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Can drought-tolerant varieties produce more food with less water? An empirical analysis of rice farming in China

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Abstract

Most of the poorest people live in rural areas worldwide, characterized by uncertain rainfall, low levels of input use, and low returns to land and labor. Farmers in these risky production environments often face drought that interacts with many other agronomic stresses to reduce yields and push them deeper into poverty and hunger. The primary objective of this paper is to estimate the effects that have resulted from the adoption of drought-tolerant rice. Food security and water shortage are two major challenges for China. Rice is a staple food for most Chinese people and has played an important role in ensuring food security in China. This paper assesses the impacts of Hanyou 3, one of the drought-tolerant rice varieties that have been released to farmers' fields already in China, on water use and rice production. The results indicated that the rice farmers gave less irrigation to DT variety as compared to non-DT variety, saving about 30-40% of water over non-DT variety. It is also found that the DT rice variety in China yielded as much as existing high-yielding varieties under normal or high rainfall conditions.

Key words: Water-saving, Drought-tolerance, Rice, China

I. Introduction

Most of the poorest people live in rural areas worldwide, characterized by uncertain rainfall, low levels of input use, and low returns to land and labor. Farmers in these risky production environments often face drought that interacts with lots of other agronomic stresses to reduce yields and push them deeper into poverty and hunger.

Global warming is making droughts and floods more likely in the future. However, there has been an on-going debate about whether it is better to concentrate research resources on the high potential irrigated areas or focus on poor areas. In the background of Green Revolution, beginning in the late 1960s and early 1970s, national research organizations had experienced great pride by raising rice yields from 1-2 tons/ha to 3-5 tons/ha in extensive irrigated areas across south and southeast Asia (O'Toole, 2004). In the light of these successes in the irrigated sector, enhancing rice production through breeding for rainfed zones was associated with a low probability of success and resulted in low priority for research support (O'Toole, 2004).

Significant expansion of irrigation does not seem likely as demand for water by industrial, housing and service sectors is growing rapidly. Simultaneously, climate change is increasing temperatures, reducing rainfall and snow, increasing variability of rainfall and reducing recharge of underground aquifers in many areas of Asia. Rural people in un-irrigated areas have learned to cope with periodic drought through a variety of mechanisms but remain caught in poverty and malnutrition (Prey el., 2011).

A number of previous studies have reported on impacts of DT varieties in experiments run by scientists, but no one has examined impacts of these varieties in farmer-managed fields. All the released DT varieties have yield advantages, especially under moderate to severe drought conditions on experiment stations, are suitable for dry and semi-dry systems. However, there is no clear evidence of how results from experiment stations will translate into benefits (or losses) in farmers' fields. To fill this gap, we conducted this study in areas where the DT rice variety has been approved for cultivation by the local governments, although very little commercial seed had yet reached farmers. The primary objective of this paper is to estimate the effects that have resulted from the adoption of drought-tolerant rice at farm-level.

Food security and water shortage are two major challenges for China. Rice is a staple food crop and has played an important role in ensuring food security in China. Rice is the first largest grain food crops in terms of sown area, with about 40% of grain food production in China. Rice is also the first largest sector in terms of water use, with about 60% of agricultural water use in China. On the other hand, drought is the largest natural disaster for agriculture in China. The crops of 20-30 million hectors suffer drought annually in the recent decade, indicating that more than 20% of total crops sown area was affected by drought. This paper assesses the impacts of Hanyou 3, one of the drought-tolerant rice varieties that have been released to farmers already in China, on water use and rice production.

II. Breeding for drought-tolerant rice in China

For many years, plant breeders have recognized the potential benefits of drought tolerance and have undertaken research aimed at identifying and incorporating drought tolerance into high-yielding varieties. Drought-tolerant variety that reduces water use in rice production can benefit farmers not only directly by keeping yield stable in various conditions but also by reducing farmers' reliance on costly coping mechanisms.

During the past five to seven years a number of institutions in China, India, Thailand and the International Rice Research Institute, Philippines have launched rice genetic improvement programs to address the loses attributed to current and anticipated water-limited rice culture (O' Toole, 2004).

