Unmanned aerial vehicles for pre-harvest biomass estimation in willow (*Salix* spp.) coppice plantations.

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Highlights: Improved methods are needed to estimate yield of bioenergy crops, such as short rotation coppice, ahead of harvest, to improve efficiency in the sector. This paper examines the potential of UAV systems, deploying low-cost consumer-grade cameras, for estimating available biomass pre-harvest and detecting differences in development between willow varieties.

Key words: *Terrestrial laser scanning, short rotation coppice, crop yield, multispectral.*

Introduction

Bioenergy crops provide a form of renewable energy, contributing to reductions in greenhouse gas emissions. Short rotation coppice (SRC) bioenergy crops, including willow (*Salix* spp.) and poplar (*Populus* spp.) are planted commercially in the UK and more widely across Europe for use in heat and power generation [1] often on set-aside or arable agricultural land. However, available data on yield of such crops, in terms of available biomass pre-harvest and spatial variations in yield, are limited [1]. Identifying the best time to harvest crops and accurately estimating yield before harvest is vital as harvesting operations comprise a major component of the costs in SRC production [2]. A range of methods have been proposed to provide above-ground biomass or basal area estimates in willow or poplar SRC plantations, including measurements of light attenuation through the canopy [2], terrestrial laser scanning [3] and field inventory with use of allometric equations [e.g.1, 4]. However, such methods are time consuming and limited in their ability to detect and map spatial variations in yield within the crop or to detect changes in crop health.

Small unmanned aerial vehicles (UAVs) are able to provide high spatial resolution imagery and have potential to be flexibly deployed as needed, providing 'on-demand' imagery over small areas. Such systems are increasingly being deployed in environmental monitoring and in agriculture, operating with a variety of sensor types. Photogrammetric methods, utilising data from UAVs, have been used in past studies to derive forest height [5, 6], whilst radiometric measurements obtained from modified consumer-grade cameras or multispectral sensors have been used to calculate vegetation indices and estimate arable crop development and health [e.g. 7, 8]. However, little research has been undertaken in the application of low-cost UAV-based sensor systems in monitoring and estimating biomass and growth of SRC crops.

This paper tests the use of a small unmanned aerial vehicle, equipped with consumer-grade red, green, blue (RGB) and near-infrared cameras, for estimating the biomass of willow (*Salix* spp.) SRC based on canopy height information and normalised difference vegetation index (NDVI). The paper aims to determine the ability of such approaches to detect differences in pre-harvest biomass in different willow varieties and to compare the obtained estimates with those from terrestrial laser scanning and field inventory.

Methods

The study was conducted at Cockle Park Farm, Morpeth, Northumberland, using a SRC willow plantation, established in 2008, containing 13 different willow varieties. The willow crop is managed under an Iggesund (Workington, Cumbria, UK) contract to supply biomass to Workington Mills's biofuel boiler and was due for harvest. The varieties are set out in 6 x 135m (0.08 ha) plots, with 4 replicate plots for each variety. Variance in willow growth between the varieties provides differences in biomass and tree health across the study area. Data was collected using a QuestUAV QPod system equipped with RGB and near infrared modified Panasonic Lumix LX5 cameras, mounted in a gimbal to adjust for roll during acquisition. The UAV was flown on a pre-programmed route, ensuring overlap between adjacent flight lines and the cameras were triggered simultaneously at two second intervals. Two UAV acquisition campaigns were carried out, consisting of at least two flights each (with imagery combined to ensure good areal coverage). The first, on 17th September 2014, imaged the willow pre-harvest after 4 years of growth. The second acquisition was carried out one week after harvest of the willow, on the 23rd March 2015 and was intended to provide a 'bare ground' digital terrain model.

During the flights, 10 GNSS positioned ground control points were established using custom-made targets to allow improved mosaicking and georegistration of the imagery. Five radiometric calibration targets with known reflectivity were also deployed in the pre-harvest flight to allow calibration of image radiometric properties to obtain accurate estimates of NDVI.

During harvest (in leaf-off conditions), the total biomass from each individual plot was determined using a chaser bin equipped with load cells, allowing the harvested biomass to be weighed on-site. Weights were recorded for each pass of the harvester through a plot, with 3 passes per plot. For a subset of plots (five in total, comprising different varieties), terrestrial laser scans (Leica P20 scanner) and hemispherical photographs of the willow canopy in leaf-off conditions (between 16th January and January 2015) were acquired at two locations per plot, separated by approximately 20 m, prior to harvesting. Field inventory measurements were also made for these plots during the same period. This data provides a secondary validation for the UAV image-based approaches and allows comparison with alternative methods of deriving above-ground biomass estimates (TLS).

