Nitrate uptake positively correlates with phosphorus use efficiency in rice

Phosphorus (P) is one of the essential elements for plants but is frequently deficient in agricultural fields. P fertilizer is expected to be depleted in the future, and in light of the soaring cost of fertilizers, farmers cannot apply sufficient P fertilizers in many developing countries where food security is particularly threatening. Thus, for the production of rice, which is the major agricultural crop in many of these developing countries lacking ample supply of P, developing P-efficient rice variety that efficiently absorb P and/or efficiently produce biomass with limited amount of P is a promising approach. However, previous investigations suggest that P use efficiency in rice is controlled by many small-effect genetic factors, thus rendering a conventional breeding approach of limited use. Our previous metabolomics study showed that several amino acids and nitrogen (N)-containing metabolites serve as markers for P use efficiency, suggesting that N utilization might be a key for efficiency use of P. Therefore, in the current study, we examined the effect of different N sources on P use efficiency.

Addition of nitrate lowered root P concentration under low P supply compared with the condition when the same amount of N was applied solely as ammonium (Fig. 1A). This resulted in higher P use efficiency in nitrate-treated plants (Fig. 1B). Comparison of gene expression patterns in 5 rice accessions that differ in P use efficiency showed that, compared with P-inefficient genotypes such as IR64 and Taichung, P-efficient genotypes such as DJ123, Mudgo, and Yodanya had lower uptake ratio of ammonium to nitrate (Fig. 2A). Accordingly, the expression of *NRT1.1B*, which encodes a nitrate transporter that likely highly contributes to nitrate uptake, was higher in P-efficient genotypes than P-inefficient genotypes (Fig. 2B). On the other hand, the expression of *AMT1.1* that encodes one of the major ammonium transporters tended to be lower in P-efficient genotypes (Fig. 2C).

A strong positive correlation was observed between the uptake efficiency of nitrate examined under the hydroponic condition and P uptake efficiency previously examined in a low P field (Fig. 3). These observations suggest that utilization of nitrate and P are interconnected, and improvement of nitrate use may increase P use efficiency. This is in accordance with a previous hypothesis that nitrate uptake increases P solubilization in the rhizosphere and contributes to increased P uptake. Further studies are necessary to confirm if altered N fertilization scheme affects P use efficiency of rice in the field and to discover the causal gene for such genotypic differences.

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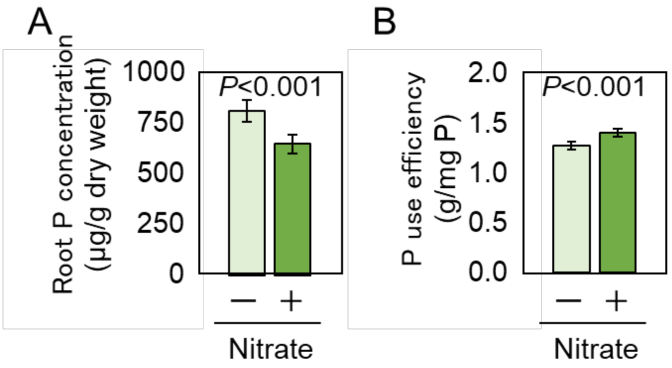

Fig. 1. Effects of nitrate on root P concentration and P use efficiency

Root P concentration (A) and P use efficiency (defined as the biomass produced per unit P) (B) of plants (cultivar: Taichung) with (+) or without (-) nitrate ion in culture solution. Mean values and standard deviations (n=4) are shown. Two-tailed Student's *t*-test was performed, and the resultant *P* value is indicated.

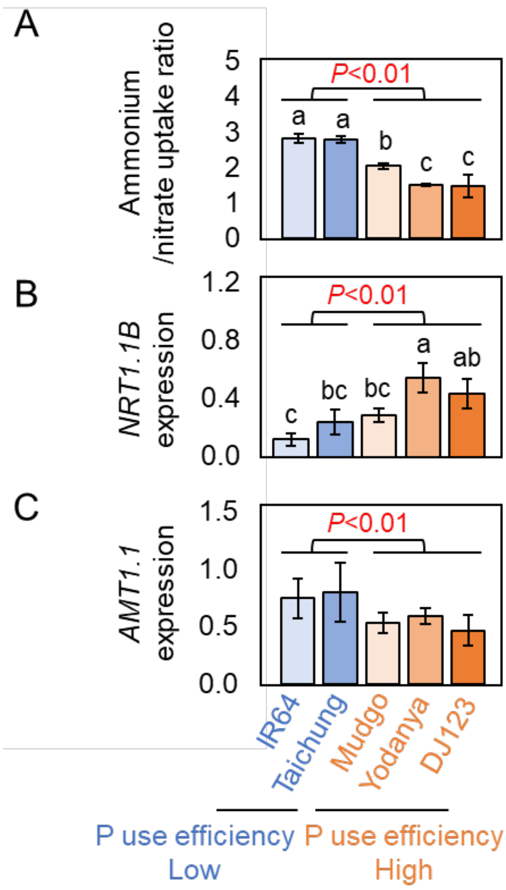

Fig. 2. N use patterns in rice accessions contrasting in P use efficiency

(A) Ratio of ammonium and nitrate uptake in roots. (B,C) The expression of *NRT1.1B* (B) and *AMT1.1* (C) in root. Mean values and standard deviations (n=4) are shown. One-way analysis of variance was performed, and the values among different genotypes were compared by Tukey-Kramer *post-hoc* test. Different alphabets indicate that the values are different at the significance level of *P*=0.05. Wilcoxon's rank sum test was further performed to further compare the values obtained from the groups with high or low P use efficiency, and the resultant *P* value is indicated.

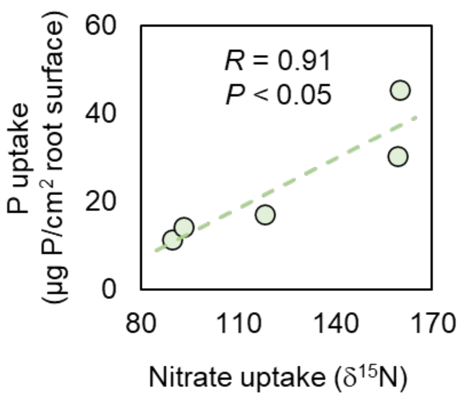

Fig. 3. Relationship between the uptake efficiency of nitrate and P

Nitrate uptake efficiency in P-limiting hydroponic condition (horizontal axis) and P uptake efficiency in P-limiting upland field (vertical axis) were compared in 5 genotypes that differ in P use efficiency. Pearson's correlation coefficient and the significance level of the correlation are indicated.

Reference: Ueda and Wissuwa (2022) *Plant and Soil* 481: 547–561.