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# Paddy Growth Monitoring Using Terrestrial Laser Scanner

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**ABSTRACT**

Rice (Oryza Sativa L.) is a primary food source for many countries especially in Asian. Sustainable rice production is really required to fulfill the needs. Thus, monitoring paddy growth at different stages is very important to ensure a high crop yield and high quality of rice productions. In this research, the MR 219 and MR 220 paddy at seven different stages i.e. early tillering, tillering, early booting, panicle initiation, milk grain, dough grain and mature grain with different amount of nitrogen was monitored using the Terrestrial Laser Scanner (TLS) based on the height derived from Crop Surface Model (CSM). Results have shown that the developed CSM maps can be used to monitor the spatial and temporal pattern of the growth. High coefficient of determination, (R2 = 0.96) gave confirmation on the high compatibility of the method. The results also showed that different rate of nitrogen treatment will affect paddy growth. Those plants that were given with 170 kg/ha and 250 kg/ha showed high growth for both MR 219 and MR 220.



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## INTRODUCTION

Rice *(Oryza Sativa L.)* is a significant plant for a large part of the world's population especially in Malaysia. The production of rice in Malaysia was recorded as 2,520,409 tonnes from 2010 to 2011 and increased to 2,663,196 tonnes from 2011-2012 (FAO, 2015). Due to a further growing population, a field management aiming at high production and sustainability of natural resources is required. Thus, the rice monitoring especially at different growing stages in the paddy field is essential for a high crop yield and high quality rice productions since the growth can be controlled by collecting data of the rice growth status. One of the important information for rice monitoring is the plant height. Sritarapipat & Rakwatin (2012); Gao *et al*.,(2013) have reported that the collected plant height can be used to analyse the variety of rice, to estimate the yield and harvest planning, for grain production management and grain marketing.

Numerous studies about rice monitoring have been done using different methods. Conventionally, data collection based on ground-survey was used. However this method was often labour and time-consuming and the data collected was also often imperfect and deceptive. Then remote sensing technology has been introduced and widely used for rice monitoring nowadays. One of the methods which focused on the use of the Synthetic Aperture Radar (SAR) has been reported by Shao *et al*., (2001), Yonezawa *et al*., (2012) and Zhang *et al*., (2014). Obtaining an up-to-date image is expensive with variable quality and complicated for data processing. Some of their spatial resolutions are also regarded as too coarse.

However, nowadays the technology of Terrestrial Laser Scanner (TLS) that provides accurate and dense 3D measurement was introduced. The high spatial resolution measurement information has made it became widely used in a wide range of research fields for example in architectural, engineering and forestry application. Wezyk *et al*. (2007) have used TLS to develop forest inventory in deciduous forest and coniferous stands by collecting few tree parameters such as position of the tree in 3D space, diameter of breast height and height of the tree. Another research has been done by Lumme *et al*. (2008) to investigate the exploitation of laser scanners and laser point data in agriculture and precision farming. They used Faro laser scanner to estimate the growth height and ear recognition of different crops which were barley and wheat.

Since TLS offered high spatial resolution data and there is not much study has been done in rice and the structure of rice plants is similar to the previous investigated cereals, which suggests that laser scanning can also be used to determine rice crop

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properties especially in height measurement. Thus, the main purpose of this study was to determine the paddy growth using TLS data.

## MATERIALS AND METHODS

### *Sample preparation:*

The study which is pot-culture experiment was conducted in a glasshouse located at a farm of Universiti Putra Malaysia, Serdang, Selangor. Seedlings of two rice cultivars, MR 219 and MR 220 were chosen as they have short maturation period and highly resistance to bacterial leaf blight and brown plant hopper. They were also the most common variety used by the farmers in Malaysia. The cultivars were sown in pots of 0.071 $m^2$ with four replications and grown under flooded condition. This experiment consisted of four different levels of Nitrogen fertilization rates which were 0 kg/ha (N1), 85 kg/ha (N2), 170 kg/ha (N3) and 250 kg N/ha (N4) while Phosphorus and Potassium fertilizer were applied equally throughout all the stages and treatments, P: 80kg/ha; K: 150 kg/ha (Saberioon *et al*., 2013).

### *Data scanning acquisition:*

A Faro laser scanner Focus 3D S (v6.1) which is a phase-shift based technology was used in this research. The data acquisitions were taken at every growth stages starting from 21 DAS until 94 DAS. Details on data acquisition were presented in Table 1.

