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Effects of micro-nano bubble aerated irrigation and nitrogen fertilizer level on tillering, nitrogen uptake and utilization of early rice

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ABSTRACT

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In order to clarify the response characteristics of tillering and nitrogen (N) uptake and utilization under micro-nano bubble aeration irrigation and nitrogen fertilizer level, the nitrogen uptake and utilization characteristics, tillering and yield of early rice under different irrigation methods and nitrogen levels were investigated. The results showed that micro-nano bubble aerated irrigation and nitrogen fertilizer have substantial influence on tillering of early rice, and the effect of N fertilizer was greater than the effect of oxygen. Nitrogen accumulation increased by 6.75–10.79% in micro-nano bubble aerated irrigation treatment compared with the conventional irrigation. The application of N in treatment of micro-nano bubble aerated irrigation and 160 kg N/ha fertilizer used (W_1N_1) was 90% of the treatment of micro-nano bubble aerated irrigation and 180 kg N/ha fertilizer used (W_1N_2), while the yield decreased by only 0.31%. The study indicated that the adoption of an appropriate deficit N rate combine with micro-nano bubble aerated irrigation can be an effective means to reduce non-beneficial N consumption, achieve higher crop yield and N utilization efficiency.

Keywords: rice yield; tillering stage; N application; spikelets per panicle; yield component

Rice is a staple food for more than half of the world population (Seck et al. 2012). It is of great significance to ensure the growth of rice yield. Rice tiller is a specialized grain-bearing branch (Li et al. 2003). Rational utilization of tillering is an important link to achieve high-yield or super-high-yield of rice. The number of tillers and percentage of earring-tillers are closely associated with nitrogen (N) uptake and utilization in rice (Ishikawa et al. 2005). China has become the largest consumer of N fertilizer in the world by relying heavily on the amount of fertilizer and water to increase production (FAO 2001). Widespread introduction of N fertilizers not only increases the ineffective tillers and reduces the percentage of available tiller, but also reduces the N utilization efficiency. Meanwhile, excess N fertilizer through soil leakage (mainly nitrate nitrogen), surface runoff, N volatilization and other factors have caused a series of environmental issues (Wesström et al. 2014, Elbl et al. 2014, Yang et al. 2016, Plošek et al. 2017).

Aerated irrigation as a new water-saving technology, Bhattarai et al. (2005) reported for the first time in 2005 that aerated irrigation can increase irrigation efficiency and crop yield. Ben-Noah and Friedman (2016) founded that aerated irri-

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gation can significantly increase the number of peppers, individual weight and yield. Oliveira and Sodek (2013) studies indicated that an oxygen-rich environment is beneficial for the absorption of N to soybean. Micro-nano bubble aerated irrigation is based on the original aeration irrigation technology, through the micro-nano bubble device, so that air can be dissolved in water with nanometer or micro and nano diameter bubbles for long time. It has many advantages, such as long time (Ohgaki et al. 2010), large surface area (Tasaki et al. 2009), strong adsorbability (Bunkin et al. 2012), good stability (Feng et al. 2009) and so on. Currently, the study of oxygen micro-nano bubble enhancement in water purification and medical care is more (Yoshida et al. 2008, Zheng et al. 2016). However, there are few studies on micro-nano bubble aeration in agricultural irrigation, especially in rice irrigation. Therefore, the objective of this study were: (1) investigate the effects of variable irrigation methods and N application ratios on the tillering, yield and N utilization of early rice; (2) provide a theoretical basis and technical reference for increasing the N utilization efficiency and reducing agricultural non-point source pollution.

MATERIAL AND METHODS

Experimental areas. The experiment was conducted at Jiangxi Irrigation Experimental Station in Nanchang (28°26'N, 116°00'E), Jiangxi province, China from 2013 to 2014. The soil texture was alluvial and a silt loam with a pH_{CaCl_2} of 5.87, organic carbon of 13.5 g/kg, total N of 1.42 g/kg, total P of 1.42 g/kg, alkali hydrolysable N of 100.98 mg/kg, available P of 6.18 mg/kg, available K of 78.92 mg/kg. The early rice cultivar was Luliang-you 996. The generator used in this study was new screw micro-nano bubble pump, which can produce bubbles with diameters from 700 nm to 12 μm and 82–90% gas content.

