Agricultural Water Savings Possible through SRI for Future Water Management in Sichuan, China

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1. General information on SRI applications in China

1.1 Brief review of the spread of SRI throughout China

The System of Rice Intensification (SRI) was developed in Madagascar and synthesized in the early 1980s and offers opportunities to researchers and farmers to expand their understanding of potentials already existing in the rice genome.

Prof. Yuan Long-ping, "the father of hybrid rice", validated SRI methods with his super-hybrid varieties in 2001, and hosted an international SRI conference at his research center in Sanya, China, in April 2002.

By 2004, the recommendations he was giving for use of hybrid rice included: 13-day seedlings, planted singly, in a square pattern of 30x30 cm, with reduced applications of water, and increased use of compost to improve soil fertility.

The most active institutions for SRI research have been the China National Rice Research Institute (CNRRI) in Hangzhou, Zhejiang province, and the Sichuan Academy of Agricultural Sciences (SAAS) in Chengdu. Both have collaborated closely with their respective Provincial Departments of Agriculture (PDAs) for SRI extension in these two provinces.

SRI spread has been proceeding throughout China, and the techniques for implementing its principles are somewhat different among provinces. The concepts and methods associated with SRI can be used with hybrid rice, with different varieties such as Japonica rice, and even with other crops such as wheat. In India, WWF and ICRISAT have collaborated in introducing Sustainable Sugarcane Initiative based on SRI experience for getting higher sugarcane yields with less inputs of water and fertilizer (www.assets.panda.org/downloads/ssi_manual.pdf)

1.2 Preliminary evaluations of SRI application in Sichuan

1.2.1 SRI is a promising methodology to increase rice yield

The average yield from hybrid rice in Sichuan Province with farmer's practice is about 8.5 t/ha. When SRI methods were first introduced, rice yield could be increased by 20%, and with a modified method of transplanting (oblong and triangle configurations), intended to suit Sichuan conditions better, the increase was still higher, approximately 55% (Table 1). These spacings used in modified SRI trials were considerably greater than the basic SRI recommendation of starting with 25x25cm spacing. With such modification, a substantial yield increase could be achieved from the set of SRI practices used.

Table 1. Yield response to different planting patterns in rice

Transplanting pattern	Yield (t/ha)	Compared to CK	
		+ t/ha	+ %
CK	8.65	--	--
SRI	10.42	1.77	20.4
Triangle	13.39	4.74	54.8

1.2.2 SRI promotes more vigorous growth in rice plants

With SRI methods, the rice plant phenotypes were improved from any given genotype. Leaf blades become bigger, especially the functional leaves (Table 2). Plant height and culm length become longer. The stem diameter of the 4th internode (from the top) was 0.49 cm for SRI, 12% more than for the control (CK). Hence, it was clear that SRI management resulted in very strong stems. Leaf area index (LAI) was also much higher with SRI methods compared to CK.

Table 2. Leaf blade size (cm) in response to application of SRI methods

Planting pattern	3rd leaf		2nd leaf		Flag leaf		Average	
	Length	Width	Length	Width	Length	Width	Length	Width
SRI	64.25	1.57	71.32	1.87	57.67	2.17	64.41	1.87
CK	56.07	1.43	62.03	1.57	48.67	2.01	55.56	1.67

1.2.3 SRI gives a higher yield with lower inputs, especially with water saving

SRI plants showed fewer insect problems and diseases and reduced seed requirements by 50-90%. During the rice-growing season, irrigation water was reduced by 25.6%. Both WUE (Water Use Efficiency) and IWUE (Irrigation Water Use Efficiency) were higher, by 54.2% and 90.0%, respectively, significantly reducing water consumption.

1.2.4 Limiting factors for original SRI in adoption

The number of foundation plants recommended with classic SRI practice has turned out to be fewer than most suitable for an ecosystem having the low solar radiation of Sichuan. Single plants in a square pattern with wide spacing do not produce sufficient panicles. Consequently, yield potential is limited. Farmers want to maximize the number of panicles/m^2, not panicles/plant. The triangular planting method appears to be a productive adaptation of SRI practices, increasing plant density by 50% while maintaining good exposure of individual plants to both sun and air.

