Summarized version of the thesis

Title: Functional roles of root plasticity in growth as affected by drought stress, nitrogen application, and soil compaction and their interaction in rice

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The relatively low productivity in rainfed lowland rice ecosystem is partly attributed to water stress and nutrient stress, especially N deficiency. Furthermore, soil compaction can cause restricted access of the root system to water and nutrients, and so decrease crop yield. For plant adaptation to such conditions, plants have the ability to developmentally alter its root phenotype and function in response to changing environmental conditions such when subjected to water and nutrient stress as well as soil compaction. Thus, roots play a vital role in the plant's ability to cope with the negative effects of drought stresses, nitrogen deficit or excess and compacted soil in the field. Plastic root system development (root plasticity) is one coping mechanism that has been suggested and validated to play significant roles in plant adaptation to water stress. The previous studies used a set of 54 chromosome segment substitution lines (CSSLs) derived from Nipponbare and Kasalath under field experiments for 3 years in the watertight experimental bed with line source sprinkler system under a rain-out shelter and found out that among 54 CSSLs, only CSSL50 consistently showed significantly higher shoot dry matter production than its parent Nipponbare as the drought intensified due to the expression of developmental plasticity of root system. Experiment 1 and 2 of the dissertation therefore aimed to examine if the expression of plasticity in root system development and its contribution to water uptake and dry matter production would be affected by the levels of N application by evaluating the plasticity in root system development, water uptake and shoot dry matter production under different water and N levels. Moreover, the variability in soil moisture condition is known to affect N form in soil, e.g., NH_4^+ under waterlogging is converted to NO_3^- and/or the mixture of NH_4^+ and NO_3^- under aerobic conditions. Thus, Experiment 3 interpreted whether the root plasticity triggered by water deficit would be affected by the changes of N forms in soil. In addition, the changes of soil moisture content affected soil nutrient availability and is the most important factor influencing soil compaction processes. The compacted soil inhibited shoot and root growth but increased nutrient uptake due to better root-to soil contact. Therefore, Experiment 4 elucidated if soil compaction affect N uptake and the expression of developmental plasticity of root system triggered by mild drought stress and N application interaction.

Two genotypes as Nipponbare and CSSL50 derived from Nipponbare and Kasalath crosses were used for 4 experiments. The fertilizers such as nitrogen (urea:46%N), phosphorus and potassium were applied in the experiment 1, 2 and 4. Experiment 1, the plants were grown under line source sprinkler in a watertight experimental bed with soil moisture gradient ranging from 2.8 to 29.1% w/w of soil moisture content (SMC) at 10 cm depth. Three fertilizer N treatments were used: 60 (low), 120 (standard) and 180 (high) kg N ha^{-1}, which was mixed well with phosphorus and potassium fertilizer at the rate of 50 kg ha^{-1} and applied as basal dressing at 8 days after transplanting (DAT). The plants were harvested 85 DAT. Experiment 2, the plants were grown for 38 days after sowing (DAS) in a PVC rootbox (25 cm x 2 cm x 40 cm, LxWxH) filled with 2.5 kg of air-dried sandy loam soil. Three soil water treatments were imposed:

Continuously waterlogged (CWL) as control, SMC at 25% and 20% w/w for water deficit treatments. Three fertilizer N treatments were applied: 30 mg (low), 60 mg (standard) and 120 mg (high) N with 80 mg phosphorus and 70 mg potassium mixed well with the soil in each root box. Experiment 3, plants were grown in pots for 50 DAS with two water treatments: continuously waterlogged (CWL) as control and 20% w/w of SMC as a water deficit condition. Six N treatments such as NH_4^+-N alone; NH_4^+-N with nitrification inhibitor; NO_3^--N alone; NO_3^--N with nitrification inhibitor; combined NH_4^+-N and NO_3^--N; combined NH_4^+-N and NO_3^--N with nitrification inhibitor were used and applied at the rate of 360 mg N per pot. The source of NH_4^+-N was $(NH_4)_2SO_4$, while that of NO_3^--N was $Ca(NO_3)_2$. The nitrification inhibitor used was dicyandiamide at 100mg per pot. The P from KH_2PO_4, and K from KCl were also added for all treatment combination at the rate of 480 mg and 420 mg, respectively. Each treatment was thoroughly mixed with soil in each pot before sowing seed. Experiment 4, the plants were grown for 38 days after sowing (DAS) in a PVC rootbox (25 cm x 2 cm x 40 cm, LxWxH) filled with air-dried sandy loam soil at bulk density of l.25 g cm^{-3} (control soil) and 1.50 g cm^{-3} (compacted soil). Two water treatments were imposed: Continuously waterlogged (CWL), water deficit treatment at 20% w/w of SMC. Three fertilizer N treatments were applied: 30 mg (low), 60 mg (standard) and 120 mg (high) N with 80 mg phosphorus and 70 mg potassium mixed well with the soil in each rootbox.

In all of 4 experiments, under severe drought stress condition (Experiment 1), well-watered condition (Experiment 1) and as well as CWL condition (Experiment 2, 3 and 4), there was no consistently significant difference between the two genotypes in shoot and root growth regardless of the N levels

(Experiment 1 and 2), N forms (Experiment 3) application and any of bulk density treatments combined with N levels (Experiment 4). In contrast, under water deficit conditions (17-25% w/w of Experiment 1; 20 and 25% w/w of Experiment 2; and 20% w/w of SMC of Experiments 3 and 4), CSSL50 consistently showed significantly higher most of traits such as shoot dry matter production, root parameter and physiological traits at any of the N levels (Experiment 1 and 2), N forms (Experiment 3) application and under both bulk density treatments (Experiment 4). However, the significant greater shoot dry matter production of CSSL50 than Nipponbare due to total root length through promoted lateral root elongation, which is considered as phenotypic plasticity, were expressed more clearly at high N levels than low N level (Experiment 1 and 2). Therefore, nitrogen application enhanced the expression of developmental plasticity of root system triggered by mild drought stress conditions (Experiment 1 and 2), increasing water uptake (Experiment 2) and consequently increased biomass. Moreover, the expression of plastic root system development of CSSL50 triggered by mild drought stress was independent of N forms (Experiment 3). Furthermore, soil compaction reduced shoot and root growth of both Nipponbare and CSSL50 at any of N levels application, but the decreased root system development of Nipponbare was higher than CSSL50 leading to lower dry matter production. The difference between CSSL50 and Nipponbare in total root length due to lateral root length were expressed more pronouncedly at compacted soil (l.50 g cm^{-3}) than control soil treatment (l.25 g cm^{-3}). In other words, soil compaction affected the expression of plasticity in root system development triggered by water deficit condition and N application interaction.

In conclusion, CSSL50 may share similar genetic control with its recurrent parent Nipponbare for root development under CWL, well-watered or severe drought stress conditions. In contrast, CSSL50 consistently showed greater growth performance than Nipponbare under mild drought stress conditions due to its greater ability for plastic root development via the maintenance in nodal root production and promoted lateral root production which increased soil water extractions. The increased soil water extractions then resulted in the maintenance of photosynthesis and ultimately biomass production. Specifically, we interpreted the root plasticity expression of CSSL50 triggered by mild drought stress was affected by N application, soil compaction and their interaction but not by N form.