During these rice research programs, China are perhaps the most aggressive in Asia in dealing with this challenge due to China's looming water crisis. In the late 1990s assessments of China's future options for fresh water resources illustrated the dire consequences with regard to water and rice (World Bank, 1997).

In 1998 the Rockefeller Foundation began a multi-year, multi-country program of support for research and technology transfer of drought-tolerant rice in Asia. A key element of this project has been an investment of several million dollars in national agricultural research services (NARS) in China, India, and Thailand, as well as in the International Rice Research Institute (IRRI) to help them develop and diffuse drought-tolerant rice (O'Toole, 2004). Since the start of Rockefeller Foundation's work on drought tolerance, considerable progress has been made. An international workshop was held at Hainan province in China in March 2000. The plant breeders and researchers from several Chinese institutions and the International Rice Research Institute (IRRI) attended the workshop and formally took stock of efforts to genetically modify rice for future water-limited production scenarios and planned collaborative research. Several outcomes from that event are noteworthy. In China, several drought-tolerant rice varieties have been developed and approved by authorities starting in 2003. Among these DT rice, Hanyou 3 was developed by Shanghai Agrobiological Gene Center (SAGC).

The Chinese DT rice program in Shanghai exemplifies large-scale development of DT rice hybrids for commercialization. With the establishment of a science-based field screening facility at Shanghai Agro-biological Gene Center in 2001, nearly800 DT rice germplasm lines were evaluated under water-controlled conditions. Out these, 46 lines showed high-level drought tolerance for further selection and improvement, and of these ,15 DT lines were used as donor parents for the molecular breeding program to identify necessary molecular markers for DT. Several drought-tolerant hybrids have been identified and developed since 2003. In 2007, the first DT rice hybrid, Hanyou 3, was approved for commercial release in Guangxi province.

In 2000, a national testing system for drought-tolerant rice varieties was also developed. However, there were not enough DT varieties to warrant a national system, So in 2005 the system was stopped. Thus, the first hybrid developed in China, Hanyou 3, could only be approved at the provincial level and at first it was only approved in Shanghai where it was developed and in Guangxi which had more drought problems than most of the country. It has gradually been approved in four more provinces so far. Another hybrid developed at the same time, Hanyou 2, was not officially released nationally until 2010 through the regular (non-drought) national testing system. It had higher yields in variety tests than check varieties and experiment station data also showed drought tolerance.

III. Source of Data

Experiment Site Select

This study focuses on southern China. In terms of rice ecological zoning, southern China accounts for 88% of the total rice area and 86% of the total rice production of the country (Zhu, 2000).

Zhejiang and Guangxi provinces in southern China were chosen as they have their own research significance. Zhejiang is relative an economically developed and industry aggregate province, located in southeast China with plenty of water resource and well-established water irrigation facilities where rice production is less affected by drought and water shortage. However, the water demand for industry is constantly increasing, which incurs the tension of water supply. Furthermore, 68% of the household income in Zhejiang's villages is from non-farm sources, indicates that non-farm activities prevail in the Zhejiang's villages (Ding, 2004). If the agricultural water use can be saved by production of DT rice, then the water can be put into industry use which will further develop industry and thus increase household income. Guangxi province represents a poorer area, with a low proportion of irrigation and low rice yields in the country. Farmers in Guangxi are relatively poorer. The overall temperature during the year is 16-22 degree centigrade and the average annual rainfall is 1500mm (Ding, 2004). Although the rainfall is sufficient, there are almost two third of cultivated land are lack of irrigation because irrigation facilities are difficult to build in Guangxi's vary topographies and Karst soil (Ding, 2004). Therefore, most of the agricultural cultivation area is susceptible to drought.

Moreover, Zhejiang and Guangxi were the only two provinces where the drought-tolerant rice variety (Hanyou 3) has been approved for commercial use since 2007. Yiwu County in Zhejiang Province, where the one of the world's biggest commodity markets is located, was chosen as it is a water-deficit county and needs to input water from adjacent area and is facing imbalance water use between agriculture and industry, which grew rapidly in the last two decades. Liubei, Xinbin and Wuxuan counties in Guangxi province were chosen with insufficient irrigation facilities due to the varying topographies and Karst soil. They suffer a lot when drought occurs. The spring drought causes the delay of transplanting and the autumn drought occurs with yield declining.

