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단 보

고랭지 배추 생산 예측을 위한 K-배추 모델 평가

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Evaluation of K-Cabbage Model for Yield Prediction of Chinese Cabbage in Highland Areas

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ABSTRACT

Process-based K-cabbage model is based on physiological processes such as photosynthesis and phenology, making it possible to predict crop growth under different climate conditions that have never been experienced before. Current first-stage process-based models can be used to assess climate impact through yield prediction based on climate change scenarios, but no comparison has been performed between big data obtained from the main production area and model prediction so far. The aim of this study was to find out the direction of model improvement when using the current model for yield prediction. For this purpose, model performance evaluation was conducted based on data collected from farmers growing 'Chungwang' cabbage in Taebaek and Samcheok, the main producing areas of Chinese cabbage in highland region. The farms surveyed in this study had different cultivation methods in terms of planting date and soil water and nutrient management. The results showed that the potential biomass estimated using the K-cabbage model exceeded the observed values in all cases. Although predictions and observations at the time of harvest did not show a complete positive correlation due to limitations caused by the use of fresh weight in the model evaluation process (R^2=0.74, RMSE=866.4), when fitting the model based on the values 2 weeks before harvest, the growth suitability index was different for each farm. These results are suggested to be due to differences in soil properties and management practices between farms. Therefore, to predict attainable yields taking into account differences in soil and management practices between farms, it is necessary to integrate dynamic soil nutrient and moisture modules into crop models, rather than using arbitrary growth suitability indices in current K-cabbage model.

Key words*: *Crop model, Climate change, Leaf development, Vegetable yield, Brassica rapa

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I. Introduction

Chinese cabbage is used as the main ingredient for Kimchi in Korea, and in 2021, 2.0 million tons of Chinese cabbage was produced from an area of 30,085 ha (MAFRA, 2022). Meanwhile, highland cultivation of spring Chinese cabbage accounts for about 12% of total cabbage production (MAFRA, 2022). Cultivation of Chinese cabbage in highland areas makes it possible to supply fresh vegetables in the summer, and the price determined at this time has a relatively large impact on the price of crops grown in the following season. Therefore, the importance of yield prediction is emphasized for the stable production and supply of Chinese cabbage.

The process-based model is based on the physiological processes of the target crop, such as photosynthesis, respiration, carbon partitioning, phenology, and morphology. The crop model explains and simulates biomass accumulation at the whole-crop level by integration of various sub-models for biochemical regulation of leaf photosynthesis, CO_2 supply rate in stomata, and increase in LAI at each growth stage (RDA, 2020). This makes it possible to select appropriate planting dates or climate-adaptable varieties under changing climates. Additionally, it can be applied to search for optimal areas that can maximize the crop yield (Kim *et al*., 2020).

The Crop Growth Information System is a website operated on a trial basis for major production areas to evaluate the applicability and behavior of crop models developed to predict the growth and yield of major vegetable crops under climate change. The information system enables running the models by generating farm-level (30 m grid) weather information based on Topo-climatic model (Kim *et al*., 2019; Yun, 2014). Current models include Chinese cabbage, garlic, and radish models, and the service areas are 13 regions, including Taebaek, Pyeongchang, and Haenam.

Current first-stage process-based models can be used to assess climate impacts through yield predictions based on climate change scenarios, but there is a need to use growth suitability indices as additional variable to reflect the impact of different cultivation practices and soil management. Also, no comparison between model predictions and big data from major production areas has been performed to date. Therefore, the aim of this study was to evaluate the applicability of the K-Cabbage model in predicting yield of Chinese cabbage by comparing model estimates with observational data from the Gangwon region, the main producing area of highland cabbage, and to identify the direction of model improvement for the development of a second-stage process-based model.

II. Materials and Methods

2.1. Model description

The K-Cabbage model (Fig. 1) integrates multiple sub-models into one based on the essential physiological processes including photosynthesis, respiration, carbon partitioning, phenology, and morphology to simulate the growth of Chinese cabbage at the whole-crop level (RDA, 2020). Topo-climatic model or Geospatial Schemes based on Topo-Climatology can be used in conditions where crop yields are greatly affected by farm microclimates due to complex topographical characteristics and narrow cultivation areas, such as in Korea. It generates farm-specific climate information at 30-meter resolution (Kim et al., 2019; Yun, 2014). As a prerequisite for running the K-Cabbage model, microclimate data was generated by entering the farm address and growing period into the crop growth information system (https://wds. agdcm.kr/).

