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主　論　文　の　要　旨

論文題目　Enhancing phosphorus use efficiency of rice with P-localized application in P-deficient paddy field
(リン欠乏水田における局在施用によるイネのリン酸利用効率の向上)

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論　文　内　容　の　要　旨

Phosphorus is crucial for plant growth, especially in rice, a vital crop in Sub-Saharan Africa. However, phosphorus deficiency in soil is a significant challenge, limiting crop yield. Conventional application of fertilizer through broadcasting is often ineffective due to phosphorus fixation in soil and the limited purchasing capacity of farmers. Recent studies suggest phosphorus localized application, such as P-dipping, as a cost-effective alternative. P-dipping involves dipping rice seedling roots in a phosphorus-enriched slurry before transplanting them into the paddy field. This method has shown promising results in increasing yield while reducing phosphorus application rates. However, it also presents challenges such as the risk of salt stress and transplanting shock of seedlings, particularly when phosphorus concentration is high and in high-*temperature* environments. Despite these challenges, P-dipping offers potential benefits, including improved resilience to submergence stress and shortened growth durations. However, limited knowledge exists regarding the role of roots in the efficacy of this technique. We hypothesized that the variability of the root volume of seedlings may impact the amount of P-slurry adhered to roots. Therefore, our study aims to determine the optimal seedling age for maximizing biomass and yield effects from P-dipping. Additionally, further research is needed to understand the synergy effect of the P-dipping and root phenotypes of specific genotypes for optimal application.

In our first chapter, we assume that a higher root volume of older seedlings may lead to an increase in P-slurry. However, old seedlings with low vigor pose risks of transplanting shock, exacerbated by fertilizer burning from high P concentration of P-dipping. On the other hand, young seedlings recover faster potentially mitigating these risks, but have relatively small root volume for significant transfer of the phosphorus slurry to the main field. Therefore, our pot experiments implying various seedling ages were conducted to investigate the change of P-amount adhered to various seedling ages. Our results identified that the amount of slurry from P-dipping increased not linearly but in a sigmoidal pattern against seedling age, plateauing around 6.0 seedling age. Correspondingly, the effect of P-dipping on initial biomass growth was maximized around the 6.0 seedling age and then was reduced when combined with much older seedlings, attributable to the prolonged period of transplanting shock. Similarly, on-farm trials among 90 farmers' fields in the central highlands of Madagascar were conducted to compare control (no P fertilizer) and P-dipping treatment. After categorizing the seedling age into three groups of young (< 4.5 seedling age), intermediate (4.5–6.3 seedling age), and old (> 6.3 seedling age), our results reported the highest biomass from P-dipping at 40 days after transplanting when combined with the intermediate seedling age. Furthermore, the yield gain of P-dipping (yield difference from P-dipping to control) was also higher with intermediate seedling age than the young seedlings group. It suggests the beneficial effect of using seedlings around 6 leaves with P-dipping. Specifically, 6-leaf seedlings have a higher root volume for adhering to P-enriched slurry than younger seedlings, while also having a lower risk of transplanting shock than older seedlings.

In another Chapter, we conducted a root pin-board experiment involving a mutant genotype called our1, and its wild type (WT). The mutant carries the our1/osbzip1 gene, responsible for inhibiting the total lateral root density by repressing thin S-type lateral roots. We compared P-dipping treatments with uniform P application (P incorporation). Our findings revealed that P-dipping stimulated greater root length, and root length density in the WT, whereas this effect was not observed in the our1 mutant. Additionally, we observed increased proliferation of S-type lateral root length in the WT compared to the our1 under P-dipping. Furthermore, the change in S-type by P-dipping significantly correlates with the change in P uptake when comparing our1 to WT. This suggests that the proliferation of S-type lateral roots under P-dipping plays a crucial role in enhancing P uptake in the WT genotype.

In conclusion, our study highlights the efficacy of P-dipping for addressing phosphorus deficiency in rice cultivation. Intermediate seedling age, around 6.0 leaf age, optimizes biomass and yield effects while mitigating transplanting shock. Furthermore, the proliferation of S-type lateral roots induced by P-dipping significantly enhances phosphorus uptake in specific genotypes. These findings emphasize the importance of seedling age and root characteristics in maximizing the benefits of P-dipping for sustainable rice production in phosphorus-deficient soils. Further research on genetic mechanisms underlying root responses to localized phosphorus application could offer insights for enhancing crop resilience and productivity in such environments.