Summary of Doctoral Thesis

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Title	Improvement of yield and quality on processing potato (*Solanum tuberosum* L.) by understanding the interactive effects of soil characteristics and plant nutrient management in Hokkaido, Japan

Introduction and purpose

The consumption of processing potatoes is increasing in Japan, owing to change in eating habits from fresh potatoes to value added processed potatoes. Trends in potato production show that global potato production has been steadily increasing over the last 50 years partly as a result of increased use of fertilizers, fungicides, and irrigation. However, potato yield in Japan have been flattering since the 1990s and have not been meeting the required demand despite a lot of investments and expertise that goes in potato industry. Given the availability of suitable climate and soil conditions for potato production and consumer demand for processing potatoes, there is a desire for Japan to be self-sufficient in potato production. Within this framework, the goal of this study was to improve yield and quality of processing potato in Hokkaido, Japan. This goal was envisaged to be achieved through understanding the potato crop and soil-environmental factors that currently limit yields that can guide formulation of better management practices to improve productivity. To understand the quality characteristics of potatoes, the study assessed the status and relationships of soil N, P, K and Ca content and concentration of these nutrients in potato tuber as well as its influence on potato tuber processing quality. In hilly upland fields of Kamikawa, we also evaluated the influence of slope direction on soil properties and potato yields.

Materials and methods

Paired soil and tuber samples were collected from 170 farmers' fields in Tokachi and Kamikawa districts in 2013 and 2014 growing seasons. The districts were purposely selected for the study because they are among the major potato producing areas in Hokkaido, accounting for almost

50% of the total production in Hokkaido. And also, the districts have contrasting soil types, Tokachi district is dominated by volcanic ash derived soils known as Andisols whilst Kamikawa district is dominated by soils of pyroclastic flow deposit origin classified as Inceptisols. Four chip processing potato cultivars thus Andover, Toyoshiro, Kitahime, and Snowden were selected for this study because they are among the most popular cultivars produced in Hokkaido region. The soil samples were collected at flowering stage while tuber samples were collected at harvest. For potato crop measurements, we determined individual weight of every tuber for calculation of yield and specific gravity was measured by hydrometer. In order to understand the current growers' management strategies, we conducted interviews with all growers participating in the study.

Soil samples were analyzed for soil available nitrogen and phosphate, exchangeable calcium and potassium. Other soil properties were also assessed. Total carbon, phosphate absorption coefficient and acid oxalate extractable aluminum. We then dried and ground the potato samples, and wet digested the samples using sulfuric acid/hydrogen peroxide and quantified P, K, and Ca using inductively coupled plasma atomic emission spectroscopy (ICP-AES). While measurement of tuber N concentration was undertaken using a dry combustion method. ArcGIS software was used to determine slope direction and potato fields were grouped into north- and south-facing slopes based on their slope orientation.

Results and discussion

In chapter 3, we found that Toyoshiro was the most suitable and best performing cultivar in terms of yield and quality characteristics for chip processing in both Andisols and Inceptisols compared to other cultivars. The good performance of Toyoshiro explains the reasons for its continuing popularity in Japan. Since growers and processors require stable yields and quality of potatoes in different environments, this information is important for growers to carefully select cultivars adapted to a given locality to maximize both yields and processing quality. The information of cultivar performance across location may be helpful to breeders to advance the breeding programs by using performing cultivars as parents in breeding for both yields and processing quality.

Stem number per plant is an important consideration with regards to purpose for which the potato crop is grown. For chip processing products, specific size category of tubers is demanded

by processing industry. Generally, in this study, we found that increase in stem number was associated with an increase in tuber number per plant that in turn affected tuber size. Growers should regulate number of stems per plant to maximize marketable yields and crop value. This can be achieved by planting juvenile seed potatoes that are associated with less number of stems. Alternatively, growers can plant high Ca content seed potato that is associated with maintaining apical dominance of the sprout and prevent some changes attributed to physiological ageing.

In chapter 4, we found that excessive NPK fertilizer application did not increase yield while excess tuber NK concentration reduced specific gravity. The implication of this result was that under high soil available NPK, addition of NPK fertilizers does not increase yields and the observed lack of yield response was attributed to high availability of N, P, and K in the soil that obscured the relationship between yields and fertilizers. Generally, soil available N, P, and K led to luxury absorption of these nutrients by the potato crop that reduced specific gravity. For potato processing, high specific gravity tubers are desired for high quality potato chip products. Growers should optimize NPK fertilizer rates based on soil test results by following Hokkaido fertilizer recommendations.

In chapter 5, we found that soil Ca was deficient in about 80% of the study fields and none of the fields had tuber Ca concentration greater than 250 mg kg^{-1} (reported value to mitigate incidence of bruise). Incidence of bruise decreased with increase in tuber Ca concentration. There are prospects of increasing tuber Ca by increasing soil Ca levels. Water soluble and exchangeable soil Ca levels were strongly related to tuber Ca concentration. There is an urgent need to ameliorate soil Ca deficiency through application of Ca fertilizer. Growers need to increase both water and exchangeable soil Ca to improve potato quality. In short term, growers can increase water soluble Ca by applying readily soluble Ca fertilizers such as $CaSO_4$ and $Ca(NO_3)_2$ fertilizers. In long term, growers can increase exchangeable Ca by applying lime materials such as $CaCO_3$ to increase exchangeable Ca.

In chapter 6, we found differences in soil characteristics between north- and south facing slope that was caused by the amount of insolation received by the opposing slopes. Variation in the amount of solar radiation received created microclimatic differences that appeared to influence rates of chemical weathering and decomposition of SOM. It is important to incorporate the topographical effects when we consider SOM dynamics not only for agricultural production

but also considering the environmental impacts. Although soil heath indicators seemed to suggest that soils in north-facing slopes to be more productive than those of south-facing slopes, potato yield between the opposing slopes depended on cultivar. This suggested that it is fundamental to consider factors that are known to determine yield potential before soil factors including solar radiation, temperature, and cultivar features when we conduct research into the relationship between soils and crop productivity.

Conclusion and recommendations

Soil and potato data collected from 170 farmer fields presented a great wealth of information for studying potato growing environments. This study found that (1) Toyoshiro cultivar performed better than other cultivars in both Andisols and Inceptisols. (2) Increase in stem number was associated with an increase in tuber number per plant that in turn affected tuber size. Growers should regulate number of stems per plant to maximize marketable yields and crop value by planting juvenile and high Ca content seed potato (3) Excess NPK fertilizer application did not increase yield while excess tuber NK concentration reduced tuber quality. Growers should optimize NPK fertilizer rates based on soil test results following Hokkaido fertilizer recommendations. Application of NPK fertilizer above the recommended rates is unnecessary cost to the growers, and raise potential environmental and human health concerns. (4) Soil Ca was deficient in over 80% of the study fields in Hokkaido and none of the fields had tuber Ca greater than 250 mg kg^{-1}. Efforts are urgently needed to increase both water soluble and exchangeable Ca to improve the quality of potato quality by applying readily soluble Ca fertilizers and lime materials. (5) In hilly upland fields of Kamikawa district, south facing slopes creates potential for accelerated loss of SOM due to more insolation that increases surface soil temperature. Growers should consider site-specific management strategies to maximize crop yield and reduce risks of nutrient loss. Future studies are required to clarify the complex interactions between soil properties and slope direction on uncultivated soils.

Three-fold difference between the highest and lowest yield suggest a considerable yield-improvement opportunities if growers follow proper management practices. In this connection, we urge growers to follow best management practices recommended by Hokkaido Fertilizer Recommendation to maximize both yields and economic returns.