications. One reason could be an easier access to plastic film at a reduced price. The Agricultural Bureau in Shi Yan distributes plastic film at a price of 6 RMB/ kg instead of the regular price of 12 RMB/ kg. Further factors could be a better access to information, demonstrations at experimental fields and more exchange between colleagues.

Farmers who adopted more innovations in the last 10 years show a statistically significant higher probability to adopt GCRPS which ranges between 1 and 3 percent per additional previous adoption.

Soil quality is also an important factor. A household farming on a yellow soil shows a lower probability to adopt GCRPS than farmers on other soil types, ranging between 8 and 18 percentage points. This is in line with findings reported by FEDER and UMALI (1993).

As described at the beginning GCRPS is a technology which is very easy to implement. The only limitation is the need of liquidity to buy the plastic film. This is captured by the variable income (*INC*) in this model. The estimated coefficient is positive and statistically significant. Consequently, farmers with a higher reported income show a higher likelihood to adopt GCRPS. A similar result is found by ABDULAI and BINDER (2005) suggesting a higher probability to restrain from slash-and-burn cultivation practice with increasing non-farm income as well as crop income.

Taking up the finding by FEDER and UMALI (1993) that the importance of farm size and education dwindles over the course of diffusion, it could be stated that GCRPS has reached a middle point of diffusion. Since extension service and liquidity are still significant determinants it is refrained to state, that this technology has reached the final stage of the diffusion process.

4. Conclusion

The question of "Who will feed the Chinese?" presently not only concerns food supply, but also pure water resources. China faces a problem of serious shortage of fresh water caused by shortage of the resource itself and, in addition, by water pollution. Water shortage has been one of the most important topics in China today, whereby competitive use of water among agriculture, industry, and households will make the conflict more acute. Although China is lacking in fresh water, about 75% of total water has been used in agriculture, particularly in rice and vegetable production. Therefore rice and vegetable production systems saving on water, as e.g. soil covering with plastic film or raw straw, has been introduced to rice and vegetable production and are promising strategies to cope with water scarcity.

In this study, a sample of 240 Chinese farm households has been used to investigate their adoption behaviour of water saving rice production technology. Soil covering with plastic film instead of permanent flooding reduces water losses and raises significantly water use efficiency. In particular, we focus on the determinants of the adoption decision. Our estimation results suggest that farmer's participation in an extension service raises the probability to adopt this technology significantly. This result may be partly caused by the distribution of plastic film at a reduced price through the Agricultural Bureau, which is in charge of the extension service too. A higher probability of adoption is positively related to the number of previous introduced innovations and the reported household income. Furthermore, adoption behaviour is significantly related to soil conditions. For example, farms located on a yellow soil exhibit a significantly lower probability to adopt GCRPS.

A major policy implication arising from the results of this study is that efforts to increase water use efficiency in paddy production should focus on the appropriate soils. Promotion of GCRPS through extension service seems to be successful, albeit interest of farmers to get subsidised plastic film is greater than current supply. Subsidising plastic film or increasing household's entitlements to increase their income will, ceteris paribus, raise their probability of adoption.

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