The sample was a stratified random sample. The final samples consisted of 144 households from eight villages of four counties in 2009, and 153 households from eight villages of three counties in 2010.

Experimental Design

In this study, we used experimental design techniques in which randomly chosen farmers were given DT hybrids along with crop management information to ensure we did not have selection bias and would be able to correctly estimate the contribution of DT to yield and other parameters.

A training course was hold in each sample village and the sample farmers were asked to participate in the course and taught how to plant DT rice in their own practice, exception of less irrigation. For incentives, the seeds of Hanyou 3 were distributed to the sample farms for free. Within a selected rice farm, one bigger plot was chosen as an experimental plot, which was divided into two parts (subplot) by a ridge. The farmers are required to plant DT and non-DT rice at this same plot to control elements such as soil quality and some farming activities as constant. The DT variety was planted at one subplot, while a non-DT variety was planted at another subplot. Beside from the experimental plot, a second plot was chosen for planting any of non-DT varieties if there were more plots on the farm.

Any such data/information as farming activities, quantity of inputs and output were recorded by the sample farmers and then the sample farmers were interviewed after harvest.

Background of the Sample Village

The total 12 villages were selected as our sample villages, namely, Loujiawu (Village 1), Yazhijie (Village 2), Gencun (Village 3), Yubu (Village 4), Gaozhao (Village 5), Tiexiang (Village 6), Beicun (Village 7), Xingcun (Village 8), Dongzhu (Village 9),Gaolin (Village 10), Changtang (Village 11) and Qingmao (Village 12).Of which, the Villages 1, 3, 4, 6, 9, 10, 11, 12 were selected in 2009, while the Villages 1-8 were selected in 2010. Note that only 4 villages (Village 1, Village 3, Village 4 and Village 6) were selected in both years of 2009 and 2010.

Loujiawu, Yazhijie and Dongzhu villages in Yiwu County were selected as less availability of water resources there. Yiwu is located in central Zhejiang Province and known as the home of “the largest small commodity wholesale market in the world’,

Loujiawu village is located in the northern part of Yiwu County, where industry and service sectors developed rapidly in the recent decades. Rising industrialization and urbanization have caused more water allocation to non-agricultural uses. Yazhijie and Dongzhu villages are both in the southern part of Yiwu County and a traditional grain food producing area in the county.

Two villages (Gencun and Yubu)in Wuxuan County, Five villages (Gaozhao, Tiexiang, Beicun, Xingcun and Gaolin) in Xinbin County, and two villages (Changtang and Qingmao) in Liubei County were selected as different irrigation system there. The all 3 counties (Wuxuan, Xinbin and Liubei) are located in central Guangxi Province. Drought occurs often in this so called “the Central Guangxi Drought Area”.

Gencun and Yubu villages are located in the northern part of Wuxuan County. There is good irrigation infrastructure in Gencun Village, irrigation service is provided by the village. There is no irrigation service provided by the village in Yubu. The farmers irrigate their crops individually as the plots are scatted over the village. There are more rice plots that are so called as “Shui Wei Tian” and far from reservoir irrigation system.

Among 5 sample villages in Xinbin County, Tiexiang Village is the one near from reservoir irrigation system and ponds and rivers are the main water sources for irrigation in Gaoling, and Xincun villages.

The irrigation system is almost the same for Gaozhao and Beicun villages in Xinbin County, and Changtang and Qingmao villages in northern Liubei County, where the most of “Shui Wei Tian” are much far from reservoir irrigation system, even far from rivers.

