NDVI 'DEPRESSION' IN PASTURES FOLLOWING GRAZING

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ABSTRACT

Pasture biomass estimation from normalized difference vegetation index (NDVI) using ground, air or space borne sensors is becoming more widely used in precision agriculture. Proximal active optical sensors (AOS) have the potential to eliminate the confounding effects of path radiance and target illumination conditions typically encountered using passive sensors. Any algorithm that infers the green fraction of pasture from NDVI must factor in plant morphology and live/dead plant ratio, irrespective of the senor used. Moreover, livestock grazing affects the morphology of pastures so the veracity of instrument calibration procedures applied under 'protected plot' conditions is questionable if the sensor is subsequently deploy as a 'calibrated sensor' into grazed fields. In this research we have simulated pasture grazing on establish plots of Tall fescue (*Festuca arundinacea*) in a heavy clay (vertosol) soil and examined the effect of such grazing on the temporal NDVI values as derived using a Crop Circle^{TM} sensor. Five plots with different soil moisture condition were maintained in the study period. Time domain reflectometer (TDR) was used to monitor volumetric soil moisture content (%) and NDVI measurements were taken on a daily basis. Following a grazing event (facilitated by uniformly mowing the grass to a height of 6 cm), biomass samples were collected on 3rd, 4th and 5th day along with coincident measures of the NDVI. For those plots with low soil moisture level (< ~37% of the full profile), the NDVI progressively decreased up to 2 or 3 days following the 'grazing' event, despite the plot biomass increasing due to regrowth. The NDVI values did not 'recover' until approximately 4 days after the 'grazing' event. However, for those plots of moderate to high soil moisture (>~37%) the NDVI-time curves monotonically increased with biomass re-growth immediately following 'grazing'. This has important ramifications for those intending to use NDVI as the basis for pasture assessment, particularly in situations involving short-term grazing rotation

Keywords: Active Optical Sensor, *Festuca arundinacea* , CropCircle^{TM}, Pasture, Remote Sensing.

INTRODUCTION

Spectral reflectance-based vegetation indices such as the normalized difference vegetation index (NDVI = $\frac{NIR-Red}{NIR+Red}$) (Rouse et al., 1973) remain popular for estimating and mapping above-ground, photosynthetically-active biomass in precision agriculture (Weiser et al., 1986). Such indices are applied to passive satellite and airborne based sensors and on-ground radiometers (e.g. Beck et al., 1990; du Plessis, 1999; Flynn et al., 2008; Huete and Jackson, 1987), and recently active optical sensors (AOS), both hand-held and deployed in aircraft (Lamb et al., 2011; Mundava et al., 2013; Trotter et al., 2010). Each form of sensor deployment, and the associated issues of spatial and spectral resolution comes with its own suite of challenges to the veracity of the generated data.

For passive satellite and airborne remote sensing systems, there are the complex radiative interactions between the atmosphere, sensor view angle and solar zenith angle (Gutman, 1987; Roujean et al., 1992). For on-ground active optical sensors, these problems are avoided (Holland et al., 2012), but then there is the issue of localised sampling scale (Lamb et al., 2011; Mundava et al., 2013; Trotter et al., 2010) which can be offset by deployment on low-level aircraft (Lamb et al., 2011).

Considerable industry interest is being shown in the use of AOS for inferring pasture biomass, with particular incentive afforded by the ease of operation and portability of such systems (Lamb et al., 2011; Mundava et al., 2013; Trotter et al., 2010). However at any scale of sensing, the use of single-dimension vegetation indices like the NDVI is often confounded by the presence of dormant, senescent, decaying, and dead vegetation, high leaf area index (LAI > 3), and varying underlying soil conditions and soil types (Todd et al., 1998). These factors reduce the reliability of NDVI and poses question on accurate prediction of above-ground plant biomass (Lawrence and Ripple, 1998; Maynard et al., 2007).