It is hard to transplant young seedlings at 2-leaf age in multiple cropping systems. Traditionally older-aged seedlings (about 7-leaf age) are transplanted into fields after wheat is harvested. If very young rice seedlings are used, the sowing date has to be postponed, which leads some unexpected results such as late maturity, lower yield, and difficulties in field management.

SRI theory and practice recommends maximum reliance on organic fertilization of the soil to improve its structure, functioning and long-term fertility. However, in Sichuan the supply of biomass for organic fertilizers is often in short supply. Also, because of the popularity of reduced or zero tillage, local livestock populations are now decreasing in rural areas. Hence, farmers cannot get enough manure for organic fertilization, and there is not enough manpower for preparing and transporting vegetative biomass for compost. Accordingly, in Sichuan there is more utilization of inorganic fertilizers with the other SRI methods than generally proposed. Possibly still better results could be obtained with more use of organic soil amendments, but labor and biomass constraints are serious in the province.

The recommended practice of controlling weeds through mechanical weeding that also aerates the soil is also less applicable in Sichuan because of labor constraints. Herbicides can be used with other SRI methods, but there can be some loss of supporting benefits from soil biota. Recognizing local limitations, management measures such as for precise weeding and keeping the soil moist are more complex than with present practices.

1.3 Improved SRI methods for Sichuan

1.3.1 Use of tray nurseries to raise seedlings.

This way the seedling nursery is managed under upland conditions, with root systems not traumatized during transplanting. With SRI methods, seedlings are removed carefully from the nursery and are transported to, and are placed gently into, the main field within 15-30 minutes. This avoids a long time recovering from transplant shock, and leaf age can be extended to 5.5.

1.3.2 Transplanting density.

Yield differs according to the various transplant spacing. The best transplanting density under most Sichuan conditions has been found to be 5-5.5 hills/m^2 --15-18 plants/m^2. This is a density much lower than usually aimed for.

1.3.3 Triangle transplanting pattern.

Transplanting of 3 separated seedlings per hill in a triangular pattern with spacing of 7-10 cm between the plants produces more panicles/m^2 and greater panicle size, giving more 'edge effect' or ‘border effect’ throughout the whole main field.

1.3.4 Application of herbicide when needed.

Because of the wide spacing between plants and the higher soil fertility, there are more weeds with SRI than conventional cultivation, especially in zero-tillage fields. By combining herbicides and mulching measures, weeds can be reduced. This approach to weed control relies more on the soil biota for soil aeration than when a mechanical weeder is used.

1.3.5 Adding chemical fertilizers to promote plant growth.

The effect of organic fertilizer is slower than chemical fertilizers. Hence, chemical fertilizers are used in SRI to promote tillering during the productive tillering stage. The objective is to optimize the combination of organic and inorganic nutrient amendments.

1.3.6 Inhibiting tillering after the productive tillering stage.

The tillering ability of rice plants is very strong, and the panicle-to-tiller ratio is often less than 50% in SRI cultivation. Mid-season drainage is thus recommended for SRI fields to inhibit excessive tillering.

1.3.7 Making shallow furrows before transplanting in the zero-till fields.

This is required as the alternate wetting and drying (AWD) method is a good way for water management, and shallow furrows facilitate AWD by making in-field drainage better. This irrigation method is easy, resulting in the surface soil being aerated while some water is still remaining in the furrows.

1.4 SRI extension in Sichuan

Large-scale field demonstrations have been undertaken with modified SRI methods at different experiment sites. Extension has been guided by the Provincial Agricultural Extension Bureau.