IV. Results and Discussion

Descriptive Analysis

The experimental design method that DT and Non-DT rice are planted in the same plot, made some major contributing elements constant, such as weather, soil quality, plot's drought feature. Thus, we can compare the mean of all the factors concerning farmers' characteristics, input, and farm activities,

Table 1 demonstrate that the producer in Zhejiang (ZJ) was about 5.5-7.5 years elder than the producer in Guangxi (GX), respectively in 2009 and 2010. The rice producer had near 2 more schooling years in Guangxi than in Zhejiang. It implies that the younger producer were educated more. The average household size was 4.4 and 4.8 people each family in 2009 and 2010, respectively. The number of family members in Zhejiang was 2.1 people less compared to that in Guangxi. The farms in Guangxi has more land than in Zhejiang. Note that both farm size and paddy field of samples in Zhejiang increased a lot in 2010 due to that one large rice farm with a paddy field of 162 mu was selected as an experimental sample in 2010. The value of assets per farm was much larger in Zhejiang, although it increased by 8% in Guangxi form RMB 92.5 thousand yuan in 2009 to RMB 100 thousand yuan in 2010. Note that the total value of assets per farm in Zhejiang increased a lot because of that the two rich farms with about 1.2 million yuan of assets each were selected as the experimental samples in 2010.

Table 1. Characteristics of rice farm by province, China, 2009-2010

	2009			2010		
	Ave	ZJ	GX	Ave	ZJ	GX
Age (years)	49.9	53.9	48.4	49.2	54.9	47.4
Education (years)	7.7	6.4	8.2	7.9	6.6	8.3
Household Size (person)	4.4	2.9	5.0	4.8	3.2	5.3
Farm Size (ha)	0.73	0.33	0.87	0.84	0.57* (0.28)	0.93
Paddy field (ha)	0.28	0.31	0.27	0.33	0.47* (0.17)	0.29
Assets (RMB 1000 yuan)	107.6	149.9	92.5	150.5	314.5** (263.2)	100.0
Sample size (number of hhs)	144	38	106	153	36	117

Source: All figures are calculated from authors' survey data.

Note: *Both farm size and paddy field of samples in Zhejiang increased a lot in 2010 due to that one large rice farm with a paddy field of 10.8 hectors was selected as an experimental sample in 2010. The numbers in the parentheses are the mean values excluding this large farm.

**Total value of assets per farm in Zhejiang increased so much because of that the two rich farmers with about RMB 1.2 million yuan of assets each were selected as the experimental samples in 2010. The number in the parenthesis is the mean value excluding these two rich farmers.

Except plot size, there are no differences between DT and non-DT varieties in terms of characteristics of plot, such as soil quality (Table 2).

Table 2. Characteristics of the experimental plots by variety, 2009-2010

	2009			2010		
	DT	NDT	Diff	DT	NDT	Diff
Plot size (ha)	0.045	0.039	0.005*	0.037	0.034	0.003**
Zhejiang	0.046	0.044	0.002	0.042	0.041	0.001
Guangxi	0.044	0.038	0.006***	0.035	0 .031	0.004***
Soil quality (plot)*	144	144	0	153	153	0
Good (plot)	23	23	0	44	44	0
Medium (plot)	111	111	0	99	99	0
Poor (plot)	10	10	0	10	10	0

Source: All figures are calculated from authors' survey data.
Note: There are 3 grades for soil quality of plots: good, medium and poor.

As we expected, there were no significant differences in levels of inputs, such as fertilizer, pesticides and labor use between DT and Non-DT rice varieties (Table 3), implying that the experiments design is good and the sample farmers followed the experimental design well.

In contrast, there are large differences between DT rice and Non-DT rice varieties in water use, significantly in Guangxi, The sample farmers in Guangxi irrigated DT rice 2.4 times per cropping season, 1.3 times less than they did for non DT rice in 2009, a normal year.