**Table 1:** Details for data acquisition.

| Date | DAS | Stage |
|---|---|---|
| 24 June 2014 | 21 | Early tillering |
| 5 July 2014 | 32 | Tillering |
| 14 July 2014 | 41 | Early booting |
| 22 July 2014 | 49 | Booting |
| 1 August 2014 | 58 | Panicle initiation |
| 12 August 2014 | 69 | Flowering |
| 22 August 2014 | 80 | Milk grain |
| 29 August 2014 | 87 | Dough grain |
| 5 September 2014 | 94 | Mature grain |

Examples of laser scanning acquisition are shown as in Figure 1. The scanner was mounted on a tripod with a fix distance above the ground which is 1.5 meter. A total of nine scanning were done. The area was scanned from four scan positions for capturing all pots. In order to join all scan positions in the post-processing analysis, mutual tie points in all scans of each scan position were required. Thus, high reflected sphere references were used. Coordinates location for each scanner was recorded using a hand-held GPS Juno 3B for geo-referencing process. The data was recorded and saved in a SD memory card. For manual measurement, the maximum plants heights were measured using measuring tape. The measurements were repeated three times for each pot from soil surface in the pot to the highest part of the plant.

(a) (b)

**Fig. 1:** Laser scanning process taken on: (a) 24 June 2014 and (b) 14 July 2014.

### *Scanner data processing:*

The main steps involved were registration, filtering and extraction of the area of interest (AOI). These were done using SCENE 5.1 software. Filtering was done to remove all the unwanted points. A scan registration was done by identifying the spheres on the scan image. The identification of spheres was automatically done using the SCENE software as well as the scan registration. From nine scanning data, only seven can be registered and used for crop surface modelling. Area Of Interest (AOI) was selected using clipping box. Clipping boxes provide an easy access to AOI of the 3D point cloud. Two clipping boxes were produced for digital elevation model (DEM) and digital surface model (DSM). Clipping box for DEM was created from the first scanning data. The soil surface in pot was observable during first scanning because the plant was still small and not crowded. The selection of 3D point cloud or AOI was then exported in PTS format (.pts).

***Development of crop surface model (CSM) for plant height measurement:***

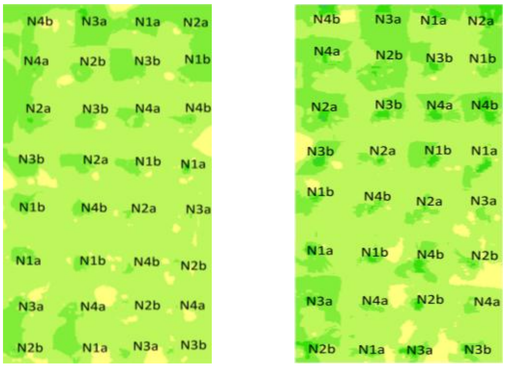
The crop surface model (CSM) was introduced by Hoffmeister *et al*., (2010) for plant growth monitoring at field level. It represents the crop surface with high spatial resolution at one scanning date, gained from the registered and filtered point cloud. The final filtered point cloud from previous analysis which was saved in PTS format (.pts) was converted into LAS format (.las) using point-zip software before exported to ArcGis Desktop version 10.1. These exported LAS format files were used to create LAS dataset in ArcGis. Raster surfaces were then created from these LAS datasets for each date and condition tool was used from spatial analysis package to extract the top surface and create new raster from existing raster with applying some conditional rules. Then, inversed distance weighed (IDW) method was used for interpolation. It was the simplest method of interpolation and it estimate the surface values for each cell using value and distance nearby points. To obtain the CSM, DEM of AOI extracted from soil surface in pots were then subtracted from the Digital Surface Model (DSM) which reflect its top canopy (CSM=DSM-DEM), resulting the plant height.

