The Journal of Animal & Plant Sciences, 31(1): 2021, Page: 97-102
ISSN (print): 1018-7081; ISSN (online): 2309-8694

CONTROLLED-RELEASE FERTILIZER AFFECTS GROWTH AND YIELD OF *JAPONICA* RICE

P. Hou[1,2], L. Xue[1], S. He[1], Y. Zhou[3], G. Li[3], Y. Feng[1], L. Yang[1] and L. Xue[1,2*]

[1]Key Lab of Agro-Environment in Downstream of Yangtze Plain, Ministry of Agriculture and Rural Affairs, Institute of Agricultural Resources and Environment, Jiangsu Academy of Agricultural Sciences, Nanjing 210014, P. R. China
[2]School of the Environment and Safety Engineering, Jiangsu University, Zhenjiang, 212001, P. R. China
[3]College of Agronomy, Nanjing Agricultural University, Nanjing 210095, P. R. China
[*]Correspondence author's email: njxuelihong@gmail.com

ABSTRACT

Resin-blending controlled-release fertilizer (RBB) is more consistent with the nutrient requirement of rice; the appropriate application rate though was unclear. To optimize the application rate of RBB for *japonica* rice in Tai-Lake region (119°54′E, 31°17′N), China, the effects of different application rate of first time used to given in full on grain yield. When conducted in 2015 and 2016, four application rates of RBB, i) conventional application rate (RBB1, 270 kg·ha^{-1}), ii) reduction by 10% (RBB2, 243 kg·ha^{-1}), iii) reduction by 20% (RBB3, 216 kg·ha^{-1}), and iv) reduction by 30% (RBB4, 189 kg·ha^{-1}); and the control, split application of conventional fertilizers (CN, 270 kg·ha^{-1}), were employed. The results showed that compared with the CN treatment, a 10-30% reduction of RBB enhanced the grain yield with the yield of RBB1 treatment (9.23 t·ha^{-1}) was the highest in 2015, when RBB3 (9.72 t·ha^{-1}) was the highest in 2016, due to higher panicle number. The larger panicle numbers and the high LAI and photosynthetic potential after anthesis were the main reasons for the higher yield. The results indicated that the application rate of RBB could be reduced to 189-216 kg·ha^{-1} without affecting the grain yield.

Keywords: *japonica* rice; resin blending controlled-release fertilizer; application amount; yield.

https://doi.org/10.36899/JAPS.2021.1.0197 *Published online August 26, 2020*

INTRODUCTION

Point source pollution and non-point pollution caused by human activities mainly were cause environment pollution (Wang *et al.,* 2018). With the increasing public awareness and supervision, point pollution such as industrial wastewater and urban domestic sewage has been well-controlled. However, the rural non-point pollution has been becoming the main source of water pollution (Shen *et al.,* 2015). For agriculture, excessive application of nitrogen fertilizer is the primary source for the non-point pollution duo to the low nitrogen utilization (Xue *et al.,* 2013). The Tai-Lake region is an important paddy-upland rotation region. Farmers normally apply large amount of nitrogen fertilizers to obtain high yield (Wang *et al.,* 2009). The previous research showed that the nitrogen loss of paddy fields in the Tai-Lake region with the conventional fertilizer rate (270 kg·ha^{-1}) reached 85.8 kg·ha^{-1}, which accounted for 31.8% of the nitrogen application (Xue *et al.,* 2014). Therefore, to control the nitrogen loss, the research on the reduction technology of farmland nutrient inputs has been highlighted (Shang *et al.,* 2014).