SRI was become the province’s preferred technique since 2005, and it is now considered a principal technique for “high-yield rice creation” in Sichuan Province. The application area is expanding rapidly, and the provincial yield record for rice is being broken year after year. Rice grain yield reached 12.8 t/ha in Guanghan (2008), certified by the Provincial Department of Agriculture and national experts. This is the new record of super-high yield in Sichuan ecosystem.

By 2010, the SRI area in Sichuan Province had reached over 301,067 ha, starting from 1,133 ha in 2004. SRI methods are currently used in 123 of its 130 rice-growing counties. The average SRI yield has been 9.5 t/ha, representing an average increase of 1.8 t/ha over conventional rice cultivation in the province (Table 4).

Table 4. Extension of SRI in Sichuan province

Year	2004	2005	2006**	2007	2008	2009	2010
SRI area (ha)	1,133	7,267	57,400	117,267	204,467	252,467	301,067
SRI yield (kg/ha)	9,105	9,435	8,805	9,075	9,300	9,495	9,555
Conv. yield (kg/ha)	7,740	7,650	7,005	7,395	7,575	7,710	7,740
SRI increment (t/ha)*	1,365	1,785	1,800	1,680	1,725	1,785	1,815
SRI % increase in yield*	17.64	23.33	25.7	22.72	22.77	23.15	23.45
Grain increment (tons)	1,547	12,971	103,320	197,008	352,705	450,653	546,436
Input increment by SRI (RMB Yuan/ha)	834	969	736.5	771	900	1,020	1,200
Grain price (RMB Yuan/kg)	1.44	1.44	1.44	1.5	1.8	1.84	1.95
Additional net income attributable to SRI in Sichuan (million RMB Yuan)*	1.28	11.64	106.51	205.10	450.85	571.69	704.27

* Compared with the Sichuan provincial average for paddy yield and profitability
** Drought year: SRI yields were relatively better than with conventional methods
Source: Data from Sichuan Provincial Department of Agriculture.

The value of additional paddy yield per hectare using SRI methods in 2010 was worth USD 185 at current exchange rates, achieved with lower costs of production. For Sichuan province as a whole, the value of the additional paddy produced was over USD 100 million. For the period 2004-10, the total additional benefit of using SRI methods in Sichuan was almost USD 320 million at the current rate of exchange, accompanied by reduced costs and less requirement of water, as discussed next.

2. Agricultural water savings for rice

2.1 General information about Sichuan province

Sichuan is located in southwest China, with a longitude at 97°21′~108°31′E and a latitude at 26°03′~34°19′N. It covers 485,000 km^2, and the population is 88.6 million. The rainfall is about 1,000 mm annually, and water resources are about 3,040 m^3 per capita, which is higher than China's average. But in the central part of Sichuan (the industrial and agricultural regions), the water resources are less than 1,000 m^3 per capita.

The hilly regions in the Sichuan Basin have the most serious water shortage. There are 2.3 million hectares of arable land and a population of 51.2 million, accounting for 57.8% and 60.4%, respectively, of the whole province. But the water resources per capita here are 940 m^3, just 30.9% of the province's water resources, and less than 40% of the national average of 2,477 m^3.

Agriculture consumes 80% of the total water resources in Sichuan. Currently, the WUE of staple crops such as rice, maize, and wheat is about 0.9 kg/m^3.

2.2 Water-using characteristics in rice cultivation

2.2.1 **Development of irrigation and drainage systems to ensure good and sustainable harvests on the Chengdu Plain**

The Chengdu Plain is located in the western part of the Sichuan Basin. The plain covers an area of nearly 10,000 km^2. The Dujiangyan irrigation system, built over 2,000 years ago, enables irrigation automatically for the majority of the crop area. It has a subtropical climate, annual average temperatures of 15-18°C, annual accumulated temperature (= 10°C) of

4,500-5,700°C, annual precipitation of about 1,000 mm, and a non-frost period of 240-300 days. The thermal condition provides adequate heat for the rice-wheat rotational cropping system. But WUE is lower because of flood irrigation or string irrigation.