## RESULTS AND DISCUSSION

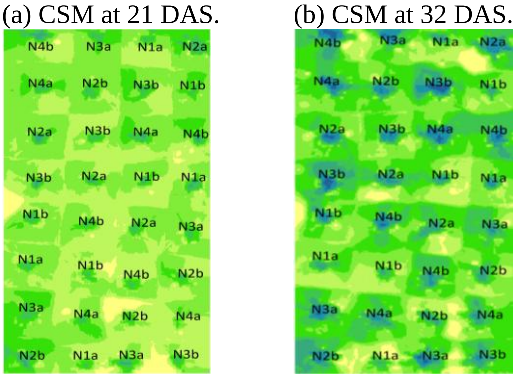
The basic principle for scan registration was achieved as all the spheres were fully detected during data post-processing analysis. The distance and arrangement of the spheres from the scanner were enough for them to be detected. Spheres with diameter of 145 mm and distance from scanner 3-4 meters were used. A small study area gives an advantage for scan registration to be successful. Higher resolution and bigger size of spheres need to be considered for larger study area. Moreover, clipping box created from SCENE software also gives an advantage for getting DEM. Since this was a pot experiment, real ground surface cannot be used as reference. The soil surface was selected manually during first scanning because that time soil surface in the pot was still observable.

***Plant height determination from CSM:***

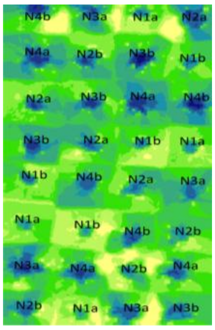
These plant heights derived from CSM were presented as maps and shown as in Figure 2. From the maps, spatial differences and temporal development in plant height for each date can be observed. Spatial differences can be seen within the CSMs. For example during 94 DAS, the variation of plant height was observable based on the difference in color intensity of the maps. Lighter blue shows plant height of 60 cm to 70 cm while darker blue represents 80 cm to 100 cm.



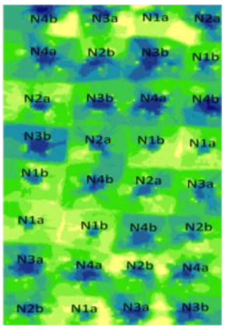

(a) CSM at 21 DAS. (b) CSM at 32 DAS.



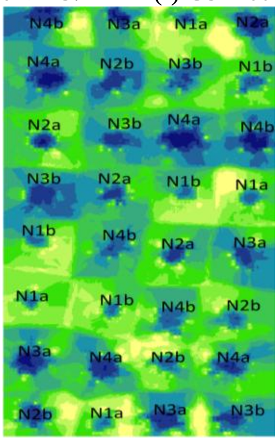

(c) CSM at 41 DAS. (d) CSM at 58 DAS.




(e) CSM at 80 DAS.




(f) CSM at 87 DAS.




(g) CSM at 94 DAS.

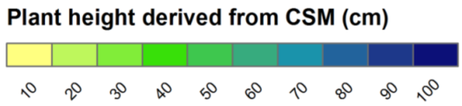



**Fig. 2:** Maps of plant height (cm) derived from CSM for whole pots at each growth stages. Note: N1= 0 kg/ha, N2=85 kg/ha, N3=170 kg/ha, N4= 250 kg/ha, a= MR219, b=MR220.

Based on the map, the ranges of plant height was 60 cm to 70 cm for plant with zero nitrogen level, N1 = 0 kg/ha; 70 cm to 80 cm for N2 = 85 kg/ha; 80 cm to 90 cm for N3 = 170 kg/ha and 90 cm to 100 cm for N4 = 250 kg/ha. On the other hand, temporal development can be seen based on the color changes from green to blue for each stages. These color changes indicates the variation in plant height from 21 DAS to 94 DAS. The ranges were from 10 cm - 20 cm, 20 cm -30 cm, 30 cm - 50 cm, 60 cm - 70 cm, 70 cm -80 cm, 80 cm - 90 cm, and 80 cm -100 cm respectively. As an overall, those plants that were given with 170 kg/ha and 250 kg/ha of Nitrogen showed higher plant heights for both varieties MR 219 and MR 220.

The mean measured plant height gave high value of coefficient determination ($R^2$) with mean plant height derived from CSM which is 0.96. It indicates that about 96% of real plant height can be predicted from CSM maps. This result is presented in a scatter plot together with a linear regression equation as in Figure 3. This has been supported by few researches done on different crops. Ehlert *et al*., (2008) in his research to determine crop height for winter rye and winter wheat using non-destructive ground-based laser rangefinder has achieved $R^2$ of 0.93-0.99, while Tilly *et al*., (2014) has achieved $R^2$ of 0.91.