The spectral reflectance characteristics of any plant canopy are inextricably linked to the reflectance of individual leaves and the overall canopy architecture. At the leaf level, scattering varies with the leaf structure, water content and the pigment content (Bousquet et al., 2005; Feret et al., 2008; Fourty et al., 1996; Jacquemoud et al., 1996) whereas at canopy level the variation occurs due to leaf angle distribution (LAD), leaf area index (LAI) and soil–canopy reflectance interactions (Myneni and Asrar, 1993). Plant leaves typically have lower reflectances in the Red spectral region due to strong absorption and negative correlation by chlorophyll concentration, and relatively higher reflectances in the near-infrared region because of no absorption and positively correlated with the amount of multiple scattering at the interfaces between cells and the air (Knipling, 1970). Therefore physiological disturbances like diseases, dehydration or grazing (leaf removal) can affect a noticeable change in the Red spectral region due to the sensitivity of chlorophyll and related pigments to leaf damage, while the NIR reflectance will likewise be affected because of changes in inter-leaf scattering within the canopy and changes in leaf cell turgidity (Blackburn, 2007). In other words, many of the day to day events that affect pasture leaf and canopy morphology will likely affect the NDVI-pasture biomass relationship.

Given the growing interest in using proximal NDVI-type sensors for estimating pasture biomass, and the fact that 'catastrophic' canopy disturbances through grazing is a recurring event in pasture management, this paper sets out to determine how much the NDVI of a pasture changes after grazing event and whether there are any carry-over effects on the NDVI of recovering pastures after a grazing event.

MATERIALS AND METHODS

An experiment was conducted in a 0.6 ha field of Tall fescue (*Festuca arundinacea*) located at the University of New England's 'SMART farm' (30°28′51″ S, 151°38′46″ E), 5 km north-west of Armidale, NSW Australia. The trial was completed during the 'peak summer' (January 2013) where pasture growth rates were considered at their highest. The soil in the study area is predominantly heavy clay (vertosol) and the pasture was at a vegetative-leaf development stage (E6 – E15; Moore et al. (1991). Within the study area, three blocks were established; each containing five 20 m^2 plots (2 m × 10 m) with pasture biomass ranging from 1200 kg/ha to 4000 kg/ha.

Each of the 5 plots within each block were given a different treatment of regular irrigation in order to develop plots of differing soil moisture level, and hence pasture re-growth rates. The soil moisture level in each of the plots was controlled by a drip irrigation system (one of the four plots in each block not being watered to provide a dry 'control'). The end result of this design was three replicates of 5 different levels of soil moisture (and hence pastures re-growth). Details of the trial layout are given in Rahman et al. (2014).

