Application of APSIM Crop Model to the Decision Support in Nitrogen Management for Wheat Cultivation in Japan

By

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Submitted to the

Graduate School of Agricultural and Life Sciences

The University of Tokyo

in Partial Fulfillment of

the Requirements for the Degree of Master of Science

in

Agricultural Sciences

2014

The University of Tokyo, Japan

Dedicated to my loving family

ACKNOLEDGEMENT

I would like to thank my supervisor Prof. Kensuke Okada for all the advice, guidance and encouragement over the past two years. He has been a wealth of knowledge and support throughout my research. Without him this research would not have been possible.

Besides my advisor, I would like to thank the rest of my thesis examining committee: Prof. Kazuhiko Kobayashi and Prof. Seishi Ninomiya for their encouragement, insightful comments.

I am grateful Prof. Taro Takahashi for his guidance and unfailing support that immensely helped to make this study a success.

I wish to express my deepest thanks to Prof. Akihiko Kamoshita, all the staff members and the graduate students at ISAS, Tanashi for providing me the facilities for the field experiments and for their unfailing support.

I am very much thanful to all the proffessors, lectureres, staff members of the Deaprtment of Global agricultural Sceiences for their advises, guidance and support extended.

I would like to express my sincere thanks to Dr. Neelam Ramaiah and staff of the OICE, staff of the graduate student secion and staff of the international student adivisory room for their support and advises provided.

Thanks to everyone in the IPADS group, Laboratory of Agricultural development studies and all my friends in Japan for being such nice friends and for helping me in numerous ways throughout my studies.

Without the love and blessings of my parents and parents-in-low I could not have carried through this work at all. They were always supporting me and encouraging me with their best wishes.

I am grateful to my teachers, in Sri Lanka who showed me the path to the success.

My sincere thanks go to all the nursery teachers who looked after my son during last two years. Without their motherly care and kind support, this work would not have been a reality.

My utmost thank, however, is to my loving wife Samanthika who was always there cheering me up and stood by me through the good times and bad.

Last but not least, I appreciate my son, for the very understanding nature he demonstrated throughout the time.

S.H. Nuwan Priyashantha de Silva

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Application of APSIM crop model for the decision support in nitrogen management for wheat cultivation in Japan

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Introduction:

Wheat is the second highest energy source in Japanese diet after rice. To increase the self-sufficiency, Japanese farmers are subsidized for wheat production through "quality bonus" depending on the grain quality indices including protein content (GPC). GPC can be controlled by N management, but it is one of the most unstable factors. Properly validated crop model can be used to predict the yield and GPC under different management options including N application. The present study focused on the parameterization of four Japanese cultivars representative of different regions in Japan for APSIM (Agricultural Production Systems sIMulator) crop growth model, validation of the APSIM model for the conditions in Kanto area in Japan, and the development of decision support on nitrogen management using the validated model as a decision support tool.

Methodology:

Field experiments

Two field experiments were conducted from October 2012 to June 2013 and from October 2013 to June 2014 at the Institute for Sustainable Agro-Ecosystem Services (35^{0}44'N, 139^{0}32'E) of the University of Tokyo. In the first experiment we tested four representative wheat varieties for different regions in Japan (Ayahikari (Kanto), Nebarigoshi (Tohoku), Nishinokaori (Chugoku/Kyushu) and Yumeshiho (Kanto)) in a split-split plot design comprised of 3 factors (sowing dates (4 levels), varieties (4), nitrogen (3)) with 3 replicates. Sowing dates were Oct. 17, Nov. 8 and 29, and Dec. 19 in 2012. Nitrogen fertilizer levels were 0, 80 and 150 kg ha^{-1} in total (applied as basel and two splits). The second experiment was comprised of two varieties representing hard wheat (Yumeshiho) and soft wheat (Ayahikari) from Kanto area, Japan and twelve nitrogen application rates with 3 replicates in a split plot design. Sowing date was 27^{th} of November 2013. Nitrogen fertilizer levels were combined with 02 levels of basal (40 and 80 kg ha^{-1}), 02 levels of split application at stem elongation stage (0 and 40 kg ha^{-1}) and 03 levels of split application at flowering stage (0, 40 and 80 kg ha^{-1}).

Model parameterization, validation and simulation experiment

The weather data recorded at ISAS was used. APSIM (ver. 7.5) was initialized with soil data of the experiment location. Then the crop model parameters were determined by trial and error methods in the order of (1) phenology, (2) LAI and dry matter at flowering, (3) dry matter and yield at physiological maturity, using the observed data from the first field experiment. Then model validation was conducted for phenology, dry matter production, grain yield and GPC using the observed data from the second field experiment and another two filed experiments, conducted in 2010-2011 and 2011-2012 at the same campus. Comparison of simulated and observed results and statistical tests (RMSE, EF, RRMSE and slope of the best fitted regression line forced though the origin-*m*) were used for the model validation. Simulation experiment was conducted using 64 N application combinations followed by economic analysis.

Results and Discussion

Parameterization of APSIM model for the conditions in the Kanto area of Japan was successful as the model could reasonably reproduce the observed values after the parameterization for crop phenology, dry matter production, and leaf area index and grain yield. The model showed relative root mean square error (RRMSE) of 19, 20, 21 and 6 % for simulating grain yield for Ayahikari, Yumeshiho, Nishinokaori and Nebarigoshi respectively after the parameterization. After the parameterization, the difference between simulated and observed dates of flowering and maturity was less than 3 days across all sowing times. The results of the model performance tests have confirmed that the APSIM model can be applied to the climatic and soil conditions in Kanto area or similar soil and climatic regions in Japan for wheat cultivation. The difference between the simulated and observed date of flowering and maturity was 1-2 days, denoting the model's ability to simulate the phonology accurately. Validation results showed RMSE of 46.3 and 43.7 for grain yield (g m^{-2}) for hard wheat and soft wheat respectively. Results of GPC validation were 0.7 and 0.8 RMSE for hard wheat and soft wheat at mid sowing period while 1.6 and 2.3 for hard wheat and soft wheat at late sowing. The simulation study showed that the economically optimum nitrogen application rate is 200 kgN ha^{-1} (120 kg at sowing and 80 kg at stem elongation stage) at the present level of fertilizer cost and government subsidy scheme.

It is concluded that APSIM model is applicable to the conditions in Japan (Kanto area) and this model thus can be used as a decision support tool for wheat cultivation. Further model validation with a wide range of soil and climatic conditions is required for wider applicability.

Chapter 1

Introduction

1.1 Wheat (*Triticum aestivum*) the second most important cereal crop in Japan

Wheat is an important cereal crop grown in Japan and it is the second highest energy source of the Japanese diet after the rice (FAO STAT, 2012). Wheat is used for bread, pasta, Japanese noodle (udon), Chinese noodle (raamen), ect., and consumed daily for most of the Japanese people. At present, Japan is importing more wheat owing to the higher cost of domestic production. Thus, wheat is the second highest of the import commodities (food and agriculture) in Japan after Maize. The imported amount of wheat was 6214 metric tons in year 2011 (FAO STAT, 2014). The mean wheat yield across Japan is about 4.1 t ha^{-1} which is lower than that of other main wheat growing countries such as New Zealand, Netherlands and Belgium whose yield is in the range of 8.3 – 8.9 t ha^{-1}. The world mean wheat yield reported is 3.1 t ha^{-1} (FAO STAT, 2014).

1.2 Self-sufficiency situation and government intervention on improving wheat production in Japan

The self-sufficiency ratio of wheat in Japan is about 10% and the production is not sufficient to meet the domestic requirement. Therefore, in order to safeguard the food security and maintain agricultural sector, Japanese government is implementing a subsidy system for wheat. Under this subsidy system, producers are given an acreage subsidy for each hectare of land that produced wheat (115,220 JPY ha^{-1}) and the quality bonus is given for the produced wheat. In this quality bonus subsidy system, the producers can receive a quality bonus payment from the government based on four grain quality parameters; grain protein content (GPC), falling number, ash content and bulk density.

Table 1.1 shows the quality bonus scheme offered based on the GPC (Takahashi and Okada, 2012, MAFF 2014).

Table 1.1 Quality bonus offered based on the GPC

Wheat type	**Rank**	**Required GPC (%) range**	**Quality bonus (¥ t^{-1})**
Hard Wheat	A	11.5 - 14.0	150,000
	B	10.0 - 11.5 and 14.0- 15.5	141,667
	C	< 10.0 and 15.5 <	118,667
Soft Wheat	A	9.7 - 11.3	107,500
	B	8.5 - 9.7 and 11.3 - 12.5	99,157
	C	> 8.5 and 12.5 <	76,333

Among these quality parameters, grain protein content varies most (unstable) depending on soil and climatic conditions and management practices. As reported in literature, wheat grain protein content is influenced by the climate, cultivar, nitrogen (N) application rate, N application timing, seeding rate, and soil fertility and interactions between these factors (Karathanasis et al., 1980; Samuel, 1990; Sato et al., 1992; Rao et al., 1993; Geleta et al., 2002; cited in Nakano and Morita, 2008). Therefore, we focused on grain protein content in this study.

There are two types of wheat grown in Japan categorized based on its usage. They are named as soft wheat and hard wheat. The soft wheat is used to make noodles and the hard is to make bread. Therefore, there are two defined ranges in grain nitrogen concentration separately for the hard wheat and soft wheat. Thus, the required grain nitrogen ranges for the hard wheat and soft wheat are 2.3 to 2.8 % and 1.9 to 2.3 % respectively (Nakano et al., 2010). In terms of grain protein content, it is 11.5 to 14% of the hard wheat and 9.7 to 11.3% of the soft wheat (Takahashi and Okada, 2012) which provide the highest quality bonus for the farmer.

Usually the protein content of grain is calculated from N content (N %). N% multiplied by the "nitrogen protein conversion factor" will be given the protein content (%). The nitrogen protein conversion factor is 5.83 for wheat grain considered in Japan (STANDARD TABLES OF FOOD COMPOSITIONS IN JAPAN, 2005).

1.3 Nitrogen management to achieve yield goals

With proper management of nitrogen (application rates and timing, etc.), yield can be maximized and the grain protein content will controlled to fit in the target range. Shimazaki and Watanabe (2010) reviewed that the application of nitrogen fertilizer at sowing or jointing stage most strongly influence the grain yield, while the nitrogen application after the booting stage more affects the protein content. Nakano et al. (2008) have indicated that N application at active tillering is more effective than that at anthesis in increasing the grain yield of Minaminokaori cultivar in south-western Japan. However, nitrogen fertilizer application at anthesis does not affect the grain yield but remarkably increases the grain protein content (Nakano and Morita, 2009). Despite the availability of the improved cultivars that has a potential to produce grains of higher protein content than standard cultivars, still the expected results cannot be obtained in the farmers' field due to the effect of climate variation and soil characteristics. For example, for above mentioned wheat cultivar, Minaminokaori, the grain quality has not yet met the required protein content. This can be ascribed to the lower nitrogen uptake by the wheat plant due to the shorter growing season in that region as a result of warmer climate and relatively high precipitation (Taya, 2001). The soils of the western part of the Japan are generally mineral soils and, their nitrogen supplying capacity is low. Therefore, farmers in this area can increase the grain protein content by a second split application of nitrogen fertilizer. However, the upland soil in Kanto and Tohoku areas is largely volcanic ash type which is high in organic matter content and capable of supplying nitrogen. Therefore, if the temperature is high enough, soil releases higher amount of nitrogen, and coincidence of such condition with the anthesis period of the crop will result in very high grain protein content. Otherwise, the grain protein content becomes lower. Thus, farmers are facing a difficult situation in achieving expected grain protein content. Therefore, understanding such interactions between crop, soil and climate are vital to make decisions on optimum nitrogen application and other agronomic practices towards achieving higher yield and appropriate grain protein content. From these reasons, the comprehensive decision support system for the proper nitrogen management is awaited in wheat production in Japan. So far numerous field experiments have been conducted for the above purposes. But there are several limitations in such field researches. They are:

1. Due to the spatial variability in climate and soil characteristics, the results of filed experiments are site specific in most situations. Existing literature also reported that the results of the field experiments are season-specific, too (e.g. Spiertz and Ellen, 1978; Spiertz and Van de Haar, 1978; Ellen and Spiertz, 1980; Chaney, 1990; Darwinkel, 1998; cited in Asseng et al, 2000).
2. Requirement of the longer duration to obtain the reasonable results; multiple year trials are needed to conclude any fertilizer or crop related recommendations.
3. Multiple experiments with different trial combinations are needed to find out any optimum conditions (e.g., optimum rate and timing for nitrogen application).

Therefore, use of crop growth models is one of the best alternative options available and properly validated crop growth model is a good decision support system for both farmers and scientists to make economically viable decisions on management practices and research perspectives. Existing reports also explain the use of crop models to optimise management practices under variable environments (Van Keulen and Seligman, 1987; Stapper and Harris, 1989; Keating et al., 1991; Meinke et al., 1993; Savin et al., 1995; Thornton et al., 1995; Asseng et al., 1998 cited in Asseng et al., 2000). But before coming up with any recommendations based on a crop model, the model should be properly validated for the local condition. APSIM (The Agricultural Production Systems Simulator) is one of such crop growth models that has successfully been used in many other countries to simulate wheat growth (e.g., Asseng et al. 2000; Wang et al., 2013; Zang et al., 2012; Mohanty et al., 2012 ; Balwinder-Singh et al., 2011)

Table 1.2 shows the different situations of using simulation models for decision support.

Table 1.2 Use of simulation models as a decision support

Type of decision support	Name of the model	Reference
Decision support for Australian dry land farming (commercial crops)	APSIM	Carberry (2009)
Decision support for wheat management in subtropical Australia	WHEATMAN	Wood ruff (1992)
Decision support on wheat N fertilization based on the date of N deficiency	Azodyn	Jeuffroy and Recous (1999)
Climate change impact on crop production	DSSAT	Hoogenboom et. al (1995)
Decision support for irrigation and water management	CADSM	Prajamwong et al; (1997)
Wheat disease management	Foliar disease model	Audsley et al; (2005)
Assessing nitrogen leaching losses from arable land	SOILNDB	Johnsson et al (2002)

1.4 APSIM (The Agricultural Production Systems Simulator)

1.4.1 An over view

APSIM (Agricultural Production Systems sIMulator) is one of the advanced cropping system model that comprised of different modules enabling to simulate systems that cover a range of plant, animal, soil, climate and management interactions (Keating et al, 2003).

1.4.2 APSIM-Wheat module

Simulation is carried out in a daily time-step on an area basis. Weather (temperature, radiation, precipitation) data should be provided externally. The initial content of water and inorganic nitrogen at different soil layers are required.

Soil water and nitrogen uptake data from the wheat module is disseminated on daily basis to the soil water and nitrogen modules. Based on that soil water and nitrogen modules are reset for the each day. Apart from that, information on crop cover is transferred to the water balance module for the calculation of evaporation rates and runoff. At the time of crop harvest, information on the amount of wheat stover and root residues are passed to the modules of surface residue and soil nitrogen, respectively. Phenological development, leaf area growth, biomass and nitrogen concentration of leaves, stems, roots and grains, grain size, grain number are simulated in the wheat module on a daily basis.

1.5 Uses of the APSIM model in wheat plant growth studies including nitrogen management

There have been very few reports on the application of crop growth models for wheat under Japanese conditions (e.g., Kuwata, 2013; Seino, 1995; Anwar et al 2003). Whereas no report on the application of APSIM model under Japanese conditions was published so far. And, in general, the literatures on the application of crop growth models are very limited in Japan. Successful applications of APSIM model are, however, found in elsewhere.

Asseng et al. (1998 and 2000) tested the performance of the APSIM model in Western Australia and the Netherlands. Their studies in Western Australia show that APSIM Nwheat model is able to simulate the wheat crop growth and yield reasonably. They, however, did not recommend the version of the model they tested for grain protein studies. Also, the model underestimated the grain yield under severe terminal drought conditions. Whereas in the Netherlands, APSIM Nwheat showed better performance to simulate the interactions between a wide range of nitrogen fertilizer applications and soil nitrogen dynamics, crop N uptake, crop growth and phenology, grain yield and grain protein content.

Zang et al., (2012) also indicated that APSIM-Wheat model could explain the changes in phenology. But leaf area index predictions were poor compared to the prediction of biomass. According to their study, simulation of the phenology became poor with delay in sowing time. They mentioned that it may be due to the use of fixed thermal time targets for each of the phases before flowering in APSIM model. Asseng et al. (1998 and 2000) also reported that over estimation of LAI by APSIM.

The climate and soil type varies spatially. Thus, wheat yield also changes from place to place with different crop management practices such as cultivars, sowing time, plant density, irrigation and fertilizer application. As I mentioned earlier, it is difficult to capture such effects via field experiments. Zhang et al. (2012) reported such study using APSIM with three sowing dates, two to three crop varieties, and three planting densities at three ecological sites in the North China Plain. Their results showed that the model could capture a larger part of the variation in phenology, biomass and crop yield for the same variety across the sites. But, errors in simulation in phenology and yield were increased with delay in sowing date and with decreased planting density. Another study was reported by Chen et al. (2010) on capturing the crop productivity responding to inter-annual climate variability and irrigation water supply with long term crop yield data under various irrigation water supply in NCP for wheat and maize double cropping systems. Their results show that APSIM model is capable to simulate growth and yield of wheat and maize in a double cropping systems. Predictions of soil water and evapo-transpiration were also good. They mentioned that it was necessary to change the low temperature threshold for leaf area damage induced by low temperature, the temperature response of crop phenologies, and temperature response of radiation use efficiency (RUE) for the better simulation of the winter wheat production

Further, Asseng et al. (2000) were able to derive the economic and environmental optima in winter wheat under the Netherlands conditions; N application up to 140 kg N ha^{-1} in February (period at which crop growth starts after the winter), 90 kg N ha^{-1} between tillering and beginning of stem elongation and 40 kg N ha^{-1} at flag leaf stage resulting in a median of 8.5 t ha^{-1} grain yield, 14.0% grain protein and 13 kg N ha^{-1} soil residual N after the harvest. Therefore APSIM has shown its capacity to be used as a decision support system upon the validation. This is what exactly needed in Japanese wheat production systems. Therefore, in this study our focus is to parameterise and validate the APSIM model for the Japanese conditions (in Kanto area of Japan) using the field experiment data and to conduct a simulation study to find out the optimum N application regime for winter wheat. Thus, the objectives of the study can be summarised as follows.

1.6 Objectives

1. To parameterise the APSIM model for conditions in Kanto area, Japan using the data from field study.

   To conduct filed study to acquire useful information on phenological changes, grain yield to different sowing times, and nitrogen application rates of representative wheat varieties in Japan for the model parameterization

2. To validate the APSIM model for the conditions in Kanto area, Japan against the field study data

   To conduct a field study to find out the effect of different nitrogen application rates on the representative two wheat varieties on grain yield and grain protein content to acquire data for model validation

3. Elucidation of optimum nitrogen management through model simulation parameterized for Japanese wheat cultivar for Kanto region in Japan.

Chapter 2

Parameterization of the APSIM model for the conditions in Kanto area, Japan with the observations from field experiment

2.1 Introduction

Parameterization of the model is a prerequisite for any study that uses a crop growth model. The parameterization or the calibration is a process by which parameters of a crop model are estimated. The calibration is done so that the output of the overall model matches expected results. For that, the model is tested using different values for a specific parameter, then values are chosen that provide the closest match to the observations of the major outputs (Soltani and Sinclair, 2012). The parameter estimation is required when such parameter values are not available in the literature for the respective cultivars. During this process mainly the cultivar specific parameters responsible for phenology, grain yield, dry matter production and leaf area index are adjusted. If necessary some other general parameters are also adjusted that indirectly affect the cultivar specific parameters. We need a set of data from field experiments conducted in the same soil and climatic conditions to conduct the parameterization.

