Impact of Reclaimed Water Irrigation on Rice Yields and Quality

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Abstract: Poultry and livestock farming wastewater is one of the main sources of agricultural non-point source pollution. Using reclaimed poultry and livestock farming wastewater for rice irrigation can not only provide nutrition for rice, but also reduce agricultural water consumption, and also further control non-point source pollution through the self-purification of rice ecosystem. It has been considered to be environmentally friendly and reliable for poultry and livestock farming wastewater treatment. However, the effect of reclaimed water irrigation on rice yield and quality is still unclear. In order to explore the effects of reclaimed water irrigation on rice yield and quality, we conducted a rice reclaimed irrigation experiment in the Erhai lake basin in 2017. The rice yield and quality were compared among different irrigation modes, different irrigation water quality and different fertilization schemes of reclaimed water. The results showed that the yield of W1F2, under intermittent irrigation with reclaimed water, was the highest, reaching 11.7t/hm^2. The differences of rice yield and its components between different irrigation and fertilization methods were not significant. The yield and its components of rice under different irrigation and fertilization treatments were not significant. In terms of yield, the intermittent irrigation was 7.6% higher than that of flood irrigation. The amount of fertilizer applied by intermittent irrigation of reclaimed water was 7.0% less than that of clear water, and the yield increased by 3.5%. Correspondingly, the amount of fertilization of flood irrigation of reclaimed water is equivalent to that of clear water, which increases yield by 1.9%. In summary, the effect of reclaimed water irrigation on yield increase is obvious. There were significant differences in brown rice rate and chalky grain rate between different irrigation modes, which showed that the brown rice rate of intermittently irrigated rice was 0.7% smaller than that of flooded rice, and the white grain of intermittently irrigated rice was 45% larger than that of flooded irrigation. Intermittent irrigation has an adverse effect on the processing quality and appearance quality of rice. There were significant differences in brown rice rate, whole milled rice rate, gel consistency and depletion value under different irrigation water quality. The results showed that the brown rice rate and the depletion value of reclaimed water irrigation were smaller than those of clear water, and the whole milled rice rate and gel consistency were larger than that of clear water. Regularity, reclaimed water irrigated rice processing quality and cooking taste quality is better. In terms of nutritional quality of rice, the crude protein content in flooding treatment was 4.2% higher than that in intermittent irrigation, and the irrigation treatment of reclaimed water was 13.8% higher than that in clear water irrigation.

1 INTRODUCTION

As a major livestock producer, China is now seeing its natural environment threatened by pollution from domesticated animal feces, which are generated in large amounts and distributed extensively (Zou 2016). Water pollution basically came from agricultural nonpoint source (NPS) pollution, in which the discharges of chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP) stood at 13.241 million tons, 2.705 million tons, and 28.5 tons, respectively, with 95.9%, 37.9% and 56.3% of these discharges from run-off livestock and poultry waste, according to the country's *First National Census of Pollution Sources* (Committee for Compiling Data of the First National Pollution Source Census Pollution 2011). It is projected that the amount of domesticated animal waste produced in China will surpass 410 million tons annually by 2030 (Zhang 2006). However, the increasingly intensive livestock farming industry (Lu 2015) means its gradual separation from crop production, and compared to conventional farming practices, the reduction of livestock and poultry waste as cropland fertilizers is particularly apparent, with 36% of all animal feces left unused (Huang 2006). This engenders a waste of resources and contaminates the environment (Martinez 2009, Zhang 2004, Chen 2010). Much substantial research on reusing domesticated animal feces, from the means and techniques of resource utilization to the available feces and the evaluation of their potential as a source of energy to the ways of fecal management and control, has been carried out worldwide (Cheng 2009, Innes 2000, Vukina 2010, Tian 2012, Zhang 2012,

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Chen,2016). However, there are few studies on animal farming techniques and the effective use of livestock wastewater from processing fecal materials. Anaerobic processes, coupled with other techniques, turn the wastewater into reclaimed water with high levels of nitrogen and phosphorus, among other nutrients. Such recycled water for irrigation provides essential nutrients for crops like rice, lowers agricultural water use, and, more importantly, curbs NPS pollution as ecosystems purify themselves. This, therefore, is regarded as eco-friendly and sustainable in treating livestock wastewater.