In the recent years, the slow/controlled release fertilizer has been developed (Azeem *et al.,* 2014), which is a good alternative fertilizer for the balance of high yield and fertilizer application (Ke *et al.,* 2017). The previous study found that with the same amount of nitrogen, the slow/controlled release fertilizer reduced the nitrogen loss in paddy fields compared with the conventional split fertilization. In addition, the resin blending controlled-release fertilizer (RBB) showed the best performance with the highest yield and lowest nitrogen loss (Hou *et al.,* 2019). In addition, RBB was more consistent with the nutrient requirement of rice growth and beneficial for high yield (Miao *et al.,* 2016). However, the application amount of RBB in current studies was the same of conventional urea rate. For bulk blending fertilizers, it is yet unclear whether the reduced dosage of RBB can still meet the needs of rice growth and maintain the yield. Therefore, it is necessary to study the effect of application rate of RBB on rice yield, to clarify the appropriate application rate of RBB for high yield and environmental protection.

MATERIALS AND METHODS

The experiment was carried out in 2015-2016 in Zhangdu Village, Yixing City, Jiangsu Province (119°54′ E, 31°17′ N). The characteristics of the topsoil (0-20 cm) used for the experiment were: soil organic matter, 24.6 g·kg^{-1}; total nitrogen, 1.42 g·kg^{-1}; Olsen-P, 21.9 mg·kg^{-1}; and available potassium, 72.2 mg·kg^{-1}. The precipitation and temperature during the experimental seasons were shown in Table 1.

The primary cropping regime for the experimental area is annual rice-wheat rotation; the soil type is a periodically waterlogged paddy soil. Soil preparation including tillage, irrigation, herbicide spraying etc. began after wheat harvesting. The experiment was a randomized split-plot design with three replications. Four different application rates of RBB treatments were set as the conventional application rate (270 $kg\cdot ha^{-1}$, RBB1), 10% reduced amount (243 $kg\cdot ha^{-1}$, RBB2), 20% reduced amount (216 $kg\cdot ha^{-1}$, RBB3), and 30% reduced amount (189 $kg\cdot ha^{-1}$, RBB4). The split application of conventional chemical fertilizers (270 $kg\cdot ha^{-1}$, CN) was set as the control. Each plot (20 m × 6 m) was separated by a ridge. The rice variety was Wuyunjing 23, a conventional japonica rice variety. The rice sown on 27 May 2015 and 30 May 2016 in nursery, then transplanted on 18 June 2015 and 20 June 2016 with the planting density of 30cm×14cm. RBB was side-deep fertilized together with transplanting using the gas blowing type transplanting and side deep fertilizing integrated machine (Iseki& Co., LTD. PZ60HVRASLF). The calcium super phosphorus (129kg P_2O_5 $\cdot ha^{-1}$) and potassium chloride (200kg K_2O $\cdot ha^{-1}$) were basal applied for all the treatments. Dry-wet alternate irrigation method was adopted.

The tiller dynamic was recorded periodically in the fixed point. From each plot, 10 consecutive holes were selected every week.

At jointing, heading and maturity stages, the tiller numbers of 40 hills were counted in each plot and 5 plant samples were collected for each plot. The leaf length and width were measured to calculate the leaf area index (LAI). The stems, sheaths, leaves and panicles of the plant were separated and fixed for 30 minutes at 105 ℃, then dried at 80℃ to a constant weight, and the dry matter weight was measured. At maturity, a 4 m^2 area without sampling in the plots was harvested and threshed with a small grain thresher to determine the grain yield (adjusted to a moisture content of 13.5%).

Photosynthetic potential ($m^2\cdot m^{-2}\cdot d^{-1}$) $=(L1+L2)\times(t2-t1)/2$, where, $L1$ and $L2$ are the leaf area per unit of field area measured before and after, and $t1$ and $t2$ are the time measured before and after.

The data were statistically analyzed using SPSS17.0 software, and the significance of difference was analyzed using Duncan method ($P\leq 0.05$).

