【Grant-in-Aid for Scientific Research (S)】

Elucidating integration mechanisms of plant nutritional information as a basis for Liebig's minimum law

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Project Information	Project Number : 22H04977 Project Period (FY) : 2022-2026 Keywords : Plant, Primary macronutrients, nutrient signal, gene expression control, Liebig's law of the minimum	

Purpose and Background of the Research

●Outline of the Research

Plants need to grow in response to diverse nutritional environments. More than 150 years have passed since the proposal of Liebig's law of the minimum that only the most deficient nutrient of the various nutrients affects the growth rate of plants. However, the mechanism integrating various nutritional information, which is necessary for this law, remains elusive. This project aims to elucidate the mechanism for integrating nutritional information and how plants optimize the acquisition of primary macronutrients (N, P, and K) required for plant growth abundantly in diverse nutritional environments. Because of the positive correlation between N acquisition and the photosynthesis rate, the possibility that this mechanism integrates nutritional information from the aerial part will also be explored in this project (Figure 1).

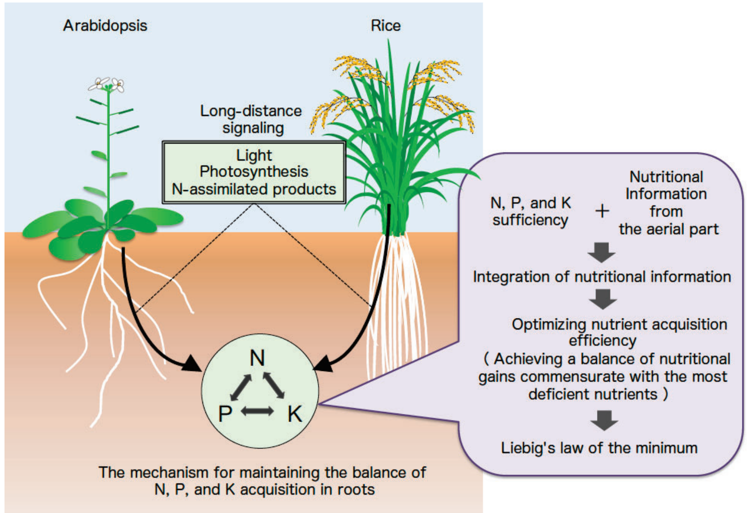

Figure 1. Conceptual diagram of optimizing nutrient acquisition efficiency in plants

● Plant nutrient signals

Nutritional status information is transmitted as nutrient signals. For example, nitrate acts as an N nutrient signal. Nitrate promotes N utilization by NLP transcriptional activators that activate the genes involved in nitrate uptake and N assimilation. NLP proteins also promote the expression of *NIGT1* genes encoding transcriptional repressors involved in the suppression of nitrate responses. Therefore, the difference in the timing of NLP and NIGT1 activity peaks elaborately regulates nitrate uptake and N assimilation, while reductions in *NIGT1* expression when nitrate is insufficient also activate the genes involved in N acquisition.

●Mutual Regulation of N and P Acquisition

PHR1 responsible for P deficiency responses activates *NIGT1* responsible for suppressing nitrate uptake, leading to reduced nitrate uptake during P deficiency. PHR1 activity is suppressed through forming a complex with SPX protein and a compound containing phosphate when P is sufficient, while when P is deficient, PHR1 is released from this complex, inducing P deficiency responses. NIGT1 suppresses *SPX* expression, promoting P acquisition when nitrate is sufficient (Figure 2). Molecular mechanisms of mutual regulations of N, P, and K acquisition may be key to Liebig's law of the minimum.

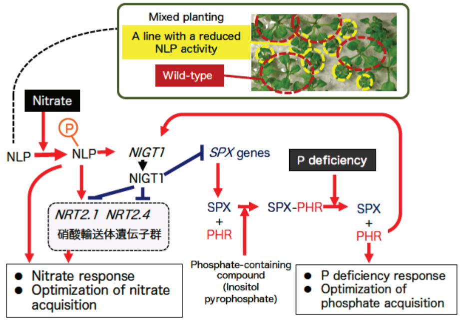

Figure 2. The molecular mechanism for the mutual regulation of N and P acquisition

Expected Research Achievements

Using Arabidopsis and rice, we will elucidate molecular mechanisms of the mutual regulation of the acquisition of N, P, and K underlying Liebig's law of the minimum.

●Comprehensive elucidation of the mechanisms for N responses.

Although the mechanism for nitrate responses is becoming better understood, the nitrate sensor has not yet been determined. Furthermore, the relationship between nitrate responses and N starvation responses is unclear. We will address these issues.

●Elucidation of the mutual regulations of K acquisition and N and P acquisition

Nitrate supply enhances K absorption. However, the molecular mechanisms balancing N, P, and K acquisition are unknown. Thus, we will elucidate this mechanism to elucidate how the balance of the acquisition of N, P, and K is maintained.

●Elucidation of long-distance signaling involved in N, P, and K acquisition

Physiology in leaves likely influences N, P, and K acquisition in roots through long-distance signaling. To reveal such signaling, we employ a new approach. Because we have successfully identified genes that regulate the N starvation response in roots by co-expression analysis (Figure 3), we apply this approach to explore new connections between gene expression patterns in shoots and roots and then find relevant signaling.

Elucidation of the regulatory network for N, P, and K acquisition will pave the way to improve crop production in diverse nutritional environments. For example, we have successfully improved light-energy efficiency in low N environments with an N response–related factor (Figure 4).

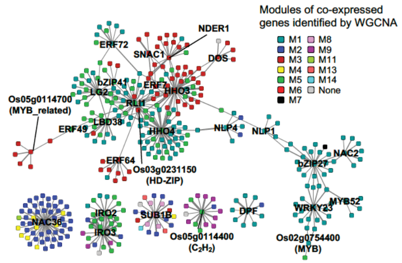

Figure 3. Model diagram of gene regulatory network for nitrogen starvation response in rice.

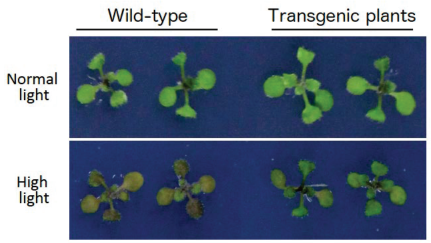

Figure 4. Genetically modified plants with enhanced light utilization in low N environments

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