Identifying within-season cotton crop nitrogen status using multispectral imagery

Jordan Romeo[1], Patrick Filippi[1], Jon Baird[2], Anastasia Volkova[3], Daniel K.Y. Tan[1]

[1] The University of Sydney, Sydney Institute of Agriculture, School of Life and Environmental Sciences, Faculty of Science, Sydney NSW 2006
[2] NSW DPI, Australian Cotton Research Institute, Narrabri, NSW 2390
[3] FluroSat, 2/4 Cornwallis St, Eveleigh NSW 2015

Abstract
Nitrogen (N) plays a key role in the growth and development of a cotton (*Gossypium hirsutum*) plant and the timing of N fertiliser application has a critical effect on yield. Under-application of N fertilizer reduces yield, while over-application encourages vegetative growth at the expense of reproductive growth, resulting in a higher production cost. In the Australian cotton industry, N fertiliser is typically applied at a uniform rate across a field at a high enough rate to ensure N is not limiting at any area of the field and this practice will not be cost effective with the rising cost of N. This study investigates the use of vegetation indices (VIs) derived from multispectral imagery from planes and satellites (Sentinel 2) to estimate plant nitrogen status to facilitate variable rate fertiliser application and also for predicting lint yield at time of harvest. Sicot 748B3F cotton was sown with six pre-season nitrogen rates 0, 37.5, 75, 112.5, 150 and 187.5 kg N/ha in three replicates in a randomised complete block design layout. Aerial multispectral imagery was collected on three dates across the growing season, as well as from satellites at 17 dates throughout the season. Imagery gathered were processed into VIs including Normalised Difference Vegetation Index (NDVI), Normalised Difference Red Edge Index, Canopy Chlorophyll Content Index (CCCI) and Modified Soil-Adjusted Vegetation Index (MSAVI). Plant tissue samples were collected for nitrogen concentration at 75 and 139 days after sowing, with coinciding aerial imagery. At plant maturity (143 DAS), the coefficient of determination values for N% were $r^2 = 0.34$ for CCCI, $r^2 = 0.34$ for NDVI and $r^2 = 0.27$ for NDRE indicating a relatively low/moderate correlation between VIs and leaf N%. The best time to predict/forecast cotton lint yield using CCCI and NDRE was at 178 DAS, based on satellite imagery. This study suggests aerial and satellite imagery can provide potential for variable rate fertiliser application, and the possibility to replace the current method of N tissue testing.

Key words: remote sensing, multispectral imagery, vegetation indices, nitrogen fertiliser, precision agriculture.

Introduction
The Australian cotton industry produces 3% of the world's cotton and is the fourth largest exporter of cotton in the world, contributing $2 billion in export revenue annually. Cotton crops with insufficient nitrogen at critical stages can experience reductions in plant growth, fruiting sites, boll formation and overall yield (Hutmacher, 2017). Therefore, large amounts of nitrogen fertilisers are often required to offset deficiency. Nitrogen fertilisers make up a significant proportion of a cotton grower's input costs (Cotton Research and Development Corporation, 2014). In areas of nutrient stress, cotton growers overcorrect and apply their fertilisers calibrated to the highest rate across a paddock. This in turn causes an unnecessary application cost in large areas. Current methods used to determine cotton nitrogen (N) status include the chemical analysis of petioles or leaf blades (first fully expanded leaf), which are generally randomly sampled across a field. This approach in plant nutrient monitoring can be labour intensive, time consuming, expensive and limited to few samples. For this reason, research has been focused on developing alternative techniques that include remote sensing from unmanned aerial vehicles (UAVs), planes, satellites and spectroscopic hand-held devices to demonstrate the potential these emerging technologies have in identifying spatial variation of nitrogen status using multispectral imagery. This study aims to use multispectral imagery from planes and satellites to identify plant nitrogen status and provide the potential for variable rate fertiliser application.
The primary objectives were to: (1) identify and determine the accuracy of various multispectral vegetation indices for estimating leaf nitrogen status within a cotton crop; and identify the best time (Days After Sowing, DAS) for yield prediction from remotely-sensed imagery.

Method
Experimental design
The field experiment was conducted from Spring 2017 to Autumn 2018 on Field 16 of "Norwood", managed by NSW DPI, located 25 km north of Moree, NSW, Australia in the Gwydir catchment area. The experimental

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site was flood irrigated, containing 1 m hills with the head ditch (water supply channel) to the east and the tail drain to the west. Plots 12 m wide run from head ditch to tail drain, with a 12 m buffer around the site. The experimental block size was 324 m wide x 690 m long totalling 22.4 ha. The experiment consisted of a randomised plot design with three replicates and six nitrogen treatments: 0, 37.5, 75, 112.5, 150 and 187.5 kg N/ha.

