Summary of Dissertation

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Dissertation Title: Genotypic Variation in Root System Response of Upland New Rice for Africa (NERICA) to Drought Stress and their Interaction with Fertilizer Management

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In sub-Saharan Africa, demand for rice has been increasing rapidly due to increases in per capita consumption and population growth. Approximately 40% of the total rice growing area in the region is rainfed upland; however average yield is estimated at about 1t ha^{-1}. The dissemination and cultivation of New Rice for Africa (NERICA) varieties, which were developed by the Africa Rice Center, is expected to boost yields under upland conditions. Currently, there are 18 NERICA varieties suited for upland cultivation. Among them NERICA 1 and 4 are the most widely cultivated in sub-Saharan Africa. However, inconsistent results for the yield have been reported between the two varieties from various upland cultivation trials conducted under rainfed conditions in some locations in sub-Saharan African countries.

The ability of plant roots to change their morphology (e.g., increased total root length and lateral root elongation) and physiological functions (e.g., alterations in water and nutrient uptake capacity) as environmental conditions change, known as phenotypic plasticity, is a key trait for adaptation of rice plants to drought. In this dissertation, I

therefore hypothesized that the differences between NERICA 1 and NERICA 4 under upland field conditions were because of differences in the drought avoidance mechanisms that are related with root traits. I evaluated the functional roles of root plasticity traits and their contribution to shoot dry matter production under drought. Furthermore, I investigated the effect of fertilizer management on the expression of root plasticity traits expressed under drought.

In chapter 2, I imposed soil moisture gradients using a sloping bed system with depths ranging 30–65 cm and a line source sprinkler system with a uniformly shallow soil layer of 20 cm depth. Varietal differences in shoot and root growths were identified only under moderate drought conditions, 11%–18% v/v of soil moisture content. Further, under moderate drought, in soil conditions where roots could penetrate into the deep soil layer, deep root development was greater in NERICA 4 than in NERICA 1, which contributed to maintaining dry matter production. However, under soil conditions with underground impediment to deep root development, higher shoot dry weight was noted for NERICA 1 than for NERICA 4 at 11–18% v/v of soil moisture content, which was attributed to increased lateral root development in the shallow soil layer in NERICA 1. Thus, the results of chapter 2 showed that NERICA 1 expressed plasticity in root branching at a shallow soil layer while NERICA 4 expressed plasticity in deep root development.

In chapter 3, I aimed to evaluate the effect of nitrogen application on the expression of plasticity in root branching in response to drought of upland NERICA varieties. Different intensities of drought were created by a line source sprinkler under field conditions with uniformly shallow soil in which a deep root trait could not be expressed. In addition, I investigated the functional roles of plasticity in root system development in relation to nitrogen uptake of NERICA varieties under different drought stress conditions using a root-box. As was the case in chapter 1, NERICA 1 enhanced its root system development in response to moderate drought conditions. As a result, shoot dry matter production was maintained compared to well-watered conditions. Furthermore, nitrogen content of shoots was higher in NERICA 1 than NERICA 4 with adequate amount of nitrogen fertilization. When plants were supplied with suboptimal nitrogen fertilization genotypic differences in shoot dry matter production and shoot nitrogen content under moderate drought were not significant because plasticity was suppressed. Thus, in this chapter, I clarified that the expression of plasticity in root branching in response to moderate drought of upland NERICA was enhanced with sufficient nitrogen fertilization.

In chapter 4, I examined the expression of root plasticity and its contribution to dry matter production in response to episodic drought and re-watering throughout the growth season of upland NERICA 1 and NERICA 4. IR72, a lowland variety, and Dular, an upland variety, were used as control varieties. During soil moisture fluctuation, all varieties reduced shoot dry weight relative to well-watered plants, regardless of nitrogen fertilization levels. However, root development for the three upland varieties was enhanced by soil moisture fluctuations, while the opposite was true for the lowland variety. Comparing root development during soil moisture fluctuations, it was revealed that NERICA 1 had greater lateral root development plasticity than NERICA 4. Furthermore, I found that NERICA varieties enhanced lateral root development during the process of soil desiccation, while Dular and IR72 reduced their root growth rate during drought and increased it after re-watering. Both root growth patterns developed from around late tillering to early maturity with sufficient nitrogen fertilization. Through regression analysis between root elongation and shoot growth with fluctuating soil moisture, I showed that an enhanced root system during drought can contribute to shoot growth when sufficient water becomes available.

In chapter 5, I evaluated the effect of phosphorus (P) application on the expression of plasticity in deep root development in response to drought of upland NERICA 1 and 4. I used polyvinyl chloride pots with an internal diameter of 16 cm and a height of 65 cm and exposed rice plants to two soil moisture treatments (drought and well-watered) with varying amounts of P application levels. Stomatal conductance (g_s) and shoot dry weights of NERICA 1 and NERICA 4 were comparable for well-watered plants, regardless of P treatments. On the other hand, under drought conditions, g_s and shoot dry weight of NERICA 4 were significantly higher than those of NERICA 1 when sufficient P was applied. Total root length in the deep soil layer (40–60-cm) was significantly higher in NERICA 4 than NERICA 1 at sufficient P levels but not at suboptimal P application, which was attributed to plastic root development. Hence, I showed that drought-induced plasticity in deep root development of NERICA 4 was clearly expressed at sufficient P levels.

The finding of this dissertation revealed that NERICA 1 and 4 expressed different root plasticity traits in response to moderate drought. I found that NERICA 1 expressed plasticity in root branching in the shallow soil layer while NERICA 4 expressed plasticity in deep root development. In addition, the plasticities in root branching and deep root development were clearly expressed at sufficient application of nitrogen and phosphorus, respectively. Furthermore, the plasticity in root branching of the NERICA varieties was triggered in the process of soil desiccation and contributed to above ground dry matter production in the subsequent re-watering period. Therefore, in order to enhance adaptability of upland rice to drought environments in sub-Saharan Africa, cultivation of varieties with relevant root plasticity traits should be matched with environmental conditions and fertilizer management that optimize their expression and function. Thus, selection of varieties adapted to a target environment coupled with appropriate management would be a better strategy for improving productivity under drought stress environments than by varieties alone.