2.2.2 **Seasonal droughts are the main restricting factor in hilly areas**

Affected by the monsoon circulation, rainfall in Sichuan is concentrated in summer and fall, from June to September. Tt accounts for more than 70% of the total rainfall, and most comes as heavy rain. Seasonal droughts are quite frequent, due to the uneven distribution of precipitation during rice growth. Seasonal drought disasters such as withered rice seedlings or waiting for rainfall for transplanting occur every year.

2.2.3 Groundwater resources are abundant, but are seldom used directly in Sichuan

Agriculture relies almost entirely on surface water. Rice depends on permanent paddy field water storage in the hilly regions of southern Sichuan, where there are no reservoirs or irrigation projects, and the area is more than 0.370 million hectares, accounting for 18.7% of the province's rice-growing area.

2.3 Individual research on water saving for SRI

2.3.1 Dry seedbed nursery

With the dry rice seedling nursery method, the seedbed is established under upland conditions and kept dry during the nursery period. It has the following advantages: earliness (early sowing, emergence, and maturation), savings of resources (water, labor, and nursery bed area), high yield, high efficiency, and greater tolerance to coldness and drought. It increases rice yield by 5% in the high-yielding regions, and by over 10% in the low-yielding areas. It was first demonstrated in 1992, and became the most important agro-technique utilized by farmers after 1995 in the province.

Because the rainfall can be used directly in upland seedbed, more than 50% of the irrigation water is saved during the nursery stage (about 45d, ≥7 leaf age). And the seedling quality is much better than with the wet seedbed nursery.

Table 5. Water consumption for rice nursery

	Rainfall m^3/ha	Irrigation water m^3/ha	Total consumption m^3/ha	Compare to CK±	
				m^3	%
DS	315	95.1	410.1	484.1	54.14
WS (CK)	315	579.2	894.2	-32.27	-

DS: Dry seedbed; WS: Wet seedbed

Table 6 Seedling quality differences between the two nursery methods

	Emergence (%)	Seedling (%)	Height (cm)	Dry matter (g/seedling)	Dry/fresh (%)	No. of tillers (/seedling)	Recovery (days)
DS	92.6	89.2	29.98	0.63	24.42	4.36	0.5
CK	82.7	79.2	39.49	0.57	17.17	2.94	7.5

DS: Dry seedbed; WS: Wet seedbed

2.3.2 Mulch cultivation.

Studies on water-saving effects of wheat straw mulching in rice cultivation in seasonally drought-affected hilly regions were conducted in 2004-2006. The results indicated that adopting the method which included dry seedbed nursery usage, ploughing, hand transplanting of rice seedlings as the way to have alternating broad and narrow rows, and mulching with wheat straw into broad rows about 10 days later, could save 30% of water; increase grain yield by

5.88%; increase water productive efficiency by 0.52 kg.m^3; and increase irrigation water productive efficiency by 1.24 kg.m^3. The water-saving effect showed a positive correlation with the amount of wheat straw used.

This methodology, which conserves soil moisture at the same time it suppresses weeds, is giving very good results in hilly and mountainous areas where water is a limiting factor and where small farmers have the labor to manage the mulching.

Some farmers can also mulch with plastic film before transplanting rice. This can save still more water and reduce losses to drought. But plastic pollution can become a serious problem from this method.

Table 7. Comparison of irrigation water amounts (m^3 per ha) in different growth stages during the rice-growing season

Treatment	LP	T-SF	SF-B	B-FH	AFH
MBR	1,650.00	651.90	603.75	327.60	273.30
CK	1,650.00	844.80	1,085.10	1,629.30	912.60

Note: MBR: mulching of wheat straw into broad rows; CK: farmers' practice.
Effective rainfall was 2,585.1 m^3·hm^{-2}.
LP: Land preparation; T: transplanting; SF: sun field; B: booting; FH: full heading; AFH: after full heading. The same is as in the following tables.