2.2. Evaluation of model performance

Data collected by the Digital Agriculture Promotion Team in RDA from major production areas of highland cabbage for four years (2019-2022) was used for analysis. The fresh weight of Chinese cabbage (cv. ‘Chungwang’) measured at 10 farms located in Taebaek and Samcheok was compared with

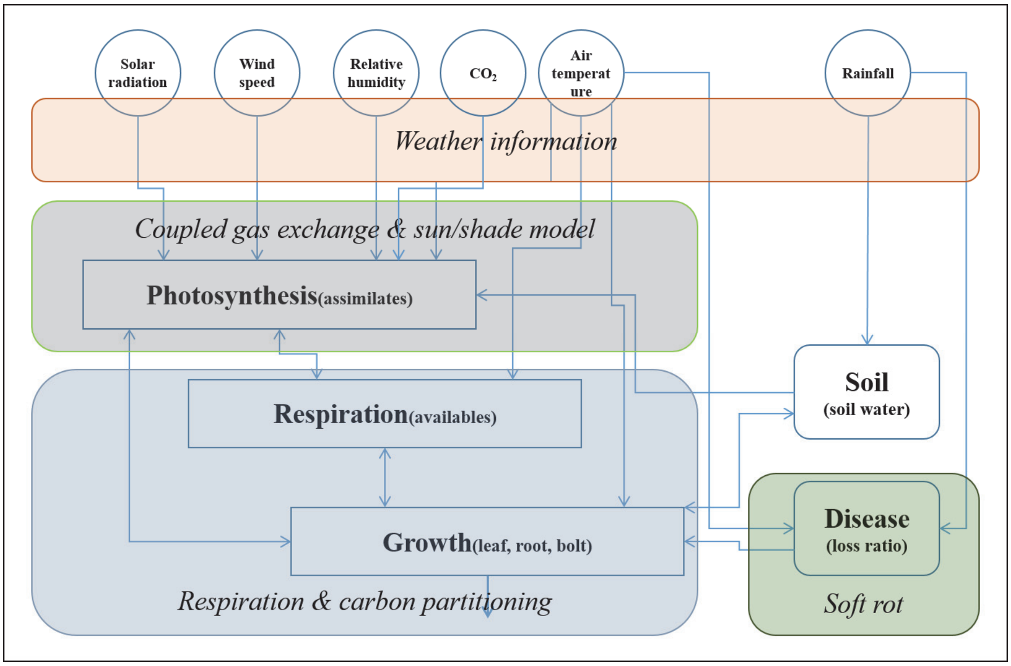

Fig. 1. The structure of process-based K-cabbage model.

the predicted value by the model. The fresh weight of Chinese cabbage was measured two to three times at weekly intervals starting two weeks before harvest. Farm-specific information such as planting density, planting date, and end date in the observation data was used as input variables for running the model. The farms investigated in this study had different cultivation methods not only in planting date but also in planting density and soil water management (Fig. 2). Model performance was evaluated based on the coefficient of determination (R^2), and RMSE value using SAS statistical package (version 9.4, SAS Institute, Cary, NC).

III. Results and discussion

3.1. Comparison between model predictions and observations

Fig. 3 shows the comparison between the potential yield estimated by the K-cabbage model, and the attainable yield adjusted by the growth suitability index, and observed values. Potential yield (Yp) of a crop, usually estimated using plant growth models,

