論 文 の 内 容 の 要 旨

農学国際　専攻
平成 21 年度博士課程入学
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論文題目 Improvement of Nitrogen Use in Lowland Rice Farming under Agroecological Management and Conventional Management
（水稲栽培における農業生態的管理と慣行施肥管理の窒素利用向上に関する研究）

Chapter1: Introduction

Nitrogen (N) is one of the essential nutrients in agriculture. Over the past decades, synthetic N fertilizer application contributed to significant increase in food production. However, intensive use of N fertilizer has caused deterioration in water quality and losses in biological diversity. The recent N fertilizer price rise due to increase in fossil fuel prices has jeopardized economic viability at farm level. To meet increasing demand for food, better N management strategy is opted for in agricultural production.

To improve N use, emphasis has been placed on enhancing congruence of N application with crop demand under synthetic fertilizer based management, Conventional Management (CNM). The other approach is to use the natural internal N cycling within agricultural farm ecosystems as N source. In other words, no synthetic fertilizer is added. This ecosystem based approach is referred to as Agroecological Management (AEM).

In my thesis, I examined possible ways to improve N use of both AEM and CNM in lowland rice (*Oryza sativa*) farming. Regarding AEM, there is little research available on lowland rice cultivation. Therefore, I took field science approach, on-farm research, to investigate soil N supply and Physiological Nitrogen Use Efficiency (PNUE) under AEM in comparison with CNM. To improve the efficiency of N application under CNM, Japan was examined as a case study in which there have been improvements in N application. I also investigated lowland rice farming in Benin, where CNM has recently become popular, in order to identify factors retarding N use efficiency under less favorable conditions.

Chapter 2. Soil N supply under Agroecological Management

In this chapter, I investigated soil N supply and its uptake by rice plants under AEM in comparison with CNM. The research was conducted in Tochigi prefecture, Japan for 2010 and 2011. The principal study fields were AEM-99, where AEM has been practiced since 1999, AEM-09, where AEM has been practiced since 2009, and CNM. For AEM, human N inputs were rice straw and rice bran. For CNM, slow release synthetic N fertilizer was used with supplemental application of cow manure. Apart from soil fertility management, all the other cultural practices were kept in the same manner.

Estimated soil N supply in AEM-99 was 19.3 g N m^{-2} and 28.1 g N m^{-2} in 2010 and in 2011, respectively. In both years, AEM-99 supplied sufficient N to satisfy N demand by the rice plants, as shown by the N uptake of rice as 11.4 g N m^{-2} in 2010 and 16.7 g N m^{-2} in 2011. Comparison between AEM-99 and AEM-09 indicated lower soil N supply under AEM-99. Components in AEM maintaining soil N supply were rice straw, rice bran, spring and winter weeds, and soil drying effect before submergence. In AEM-99, a large difference of soil N supply was observed between 2010 and 2011. It may be attributed to higher soil drying effect with less rainfall during the winter before submergence in the latter year.

Chapter 3. Physiological N Use Efficiency under Agroecological Management and Conventional Management

With the same field and research design as in chapter 2, I investigated differences in the use of N absorbed by rice plants grown under AEM and CNM. To examine differences in yields and physiological development among the fields, plant growth characteristics, leaf senescence, and yield components were measured in 2010 and 2011.

Under the record high temperature in summer 2010, PNUE for filled grains was higher in AEM-99, 48.4 g $(g\ N)^{-1}$, than in CNM, 35.6 g $(g\ N)^{-1}$. Difference in the growth characteristics between AEM-99 and CNM implies that higher PNUE in AEM-99 was most likely caused by relatively high N contents in leaves at heading, vigorous root development, and slow leaf senescence during the ripening phase. Although crop management was unchanged between 2010 and 2011, rice plants in AEM-99 were more susceptible to lodging in 2011 than in 2010. This was most likely attributable to high N uptake estimated from leaf color and growth during the vegetative stage in 2011. PNUE in AEM-99 was also higher than in CNM. However, PNUE in 2011 was lower than that in 2010. It was caused by lodging and high N concentration in panicles which may have resulted from larger amount of mineralized N supply in 2011.

Chapter 4. Transition to N efficient Conventional Management in lowland rice farming in Japan

CNM is the dominant soil fertility management for lowland rice in Japan. In this chapter, I reviewed the literature on lowland rice farming to examine how the transition to more N efficient CNM took place in Japan.

Between 1990 and 2007, national average Nitrogen Application Efficiency (NAE) for lowland rice increased from 50 kg (kg N)$^{-1}$ to 70 kg (kg N)$^{-1}$. Three agronomic factors that improved this efficiency were varietal change to high palatability rice with less N content in grains, development of slow release fertilizer and more efficient application method, and improved crop management practices eliminating yield reduction. During the period, socioeconomic changes in the Japanese agro-food system took place. Relative advantages of N efficient practices that emerged from these changes may have facilitated rice farmers' adoption of these practices.

Chapter 5. Nitrogen Application Efficiency in lowland rice farming in Central-Southern Benin

The field survey study was conducted in Benin during the 2010-2011 dry season. I investigated the variation of yields, NAE, and factors affecting the variation based on the crop management information and soil properties.

Rice yields ranged from 1.3 to 7.8 Mg ha^{-1} with average yield of 4.8 Mg ha^{-1}. NAE ranged from 17.2 kg (kg N)$^{-1}$ to 191.4 kg (kg N)$^{-1}$ with the average NAE of 55.3 kg (kg N)$^{-1}$. Multiple regression analysis revealed that 75% of the variation in yield could be explained by seven factors: water stress, residue management, plowing method, rat damage, N application rate, field slope, and sand content in the soil. The study indicated that insufficient rice management skills decreased NAE among the low yielding plots. This phenomenon was pronounced in the newly developed irrigation scheme. Among high yielding plots, sand content was identified to explain low NAE. Declining in yields despite high N apply implies soil N loss.

Chapter 6. General discussion

In this chapter, I synthesized the findings from previous chapters. Insufficient N supply has been reported as the major limitation of AEM in previous researches. However, this study demonstrated that AEM in lowland rice cultivation could supply sufficient N to rice plants. Under AEM, soil N supply was based on internal N cycling through recycling N in rice straw and rice bran, retaining N by weeds during the fallow period, and facilitating dry soil effect. Capacity of N cycling in supplying sufficient N to rice plants suggests that AEM is a viable soil fertility management option without posing further burden on terrestrial N deposition. Under high temperature, growth characteristics of AEM might have increased heat tolerance against spikelet sterility. The study also demonstrated that high fluctuation of soil N supply under AEM due to climatic condition. Sensitivity to environmental factors emphasizes the importance of management skill in controlling soil N mineralization. It warrants further research in understanding the mechanism of N mineralization in paddy field especially when temperatures exceed 30℃.

Under less favorable condition, such as in the case of Benin, findings of this study imply that there are several ways to improve N use. The primary importance lies in avoiding yield loss through farming management improvement. Efficient N application method like site specific N management could also facilitate recovery of N applied as synthetic fertilizer. Furthermore, strengthening internal N cycling within agricultural ecosystems could provide alternative or supplementary N source, which would lead to efficient use of available N on farm. It would be especially important for resource poor farmers who have difficulties in purchasing synthetic fertilizer.