Experimental design. The seeds were planted on March 25, 2013 and March 25, 2014, and the uniform seedlings were transplanted on April 22, 2013 and on April 22, 2014, 3 seedlings per point and plant spacing was 13.3 × 23.3 cm, and early rice were harvested on July 10, 2013 and on July 13, 2014. The experiments were conducted in a split design, micro-nano bubble aerated irrigation (W_1) and conventional irrigation (W_0) as the primary treatment, and three levels of N fertilization (0 (N_0); 162 (N_1) and 180 (N_2) kg N/ha) were treated as secondary treatment. The experimental design consisted of six treatments with three replicates per treatment, with an area of 23.85 m^2 for each plot. All plots received phosphorus at 29.7 kg P/ha and potassium at 124.5 kg K in both years. Calcium magnesium phosphate fertilizer as a base fertilizer, potassium chloride by the base, panicle mass ratio of 9:11 was applied, and carbamide by the base, tiller, panicle mass ratio of 5:3:2 was applied. The experimental design is shown in Table 1.

Measurement items and methods. Determination of nitrogen content in plants. The weighed samples of plant biomass were dried, crushed and sieved, and then digested with H_2SO_4-H_2O_2 for total nitrogen analysis by the Kjeldahl method using a Kjeldahl 2300 analyzer (Foss Tecator AB, Hoeganaes, Sweden).

Yield estimation and plant inquisition. 100 hills in each plot were harvested at maturity for the determination of effective panicle number, and 5 hills in each plot were harvested at maturity for the determination of grain yield. Yield components including spikelets per panicle, seed-setting rate, 1000-grain weight. Each plot harvest separately, according to the actual conversion of area production.

Evaluation of nitrogen uptake efficiency. The following parameters were derived according to Moll et al. (1982):

N utilization efficiency (NUE, %) = ((total N_{up} by plant with added N – total N_{up} by plant with no N)/N application amount) × 100;

N Harvest index (NHI, %) = N_{up} by grain/total N_{up} by plant × 100;

N agriculture efficiency (NAE, kg grain/kg Nf) = (grain yield with added N – grain yield with no N)/ N application amount;

N physiological efficiency (NPE, %) = (grain yield with added N – grain yield with no N)/(total N_{up} by plant with added N-total N_{up} by plant with no N);

N-requirement for 100 kg grain (NRG, kg) = total nitrogen accumulation/grain yield × 100;

productivity of grain fertilized with N (PGFN, %) = grain yield/nitrogen accumulated in plant shoot.

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Table1. Test design

Treatment	Irrigation method	Total nitrogen (kg/ha)
W_0N_0	conventional irrigation	0
W_0N_1		162
W_0N_2		180
W_1N_0	micro-nano bubble aerated irrigation	0
W_1N_1		162
W_1N_2		180

Statistical analysis. The experimental data listed in this paper were the average of the two years test data. All data were analyzed using least significant difference (*LSD*) tests, within the SPSS 20.0 Statistical software package (SPSS, Chicago, USA).

RESULTS AND DISCUSSION

Tillering. Figure 1 showed that W_1 was promoted the tillering of early rice. On the condition of equal N level, the number of tillers in the treatment of W_1 was higher than that in treatment of W_0 in the period from twenty-fifth days to seventy-seventh days after transplanted. The reasons for this are mainly the aerated irrigation that improved the root activity and root zone microbial activity, speeded absorption and utilization of soil nutrient, and increased the growth of the upper part of rice (Bhattarai et al. 2008). Under the same irrigation mode, the number of tillers increased significantly with an increasing N application ratio in the field experiment. In W_0N_2 and W_0N_1 treatment the number of tillers were increased by 1406 and 1884 thousand/ha higher than in W_0N_0. The reason for this are that application of N fertilizer could speed N metabolism and increase endohormone, and significantly increase tillers of early rice (Liu et al. 2011).

In W_1N_0 and W_0N_1 treatment, the number of tillers were increased by 195 and 1406 thousand/ha higher than in W_0N_0. It is obvious that tillers effect in N fertilizer is much greater than that in aerated irrigation. At seventy-seventh days after transplanted, final number of tillers per hectare were increased by 71.9% (W_0N_1), 86.9% (W_0N_2), 8.9% (W_1N_0), 82.6% (W_1N_1) and 94.1% (W_1N_2), respectively. Additionally, the number of tillers was no significant difference in W_1N_1 and W_0N_2 treatment. This mean that micro-nano bubble aerated irrigation could reduce the amount of N fertilizer and increase the number of tillers. W_0N_2 treatment compared with W_1N_1 treatment showed that rhizosphere oxygen deficiency significantly inhibited the absorption of ions to the root and the transport of ions to the upper part of the ground (Drew and Sisworo 1979).

