Deep Placement of Nitrogen Fertilizer Affects Grain Yield, Nitrogen Recovery Efficiency, and Root Characteristics in Direct-seeded Rice

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Abstract

Background Deep placement of nitrogen (N) fertilizer has become one of the effective management practices for increasing crop yield and improving N recovery efficiency (NRE). However, the effects of N fertilization depth on direct-seeded rice are not well understood. The objective of this experiment was to evaluate the effects of N fertilization depth at four fertilization depths (0, 4, 8, and 12 cm, D0, D4, D8 and D12, respectively) with a conventional ammonium bicarbonate fertilizer (TN=17.7%) (150 kg N ha⁻¹) and a control (no N fertilizer applied, CK) on grain yield, NRE and root characteristics of direct-seeded rice. **Results** The results indicated that both D8 and D12 increased grain yields by 72.91 and 81.84%, respectively, compared with CK. The main reason was ascribed to the increases of productive panicle and spikelet number. The highest nitrogen agronomic efficiency (NAE) and NRE were found under D12 treatment, which were increased by 165.42 and 129.45% compared to D0, respectively. We also found that deep placement of N fertilizer (both D8 and D12) could also promote rice root growth such as larger root length, root superficial area, and heavier root diameter, increase nitrate reductase (NR), glutamine synthetase (GOGAT), and glutamine synthetase (GS) activities at the heading stage. **Conclusions** The results show that 8 cm is relatively proper fertilizer placement depth when ammonia bicarbonate fertilizer is used in direct-seeded rice production because of requiring less mechanical power input.

Background

Rice is one of the most important staple food crops in the world and for nearly two-thirds of the Chinese population (Miao et al., 2011; Huang & Zou, 2018; Li et al., 2019). Therefore, the production of rice becomes more urgent for increasing population globally (Ashraf et al., 2018; Chen et al., 2018; Liu et al., 2019). Traditionally transplanted rice is facing severe problems such as labor scarcity and low profit because of numerous agronomic procedures such as raising seedling, pulling of seedling, and transplanting seedling (Peng, 2016; Tao et al., 2016). Accordingly, a feasible alternative rice production technique with high efficiency and labor-saving is the need of the day to solve conventional transplanted rice production related problems.

Previous studies showed that direct-seeded rice (DSR) was endowed with multiple benefits/advantages over transplanted puddled rice through savings in labor, water, fuel/energy (Liu et al., 2015; Pan et al., 2017). Furthermore, grain yield and nitrogen use efficiency of DSR is similar to or higher than yield of conventional transplanted rice (Chen et al., 2009; Mahajan et al., 2012; Wang et al., 2017).

Nitrogen (N) often plays a vital role in maintaining rice production (Peng et al., 2006; Pan et al., 2012; Ke et al., 2018). Farmers often apply excessive N to obtain higher grain yields (Albornoz, 2016; Liu et al., 2019). However, overuse of N fertilizer is often associated with diseases occurrence, low nitrogen recovery efficiency and environmental pollution such as soil degradation and greenhouse gas emissions (Guang et al., 2010; Wang et al., 2018). N broadcasting is often adopted by farmers in the cultivation of DSR (Guan, 2011). However, it is considered as the most inefficient method for DSR production (Tao et al., 2016).

Many researchers reported that deep placement fertilization technique can be a promising alternative to broadcast fertilizer (Rochette et al., 2013; Liu et al., 2015; Ke et al., 2018). Savant & Stangel (1990) considered deep placement of N fertilizer as the most efficient and promising method to reduce total N losses and increase N-use efficiency in wetland rice. Huda et al. (2016) found that deep placement of urea briquettes of NPK could significantly improved NRE and grain yield than broadcasting prilled briquettes across different water managements. Pan et al. (2017) also observed that mechanically deep placement of N fertilizer significantly enhanced nitrogen use efficiency and grain yield compared to surface broadcasting. However, some studies found no effects of deep N placement on rice grain yields (Setyanto et al., 2000). Besides, Sun et al. (2014) considered that shallow fertilization in the soil of 1 cm could improve root activity, benefit of root architecture, and promote root growth in rice. Liu et al. (2015) found that deep placement of N fertilizer in 10 cm soil markedly increased nitrogen utilization efficiency and grain yield due to decreased mean floodwater NH₄⁺-N concentration compared to N broadcasting. Hence, Deep placement of N fertilizer at suitable depth will be more important. However, little information is available in the literature regarding the effects of N fertilization depth on grain yield, nitrogen recovery efficiency, and root characteristics in DSR. Therefore, one stainless steel-box experiment was conducted with the aims of: (1) to examine the effects of N fertilization depth on nitrogen recovery efficiency of DSR; (2) to address the effects of N fertilization depth on grain yield and its components of DSR; and (3) how does N fertilization depth affects rice root characteristics of DSR.