RESULTS AND DISCUSSION

Tiller dynamic of rice depends on and reflects the nutrient supply and water condition of paddy fields (Ling *et al.*, 2000). There was a significant difference in tiller dynamic between years and treatments (Fig. 1). The population reached the peak of tiller number in 48 days after transplanting in 2015 and in 38 days in 2016. In addition, the peak seedling number in 2016 was obviously higher than that in 2015, but it fell sharply at later growth stages in 2016. The peak seedling number under flooding irrigation is often higher than that under dry-wet alternate irrigation method; by contrast, the percentage of productive tillers under flooding irrigation is often significantly lower (Liu *et al.*, 2013). In this study, rice seedling grew in flooded environment at tillering stage due to the heavy and frequently rainfall in 2016 (Table 1). This may be the main reason for the higher peak seedling number and sharply fell at later growth stages in 2016.

It has been proved that RBB integrated resin-coated urea of different release characteristic can release at all stages and is more consistent with the nutrient requirement of rice (Ke *et al.*, 2017). By comparison, there was no significant difference in the tiller number among the treatments during the early tillering stage in 2015 due to the release characteristic of RBB. During the following stages, the tiller occurred faster under CN and RBB1, and the peak seedling number were 434 m^{-2} and 471 m^{-2} respectively, which were significantly higher than other treatments. After that, the tiller number with the CN treatment decreased rapidly. The tiller development rate, peak seedling number and panicle number with RBB treatments were significantly higher than those with CN treatment in 2016. This may be related to the runoff losses of inorganic fertilizers. In previous study, we have proved that the rainfall probability of basal fertilization stage and tillering fertilization stage were obviously higher than other stages in this region, implying high probability for paddy runoff in these two periods. Hence, the nitrogen loss from paddy field under CN treatment increased due to the easily soluble characteristics of urea and the heavy rainfall in 2016 (Hou *et al.*, 2017a). The panicle number with reduced RBB treatments was significantly higher than those with CN and RBB1 treatment in 2016. The results indicated that regardless of rainfall during the growing season, there was no significant difference in the panicle number among the reduced RBB treatments, but the tiller development rate and peak seedling was different in different year.

The interactive effect of year and treatment on dry matter accumulation at different growth stage was not significant (Table 2). The dry matter weight at jointing and heading stages in 2015 (3.65 $t\cdot ha^{-1}$, 8.38 $t\cdot ha^{-1}$) was significantly lower than that in 2016 (4.67 $t\cdot ha^{-1}$, 9.83 $t\cdot ha^{-1}$) ($P\leqslant 0.01$). This may be related to the differences in tiller development rate and peak seedling (Fig. 1). When compared with all treatments, there was no significant difference in dry matter weight at heading and maturity stages among RBB treatments (Fig. 2). The dry matter accumulation in rice population is closely related to the leaf area and photosynthetic potential (Hossain *et al.,* 2017). In present study, an increasing trend in LAI and photosynthetic potential for RBB treatments was observed. Particularly, the LAI at the heading stage was significantly higher under the RBB1 treatment in 2015 and RBB4 in 2016 than CN, which was helpful for the accumulation of photosynthate (Table 3). In addition, the LAI at heading stage was not significantly affected by the different experimental years (Table 2).

Paddy water condition is the key factor affecting rice population (Khalid *et al.,* 2018). Pan *et al.* (2009) documented that the water use efficiency and rice yield under dry-wet alternate irrigation were higher than that under flooding irrigation. It was also found that the rice yield with CN in wet years was lower than that in normal years (Fig. 3). This may be related to the runoff losses of inorganic fertilizer due to the easily soluble characteristics of urea and the heavy rainfall in 2016. Peng *et al.* (2014) found that rice yield with slow/controlled release fertilizers (sulfur-coated urea, resin-coated urea) under the controlled irrigation were higher than those under flooding irrigation. In the present study, the crop with RBB treatments had better stress resistance than CN treatment. This may be related to the nutrient release characteristics of the slow/controlled fertilizer type in the present study. Hou *et al.* (2017b) found that the nutrient release of sulfur-coated urea mainly happened in the early stage, while the nutrient release of RBB fertilizer was less affected by water and released evenly, which could meet the requirement of rice growth at different stages.