Nitrogen accumulation and utilization. The amount of N accumulation at each stage in W_1 treatment were higher than that in W_0 treatment (Table 2). Compared with W_0, N accumulation at each stage of W_1 treatment were increased by 10.79% (tillering stage), 9.93% (jointing-booting stage), 8.93% (heading stage) and 6.57% (yellow ripening stage), respectively. It was mostly due to the increase in rhizosphere oxygen, so root respiration was strengthened, caused more energy to be provided for N absorption (Nakamura et al. 2013).

Additionally, N accumulation at different growth stages was a significant difference in W_1N_2 and W_0N_0 treatment, and N accumulation of W_1N_2 were higher than W_0N_0 treatments, increasing by 29.05 kg/ha (tillering stage), 58.53 kg/ha (jointing-booting stage) and 112.08 kg/ha (heading stage) and 113.81 kg/ha (yellow ripening stage), respectively. However, total N uptake was no significant difference in W_1N_1 and W_0N_2 in jointing-booting and yellow ripening stages (Table 2). This indicated that W_1 reduced the amount of N fertilizer, and increased N accumulation and NUE in early rice compared to W_0 in jointing-booting and yellow ripening stages. Steffens et al. (2005) suggested

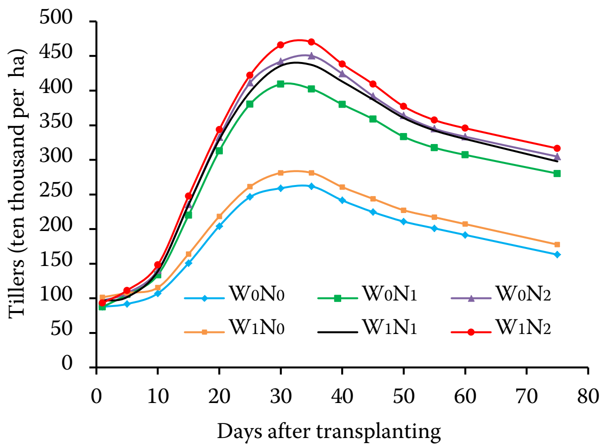

Figure 1. Tiller dynamics in different treatments. W_1 – aerated irrigation; W_0 – conventional irrigation; three levels of nitrogen fertilization: N_0 – 0, N_1 – 162, N_2 – 180 kg N/ha

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Table 2. Nitrogen accumulation (kg/ha) at different growth stages in different treatments

Treatment	Tillering stage	Jointing-booting stage	Heading stage	Yellow ripening stage
W_0N_0	12.97^f	25.95^d	35.42^f	53.58^e
W_0N_1	32.49^d	69.61^c	122.01^d	152.50^c
W_0N_2	39.03^b	77.49^b	142.66^b	161.28^b
W_1N_0	15.80^e	28.10^d	40.73^e	62.25^d
W_1N_1	35.79^c	77.65^b	138.68^c	161.86^b
W_1N_2	42.01^a	84.48^a	147.50^a	167.38^a

Values with the same letter within a column are not significantly difference at $P = 0.05$. W_1 – aerated irrigation; W_0 – conventional irrigation; three levels of nitrogen fertilization: N_0 – 0, N_1 – 162, N_2 – 180 kg N/ha

that this is due to oxygen affects the synthesis of ATP and thus affects the uptake of nutrients.

As shown in the Table 3, under the same irrigation condition, NUE, NHI, NAE and productivity of grain fertilized with N were negatively correlated with N application. Additionally, the effect of the N-requirement for 100 kg grain was positively correlated with N application. The NPE was increased with an increasing of N application ratio in W_0 treatment. However, the NPE was decreased with an increasing of N application ratio in W_1 treatment. The NPE in each treatment was: $W_1N_1 > W_1N_2 > W_0N_2 > W_0N_1$, thus, increasing the amount of oxygen and nitrogen in the rhizosphere in a certain range is improved the NPE. The NPE of W_1N_1 was higher than that of W_1N_2 treatment, it may be due to the coupling effects of oxygen and N fertilizer (Zhao et al. 2011). The coupling effect of NPE in W_1N_1 treatment is greater than that of W_1N_2. Additionally, the productivity of grain fertilized with N decreased with an increasing N application rate, and the productivity of grain fertilized with N in W_1N_1 was higher than that of W_0N_1. There is in agreement with dissolved oxygen have positive effects on promoting the uptake of nitrogen and the increasing of rice yield (Chen et al. 2011, Nakamura et al. 2013).