Irrigation increased for the both varieties of DT rice by 1.71times from 1.96 times in 2009 to 3.67 times in 2010 and non-DT rice by 1.12 times from 3.01 times in 2009 to 4.13 times in 2010, because more water were available for irrigation during the rice growing season in 2010（June-October for the single cropping rice in Zhejiang and the middle of July-November for the late double cropping rice in Guangxi, Figure 1). Another reason of more irrigation in 2010 is that to protect crop from low temperature caused by a cold dew wind (CDW), most farmers irrigated often to keep more water on surface of rice field. CDW often occurred around the day of "Cold Dew", the 17th one of the 24 Chinese solar terms in a year. The day of "Cold Dew" is usually on the day of Oct.8 or Oct.9. CDW often causes the temperature significant dropping in southern China. During the period of rice earring and flowering, rice farmers are likely to suffer yield losses if the daily average temperature is less than 18-20℃ (for Japonica varieties) or 20-22℃ (for indicia varieties） and lasts more than three days. A long lasting low temperature heavily affects rice flowering, pollination, fertilization and normal process of grouting, resulting in a high rate of unfulfilled grain and a yield loss at all. So, to avoid yield less caused by CDW, farmers would irrigate more frequently if water is more available.

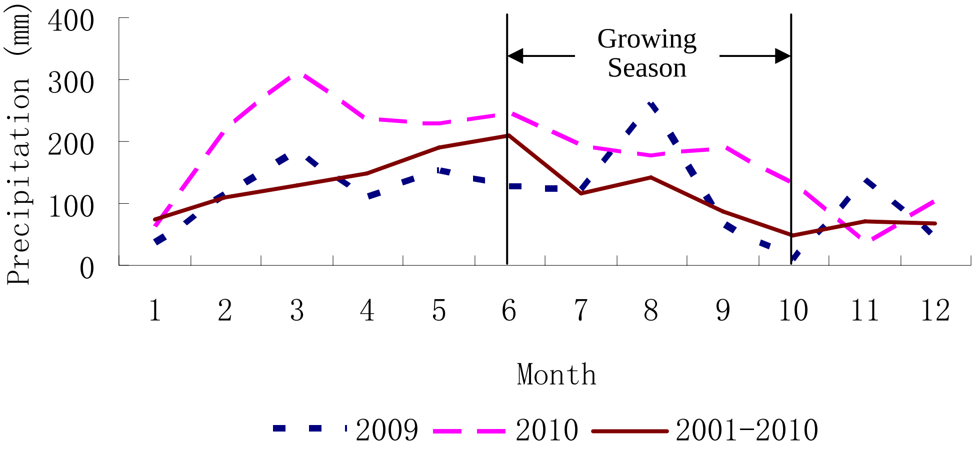
Table 3. Average levels of inputs for rice production by variety, 2009-2010

	2009			2010		
	DT	NDT	Diff	DT	NDT	Diff
Fertilizer (kg/ha)	305.6	314.0	8.4	347.2	344.2	-3.0
Zhejiang	237.6	244.8	7.2	267.7	264.0	-3.7
Guangxi	330.0	338.9	8.9	371.7	368.9	-2.8
Pesticide (kg/ha)	14.1	14.7	-0.6	21.5	21.6	-0.1
Zhejiang	12.8	14.2	-1.4	29.4	29.0	0.4
Guangxi	14.6	14.9	-0.3	19.1	19.3	-0.2
Labor (hour/ha)	442.7	474.4	31.7	525.1	554.1	29.0
Zhejiang	621.0	641.8	20.8	616.2	615.6	0.6
Guangxi	378.8	414.4	35.6	497.1	535.2	38.1
Irrigation (times)	1.96	3.01	-1.05***	3.67	4.13	-0.46*
Zhejiang	0.74	1.13	-0.39	3.58	3.89	-0.31
Guangxi	2.40	3.68	-1.28***	3.70	4.21	-0.51*

Source: All figures are calculated from authors' survey data.

Note: "***", "**", and "*" indicate that the differences are statistically significant at the levels of 1%, 5%, and 10%, respectively.

