BIOSYSTEMS ENGINEERING 129 (2015) 341–351

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/issn/15375110

Research Paper

Monitoring of crop biomass using true colour aerial photographs taken from a remote controlled hexacopter

Ramia Jannoura [a,*], *Katja Brinkmann* [b], *Daniel Uteau* [c], *Christian Bruns* [d], *Rainer Georg Joergensen* [a]

[a] Soil Biology and Plant Nutrition, University of Kassel, Nordbahnhofstr. 1a, 37213 Witzenhausen, Germany
[b] Organic Plant Production and Agroecosystems Research in the Topics and Subtropics, University of Kassel, Witzenhausen, Germany
[c] Soil Science, University of Kassel, Nordbahnhofstr. 1a, 37213 Witzenhausen, Germany
[d] Organic Farming and Cropping Systems, University of Kassel, Nordbahnhofstr. 1a, 37213 Witzenhausen, Germany

ARTICLE INFO

Article history:
Received 5 April 2014
Received in revised form
7 November 2014
Accepted 7 November 2014
Published online 28 November 2014

Keywords:
Hexacopter
True colour images
Above ground biomass
NGRDI
Pea
Oat

The use of unmanned aerial vehicles has been recently increasing in precision agriculture as an alternative to very costly and not readily available satellites or airborne sensors. Vegetation indices based solely on visible reflectance, which can be derived from true colour images may be a simple and cheap alternative compared to near infrared indices. A remote-controlled hexacopter with an RGB digital camera was tested for evaluating crop biomass. The hexacopter was flown over a field in which peas and oats were grown as sole crops and intercrops, fertilised with horse manure and yard–waste compost (10 t C ha^{-1}). The images were taken at flowering stage. Based on the aerial photographs, the Normalised Green–Red Difference Index (NGRDI) was calculated, and related to aboveground biomass and leaf area index (LAI). The mean of NGRDI values ranged from 0.09 to 0.13 without any effect of cropping system, while the fertiliser significantly affected the yield and the corresponding NGRDI values. NGRDI values were positively and significantly correlated with the aboveground biomass ($r = 0.58$–0.78). A high autocorrelation of NGRDI, and thus biomass, was found within the treatment plots and used for block kriging to show the spatial variability in the field. No relationship was found between NGRDI and LAI in peas ($P = 0.68$) or oats ($P = 0.15$). Nevertheless, true colour images from a hexacopter and the derived NGRDI values are a cost-effective tool for biomass estimation and the establishment of yield variation maps for site-specific agricultural decision making.

* *Corresponding author*. Tel.: +49 17624714637; fax: +49 5542981596.
E-mail address: ramiajannora@hotmail.com (R. Jannoura).
http://dx.doi.org/10.1016/j.biosystemseng.2014.11.007
1537-5110/

Nomenclature

DAS	Day after sowing.
DM	Dry matter.
GCPs	Ground control points.
GRVI	Green-red ratio vegetation index.
LAI	Leaf area index.
NDVI	Normalised Difference Vegetation Index.
NGRDI	Normalised Green–Red Difference Index.
NIR	Near-infrared.
RGB	Red green and blue colour.
UAV	Unmanned aerial vehicle.
VI	Visible vegetation index.

1. Introduction

Remote sensing has been successfully applied for monitoring crop growth and development during the growing season and for site specific management (Chang, Clay, Dalsted, Clay, & Neill, 2003; Swain, Thomson, & Jayasuriya, 2010). The traditional tools (e.g. satellites or conventional aircraft) are the primary platforms used to obtain remote sensing images. However, satellite and airborne sensors can be prohibitively expensive and inaccessible for researchers and farmers (Hunt, Cavigelli, Daughtry, McMurtrey, & Walthall, 2005; Robert, 2002). In addition, they have several critical disadvantages, such as a relatively low image resolution restricting their use to large scale applications and limited availability of high quality imagery in time and space, which also depends on weather conditions and satellite sensor characteristics (Xiang & Tain, 2011).

