Effects of Nutrient Elements on Yield, Nitrogen Use Efficiency and Grain Quality of Paddy Rice in Andosol

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Rice (*Oryza sativa* L.) is the most important staple food in the world, feeding more than 50 % of the world's population. Rice production needs to increase to approximately 60 % more than current levels by 2025, corresponding to annual yield increases of at least 1.2 %, to meet the food demands of the growing world population. Increasing fertilizer nutrient input, especially nitrogen (N), phosphorus (P) and potassium (K) fertilizers, has contributed considerably to improved crop yields globally. However, overuse of fertilizer and unbalanced NPK application rates leads to a yield decrease in rice production systems. Appropriate nutrient management is one of the most important factors for improving rice yield and maintaining sustainability. Nitrogen use efficiency (NUE), which relates both to production quantity and environmental safety, is the important index used to evaluate crop production systems. NUE reflects the relative balance between the amount of fertilizer supplied and the amount absorbed or used by a crop to produce grain, biomass or other end-products. Trends in reduction of NUE have been reported due to unbalance between N application and crop demand. Improving NUE becomes an urgent requirement in crop production. Not only N, but also other fertilizers such as P and K may affect NUE but have less been studied. On the other hand, with the rapid economic growth and improved living conditions, consumers pay more attention to rice quality, requiring researchers should also focus on enhancing grain quality. Grain quality is not only controlled by genotype but also affected by field management and environmental conditions. Considering simultaneously genetic and management practices is crucial requirement to achieve the target amelioration of rice-grain quality.

This research aimed to elucidate role of essential nutrient elements on rice yield, NUE and grain quality. Effects of N, P, K, Si and compost (Co) on rice production in two cultivars, Nipponbare and Koshihikari were evaluated in a long-term fertilization paddy field in Andosol. Secondly, the effect of N levels on rice yield, NUE and grain quality in Nipponbare and Koshihikari was investigated in general paddy field. Lastly, the pot experiment was conducted to investigate the effect of N levels on rice growth, NUE and grain quality using different soil media which collected from long-term fertilization plots. The results of study will contribute to improve the efficiency of fertilizer management on rice production in Andosol.

In long-term fertilization study, the application rate for each element in a standard (NPK) plot was 7.5 g m^{-2}. Plots with no fertilizer, with a deficiency or double dose of N, P, and/or K, with Co, and with NPK plus calcium silicate or Co were investigated. Six NUE parameters, N use efficiency for biomass (NUEb), N use efficiency for grain yield (NUEg), recovery efficiency of N (REN), agronomic efficiency of N (AEN), physiological efficiency of N (PEN) and partial factor productivity

of N (PFPN), were measured. Deficiency of P fertilizer had the most severe effect on rice production in Andosol. 2NPK and N2PK plots increased grain yield compared to the NPK plot with the increase being greater in Nipponbare than in Koshihikari. NP and NP2K plots had negligible effects on the grain yield of Nipponbare, while K deficiency slightly decreased the grain yield of Koshihikari. The 2N2P2K plot increase grain yield of Nipponbare 22 - 38 %, while decreased it of Koshihikari 36 - 56 % because of lodging at ripening stage. The NPKSi plot increased grain yield slightly in Koshihikari, by 3 - 9 %, but to a much greater extent in Nipponbare, by 25 % in 2018. For both cultivars, grain yield in the Co plot was higher than that in the Zero plot but grain yield in the NPKCo plot was almost similar to that in the NPK plot. NK, 2NPK, NPKCo and 2N2P2K plots showed reduced NUE parameters. K fertilizer affected negligibly NUE parameters in Nipponbare but the NP plot reduced NUEg and PEN in Koshihikari. The N2PK plot increased REN, AEN and PFPN, but usually decreased NUEb, NUEg and PEN compared to the NPK plot, showing that N absorbed by plants was not always converted to biomass or grain efficiently. The NPKSi plot increased NUE parameters in both cultivars in 2018. The NUEb, NUEg and PEN of Koshihikari decreased considerably in 2019 and were lower than those of Nipponbare, although the higher values were observed in 2018. Thus, N utilization efficiency can be enhanced through genetic improvement but is also dependent on environmental conditions during the rice growing season. Taste value of both cultivars did not correlate to K level, while it had negative correlation with N level and positive correlation with P level. Si and Co had no effect on taste value of Nipponbare, while Si enhanced it of Koshihikari in 2018. High temperature in ripening stage increased the occurrence of immature grain, led to low perfect grain ratio in present study. Perfect grain ratio in the N2PK plot was relatively low due to large spikelet numbers.