Genotypic coefficients or cultivar parameters are used to define varietal difference within the APSIM framework. Cultivar parmeter values are variety specific and should be derived with a trial and error simulation study, using observed phenology and yield data, if those values are not available in existing reports. Wang et al. (2013) explained in detail about deriving the genotypic coefficients and Chen et al. (2010), Mohanty et al. (2012), Balwinder-Sing et al. (2011) also used the same approach for their studies. As the genotypic coefficient values were not available in the literature for the Japanese wheat varieties used for this study, we used trial and error study to derive those parameters. In this research I focused on elucidating genetic parameters of 4 wheat varieties in Japan including two soft wheat varieties from different regions of Japan and two hard for the central part of Japan.

2.2 Materials and Methods

Two soft wheat and two hard wheat varieties were used. The soft wheat varieties were Ayahikari, mainly for the central part of Japan, most suited from North-Kanto to Toukai area, and Nebarigoshi, for Tohoku and Hokuriku region. The hard wheat varieties were Yumeshiho (from Kanto to Kinki region), and Nishinokaori (mainly for west-south part of Japan, expanding from Kanto to South Kyushu area). The seeds of Ayahikari and Yumeshiho were provided by NARO (National Agricultural Research Organization) Institute of Crop Science. Nebarigoshi seeds were provided by NARO Tohoku Agricultural Research Center. Nishinokaori seeds were purchased from the Association of Major Crops Improvement of Oita Prefecture.

I conducted a field experiment with different sowing dates and nitrogen rate at Kanto area. Parameterization for the phenology was carried out by driving APSIM for the particular experimental conditions with different genotypic parameter settings and compared observed and simulated dates for the flowering and physiological maturity, for leaf expansion, growth and yield.

2.2.1 Field experiment in 2012-2013 cropping season

Field experiment was conducted at the Institute for Sustainable Agro-ecosystem Services (ISAS) of the University of Tokyo, Nishi-Tokyo, Japan ($35^0$44'N, $139^0$32'E) from October 2012 to July 2013. The soil of the study site was a volcanic ash soil classified as Typic Melanudand by USDA soil taxonomy, or Andosol by FAO soil classification (Kato et al., 2011). Soil layer from surface to 40cm depth was Kuroboku andisol and from 40cm to 100cm depth was Tachikawa loamy andisol (Kato et al., 2010). The soil data on LL (lower limit), DUL (drain upper limit) and BD (bulk density) were obtained from published data (Kato T , 2003).

2.2.1.1 Experimental design

The experimental design was split-split plot design (plot size 6x6.1m) comprised of three factors: four sowing dates, four varieties and three nitrogen fertilizer levels with three replications. Sowing dates were October 17, November 8 and 29, and December 19 in 2012, covering the early, mid and late sowing times for the winter wheat cultivation in the Kanto area in Japan. Nitrogen fertilizer levels were 0, 80 and 150 kg ha^{-1} applied as basal, and two split applications at booting stage and just before the flowering stage. Ammonium sulphate was used for nitrogen fertilizer. Phosphorus and potassium was applied solely as basal application at sufficient level to the growth of the wheat crop (P_2O_4 100 kg ha^{-1} and K_2O 75 kg ha^{-1}). Sowing was conducted using non-till seeder. Sowing density and depth were 80 kg ha^{-1} and 25mm depth respectively. The distance between the rows was 0.19 m. Detail experimental design is illustrated in Fig. 2-1. Only three varieties were sown in Oct. 17 due to the unavailability of the seeds of Nebarigoshi variety.

Table 2.1 Nitrogen fertilizer rates (kg ha^{-1}) and time of application

Nitrogen Treatment	Total	Basel application	First split application (booting stage)	Second split application (10 days after heading)
N0	0	0	0	0
N1	80	40	20	20
N2	150	80	40	30

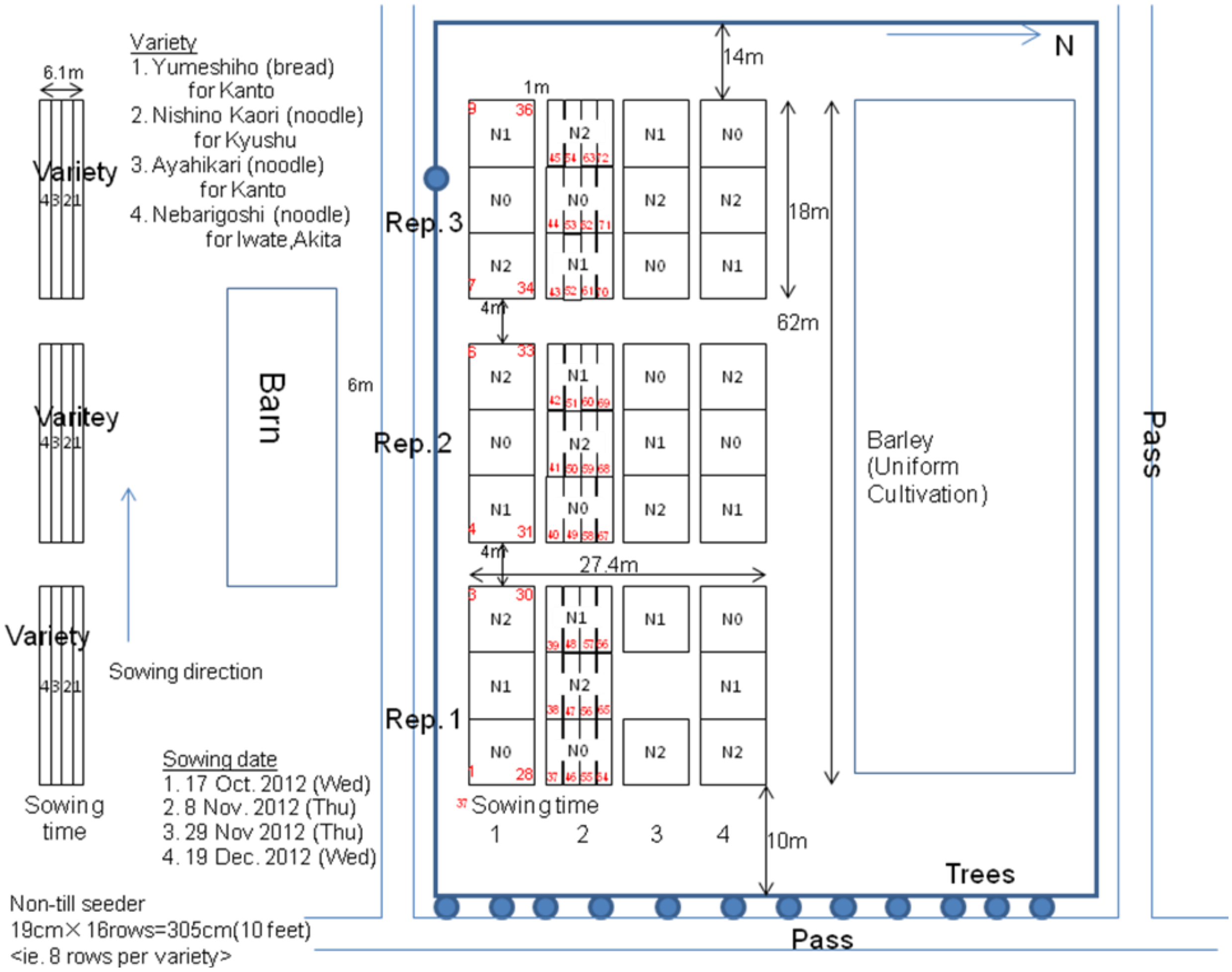

Fig. 2-1. Field layout of the 2012-2013 experiment

2.2.1.2 Sampling, data collection and data analysis

Crop phenology was observed and recorded every week starting from stem elongation to maturity. Zadok scale was used to identify the growth stage of the crop (Fig. 2.2). If the new stage started between two observation days, the date was interpolated within the two dates with field observation. During the critical period such as around the flowering date, 2-3 observation per week was carried out.

First plant sampling was conducted at around the time of flowering. All above ground parts of plants were harvested from a sample area of 0.5 x 0.57 m and sub sampled (15 heads for each sub sample). Sub sampled plants were separated into leaves, stems (with leaf sheath) and spikes. Leaf area was measured for the leaf samples from replicate one (sub sampled) only using the area meter (Li-cor LI-3100C, Lincoln, USA)**.** All samples were dried in a forced air oven for 72 hours to obtain the dry weights.

Second sampling was carried out at the time of physiological maturity. All above ground parts of plants were harvested from 1 x 0.76 m of sample area and allowed to air-dry for one week in a green house. Air dried samples were threshed and winnowed to separate the grain. Sub samples of grain and straw (around 100 g) were dried in a forced air oven for 72 hours to measure the water content in the original samples. Number of grains (ca. 10g of dried sub samples) were counted by High Speed Seed Counter (Weaver IC-1, Aidex Co., Ltd., Nagoya, Japan). Number of heads in a 0.5 m row length in each plot was counted and recorded. Grain yield, total above ground dry matter production, harvest index (HI), number of heads per area, 1000 grain weight, and number of grains per head were calculated.

Weather data including maximum and minimum daily temperature, rainfall and intensity of the solar radiation were obtained from the data recorded at ISAS.

2.2.1.3 Soil analysis

Soil samples were taken from different depths (0-15, 15-25, 25-35, 35-50, 50-65, 65-80, 80-100 cm) in each replicate (one sample from one replicate) before the basal fertilizer application (on 2012.10.10) with a soil auger of 2.5 cm in diameter and 1m in length. Samples of soils were air dried and passed through 2 mm sieve. Thereafter, ammonium nitrogen (NH_4^+) and nitrate nitrogen (NO_3^-) were analysed of 5g of soil from each sample, by extracting with 2M KCl and deionized water, respectively, and the NH_4^+ and NO_3^- concentration were measured by ion selective electrodes, (Thermo Fisher Scientific, Waltham, USA) respectively. Soil pH was also analysed for 5 g soil with soil to water ratio of 1:2.5.

2.2.2 Parameterization of the APSIM model

APSIM version 7.5 was used for this study. First the model was initialized using weather data, soil data (both obtained from literature and soil analysis). No surface residue was assumed because there was no crop residue remaining in the field at the sowing. Initial soil water content was set to 70% of the available water content (between LL and DUL) filled from the top. The soil type Lexton no.710 was chosen from the APSIM data base which is similar to our experiment location in terms of the latitude and texture. Soil parameters, LL (lower limit), DUL (drain upper limit) , BD (bulk density), NH_4^+ and NO_3^- nitrogen were set to the obtained values.

Then the cultivar parameters or genotypic coefficients for Ayahikari, Nishinokaori, Nebarigoshi and Yumeshiho were obtained. To begin with that, four simulations were created based on sowing dates. Sowing density, sowing depth and row spacing used for the simulation were 300 plants m^{-2}, 25 mm and 190 mm, respectively, based on the field experiment. Detailed information on deriving cultivar parameters are explained under 2.2.2.1.

2.2.2.1 Deriving the cultivar parameters

The APSIM wheat module document explains that wheat crop takes 400 °C days to reach terminal spikelet stage. The rate at which wheat crop attains this target depends on the photoperiod and vernalisation. The daily rate of accumulation of thermal development rate is sensitive to photoperiod and accumulation of vernalising days. Therefore, photoperiod sensitivity and vernalisation sensitivity are cultivar specific.

Therefore, we first focused on determining the photoperiod sensitivity (*photop_sens* (P)) and vernalisation sensitivity (*vern_sens* (V)) for each variety that produce the simulated date of flowering similar to the observed date of flowering (growth stage 64). Wang et al. (2013) also indicated that they have started deriving cultivar parameters with P and V parameters.

The *photop_sens* and *vern_sens* are in the ranges from one to five (APSIM wheat source code file and Zang et al. (2012)). Therefore, simulation trails were run for all combinations with Nov. 8 sowing and calculated the difference between simulated and observed flowering date (DIF) for every combination, based on which the range was further narrowed down considering the range that produces the lower DIF.

Thereafter, simulations were carried out for the narrowed down range for all the sowing times 0.1 steps for both V and P, and DIF was recorded. Using the DIF data for all sowing times, contour graphs were created for each sowing time (JMP statistical software was used), and based on the zero line values collected from the contour graphs, the point at which the zero lines of different sowing time converged was determined. Then again a trial and error simulation study was carried out and final V and P values were determined.

Secondly, in order to match the simulated date of maturity with the observed date (growth stage 91) the *startgf_to_mat* was adjusted accordingly with another set of simulation trials. This parameter is the duration of grain filling which is cultivar specific and ranges from 500 to 800 °C days (http://www.apsim.info/). So far is the parameterisation regarding the phenology.

Finally, maximum specific leaf area for delta LAI (specific leaf area), grains per gram stem, maximum grain size and *potential_grain_filling_rate* (grain growth rate during grain fill) parameters were adjusted accordingly to match the simulated grain yield and observed grain yield.

This total procedure is to derive the respective parameters for one variety concerned and therefore the same procedure was repeated for the other three varieties.

Relative root mean square error (RRMSE) was calculated to quantify and compare the simulation error after the parameterization (Wu et al; 2013)

2.3 Results

Winter wheat crop is sown by the farmers in Kanto area, Japan in November (towards mid). Therefore, plants emerged before the winter and become dormant during the winter. Again re-growth starts around March and reached anthesis and maturity in May and June, respectively. Therefore, the four sowing times of our filed experiment consisted of early, mid, slightly late, and late sowing periods. Rainfall was evenly distributed throughout the season. Whereas averaged daily precipitation from December to March and May it was lower than 2 mm.

2.3.1 Weather data

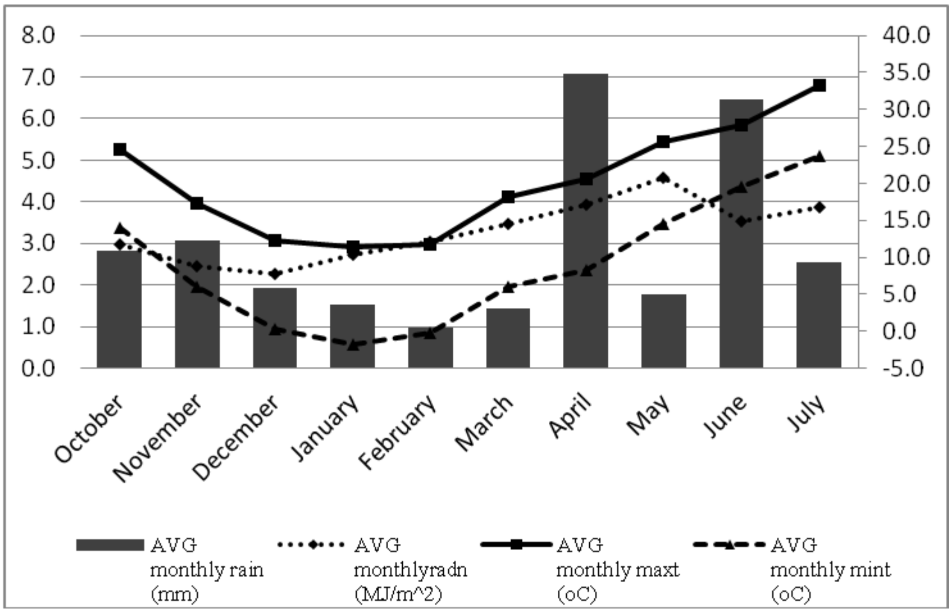

Fig. 2-2. Daily solar radiation, maximum and minimum temperature and rainfall averaged over a month. Data recorded by ISAS, Nishitokyo, Japan (experiment location).

2.3.2 Soil data

Soil type is favourable for plant growth and consists of higher nitrogen supplying capacity coupled with ample rainfall.

Table 2.2 Soil nitrogen and pH status at the time of sowing

Depth(cm)	NO_3^- nitrogen (mg kg^{-1} soil)	NH_4^+ nitrogen (mg kg^{-1} soil)	pH
0-15	3.3	8.3	5.7
15-25	4.8	6.6	5.8
25-35	4.5	24.9	5.8
35-50	21.7	6.9	5.7
50-65	10.6	5.0	5.6
65-80	7.2	3.9	5.7
80-100	5.2	2.7	5.8

Table 2.3 Fbiom and Finert values obtained after the adjustment to comply with zero nitrogen treatment observed values (for 0-10 and 10-40 soil layers)

Depth(cm)	OC(%)	FBiom	FInert
0-10	6.3	**0.055**	**0.65**
10-40	6.3	**0.035**	**0.62**
40-70	6.5	0.020	0.70
70-100	6.5	0.020	1.00
100-130	6.5	0.010	1.00

2.3.3 Phenology and yield

Table 2.4 Observed dates of flowering and maturity

	Date of flowering				Date of Maturity			
	Sowing date				Sowing date			
Variety	**17-Oct**	**08-Nov**	**29-Nov**	**19-Dec**	**17-Oct**	**08-Nov**	**29-Nov**	**19-Dec**
Ayahikari	21/04/2013	3/05/2013	8/05/2013	13/05/2013	3/06/2013	12/06/2013	18/06/2013	18/06/2013
Nebarigoshi		5/05/2013	11/05/2013	13/05/2013		12/06/2013	18/06/2013	18/06/2013
Nishinokaori	17/04/2013	3/05/2013	9/05/2013	13/05/2013	2/06/2013	12/06/2013	18/06/2013	18/06/2013
Yumeshiho	20/04/2013	2/05/2013	9/05/2013	13/05/2013	2/06/2013	12/06/2013	18/06/2013	18/06/2013

*no observation for Nebarigoshi in 17-Oct sowing as this variety was not sown due to seed unavailability

Growth stage 64 of the Zadok scale was used as the observed flowering time in which 50% of flowering completed. Flowering dates were interpolated from graphs created using all observed data for the respective variety when the exact flowering date was not able to observe or not clear at the time of observation since observations were carried out weekly. There was no deviation in either flowering time or maturity depends on the nitrogen treatment (Annexure 1).

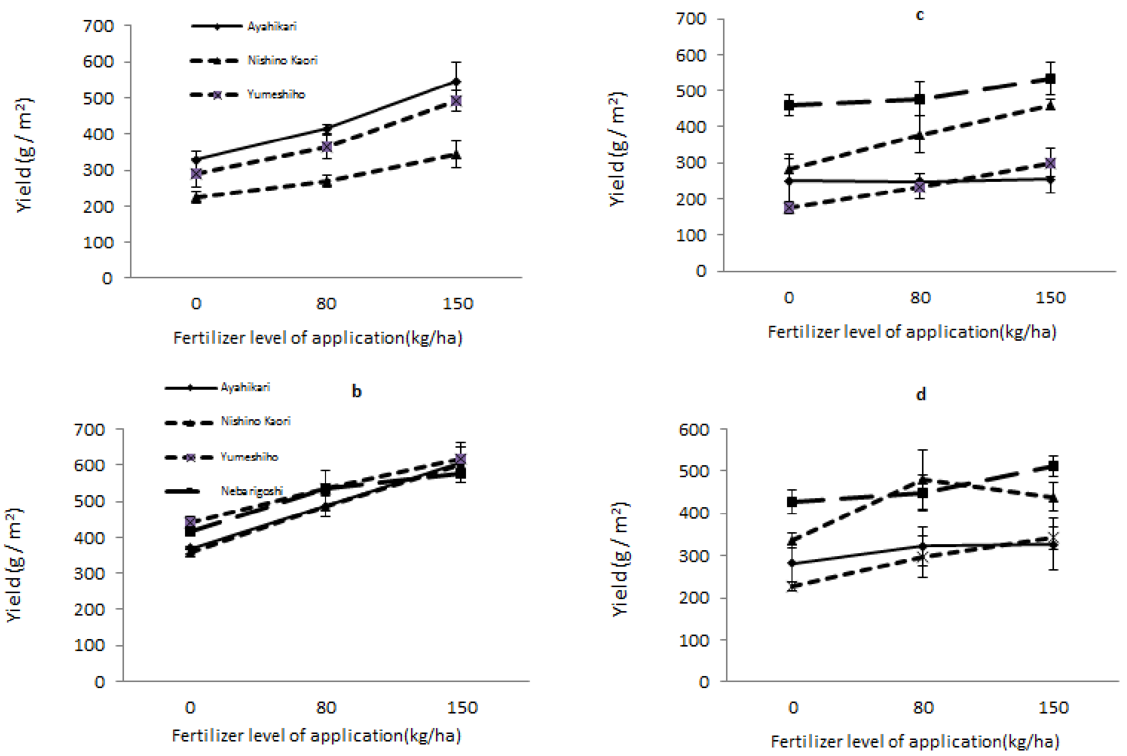

Fig. 2-3 Yield response of each variety to different nitrogen treatments in Oct-17(a), Nov-8(b), Nov-29 (c) and Dec-19(d) sowing times. Vertical bars represent standard errors.