Over the past decade, the development of light weight, unmanned aerial vehicles (UAVs) has offered a new solution for crop management and monitoring (Primicerio, Di Gennaro, Fiorillo, Genesio Lugato, Matese, & Vaccari, 2012). UAVs have several advantages: (1) they can be deployed quickly and repeatedly at low cost, (2) they are user-friendly and flexible in terms of flying height and timing of missions and (3) they can deliver very fine image resolution and are thus suitable for small-scale investigations (Colomina & Molina, 2014). The use of small rotary wing UAVs to remotely detect crop and soil properties may become a key factor for farmers in the future, with promising capabilities for remote sensing applications in agriculture (Primicerio et al., 2012; Zhang & Kovacs, 2012).

Aerial photography with either true colour or colour infrared film is an appropriate technique for plant monitoring, providing quantitative information on crop status and spatial variability for the whole study site. Vegetation indices obtained from aerial images can be used to estimate changes in the vegetation state, biomass, leaf area index and chlorophyll concentration (Gitelson, Kaufman, & Merzlyak, 1996; Gitelson et al., 2003; Swain et al., 2010). A widely used index for vegetation monitoring is the Normalised Difference Vegetation Index (NDVI), which is the ratio of the reflectance in the near-infrared and red portions of the electromagnetic spectrum (Tucker, 1979). Some other authors have used vegetation indices based solely on visible reflectance and using an RGB digital camera (Hunt et al., 2005; Rasmussen, Nielsen, Garcia-Ruiz, Christensen, & Streibig, 2013; Torres-Sánchez, López-Granados, De Castro, & Peña-Barragán, 2013).

The green-red ratio vegetation index (GRVI) or Normalised Green–Red Difference Index (NGRDI) are calculated from the reflectance in the green and red parts of the spectrum, which can be derived from true colour images. These indices have been applied to monitor vegetation phenology (Motohka, Nasahara, Oguma, & Tsuchida, 2010), to determine aboveground biomass and nutrient status (Hunt et al., 2005) and for site-specific weed management (Torres-Sánchez et al., 2013). However, visual vegetation indices are not applied as often as near-infrared (NIR) indices, because the difference in digital numbers between the green and red bands for vegetation and soil is small compared with that between near-infrared and red bands (Hunt et al., 2005). NIR bands provide more information on the geometric features of crops and on biophysical parameters, such as the leaf area index (LAI), than visual bands (Breunig, Galvao, Formaggio, & Epiphanio, 2013; Houborg & Boegh, 2008). Also, remote sensing technologies combined with spatial analysis make it possible to gain a detailed understanding of the spatial complexity of a field and its crop (Zhang, Lacey, Hoffmann, & Westbrook 2011). Spatial interpolation methods such as kriging can be used to create continuous surface maps. The resulting maps can be used as a model to provide spatially distributed information for site specific management (Basnyat, McConkey, Noble, & Meinert 2001; Zhang, Lan, Lacey, Hoffmann, & Westbrook, 2011).

The field pea (*Pisum sativum* L.) is the most common grain legume in middle Europe for human nutrition and domestic protein fodder for farm animals. In organic farming, N_2 fixation by legumes, such as peas (*P. sativum* L.), is the main source of N input (Berry et al., 2002). Oat (*Avena sativa* L.) is a cereal crop that is used throughout the world for human food and animal feed. The area harvested in Germany is 146,000 and 50,000 ha of oats and peas, respectively (FAO, 2012). Legume-cereal intercropping is widely practised, especially in organic farming systems, to enhance productivity, yield stability and land use efficiency of intercrops compared to sole crops (Hauggaard-Nielsen & Jensen, 2001; Jensen, 1996).

In the current study, a small remotely controlled hexacopter equipped with an RGB digital camera as an image sensor was tested for small-scale monitoring of crop biomass. The relationships between the NGRDI and aboveground plant biomass, and LAI were tested. In addition, NGRDI data obtained from true colour aerial images of the field were tested for spatial autocorrelation to predict spatial distribution of aboveground biomass within a managed field.

The data analysis was based on a field experiment, which was established to examine the effects of organic fertiliser on the growth, crop yield, and soil microbial indices in sole and intercropped peas and oats under organic farming conditions (Jannoura, Joergensen, & Bruns, 2014) and monitored using ground measurements and high resolution true colour aerial photographs.