論文の内容の要旨

農学国際 専攻
平成 26 年度博士課程進学
氏名　サルパドール　ヘワワサム　ヌワン　プリヤシャンタ　デ　シルワ
指導教員名　岡田 謙介

Optimizing Productivity and Quality of Wheat through Modelling Approach

(モデリングアプローチによるコムギの生産性と品質の最適化)

Introduction

Wheat is the second most important cereal crop in Japan. However, the national average wheat yield in Japan (4.1 t ha^{-1}) is lower than that in other major wheat producing countries. In the last decade, per capita consumption of wheat increased by 4.1% while that of the staple food rice decreased by 11%. The self-sufficiency ratio of wheat in Japan is only 13.3%. Therefore, in order to safeguard the food security and maintain agricultural sector, Japanese farmers are subsidized for wheat production through "quality bonus" depending on the grain quality indices including grain protein content (GPC). GPC can be controlled by nitrogen (N) fertilizer management, but it is the most variable factor depending on the soil and climatic conditions and the management practices. Therefore, it is an important matter at both national and farm level to improve the N management of wheat to increase grain yield by maintaining adequate GPC.

Modelling approach with field experiments and proper validation would be useful to predict the yield and GPC under different management options including N application and to provide necessary decision support for the producers to improve wheat productivity.

The present study focused on first, evaluating the interactive effects of nitrogen application at flowering and sowing date on grain yield and GPC of hard and soft wheat varieties, and elucidating the mechanisms of yield and GPC change under late sowing conditions. Second, integrating that knowledge for the parameterization of two Japanese cultivars (hard and soft wheat) representative of Kanto region in Japan for APSIM (Agricultural Production Systems sIMulator) crop growth model, and validating the APSIM model for the conditions in Kanto area for the optimal sowing conditions and improving the model for late sowing conditions. Third, developing a decision support on optimum nitrogen management using the validated model to improve the wheat productivity for Kanto region. And fourth, extending the same modelling approach to Hokkaido region.

Materials and methods

To study the effect of nitrogen application at flowering time and sowing time interactions three field experiments were conducted from November 2010 to June 2013, at the Institute for Sustainable Agro-Ecosystem Services (ISAS) of the University of Tokyo at Nishitokyo City, Tokyo. The factors of the first experiment were 2 sowing dates and 4 N application level. Those of the second experiment were 1 sowing date and 4 N application

level. Those of the third experiment were 4 sowing dates, 3 N application level. N was applied as basal and two splits (split at the time of stem elongation and flowering) in all these experiments. Two hard wheat cultivars, Yumeshiho and Nishinokaori, and two soft wheat cultivars Ayahikari and Nebarigoshi were used for the 2012-2013 experiment and only Yumeshiho and Ayahikari were used for the other two experiments.

Further, to elucidate the mechanisms of yield and GPC change under late sowing conditions, two field experiments were conducted from 2014 to 2016 at the same location. The cultivars Yumeshiho and Ayahikari were used. The 4 sowing dates including very late sowing and 2 levels of N application were tested.

Phenology, dry matter production, LAI, grain yield and GPC data from 2012-2013 field experiment were used to parameterize the APSIM model for Ayahikari and Yumeshiho. Then, APSIM model was validated for phenology, dry matter production, LAI, grain yield and GPC and, soil NO_3 using independent experimental data from 2010-2016. Further, APSIM model was validated for a hard and a soft wheat cultivars representative to Hokkaido using soil and climatic data of the area and crop experimental data from the literature.

APSIM model was improved to be applied under late sowing conditions by integrating an empirical model developed from plant emergence data into APSIM model. Then the improved model was revalidated with data set including both optimum and late sowing conditions.

Scenario analysis were conducted with validated model with 64 N treatments ranged from 0 – 360 kg total N ha^{-1} with different proportion of basal and split applications at standard sowing date by using 55 years daily weather data of Tokyo for the wheat cultivars Yumeshiho and Ayahikari in Kanto region. Similar scenario analysis was conducted for two Hokkaido cultivars, Yumechikara (hard wheat) and Kitahonami (soft wheat), using 30 years weather data to find out economically optimal N application regime.

Results and Discussion

The results of the field experiments suggested that the N management strategy at flowering time for increasing the GPC is suitable under optimum sowing conditions, and the GPC content of both hard and soft wheat sown at optimum timing can be adjusted for fitting into the quality bonus window, by altering the fertilizer application rate at flowering time. The study contributes toward improving our understanding of the effects of split N fertilizer application at the stem elongation and flowering stages, and the effect of sowing time on the grain yield and GPC of both hard and soft wheat grown in volcanic ash soils. This was the first study to report the interactive effect N application at flowering and sowing time for both hard and soft wheat varieties grown in volcanic ash soils.

We demonstrated that the late sowing conditions decreased grain yield and increased GPC of both hard and soft wheat grown in Kanto region. Grain yield reduction by late sowing was mainly caused by reduced number of heads per area, which was mainly caused by the reduced emergence. The lower temperature which the late sown seeds has to face not only delayed the emergence but also reduced the ultimate emergence percentage. The reduction in the ultimate emergence percentage was quantitatively linked to the time required from the sowing to emergence with quadratic function.

Model validation confirmed that parameters derived from the calibration were accurate and these parameters can be used for the prediction of wheat phenology and growth parameters such as yield and GPC. The results showed that RMSE for grain yield was 79.9 and 69.0 g m^{-2} for Ayahikari and Yumeshiho, respectively and that for GPC was 1.8 and 2.4 %. Similarly, validation results for Hokkaido for optimal sowing showed that RMSE for grain yield was 75 and 86 g m^{-2} for Kitahonami and Yumechikara, respectively, and that for GPC was 1 and 0.5 %. These results are within the range of RMSE in the APSIM model validation studies reported elsewhere.

The results of the scenario analysis indicated that economically optimum rate of total N application for Yumeshiho (hard wheat) and Ayahikari (soft wheat) in Kanto region was both 280 kg N ha^{-1} although the proportion of the split application was different. With these optimum N treatments, the producers can obtain by 85 and 146 % higher median gross margin for Yumeshiho and Ayahikari, respectively, compared to that can be obtained with current fertilizer recommendations. The simulation results showed that optimal N application scheme tended to fluctuate to some extent from year to year due to the climate variation. However in the years with normal precipitation it was at or closer to the optimal N scheme.

In the scenario analysis in Hokkaido, the economically optimum rates of total N application for Yumechikara (hard wheat) and Kitahonami (soft wheat) were 280 and 160 kg N ha^{-1} respectively. With these optimum N treatments, it was simulated that the producers can obtain by 29 and 20.5 % higher median gross margin for Yumechikara and Kitahonami, respectively. The simulation results showed that yearly optimal N application scheme tended to be relatively stable during the 30 years' period.

Conclusions

The purpose of this study was to optimize productivity and grain protein content of wheat through modelling approach. N management was focused as the main agronomical option. The strategy to cope with the late sowing issue was also tested with the same approach. It was demonstrated that, by increasing total rate of N application, current yield level region can be increased particularly in Kanto region to the level similar to that of other high yielding countries with reasonably appropriate GPC, and thereby profitability of the producers could be increased. This is the first study to use APSIM model for wheat management in Japan. The section of the model improvement also contains originality, with which the model better fit to the late sowing situation by incorporating the algorism of reducing the plant number at low temperature. For the future research, it was suggested to extend and test this modelling approach to other regions such as Kyushu.