The results showed that variety Ayahikai and Yumeshiho performed well in early sowing and Nebarigoshi and Nishinokaori performed well in late sowing. All varieties had a positive response to N at Oct 17 and Nov 8 sowing whereas for Nov 28 and Dec 19 sowings the response was not observed for some varieties. The highest grain yield was observed in Yumeshiho (619 g m^{-2}) at Nov 8 sowing at highest nitrogen application level, and the lowest values were observed in Nishinokaori (224 g m^{-2}) at Oct 17 sowing and Yumeshiho (227 g m^{-2}) at Nov 28 sowing. However, in general, all varieties have shown good performance in Nov 8 sowing time.

2.3.4 APSIM model parameterization

2.3.4.1 Parameterization for phenology

Derivation of cultivar parameters was first tried with Nov 8 sowing data (average of three replicates) as all varieties performed well in this sowing time. Then adjustments were made for other sowing times. Thus, parameters vernalization sensitivity, photoperiod sensitivity and thermal time from beginning of grain filling to maturity were determined.

Table 2.5 Combinations of Photo period and vernalisation sensitivity values

	P0	P1	P2	P3	P4	P5
V0	-44	-39	-29	-18	-3	11
V1	-39	-37	-29	-18	-3	11
V2	-33	-31	-27	-14	-2	11
V3	-28	-26	-21	-14	-2	11
V4	-23	-20	-15	-8	1	12
V5	-20	-16	-12	-5	4	13

Table 2.5 illustrates the combinations of *photop_sens* (P) and *vern_sens* (V) values and the differences in days between simulated and observed dates for flowering. Area highlighted in ash colour is the further narrowed down range. This narrowed down range was the base for further repeated simulation analysis to find out the final values for all varieties.

Table. 2.6 Cultivar parameters for each variety

	Values			
Parameters	**Ayahikari**	**Nebarigoshi**	**Nishinokaori**	**Yumeshiho**
vern_sens^p (sensitivity to vernalization)	2	2	2	2
photop_sens^p (Sensitivity to photoperiod)	4.3	4.4	4.3	4.3
startgf_to_mat^p [thermal time from beginning of grain filling to maturity(^{0}C d^{-1})]	645	645	645	645

^{p}Parameters of crop phenology

These three parameters (table. 2.6) are responsible for the simulation of phenology.

Table. 2.7 Difference between simulated and observed dates of flowering and maturity for the finalized cultivar parameters

Variety	Sowing time	Date of Flowering			Date of Maturity		
		Simulated	Observed	Difference	Simulated	Observed	Difference
Ayahikari							
	17-Oct	17/04/2013	20/04/2013	-3	1/06/2013	3/06/2013	-2
	08-Nov	3/05/2013	3/05/2013	0	11/06/2013	12/06/2013	-1
	29-Nov	9/05/2013	8/05/2013	1	16/06/2013	18/06/2013	-2
	19-Dec	12/05/2013	13/05/2013	-1	18/06/2013	18/06/2013	0
Nebarigoshi							
	08-Nov	5/05/2013	5/05/2013	0	12/06/2013	12/06/2013	0
	29-Nov	11/05/2013	10/05/2013	1	17/06/2013	18/06/2013	-1
	19-Dec	13/05/2013	13/05/2013	0	19/06/2013	18/06/2013	1
Nishinokaori	17-Oct	17/04/2013	17/04/2013	0	1/06/2013	2/06/2013	-1
	08-Nov	3/05/2013	3/05/2013	0	11/06/2013	12/06/2013	-1
	29-Nov	9/05/2013	9/05/2013	0	16/06/2013	18/06/2013	-2
	19-Dec	12/05/2013	13/05/2013	-1	18/06/2013	18/06/2013	0
Yumeshiho	17-Oct	17/04/2013	20/04/2013	-3	1/06/2013	2/06/2013	-1
	08-Nov	3/05/2013	2/05/2013	1	11/06/2013	12/06/2013	-1
	29-Nov	9/05/2013	9/05/2013	0	16/06/2013	18/06/2013	-2
	19-Dec	12/05/2013	13/05/2013	-1	18/06/2013	18/06/2013	0

With the determined 3 parameters, the difference between simulated and observed dates was within 2 days in all varieties at all sowing times for both date of flowering and maturity, except in Oct. 17 sowing time for Ayahikari and Yumeshiho for the date of flowering (3 days difference).

2.3.4.2 Parameterization for the yield (grain yield, dry matter production and leaf area index)

The parameterized model for phenology was then checked for its ability to simulate the leaf area index (LAI), dry matter production at flowering, dry matter production at maturity and grain yield. As the model over estimated these values, some model parameters responsible for simulating those yield parameters were adjusted with a trial and error study. The target parameters I chose were, specific leaf area, potential grain filling rate, grains per gram stem[1], maximum grain size. The adjusted parameter values are shown in the Table 2-7.

Table 2.8 Adjusted parameter values for each variety to receive a better simulation results for LAI, dry matter production and grain yield.

Parameters	Values			
	Ayahikari	Nebarigoshi	Nishinokaori	Yumeshiho
Maximum specific leaf area for delta LAI (27000-22000)*	25000- 20000	20000-14000	22000-17000	20000-16000
Grains per gram stem (25) 1*	17	16.5	16.5	17.5
Maximum grain size (0.048)*	0.048	0.047	0.048	0.047
Potential grain filling rate (0.002)*	0.0025	0.0020	0.0026	0.0022

*Default value

But then the variables related to growth (LAI, dry matter, yield) overestimated in the late sowing cases. I observed that the number of the remaining plants during the winter season was much lower than planting density for the late sowing treatments. It was assumed that the number of the plants were decreased due to the coldness of the winter. But in APSIM there is no algorithm to account for the mortality of the seedlings due to the cold

[1] In APSIM, the number of the grains per plant is set by multiplying this parameter (*grains_per_gram_stem*) with the stem dry weight at flowering.

temperature. Therefore, tentatively we tried to simulate the decreased survival plants by decreasing the sowing density. The adjusted sowing density was shown in Table 2-9.

Table 2.9 Adjusted sowing density values for each variety (actual value is 300 plants per m^2)

Sowing time	Density (plants m^{-2})			
	Ayahikari	Nebarigoshi	Nishinokarori	Yumeshiho
17-Oct	300		25	150
29-Nov	10	10	30	15
19-Dec	12	20	30	20

Table. 2.10 Relative root mean square error (RRMSE) for LAI, dry matter production at flowering ,dry matter production at maturity and grain yield for all varieties calculated from the error (simulated – observed) values after the parameterisation.

Variety	RRMSE (%)			
	LAI	Dry matter production at flowering	Dry matter production at maturity	Grain yield
Ayahikari	51	22	17	19
Yumeshiho	34	12	18	20
Nishinokaori	29	18	11	21
Nebarigoshi	39	14	14	6

Table. 2.11 Simulated and observed dry matter production at flowering and maturity, Grain yield, and LAI (at flowering) for each variety at each sowing time for three N application rates.

a. Yumeshiho

Nitrogen Application rates	Sowing time	Dry matter production at floweirng			Dry matter production at Maturity			Grain yield			LAI at flowering		
		Simulated	Observed	Relative(%)	Simulated	Observed	Relative(%)	Simulated	Observed	Relative(%)	Simulated	Observed	Relative(%)
N0 (0 kg/ha)	17-Oct	907.0	707.6	128.2	642.0	838.3	76.6	446.0	290.8	153.4	2.7	1.4	192.9
	8-Nov	**891.0**	**893.4**	**99.7**	**564.0**	**710.8**	**79.3**	**448.0**	**441.9**	**101.4**	**2.0**	**2.2**	**89.5**
	29-Nov	555.0	463.6	119.7	461.0	252.0	182.9	280.0	174.0	160.9	1.0	0.5	200.0
	19-Dec	550.0	502.0	109.6	469.0	335.3	139.9	279.0	227.0	122.9	0.9	0.5	180.0
N1(80 kg/ha)	17-Oct	1018.0	900.4	113.1	847.0	844.4	100.3	505.0	363.7	138.9	3.1	2.6	119.2
	8-Nov	**1101.0**	**1139.6**	**96.6**	**769.0**	**907.6**	**84.7**	**540.0**	**534.9**	**101.0**	**2.8**	**2.3**	**121.7**
	29-Nov	555.0	501.9	110.6	463.0	360.9	128.3	280.0	233.3	120.0	1.0	0.6	166.7
	19-Dec	550.0	612.7	89.8	472.0	424.6	111.2	279.0	298.3	93.5	0.9	0.7	128.6
N2(150/ kg/ha)	17-Oct	1022.0	912.1	112.0	912.0	901.9	101.1	506.0	491.2	103.0	3.1	3.0	103.3
	8-Nov	**1222.0**	**1228.1**	**99.5**	**937.0**	**1034.1**	**90.6**	**590.0**	**619.4**	**95.3**	**3.5**	**3.1**	**112.9**
	29-Nov	560.0	621.8	90.1	463.0	448.3	103.3	280.0	300.2	93.3	1.0	0.8	125.0
	19-Dec	550.0	440.1	125.0	472.0	505.3	93.4	279.0	341.2	81.8	0.9	0.4	225.0

b. Ayahikari

Nitrogen Application rates	Sowing time	Dry matter production at floweirng			Dry matter production at Maturity			Grain yield			LAI at flowering		
		Simulated	Observed	Relative(%)	Simulated	Observed	Relative(%)	Simulated	Observed	Relative(%)	Simulated	Observed	Relative(%)
N0 (0 kg/ha)	17-Oct	861.0	734.0	117.3	591.0	810.1	73.0	468.0	327.7	142.8	2.2	1.9	114.5
	08-Nov	**916.0**	**930.0**	**98.5**	**594.0**	**675.5**	**87.9**	**457.0**	**370.1**	**123.5**	**2.2**	**1.5**	**146.7**
	29-Nov	593.0	265.7	223.2	482.0	367.3	131.2	317.0	250.9	126.4	1.0	0.4	250.0
	19-Dec	558.0	427.1	130.7	491.0	414.0	118.6	323.0	281.3	114.8	0.8	0.7	114.3
N1(80 kg/ha)	17-Oct	854.0	848.8	100.6	1042.0	845.9	123.2	528.0	413.7	127.6	2.4	2.4	99.8
	08-Nov	**1130.0**	**1044.0**	**108.2**	**811.0**	**816.1**	**99.4**	**551.0**	**488.1**	**112.9**	**3.4**	**2.4**	**141.7**
	29-Nov	593.0	459.5	129.1	482.0	356.4	135.2	317.0	247.7	128.0	1.0	0.7	152.4
	19-Dec	558.0	466.5	119.6	496.0	472.6	105.0	323.0	322.0	100.3	0.8	0.5	160.0
N2(150/ kg/ha)	17-Oct	1105.0	904.9	122.1	994.0	1094.3	90.8	588.0	545.7	107.8	3.4	3.1	108.8
	08-Nov	**1276.0**	**1067.2**	**119.6**	**978.0**	**966.4**	**101.2**	**611.0**	**606.9**	**100.7**	**4.6**	**2.6**	**180.2**
	29-Nov	593.0	446.7	132.8	482.0	368.0	131.0	317.0	255.2	124.2	1.0	0.6	166.7
	19-Dec	558.0	501.9	111.2	496.0	487.4	101.8	323.0	326.7	98.9	0.8	0.6	133.3

b. Nishinokaori

Nitrogen Application rates	Sowing time	Dry matter production at floweirng			Dry matter production at Maturity			Grain yield			LAI at flowering		
		Simulated	Observed	Relative(%)	Simulated	Observed	Relative(%)	Simulated	Observed	Relative(%)	Simulated	Observed	Relative(%)
N0 (0 kg/ha)	17-Oct	760.0	826.8	91.9	705.0	664.4	106.1	380.0	223.7	169.9	2.5	1.4	176.9
	08-Nov	**896.0**	**985.4**	**90.9**	**599.0**	**722.2**	**82.9**	**435.0**	**359.0**	**121.2**	**2.0**	**2.1**	**95.2**
	29-Nov	867.0	833.1	104.1	639.0	484.2	132.0	426.0	280.9	151.7	2.0	1.0	200.0
	19-Dec	735.0	879.4	83.6	609.0	563.7	108.0	386.0	336.7	114.7	1.4	0.8	175.0
N1(80 kg/ha)	17-Oct	760.0	931.8	81.6	771.0	652.6	118.1	380.0	269.9	140.8	2.5	2.2	111.2
	08-Nov	**1111.0**	**1229.8**	**90.3**	**819.0**	**883.3**	**92.7**	**526.0**	**486.9**	**108.0**	**2.9**	**2.7**	**108.4**
	29-Nov	867.0	916.0	94.7	720.0	633.5	113.7	426.0	378.5	112.6	2.0	3.0	66.7
	19-Dec	735.0	1114.4	66.0	671.0	773.3	86.8	386.0	478.8	80.6	1.4	1.5	93.3
N2(150/ kg/ha)	17-Oct	760.0	976.0	77.9	771.0	744.5	103.6	380.0	344.7	110.2	2.5	2.6	97.1
	08-Nov	**1247.0**	**1258.8**	**99.1**	**972.0**	**1047.8**	**92.8**	**580.0**	**601.4**	**96.4**	**3.8**	**3.3**	**116.4**
	29-Nov	867.0	1143.8	75.8	720.0	775.3	92.9	426.0	460.9	92.4	2.0	2.2	90.9
	19-Dec	735.0	1034.7	71.0	671.0	687.8	97.6	386.0	438.3	88.1	1.4	1.1	127.3

b. Nebarigoshi

Nitrogen Application rates	Sowing time	Dry matter production at floweirng			Dry matter production at Maturity			Grain yield			LAI at flowering		
		Simulated	Observed	Relative(%)	Simulated	Observed	Relative(%)	Simulated	Observed	Relative(%)	Simulated	Observed	Relative(%)
N0 (0 kg/ha)	08-Nov	873.0	850.3	102.7	559.0	743.0	75.2	425.0	417.7	101.8	1.8	1.5	120.0
	29-Nov	854.0	704.2	121.3	560.0	698.7	80.1	439.0	459.9	95.4	1.5	**1.4**	107.1
	19-Dec	882.0	763.7	115.5	581.0	639.6	90.8	431.0	429.0	100.5	1.6	**0.9**	177.8
N1(80 kg/ha)	08-Nov	1085.0	1039.0	104.4	752.0	936.5	80.3	517.0	536.4	96.4	2.5	**2.0**	125.0
	29-Nov	1067.0	868.9	122.8	767.0	697.6	109.9	540.0	477.4	113.1	2.1	**1.7**	123.5
	19-Dec	1086.0	996.5	109.0	794.0	665.6	119.3	525.0	449.4	116.8	2.4	**1.4**	171.4
N2(150/ kg/ha	08-Nov	1216.0	950.4	127.9	901.0	987.3	91.3	568.0	578.2	98.2	3.2	**2.2**	147.0
	29-Nov	1133.0	911.3	124.3	888.0	767.4	115.7	559.0	534.4	104.6	2.5	2.0	125.0
	19-Dec	1108.0	1025.8	108.0	862.0	723.4	119.2	527.0	511.0	103.1	2.6	1.4	185.7

After adjusting respective model parameters, the simulated results were much improved. Nov 8 – mid sowing time showed the best performance (relative percentage is closer to 100) but the error still tended to increase with early or delay sowing times a little.

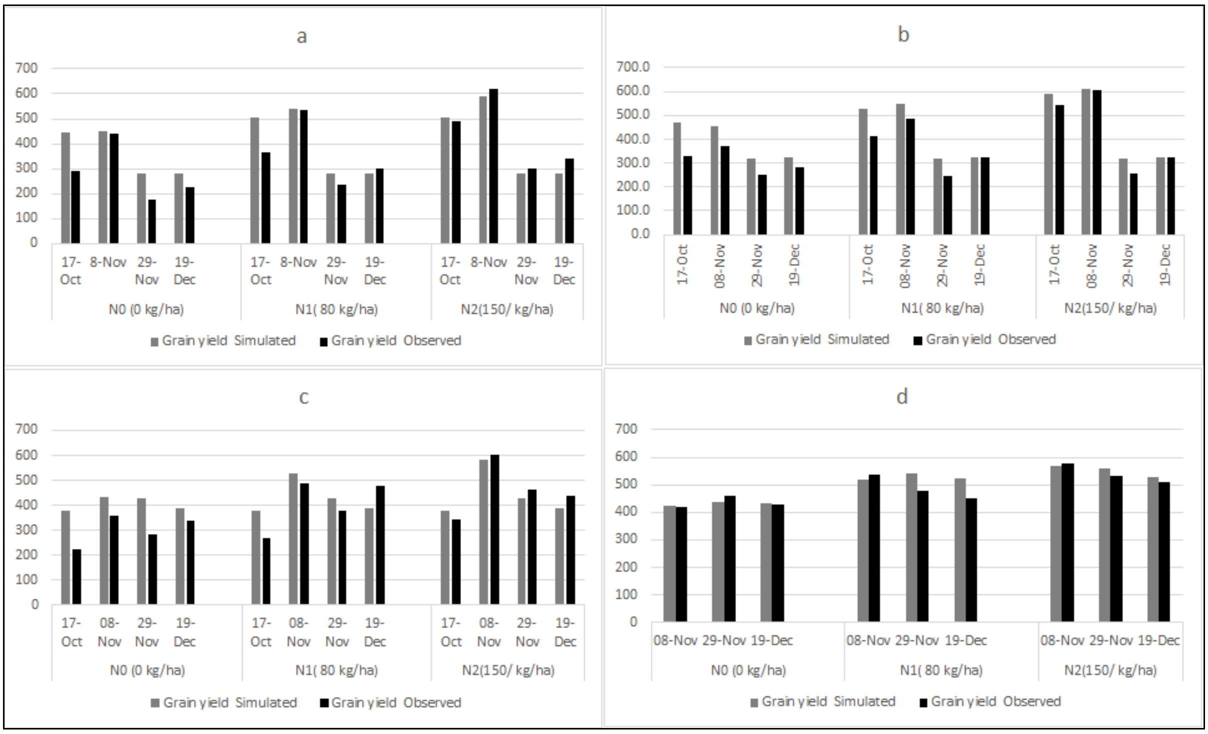

Fig. 2-4 Simulated and observed grain yields of each variety (a. Yumeshiho, b. Ayahikari, c. Nishinokaori and d. Nebarigoshi) to different nitrogen treatments (N0, N1 and N2) in Oct-17, Nov-8, Nov-29 and Dec-19 sowing times.

The model could reproduce the yield response to the nitrogen application that is observed in the field experiment. Further, the predictions were best at higher N applications. At the zero nitrogen level the deviation was much larger.