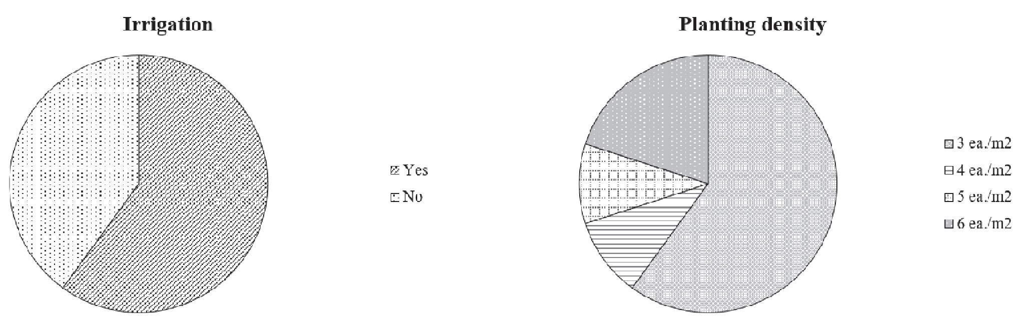

Fig. 2. Differences in irrigation and planting density between farms.

is defined as the theoretical maximum yield in a particular season, determined solely by climate and germplasm, assuming sufficient supply of water and nutrients and the absence of any yield-reducing factors such as diseases or pest insects (Yang et al., 2004).

The growth suitability index is a variable that is inserted into the K-Cabbage model to predict actual

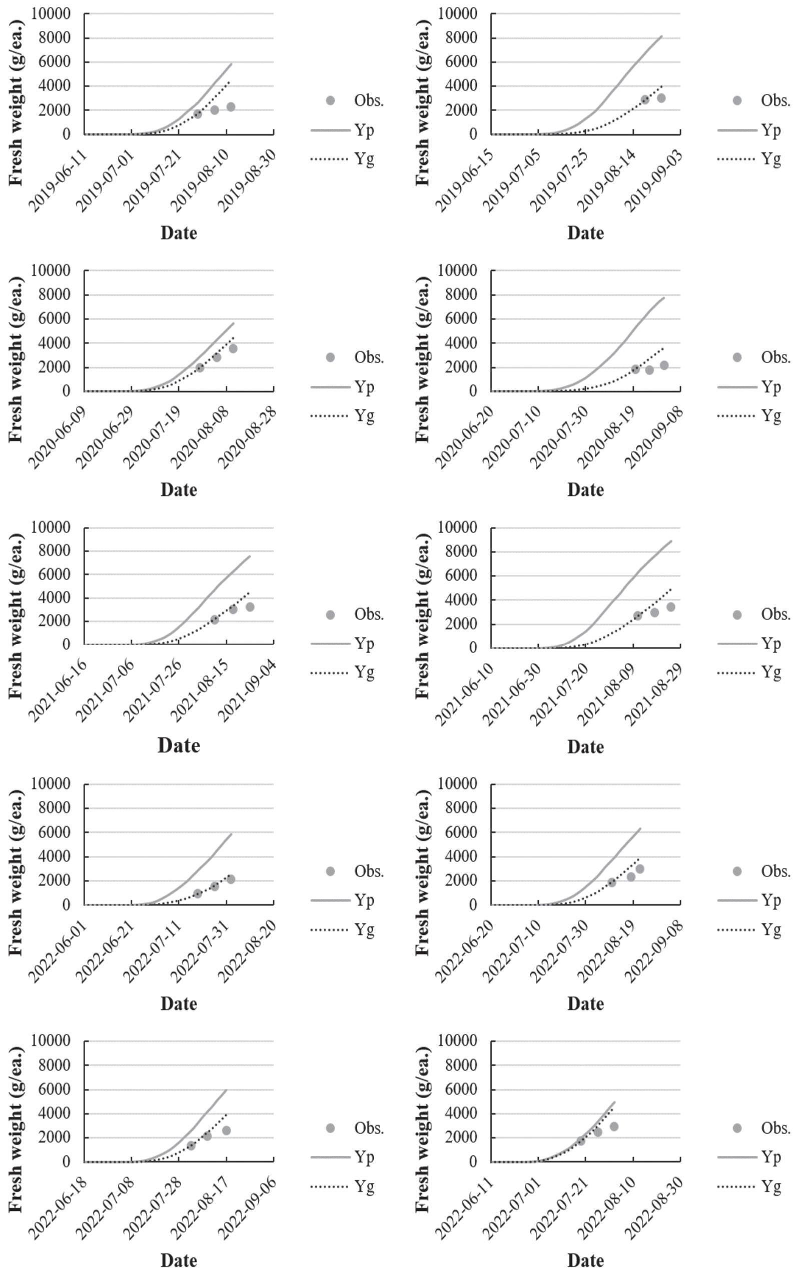

Fig. 3. Comparison between the potential yield (Yp) estimated by the K-cabbage model, the attainable yield adjusted by the growth suitability index (Yg), and observed values (Obs.).

