学 位 論 文 要 旨

Development of evaluation methods for biomass production and lodging in rice by digital surface model using unmanned aerial vehicle

無人航空機を用いた数値表層モデルによるイネの物質生産および倒伏の評価手法の開発

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A digital surface model (DSM) is a 3D structure that represents the reflective surface of an object observed above the earth. It is part of remote sensing (RS) technology used for rapid evaluation of crop status and is less affected by weather, unlike satellite data. DSM can provide a 3D canopy height information on the field and has been widely used in assessing relatively taller and heterogeneous canopies compared to homogenous and shorter canopies such as in paddy fields where there is little variation in plant height. However, accurate evaluation of such little variation has the potential for modelling other growth-related traits in rice. Therefore, this study focused on; (1) Using unmanned aerial vehicle (UAV)-based images to develop a DSM to determine plant height in rice varieties, (2) Spatio-temporal monitoring of growth dynamics to estimate biomass increase from canopy height (CH) using DSM, and (3) analyse the feasibility of using a simple and direct assessment of lodging method in a multi-varietal rice field using DSM canopy height by conducting the following studies.

【1; CHAPTER 2】 Plant height (PL) is important for phenotyping because it affects aboveground biomass (TDW) increase. However, manual measurement is time-consuming. Hence, UAV DSM to estimate plant height was studied. Three rice cultivars; Nipponbare (japonica), IR64 (indica), and Basmati370 (indica), were cultivated in paddy fields under different fertilizer conditions. RGB images with 80% forward and lateral overlap at an altitude of 30 m were taken above the rice canopies every week and processed. The PL of four hills was manually measured. A canopy surface model (CSM) was developed based on the differences observed between each DSM and the first DSM after transplanting. The average reflectance of eight hills in each plot was used for the calculation of CH using polygons (15cm x 30 cm). There were large variations in PL (from 0.46 to 1.80 m) and CH (from 0.1 to 1.4 m) depending on

the growth stage and genotypes. CH correlated well with PL (R^2 = 0.947) which shows DSM could explain the large variation in PL throughout the growth stages. However, there was a trend of underestimation, because PL refers to the highest point in an area, whereas DSM considers the average of heights in an area. Nevertheless, DSM can estimate a relatively smaller range of PL, which is useful at every growth stage.

【2; CHAPTER 3】 After the usefulness of the DSM was confirmed, a model transfer was done to monitor and estimate other crop growth-related traits like leaf area index (LAI) and TDW to assess the effect of spatial and temporal variations on the model as such information is limited on paddy fields. Materials were the same as in Chapter 2, but the plants were harvested after aerial photography to measure LAI and TDW. There were large variations in LAI (from 1.03 to 7.93 m^2 m^{-2}) and TDW (from 64.7 to 1237.2 g m^{-2}) depending on the growth stage and genotypes. The results showed a linear relation between PL and LAI or TDW, so a model was developed from this relationship to estimate LAI or TDW. The estimation accuracy of the model was high for TDW and LAI with large variations among the genotypes. This implies that developing genotype-specific estimation models are necessary.

【3; CHAPTER 4】 Lodging, regarded as the displacement of a plant from its upright position or anchorage system, highly affects crop quality and output. However, no simple method for assessing lodging using DSM has been developed. Thus, a simple attempt of the DSM for lodging assessment was evaluated as lodging is related to canopy height. Twenty-four different genotypes were cultivated under the same fertilizer conditions and their angles of inclination were measured during the ripening stage, and their CH was evaluated as in the previous studies. Four lodging estimation methods; ΔPL (difference between CH of the target area and PL at heading stage), ΔCH_{max} (difference between CH at evaluation time and the maximum CH (at around heading stage) of the target area), ΔCH_{border} (difference between CH of border plants and target area), and CH_{CV} (coefficient of variation of CH among plants hills of target area) were used to assess the canopy structure anomalies. The results showed that CH_{CV} can be used to detect and quantify lodging with high accuracy (R^2 = 0.59). When CH_{CV} exceeds 0.05, the lodging angle dramatically increased. Hence, CH_{CV} could be a good indicator for estimating lodging.

In conclusion, the proposed UAV DSM has a great potential to assist in the rapid evaluation of biomass and natural occurrences like lodging. It will be possible to use this technology for future breeding programs in screening and phenotyping rice fields on a large scale. However, the challenge remains with the model improvement to increase the estimation accuracy which needs redress.