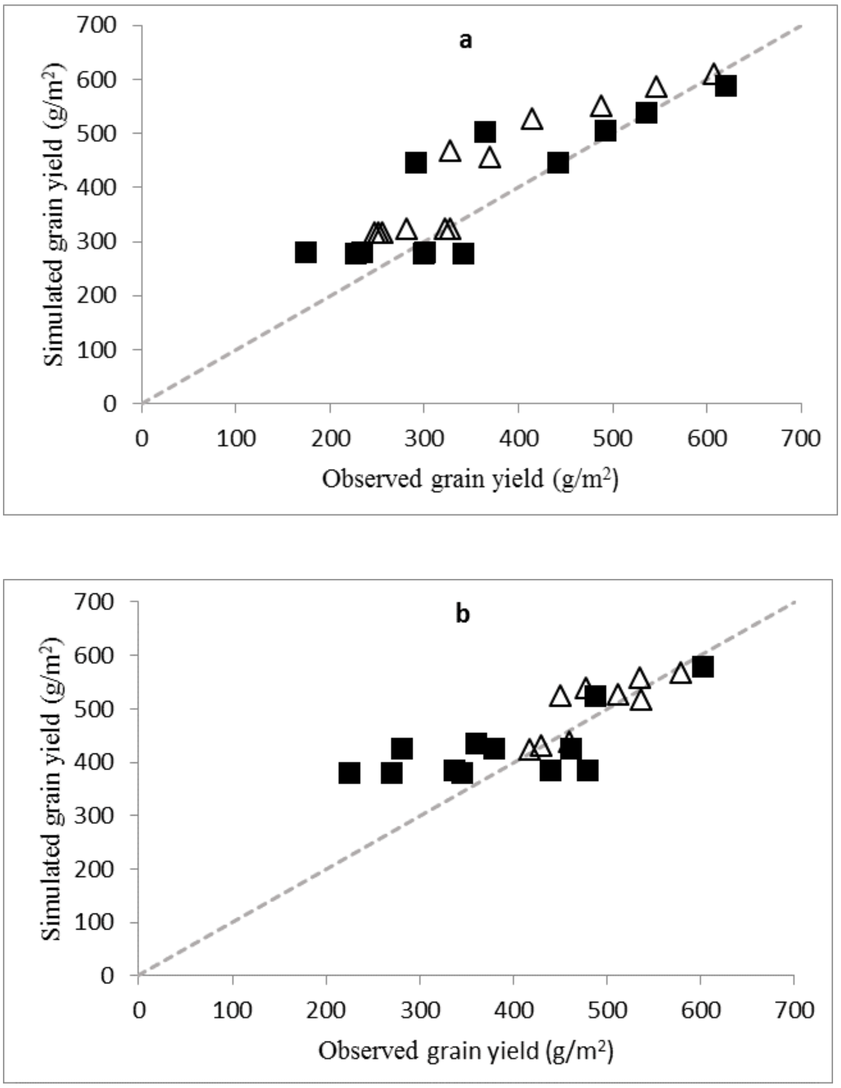

Figure 2-5: Observed and Simulated grain yields at all sowing times for 03 N treatments (a: Ayahikari Δ , Yumeshiho ■; b: Nebarigoshi Δ, Nishinokaori ■).

2.4 Discussion

This chapter explains the first field experiment conducted and the methods followed for the parameterization of the APSIM model for Kanto area in Japan. Therefore, this is towards achieving the first objective of the entire research.

The optimum sowing time and the farmers' general practice for winter wheat in Kanto area, Japan is considered as mid to late November (http://www.pref.saitama.lg.jp). Results from our field experiment are also complied with this, as Nov 8 sowing time showed the best performance compared to the other three sowing times which falls on early and late sowing periods in comparison to the optimum time mentioned. In the Nov 8 sowing time, all wheat verities showed a very good response to the nitrogen fertilizer application achieving the highest yields for each variety concerned, throughout the experiment, at highest nitrogen application rate (150 kg N ha^{-1}); Ayahikari, 606.9 g m^{-2}, Nebarigoshi, 578.2 g m^{-2}, Nishinokaori, 601.3 g m^{-2} and Yumeshiho, 619.4 g m^{-2}. Of the four varieties, Yumeshiho had the highest yield while the Ayahikari were the second. These two varieties are recommended wheat verities for the Kanto area in Japan. Previous studies also had indicated that these two varieties achieved similar yield at the highest nitrogen application (Takahashi and Okada, 2012). Nishinokaori and Nebarigoshi are recommended varieties for Kumamoto Prefecture and Touhoku area respectively. Further, the experiment results showed that variety Ayahikai and Yumeshiho are suitable for early sowing conditions and Nebarigoshi and Nishinokaori for late sowing conditions.

By using the field experiment results, trial and error study for the cultivar parameter derivation was initiated starting with the data from Nov 8 sowing time. These parameters were needed to be derived as those values are not available in the existing literature (This is the first attempt to apply APSIM model in Japanese conditions). Therefore, the parameter values obtained would be a good source for future research works of similar types. Of the four parameters concerned, "sensitivity to vernalization" and "sensitivity to photoperiod" are related with flowering time, and the thermal time from beginning of grain filling to maturity is related to the date of maturity. For all four varieties the vernalization sensitivity value was two (low vernalization requirement). Kiribuchi-Otobe (2009) and Yoshida et al. (2001) have indicated that Yumeshiho and Ayahikari are spring type verities (degree of winter habit is low) respectively, which means these two varieties need low vernalization requirement. In the mean time, Taya et al. (2003) have mentioned that degree of winter habit of Nishinokaori also is low.

Simulated values for the date of flowering and maturity were very close to that of observed except in Ayahikari and Yumeshiho at Oct. 17 sowing for the date of flowering (difference between simulated and observed were minus three days, i.e., the simulated dates were 3 days earlier than the observed dates). The observed flowering dates of these two cases were the ones interpolated because the exact date of flowering did not fall with the date of observation, which can be the possible reason for this relatively larger error. Simulation of the date of maturity was good for all varieties in all sowing times.

Once the parmeterization is done for the phenology, the model predictions were checked for the dry matter production (at flowering and maturity), leaf area index (LAI) and grain yield. But, overall model predictions were overestimated, especially dry matter productions at maturity, LAI and grain yield. Therefore, parameterization was continued further with some more parameters (Table 2.8) until model predictions become reasonable. Asseng et al. (1998, 2000) also used the same parameters during the model parameterization. Adjusting the parameters was initiated with specific leaf area followed by grains per gram stem, maximum grin size and potential grain filling rate. Numerous simulations were run (trail and error) to adjust these parameters to have finally improved model predictions in terms of grain yield, LAI and dry matter production. With this parameterization, the model predictions were much improved for mid sowing time (Nov-8). However, APSIM overestimated the grain yield and leaf area index for the early sowing (Oct 17th) and late sowings (Nov 29th and Dec 19th) even after the parameterization mentioned above, to some extent. Zhang et al. (2012) also found that the errors of simulation in phenology and yield were increased with delay in sowing date in the APSIM. Overall simulation of dry matter production was not satisfactory either and that was over estimated.

As the Japanese soil parameters are not included in APSIM soil data base, one of the soil types very close to the soil characteristics in the experiment location was selected and then adjusted for the local soil type. Thus, under the zero nitrogen treatment simulated dry matter and yield values were very low. This may be because the higher nitrogen supplying capacity of the volcanic ash soil was not represented by the soil type we used from the APSIM model and present soil parameterization. Therefore, "FBiom and FInert" soil paramerter values in the APSIM were adjusted in order to get closer simulated values for that of observed in zero nitrogen treatment.

This parameterization was conducted for all four varieties. Model performance validation is to be done using an independent set of experimental data as the next step. For that purpose, a field experiment was conducted during the 2013-2014 cropping season. Chapter 3 explains in detail about the field experiment and validation procedure

Chapter 3

Validation of the APSIM model for Japanese wheat cultivars grown in Kanto area of Japan

3.1 Introduction

In the previous chapter I determined plant parameters of four Japanese varieties based on one field experiment. The validity of these parameters should be tested under different conditions, which is called "validation" or "evaluation". Model validation is defined as the process of demonstrating that a given site-specific model is capable of making sufficiently accurate predictions. This implies the application of the calibrated model without changing the parameter values that were set during the calibration, when simulating the response for a period other than the calibration period. The model is said to be validated if its accuracy and predictive capability in the validation period have been proven to lie within acceptable limits (Refsgaard, 1997).

There are two methods to evaluate the model performance, ie., either comparing the simulated against observed values graphically or using statistical tests. The evaluation of the model is necessary if the model is to be used in an application (Soltani and Sinclair, 2012). The experiment data other than the one used for the parameterization should be used for the evaluation of the model. APSIM crop growth model that we parameterized has been validated and successfully used for wheat over a broad range of soils and climates in various parts of the world. But there is no such use of the APSIM model in Japanese conditions so far. Therefore, validation of the APSIM model under Japanese conditions has a significant importance when the model potential for applications in the future is taken into the consideration. This chapter describes about an independent field experiment conducted to acquire the necessary data for the validation and detailed model validation procedures.

3.2 Materials and methods

I used the data of three field experiments conducted at the same campus where the parameterization was conducted, but in different years. For this purpose I conducted an experiment in 2013-2014, and used the data conducted in 2010-2011 and 2011-2012 by the laboratory.

3.2.1 Methods to obtain the observed data

3.2.1.1 Field experiment in 2013-2014 cropping season

A field experiment was conducted at the plot in area no. 4PF of the Institute for Sustainable Agro-ecosystem Services (ISAS) of the University of Tokyo, Nishi-Tokyo, Japan ($35^{0}44$'N, $139^{0}32$'E) from November 2013 to July 2014. This plot was about 0.2 km to the north from the one used for the parameterization. The basic characteristics were similar to the ones in 2.3.2. Weather data including maximum and minimum daily temperature, rainfall and intensity of photosynthetically active solar radiation were obtained from the data recorded at ISAS.

Soil moisture was measured using Delta-T moisture probe (PR2, Delta-T Devices Ltd, Cambridge), almost every two weeks throughout the cropping season at 10, 20, 30, 40, 60 and 100 cm depth, within two plots each in all three replicates of the Ayahikari. Two plots represented the lowest and highest nitrogen treatments (N1 and N12).

3.2.1.1.1 Experimental design

The experimental design was split plot design (plot size 5 x 3.05 m) which comprised of two factors; the primary factor was the variety and the secondary factor was the nitrogen fertilizer management, which includes the rate of the application at the basal and two top dressing. The experiment was conducted with three replications. Sowing date was November 27, 2013. Nitrogen fertilizer applied as basal, and two split applications at the stem elongation stage and just before the flowering stage of the crop (Table 3-1). PK fertilizer was applied as a basal application at sufficient level to the growth of the wheat crop (P_2O_4 100kg ha^{-1} and K_2O 75 kg ha^{-1}). Sowing was conducted using non-till seeder. Sowing rate and sowing density were 100 and 95 kg ha^{-1}, and 336 and 202 seeds m^{-2}, for Yumeshiho and Ayahikari, respectively. Sowing depth was 25mm and the distance between the rows was 190 mm. The experimental design is illustrated in Figure 3-1.

Table 3-1 Nitrogen fertilizer rates and time of application

	Total	Basal application	Split application (stem elongation stage)	Split application (10 days after heading/just before flowering)
N1	40	40	0	0
N2	80	40	0	40
N3	120	40	0	80
N4	80	40	40	0
N5	120	40	40	40
N6	160	40	40	80
N7	80	80	0	0
N8	120	80	0	40
N9	160	80	0	80
N10	120	80	40	0
N11	160	80	40	40
N12	200	80	40	80

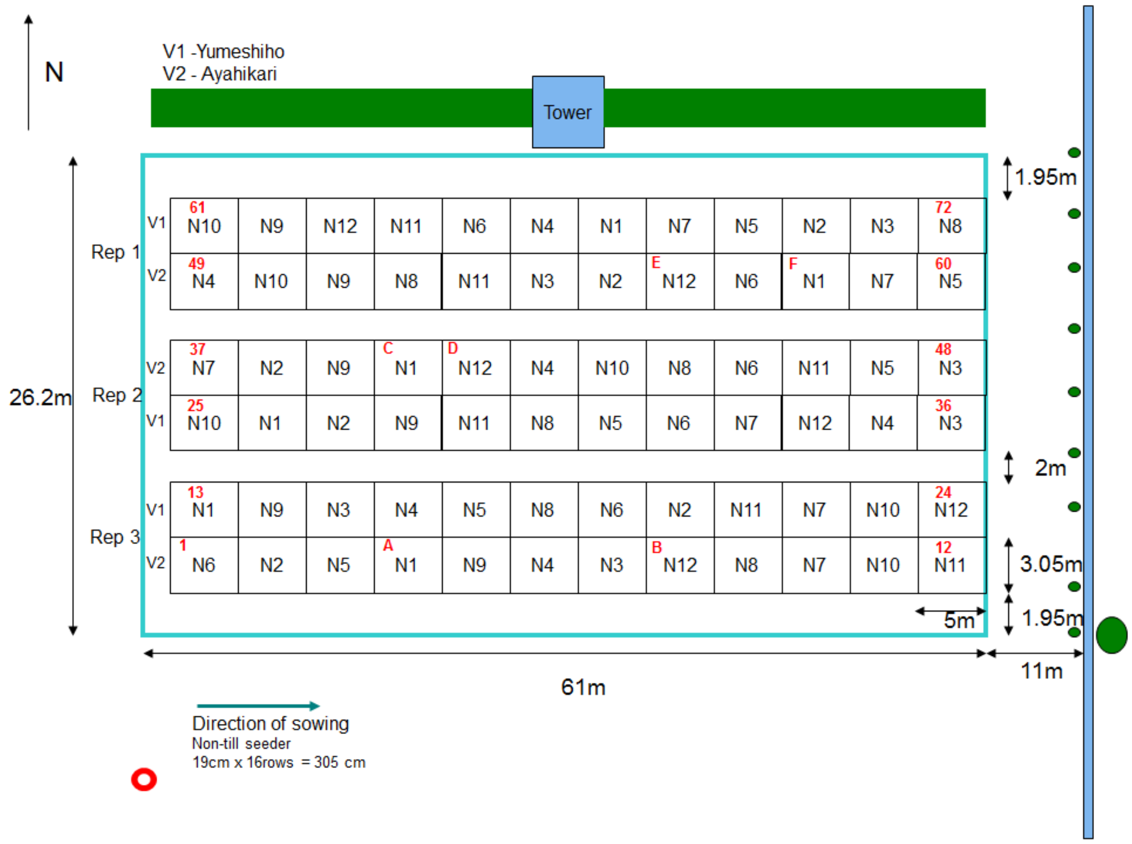

Fig. 3-1 Field layout of the 2013-2014 experiment.

(The numbers in red denote plot numbers. A-F denote the plots in which soil moisture measurements were conducted.)

3.2.1.1.2 Sampling, data collection and data analysis

Crop phenology was observed and recorded every week starting from seedling growth to maturity. Zadok decimal code scale (Zadoks et al., 1974) was used to identify the growth stage of the crop.

First sampling was done at the time of flowering. All above-ground parts were sampled from 0.5 x 0.57 m area and sub sampled (15 heads for each sub sample). Sub sampled plants were separated in to leaves, stems (with leaf sheath) and spikes, and fresh weight was measured separately. Leaf area was measured of the leaf samples from replicate two (sub sampled) using the electronic leaf area meter (LI-COR/LI 3100). All sub samples were dried in a forced air oven for 72 hours at 70 °C to obtain the dry weights. Dry matter of each plant parts, specific leaf area, and leaf area index were calculated.

Second sampling was carried out at the time of physiological maturity. All above ground parts of plants were harvested from 1 x 0.95 m of sampling area and allowed to air dry about one week in a green house. Air dried samples were threshed and winnowed to separate the grain, and the fresh weight was measured. Sub samples were taken from grain samples and straw samples (around 100g), and they were dried in a forced air oven for 72 h at 70 °C to obtain the dry weights. Number of grains was measured with (Weaver IC-1, Aidex Co., Ltd., Nagoya, Japan) for ca. 10 g of dried sub samples to calculate the 1000 grain weight. Number of heads in a 1 m raw length in each plot was counted and the number of heads per square meter was calculated. Grain yield, total above ground dry matter, harvest index (HI), number of heads per area, 1000 grain weight were calculated. And number of grains per head were derived from the calculation taking into the measure grain yield.

Phenology, leaf area, Grain yield and dry matter production data obtained were used for the validation of the APSIM model. Data were statistically analyzed using split plot desing in R statistical software.

3.2.1.2 Data for the grain protein validation

Grain protein data from another experiment conducted in the same experimental location during the 2010-2011 cropping season (Takahashi and Okada , 2012) were used for the model validation for grain protein. The experiment was comprised of 2 sowing times, 2 varieties and 4 fertilizer application levels.

Table 3.2 Nitrogen application rates (2010-2011 experiment)

	Total	**Base application**	**Split application(booting)**	**Additional application (grain filling)**
N0	0	0	0	0
N1	80	60	20	0
N2	110	60	20	30
N3	140	60	20	60

3.2.1.3 Additional validation with 2011-2012 experiment data

Additional validation was conducted using the grain yield and dry matter data from another field experiment which was conducted in the same experimental location during the 2011-2012 cropping season by our laboratory. The summery of the experiment are as follows;

1. Treatment 2(Variety) × 4 (N fertilizer level) × 3 (replication) = 24 plots

Variety ,2 levels and Nirtogen application, 4 levels (Table 3.3)

1. ”Ayahikari” (mainly grown in Saitama and Mie prefecture) for noodle
2. ”Yumeshihou” new variety for bread

Table 3.3 Nitrogen application rates (2011-2012 experiment)

	Total	Base application	Split application(booting)	Additional application (10 days after heading)
1	0	0	0	0
2	80	60	20	0
3	110	60	20	30
4	140	60	20	60

2. Design

Split plot design with 3 replications

Each plot 4 m (length) × 12.2 m (width) (32 rows)

Total experiment area: cv. 15 a (1500 m^2)

Sowing density: 80 kg ha^{-1}

Blanket application P_2O_4 70 kg ha^{-1} K_2O 70 kg ha^{-1}

3. Place: Institute for Sustainable Agro ecosystem Services (Nishi-Tokyo city)

4. Date of sowing: 16 November 2011

5. Duration: 16 November 2011～22 June 2012

3.2.2 Methods to obtain the simulated data

The wheat varieties concerned in the validation were Ayahikari and Yumeshiho. Using field three experiments mentioned in 3.2.1, simulations were conducted to obtain the simulated date of flowering and maturity, dry matter production, LAI, grain yield and grain protein content with the parameterized model configuration.

3.2.3 Methods of model evaluation

3.2.3.1 Comparison of observed and simulated values

Observed and simulated grain yield, dry matter production, leaf area index (LAI) and grain protein content were compared graphically while the date of flowering and maturity were compared in a table.

3.2.3.2 Quantifying the model performances

The model performances were quantified using four statistical indices which have been widely used in previous reports. (eg. Asseng et al. (1998, 2000) ; Wang et al., (2013); Chen et al., (2010); Zang et al., 2012; Balwinder-Singh et al., 2011; Mohanty et al., 2012; Wu et al., 2013).

Root mean square error (RMSE), relative root mean square error (RRMSE), slope (*m*) of a best-fit regression line forced through the origin and modelling efficiency (EF) are four statistical parameters used for the model validation.