UAV image data was processed in Agisoft PhotoScan software using structure from motion (SfM) approaches to align the imagery, extract a dense point cloud and subsequently generate an orthomosaic for the RGB and near infrared imagery and a digital surface model (based on the RGB camera). Ground control points were used in the processing workflow, resulting in a reported error of 0.008 m (0.14 pixels) following camera optimization. The final othophoto mosaics for the pre-harvest acquisition had a spatial resolution of 4 cm. The digital surface models were generated with a spatial resolution of 8 cm. For calculation of NDVI, RGB and NIR imagery was resampled to 20 cm resolution, to minimise the impact of any misalignment between the image layers and align pixels to a common grid. NDVI was then calculated on a pixel-by-pixel basis from the resampled data. Radiometric calibration to reflectance has not currently been applied, as only a single image date is under consideration, illumination conditions were stable on the day of acquisitions and only relative differences between plots are of interest. Processing of the post-harvest data is on-going, but this will provide a digital terrain model of the underlying surface, allowing calculation of canopy height from the pre-harvest surface model.

Further analysis is on-going but will develop empirical relationships between canopy height, NDVI and canopy cover and harvested biomass at a plot level to determine the optimal predictors of biomass from UAV data. The value of combining radiometric and structural variables obtained from UAV data and of use of metrics extracted from the photogrammetric point cloud for estimation of biomass will also be explored and comparisons made to metrics (e.g. height, gap fraction, volume) from TLS data. This paper will present the initial results of this analysis.

Preliminary results.

Significant variation in yield (harvested biomass) was observed between willow varieties with 'Sven' producing significantly higher biomass (Figure 1). Harvested weight varied from a mean of 986 kg per harvester pass for the 'Parfitt' variety to a mean of 2471kg per harvester pass for 'Sven'.

Figure 1: Mean harvested weight per pass for each plot with varieties labelled.

Figure 2 shows the orthomosaic generated from the pre-harvest data acquisition as well as subsets of imagery pre- and post-harvest. Significant visual differences in greenness can be observed between willow varieties. These are likely to result from a combination of differences in canopy structure, leaf area index and tree health, but may also reflect differences between varieties in phenology and the time of onset of leaf senescence due to the time of survey (late September).