Table 3 shows that NUE, NHI, NAE, NPE and productivity of rice fertilized with N were the highest under the W_1N_1. However, the N-requirement for 100 kg grain was the lowest. In W_1N_1, the application of N was 90% of W_1N_2, while the NUE was about 3 percentage points higher than W_1N_2. This indicated that micro-nano bubbles irrigation reduced the amount of N fertilizer and enhanced the NUE.

Yield and its components. The effects of different irrigation methods and nitrogen application rates on rice yield were significant (Table 4). In W_1N_1 the application of N was 90% of W_1N_2, while the yield decreased by only 0.31%. The study indicated that the adoption of an appropriate deficit N rate combine with micro-nano bubble aerated irrigation was achieved higher yield. This result due to the increase of soil enzyme activity in the root zone, the improvement of the soil microenvironment in the root zone, the increase of the aerobic respiration level of the roots, the improvement of the water and fertilizer uptake efficiency of the

Table 3. Evaluation of nitrogen uptake efficiency (NUE) in different treatments

Treatment	NUE (%)	NHI (%)	NAE (kg/kg)	NPE (%)	NRG (kg)	PGFN (%)
W_0N_1	61.07^{ab}	61.65^a	21.80^b	35.74^b	1.99^a	50.50^a
W_0N_2	59.84^{ab}	61.46^a	21.38^b	35.78^b	2.02^a	49.74^a
W_1N_1	61.49^a	63.35^a	24.07^a	39.19^a	1.97^a	50.80^a
W_1N_2	58.40^b	62.01^a	21.81^b	37.31^{ab}	2.04^a	49.23^a

Values with the same letter within a column are not significantly difference at $P = 0.05$. NHI – N Harvest index; NAE – N agriculture efficiency; NPE – N physiological efficiency; NRG – N-requirement for 100 kg grain; PGFN – productivity of grain fertilized with N. W_1 – aerated irrigation; W_0 – conventional irrigation; three levels of nitrogen fertilization: N_0 – 0, N_1 – 162, N_2 – 180 kg N/ha

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Table 4. Early rice yields and its components of different treatments

Treatment	No. of panicles (10^4/ha)	Spikelets per panicle	Seed-setting rate (%)	1000-grain weight (g)	Grain yield (kg/ha)
W_0N_0	147.53[e]	104.96[c]	93.60[ab]	28.48[a]	4169.28[e]
W_0N_1	265.57[c]	129.81[b]	91.11[bc]	27.94[a]	7700.98[c]
W_0N_2	280.80[b]	134.35[a]	88.91[c]	27.71[a]	8017.43[b]
W_1N_0	155.89[d]	107.60[c]	94.86[a]	28.61[a]	4317.01[d]
W_1N_1	278.87[b]	133.09[ab]	91.76[bc]	28.21[a]	8216.74[a]
W_1N_2	286.52[a]	136.32[a]	88.89[c]	27.82[a]	8242.31[a]

Values with the same letter within a column are not significantly difference at $P = 0.05$. W_1 – aerated irrigation; W_0 – conventional irrigation; three levels of nitrogen fertilization: N_0 – 0, N_1 – 162, N_2 – 180 kg N/ha

roots and the increase of yield (Heuberger et al. 2001, Nakano 2007). Under the W_1N_1 treatment, the yield of early rice was 8216.74 kg/ha, which was increased by 97.08% than that of W_0N_0. It indicated that the adoption of an appropriate deficit N rate combine with micro-nano bubble aerated irrigation affected means significantly to increase early rice yield (Cabangon et al. 2004).

With an increasing N application ratio in the field experiment, number of panicles and spikelets per panicle of early rice increased, and seed-setting rate and 1000-grain weight showed a decreasing trend. On the condition of equal N level, number of panicles, spikelets per panicle, seed-setting rate and 1000-grain weight in the treatment of W_1 were significantly higher than W_0 treatment. Compared to W_0 treatment. This indicated that micro-nano bubbles irrigation increased number of panicles, spikelets per panicle, seed-setting rate and 1000-grain weight, and increased of early rice yield significantly.

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