yield by considering the effect of yield reduction due to differences in cultivation methods, soil nutrient and water management, soil properties, and pest management on potential yield (RDA, 2020). Assuming that the period required for root establishment is 14 days and the growth suitability index is 1, the predicted fresh weight of Chinese cabbage always exceeds the observed value in all cases. This can be explained in the same way as discussed in the study using a process-based garlic model to predict crop yield based on future climate change scenarios. Potential growth models inevitably tend to overestimate observations (Yun *et al*.,, 2022).

3.2. Evaluation of model performance and growth suitability index

When the model was fitted based on the fresh weight of Chinese cabbage two weeks before harvest, the growth suitability index showed different values (0.52～0.94) depending on the farm (Fig. 4). This is believed to be because the degree of climate influence on crop growth varies depending on soil properties and management practices (Yang *et al*., 2004).

Meanwhile, even though the model was fitted by assigning different growth suitability indices to individual farms based on the fresh weight of Chinese cabbage two weeks before harvest, the predicted and observed values did not show a completely positive correlation (R^2=0.74, RMSE=866.4). By adding an investigation into the dry weight of Chinese cabbage when generating observation data in the future, it is expected that more precise results will be possible. This is because, due to the nature of vegetable crops with moisture content of more than 80% (Chun *et al*., 2016), model evaluation is generally performed based on periodic observations of dry weight.

In addition, changes in the water potential of cabbage according to the growth stage of individual leaves and soil moisture content should be identified and ultimately reflected in the relationship between the dry weight and fresh weight of cabbage. That is because, soil moisture is often considered the most important properties required for model calibration and evaluation under water and nitrogen limiting conditions (Timsina, 2007).

Finally, in order to overcome the current limitations of relying on growth suitability indices and more reasonably predict attainable yields that reflect

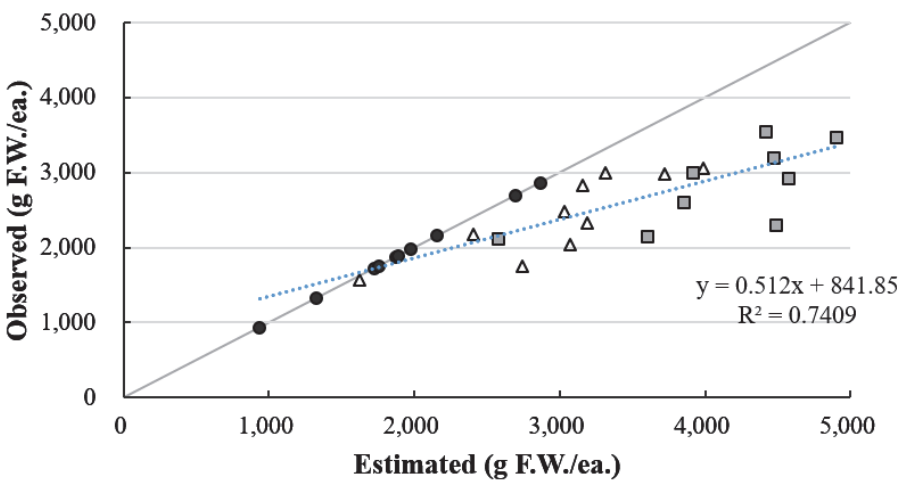

Fig. 4. Relationship between estimated and observed fresh weight of Chinese cabbage. The black circle is the fresh weight of Chinese cabbage measured 2 weeks before harvest, the white triangle is 1 week before harvest, and the gray square is the fresh weight of Chinese cabbage measured on the day of harvest. A baseline has been added to indicate a 1:1 relationship.

differences in cultivation methods between farms, it is necessary to integrate dynamic soil nutrient and moisture modules into crop models.