The Root Mean Square Error (RMSE) between measured and derived plant height was calculated as 8.86 cm while the mean was 7.84 cm. The RMSE was 6.83% from mean measured plant height. This difference was caused by noises such as wind, insects and small particle in the air. The wind causes the plant to shift. As a result, the laser does not hit to the plant accurately.

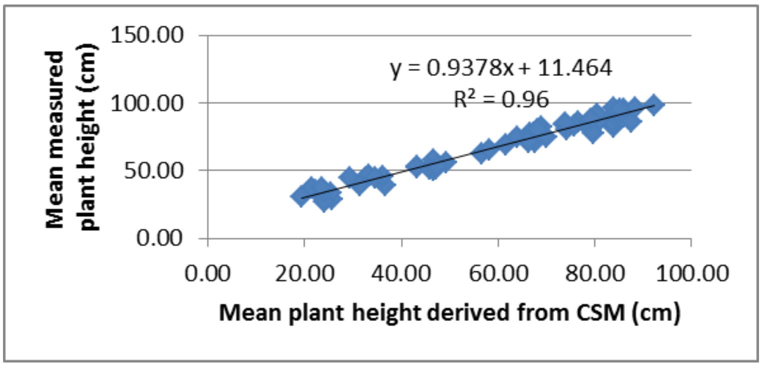



**Fig. 3:** Regression mean of plant height from manually measured and from derived CSM (n=56).

***Effect of nitrogen treatments to plant growth:***

Duncan Multiple Range Test (DMRT) was done to identify the effect of nitrogen treatment to plant growth by analysing significant different of mean height at different growth stage. The results were presented as in Table 2 and Table 3 for MR 219 and MR 220, respectively. Based on Table 2, the results of plant height were grouped differently for each nitrogen treatment and growth stages. The height of paddy was increasing with the increasing amount of nitrogen especially during milk grain to mature grain stage. The growth of paddy during these stages at 250 kg/ha was almost similar. There was no significant difference within this group. Slow or constant growth can also be seen during milk and dough grain for 0 kg/ha, 85 kg/ha and 170 kg/ha. In overall, the 170 kg/ha and 0 kg/ha gave significant changes at different growh stage where it can classify the six growth stages out of seven i.e early tillering, tillering, early booting, panicle initiation, milk grain and mature grain.

**Table 2:** Mean comparison for derived plant height from CSM at different growth stages for MR 219.

| NITROGEN/ GROWTH STAGES | 0 kg/ha | 85 kg/ha | 170 kg/ha | 250 kg/ha |
|---|---|---|---|---|
| | CSM | CSM | CSM | CSM |
| Early tillering (21 DAS) | 25.73$^{a}$ | 25.43$^{a}$ | 22.19$^{a}$ | 21.43$^{a}$ |
| Tilllering (32 DAS) | 36.65$^{b}$ | 32.55$^{a}$ | 32.73$^{b}$ | 29.47$^{a}$ |
| Early booting (41 DAS) | 46.55$^{c}$ | 49.26$^{b}$ | 46.69$^{c}$ | 43.26$^{b}$ |
| Panicle Initiation (58 DAS) | 56.53$^{d}$ | 64.06$^{c}$ | 67.59$^{d}$ | 66.65$^{c}$ |
| Milk grain (80 DAS) | 66.40$^{e}$ | 79.33$^{d}$ | 79.70$^{e}$ | 83.93$^{d}$ |
| Dough grain (87 DAS) | 68.15$^{e}$ | 81.08$^{d}$ | 80.49$^{e}$ | 83.99$^{d}$ |
| Mature grain (94 DAS) | 75.80$^{f}$ | 87.48$^{e}$ | 88.29$^{f}$ | 92.32$^{d}$ |

Sample plants taken from 0 kg/ha and 170 kg/ha of nitrogen showed that the height were significantly separated from early tillering till panicle initiation, and later was grouped together during milk and dough grain stage and got separated again during mature grain stage. This trend of grouping showed that samples taken from this treatment have good growth condition from early stage before slowing down at the later stage. For 85 kg/ha, and 250 kg/ha, the plants height were not significantly different during early tillering till tillering stage and milk grain stage till dough grain stage except for 250 kg/ha, the plants height were not separated from milk grain stage till mature grain stage.