Data collection

The multispectral plane imagery was acquired using the pushbroom line-scan imaging technique. The plane flights produced line scans of Field 16 in two dimensional images constructed by translating the trial sample relative to the camera. Three plane flights were carried out on 12th December 2017 (73 DAS), 18th January 2018 (119 DAS) and 11th February 2018 (143 DAS) with the pixel resolution ~0.7 m. A combination of Sentinel A (10 m resolution) and Sentinel B (20 m resolution) satellite imagery (re-visited 5 to 10 days) was used. Tissue test were geo-referenced and carried out on the 14th December 2017 (75 DAS) and the second on 7th February 2018 (139 DAS) with a total of 55 samples collected for each time point. Plant tissue (leaf blades) were collected from the first fully expanded leaf on the plant (~4th node from the top of the plant). The plant tissue was collected over a 20 m line along the 4th row within the 12 m plot. Collected leaves were dried, milled and analysed for nitrogen concentration using a Lachat QC8500 Series 2 flow injector (LECO). The optimum leaf N% for cotton grown in Australia is between 3.5 and 4.5% (Nutripak 2018). The experimental yield was measured by weighing the harvested cotton (lint and seed) removed from the plots. Final lint yield was determined by separating the lint from the seed and a small amount of desiccated plant matter in the harvested sample through a cotton gin.

Statistical analysis

Plane and satellite multispectral imagery were used to produce several vegetation indices. Canopy Chlorophyll Content Index (CCCI) estimates the chlorophyll in the leaves, The modified soil adjustment vegetative index (MSAVI) minimises the soil brightness that is affected by red and near-infrared (NIR) wavelengths, Normalised Difference Red Edge is a metric used to investigate whether the multispectral imagery obtained consists of healthy vegetation (plant growth) without interference from non-plant returns (e.g. soil) and Normalised Difference Vegetation Index (NDVI) measures the difference between near-infrared and red light living green biomass (Borgogno-Mondino *et al.*, 2018).

$\boldsymbol{CCCI} = \frac{(\boldsymbol{NDRE} - \boldsymbol{NDREmin})}{(\boldsymbol{NDREmax} - \boldsymbol{NDREmin})}$	$\boldsymbol{MSAVI} = \frac{(\boldsymbol{NIR} - \boldsymbol{RED})(\boldsymbol{1} + \boldsymbol{L})}{\boldsymbol{NIR} + \boldsymbol{RED} + \boldsymbol{L}}$	$\boldsymbol{NDRE} = \frac{(\boldsymbol{NIR} - \boldsymbol{RED\ EDGE})}{(\boldsymbol{NIR} + \boldsymbol{RED\ EDGE})}$	$\boldsymbol{NDVI} = \frac{(\boldsymbol{NIR} - \boldsymbol{Red})}{(\boldsymbol{NIR} + \boldsymbol{Red})}$

All statistical analyses were performed in the program R. The relationship between the VIs and the leaf nitrogen levels were then determined using r^2 and Root Mean Square Error (RMSE). A linear model was built with the leaf N% as the response variable, and the VI as the predictor variable. A spatial layer/map of leaf N% was then produced by predicting with the linear model onto the VI map.

Results and Discussion

Relationship between leaf N% and Vegetation Indices from plane at maturity (143 DAS)

At time of plant maturity (143 DAS) the relationship between leaf N% and the chlorophyll sensitive indices, CCCI and NDVI had the highest correlation coefficient (r) of 0.59. The correlations were positive for all three indices, NDRE with coefficient of determination, $r^2 = 0.2758$ and NDVI and CCCI had the highest $r^2 = 0.345$ (Fig. 1, Table 1). A comparable study conducted by (Ballester, 2017), assessed in-season cotton nitrogen status, VIs, and lint yield from unmanned aerial imagery and similarly identified poor performance of multispectral indices in explaining the plant N% variability in the earlier crop stages. The NDVI and CCCI were the best VIs for assessing leaf N% cotton at maturity, before defoliation. Hence, NDVI and CCCI during time of plant maturity potentially can be used as a tool to identify management zones requiring varying amounts of defoliant aids (e.g. Ethephon and Thidiazuron).

Table 1. The relationship between plant tissue (leaf blade) N concentration and VIs (CCCI, NDVI & NDRE).