The slope (*m*) of the best fitted regression line forced through the origin quantifies the possible over or underestimation (if it is not forced through the origin the slope is not relevant for the test). The root mean square error (RMSE) gives a measure of the absolute magnitude of the error. RMSE has the same units of measured and simulated values. The

RRMSE is a meaningful measure to compare simulation quality of data with highly different averages (ex. yield in kg ha^{-1} and LAI) and it is independent of the unit used. RRMSE is calculated by dividing the RMSE by the mean of the observed values (Asseng et al., 1998; Wu et al., 2013; Wallach, 2006). The modelling efficiency (EF) (also named as Nash-Sutcliffe modelling efficiency) presents the variation in measured values accounted for the model. The Figure 3-2 shows the equations for calculating RMSE and EF

$$\text{Root mean square error} \quad (\text{RMSE}) = \sqrt{\left(\sum_{i=1}^{i=n} \frac{(P_i - O_i)^2}{n}\right)}$$

$$\text{Modelling efficiency} \quad (\text{EF}) = 1 - \left[\frac{\sum_{i=1}^{i=n}(P_i - O_i)^2}{\sum_{i=1}^{i=n}(O_i - \bar{O})^2}\right]$$

where P_i, predicted value, O_i, observed value, $\bar{O}$, mean of the observed values, n, number of observation.

(Source of equations: Mohanty et al, 2012)

Figure 3-2 The equations for calculating RMSD and EF

RMSE closer to 0 denotes the best model performance (lower the RMSE value better the performance), EF = 1 denotes perfect match of predicted and observed values and EF = 0 if the predicted values are equal to the mean of the observed values. A model with acceptable quality should be EF > 0.5 (Wallach, 2006) A variant of the RMSE is the RRMSE.

3.3 Results

3.3.1 Weather data

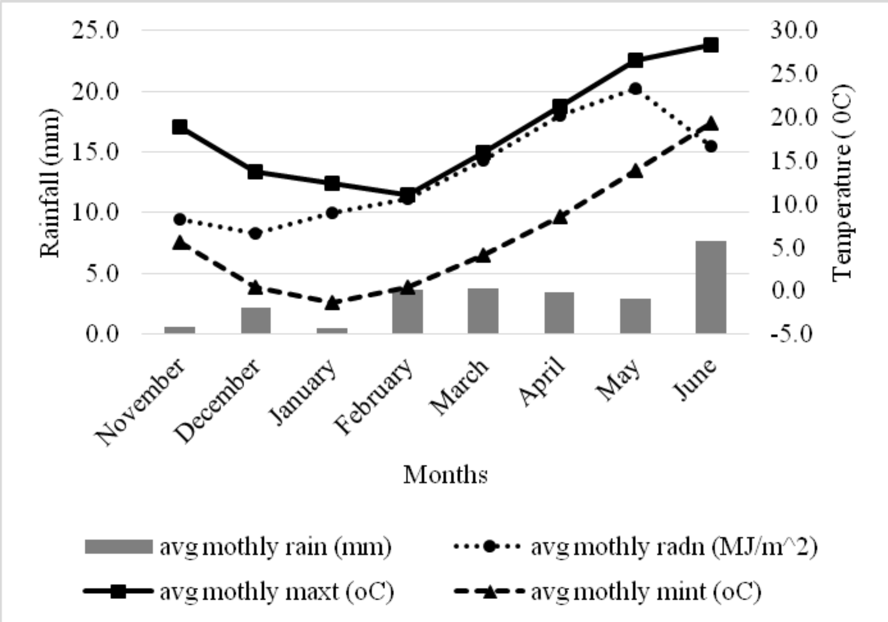

Fig. 3-3 Daily solar radiation, maximum and minimum temperature and rainfall averaged over a month. Data recorded by ISAS, Nishitokyo, Japan (experiment location) in 2013-2014 wheat growing season.

The weather data observations of this year indicated that there was less rainfall compare to the previous year (Fig. 2-3). Specially during the periods from April to June in which wheat plants flower, fill the grains and mature, and from December to January in which tillering of the wheat plants is initiating. Also, the maximum and minimum temperatures in April were slightly higher than those in the previous year. The minimum temperature was below 0 ^{0}C in December and February whereas which was 0 in the previous year. Therefore, for this year, the temperature was lower during the winter and higher during the spring season, compare to the previous year.

3.3.2 Soil water

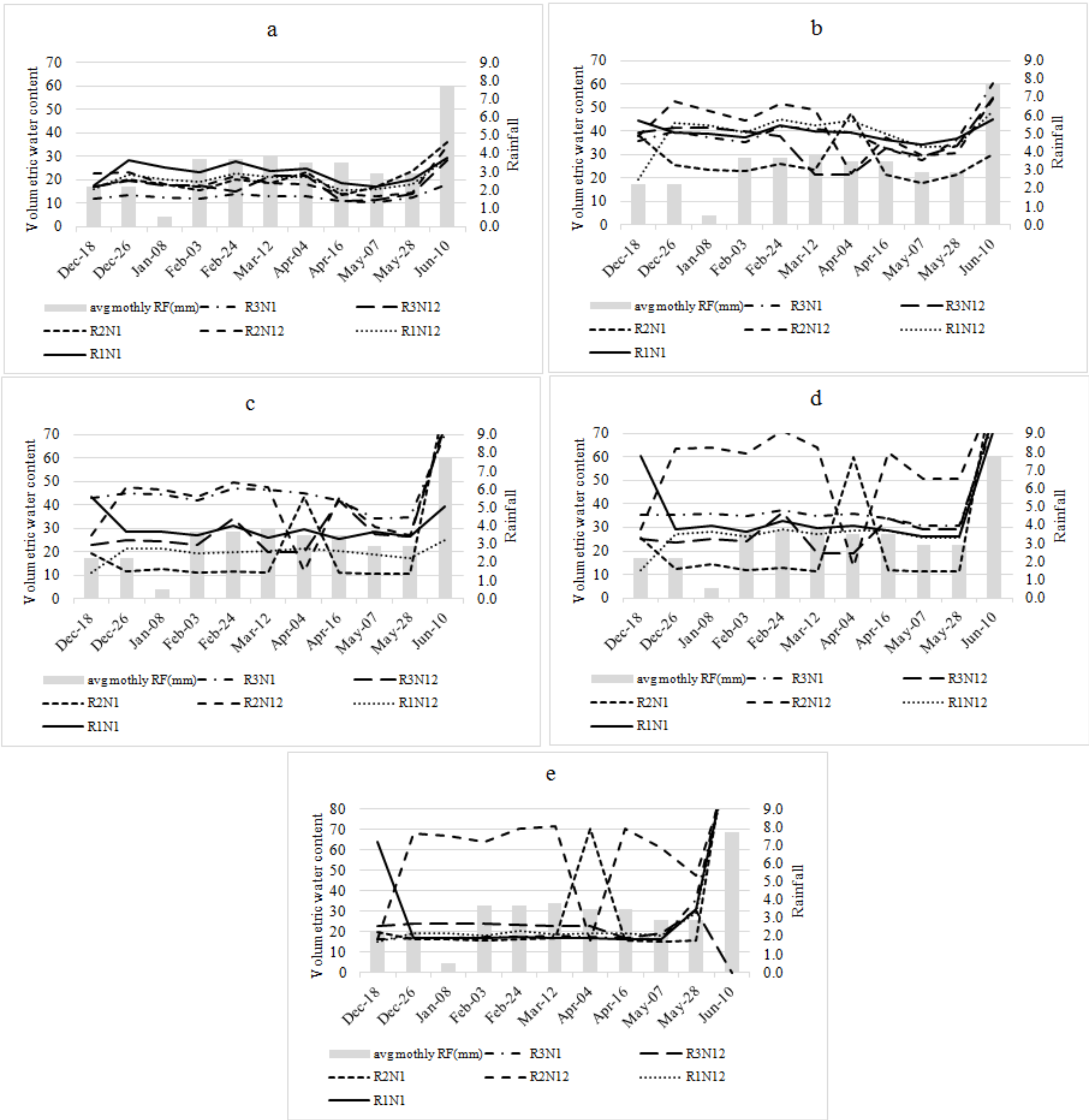

Fig. 3-4 Soil water changes at different depth of the soil layer. (a- 10 cm, b- 20 cm, c-30 cm, d-40 cm and e- 60 cm; R1, R2 and R3 are replicate numbers; N1 and N12 are lowest and the heights N treatments of the Ayahikari cultivar was grown . Primary y-axis is soil volumetric water content (V/V %) and secondary y-axis is rain fall (mm)

Soil water content varied among the replicates and even within a replicate (Fig. 3-4). the variability was so high and it was difficult to draw any conclusion. Therefore, more measurement should be done to quantify the variation.

3.3.3 Grain yield

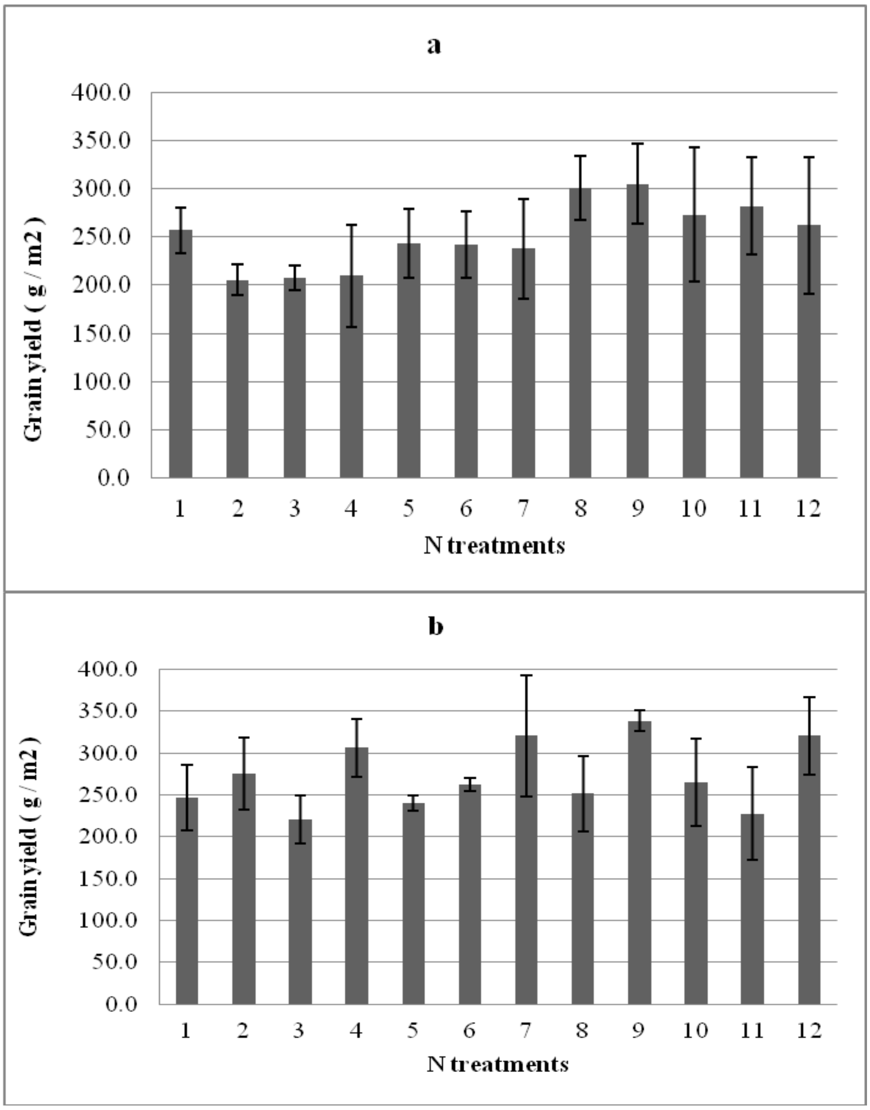

Fig. 3-5 Effect of different N treatments on grain yield. a-Yumeshiho; b- Ayahikari; X axis is nitrogen treatments (1-12) and Y axis is grain yield (g / m^2). Vertical bars denote the standard error.

As shown in Fig. 3-5 yield response to the increasing N rate was not so prominent. But, yield increase can be observed when the level of basal fertilizer and first split application is increased to a certain extent but did not follow the excepted trend correctly (expected based on nitrogen application pattern). Standard error was higher except for the 2 & 3 of Yumeshiho and 5 & 6 of Ayahikari.

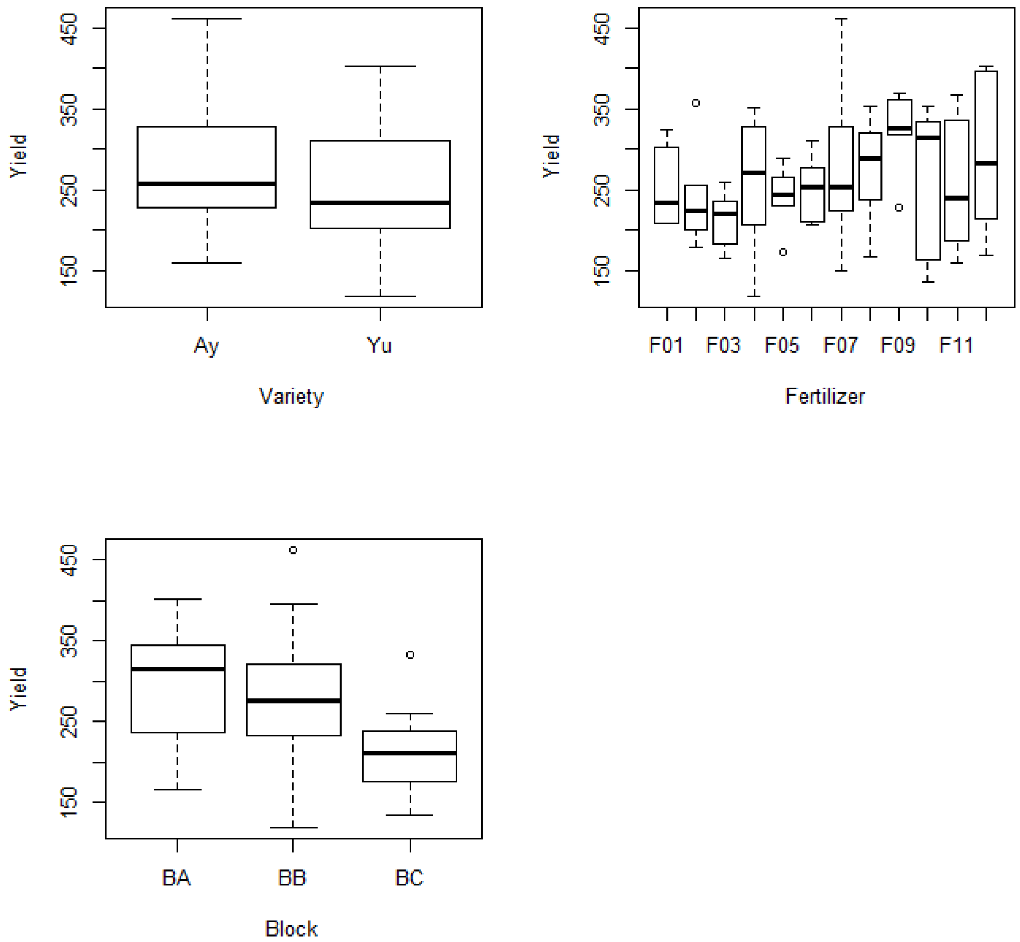

Fig. 3-6 Box plots showing: a- variety vs. grain yield; b- fertilizer vs. grain yield; c- Block (replicate) effect for grain yield. Ay –Ayahikari; Yu-Yumeshiho cultivars. F01-F12 – Nitrogen treatments. BA- replicate 1, BB- Replicate 2 and BC- Replicate 3

Statistical analysis showed that neither variety (P= 0.145) nor fertilizer (P= 0.425) had significant effect on grain yield. But the effect of block (P= 0.00045) was statistically significant giving insight that there was a heterogeneity in the field.

3.3.4 APSIM model performance

3.3.4.1 APSIM model performance with 2013-2014 filed experiment data for Phenology, grain yield, dry matter production at flowering and maturity, LAI at flowering

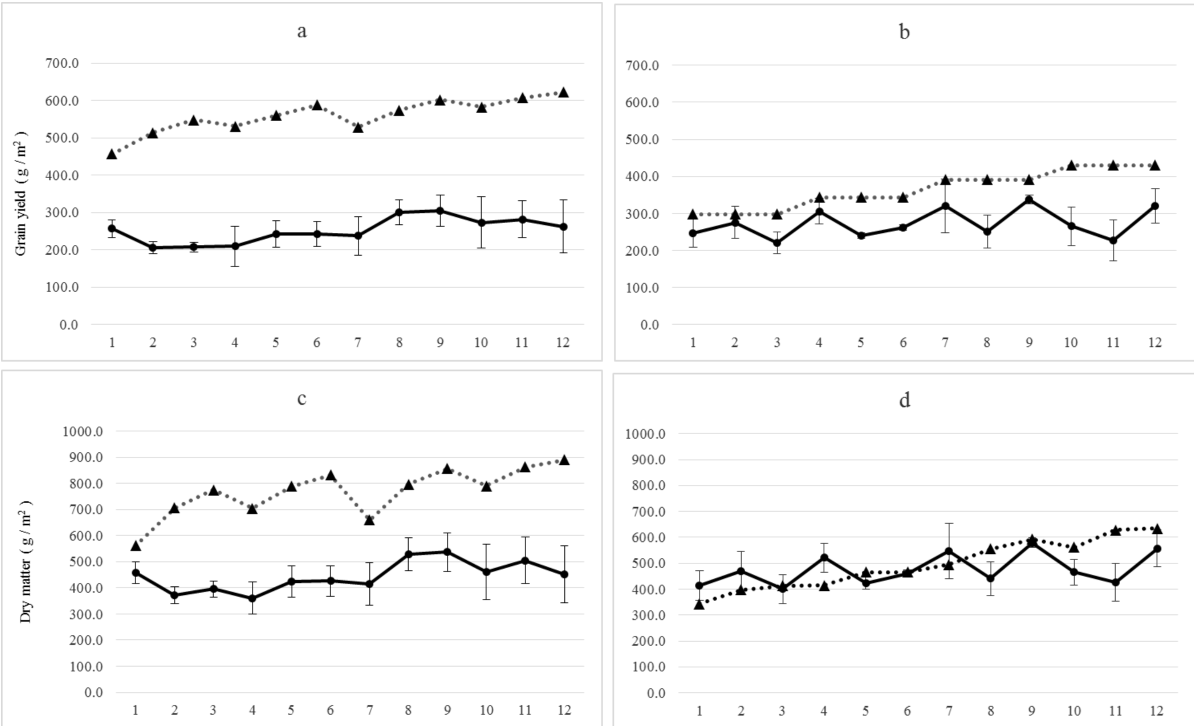

Fig. 3-7 Comparison of simulated and observed grain yield (a –b) and dry matter production at maturity (c-d). Plots; a and c are Yumeshiho; b and d are Ayahikari.

Y-axis is grain yield (g m^{-2}) for a-b and dry matter production (g m^{-2}) for c-d. X axis is N treatments (1-12). Solid line with error bars denote the observed values and dotted line denote the simulated values. All observed values are averages of three replicates

Both grain yield and the dry matter at maturity were overestimated by the model compared to the experimental observations. The model could capture the trend of N response to the nitrogen application to some extent. Model prediction for variety Ayahikari was much better compare to that of Yumeshiho. Both simulated and observed values showed that there was an impact of nitrogen application at flowering for the grain yield of Yumeshiho (Fig. 3-7).