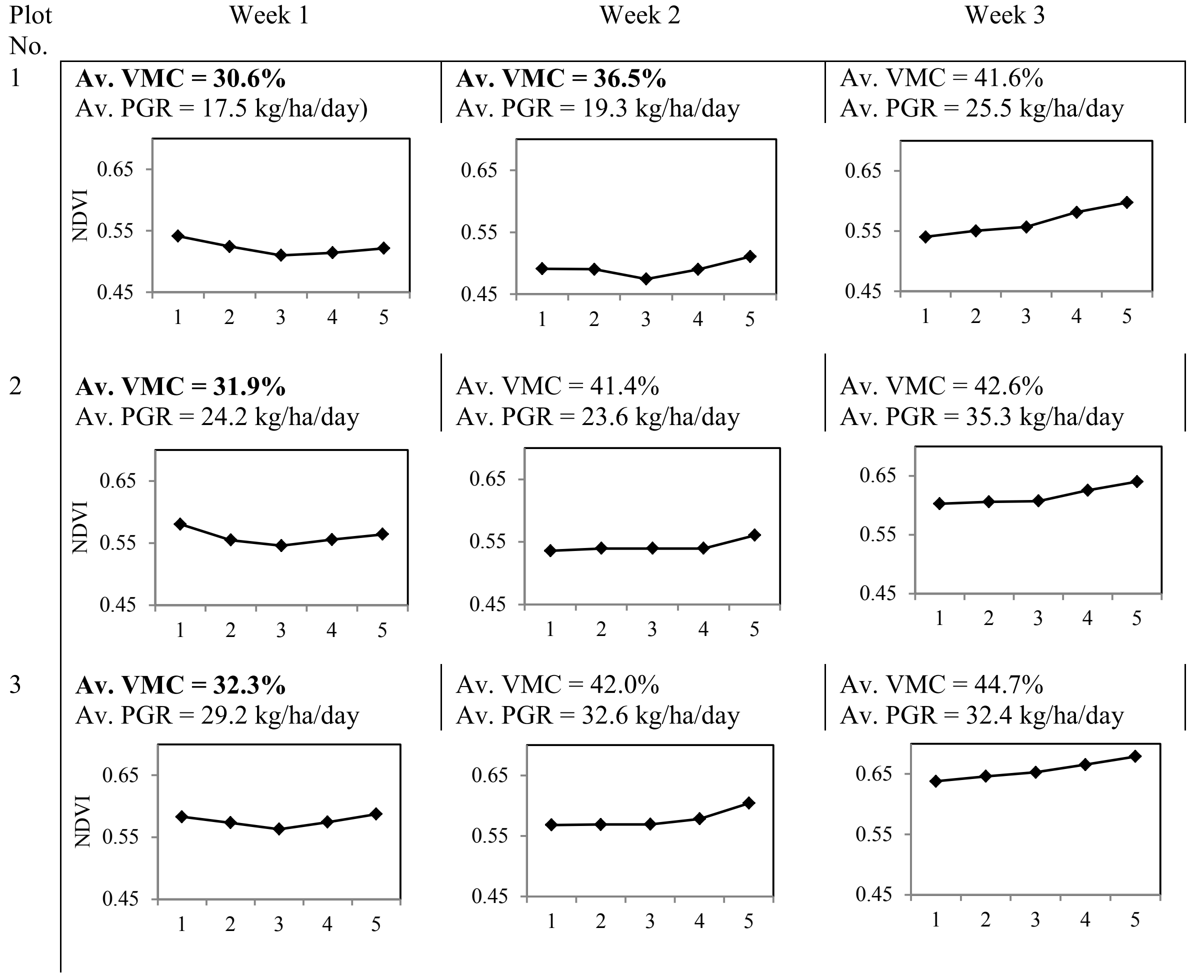
Daily NDVI data were acquired in each plot using the CropCircle^{TM} ACS-210, from Day 0 through to Day 5. At each plot CropCircle^{TM} ACS-210 was positioned at a height of about 90 cm above the ground level where it produces an illumination (and hence measurement) footprint of ~50 cm × 13 cm; and moved steadily backwards and forwards along the length of the plot (four times per record) in order to cover the 2-m width of each plot. Completing each plot scan over a period of 2 minutes produced in the order of 1200 individual data records. NDVI data for each scan was recorded by a GeoSCOUT GLS 400 data logger (Holland Scientific Inc., Lincoln, NE, USA) and the values were subsequently averaged to provide a mean NDVI value for each plot.

The soil volumetric moisture content (VMC (%)) for each plot was measured each recording day to a depth of 10 cm using a Time- Domain-Reflectometry (TDR, Mini Trase Kit – Model 6050X3K1B; Soil Moisture Equipment Corp, Santa Barbara, CA, USA) and the volumetric water content (%) determined following the procedures established in earlier work (Brisco et al., 1992; Topp et al., 1984; Zegelin et al., 1989). For each measurement the two 10 cm wave guides were randomly positioned in each plot.

At the commencement of experiment (Day '0'), the pasture in every plot within every block was completely and uniformly 'grazed' down to a residual height of 6 cm above ground level using a plot mower. The use of a mower with its rapidly spinning blades was considered the best option for mimicking the biting action of cattle. After an interval of three days (Day 3), and thereafter on consecutive days (Day 4 and Day 5), one third of each of the plots was re-cut down to the 6 cm residue height and the extracted pasture oven-dried at 70° C for 48-hrs and then weighed to provide a measure of average pasture growth rate (PGR: kg dry matter/hectare/day) in that interval. This approach provided for an uninterrupted sequence of NDVI data for each plot (taken from the segment of each plot only cut at the final, third cutting date). The entire process (Day 0 – Day 5) was then repeated for two consecutive weeks.

RESULTS AND DISCUSSION

The NDVI-time data for each plot (Plot 1 = lowest VMC % to Plot 5 = highest VMC %) in the three repeated sampling weeks is given in Figure 1. Unsurprisingly the PGR is generally highest for those plots with the highest average VMC (linear, R = 0.42, p~0.1). The NDVI-time trends for all plots with VMC below ~37% exhibited a decrease in NDVI in the days following the 'grazing' event, despite verification that the pasture biomass was starting to recover (indicated in bold font in Figure 1). For those plots with VMC exceeding ~37% the NDVI started to increase the very next day after 'grazing'.