Nonetheless, how rice yields and quality will be affected by reclaimed water remains unclear. With nitrogen and phosphorus, reclaimed water can be reckoned as a mixture of fresh water and fertilizers when it comes to irrigation, yet studies found that fertilization frequency makes a difference to rice yields (Mei 2016, Bai 2016, Chen 2015, Ren 1997). And the provision of nutrients through reclaimed water irrigation is not the same as multiple fertilizer applications, meaning the effect of the irrigation method on the yield of rice invites further research. Moreover, the public has grown more conscious of rice quality due to an improvement in living standards. Researchers have investigated how rice quality is influenced by such factors as light exposure, temperatures during the grain-filling period, varied planting methods, and different approaches to watering and fertilization (Meng 1997, Huo 2012, Haefele 2008, Pan 2009, Wang 2015, Li 1998). But studies about the effect of reclaimed water on rice quality are scarcely in the public eye. As such, the paper is designed to identify how reclaimed water irrigation makes an impact on rice yields and quality by examining diverse recycled water irrigation modes, the difference with or without such irrigation, and varied fertigation systems.

2 MATERIALS AND METHODOLOGY

2.1 Research Area Description

The research was conducted at the Dali Environmental Monitoring Station (100°07’4’’E, 25°49’5’’N, an elevation of 1975m) under the Ministry of Agriculture and Rural Affairs (MARA) in southern China’s Yunnan Province in 2017. The annual average temperature of the Station is 15.1℃. The coldest month (January) sees its temperature at 8.5℃ on average and dipping down to minus 3.7℃, whereas the hottest month is July, with the average and maximum temperatures of 20.3℃ and 28.9℃. The yearly rainfall of the area averages 1078.9 mm. The soil bulk density is 1.14 g/cm^3; the volumetric water content (VWC) and gravimetric water content (GWC) are 55% and 48.2%, respectively; the volumetric and gravimetric field capacities stand at 47.2% and 41.5%, respectively. The soil is silty, with its particles averaging 19.26 um in diameter.

2.2 Research Design

The research was simultaneously carried out on plots and microplots, which represent areas of 54m^2 (12m long and 4.5m wide) and 12m^2 (4m long and 3m wide), respectively. Given the limited access to reclaimed water and its unknown effect on rice fields, reclaimed water was used to irrigate nine microplots and fresh water to six plots. To avoid water leakage and seepage, all microplots and plots were separated from each other by ridges wrapped in plastic films, which were 0.4m high and wide. The sampled rice variety was 03-44.

In the research, we introduced two irrigation systems, namely flood irrigation (W0) and intermittent irrigation (W1), whose water layer specifics are illustrated in Table 1. And three fertilization approaches were put in place: F1 (end-to-end freshwater irrigation coupled with the application of all chemical fertilizers), F2 (reclaimed water irrigation from tillering through stem elongation to booting, along with the application of partial chemical fertilizers), and F3 (reclaimed water irrigation from seedling establishment through tillering to stem elongation and booting, together with the application of partial chemical fertilizers). Five fertigation models, namely W0F1, W1F1, W0F2, W1F2, and W0F3, were developed, with each repeated three times.

All fertigation processes saw 193 kg of nitrogen fertilizer, or urea in our case, used per square hectometer, with 70% for tillering and 30% for booting. The application rates of phosphorus (P_2O_5) and potassium (P_2O_5) fertilizers, or calcium phosphate and potassium sulfate fertilizers, respectively, were both 62.5 kg/hm². For the F1 approach, fresh water was used for irrigation, chemical fertilizers were applied, and phosphorus and potassium fertilizers were all applied in rice fields at the tillering stage. For the F2 and F3 approaches, nitrogen and phosphorus fertilizers were injected through reclaimed water irrigation, and potassium fertilizers were replaced by chemical fertilizers that also acted as supplements to nitrogen and phosphorus, with all the supplemental phosphorus fertilizers applied in rice fields at the tillering stage. The reclaimed water was converted from the wastewater from the Environmental Monitoring Station’s livestock farms. And the nitrogen and phosphorus contents of the recycled water were 30 mg/L and 2 mg/L, respectively, as had been measured on the site previously, and the freshwater came from the Station’s ditch, whose water is from streams at the foot of Mount Cangshan, Yunnan.