Methods

Experimental treatments and design

Two widely adopted rice cultivars, i.e., *Tianyou998* (a three line hybrid type rice, *TY998*) and *Yuxiangyouzhan* (the inbred rice type, *YXYZ*) were used in this study, which has a growth period of 122 and 120 days, respectively. And these two rice cultivars were provided by Rice Research Institute, Guangdong Academy of Agricultural Science. The stainless steel-box (length × width × height = 100 cm × 80 cm × 50 cm) experiment was conducted in the greenhouse of the Experimental Research Farm, College of Agriculture, South China Agriculture University, Guangzhou, China (113.18°E, 23.10°N with 18 m of elevation) in the late season of 2016. The experimental soils in the stainless steel-boxes were taken from the paddy field, which was sandy loam with 1.36 g kg⁻¹ total N, 0.95 g kg⁻¹ total P, 17.52 g kg⁻¹ total K, 74.37 mg kg⁻¹ available P, 103.20 mg kg⁻¹ available K, and 25.65 g kg⁻¹ organic C. The pH of soil was 6.54. The weight of dry soil per stainless steel-box is 324 kg.

There were four different fertilization depths (0, 4, 8, and 12 cm, written as D0, D4, D8 and D12 in order, respectively) and a control (no N fertilizer applied, CK). 68 g ammonium bicarbonate fertilizer (TN = 17.7) per steel-box was applied at the rate of 150 kg N.ha⁻¹ before sowing. For the N fertilizer deep placement treatments, the ammonium bicarbonate was manually point deep-placed at one time as a basal fertilizer (3.40 g ammonium bicarbonate per hill) to 4, 8, and 12 cm soil depth using a steel-pipe tool (the pipe structure is similar to the injection syringe), respectively.

All treatments also received the same amount of 150 kg P₂O₅ ha⁻¹ as super phosphate (SOP) and 150 kg K₂O ha⁻¹ as potassium chloride (KCL). All P fertilizers were applied as basal, whilst 50% of K-fertilizer was applied as basal and 50% was top-dressed at panicle initiation stage.

Before sowing, seeds of both two cultivars were soaked in water for 24 h at room temperature and germinated under moisture conditions. Pre-germinated seeds of the both *Tianyou 998* and *Yuxiangyouzhan* were hill-seeded manually at a space of 25×17 cm while each hill was planted with 5 seeds in the stainless steel-boxes (100 cm × 80 cm × 50 cm) on 15th July in 2016. There were 20 hills rice seedlings per stainless steel-box.

The boxes were drained off completely before seeding. There was no standing water in the box before the three-leaf stage of rice. About 3 cm water depth was kept until to maturity stage.

Determination of yield and its components

Grain yield and related-traits were determined by following the methods of Peng et al. (2004).

Total nitrogen accumulation and nitrogen use efficiency

Total nitrogen accumulation and nitrogen use efficiency such as nitrogen recovery efficiency (NRE), nitrogen agronomic use efficiency (NAE), nitrogen grain production efficiency (NGRE), and nitrogen harvest index (NHI) were measured according to the methods of Pan et al. (2017).

Roots sampling and measurements

Root sampling measurements were accomplished according to Pan et al. (2016).

Root enzyme activities assay

The activities of nitrate reductase (NR), glutamine synthetase (GS) and glutamate synthetase (GOGAT) in rice roots were determined according to Li.(2006).

Experimental design and statistical analyses

The stainless steel-boxes were arranged in randomized complete design with 4 stainless steel-boxes in each treatment. All statistical analyses were performed by using Statistix 8 (Analytical software, Tallahassee, Florida, USA). The data were analyzed by one-way analysis of variance and the differences amongst means were separated by using least significant difference (LSD) test at 5% significance level.