적 요

과정 기반 작물모형인 K-배추 모델은 광합성, 생물계절 등의 생리학적 과정을 기반으로 이전에 경험하지 못한 다양한 기후 조건에서 작물의 생장을 예측할 수 있게 해준다. 현재 1단계 프로세스 기반 모델은 기후변화 시나리오에 따른 생산량 예측을 통해 기후영향을 평가하는 데 활용될 수 있지만, 지금까지 주산지 빅데이터와 모델 예측 간의 비교는 수행되지 않았다. 본 연구는 생산량 예측을 위해 현재 모델을 사용하고자 할 때 모델의 개선 방향을 검토하기 위해 수행되었다. 이를 위해, 강원 태백 및 삼척에서 수집된 관측 자료를 바탕으로 모델의 예측력을 평가하였다. 조사 대상 농가들은 정식일 및 토양관리 면에서 재배방법이 상이하였다. 분석 결과는 K-배추 모델을 사용하여 추정한 잠재적 바이오매스가 모든 경우에서 관측 값을 초과하는 것으로 나타났다. 한편, 모델 평가 과정에서 생체중 사용에 따른 한계 등으로, 수확 2주 전의 값을 기준으로 모델을 피팅했음에도 수확기 무렵 예측값과 관측값은 완전한 양의 상관관계를 보이지 않았다(R^2=0.74, RMSE=866.4). 또한 생장적합지수는 농장별로 상이하였는데, 이러한 결과는 농가 간 토양특성 및 관리방식의 차이에 의한 것으로 추정된다. 따라서 농장별 토양 및 관리방식의 차이를 고려한 생산 예측기술 고도화를 위해서는 현재 K-배추 모델에서 임의의 생장적합지수를 사용하는 대신 동적 토양 양분 및 수분 모듈을 작물 모델에 통합하는 것이 필요하다.

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REFERENCES

Chun, J. H., N. H. Kim, M. S. Seo, M. Jin, S. U. Park, M. Valan Arasu, S. J. Kim, and N. Al-Dhabi, 2016: Molecular characterization of glucosinolates and carotenoid biosynthetic genes in Chinese cabbage (*Brassica rapa* L. ssp. pekinensis). *Saudi Journal of Biological Sciences* **25**(1), 71-82.

Kim, D. J., S. O. Kim, J. H. Kim, and E. J. Yun, 2019: Establishment of Geospatial Schemes Based on Topo-Climatology for Farm-Specific Agrometeorological Information. *Korean Journal of Agricultural and Forest Meteorology* **21**(3), 146-157.

Kim, S. H., J. Hsiao, and H. Kinmonth-Schultz, 2020: Advances and improvements in modeling plant processes. In: Boote K, ed. *Advances in Crop Modelling for a Sustainable Agriculture*. Cambridge, UK: Burleigh-Dodds.

Ministry of Agriculture, Food and Rural Affairs (MAFRA), 2022: Statistical Yearbook of Agriculture, Food and Rural Affairs. MAFRA, 90-92.

Rural Develpment Administration (RDA), 2020: Development of growth model and farm-level information service system with onion and alpine napa cabbage. RDA, 78pp.

Timsina, J., 2007: Procedures for evaluating crop models and datasets intended for model applications. *Journal of the Institute of Agriculture and Animal Science* **28**, 1-13.

Yang, H. S., A. Dobermann, J. L. Lindquist, D. T. Walters, T. J. Arkebauer, and K. G. Cassman, 2004: Hybrid-maize—a maize simulation model that combines two crop modeling approaches. *Field Crops Research* **87**(2-3), 131-154.

Yun, J. I., 2004: Visualization of Local Climates Based on Geospatial Climatology. *Korean Journal of Agricultural and Forest Meteorology* **6**(4), 272-289.

Yun, K., M. Shin, K. H. Moon, and S. H. Kim, 2022: An Integrative Process-Based Model for Biomass and Yield Estimation of Hardneck Garlic (*Allium sativum*). *Frontiers of plant science* **13**, 783-810. doi: 10.3389/fpls.2022.783810