The application amount of RBB is mainly determined depending on the use of conventional urea (Miao *et al.,* 2016). It is still unclear whether the reduction dosage can still meet the requirements of rice growth. The present study results showed that RBB reduction by 10-30% had a similar yield compared with CN treatment (Fig. 3). The yield (9.23 t·ha^{-1}) under RBB1 treatment was the highest in the normal year, when the yield of RBB3 treatment was the highest (9.72 t·ha^{-1}) in the wet year. It has been suggested that the panicle number and grain number per panicle (sink size) is considered widely as well related to yield (Guo *et al.,* 2018). The same has been indicated that the sink size formed at the early stage was the key factors that determined the yield in paddy fields with RBB; there was significant positive correlation between photosynthetic potential during transplanting to jointing stages and grain yield ($P \leqslant 0.05$) (Table 4). Although continuous heavy rains after transplanting resulted in a long-term flooding condition at tillering stage in 2016, the one-time deep application of RBB was conducive for yield stability (Table 2). Also, the dry matter accumulation from heading to mature stage was positively correlated with the yield (Ling, 2000). The present results suggested that the dry matter accumulation and yield with reduced RBB treatments were not decreased. The dry matter accumulation at the late stage can be represented by the LAI at heading stage (Ling, 2000). It also represents plants leaf photon interception, which highly influences biomass as well as yield production (Firouzabadi *et al.,* 2015). The correlation analysis also indicated that the grain yield was positively correlated with LAI at heading stage (Table 4). Therefore, the higher LAI at the heading stage under RBB1 treatment in 2015 and RBB4 in 2016 may be the main reason for the difference in dry matter and yield among the treatments.

In conclusion, RBB proved to be a good alternative fertilizer to balance high yield and nutrients' wastage. The present results also highlight that application amount of RBB fertilizer in reference to conventional chemical fertilizer is overuse. RBB rate could be reduced by 20-30% to 189-216 kg·ha^{-1} without affecting grain yield of japonica rice in Tai-lake region. Rice varieties differ from each other in growth duration worldwide; the soil fertility and atmospheric environment also differ. The application rate of RBB in the present study may not be suitable for the other rice varieties. But, the opinion could provide a reference for selection and application of controlled release fertilizer for different types of rice in the world.

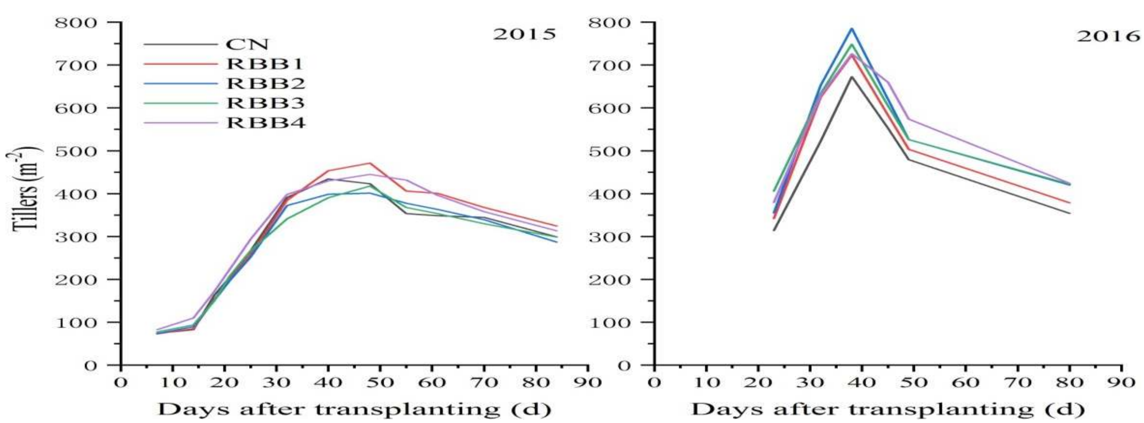

Fig. 1. Dynamic changes of tillers of reduced RBB treatments.