a. Zhejiang



b. Guangxi

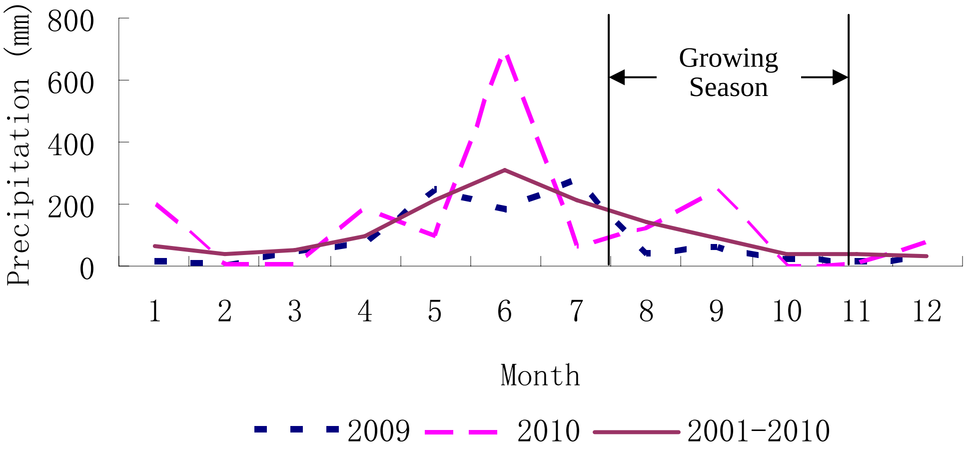


Figure 1 the precipitation by month at the sites in Zhejiang and Guangxi, China, 2009 and 2010.

Source: China's National Meteorological Information Center of CMA. (http://cdc.cma.gov.cn/).

The Table 4 shows that except for Zhejiang in 2009, there are significantly yield differences between DT rice and Non-DT rice varieties. In 2009, while there was no yield difference significantly between DT rice and Non-DT rice varieties in Zhejiang, DT rice yield was higher by than non-DT significantly in Guangxi.

Note that there were yield losses for DT rice variety due to the CDW hazard in early October 2010. Whether a CDW can affect rice production is depended on the starting date, the lasting duration and intensity of low temperature. In general, the earlier the starting date, or the longer the lasting duration, or the lower the temperature, the larger the effects are. In practice, rice farmers are always encouraged to plant rice as earlier as possible to avoid CDW. However, many farmers in some villages delayed their rice planting as their early cropping season rice could not be able to harvest on time. The CDW started earlier and lasting for one more month in 2010. As a result, DT rice variety yielded 590 kg per ha less than non-DT did significantly in 2010, implying that DT rice variety was affected by CDW much more than NDT one.

Table 4 Average yield by variety and province in 2009 and 2010

	2009 (kg/ha)			2010 (kg/ha)		
	DT Rice	Non-DT	Difference	DT Rice	Non-DT	Difference
Zhejiang	6182.5	6337.7	-155.2	5916.4	6754.8	-838.4***
	(518.1)	(651.4)	(135.0)	(902.5)	(837.4)	(205.2)
Guangxi	6023.6	5560.0	463.6***	5264.4	5777.5	-513.1***
	(980.8)	(1060.9)	(140.3)	(1276.0)	(848.5)	(141.7)
Average	6065.5	5765.3	300.2***	5417.8	6007.5	-589.7***
	(883.6)	(1026.9)	(112.9)	(1227.7)	(940.1)	(125.0)

Source: All figures are calculated from authors' survey data.
The numbers in the parentheses are the values of Std. Err..
"***" indicate that the difference is statistically significant at1% level.

Estimating irrigation effects

This paper relies on the data collected from the years in which crops did not suffer from drought. Compared to the gains that DT rice variety may bring on drought year (reduce yield loss or keep yield stable), DT rice variety's water-saving performance on regular year are a lot more significant.

The results of descriptive data analysis (row 10 in Table 3) show that the farmers irrigated less (1.1 times less in 2009and 0.5 times less in 2010) for DT rice variety as compared to non-DT one, a water saving of 34.9% in 2009 and 11.1% in 2010. As mentioned earlier, the year of 2009t was a normal year, while 2010 was a year when water were more available

Aside from DT variety effect, however, there may be other effects that are affecting the difference in irrigation between DT and non-DT rice. So a multivariate regression analysis is needed to determine the net impact of the adoption of DT varieties on irrigation water use at farm level. In order to control for the unobservable elements that could be affecting the results from descriptive data analysis, the following equation was used in our regression analysis:

Irrigation Times = f (DT Variety Effect, Year Effect, Village Effects, Unobservable Elements)

