Evaluation of a proximal vision data acquisition system for measuring spatial variability in lettuce growth

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Abstract

In-field crop mapping provides the growth and yield data required to spatially manage inputs such as irrigation water and fertiliser. This study evaluated the potential to use low cost cameras as proximal sensors to spatially map lettuce growth throughout a growing season. Two 9 x 11 m measurement plots of 42 sampling points each were established within a sprinkler irrigated lettuce crop. Ten non-uniform irrigations were applied during the season. After each irrigation, the canopy and head diameter of two plants at each sampling point were physically measured. Colour digital cameras were also used to capture images of the lettuces from either 1.15 m or 10 m above the ground surface. Image processing software was then used to calculate the individual plant canopy area and lettuce head diameter. The lettuce growth measurements obtained using the 1.15 m camera were generally well correlated (R^2 = 0.73-0.89) with the physical measurements 23 days after transplanting. Weaker correlations (R^2 = 0.35-0.74) were observed at earlier dates possibly due to physical measurement errors of plant size early in the season. The correlations between the canopy measurements obtained using the 10 m camera and the physical measurements were generally 0.1 to 0.2 lower than those obtained using the 1.15 m camera, presumably due to lower pixel resolution. Correlations between the head diameter obtained using the 1.15 m camera and the physical measurements ranged from 0.83 to 0.92.

Introduction

The horticultural production industry is increasingly demanding high quality products at a lower cost in order to compete in the market. Precision agricultural practices may be used to improve the targeting of inputs (e.g. water and fertiliser) and reduce production costs. Yield monitoring plays an important role in precision agriculture (Plant 2001). However, methods are required to map crop variability during the growing season. Point based sampling is labour demanding, costly and time intensive (Plant 2001). Field spatial variability can be measured by continuous, discrete and remote sensing techniques (Senay et al 1998). Aerial photography has been used to study crop growth (Irmark et al 2002) and assess the spatial variability of crop yield (Vellidis et al 2004). However, proximal sensing using inexpensive digital cameras has also recently been investigated. For example, Caton (2004) compared camera measurements with physical sampling in rice and observed that the correlations were weak for the first 14 and 21 days after planting but improved at 28 days after planting. Similarly, significant correlations have been found between photo-derived projected foliage areas and both cabbage growth (Yang et al 2007) and wheat yield (Jensen et al 2007). Stereo-imaging has also been used to measure canopy area in soybean (Biskup et al 2007) and aerial digital videography used to measure spatial variability in sorghum yield (Yang and Anderson 1999). This study investigated the potential to use low-cost, colour digital cameras as non-destructive, proximal sensors for obtaining growth and yield measurements in lettuce crops.

Methods

Trial design

This trial was conducted at the Department of Primary Industry and Fisheries Research Station, Gatton, Queensland. The overall lettuce planting (92 × 11 m) was cultivated into seven longitudinal beds, each 1.3 m wide and separated by 0.3 m furrows. Two treatment plots, Plot A (9-18 m from the irrigation sub-main) and Plot B (72-81 m from the sub-main) were established within the trial site. Forty-two sampling points with a 1.5 x 1.56 m spacing were established within each treatment plot. The trial was irrigated by a solid set sprinkler system and the sprinkler pressure in the measurement plots was asymmetrically reduced eight days after transplanting to investigate the impact of non-uniform water application on lettuce growth. Ten irrigations were applied throughout the season and the uniformity of the water application was calculated according to Christiansen (1942) (Table 1). The diameters of two tagged plants on either side of each sampling point were physically measured throughout the season using a tape to enable the calculation of the

Global Issues Paddock Action. Proceedings of the 14th Australian Agronomy Conference. September 2008, Adelaide South Australia.

projected canopy area. The diameter of the actual lettuce head was also physically measured 53 and 57 days after transplant (DAT).

Table 1. Depth of water applied and uniformity of water application for each irrigation

Irrigation dates (days after transplant)	Average depth of water applied (mm)		Coefficient of uniformity (%)	
	Plot A	Plot B	Plot A	Plot B
0	24.8±12.2	18.3±3.8	61.1	84.9
2	19.5±4.0	19.0±3.5	84.1	86.2
6	10.1±3.5	10.4±3.4	69.8	72.7
9	13.9±4.3	14.7±3.4	75.4	82.6
23	12.1±3.0	11.2±3.7	80.0	72.0
35	13.4±9.6	13.2±6.0	48.1	63.7
41	15.4±7.6	14.9±7.7	65.1	58.3
47	16.0±8.8	14.4±8.0	59.4	55.0
51	6.1±5.0	6.7±3.7	37.0	55.2
55	13.6±6.7	12.9±8.2	62.0	46.1

Image acquisition
Two colour digital camera systems were used to obtain images of the crop canopy. Images were obtained on ten occasions during the season using a 3.2 megapixel Olympus C-360 Zoom (Olympus Corporation, Tokyo Japan) camera mounted perpendicularly above the crop at a distance of 1.15 m from the ground surface (Figure 1a). These images were acquired on the same day that the physical plant measurements were obtained. Images were also acquired on four occasions using a 5.0 megapixel Kodak CX7525 (Eastman Kodak Company, Rochester, New York) camera mounted on a 10 m vertical mast and offset boom above the crop (Figure 1b) and operated remotely from the ground.