Rainfall uncertainty makes it impossible to determine how much reclaimed water is required to irrigate rice at different growth stages, let alone calculate the quantity of the nitrogen and phosphorus contents the water can inject and the needed supplemental fertilizers. Yet the fertilization regime should be established prior to rice cultivation. On the basis of rainfall statistics in the rice growing season of 1993, the normal flow year, and built on the baseline nitrogen and phosphorus concentrations of reclaimed water (30 mg/L and 2 mg/L, respectively), we measured the quantity of the nitrogen and phosphorus contents the recycled water could inject and of the needed supplemental fertilizers. And the proposed fertilization regime is displayed in Table 2. Given the difference in rainfall data between 2017’s rice growing season and 1993’s, the designed fertilizing reality diverged from the actual one, which is shown in Table 3.

As illustrated in Table 2 and Table 3, we established that across the W0F1, W1F1, and W0F3 fertigation models, the actual and designed fertilizer application rates were equal, at 193 kg/hm^2. It is known that a comparison between different irrigation modes and between varied water types needs to be founded on the same application rate. Hence, we compared W0F1 and W1F1 to see the difference in rice yields and quality across varied irrigation systems and looked into how rice yields and quality were affected by both freshwater and reclaimed water irrigation by studying W0F1 and W0F3. At the same time, with a focus on the W0F2, W0F3, and W1F2 treatments, we investigated how reclaimed water fertilization regimes could vary. And the W0F3 and W0F2 models were a testimony to the pros and cons of irrigating rice fields at the seedling establishment stage.

Table 1 Field water layer control standards under different irrigation modes mm

Irrigation mode	Aquifer control	Reproductive stage						
		Rejuvenation period	Prophase of tillering	Late tillering stage	Jointing booting stage	Heading and flowering stage	Milk ripening period	Yellow ripening stage
W0 (flooding irrigation)	Lower limit before irrigation	10	10	10	10	10	10	Abscission
	Upper limit after irrigation	30	50	Sun the field	50	50	30	
	Limit after rain	40	80		80	80	50	
W1 (intermittent irrigation)	Lower limit before irrigation	10	80% saturated moisture content of soil	80% saturated moisture content of soil	80% saturated moisture content of soil	80% saturated moisture content of soil	80% saturated moisture content of soil	Abscission
	Upper limit after irrigation	30	40	Sun the field	40	40	30	
	Limit after rain	40	60		60	60	40	
	Dehydration days	0	5	5	5	5	5	

Table 2 Design of Fertilization System for Different Treatment

treatment	Growth stage of reclaimed water irrigation	Reclaimed water irrigation amount mm	Fertilizer brought in by reclaimed water irrigation kg/hm²		Fertilizer application standard kg/hm2		Total kg/hm^2	
			N	P_2O_5	N	P_2O_5	N	P_2O_5
W0F1	Tillering stage	0	0	0	135.1	62.5	193	62.5
	Jointing booting stage	0	0	0	57.9	0		
W1F1	Tillering stage	0	0	0	135.1	62.5	193	62.5
	Jointing booting stage	0	0	0	57.9	0		
W0F2	Tillering stage	133.5	40	6.14	95.1	53.41	193	62.5
	Jointing booting stage	66.7	20	2.95	37.9	0		
W1F2	Tillering stage	80	24	3.64	111.1	53.4	193	62.5
	Jointing booting stage	120	36	5.46	21.9	0		
W0F3	Rejuvenation period	66.7	20	2.95	0	0	193	62.5
	Tillering stage	133.5	40	6.14	75.1	50.46		
	Jointing booting stage	66.7	20	2.95	37.9	0		