Table 8. Comparison of water efficiency under different models

Treatment	Yield kg·hm^{-2}	Irrigation m^3·hm^{-2}	TWC m^3·hm^{-2}	WUE kg·m^{-3}	To CK± kg·m^{-3}	IWUE kg·m^{-3}	To CK± kg·m^{-3}
MBR	9,467.10	3,506.55	6,091.65	1.55	0.52	2.70	1.24
CK	8,941.65	6,121.80	8,706.90	1.03	-	1.46	

Note: TWC: total water consumption; WUE: water using efficiency; IWUE: irrigation water using efficiency. The same is as in the following tables.

2.3.3 Irrigation methods

There are so many methods for paddy rice irrigation, such as AI, aerobic irrigation, as recommended for SRI; AWD, alternative wetting and drying; SWD, shallow\wet\dry sequential management; and CF, continuous flooding, as is farmers' current practice.

The effects of water management and organic fertilization used with SRI practices on hybrid rice were conducted by the China National Rice Research Institute. The crop management practices employed generally followed the recommendations of the SRI method. The aim of the research was to learn how water management and organic fertilization together would affect crop outcomes. The water management factor was evaluated in terms of two options:

Aerobic irrigation (AI): intermittent applications with no standing water in the field during the vegetative growth stage; then continuous irrigation with shallow standing water (3 cm) during the reproductive stage; and finally draining of the field 7 days before harvest.

Continuous flooding (CF): maintenance of standing water (6 cm) on the field during the vegetative growth and ripening stages; with draining 7 days before harvest, as is currently done by farmers.

The fertilization applications were for same level of nitrogen (N) but supplied in different forms: 100% organic (F100), 50% organic/50% chemical (F50), and 25% organic/75% chemical (F25). The results indicated that a combination of organic and inorganic fertilization was optimal.

The highest yield was attained with treatment combination F50/AI, i.e., aerobic irrigation with equal proportions of organic and inorganic nutrient provision. With the same 50:50 fertilization and flooded irrigation (F50/CF), the grain yield was lowered by 10%.

With all fertilization treatments, the differences in yield between AI and CF were significant (P\0.01). Across the fertilization treatments, AI increased yield by 10.5–11.3% compared to CF. The basis for this yield difference was having more grains per panicle under all AI treatments (Table 9).

Table 9 Effects of irrigation methods and organic fertilization on grain yield and yield components

Treatment	Panicles (m-2)	1000-grain weight (g)	Grains panicle-1	Filled grains (%)	Yield (kg ha-1)	Harvest Index (HI)
F25/AI	223.7b	29.2	170.5	71.4	7,686.6b	0.4538
F25/CF	230.2ab	29.1	160	69.3	6,956.0d	0.427
F50/AI	230.0ab	29	173.9	70.5	8,094.2a	0.4767
F50/CF	237.5a	28.7	162.1	70.6	7,273.7c	0.5083
F100/AI	232.7ab	29.8	175.6	64.1	7,771.3b	0.4251
F100/CF	231.3ab	28.4	161.1	69.4	7,019.6d	0.4293
AI	228.8	29.3	173.3	68.7	7,850.7	0.4519
CF	233.0	28.7	161.1	69.8	7,083.1	0.4549

Different letters in the same column indicate a statistically significant difference (P\0.05)
AI = aerobic irrigation; CF = continuous flooding; F25 = 25% organic fertilization, 75% chemical fertilization; F50 = 50% organic fertilization, 50% chemical fertilization; F100 = 100% organic fertilization

The interaction of different fertilizer treatments and watering methods may have contributed to the increase in water productivity as the experimental results showed AI increasing total WUE and IWUE, compared to CF, under all three organic fertilization treatments (Table 10). With the lower proportion of organic fertilization (F25), AI increased WUE by 43–44%, and IWUE by 78–79%, compared with CF.