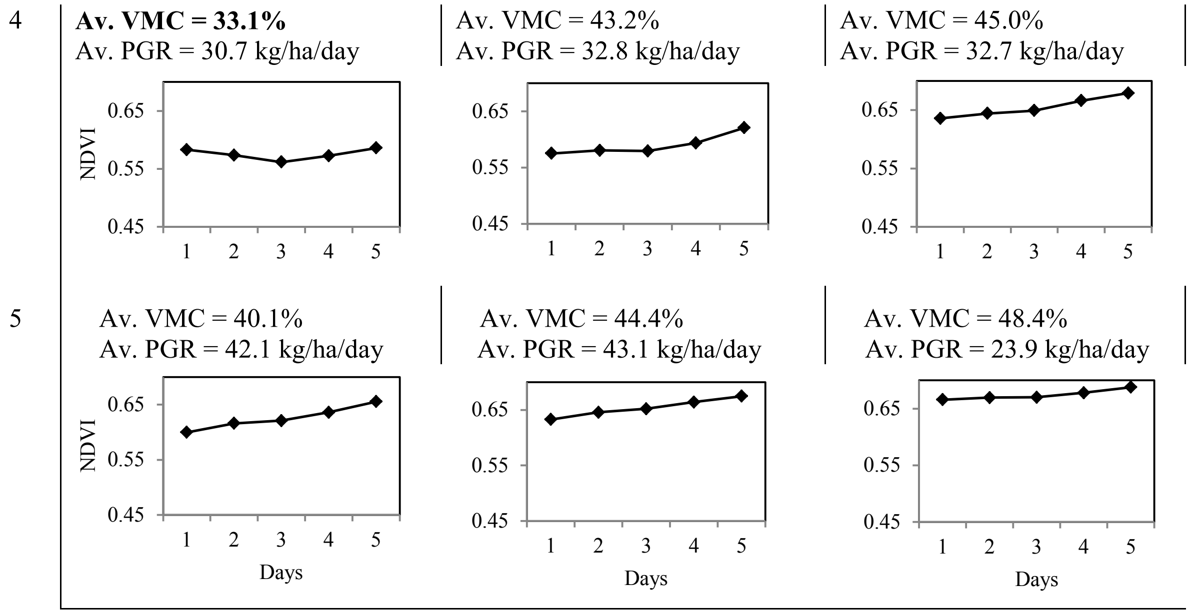


Fig. 1 NDVI as a function of days after 'grazing'. All data points are the average of 3 plots. Those plots with VMC < 37% are indicated in bold font.

This experiment was not designed to quantify architectural or physiological changes after grazing, nor can it be concluded that 37% VMC is a 'magic number' for this particular phenomenon to occur. Nevertheless, it is apparent that plots with lower VMC % are associated with this initial decline in NDVI following 'grazing', and that the NDVI values only start to increase, in line with progressively increasing biomass, approximately 4 days post-grazing. Moreover, it should be noted that the starting value of NDVI (hence biomass) in each plot were in some cases higher for those with lower VMC (below the ~37% threshold) than those of higher VMC (for example, note week 2 versus week 1).

Reserves of fixed carbohydrate and nutrients are important resources for plant regrowth after damage (grazing), and even more so in resource-limited environments such as related to available moisture (Hendry et al., 1987). Mobilization of nutrients occurs into plant parts after cutting leaf edges which deteriorate the chloroplast in the cutting edges of leaves and changes the optical properties of leaf tissue (Pinter et al., 1985). Changes of leaf angle distribution (LAD) after cutting due to stress condition would likely to be another factor causing deviations in leaf spectral properties (Jackson and Ezra, 1985; Jackson and Pinter Jr, 1986). Of course, variability in leaf tissue optical properties is wavelength-dependent. For the desiccated top portion of leaves at the damage site, this results in an increases in the visible (RED) spectral region and decrease in the near-infrared (NIR), which ultimately reduces the NDVI values. The reduced NDVI observed in this exploratory trial is presumably aggravated by potentially water-limited growth conditions.

CONCLUSIONS

This exploratory study has identified a tendency for NDVI to decline initially after a 'grazing' event for pasture biomass growing under potentially water-limited growth conditions. While only preliminary, these results imply that caution must be used when deploying NDVI-based pasture biomass assessment tools in situations where grazing has only been recent (< ~4 days).

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