Table 3 Actual fertilization system for different reclaimed water irrigation treatment

treatment	Reproductive stage	Date of filling reclaimed water	Reclaimed water irrigation amount mm	Fertilizer brought in by reclaimed water irrigation kg/hm²		Fertilization date	Fertilization amount kg/hm²		Total kg/hm²	
				N	P_2O_5		N	P_2O_5	N	P_2O_5
W0F1	Tillering stage					6/13	135	62.5	193	62.5
	Jointing booting stage					8/3	58			
W1F1	Tillering stage					6/13	135	62.5	193	62.5
	Jointing booting stage					8/3	58			
W0F2	Tillering stage	6/8	50	15	2.27	6/13	95.1	44.29	208.6	62.81
		6/17	50	15	2.27					
		7/7	52.3	15.69	2.38					
	Jointing booting stage	7/13	50	15	2.27	8/3	37.9	0		
		8/9	50	15	2.27					
W1F2	Tillering stage	6/8	45	13.5	2.05	6/13	111.1	53.40	179.5	60.45
		6/19	50	15	2.27					
		7/7	60	18	2.73					
	Jointing booting stage					8/3	21.9	0		

W0F3	Rejuvenation period	6/2	35	10.5	1.59	6/13	75.1	50.36	192.38	62.40
	Tillering stage	6/8	45	13.5	2.05					
		6/17	45	13.5	2.05					
		7/5	50	15	2.27					
	Jointing booting stage	7/13	45	13.5	2.05	8/3	37.9	0		
		8/9	44.6	13.38	2.03					

2.3 Measurement Items and Methods

The measurement of the rice yield of each plot was based on three one-square-meter diagonal quadrats, while the rice yield of each microplot was measured in real terms upon the removal of border row factors. We selected 30 holes in each plot and five holes in each microplot for evaluating seeds from the perspectives of panicle length, the number of kernels per spike, seed setting rate, and the 1,000-kernel weight. After three months of air-seasoning, measurement was undertaken on rice in multiple ways, such as the unpolished, polished, and head rice ratios, grain length, grain width, length-width ratio, chalky kernel percentage, gelatinization temperature, gel consistency, and crude protein content. The measurement followed China’s national standard on high-quality rice GB/T17891-1999 and the standard on rice grain quality determination NY147-88, formulated in 1988 by the Ministry of Agriculture (now “MARA”). The amount of crude protein content in this research was determined as the amount of nitrogen in polished rice multiplied by the conversion factor of 5.95. The unpolished rice rate is the percentage of the weight of the whole grain rice with the hull removed to that of paddy rice samples. The polished rice rate represents the percentage of the weight of the milled rice to that of paddy rice samples. The head rice rate suggests the percentage of the weight of the whole grains of milled rice to that of paddy rice samples. And the unpolished, polished, and head rice ratios were calculated using Equations (1), (2), and (3), respectively.

$$\text{Unpolished Rice Rate (\%)} = \frac{\text{Unpolished Rice Weight } (g)}{\text{Sampled Paddy Rice Weight } (g)} \times 100\% \tag{1}$$

$$\text{Polished Rice Rate (\%)} = \frac{\text{Polished Rice Weight } (g)}{\text{Sampled Paddy Rice Weight } (g)} \times 100\% \tag{2}$$

$$\text{Head Rice Rate (\%)} = \frac{\text{Head Rice Weight } (g)}{\text{Sampled Paddy Rice Weight } (g)} \times 100 \tag{3}$$

3 RESULTS AND ANALYSIS

3.1 Rice Yield and Its Composition under Diverse Fertigation Models

Table 4 shows the rice yield and its contributing factors under different fertigation models. Overall, these models made little difference to the yield of rice and its composition. Compared to flood irrigation, intermittent irrigation was a little behind in panicle length, effective spike, and the 1,000-kernel weight, but gained an edge over the number of kernels per spike and seed setting rate, resulting in a 7.6% yield increase. This echoed the research results previously achieved, which have established that intermittent irrigation facilitates rice production as it helps to grow robust rice roots, prevents premature aging, and increases the leaf area index at the later rice growth stages(Lu1997,Sun2010).