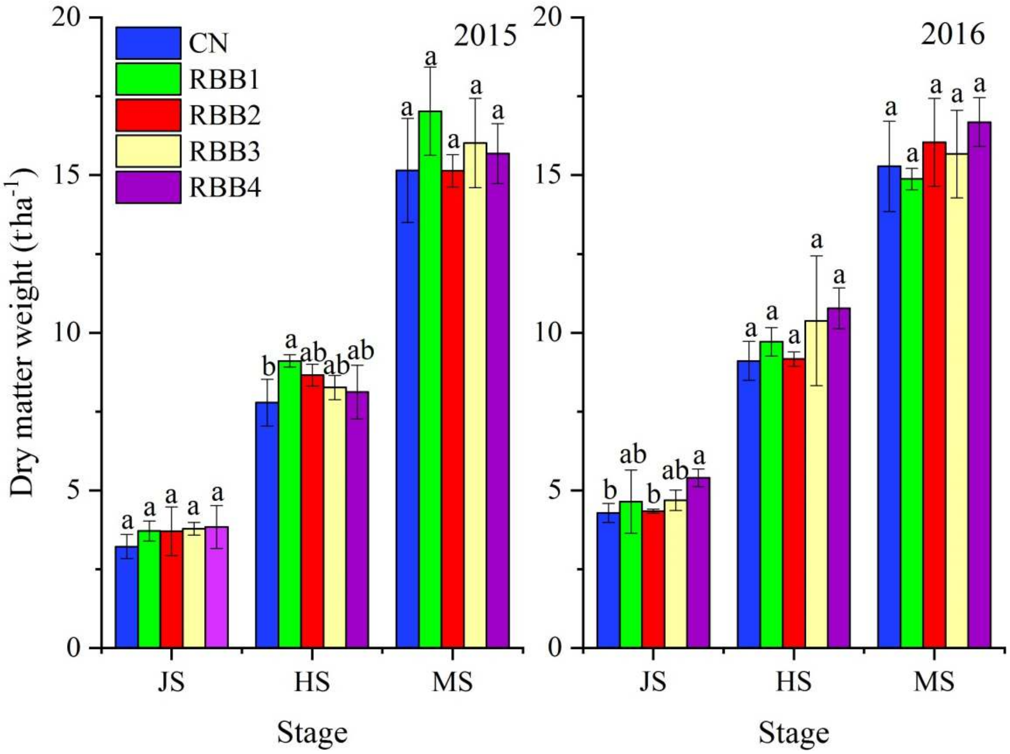

Fig. 2. Dry matter accumulation of reduced RBB treatments at different stages.
JS, jointing stage; HS, heading stage; MS, maturity stage. Different letters above the histogram indicate there are significant differences between different treatments at the $P \leq 0.05$ level (Duncan).