Four N levels (0, 7, 8.5 and 10 g m^{-2} in 2018 and 0, 4, 7 and 10 g m^{-2} in 2019) were used to assess the effect of N on rice production in Nipponbare and Koshihikari in general paddy field. There was no interaction between N level and cultivar for all evaluation parameters. N fertilization increased dry weight, N uptake and grain yield compared to control (0 g m^{-2}). Low N input condition (4 g m^{-2}) decreased sink capacity compared to other N rates due to decrease in spikelet number. However, dry weight and grain yield under N applied plots in both years were not significantly different among the N levels. NUEb, NUEg, AEN and PFPN in 2018; and NUEb and PFPN in 2019 decreased significantly with increasing N level. The REN value was relatively high and was not affected by N level. REN was closely correlated with N uptake and dry weight but was not correlated with grain yield and sink capacity. Meanwhile, grain yield had positive correlation with NUEg, AEN and PEN. So, improving the efficiency of assimilation and remobilization of absorbed N is important to improve

grain yield. Milling quality and perfect grain ratio were not affected by N fertilization while taste value of Koshihikari correlated negatively to N level. High N application was unbeneficial for NUE and taste value while grain yield increase was not commensurate with increasing N level. To obtain the balance among rice yield, grain quality and NUE, the low N input practices will be necessary.

In pot experiment, Koshihikari was cultivated with three N applied levels (0.3, 0.5 and 0.7 g pot^{-1}) using five soil media collected from Zero (S_0), PK (S_{PK}), NK (S_{NK}), NP (S_{NP}) and NPK (S_{NPK}) plots of long-term fertilization study. Total N content in S_0 and S_{NK} were lower than those in S_{PK}, S_{NP} and S_{NPK}. Three NUE parameters, N use efficiency for biomass (NUEb), N use efficiency for grain weight (NUEg), and partial factor productivity of N (PFPN), were measured. Brown rice weight was used to calculated NUEg and PFPN. N applied level had positive correlation with panicle number, whole grain number, dry weight and N uptake in all soil media. Dry weight and N uptake in panicle and in brown rice in S_0 and S_{NK} was significantly lower than those in S_{PK}, S_{NP} and $S_{NPK,}$ especially at low N applied level. There was negative correlation between N applied level and NUEb in S_0 and PFPN in S_0, S_{PK}, S_{NP} and S_{NPK}. NUEg was not affected by N applied level. The NUEb value was the lowest in S_{NP} and S_{NPK} under all N application rates. N applied level did not affect whole grain percentage in S_{PK}, S_{NP} and S_{NPK} but increased significantly this value in S_0 and S_{NK}. Protein content was increased with the increase of N applied level in S_0 and S_{PK}. The results indicated that Koshihikari could accumulate larger amount of N from soil rather than fertilizer N. The presence of P fertilizer increase N content in soil, further contributes to decrease the amount of N fertilizer application. Applying N fertilizer in high N content soils such as S_{PK}, S_{NP} and S_{NPK} led to luxury N absorption without efficient use to create biomass. Effect of N applied level on rice growth in non-N fertilization soil and non-K fertilization soil was similar to that in balance-fertilization soil.

In conclusion, P fertilizer has the most important role in rice production in Andosol paddy field. The contribution ratios of P to biomass production, N accumulation and grain yield was the greatest among nutrient elements. Under the same N application rate, the rice growth and development on soil derived from non-P fertilization plot was obviously poorer and was more dependent on N fertilizer than that on soil derived from P-sufficient application plot. Koshihikari was more sensitive to P deficiency than N deficiency. N fertilizer is essential for rice growth and yield, but high N applied level adversely affects NUE and grain quality. Grain yield increase was not commensurate with increasing N level. To maintain grain yield and improve NUE and grain quality, we can reduce N application rate in combination with adequate P application. Unlike N and P, K fertilizer had negligible role for rice production in Andosol. The deficiency of K fertilizer in prolonged time seems

to be no effect on soil N content. However, K fertilizer may not be required for Nipponbare but should be applied to Koshihikari to maintain grain yield, NUE and taste value. The effectiveness of Si fertilizer on grain yield, NUE and grain quality was little different between two experimental years. Nevertheless, rice is a Si accumulator so we should to supply Si in rice production as a component of balance nutrition. One of the effective ways to ensure grain yield and sustainable environment is to combine use of organic and inorganic fertilizer. Application compost improved significantly rice growth and yield as compared to no fertilizer supplement. However, due to low N content and high C-N ratio, combination compost with standard fertilization did not lead to considerable improvement in rice yield and grain quality while decreased NUE of both rice cultivars.