Results

Grain yield and its components

Grain yield and its components varied with different nitrogen fertilization depths in both rice cultivars (Table 1). D12 produced the highest grain yield than all other treatments whilst differences in the grain yields did not differ significantly between D8 and D12 treatments in *YXYZ*. In contrast to the other treatments, the lowest grain yield was found under the CK treatment. Both D8 and D12 increased grain yields by 72.91 and 81.84%, respectively, compared with CK. Compared to the differences between the various yield components among all the treatments, productive panicle was significantly higher than that under both D8 and D12 treatments, respectively. However, there was no remarkable difference in productive panicle between D8 and D12. The lowest productive panicle was recorded under CK. No significant difference was observed in productive panicle between CK and D0 treatments. The highest spikelet per panicle was found for D12, however, the lowest was found under CK and D0. Furthermore, significant improvement in 1000-grain-weight was found under D12 in *YXYZ*, compared with CK and D0. Furthermore, there was also significant difference in grain-filling percentage under D12 than all other treatments.

Total nitrogen accumulation

Total nitrogen accumulation (TNA) of leaves and stems in two rice cultivars at different growth stages were depicted in Figure 1. Compared with the CK, significantly higher TNA of leaves in both rice cultivars at both heading stage (HS) and maturity stage (MS) were recorded for D8 and D12, respectively. There was no significant difference in TNA of leaves between D8 and D12 at both HS and MS. No pronounced difference in TNA of leaves was found at HS and MS among CK, D0 and D4 treatments. And there was no significant difference in TNA of leaves at mid-tillering stage (Mt) among all the treatments. TNA of stems at MS in both rice cultivars was also similar (Fig 1). The D12 treatment resulted in the highest TNA of stem among all the treatments followed by D8 and D4, whilst the lowest was found under the CK treatment. However, there was apparently different trend in TNA of stem at PI for two rice cultivars. Significantly higher TNA of stems at PI in *TY998* and *YXYZ* was recorded for D0 and D4, respectively.

Nitrogen use efficiency

Nitrogen fertilization depth significantly affected NAE, NRE, nitrogen grain production efficiency (NGPE) and nitrogen harvest index (NHI) in *TY998* and *YXYZ* (Table 2). The highest NAE was found under D12 treatment, followed by the D8 and the D4, while the lowest was found in D0 treatment in both *TY998* and *YXYZ*. The significant difference in NAE was also found among all the treatments. The same trend happened in NRE among all the treatments. There was significant difference in NRE among all the treatments. The D12 treatment resulted in the highest NRE among all the treatments followed by D8 and D4, while the lowest was found under the D0 treatment. NAE and NRE of D12 was increased by 165.42 and 129.45% compared to D0, respectively. In contrast to the other treatments, the NGPE in the CK treatment was the lowest for both *TY998* and *YXYZ*, respectively. No significant difference in NGPE was found between D8 and D12 treatments for two rice cultivars, respectively. However, the CK showed the highest NHI, while the D8 had the lowest NHI among all the treatments. No significant difference was also found in NHI among D4, D8, and D12 treatment for two rice cultivars (Table 2).

Root morphological characteristics

Effects of nitrogen fertilization depth on root morphological characteristics at heading stage for two rice cultivars were presented in Fig 2a and Fig 2b. Compared with the CK, significantly ($P \leq 0.05$) higher total root length per hill, total root superficial area per hill, average root diameter per hill and total root volume per hill were recorded for D12 treatment for *Tianyou998*. However, no significant difference in total root length, total root superficial area, average root diameter and total root volume were found between D8 and D12 treatment. The same trend happened for *YXYZ*. The D12 treatment significantly ($P \leq 0.05$) improved total root length per hill, total root superficial area per hill, average root diameter and total root volume per hill as compared with the CK. However, there was no significant difference in total root superficial area and total root volume per hill among D4, D8 and D12 treatment.