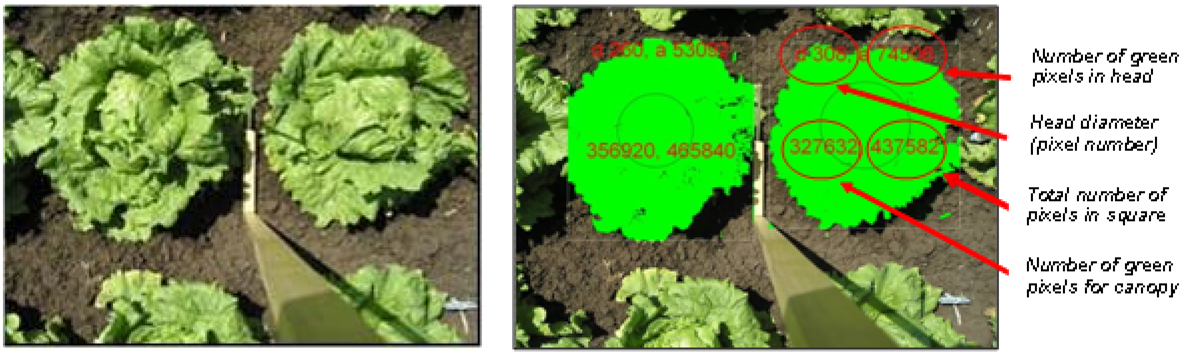
(a) (b)

Figure 1. Image acquisition of the lettuce plants using digital cameras mounted at (a) 1.15 m and (b) 10 m above the ground surface

The pixel resolution for the 1.15 m images was 0.51 mm and for the 10 m images was 6.19 mm. A customised program developed in Microsoft Visual Studio was used to measure the number of green pixels for each plant in the image. For the 1.15 m images, the software was able to "automatically" identify individual plants and calculate the foliage area early in the season when there was no overlap of the individual plant canopies. "Manual" identification of individual plants in both the 1.15 m (Figure 2) and 10 m images (Figure 3) were also conducted on all images. The heads were visually identified in the 1.15 m images at 53 and 57 DAT and the diameter calculated assuming a circular shape (Figure 2b).

Results

The physical and image-derived measurements of the canopy area were significantly correlated, with the correlation generally improving throughout the season (Table 2). For the 1.15 m images, the correlations ranged from 0.35 to 0.74 for periods up to 16 DAT but ranged from 0.73 to 0.89 for measurements taken later in the season. One reason for the lower correlation early in the season may be the difficulty in taking accurate physical measurements due to the asymmetrical shape of the canopy during this period. The small leaf size relative to the pixel resolution early in the season may also have contributed. However, the overlap of canopy leaves between adjacent plants later in the season also leads to inaccuracies in both the physical and image derived measures. Automatic software detection of the individual plants early in the season generally produced slightly lower correlations than the manual detection of plants up to 16 DAT but there were no substantial differences at 23 and 31 DAT. It was not possible to use automatic detection after 31 DAT as the software was unable to identify individual plants due to canopy overlap. Significant correlations (R^2 = 0.83 to 0.92) between physical and image derived measurements of lettuce head diameter were also observed (Table 2) suggesting that this approach may be suitable for lettuce yield monitoring, possibly as part of a real-time digital video acquisition system.



(a) (b)

Figure 2. Example of (a) image acquired from 1.15 m camera and (b) calculation of the green pixels in the image where the plants have been manually selected.

Figure 3. Example of an image acquired using the camera mounted on a 10 m mast and offset boom showing the green pixel mask of the physically measured plants.

The correlations between physical canopy measurements and the 10 m image derived measurements ranged from 0.5 to 0.82 (Table 2). For the four measurement dates, the correlation was typically 0.1 to 0.2 lower than the correlation obtained using measurements derived from the 1.15 m images, presumably due to the lower resolution (larger pixel size) associated with the 10 m images and possibly due to parallax errors in the images.

Table 2. Correlations (R^2) between physically measured and image derived lettuce canopy area and head diameter measurements

DAT	1.15 m images				10 m images	
	Plot A	Plot B	Plot A	Plot B	Plot A	Plot B
	Manual detection of individual plants		Automatic detection of individual plants		Manual detection of individual plants	
7	0.49	0.35	0.35	0.37	-	-
11	0.60	0.58	0.45	0.52	-	-
16	0.73	0.74	0.63	0.70	-	-
23	0.85	0.89	0.72	0.89	0.64	0.68
31	0.84	0.89	0.84	0.89	-	-
36	0.73	0.86			-	-
42	0.81	0.89			0.69	0.79
48	0.75	0.89			0.50	0.72
53	0.80 0.83*	0.86 0.92*			0.70	0.82
57	0.87 0.90*	0.89 0.92*			-	-

* Correlation of head diameter measurements, DAT- days after transplant

Conclusion

Physical measurements of lettuce canopy area and head diameter were well correlated with measurements obtained from images acquired using digital cameras, particularly in the mid to late growing season. This work has demonstrated the potential to use proximal vision sensing for yield mapping of lettuce. However, further work is required to determine the optimal combination of camera resolution and height and to refine the software and image acquisition procedure to obtain real-time infield measurements.

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