Table 10 Effect of organic matter treatments and irrigation method on water productivity (paddy produced per m^3 water)

Fertilizer	Irrigation water ($m^3\ ha^{-1}$)		Available rainfall ($m^3\ ha^{-1}$)		WUE ($kg\ m^{-3}$)		IWUE ($kg\ m^{-3}$)	
	AI	CF	AI	CF	AI	CF	AI	CF
F25	4,726.5	7,606.5	5,110.5	5,110.5	0.7814	0.5470	1.6236	0.9145
F50	4,726.5	7,606.5	5,110.5	5,110.5	0.8228	0.5720	1.7125	0.9562
F100	4,726.5	7,606.5	5,110.5	5,110.5	0.7900	0.5520	1.6442	0.9228
Mean					0.7981	0.5570	1.6601	0.9312

F25 = 25% organic, F50 = 50% organic, F100 = 100% organic, AI = aerobic irrigation, CF = continuous flooding

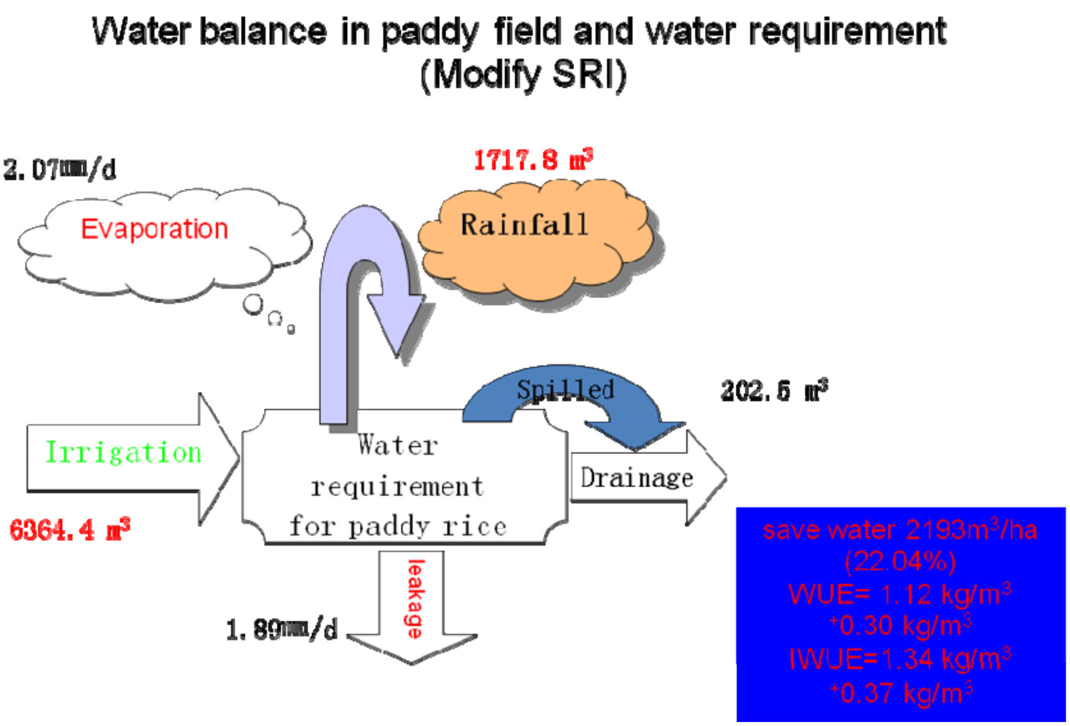
2.3.4. Impact of water-saving techniques and demonstrations in Sichuan

SRI has shown consistent water-saving effects coupled with a higher grain yield. However, it should be noted that SRI fields have to be irrigated more frequently than current farmer's fields, probably due to higher temperatures and evaporation during the rice-growing season. Applying water more carefully in smaller amounts does require more management effort, and this may discourage adoption by some farmers.

So we had to modify some ideals according to the local ecosystem and traditional methods of operation; and to simplify the techniques for farmers demonstration. The technical approach includes tillage, paddy preparation, nursery usage, and water and fertilizer management during the rice-growing period. Significant quantities of irrigation water have been saved in Sichuan province.