Root enzyme activities

There were significant differences in root enzyme activities at the heading stage in both two rice cultivars (Table 3). D12 produced the highest nitrate reductase (NR) and glutamine synthetase activity (GOGAT) activities, however, the CK treatment resulted in the lowest NR and GOGAT activities. And significant differences in NR and GOGAT were also found between CK and D12 treatment. There were also significant differences in NR and GOGAT under D4 and D8 treatment compared to the CK treatment, respectively. Compared to the CK treatment, significantly higher GS activity was found than that under D8 and D12 treatments in both two rice cultivars. However, there was no significant difference in GS activity between D8 and D12 treatment.

Relationship between root morphological characteristics and nitrogen recovery efficiency

Correlations among root morphological characteristics at the heading stage and their relationships with NRE are presented in Table 4. NRE had significant and positive correlations with root superficial area (RSA), average root diameter (ARD), and total root volume for two rice cultivars, however, no significantly positive correlation was recorded between NRE and total root length (TRL) at 5% probability level. There were also significant and positive correlations among total root volume (TRL) and RSA and ARD. And significantly positive correlation was found between ARD and RSA. At the same time, there was significantly positive correlation between RSA and TRL at the probability level of 1% (Table 4).

Discussion

Deep placement of nitrogen fertilizer is an alternative for increasing the N use efficiency of DSR besides minimizing the adverse effects of fertilizers on the environment. In present study, the results showed that both D8 and D12 produced higher grain yields compared with all other treatments. The lowest grain yield was observed under the CK treatment (Table 1). Reasonable N application could improve rice grain yield (Peng et al., 2006). Previous study showed that fertilizer deep placement could significantly increase rice grain yields in comparison to surface broadcasting (Alimata et al., 2015; Azmul H et al., 2016). However, some studies found no effects of deep N placement on grain yields (Setyanto et al., 2000; Maria et al., 2016). We found that deep placement of N fertilizer could increase grain yield due to the increase of productive panicle and spikelet number. The main reasons were for larger leaf area index, and stronger enzyme activities of leaves at the late growth stage (Table 3), which can product more carbohydrate by photosynthesis.

It has been well documented that the effects of deep placement of N fertilizer on nitrogen absorption and utilization (Kirda et al., 2005; Geng et al., 2015; Azmul et al., 2016); however, few studies have focused on the differences in fertilization deep placement depth on crop growth. Our results indicated that significantly higher TNA of leaves in both rice cultivars were recorded for both D8 and D12. And the D12 treatment also resulted in highest TNA of stem among all the treatments followed by D8 and D4, whilst the lowest was found for CK (Fig 1). Huda et al. (2016) found that deep placement of urea birquettes of NPK could significantly increase NRE than broadcast prilled briquettes because of slow movement of $\text{NH}_4^+\text{-N}$ from the deep soil layer to the soil's surface or floodwater. Liu et al. (2015) also observed that compound fertilizer point deep placed at 10 cm depth significantly decreased cumulative ammonia volatilization (AV) and increased NRE, nitrogen partial factor productivity, nitrogen agronomic efficiency, and grain yield in no-tillage paddy fields compared to deep placed at 5 cm and 20 cm depths treatments. In present study, the highest NAE and NRE were found under D12 treatment, while the lowest was found in D0 treatment in both *TY998* and *YXYZ* (Table 2), which was consistent with the finding of Li et al (2015). Yao et al. (2018) found that nitrogen deep placement could increase the contact of nitrogen fertilizer granules with soil, decrease nitrogen losses through runoff and AV. The D0 treatment (surface broadcasting) resulted in the lowest NRE in our study. This result agrees with Xu et al. (2013), who found that surface broadcasting ammonium bicarbonate resulted in lower nitrogen recovery efficiency because of much higher ammonia volatilization (AV) compared to urea and control released urea, whilst deep placement of N could reduce AV rates and lag the AV process.