Results tabulated in Table 3 has shown that all different types of treatment gave significant different on the height of paddy during all growth stages except for milk grain stage till mature grain. It showed that the plant heights were not increase significantly during final stage of growth but showed clear difference during early tillering, tillering, early booting and panicle initiation stages. Those plants heights that were grouped together in some stages were actually had no or less changes. It apparently gave us the idea that at certain stages, the growth was a bit slower compared to the other stages.

**Table 3:** Mean comparison for derived plant height from CSM at different growth stages for MR 220.

| NITROGEN/ GROWTH STAGES | 0 kg/ha | 85 kg/ha | 170 kg/ha | 250 kg/ha |
|---|---|---|---|---|
| | CSM | CSM | CSM | CSM |
| Early tillering (21 DAS) | 23.99[a] | 19.30[a] | 24.24[a] | 23.72[a] |
| Tilllering (32 DAS) | 31.45[b] | 33.27[b] | 36.30[b] | 34.53[b] |
| Early booting (41 DAS) | 45.97[c] | 43.30[c] | 47.10[c] | 47.55[c] |
| Panicle initiation (58 DAS) | 58.14[d] | 61.74[d] | 67.33[d] | 68.84[d] |
| Milk grain (80 DAS) | 69.89[e] | 74.23[e] | 83.86[e] | 84.54[e] |
| Dough grain (87 DAS) | 73.64[e] | 76.57[e] | 83.88[e] | 84.54[e] |
| Mature grain (94 DAS) | 74.07[e] | 79.17[e] | 84.82[e] | 85.90[e] |

The result from this study also shows that application of different rate of Nitrogen does gave response to plant height and growth. These findings were consistent with findings from past studies about the effect of nitrogen fertilizer on growth of maize done by Omer (1998), Gasim (2001) and Sawi (1993). Another study about response of nitrogen to maize was done by Sharma (1973). From the study, he reported that the plant height increased by increment amount of nitrogen due to the fact that nitrogen promotes plant growth, increases the number of internodes and length of the internodes (Gasim, 2001). A great difference of plant height and growth can be seen during vegetative stage. For instance, from Table 2 at level of 0 kg/ha and 175 kg/ha, the plants heights were grouped separately during early tillering but when it comes to reproductive stage which was milk grain, the plants heights were now group together as the changes in plants heights difference was slower compared to early stage. The vegetative stage was the stage where active tillering and stems elongation occurred. This also can be seen from Table 2 where all treatments do affected the plant height during vegetative stage.

During panicle initiation stage, the panicle formed and emerged from the base of the tiller. At this stage, rapid growth of panicle also occurred as the nitrogen absorbed promotes the development of panicle. The panicles extended from the base of plant near the sheaths leaf making the plant growth higher. The panicle stage ends when the plant start flowering. The emergence of anthers from uppermost spikelets on each panicle denotes the flowering stage. The period from panicle initiation to flowering was known as reproductive stage. For MR 219, treatment of 170 kg/ha gave the highest plant height of 67.59 cm while for MR 220, it was from 250 kg/ha treatment which was 68.84 cm.

The last stage in paddy growth was ripening stage. During this stage, there was not much difference in plant height as nitrogen was no longer used for elongation of stems. Instead, it was used for grain formation and grain filling. At this stage, nitrogen helps to stimulates nutrient absorption and assimilation. Thus, it can be seen from Table 2 and Table 3 that most of plants heights during milk grain, dough grain and mature grain were not significantly different for all given Nitrogen treatment.

***Conclusion:***

From this research, few conclusions have been made. The preparation for data scanning should be well design so that there is no problem occurred during post-processing analysis. The diameters of spheres and distance from scanner should be taken into consideration for a large area. Arrangement of spheres should not be covered by any object. The CSM developed from this research which was produced using TLS data can be used as non-destructive tool for collecting and monitoring of the paddy growth. Spatial and temporal pattern of the growth could be observed clearly due the fact that TLS provide high spatial resolution and accuracy of the points cloud. Moreover, a high correlation of coefficient of determination ($R^2 = 0.96$) was gathered between height derived from CSM and the measured height. Another conclusion was that the difference treatment of Nitrogen level used showed variations in plant height. It does affect the paddy growth. With the increment of Nitrogen, the height of paddy was also increased. The growth of paddy was higher during early stage which was early tillering stage till panicle stage then it starts slowing down during milk grain stage to mature grain.

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