Given a certain range of nitrogen fertilizer application levels, rice yields rise with an increasing nitrogen fertilizer application rate(Yi2005, Shao2015, Zhou2008). But in our study, results from reclaimed water irrigation differed from those from irrigation with fresh water. The W1F2 fertigation model consumed the nitrogen fertilizer 7% less than the W1F1 treatment did, but yielded 3.5% higher; with the nitrogen fertilizer rate unchanged, the yield under the W0F3 model was 1.9% higher than W0F1. This was associated with that reclaimed water irrigation overtook freshwater irrigation in the number of kernels per spike, the seed setting rate, and the 1,000-kernel weight. In contrast to the application of chemical fertilizers, reclaimed water irrigation contributes to an increase in the soil organic matter and nutrients and an improvement in soil microbial activity and physicochemical properties (Peña 2014, Li 2006, Nan 2009), ensuring an enabling climate for rice cultivation. Beyond that, reclaimed water irrigation makes possible higher rice production given its capabilities to boost the 1,000-kernel weight and seed setting rate and instill more potassium that improves lodging resistance (Lu 1990). The fact that the W0F3 fertigation model consumed 7.8% fewer fertilizers but yielded 3.9% higher than the W0F2 treatment indicated that reclaimed water irrigation at the seedling establishment stage helps increase rice production.

Table 4 Yield and its components under different irrigation and fertilization treatments

treatment	Spike length cm	Effective panicle	Number of grains per ear	Total grains	Seed setting rate	Planting density Ten thousand acupoint t/hm^2	1000 grain weight g	Theoretical output t/hm^2	Actual output t/hm^2
W0F1	16.1a	11.4a	99.69a	110.2a	0.891a	38.46a	23.63a	10.30a	10.5a
W0F2	14.8a	11.3a	100.4a	112.0a	0.902a	38.46a	23.705a	10.33a	10.4a
W0F3	15.8a	11.2a	103.44a	113.7a	0.910a	38.46a	23.931a	10.62a	10.7 a
W1F1	15.2a	11.2a	99.75a	110.8a	0.900a	38.46a	23.262a	10.55a	11.3a

W1F2	16.1a	11.2a	106.15a	117.59a	0.904a	38.46a	23.544a	10.74a	11.7a

Note: different letters in the same column indicate significant at the level of 0.05

3.2 Rice Milling Quality under Diverse Fertigation Models

Rice milling quality suggests the status of the paddy rice upon milling and is measured by the unpolished, polished, and head rice rates, which, under different fertigation models, were calculated using Equations (1), (2), and (3), respectively, as shown in Table 5. The data implied that the unpolished, polished, and head rice rates wildly varied with different irrigation systems. Specifically, compared to flood irrigation, intermittent irrigation lowered the unpolished, polished, and head rice rates by 0.7%, 1.3%, and 3.5%, respectively. Research findings by Chuangen Lyu et al. suggested that the 1,000-kernel weight determines the unpolished rice rate and has a significant positive correlation with the polished rice rate when resistance to abrasive milling remains unchanged (Cai 2002). As was mentioned above, the 1,000-kernel weight was lower under the W1F1 fertigation model than under the W0F1 one, resulting in a decline in the unpolished, polished, and head rice rates. Different fertilization approaches made an insignificant difference to these rice rates; apart from the unpolished rice rate, the polished and head rice ratios were barely affected by the proposed fertigation models.

Regarding the impact of reclaimed water and freshwater irrigation (as in W0F3 and W0F1, respectively) on rice milling quality, only the unpolished rice rate registered a significant difference. The law that reclaimed water irrigation contributes to a lower unpolished-rice rate and greater polished- and head-rice rates than freshwater irrigation does still holds. This, once again, proved the aforementioned notion that irrigation with reclaimed water means applying extra potassium fertilizers and increasing the 1,000-kernel weight to a certain extent.

A comparison among fertilization regimes with recycled water (as in W0F2, W0F3, and W1F2) found no significant difference in the unpolished, polished, and head rice ratios. Under the W0F3 model, these ratios were greater than the other two treatments. This indicated that reclaimed water irrigation at the seedling establishment stage would push up the unpolished, polished, and head rice rates with an increase in irrigation frequency and the volume of irrigation water instead of having an adverse impact on rice milling quality.