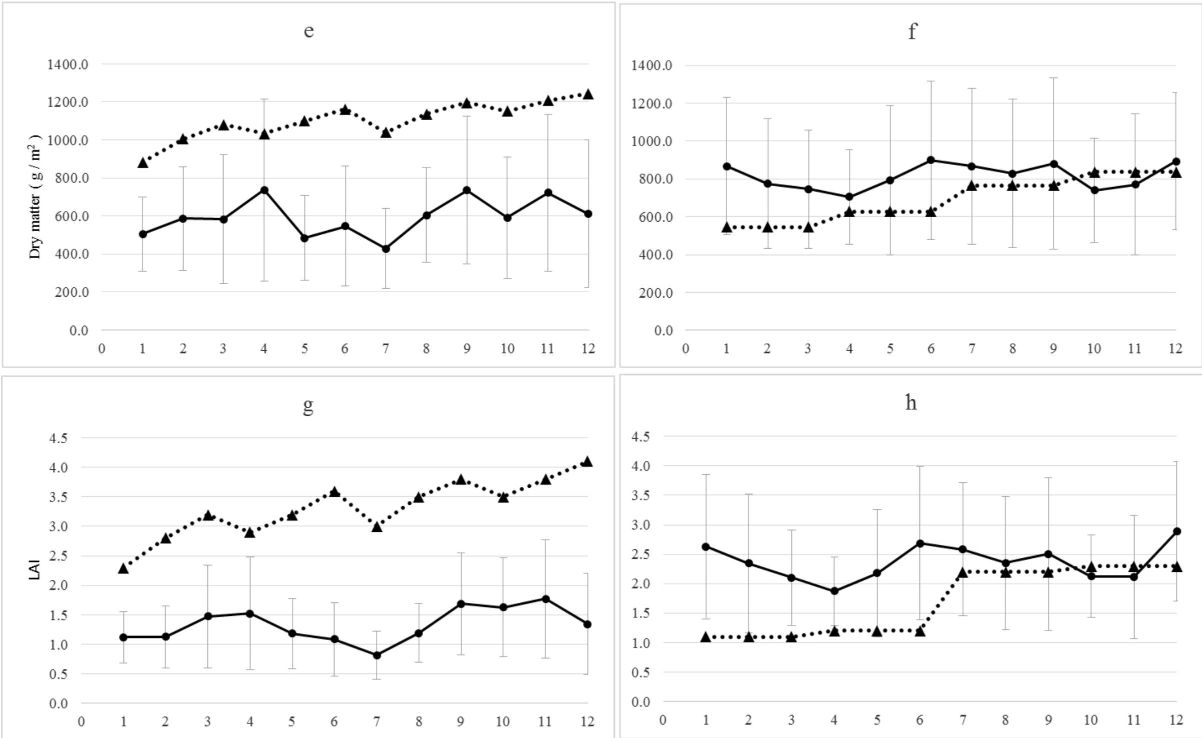

Fig. 3-8 Comparison of simulated and observed dry matter production at flowering (e –f) and leaf area index at flowering (g-h). Plots; e and g are Yumeshiho; f and h are Ayahikari. Y axis is dry matter production (g m^{-2}) for e-f and LAI for g-h. X axis is N treatments (1-12). Solid line with error bars denote the observed values and dotted line denote the simulated values. All observed values are average of three replicates.

According to the observed values the dry matter production and LAI in Yumeshiho at N7 nitrogen treatment was very low but that was not observed in Ayahikari. Whereas Ayahikari had a higher dry matter and LAI after the N4 (Fig. 3-8). This shows that both varieties are sensitive for the first split application and Yumeshiho is more sensitive.

Table 3.4 Comparison of observed and simulated date of flowering and maturity

	Date of flowering			Date of Maturity		
Variety	Simulated	Observed	Difference	Simulated	Observed	Difference
Yumeshiho	09/05/2014	07/05/2014	2	15/06/2014	16/06/2014	1
Ayahikari	09/05/2014	07/05/2014	2	15/06/2014	16/06/2014	1

As indicated in Table 3.4, date of flowering and maturity for both varieties were predicted by the model with a very minimum error (1-2 days).

Table 3.5 Summary of the APSIM model performance (for 2013-2014 experiment)

Variety		**RMSE**	***m***	**EF**	**RRMSE**
Yumeshiho	Grain yield (g / m^2)	310	2.19	-87.7	1.20
	DM – maturity (g / m^2)	334	1.71	-36.2	0.75
	DM – flowering (g / m^2)	518	1.82	-29.2	0.87
	LAI	2	2.37	-39.8	1.50
Ayahikari	Grain yield (g / m^2)	106	1.32	-6.9	0.39
	DM – maturity (g / m^2)	89	1.04	-1.35	0.19
	DM – flowering (g / m^2)	170	0.84	-6	0.20
	LAI	0.88	0.71	-8.4	0.37

APSIM model performance for the 2012-2013 observed data showed a higher RMSE for grain yield, dry matter production and leaf area index in the variety Yumeshiho. Whereas that of Ayahikari were satisfactory except for dry matter at flowering. But, having minus EF values showed the model validation is not satisfactory. Owing to the poor statistical performances especially for the grain yield with the data set from 2011-2012 experiment the second validation was performed using another data set obtained from a field experiment conducted in 2012-2013. However, it can be said that the model performance for Ayahikari were better than Yumeshiho for dry matter production at flowering and LAI as explained by RMSE, *m* and RRMSE values (Table 3.5).

3.3.4.2 APSIM model performance with 2011-2012 filed experiment data for grain yield and dry matter production at maturity.

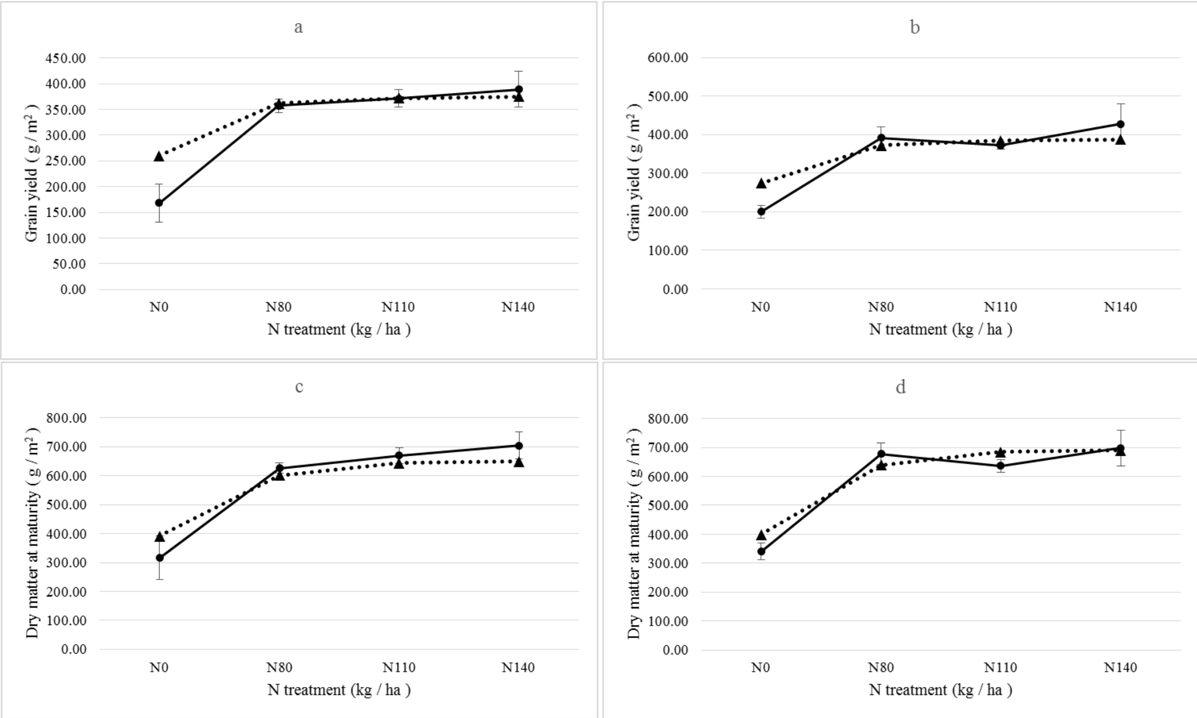

Fig. 3-9 Comparison of simulated and observed grain yield (a –b) and total dry matter production at maturity (c-d). Plots; a and c are Yumeshiho; b and d are Ayahikari. Solid line with error bars denote the observed values and dotted line denote the simulated values. All observed values are averages of three replicates.

As shown in Fig. 3-9 APSIM model showed very good accuracy in simulating the grain yield and total dry matter production at maturity. The model was able to simulate the nitrogen response to the grain yield as that was observed in the field experiment. However, the simulation error is little bit lager at zero nitrogen level.

Table 3.6 Summary of the APSIM model performance (for 2011-2012 experiment)

Variety		RMSE	*m*	EF	RRMSE
Yumeshiho	Grain yield (g / m^2)	46.3	1.02	0.73	0.14
	DM – maturity (g / m^2)	50	0.96	0.89	0.08
Ayahikari	Grain yield (g / m^2)	43.7	0.98	0.77	0.12
	DM – maturity (g / m^2)	43.1	1.01	0.91	0.07

The APSIM wheat model performances against the 2011-2012 data were much better than that of 2013-2014 validation. **RMSE** values were very low and **RRMSE** values were closed to zero for grain yield and total dry matter production at maturity in both varieties. All ***m*** values were very close to one showing that over or under prediction is very little. The **EF** values were very close to one for both varieties for grain yield and total dry matter production (Table 3.6). Model performance could not be tested with respect to LAI and dry matter production due to the lack of data for LAI and dry matter production before the maturity in 2011-2012 data set.

3.3.4.3 APSIM model performance for grain protein content

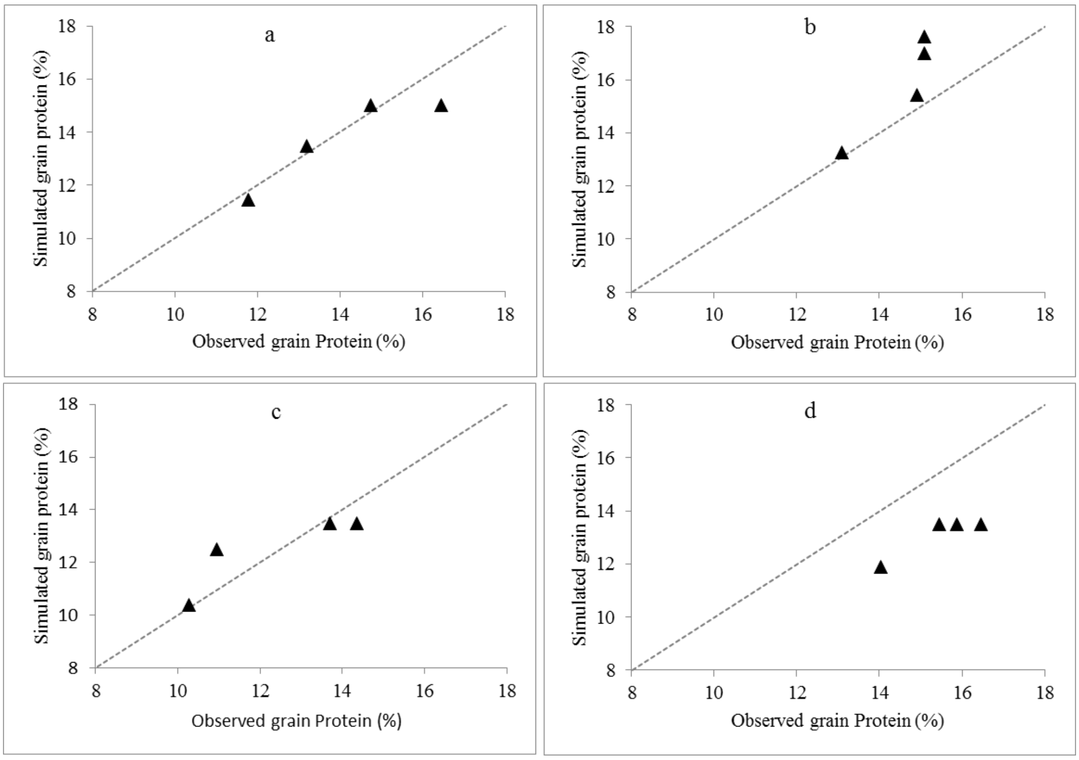

Fig. 3-10 Comparison of simulated and observed grain protein content (a –d). Varieties Yumeshiho (a, b) and Ayahikari (c, d) were used. The sowing date was Nov. 2 (a, c) and Dec. 1 (b, d).

Grain protein content simulated by APSIM followed the same trend that was observed (GPC was increased with increased N application). GPC were reasonably simulated for Nov 2 sowing for both varieties but the error was larger in Dec 1 sowing for both varieties. Additional nitrogen application after the flowering (N2 and N3, Table 3.2) resulted in the increase in GPC from 12 to 15 % in Yumeshiho and 11 to 14% in Ayahikari. APSIM simulation also had captured the same effect (Fig. 3-10)

Table 3.7 Summary of the APSIM model performance for grain protein content

Variety	Sowing time	Parameter	RMSE	*m*	EF	RRMSE
Yumeshiho	Nov-02	Grain protein content (%)	0.77	0.97	0.8	0.05
	Dec-01	Grain protein content (%)	1.60	1.09	-2.6	0.11
Ayahikari	Nov-02	Grain protein content (%)	0.89	1.004	0.73	0.07
	Dec-01	Grain protein content (%)	2.38	0.84	-6	0.15

Grain protein simulations had RMSE of 0.77 and 0.89, ME of 0.8 and 0.7, RRMSE of 0.05 and 0.07 for Yumeshiho and Ayahikari respectively at Nov 2 sowing. For Dec. 1 sowing group RMSE 1.6 and 2.38, ME -2.6 and -6, RRMSE 0.11 and 0.15 for Yumeshiho and Ayahikari respectively. Therefore, overall APSIM performance in GPC simulation was satisfactory and acceptable for the case of Nov. 02 sowing.

3.3.4.4 APSIM model performance for soil water prediction

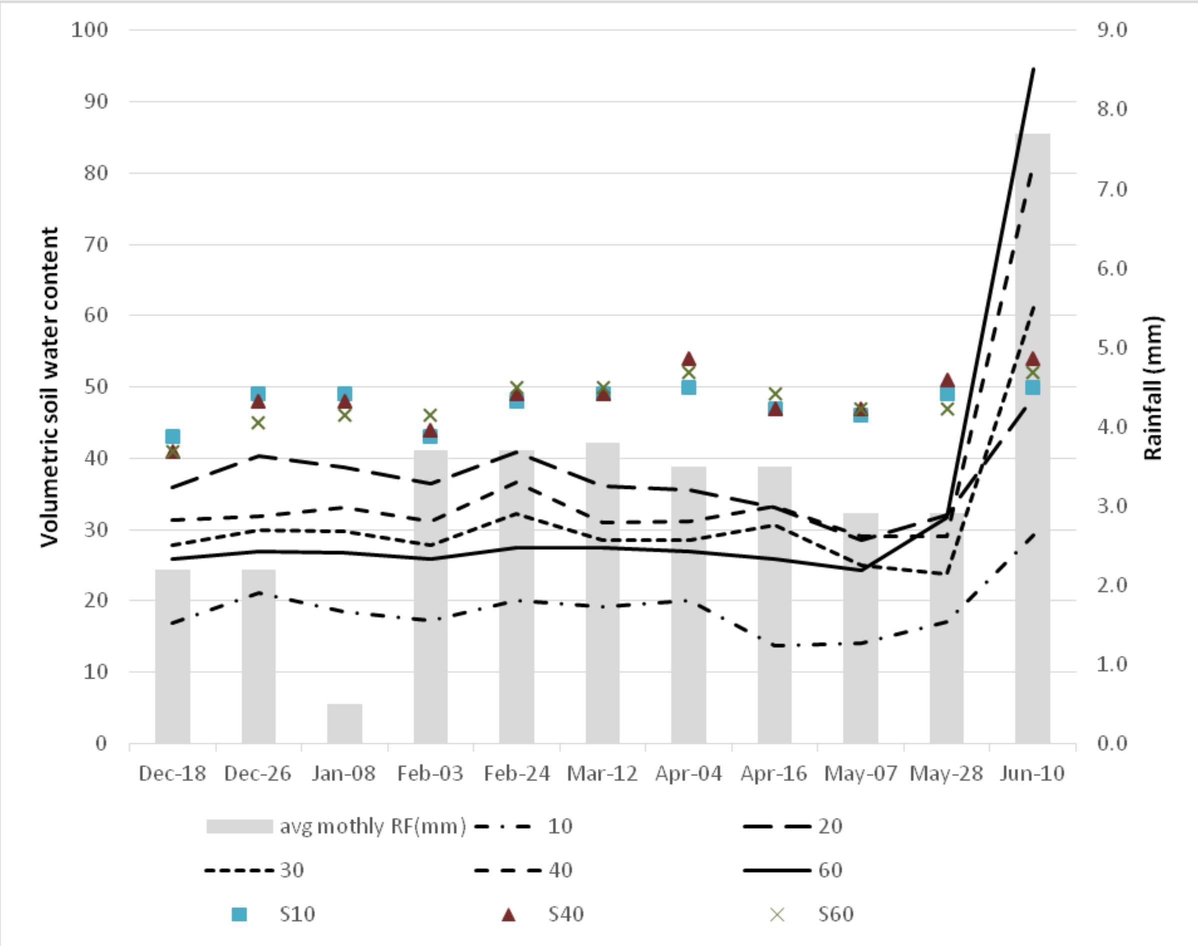

Fig. 3-11 Simulated and measured soil water at different depths (10, 20, 30, 40, 60 cm).

10 20 30 40 60 **Measured soil moisture values (average of three replicates)**

S10 S40 S60 **Simulated at 10, 40 and 60 cm depths**

The model overestimated the soil moisture in each soil layer concerned. But interestingly, simulated trend of soil moisture variation had a good agreement with that of observed (fig. 3-11).

3.3 Discussion

The results of the model performance tests have confirmed that the APSIM model can be applied to the climatic and soil conditions in Kanto area or similar soil and climatic regions in Japan for Japanese wheat cultivars.

Asseng et al. (1998, 2000) and Chen et al. (2010) also indicated successful validation of APSM model (APSIM Nwheat model) for wheat in Western Australia, the Netherlands and China (North China Plain). According to their model performances, they had RMSE of 40, 80 and 83 respectively for grain yield (g m^{-2}). From our validation results from 2011-2012 experiment we got RMSE of 46.3 and 43.7 for two varieties concerned (Yumsehiho and Ayahikari respectively) for grain yield (g m^{-2}).

Asseng et al. (1998, 2000) had RMSE of 80 and 120 for dry matter (g m^{-2}) production and 0.6 and 1.2 for leaf area index respectively while Chen et al. (2010) reported 140 and 1.6 of RMSE for dry matter production and leaf area index respectively. Interestingly, our results showed 50 and 43.1 of RMSE for total dry matter production at maturity (g m^{-2}) and 2 and 0.88 for LAI for Yumeshiho and Ayahikari respectively.

For the grain protein content (GPC %) Asseng et al., 1998 and 2000 had RMSE of 3.2 and 1.6 %. Results of GPC validation in our study were 0.7 and 0.8 RMSE for Yumeshiho and Ayahikari at Nov 2 sowing time (mid sowing period) while 1.6 and 2.3 for Yumeshiho and Ayahikari at Dec 1 sowing time (late sowing period). This give insight that grain protein validation in our study have got even better results including different sowing time as well compare to the existing reports.

Therefore, our results are compatible with the previous reports on APSIM model validation. Furthermore, our results had model efficiency (EF) values which were closer to one denoting perfect match of predicted and observed values. Also, the difference between simulated and observed date of flowering and maturity was 1-2 days showing the perfect simulation of phenology.

Considering all these model performance indices and comparative results, we have a confidence in using APSIM model for decision support in nitrogen management in obtaining the higher yield and expected grain protein content for the Kanto region in Japan. But, The result for the model performance from past three experiments were mixed. And certainly more validation is needed.

As indicated in our results, the APSIM predictions were relatively poor in zero or lower nitrogen application levels (Fig. 3-8). Further, APSIM overestimated the soil water content while capturing the real trend in soil was changes over the time. Both reasons showed the overall soil parameterization may requires further fine tuning. Therefore, additional complete parameterization of APSIM soil water and nitrogen modules will be advantageous in future that will enable us to use the APSIM model for wide range of applications including soil water and soil nitrogen dynamics as well.