Traditional water consumption for rice cultivation in paddy fields was 9,795.2 m^3/ha, with 8,279.85 m^3/ha of this being irrigation water. The average evaporation rate was calculated as 2.07 mm/d, and the leakage rate was 1.89 mm/d. Resulting water productivity was 0.82 kg/m^3, and the irrigation water use efficiency was 0.97 kg/m^3.

The modified water-saving techniques with SRI practices increase rice yield by 0.49 t/ha compared to traditional techniques. SRI can save 2,193 m^3/ha of water (22%) during the rice-growing season, with irrigation water reduced by 1,933.5 m^3/ha (23%). Water productivity was 1.12 kg/m^3, with an increase of 0.30 kg/m^3 (36%), and irrigation water use efficiency was 1.34 kg/m^3, an increase of 0.37 kg/m^3 (38%).



3. Future prospects of water management in Sichuan province and China

Rice is the world's most important food crop and a major staple food for more than a third of the world's population. China's 31.7 million hectares of rice fields, which accounts for about 20% of the world's rice production area, produces about 35% of its total rice output. Rice production consumes large quantities of irrigation water, up to about 90% of the total water for all crops. However, fresh water for irrigation is becoming scarce because of increasing competition from urban, industrial, and environmental factors.

Water resource limitations threaten the sustainability of irrigated rice systems in many countries. Rice offers great potential for saving irrigation water because its physiological water requirement (4500 m^3 water/ha) is much less than what is currently considered to be needed and what is currently applied. Water-saving rice cultivation methods that can offer greater water productivity are urgently needed to keep up with future food demands, while they are at the same time important for ensuring the future viability of rice production systems.

3.1 Future trends in crop cultivation

As society has progressed, the structure of the rural labor force has gone through various changes and has reduced the labor available for agriculture. To promote sustainable development in agriculture, China is left with no other choice but to simplify the cultivation process and lighten the workload.

The techniques include mechanical direct-seeding for rice, no-tillage cultivation for crops, mechanical seedling transplantation, precise surface seeding, and mulching straw for wheat, and rice straw mulching with zero-tillage for potatoes. These are being extended in the Chengdu Plain in recent years. Direct sowing of rice and mid-season rice + ratooning rice will be popular in the future, but some agronomic questions still need to be answered.

At the same time, improved agricultural machinery must be introduced for the sowing, transplanting, and harvesting stages of crops for better management.

SRI is not a fixed technology, but rather a set of ideas for creating a more beneficial growing environment for rice plants. As such, there should be continuing variations and evaluations by researchers, and also we should expect farmers to further modify and improve this system.

3.2 Key research subjects for water saving in rice cultivation

3.2.1 Water balance in paddy fields and water requirements in different ecosystems.

According to the results, the size of the area for growing rice must be based on scientific knowledge and balanced consideration of the following factors: regional ecological conditions, cropping systems, natural rainfall, available irrigation resources, and so on.

3.2.2 Varieties for drought tolerance and screening methods.

There is a considerable difference among varieties of rice regarding to their drought tolerance, which deserves to be measured and documented by more studies. This can help researchers to identify varieties which can be suitable in arid areas or areas with more uncertain water availability. At the same time, drought tolerance is affected by the environment above and below-ground of the rice plants, as well as by genotype. So interactions between management and variety should be systematically assessed.

3.2.3 Sensitive growth stages for water stress and their influence.

Limited water resources to be allocated for use during rice's most sensitive growth stages. Natural rainfall needs to be used as efficiently as possible, and the water demands for rice growing should be reduced as much as possible.

3.3.4 Engineering approach for saving water.

Increased water conservation projects in hilly regions should be pursued, along with reductions in water losses in irrigation channel systems; and the appropriate use of groundwater warrants systematic development.

To realize these objectives, China needs to cooperate with national and international research teams working on similar issues.

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