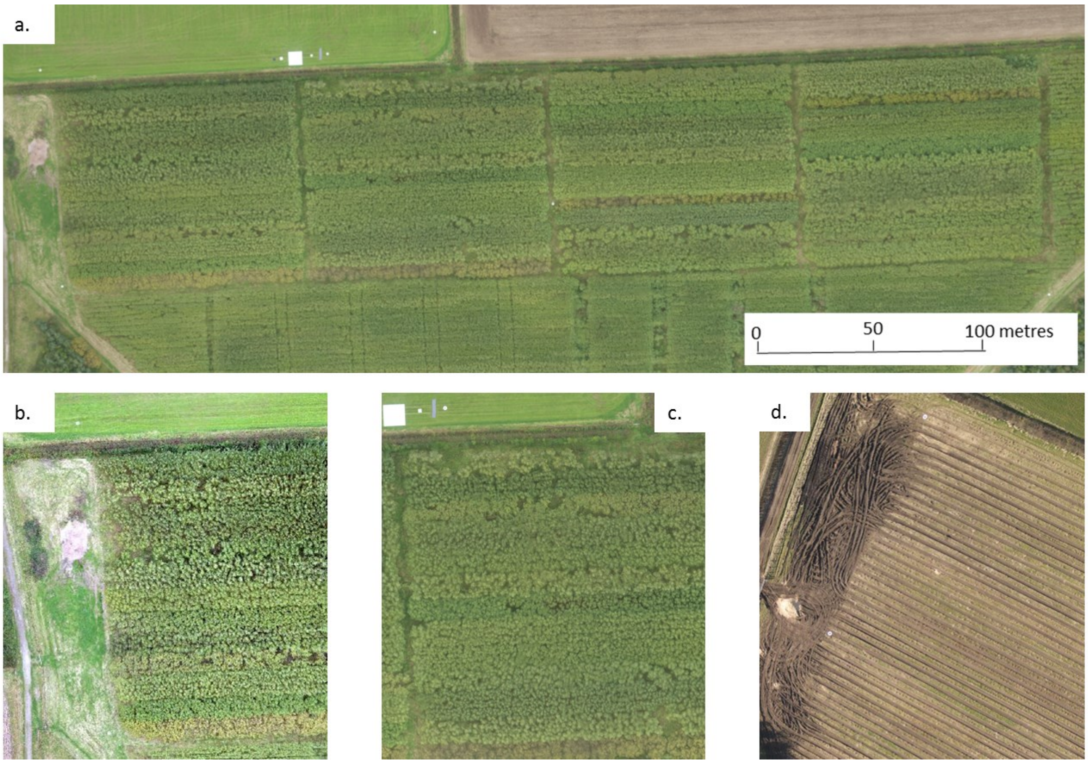

Figure 2: Examples of UAV RGB imagery. 2a. Orthomosaic for the entire willow crop, generated in PhotoScan. 2b. A subset of the orthomosaic for the most easterly block in which TLS and hemispherical photo data were acquired. 2c. A subset of the orthomosaic for a central block showing ground radiometric calibration targets. This block is the same area displayed in Figure 3. 2d. An example of UAV imagery from the post-harvest flight.

A digital surface model derived from RGB imagery (subset shown in Figure 3a) reveals canopy height differences between the varieties, with the low-yield 'Parfitt' variety in particular showing lower heights. The differences in biomass on harvest can be seen to be variously due to low growth (e.g. Parfitt or Nimrod in this block) or poor establishment of trees (e.g. Discovery in this block). Further work is being conducted to correct the canopy surface model to a canopy height model, based on the post-harvest digital terrain model and to validate estimates of canopy height. In terms of radiometric differences, Figure 3b shows the retrieved NDVI for a section of the crop. Noticeable differences are present both between and within plots, with Parfitt showing particularly low NDVI and Endeavour the highest.

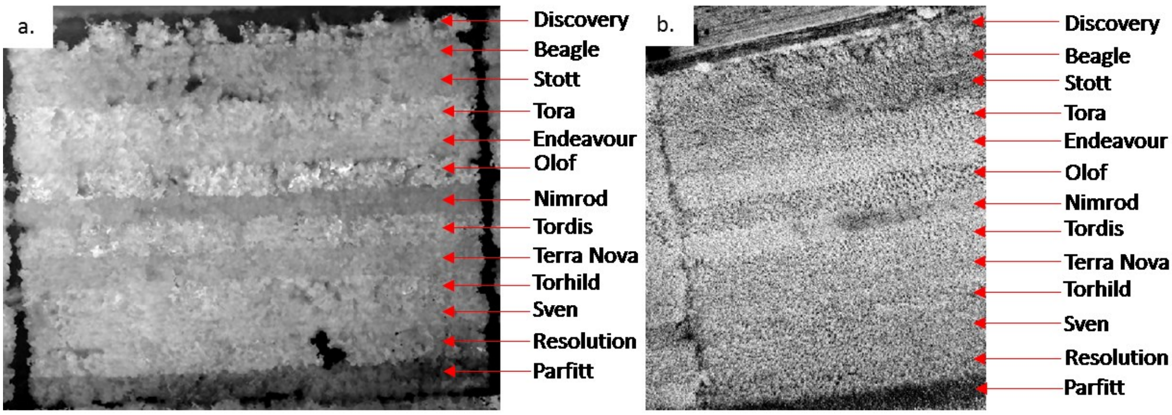

Figure 3: UAV imagery-derived products. 3a. Extract of UAV RGB image-derived digital surface model for one block of replicates. 3b. An example of NDVI derived from the RGB and near-infrared cameras for the block.

Work is on-going to develop quantitative relationships between UAV-derived variables, harvested biomass and ground-based estimates of willow crop structure.

Conclusions

Improved methods to monitor the growth and development of SRC plantations and to flexibly and non-invasively estimate yield of biomass on harvest are needed to improve the efficiency of the bioenergy sector. Unmanned aerial vehicles equipped with low-cost consumer grade cameras have potential to provide information on both structure (height and density) and reflectance properties (e.g. NDVI) of vegetation, including bioenergy crops, as and when required by farmers and to detect spatial variations in growth or estimate yield differences between different varieties. This research provides a pilot study of this capability, based on a varietal trial of willow (*Salix* spp.) SRC in Northumberland, UK.

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