The model performance for LAI was showed higher RRMSE values (0.37 - 1.5) compared to the one values of grain yield (0.12 - 0.14) and dry matter production (0.07 -0.08). This may be due to the tendency of the model for slight over prediction of the LAI. Asseng et al. (1998, 2000) also reported the over prediction of the LAI in their studies but also indicated that there had not shown major effect on the performance of other model components. APSIM wheat model uses specific leaf area range of 22000 – 27000 mm^2 g^{-1} dry weight with respect to the maximum LAI = 5 and minimum LAI= 0. We can adjust this range during the parameterization to have best mach for the simulated LAI for respective cultivars. Therefore, adjusting the specific leaf area range during the parameterization for respective cultivars is very important to have good predictions for LAI. In the measurement of the leaf area we consider only the leaf blade and leaf sheath is calculated for the drymatter together with the stem. This might lead to an underestimation of the LAI in observed values and can be accounted for the error between simulated and observed LAI.

With respect to the 2013-2014 wheat experiment, even though we conducted the experiment at same location (ISAS) as previous years, we used a different experiment plot of the same location. By observation and supported with the statistical analysis conducted we can suspect that there was a heterogeneity within the field and owing to that nitrogen response was not so clear despite we have used a wider range of nitrogen application rates and different combinations. Therefore, that data set may not be useful for the model validation purposes and that can be the most reasonable explanation for poor model performance with the 2013-2014 data sets (Table 3.5). High variation of soil moisture among the replicates and even within each replicate added more clues us to make such assumption.

The next chapter (Chapter 4) explains in detail about the simulation experiment conducted to drive the economic optima for N application using the model as a decision support tool.

Chapter 4

Elucidation of optimum nitrogen management through model simulation parameterized for Japanese wheat cultivar for Kanto region in Japan

4.1 Introduction

Japanese farmers are subsidized for wheat production through "quality bonus" depending on its grain quality indices including grain protein content (GPC). GPC can be controlled by N management but it is one of the most unstable factors affected by soil, climatic and management. The highest quality bonus is offered for the hard wheat and soft wheat with the grain protein range 11.5 - 14% and 9.7 – 11.3% respectively (MAFF 2014). Therefore, decision support with nitrogen management optima for attaining higher yield and required range of GPC is really indispensible for the producers. The validated crop simulations models can be used for such tasks and this chapter describes about developing economic management optima for N management for Kanto region, Japan using validated APSIM model with the support of a simulation experiment followed by an economic analysis.

4.2 Methodology

4.2.1 Simulation experiment for obtaining optimum nitrogen management

A simulation experiment was conducted to find out the optimum nitrogen application rate and timing of application using the validated APSIM model configurations for both hard wheat (Yumeshiho) and soft wheat (Ayahikari) varieties. For the weather data, average of past 30 years (1981 - 2010) obtained at the Tokyo District Meteorological Observatory (N35°41.4', E139°45.6') (Japan Meteorological Agency http://www.data.jma.go.jp/obd/stats/etrn/index.php). APSIM model validated as per the previous chapter of the thesis was used to run the simulations. The simulation experiment comprised of 16 different nitrogen application rates with a basal and two split application at stem elongation stage (DC 30) and flowering stage (DC 58-64) as shown in Table 4-1 . Following the each combination of N rate altogether 64 simulations were conducted for one variety. Thus, simulation experiment was conducted for both Yumeshiho (hard wheat) and Ayahikari (soft wheat). Growth stages are described as in Zadoks decimal code scale (Zadoks et al., 1974). Date of sowing was 15 of November and sowing density is 80 kg ha^{-1} (200 plants per m^{2}) representing farmers practice in the region. Simulated grain yield and GPC were adjusted to the standard moisture contents; gain yield to 12.5% and GPC to 13.5% moisture percentage respectively prior to the economic analysis.

Table 4.1 Different N scenarios used for the simulation experiment

N Scenarios		N application (kg N ha^{-1})			
		Total	**Basel**	**Split1(DC 30)**	**Split2 (DC 58-64)**
1	N1	**0**	0	0	0
	N2	**40**	0	0	40
	N3	**80**	0	0	80
	N4	**120**	0	0	120
2	N5	**40**	0	40	0
	N6	**80**	0	40	40

	N7	**120**	0	40	80
	N8	**160**	0	40	120
3	N9	**80**	0	80	0
	N10	**120**	0	80	40
	N11	**160**	0	80	80
	N12	**200**	0	80	120
4	N13	**120**	0	120	0
	N14	**160**	0	120	40
	N15	**200**	0	120	80
	N16	**240**	0	120	120
5	N17	**40**	40	0	0
	N18	**80**	40	0	40
	N19	**120**	40	0	80
	N20	**160**	40	0	120
6	N21	**80**	40	40	0
	N22	**120**	40	40	40
	N23	**160**	40	40	80
	N24	**200**	40	40	120
7	N25	**120**	40	80	0
	N26	**160**	40	80	40
	N27	**200**	40	80	80
	N28	**240**	40	80	120
8	N29	**160**	40	120	0
	N30	**200**	40	120	40
	N31	**240**	40	120	80
	N32	**280**	40	120	120
9	N33	**80**	80	0	0
	N34	**120**	80	0	40
	N35	**160**	80	0	80
	N36	**200**	80	0	120
10	N37	**120**	80	40	0
	N38	**160**	80	40	40
	N39	**200**	80	40	80
	N40	**240**	80	40	120
11	N41	**160**	80	80	0
	N42	**200**	80	80	40
	N43	**240**	80	80	80
	N44	**280**	80	80	120
12	N45	**200**	80	120	0
	N46	**240**	80	120	40
	N47	**280**	80	120	80
	N48	**320**	80	120	120
13	N49	**120**	120	0	0
	N50	**160**	120	0	40
	N51	**200**	120	0	80
	N52	**240**	120	0	120
14	N53	**160**	120	40	0

	N54	**200**	120	40	40
	N55	**240**	120	40	80
	N56	**280**	120	40	120
15	N57	**200**	120	80	0
	N58	**240**	120	80	40
	N59	**280**	120	80	80
	N60	**320**	120	80	120
16	N61	**240**	120	120	0
	N62	**280**	120	120	40
	N63	**320**	120	120	80
	N64	**360**	120	120	120

4.2.2 Finding economic optima for the nitrogen application

Economic analysis was conducted for all 64 combinations of N applications to find out the gross margin with respect to the respective N combination. The calculation of the gross margin was conducted using Excel spread sheet based on the procedure described by Takahashi and Okada (2013) and a web based program developed based on which (http://econ.ipads.jp/wheat.asp). The economically optimum N application combination is the one which gives the highest gross margin. The fertilizer cost used for the analysis was JPY 248 kg^{-1}N. All background data used were based on Ministry of Agriculture, Forestry and Fisheries, Japan (MAFF) 2012.

Further, a sensitivity analysis was conducted to see the effect of fertilizer cost on optimum nitrogen application rate by increasing the cost of fertiliser 2, 3, 4, 5 and 10 times of the current cost of fertilizer (JPY248 kg^{-1}N).

4.3 Results

Both hard wheat (Yumeshiho) and soft wheat (Ayahikari) followed the same trend for the increasing nitrogen application. Whereas, different responses to N was shown by both varieties based on the timing of the nitrogen application. Variation in grain yield is much higher at 120 – 200 kgN ha^{-1} application ranged depend on the time of the application. The GPC varied most at 40 – 120 kgN ha^{-1} range depend on the timing of application and beyond that GPC was almost stable irrespective of the timing of application. The grain yield and GPC ranged from 3 – 6 t/ha and 7.6 – 13.1% respectively in Yumeshiho. Grain yield in Ayahikari was almost same (3 – 6.2 t ha^{-1}) whereas the GPC was lower than that of Yumeshiho (7.4 – 11.7 %). Owing to the higher quality bonus received for hard wheat compare to that of soft wheat, the gross margin ranged from 245,000 – 694,000 JPY in Yumeshiho (hard wheat variety) whereas 117,000 – 453,000 JPY in Ayahikari (soft wheat variety) which is much lower than Yumeshiho (Fig. 4-2). The economically optimum nitrogen combination was N57 in both varieties (Fig. 4-2). At this point Yumeshiho had 6 t ha^{-1} grain yield and 13.1 % GPC. As for the Ayahikari it was 5.9 t ha^{-1} grain yield and 11.7 % GPC. However, at N57 nitrogen rate is quite high (200 kgN ha^{-1}) and no spilt application of N at the time of flowering. Interestingly this rate of nitrogen application falls within the range beyond which wheat plant did not show any significant response to the N and yield is almost stable.

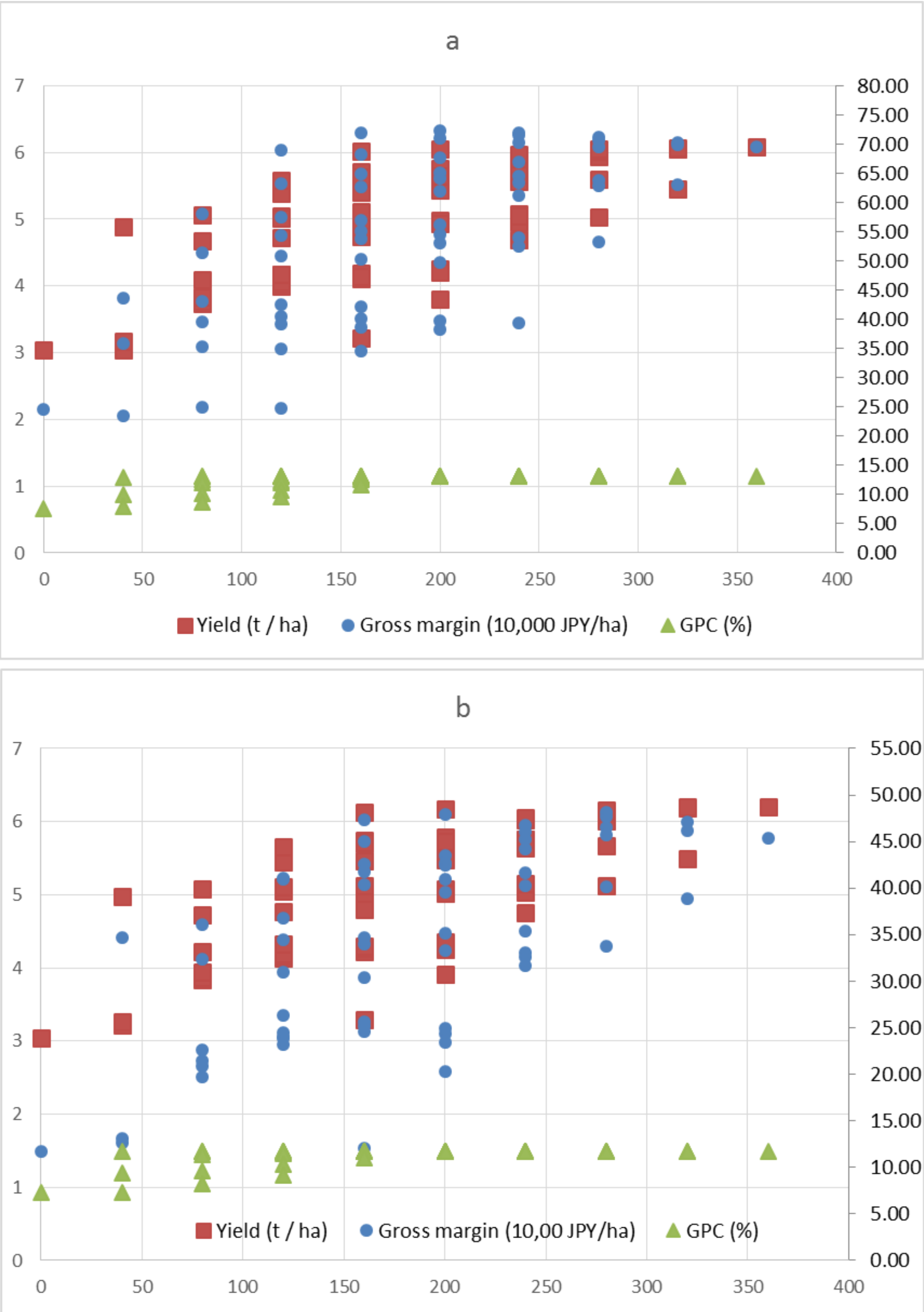

Fig. 4-1 Variation of grain yield, GPC and gross margin with the amount of N applied. Primary Y-axis is grain yield (t/ha), secondary Y-axis is gross margin (10,000* JPY ha^{-1}) and GPC (%) and X-axis is amount of N applied (0 – 360 kg/ha). Plot "a" denotes Yumeshiho and plot "b" denotes Ayahikari.

*Gross margin is showed in 10,000 JPY inorder to show the variation in GPC clearly in the graph

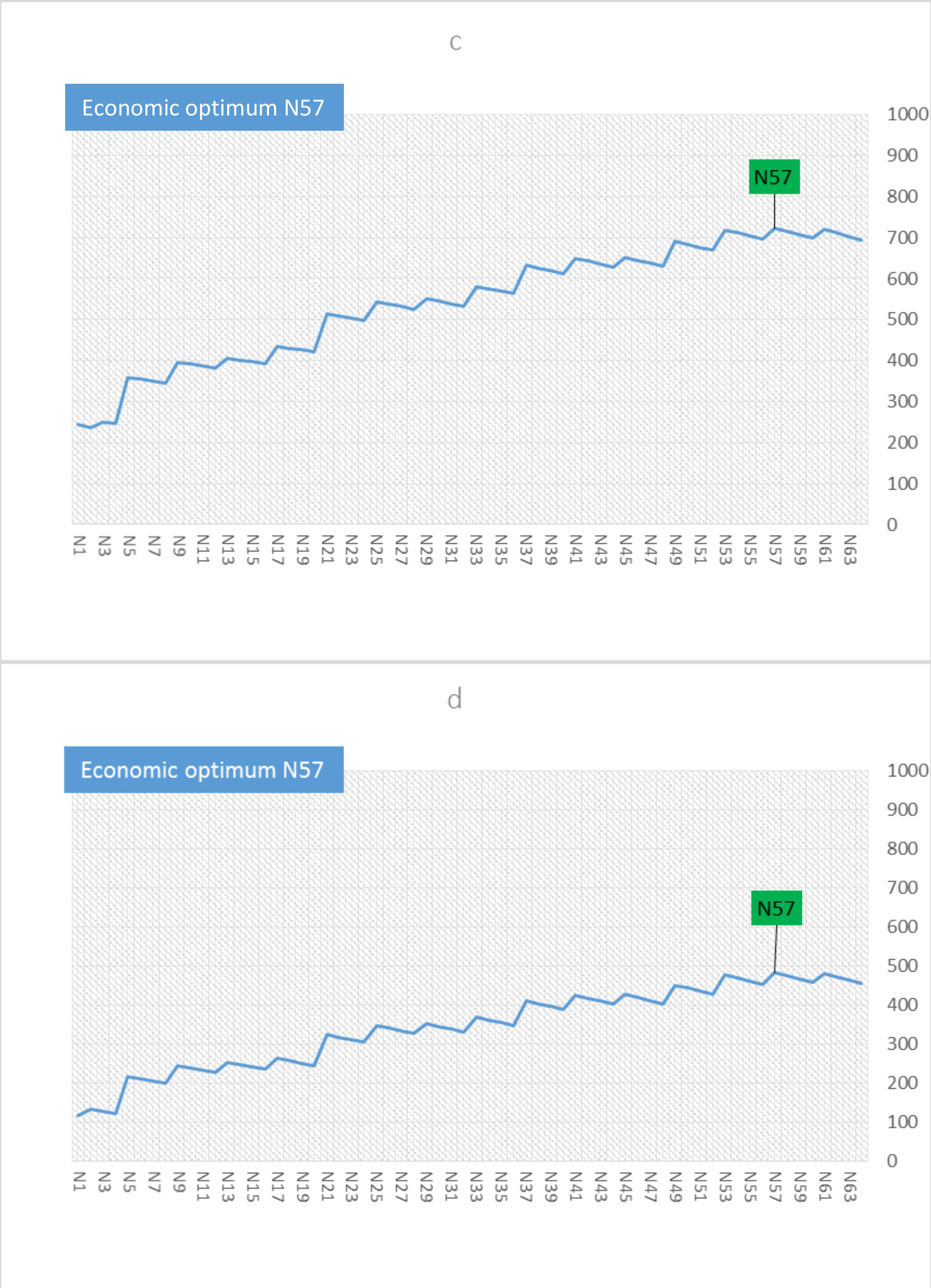

Fig. 4-2 Gross margin vs. different nitrogen combinations. Y-axis is gross margin (1000 JPY ha^{-1}) and X-axis is different nitrogen combinations (N1-N64). Plot "c" denotes Yumeshiho and plot "d" denotes Ayahikari.

Fig. 4-3 shows the results of the sensitivity analysis conducted to check the effect of increased fertilizer cost on the economical optimal compared to the current fertilizer rate (JPY248 $kg^{-1}N$). Results showed that optimum N application rate move to a lower rate (N53: 160 kgN ha^{-1}) when the fertilizer cost is increased by two folds of the current rate. It was stable at that point up to the fivefold increase. When the fertilizer cost is five times and ten times higher than the current fertilizer cost economic optimal application is 120 kgN ha^{-1} (N49). This gives insight that the current fertilizer cost is low and therefore there is a possibility to maximize the profit increasing the rate of fertilizer application up to the maximum N response.

Simulations showed that split application of N fertilizer at flowering stage had a significant effect of GPC in Yumeshiho. In Yumeshiho, GPC was increased from 7.6 to 13% when 40 kgN ha^{-1} was applied at the time of flowering compare to the no application of fertilizer. But, increasing the rate of application (80 and 120 kgN ha^{-1}) did not show any further increase in GPC. N application at stem elongation stage had very little effect on GPC but increased the grain yield. When 40 kgN $ha^{-1}$was applied only at stem elongation stage grain protein increased from 7.6% (at zero N application) to 9.9% whereas grain yield was increased from 303.8 to 373.4 gm^{-2} .

Both varieties showed positive gross margin even with no nitrogen application and the profit from the Yumeshiho is two folds that of Ayahikari at zero nitrogen treatment. Comparing with the gross margin at optimum nitrogen level it was three times lower in Yumeshiho (720,000 and 240,000 JPY ha^{-1}) and four times lower in Ayahikari (480,000 and 117,000 JPY ha^{-1}).