Table 5 Processing quality of rice under different irrigation and fertilization treatments

Irrigation mode	Fertilization method	Brown rice rate	Milled rice rate	Head rice rate
W0	F1	（84.1±0.12）%a	（76.6±0.09)%ab	(62.7±0.02)%ab
	F2	（83.8±0.12）%b	(76.9±0.09)%ab	(62.8±0.02)%ab
	F3	（83.8±0.12）%b	(77.1±0.09)%a	(63.5±0.02)%a
W1	F1	（83.5±0.12）%c	(75.6±0.09)%b	(60.5±0.02)%b
	F2	（83.7±0.12）%b	(76.1±0.09)%b	(61.0±0.02)%b
variance analysis	W	18.887**	7.41**	12.009**
	F	1.546	1.21	0.744
	W× F	6.955**	0.077	0.111

Note: different letters in the same column indicate significant at the level of 0.05

3.3 Rice Exterior Quality under Diverse Fertigation Models

Rice exterior quality determines the popularity of the rice among the public and holds the key to its value as a commodity. As is shown in Table 6, significant differences in exterior quality across the fertigation treatments found expression in the chalky kernel percentage and grain length, and the length-width ratios under these fertigation models differed insignificantly. With varied fertigation or fertilization approaches, only the chalky kernel percentage would change dramatically, and among other exterior quality indicators, only grain length could demonstrate the interplay between irrigation systems and fertilization approaches.

Among rice exterior quality indicators, only the chalky kernel percentage differed significantly between intermittent irrigation and flood irrigation, with chalkiness 45% higher under the former model than under the latter. The relevant academic literature documented that water stress at the grain-filling stage could slow down the accumulation of nutrients for rice kernels, thus increasing the chalky kernel percentage and worsening rice exterior quality (Liu 2011).

There was no significant difference concerning rice exterior quality indicators between reclaimed water and freshwater irrigation. But compared to freshwater irrigation, irrigation with recycled water could lower the chalky kernel percentage by 36.4%. With reclaimed water irrigation, rice exterior quality will improve, to a certain degree, for potassium is able to regulate root exudates. At the grain-filling stage, potassium levels have a significant positive correlation with chalkiness (Lu 2011). As such, a certain amount of potassium from reclaimed water during the grain-filling period could lower the chalky kernel percentage and thus improve the quality of the rice exterior.

On fertilization regimes, the chalky kernel percentage was significantly higher under the W1F1 fertigation model than under other models, among which W0F2 saw the smallest percentage of chalkiness.

Table 6 Appearance quality of rice under different irrigation and fertilization treatments

irrigation method	Fertilization method	length	width	Aspect ratio	Chalky grain rate
W0	F1	4.35±0.0289 ab	2.68±0.0619 a	1.62±0.0386 a	0.11±0.0159 b
	F2	4.35±0.0289 a	2.69±0.0619 a	1.62±0.0386 a	0.04±0.0159 b
	F3	4.29±0.0289 ab	2.64±0.0619 a	1.63±0.0386 a	0.07±0.0159 b
W1	F1	4.29±0.0289 a	2.63±0.0619 a	1.63±0.0386 a	0.16±0.0159 a
	F2	4.27±0.0289 b	2.64±0.0619 a	1.62±0.0386 a	0.07±0.0159 b
variance analysis	W	0.307	0.006	0.007	9.671**
	F	0.862	0.136	0.087	24.338**
	W × F	11.172**	1.502	0.025	1.075

Note: different letters in the same column indicate significant at the level of 0.05

3.4 Rice Cooking Quality under Diverse Fertigation Models

Cooking quality serves as a central trait in evaluating the overall quality of rice. As illustrated in Table 7, there was no significant difference in a gel consistency and gelatinization temperature between intermittent irrigation and flood irrigation. In value terms, intermittent irrigation was 2.3% higher in gel consistency than flood irrigation, but the alkali digestion value and gelatinization temperature remained unchanged across the two irrigation techniques.

Both reclaimed water and freshwater irrigation contributed to soft gel consistency, but its value was 16.3% higher under the former model than the latter. In contrast to freshwater irrigation, reclaimed water irrigation could take the alkali digestion value to a higher level while lowering the gelatinization temperature by about 4℃. It is believed that gelatinization temperature has an impact on the water absorption, expansion, and extension of rice grain. A lower gelatinization temperature helps improve rice quality as the cooking time, and the amount of water needed are both reduced (Wang 2016). Gel consistency, however, measures the softness of cooked rice, and rice varieties with soft gel consistency tend to cook more tenderly than their equivalents with medium or hard gel consistency (Lei 2007). That means reclaimed water irrigation can enhance rice cooking quality to a certain extent.