VI	Equation y = N%	r	r^2	Adjusted r^2	RMSE
CCCI	$y = 3.11 + 1.70\ CCCI$	0.59	0.34	0.32	0.188
NDVI	$y = 1.56 + 4.86\ NDVI$	0.59	0.34	0.31	0.156
NDRE	$y = 3.79 + 1.34\ NDRE$	0.53	0.28	0.258	0.188

Note: MSAVI

data unavailable

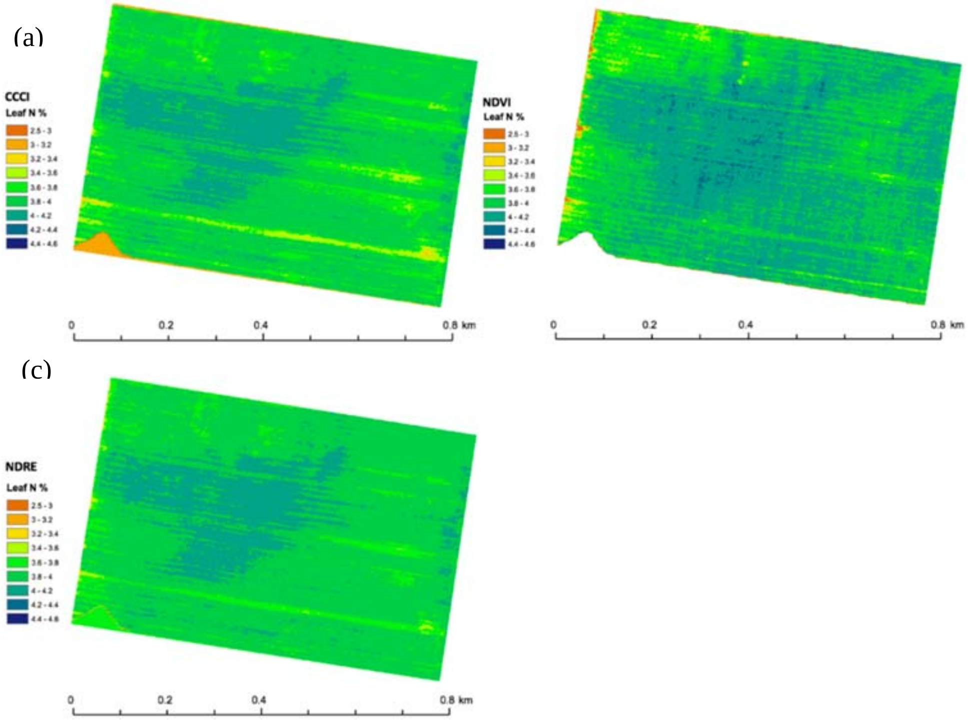

Figure 1. The relationship between leaf nitrogen concentration (N%) and (a) the canopy chlorophyll content index (CCCI), (b) normalised difference vegetation index (NDVI) at plant maturity and (c) normalised difference red edge index.

Lint yield and its relationship with VIs

A time series from 0 to 189 (DAS) was produced for the respective VIs and their relationship with lint yield (correlation coefficient - R) determined. Lint yield was obtained from the yield monitor in the John Deere 760 picker. At 148 DAS, there was a significant correlation between lint yield and CCCI, and NDRE, and continued to rise reaching a maximum of r = 0.38 at 174 (DAS). There was low correlation between the vegetation indices NDVI and MSAVI and lint yield. The VIs, NDVI and MSAVI produced a random pattern throughout the growing season providing no clear relationship between yield and VI. In cotton production, the crop biomass is usually correlated to lint yield. In the current study none of the four VIs was correlated with lint yield during the early stages of crop development. There was no correlation between yield and the vegetation indices, NDVI and MSAVI in agreement with studies conducted by (Gutierrez *et al.*, 2012). A high absolute R value identified a significant relationship between VIs, CCCI & NDRE and potential lint yield at maturity (174 DAS) rather than earlier in the season. The best time to predict yield is to fly a plane at 178 DAS to obtain CCCI or NDRE. Furthermore, 187.5 kg N/ha was the best rate for achieving the highest yield for cotton production.

Conclusions

This experiment fulfilled its primary aims in estimating spatial variation distribution of nitrogen in the cotton canopy. CCCI and NDVI were the best vegetation indices for estimating the cotton canopy nitrogen status. There was a relationship between the vegetation indices and nitrogen levels in cotton leaves, however this particular experiment established a low correlation. There is a need for further assessment as the science is difficult to replicate due to daily variation in surface reflectance and absolute quantity.

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