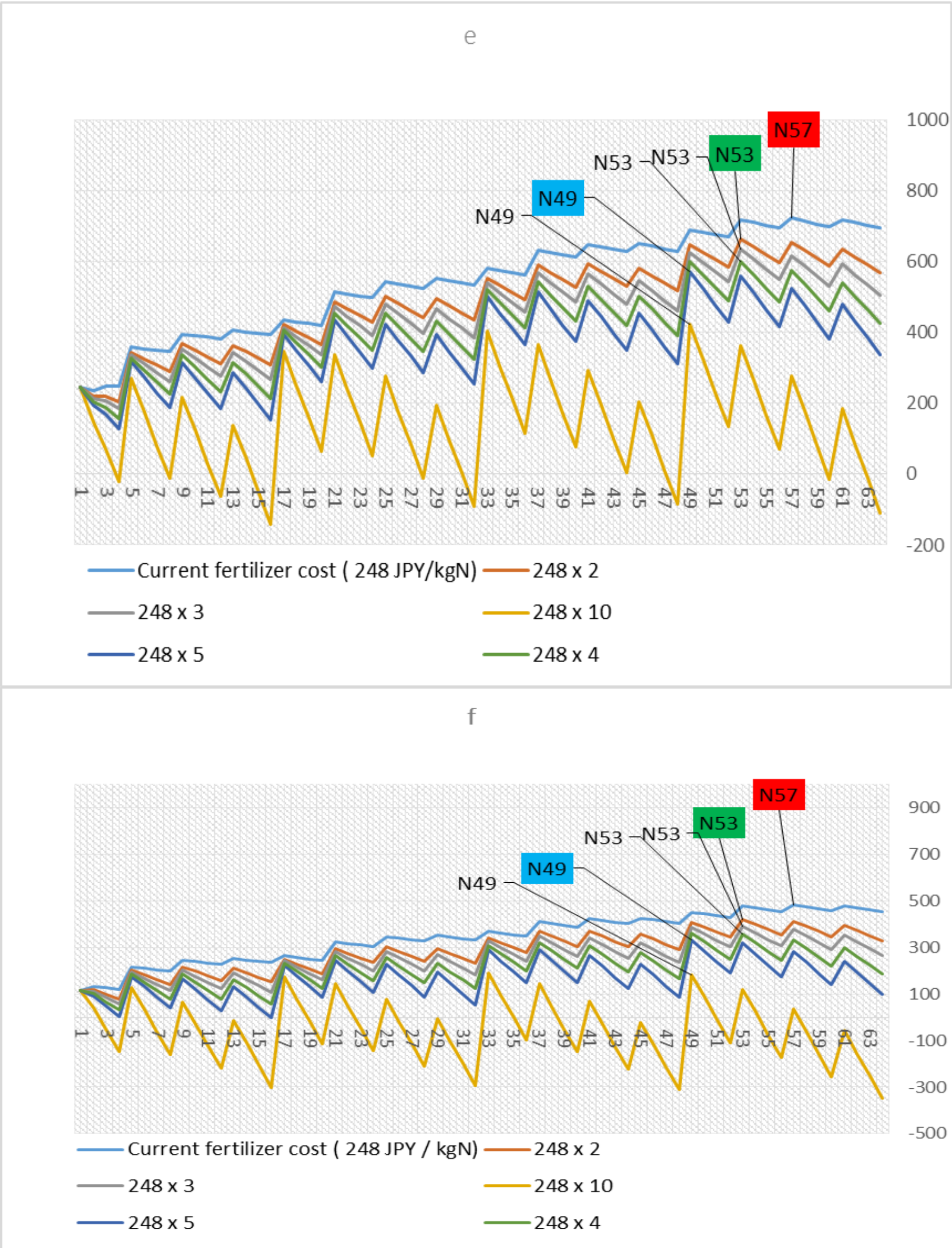

Fig. 4-3 Effect of cost of fertilizer on optimum N rate. Y-axis is gross margin (1000 JPY ha^{-1}) and X-axis is different nitrogen combinations (N1-N64). Each line in the graph denotes gross margin at different fertilizer costs. Plot "e" denotes Yumeshiho and plot "f" denotes Ayahikari.

4.4 Discussion

The main objective of this simulation study was to find out the economically optimum nitrogen application rate that would help to increase the profitability of the wheat farmers in Kanto area Japan by increasing the yield and obtaining the benefits from quality bonus offered for grain protein content under the average climatic conditions. The simulation study showed that 200 kgN ha^{-1} (120kg at sowing and 80kg at stem elongation stage) is the optimal rate of N application for both hard wheat and soft wheat at which farmers can attain the maximum gross margin (as a result of higher yield and quality bonus received for GPC). This rate of application is for the current cost of fertilizer. Therefore, having the opportunity to maximize the profit using higher rate of nitrogen within which the range of maximum nitrogen response occurs, denotes that current cost of fertilizer is not so high. This was further confirmed by sensitivity analysis. When the cost of fertilizer increased by two folds economic optimum rate was reduced and was stable up to five fold of increase. From fivefold to tenfold there had a lower rate again. Thereby the maximum profit also decreased by 2-3 folds (at current cost of fertilizer 720,000 – 480,000 JPY ha^{-1} and at ten times of current cost 420,000 – 180,000 JPY ha^{-1}). Therefore, higher fertilizer costs prevent farmers to obtain the benefit of plant response to the nitrogen to maximize their profits.

The results of field experiments and simulation experiments have shown that nitrogen application at flowering stage has significant effect on increasing GPC but small effect on grain yield of wheat while N applied at stem elongation stage would increase the yield. (Nakano and Morita, 2009; Asseng et al., 2000; Ellen and Spiertz, 1980). Our simulation study showed that results for hard wheat (Yumeshiho) are consistent with the literature data. The results of soft wheat showed some interesting response that 40 kg of nitrogen applied either stem elongation or flowering stage had significant positive effect on GPC. But application at both stages did not have any effect and nitrogen applied at flowering beyond 40 kgN ha^{-1} rate resulted decreased in GPC. However for the hard wheat cultivar, N application beyond 40 kgN ha^{-1} neither decrease yield nor increased yield. Therefore, farmers should be cautious when they plan to apply additional nitrogen at flowering for both soft wheat and hard wheat cultivars. For both varieties, basal fertilizer application had no effect on GPC.

The simulation study showed that wheat cultivation is profitable even with no fertilizer application giving insights the higher nitrogen supply capacity of the volcanic ash soil in Kanto area. Further, growing hard wheat is more profitable than soft wheat for farmers in Kanto area Japan.

Chapter 5

General Discussion

5.1 Parameterization of APSIM model for wheat in Japanese conditions, Kanto area in Japan

Parameterization of APSIM model for the conditions in Kanto area of Japan was success as the model could reasonably reproduce the observed values after the parameterization for crop phenology, dry matter production, and leaf area index and grain yield. The model was parameterized for four Japanese wheat varieties across early, mid (farmers' practise or optimal sowing) and late sowing times. The error in simulation tended to be higher at early and delayed sowing (mostly) times compared to at the optimal time for yield, dry matter and LAI. This showed that the model could not capture the effect of sowing time very well during the parameterization. Zhang et al. (2012) also reported that errors in simulation in APSIM, increase with delay in sowing time. During the parameterization we derived the cultivar parameter values that need to differentiate the cultivar differences on phenology, dry matter production and grain yield. The derived cultivars could explain the cultivar differences very well and accurately simulate the phenology both at the parameterization and at the validation. Therefore, these cultivar parameters are very good source of data for future modelling studies that will be conducted using the APSIM for respective cultivars. The derivation of cultivar parameters took a longer time as it was conducted with trial and error simulations. Therefore, those who will directly use these parameters can save the time and conduct their work more efficiently. Asseng et al. (2000), also have used the cultivar parameters derived by Ritchie et al., 1985 for the wheat cultivar that they used for the study. The values we obtained for the parameters responsible for phenology. For all four varieties we used the vernalization sensitivity was two (low vernalization requirement). Kiribuchi-Otobe (2009) and Yoshida et al. (2001) have indicated that Yumeshiho and Ayahikari are spring type verities (degree of winter habit is low) respectively, which means these two varieties need low vernalization requirement. In the mean time, Taya et al. (2003) have mentioned that degree of winter habit of Nishinokaori also is low. In general model showed relative root mean square error (RRMSE) of 19%, 20%, 21% and 6% in simulating grain yield for Ayahikari, Yumeshiho, Nishinokaori and Nebarigoshi respectively (Table 2.10) after the parameterization. The RRMSE is a meaningful measure to compare simulation quality with different averages (Wu et al., 2013). RRMSE is calculated by dividing the Root mean square error (RMSE) from the mean of the observed values.

As the Japanese soil parameters are not included in APSIM soil data base, one of the soil types very closed to the soil characteristics in the experiment location was selected from the APSIM soil data base and then adjusted for soil parameters of the volcanic ash soil type. Even after the adjustment, the simulated dry matter and yield values were very low at zero nitrogen treatment. This may be because the higher nitrogen supply capacity of the volcanic ash soil was not represented by the soil type that we selected from the APSIM data base. Therefore, FBiom and FInert values were adjusted in order to get closer simulated values for observed values under zero nitrogen treatment. FBiom (BIOM as fraction of susceptible HUM) and FInert (fraction of HUM/humus that is not susceptible to decomposition) values are input parameters related to decomposition (Probert et al. 1998). By modifying these parameters the model could reproduce the yield response to the nitrogen application that is observed in the field experiment. Further, the predictions were better at higher N applications. At the zero nitrogen level the deviation was still larger. This implies that still the soil parameterisation was not optimal and the nitrogen supplying capacity of the soil was not fully captured by the model. Therefore, comprehensive parameterization of APSIM soil module would be needed in future.

5.2 Validation of APSIM model for wheat for Japanese conditions, Kanto area in Japan

The results of the model performance tests have confirmed that the APSIM model can be applied to the climatic and soil conditions in Kanto area or similar soil and climatic regions in Japan for wheat cultivation. This confirmed us the applicability of APSIM model for simulation studies aiming decision support system.

Asseng et al., (1998, 2000) and Chen et al. (2010) have also indicated successful validation of APSM model (APSIM Nwheat model) for wheat in Western Australia, Netherland and China (North China Plain). According to their model performances, they had RMSE of 40, 80 and 83 respectively for grain yield (g m^{-2}). From our validation results we got RMSE of 46.3 and 43.7 for two varieties concerned (Yumsehiho and Ayahikari respectively) for grain yield (g/m^2).

Asseng et al. (1998, 2000) had RMSE of 80 and 120 for dry matter (g m^{-2}) production and 0.6 and 1.2 for leaf area index respectively while Chen et al. (2010) reported 140 and 1.6 of RMSE for dry matter production and leaf area index respectively. Interestingly, our results showed 50 and 43.1 of RMSE for total dry matter production at maturity (g m^{-2}) and 2 and 0.88 for LAI for Yumeshiho and Ayahikari respectively.

For the grain protein content (GPC %) Asseng et al. (1998, 2000) had RMSE of 3.2 and 1.6 %. Results of GPC validation in our study were 0.7 and 0.8 RMSE for Yumeshiho and Ayahikari at Nov 2 sowing time (mid sowing period) while 1.6 and 2.3 for Yumeshiho and Ayahikari at Dec 1 sowing time (late sowing period). This give insight that grain protein validation in our study have got even better results including different sowing time as well compare to the existing reports.

Therefore, our results are compatible with the existing reports on APSIM model validation. Furthermore, our results had model efficiency (EF) values which were closer to one denoting perfect match of predicted and observed values. Also, the difference between simulated and observed date of flowering maturity was 1-2 days showing the sufficient simulation of phenology.

As was indicated in Chapter 3, the APSIM predictions were relatively poor in zero or lower nitrogen application levels (Fig. 3-8) and the same observations we had during the parameterization as well. This implies that still some fine-tuning may be required for the soil nitrogen module parameterization. Event though, the trend in soil water changing was able to simulate to some extent, APSIM overestimated the soil water content . This deviation may be due to the use of similar soil type in the APSIM data base with a modification using local conditions. Therefore, additional complete parameterization of APSIM soil water and nitrogen models will be advantageous in future that will enable us to use the APSIM model for wide range of applications including soil water and soil nitrogen dynamics as well.

The model performance for LAI was showed higher RRMSE values (0.37 - 1.5) compared to the one values of grain yield (0.12 - 0.14) and dry matter production (0.07 -0.08). This may be due to the tendency of the model for slight over prediction of the LAI. Asseng et al. (1998, 2000) also reported the over prediction of the LAI in their studies but also indicated that there had not shown major effect on the performance of other model components. APSIM wheat model uses specific leaf area range of 22000 – 27000 mm^2 g^{-1} dry weight with respect to the maximum LAI = 5 and minimum LAI= 0. We can adjust this range during the parameterization to have best mach for the simulated LAI for respective cultivars. Therefore, adjusting the specific leaf area range during the parameterization for respective cultivars is very important to have good predictions for LAI. In the measurement of the leaf area we consider only the leaf blade and leaf sheath is calculated for the drymatter together with the stem. This might lead to an underestimation of the LAI in observed values and can be accounted for the error between simulated and observed LAI.

With respect to the 2013-2014 wheat experiment, even though we conducted the experiment at same location (ISAS) as previous years, we used a different experiment plot of the same location. By observation and supported with the statistical analysis conducted we can suspect that there was a heterogeneity within the field and owing to that nitrogen response was not so clear despite we have used a wider range of nitrogen application rates and different combinations. Therefore, that data set may not be useful for the model validation purposes and that can be the most reasonable explanation for poor model performance with the 2013-2014 data sets. High variation of soil moisture among the replicates and even within each replicate added more clues us to make such assumption. The data from the multilocation experiments and multiple years are awaited for the full validation

5.3 Decision support for N application in wheat cultivation for conditions in Kanto area Japan

The economically optimum nitrogen application rate was 200 kgN ha^{-1} (120kg at sowing and 80kg at stem elongation stage). This is the optimal rate of N application for both hard wheat and soft wheat at which farmers can enjoy the maximum gross margin (as a result of higher yield and quality bonus received for GPC). This rate of application is for the current cost of fertilizer concerned. Therefore, having the opportunity to maximize the profit using higher rate of nitrogen within which the range of maximum nitrogen response occurs, denotes that current cost of fertilizer is not so high. This was further confirmed by sensitivity analysis that when the cost of fertilizer increased the economic optimum N rate tend to decrease. Therefore, higher fertilizer costs prevent farmers to obtain the benefit of plant response to the nitrogen to maximize their profits.

The results of field experiments and simulation experiments have shown that nitrogen application at flowering stage has significant effect on increasing GPC but small effect on grain yield of wheat while N applied at stem elongation stage would increase the yield. (Nakano and Morita, 2009; Asseng et al., 2000; Ellen and Spiertz, 1980). Our simulation study also showed that results for hard wheat are consistent with the literature data. The results of soft wheat showed some interesting response that 40 kg of nitrogen applied either stem elongation or flowering stage had significant positive effect on GPC. But application at both stages did not have any effect. Nitrogen applied at flowering beyond 40 kgN ha^{-1} rate decreased GPC. However for the hard wheat cultivar, N application beyond 40 kgN ha^{-1} neither decreased nor increased yield. Therefore, farmers should be cautious when they plan to apply additional nitrogen at flowering for both soft wheat and hard wheat cultivars. For both varieties, basal fertilizer application had no effect on GPC.

The simulation study showed that wheat cultivation is profitable even with no fertilizer application giving insights the higher nitrogen supply capacity of the volcanic ash soil in Kanto area supported with the current subsidy system. Further, growing hard wheat is more profitable than soft wheat for farmers in Kanto area Japan.

In order to elucidate the effect of climatic variation (year to year) on the optimum N management, the simulation for the weather data for 30 years are awaited to be conducted.

5.4 Concluding remarks

From the results of parameterization and validation it is concluded that APSIM model is reasonably applicable to the conditions in Japan (Kanto area) and this model can be used as a decision support tool for wheat cultivation.

Comprehensive soil parameterization is needed for the volcanic ash soil including soil N and soil water modules to increase the model validity. Further validation with a range of soil, climatic and management interactions is suggested to enhance the range of validation.

At the present level of fertilizer cost and government subsidy scheme, farmers can increase the N fertilizer application up 200 kgN ha^{-1} and attain maximum gross margin from the wheat production. Production of hard wheat is more profitable than soft wheat production.

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ANNEXURE 1

Date of observation			4/11/2013	17/4/2013	25/4/2013	5/01/2013	5/09/2013	13/5/2013	23/5/2013	29/5/2013	6/05/2013	6/12/2013	18/6/2013	25/6/2013
Variety	Sowing Date	N treatment	Growth stage (Zadoks Scale)	Growth stage (Zadoks Scale)	Growth stage (Zadoks Scale)	Growth stage (Zadoks Scale)	Growth stage (Zadoks Scale)	Growth stage (Zadoks Scale)	Growth stage (Zadoks Scale)	Growth stage (Zadoks Scale)	Growth stage (Zadoks Scale)	Growth stage (Zadoks Scale)	Growth stage (Zadoks Scale)	Growth stage (Zadoks Scale)
Ayahikari	17-Oct	N0	56	60	68	71	75<77	83	85	87	92			
	17-Oct	N1	56	60	68	71	77	83	85	87	92			
	17-Oct	N2	56	58<60	68	71	77	83	85	87	92			
	8-Nov	N0	33-34	45	58	64	68	71	77	83	85-87	91	92	
	8-Nov	N1	33-34	45	58	60<64	68	71	77	83	85-87	91	92	
	8-Nov	N2	33-34	45	58	60	68	71	77	83	85-87	91	92	
	29-Nov	N0	32	37<39	54	58	64	68	73<75	77<83	83>85	87	91-92	92
	29-Nov	N1	32	37<39	54	58	64	68	73<75	77<83	83>85	87	91-92	92
	29-Nov	N2	32	37<39	54	58	64	68	73<75	77<83	83>85	87	91-92	92
	19-Dec	N0	31	33	45	58	60	64	71<73	77>83	83	85	91	92
	19-Dec	N1	31	33	45	58	60	64	71<73	77>83	83	85	91	92
	19-Dec	N2	31	33	45	58	60	64	71<73	77>83	83	85	91	92
Nebarigoshi	8-Nov	N0	32	41	54	58	68	68<71	77	83	85	91	92	
	8-Nov	N1	32-33	41	54	58	68	68<71	77	83	85	91	92	
	8-Nov	N2	32	41	52	58	68	68<71	77	83	85	91	92	
	29-Nov	N0	32	37	45	56	60	68	73<75	77<83	83	87	91-92	92
	29-Nov	N1	32	37	45	56-58	60	68	73<75	77<83	83	87	91-92	92
	29-Nov	N2	32	33<37	45	56	60	68	73<75	77<83	83	87	91-92	92
	19-Dec	N0	31	33	41	56	58<60	64	71<73	77>83	83	85	91	92
	19-Dec	N1	31	33	41	54	58<60	64	71<73	77>83	83	85	91	92
	19-Dec	N2	31	33	41	54	58<60	64	71<73	77>83	83	85	91	92
Nishinokaori	17-Oct	N0	58	64	68	71	77	83	85<87	87<91	92			
	17-Oct	N1	58	64	68	71	77	83	85<87	87<91	92			
	17-Oct	N2	58	64	68	71	77	83	85<87	87<91	92			
	8-Nov	N0	33	45	58	64	68	71	77	83	85	91	92	
	8-Nov	N1	33	45	58	64	68	71	77	83	85	91	92	
	8-Nov	N2	33	45	58	60	68	71	77	83	85	91	92	
	29-Nov	N0	33	37<39	47	58	64	68	73<75	77<83	83	87	91-92	92
	29-Nov	N1	33	37<39	47	58	64	68	73<75	77<83	83	87	91-92	92
	29-Nov	N2	33	37<39	47	58	64	68	73<75	77<83	83	87	91-92	92
	19-Dec	N0	32	33<37	45	56	60	64	71<73	77>83	83	85	91	92
	19-Dec	N1	32	33<37	45	56	60	64	71<73	77>83	83	85	91	92
	19-Dec	N2	32	33<37	45	56	60	64	71<73	77>83	83	85	91	92
Yumeshiho	17-Oct	N0	56	58>60	68	68	75>77	83	85	87<91	92			
	17-Oct	N1	56	58	68	68	75>77	83	85	87<91	92			
	17-Oct	N2	56	58	68	68	75>77	83	85	87<91	92			
	8-Nov	N0	34	45>47	58	64	68	71	77	83	85	91	92	
	8-Nov	N1	34	45<47	58	64	68	71	77	83	85	91	92	
	8-Nov	N2	34	45<47	58	60<64	68	71	77	83	85	91	92	
	29-Nov	N0	32	39	52	58	64	68	73<75	77<83	83	87	91-92	92
	29-Nov	N1	32	39	52	58	64	68	73<75	77<83	83	87	91-92	92
	29-Nov	N2	32	39	52	58	64	68	73<75	77<83	83	87	91-92	92
	19-Dec	N0	30	33	41	56	60	64	71<73	77>83	83	85	91	92
	19-Dec	N1	30	33	41	56	60	64	71<73	77>83	83	85	91	92
	19-Dec	N2	30	33	41	56<58	60	64	71<73	77>83	83	85	91	92