There was a significant difference concerning gel consistency and the alkali digestion level between the fresh-water-irrigated F1 mode and the F2 and F3 modes that employed reclaimed water irrigation. Under the W0F3 model, the gel consistency value stood at 74.4 mm, greater than other fertigation models. The alkali digestion value reached Level 6 in the approaches of F2 and F3, compared to Level 5 for F1.

Table 7 Edible quality of rice under different irrigation and fertilization treatments

treatment	Glue consistency mm	Gel consistency classification	Subtraction value classification	Gelatinization temperature℃
W0F1	64.0±3.543 b	Consistency of soft glue	5 b	70~74
W0F2	68.0±3.543 ab	Consistency of soft glue	6 a	<70
W0F3	74.4±3.543 a	Consistency of soft glue	6 a	<70
W1F1	65.5±3.543 b	Consistency of soft glue	5 b	70~74
W1F2	68.2±3.543 ab	Consistency of soft glue	6 a	<70

Note: different letters in the same column indicate significant at the level of 0.05

3.5 Rice Nutritional Quality under Diverse Fertigation Models

As an essential rice quality indicator, crude protein content is influenced more by the environment than by genetic factors (Xu 2007). Table 8 illustrates that across all fertigation models, crude protein content ranges from 6.9% to 8.2%, suggesting no significant difference.

With flood irrigation, crude protein content increased by 4.2% compared to intermittent irrigation, and reclaimed water could contribute 13.8% higher crude protein content than fresh water. That justified how the crude protein content of rice could be affected by both irrigation systems and fertilization approaches. And under W0F2 and W0F3 fertigation models, the crude protein levels were higher. Rice varieties with more than 9% protein content tend not to taste good, and the increase of crude protein content within a certain range is conducive to improving the nutritional quality of rice(Mi2011, Mo1994). Therefore, reclaimed water irrigation can enhance rice nutritional quality without remarkably affecting the taste.

Table 8 Crude protein content under different irrigation and fertilization treatments

treatment	W0F1	W0F2	W0F3	W1F1	W1F2
Crude protein content	7.2%±0.69% a	8.0%±0.69% a	8.2%±0.69% a	6.9%±0.69% a	7.2%±0.69 a

Note: different letters in the same column indicate significant at the level of 0.05

4 CONCLUSIONS

(1) Different fertigation models made no significant difference to rice yields and their contributing factors. Specifically, compared to flood irrigation, intermittent irrigation saw an increase in the number of kernels per spike and seed setting rate, and irrigating paddy rice with reclaimed water could also push up these figures, in contrast to freshwater irrigation. Moreover, intermittent and reclaimed water irrigation models gained an edge over rice yields, with the W1F2 fertigation model having the highest yield, at 11.7 t/hm^2. Rice yields were 3.9% higher with reclaimed water irrigated at the seedling establishment stage than without it.

(2) Irrigation systems were essential for the cooking and exterior quality of rice. There was a significant difference with regard to the unpolished rice rate and chalky kernel percentage between intermittent and flood irrigation models. Compared to flood irrigation, intermittent irrigation could bring down the unpolished rice rate while pushing up the chalky kernel percentage, leading to poor cooking and exterior quality.

(3) Varied fertilization approaches made a significant difference to nothing but the chalky kernel percentage, and the unpolished rice rate and chalky kernel percentage changed significantly under different fertigation models. In contrast to freshwater irrigation, reclaimed water irrigation, with a decreasing unpolished rice rate though, helped increase the polished and head rice rates and keep the chalky kernel percentage much lower. Furthermore, while inching up gel consistency, it brought the gelatinization temperature down and allowed crude protein content to rise to a proper extent, in a way that improved overall rice quality. Irrigation with reclaimed water at the seedling establishment stage had no impact on the exterior and cooking quality of rice, but could, to a certain degree, contribute to better milling quality than without it.

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ACKNOWLEDGEMENT

This research is supported by the Yunnan Provincial Science and Technology Department's Science and Technology Personnel Yunnan Project (YKK2019092733)

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