Sun et al. (2015) found that both 10 cm and 15 cm deep fertilization could significantly promoted greater taproot length and dry weight. In present study, we observed that deep placement of N fertilizer (both D8 and D12) could promote rice root growth (such as larger root length, root superficial area, and thicker

root diameter) (Fig 2a, 2b), increase nitrogen uptake by rice plants and improve nitrogen utilization efficiency, compared with all other treatments (Table 2). However, least total root length per hill, total root superficial area per hill, average root diameter per hill and total root volume per hill were recorded for D0 treatment for both rice cultivars. The main reason was that broadcasting N fertilizer onto the soil surface resulted in more AV due to the higher $\text{NH}_4^+ - \text{N}$ concentration in the flood water at the early growth stage. And the root of rice plant is very small and less plant N demand. However, there is no need to maintain a high N concentration when rice plant requires more N during the late growth stage. Our results agreed with the finding of Li et al. (2016), who found that surface broadcasting fertilizer onto the soil surface as basal fertilizer markedly decreased NRE due to higher $\text{NH}_4^+ - \text{N}$ concentration in the flood water because of smaller rice root and less plant N demand. Correlation analysis also indicated that there were significantly positive correlations between root superficial area (RSA), average root diameter (ARD), total root volume (TRV) and NRE (Table 4). These results clearly showed that deep placement of N fertilizer could promote rice root growth, thus, absorb more N, increase nitrogen recovery efficiency.

NR is the rate-limiting enzyme in NO_3^- assimilation. Numerous studies have reported that reasonable N fertilization could increase NR and GS activities and nitrogen accumulation (Zhong et al., 2018; Liu et al., 2019). GS and GOGAT are key enzymes in incorporation with NH_4^+ into amides and amino acids (Lawlor, 2002; Masclaux-Daubresse et al., 2006). Tian et al. (2018) observed that excess of N fertilization did not increase the leaf area index, flag leaf photosynthesis rate, flag leaf NR and GS activities, dry matter accumulation, and N uptake in wheat. Wang et al. (2018) also found that higher N application increased carbon and N content, NR and GS activities in rice leaves, while it decreased GOGAT and glutamate dehydrogenase activities. In this study, we found that D12 produced the highest nitrate reductase (NR) and glutamine synthetase activity (GOGAT) of roots at the heading stage for both two rice cultivars. Compared to the CK treatment, significantly higher GS activity was found than that under D8 and D12 treatments in both two rice cultivars. No markedly differences were found in GOGAT and GS between D8 and D12. Our finding was not consistent with Wang et al. (2018), which was probably influenced by the nitrogen rate.

Conclusion

In summary, these results preliminarily suggest that both 8 cm and 12 cm are relatively reasonable fertilization depths when the practice of ammonia bicarbonate fertilizer is used in direct-seeded rice production. But from the viewpoint of diminishing the production cost, 8 cm deep fertilization should be adopted in actual farming. Because 12 cm deep fertilization may need more power input, and thus resulting in higher cost of production.

Abbreviations

ARD: Average root diameter; DSR: Direct-seeded rice; GOGAT: Glutamine synthetase; GS: Glutamine synthetase; HS: Heading stage; KCL: Potassium chloride; Mt: Mid-tillering stage; MS: Maturity stage; NAE: Nitrogen agronomic efficiency; NGRE: Nitrogen grain production efficiency; NHI: Nitrogen harvest index; NR: Nitrate reductase; NRE: Nitrogen recovery efficiency; RSA: Root superficial area; SOP: Super phosphate; TNA: Total nitrogen accumulation; TRL: Total root length; TY998: Tianyou 998; YXYZ: Yuxiangyouzhan;

Declarations

Ethics approval and consent to participate

Two rice cultivars, Tianyou998 and Yuxiangyouzhan, are common and broadly cultivated varieties in China. The seeds were invented by Rice Research Institute, Guangdong Academy of Agricultural Science. Our present work didn't use transgenic technology or material therefore they do not require ethical approval. The experimental research on plants performed in this study complies with institutional, national and international guidelines. The experimental study was conducted in accordance with local legislation.

Consent for publication

Not applicable

Availability of data and material

The datasets generated and analysed during the current study are available from the corresponding author on reasonable request

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

S. G. and X. R. initiated and designed the research, Y. Y., P. S., H.T, Z. W. and M. Y. performed the experiments, Y. Y. and P. S. analyzed the data and wrote the manuscript, Umair and S. G. revised and edited the manuscript and also provided advice on the experiments.