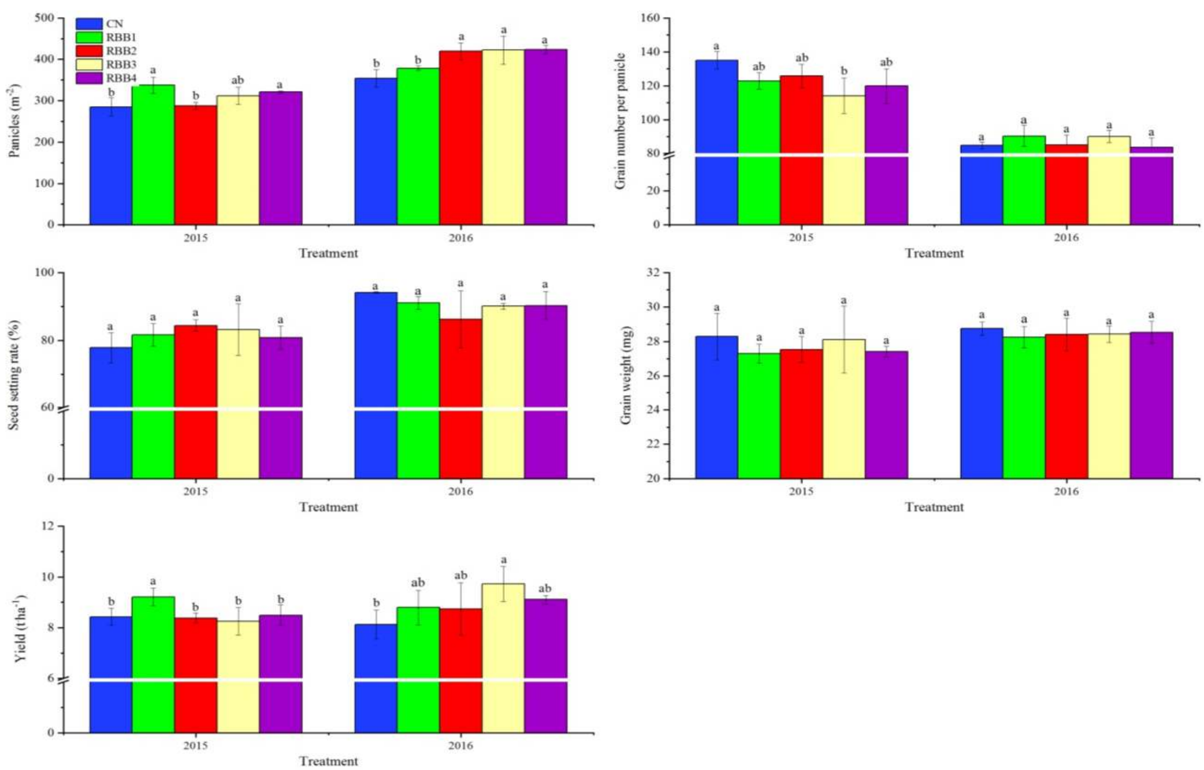

Fig. 3. Yield and its components of reduced RBB treatments.
Different letters above the histogram indicate there are significant differences between different treatments at the $P \leq 0.05$ level (Duncan).

Table 1. Average daily temperature and cumulative precipitation of the experimental site during the rice growing season.

Parameter	2015	2016
Average daily temperature (ºC)	24.3	25.4
Cumulative precipitation (mm)	819	1530

Table 2. Mean for the investigated variable and the factorial analysis.

Variable		Mean		*F*-value		
		2015	2016	Year (Y)	Treatment (T)	Y× T
Yield and its components	Panicle number (m^{-2})	308.57	399.71	177.65^{**}	7.33^{**}	5.51^{**}
	Grain number per panicle	123.47	86.79	233.67^{**}	1.59^{ns}	3.28^{*}
	Seed setting rate (%)	81.52	90.31	29.73^{**}	0.09^{ns}	2.08^{ns}
	Grain weight (mg)	27.73	28.47	4.83^{*}	0.59^{ns}	0.20^{ns}
	Yield ($t·ha^{-1}$)	8.55	8.90	2.86^{ns}	1.86^{ns}	2.85^{ns}
Dry matter weight ($t·ha^{-1}$)	JS	3.65	4.67	29.65^{**}	2.29^{ns}	0.67^{ns}
	HS	8.38	9.83	22.71^{**}	1.59^{ns}	1.93^{ns}
	MS	15.80	15.71	0.05^{ns}	0.57^{ns}	1.69^{ns}
Leaf area index	JS	4.06	5.46	57.44^{**}	1.82^{ns}	0.38^{ns}
	HS	7.11	7.19	0.31^{ns}	3.41^{*}	4.01^{*}
Photosynthetic potential ($m^2·m^{-2}·d^{-1}$)	TS-JS	113.79	136.42	22.43^{**}	1.84^{ns}	0.35^{ns}
	JS-HS	134.10	183.38	221.85^{**}	3.90^{*}	2.13^{ns}

JS, jointing stage; HS, heading stage; MS, maturity stage; TS-JS, transplanting stage-jointing stage; JS-HS, jointing stage-heading stage. $^{*}P\leq 0.05$; $^{**} P\leq 0.01$.