In the equation above, the village effects were included as that within village the farmers were randomly selected. Note that some elements were fixed in the regressions, such as characteristics of producer (gender, age and education), farm (size and assets), and plot (topographies and soil quality). In order to measure independent variables' effect on irrigation water, we used OLS Fixed-effects Model to estimate the effects separately for 2009, 2010, and 2009-2010 as a whole

To asses the impacts of DT rice variety on water use, we firstly run the irrigation regressions by simply using DT variety as only one independent variable (the Models 1 & 3 in Table 5). The regression estimates show that DT rice variety used 1.05 and 0.46 times less irrigation water than non-DT one in 2009 and 2010, respectively. Considering that the effects of DT variety on irrigation would be different as irrigation infrastructures vary across regions, the interaction of DT variety with village dummy was introduced into the irrigation regressions (the Models 2 & 4 in Table 5). Note that we dropped the dummies of interaction of DT variety with village 12 and village 7 as irrigation and rice production were stable in 2009 and 2010, respectively. The regression estimates show that DT rice variety had significant effects on water use with 1-2 irrigation times les in most of the sample villages in 2009 (the Models 2 in Table 5). It was found that DT rice had a significant effect on water use with 1.2 irrigation times less in 2010 as compared to non-DT rice in Gencun (Village 3), a sample village with a good irrigation system, although it had no significant effects for other villages in 2010, a year with more availability of water (the Models 4 in Table 5).

However, when we run the irrigation regression for 2009-2010 as a whole, the regression estimates indicate that DT rice was irrigated 0.64 times more in 2010, as compared to that in 2009, a regular year (the Models 5 in Table 5). Moreover, DT rice variety had significant effects on water use with 1-2 irrigation times les in villages 3, 4, 6, 8 and 10 (the Models 5 in Table 5), .implying that the DT variety had significant and large effects on irrigation in the villages with good irrigation system.

Table 5. OLS fixed-effects regression of irrigation, China, 2009-2010

Independent Variable	2009		2010		2009-2010
	Model 1	Model 2	Model 3	Model 4	Model 5
DT	-1.05*** （-7.03）	0.00 (0.00)	-0.46*** （-4.1）	-0.16 （−0. 51）	-0.00 (-0.00)
DT*D2010					0.64*** (2.62)
Village1*DT		-0.00 (-0.00)		-0.40 （−0. 89）	-0.53 (-1.04)
Village2* DT				0.06 （0. 13）	-0.74 (-1.22)
Village3* DT		-1.35** （−2. 3）		-1.16*** （−2. 65）	-1.64*** (-3.21)
Village4* DT		-1.3** （−2. 22）		−0. 00 （−0. 00）	-1.05** (-2.06)
Village5* DT				0.16 （0. 37）	-0.64 (-1.06)
Village6* DT		-2.6*** （−4. 43）		-0.64 （−1. 49）	-2.02*** (-3.95)
Village7* DT					-0.80 (-1.31)
Village8* DT				-0.44 （−1. 02）	-1.24** (-2.05)
Village9* DT		-0.83 （−1. 39）			-0.83 (-1.48)
Village10* DT		-1.55*** （−2. 64）			-1.55*** (-2.81)
Village11* DT		-0.00 (-0.00)			0.00 (0.00)
Cons	3.01*** （28.49）	3.01*** （31. 76）	4.13*** （52.32）	4.13*** （53. 66）	3.59*** (57.94)
observations	288	288	306	306	594

Note: There were total 12 villages in the experimental survey, of which only 4 villages were selected in both years of 2009 and 2010. The numbers in the parentheses are the t values. "***", "**", and "*" indicate that the coefficients are statistically significant at the levels of 1%, 5%, and 10%, respectively.

Estimating yield effects

The results of descriptive data analysis (row 5 in Table 4) show that DT rice variety yielded 300 kg per ha more than non-DT did significantly, a gain of 5.2% in 2009. As mentioned earlier, there were yield losses for DT rice variety due to the CDW hazard in 2010. There was a net yield decrease of 590 for DT rice as compared to non-DT rice variety, a loss of 9.8% in 2010.