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References

1. Albornoz F. Crop responses to nitrogen over fertilization: a review. *Sci. Hortic*, 2016, 205: 79–83.
2. Alimata Bandaogo, Fofana Bidjokazo, Sansan Youl, Ebenezer Safo, Robert Abaidoo, Opoku Andrews. Effect of fertilizer deep placement with urea supergranule on nitrogen use efficiency of irrigated rice in Sourou Valley (Burkina Faso). *Nutr Cycl Agroecosyst*, 2015, 102:79–89.
3. Ashraf U, Mo ZW, Tang X. Direct seeded vs transplanted rice in Asia: climatic effects, relative performance, and constraints, a comparative outlook. In: Verma DK, Srivastav PP, Nadaf AB, (Eds). *Agronomic rice practices and postharvest processing: production and quality improvement*. CRC Press, 2018, 27–76
4. Azmul Huda, Yam Kanta Gaihre, M R Islam, Upendra Singh, Md R Islam, Joaquin Sanabria, M Abdus Satter, Hasina Afroz, Alee Halder, M Jahiruddin. Floodwater ammonium, nitrogen use efficiency and rice yields with fertilizer deep placement and alternate wetting and drying under triple rice cropping systems. *Nutr Cycl Agroecosyst*, 2016, 104:53–66.
5. Chen S, Cai SG, Chen X, Zhang GP. Genotypic differences in growth and physiological responses to transplanting and direct seeding cultivation in rice. *Rice Sci*, 2009, 16 (2):143–150.
6. Chen S, Liu SW, Zheng X, Yin M, Chu G, Xu CM, Yan JX, Chen LP, Wang DY, Zhang XF. Effect of various crop rotations on rice yield and nitrogen use efficiency in paddy-upland systems in southeastern China. *The Crop Journal*, 2018 (6): 576–588.
7. Chien SH, Prochnow LI, Cantarella H. Recent development of fertilizer production and use to improve nutrient efficiency and minimize environmental impacts. *Adv Agron*, 2009, 102:267–322.
8. Geng JB, Sun YB, Zhang M, Ch Li CL, Yang YC, Liu ZG, Li SL. Long-term effects of controlled release urea application on crop yields and soil fertility under rice-oilseed rape rotation system. *Field Crops Res*, 2015, 184: 65–73.
9. Guan CY. *Modern crop cultivation*. Chinese Higher Education Press, 2011, Beijing (in Chinese).
10. Guo GH, Liu XJ, ZhangY, Shen JL, Han WX, Zhang WF, Christie P, Goulding KWT, Witousek PM, Zhang FS. Significant acidification in major Chinese croplands. *Science*, 2010, 327(19): 1008–1010.
11. Kapoor V, Singh U, Patil SK, Magre H, Shrivastava LK, Mishra VN, Das RO, Samadhiya VK, Sanbria J, Diamond R. Rice growth, grain yield, and floodwater nutrient dynamics as affected by nutrient placement method and rate. *Agron J*, 2008, 100:526–536.
12. Ke J, He RC, Hou PF, Ding C, Ding YF, Wang SH, Liu ZH, Tang S, Ding CQ, Chen L. Li GH. Combined controlled-released nitrogen fertilizers and deep placement effects of N leaching, rice yield and N recovery in machine-transplanted rice. *Agric, Ecosyst. Environ*, 2018, 265: 402–412.
13. Lawlor, D W. Limitation to photosynthesis in water-stressed leaves: stomata VS. metabolism and role of ATP. *Ann. Bot*, 2002, 89: 871–885.
14. Liu K, Yang R, Lu J, Wang X, Lu B, Tian X, & Zhang Y. Radiation Use Efficiency and Source-Sink Changes of Super Hybrid Rice under Shade Stress during Grain-Filling Stage. *Agronomy Journal*, 2019;111:1–11.
15. Liu K, Deng J, Lu J, Wang X, Lu B, Tian X & Zhang Y. High nitrogen levels alleviate yield loss of super hybrid rice caused by high temperatures during the flowering stage. *Frontiers in Plant Science*, 2019, 10, 357.
16. Maria Arlene A. Adviento-Borbe, Bruce Linquist. Assessing fertilizer N placement on CH₄ and N₂O emissions in irrigated rice systems. *Geoderma*, 2016, 266: 40–45.
17. Masclaux-Daubresse C, Reisdorf-Cren M, Pageau K, Lelandais M, Grandjean O, Kronenberger J. Glutamine synthetase-glutamate synthase pathway and glutamate dehydrogenase play distinct roles in the sink-source nitrogen cycle in tobacco. *Plant Physiol*, 2006, 140:44–456.
18. Sun HY, Li XK, Ren T, Cong RH, Lu JW. Effects of fertilizer in shallow soils on growth and distribution of rice roots at seedling stage. *Chin.Agric.Sci*, 2014, 47(12):2476–2484 (in Chinese with English abstract).
19. Kirda C, Topcu S, Kaman H, Ulger AC, Yazici A, Cetin M, Derici MR. Grain yield response and N-fertilizer recovery of maize under deficit irrigation. *Field Crops Res*, 2005, 93:132–141.
20. Li HS. *Principles and Techniques of Plant Physiology and Biochemistry*, Higher Education Press, 2006, Beijing, China (in Chinese).
21. Li S, Jiang H, Wang J, Wang Y, Pan S, Tian H, Duan M, Wang S, Tang X. and Mo, Z. Responses of plant growth, physiological, gas exchange parameters of super rice to rhizosphere temperature at the tillering stage. *Scientific Reports*, 2019, 9: 10618
22. Li XW, Wang HY, Zhou JM, Hu FQ, Zhu DJ, Chen ZM, Liu YZ. Effect of N fertilization pattern on rice yield, N use efficiency and fertilizer–N fate in the Yangtze River Basin, China. *PLoS One*, 2016:1–20.