Table 3. Leaf area index and photosynthetic potential of reduced RBB treatment at different stages.

Year	Treatment	LAI		Photosynthetic potential ($m^2•m^{-2}•d^{-1}$)	
		JS	HS	TS-JS	JS-HS
2015	CN	3.85a	6.78b	107.74a	127.58b
	RBB1	4.36a	7.96a	121.97a	147.84a
	RBB2	3.87a	6.64b	108.49a	126.23b
	RBB3	3.98a	7.01b	111.53a	131.88b
	RBB4	4.26a	7.16b	119.20a	136.96ab
2016	CN	4.90a	6.73b	122.49a	168.65b
	RBB1	5.57a	7.01ab	139.18a	182.32ab
	RBB2	5.44a	7.28ab	135.98a	184.37ab
	RBB3	5.46a	7.44ab	136.57a	187.15ab
	RBB4	5.91a	7.49a	147.88a	194.38a

LAI, leaf area index; JS, jointing stage; HS, heading stage; TS-JS, transplanting stage-jointing stage; JS-HS, jointing stage-heading stage. Different letters after the data represent that there are significant differences (Duncan) between different treatments at the level of $P\leq 0.05$.

Table 4. Correlation analysis between growth index and grain yield for the two years.

	LAI at JS	LAI at HS	Photosynthetic potential during TS-JS	Photosynthetic potential during JS-HS
LAI at HS	ns			
Photosynthetic potential during TS-JS	0.98^{**}	ns		
Photosynthetic potential during JS-HS	0.99^{**}	Ns	0.96^{**}	
Yield	ns	0.77^{**}	0.64^{*}	ns

JS, jointing stage; HS, heading stage; TS-JS, transplanting stage-jointing stage; JS-HS, jointing stage-heading stage. $^{*}P\leq 0.05$; $^{**} P\leq 0.01$.

Acknowledgements: This work was supported by The National Key Research and Development Program of China (2017YFD0300104; 2016YFD0801101), The National Natural Science Foundation of China (41601319), National Science and Technology Major Project of China (2017ZX07202-004-03) and The Special Fund for Agro-scientific Research on Public Interests (201503106).

REFERENCES

Azeem, B., K.Z. KuShaari, Z.B. Man, A. Basit, and T.H. Thanh (2014). Review on materials & methods to produce controlled release coated urea fertilizer. J. Control. Release. 181: 11-21.

Firouzabadi, A.G., M. Raeini-Sarjaz, A. Shahnazari, and H. Zareabyaneh (2015). Non-destructive estimation of sunflower leaf area and leaf area index under different water regime managements. Arch. Agron. Soil Sci. 61(10): 1357-1367.

Guo, T., K. Chen, N.Q. Dong, C.L. Shi, W.W. Ye, and J.P. Gao (2018). *GRAIN SIZE AND NUMBER1* negatively regulates the OsMKKK10-OsMKK4-OsMPK6 cascade to coordinate the trade-off between grain number per panicle and grain size in rice. Plant Cell. 30(4): 871-888.

Hossain, S.A.A.M., L. Wang, T. Chen, and Z. Li (2017). Leaf area index assessment for tomato and cucumber growing period under different water treatments. Plant Soil Environ. 63(10): 461-467.

Hou, P., L. Xue, Y. Yu, Y. Jiang, J. Wang, L. Xue, and L. Yang (2017a). Nitrogen loss risk of paddy field under different fertilizations in runoff prone period. J. Agro-Environment Sci. 36(7): 1353-1361.