Aside from DT variety and CDW effects, however, there may be other effects that are confounding the yield difference between DT and non-DT rice. So a multivariate regression analysis is needed to determine the net impact of the adoption of DT varieties on farm-level yield. In order to control for the unobservable elements that could be affecting the results from descriptive data analysis, the following equation was sued in our regression analysis:

Yields = f (DT Variety Effect, Irrigation Effect, CDW Effect, Input Effects, Village Effects, Unobservable Elements)

In the equation above, the village effects were included as that within village the farmers were randomly selected. Note that some elements were fixed in the regressions, such as characteristics of producer (gender, age and education), farm (size and assets), and plot (topographies and soil quality). In order to measure independent variables' effect on production of rice, we used OLS Fixed-effects Model to estimate separately for 2009 and 2010.

The regression estimates on the effect of DT variety on rice yield indicate that DT rice has no net significant effect on yield in both years of 2009 and 2010(row 1 in Table 6). We are also interested in understanding other effects on yields. CDW had a big effect on DT rice yield with a loss of 1333 kg per ha as compared to non-DT rice in 2010. Among the main inputs, only pesticide use had significantly a marginal effect on rice production with a gain of yield 167 kg per ha in 2010, but no significant effect in 2009. Note that we dropped the dummies of interaction of DT variety with village 12 and village 7 as irrigation and rice production were stable in 2009 and 2010, respectively. In general, village effects of DT variety on yield were insignificant, excepted that DT rice had a significant positive effect in Village 6 and a negative effect in Village 1 in 2009, and a significant positive effect in Village 2 in 2010. These results suggested that there were no difference in yield between DT and non-DT varieties.

Table 6. OLS fixed-effects regression of yield, China, 2009-2010

Independent Variable	2009 (Model 1)		2010 (Model 2)	
	Coefficient	t values	Coefficient	t values
DT	200.72	0.74	119.50	0.47
DT*IRRI	-73.55	-1.34	-59.44	-1.38
DT*D_{CDW}			-1333.00***	-3.96
Irrigation (times)	-21.98	-0.50	-42.33	-0.69
Fertilizer (kg/ha)	0.73	0.61	0.40	0.15
Labor (hour /ha)	0.48	0.51	0.17	0.24
Pesticide (kg/ha)	-17.16	-0.93	167.05***	3.60
Village1*DT	-570.73*	-1.77	-430.72	-1.24
Village2*DT			-1141.88***	-3.54
Village3*DT	446.62	1.48	494.64	1.52
Village4*DT	372.32	1.23	134.47	0.41
Village5*DT			152.73	0.45
Village6*DT	1178.58***	3.60		
Village7*DT				
Village8*DT			-490.58	-1.48
Village9*DT	-39.11	-0.13		
Village10*DT	0.26	0.00		
Village11*DT	385.49	1.19		
Cons	5629.16***	14.80	2349.68*	1.86
Observations	288		306	

Note: There were total 12 villages in the experimental survey, of which only 4 villages (Village 1, Village 3, Village 4 and Village 6) were selected in both years of 2009 and 2010. Fertilizer is measured by the contents of pure N-P-K. The numbers in the parentheses are the t values. "***", "**", and "*" indicate that the coefficients are statistically significant at the levels of 1%, 5%, and 10%, respectively.

V. Conclusion

The results from the regressions on the effects of DT rice variety adopted by the sample farmers on water use and yield levels imply that DT variety is a water-saving and high-yielding type. The estimates of the regression on irrigation indicate that the rice farmers gave less irrigation to DT variety as compared to non-DT variety, saving about 30-40% of water over non-DT variety, especially in the sample villages in Guangxi Province.

As there was no drought in the years when the experimental trials were conduced, one cannot generalize the potential yield advantage of DT variety over non-DT variety in drought years. The estimates of the regression on yield, however, indicate that there were no significant difference in yield between DT rice and non-DT rice. This result implies that DT and non-DT varieties as high-yielding one have the same production ability even in normal year or year of more water available. In other words, DT rice variety in China yielded as much as existing high-yielding varieties under normal or high rainfall conditions.

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