23. Liu H, Hussain S, Zheng M, Peng S, Huang J, Cui K, Nie L. Dry direct-seeded rice as an alternative to transplanted-flooded rice in Central China. *Agron.Sustain. Dev*, 2015, 35: 285–294.
24. Liu TQ, Fan DJ, Zhang XX, Chen J, Li CF, Cao CG. Deep placement of nitrogen fertilizer reduces ammonia volatilization and increases nitrogen utilization efficiency in no-tillage paddy fields in central China. *Field Crops Res*, 2015, 184: 80–90.
25. Mahajan G, Chauhan BS, Timsina J, Singh PP, Singh K. Crop performance and water- and nitrogen-use efficiencies in dry-seeded rice in response to irrigation and fertilizer amounts in northwest India. *Field Crops Res*, 2012, 134: 59–70.
26. Miao YX, Stewart Bobby A, Zhang FS. Long-term experiments for sustainable nutrient management in China. a review. *Agron. Sustian. Dev*, 2011, 31(2), 397–414.
27. Pan SG, Huang SQ, Zhai J, Wang JP, Cao CG, Cai ML, Zhan M, Tang XR. Effects of N management on yield and N uptake of rice in Central China. *J. Integr. Agric*, 2012, 11(12):1993–2000.
28. Pan SG, Liu HD, Mo ZW, Patterson Bob, Duan MY, Tian H, Hu SJ, Tang XR. Effects of nitrogen and shading on root morphologies, nutrient accumulation, and photosynthetic parameters in different rice genotypes. *Sci. Rep*, 2016, 6: 32148.
29. Pan SG, Wen XC, Wang ZM, Ashraf Umair, Tian H, Duan MY, Mo ZW, Fan PS, Tang XR. Benefits of mechanized deep placement of nitrogen fertilizer in direct-seeded rice in South China. *Field Crops Res*, 2017, 203: 139–149.
30. Peng SB, Huang JL, Sheehy John E, Laza Rebecca C, Viseras Romeo M, Zhong XH, Centeno Grace S, Khush Gurdev S, Cassman Kenneth G, 2004. Rice yields decline with higher night temperature from global warming. *PNAS*, 101: 9971–9975.
31. Peng SB, Buresh Roland J, Huang JL, Yang JC, Zou YB, Zhong XH, Wang GH, Zhang FS. Strategies for overcoming low agronomic nitrogen use efficiency in irrigated rice systems in China. *Field Crops Res*, 2006, 96: 37–47.
32. Peng SB. Dilemma and way-out of hybrid rice during the transition period in China. *Chin.Agric.Sci*, 2016, 42(3): 313–319 (in Chinese with English Abstract).
33. Rochette P, Angers DA, Chantigny MH, Gasser MO, MacDonald JD, Pelster DE, Bertrand D. Ammonia volatilization and nitrogen retention: How deep to incorporate urea?. *J. Environ. Qual*, 2013, 42(6): 1635–1642.
34. Savant NK, Stangel PJ. Deep placement of urea super granules in transplanted rice: principles and practices. *Fertil Res*, 1990, 25:1–83.
35. Setyanto P, Makarim AK, Fagi AM, Wassmann R, Buendia LV. Crop management affecting methane emissions from irrigated and rainfed rice in Central Java (Indonesia). *Nutr. Cycl. Agroecosyst*, 2000, 58: 85–89.
36. Su W, Liu B, Liu XW, Lia XK, Ren T, Cong RH, Lu JW. Effect of depth of fertilizer banded-placement on growth, nutrient uptake and yield of oilseed rape (*Brassica napus* L.). *Europ. J. Agronomy*, 2015, 62: 38–45.