Hou, P., L. Xue, Y. Yu, L. Xue, L. Fan, and L. Yang (2017b). Control effect of side deep fertilization with slow-release fertilizer on ammonia volatilization from paddy fields. Environ. Sci. 38(12): 5326-5332.

Hou, P., L. Xue, Y. Zhou, G. Li, L. Yang, and L. Xue (2019). Yield and N utilization of transplanted and direct-seeded rice with controlled/slow-release fertilizer. Agron. J. 111(3): 1208-1217.

Ke, J., X. Xing, G. Li, Y. Ding, F. Dou, S. Wang, Z. Liu, S. Tang, C. Ding, and L. Chen (2017). Effects of different controlled-release nitrogen fertilisers on ammonia volatilisation, nitrogen use efficiency and yield of blanket-seedling machine-transplanted rice. Field Crop Res. 205: 147-156.

Khalid, H.M., I.F. Mahmod, S.S. Barakbah, and N. Osman (2018). Impact of water management on fertilizer and tillering dynamics in rice. Int. J. Agric. Biol. 20(1): 37-40.

Ling, Q. (2000). Crop population quality. Shanghai Scientific and Technical Publishers; Shanghai (China).

Liu, L., T. Chen, Z. Wang, H. Zhang, J. Yang, and J. Zhang (2013). Combination of site-specific nitrogen management and alternate wetting and drying irrigation increases grain yield and nitrogen and water use efficiency in super rice. Field Crop Res. 154: 226-235.

Miao, X., X. Xing, Y. Ding, J. Ke, Z. Liu, S. Tang, C. Ding, S. Wang, and G. Li (2016). Yield and nitrogen uptake of bowl-seedling machine-transplanted rice with slow-release nitrogen fertilizer. Agron. J. 108(1): 313-320.

Pan S.G., C.G. Cao, M.L. Cai, J.P. Wang, R.H. Wang, J. Zhai, and S.Q. Huang (2009). Effects of irrigation regime and nitrogen management on grain yield, quality and water productivity in rice. J. Food Agric. Environ. 7(2): 559-564.

Peng,Y., Y. Sun, M. Jiang, H. Xu, J. Qin, Z. Yang, and J. Ma (2014). Effects of water management and slow/controlled release nitrogen fertilizeron biomass and nitrogen accumulation, translocation, and distribution in rice. Acta Agron. Sin. 40(5): 859-870.

Shang, Q., C. Gao, X. Yang, P. Wu, N. Ling, Q. Shen, and S. Guo (2014). Ammonia volatilization in Chinese double rice-cropping systems: a 3-year field measurement in long-term fertilizer experiments. Biol. Fert. Soils. 50(5): 715-725.

Shen, Z.Y., Y.C. Zhong, Q. Huang, and L. Chen (2015). Identifying non-point source priority management areas in watersheds with multiple functional zones. Water Res. 68: 563-571.

Wang, H., Y. Xi, R. Chen, X. Xu, Q. Wei, and J. Li (2009). Investigation on excessive application of fertilizer and pesticides in Taihu Lake region. Agro-Environment & Dev. 26(3): 10-15.

Wang, Y., J. Yang, J. Liang, Y. Qiang, S. Fang, and M. Gao (2018). Analysis of the environmental behavior of farmers for non-point source pollution control and management in a water source protection area in China. Sci. Total Environ. 633: 1126-1135.

Xue, L., L. Yang, W. Shi, and S. Wang (2013). Reduce-retain-reuse-restore technology for controlling the agricultural non-point pollution in countryside in China: source reduction technology. J. Agro-Environment Sci. 32(5): 881-888.

Xue, L., Y. Yu, and L. Yang (2014). Maintaining yields and reducing nitrogen loss in rice–wheat rotation system in Taihu Lake region with proper fertilizer management. Environ. Res. Lett. 9(11): 115010.