37. Tao Y, Chen Q, Peng SB, Wang WQ, Nie LX. Lower global warming potential and higher yield of wet direct-seeded rice in Central China. *Agron.Sustain. Dev*, 2016, 36:24.
38. Wang DY, Xu CM, Ye C, Chen S, Chu G, Zhang XF. Low recovery efficiency of basal fertilizer-N in plants does not indicate high basal fertilizer-N loss from split-applied N in transplanted rice. *Field Crops Res*, 2018, 229: 8–16.
39. Wang WQ, Peng SB, Liu HY, Tao Y, Huang JL, Cui KH, Nie LX. The possibility of replacing puddled transplanted flooded rice with dry seeded rice in central China: A review. *Field Crops Res*, 2017, 214:310–320.
40. Wang ZQ, Zhang WY, Beebout Sarah S, Zhang H, Liu LJ, Yang JC, Zhang JH. Grain yield, water and nitrogen use efficiency of rice as influenced by irrigation regimes and their interaction with nitrogen rates. *Field Crops Res*, 2016, 193:54–69.
41. Xu JZ, Liao LX, Tan JY, Shao XH. Ammonia volatilization in gemmiparous and early seedling stages from direct seeding rice fields with different nitrogen management strategies: A pots experiment. *Soil Tillage Res*, 2013, 126: 169–176.
42. Yao YL, Zhang M, TianYH, Zhao M, Zhang BW, Zhao M, Zeng K, Yin B. Urea deep placement for minimizing NH₃ loss in an intensive rice cropping system. *Field Crops Res*, 2018, 218: 254–266.
43. Zhong C, Cao XC, Bai ZG, Zhang JH, Zhu LF, Huang JL, Jin QY. Nitrogen metabolism correlates with the acclimation of photosynthesis to short-term water stress in rice (*Oryza sativa* L.). *Plant. Physiol. Biochem*, 2018, 125: 52–62.
44. Zhou YJ, Li XX, Cao J, Li Y, Huang J L, Peng SB. High nitrogen input reduces yield loss from low temperature during the seedling stage in early-season rice. *Field Crops Res*, 2018, 228: 68–75.
45. Tian ZW, Zhong W, Liu XX, Gu SL, Yu JH, Zhang L, Zhang WW, Jiang D, Cao WX, Dai TB. Postponed and reduced basal nitrogen application improves nitrogen use efficiency and plant growth of winter wheat. *J. Integr. Agric*, 2016, 17: 2648–2661.
46. Wang JL, Fu ZS, Chen GF, Zou GY, Song XF, Liu FX. Runoff nitrogen losses and related metabolism enzyme activities in paddy field under different nitrogen fertilizer levels. *Environ. Sci. Pollut. Res*, 2018, 25:27583–27593.

Tables

Due to technical limitations, all Table(s) are only available as a download in the supplemental files section.

Figures

Note: a & b: leaf; c & d: stem; Mid-tillering stage, Mt; Panicle initiation, PI; Heading stage, HS; Maturity stage, Ms.

Figure 1

Total nitrogen accumulation of leaf and stem at different growth stages.

Note: a, total root length per hill; b, total root superficial area per hill; c, average root diameter; d, total root volume per hill

Figure 2

a. Root morphological characteristics at heading stage of Tianyou998. b. Root morphological characteristics at heading stage of Yuxiangyouzhan.

Supplementary Files

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