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REMOTELY PILOTED VEHICLES AND PRECISION AGRICULTURE APPLICATIONS

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ABSTRACT

Extensive research has been conducted using satellite and aerial imagery to observe vegetation status. Nonetheless, these platforms have limitations, particularly with regard to cost, limited spatial and temporal resolution. Remotely piloted vehicles (RPV) are effective, low cost alternatives to satellites and manned aircraft for acquiring high-resolution images. In this study, remotely piloted vehicles (RPV) constructed from a commercially available remote control model airplane was used as a remote sensing platform to determine normalized difference vegetation index (NDVI) as a measure of percent canopy cover over a controlled experimental sight in central Arizona.

The RPV collected digital images above a controlled experimental site with a multi-spectral camera (DYCAM) with spectral bands at 600 nm and 1100 nm, visible red and near infrared (NIR), respectively. The experimental design included 12 different treatment combinations of nitrogen, water, and plant density. Two levels of nitrogen were applied, which were “high” at 150 kg N ha^{-1} (63 kg N / Feddan) and “low” at 93 kg N ha^{-1} (39 kg N / Feddan). Plant density treatments were: sparse (90 plants m^{-2}, single line planting); typical (164 plants m^{-2}, single-line planting) and dense (291 plants m^{-2}, double-line planting). Water treatments included comparison of two different calculation methods for crop coefficient: FAO-based versus remote sensing-based. Three RPV flights at days of year 57, 71 and 113 were the focus of this study. Field measurements of percent canopy cover (canopy width) and hand held radiometer data at these three days constituted ground truthing for the RPV data. NDVI data of the DYCAM and the hand-held radiometer were compared to the field measurements of percent canopy cover. For the first two data days, the NDVI developed with the DYCAM (i.e. RPV) was highly correlated to both percent canopy cover and NDVI developed with the Exotech radiometer (ground data). Though, due to senescence on DOY 113, DYCAM was poorly correlated to Exotech and canopy percent cover. The high correlation of the NDVI to percent cover demonstrates a potential of RPVs as a convenient, cost effective, real-time tool in precision agriculture. The ease in obtaining flying lessons, the accessibility of the platform and sensors, and the associated cost savings may make the RPVs appealing tools for monitoring crop health to agricultural producers and academia as well.

INTRODUCTION

Remote sensing has been identified as a relatively inexpensive source of data for site-specific crop management (Moran *et al.*, 1997). Remote sensing technologies offer the feasibility of monitoring agricultural areas for quick and continuous assessment of plants, soil and water resources and interrelated problems (Myers *et al.*, 1975). Historically, the expense of data collection from manned aircraft and/or satellites has led to limited implementation in agriculture, especially for real time management of crops. Aerial photography from remotely piloted vehicles (RPV) can bridge the gap between ground-based observations and remotely sensed imagery from aerial and satellite platforms. RPVs are easily deployed, safer and lesser cost than piloted aircraft. Various terms have been used to describe remotely controlled platforms including unmanned aerial vehicle (UAV), automatically piloted vehicle (APV), remotely operated aircraft (ROA), pilot less airplane, model airplane, and remotely piloted vehicle (RPV). The main difference between a RPV and a UAV is the UAV's ability of autonomous flight.

Remote Sensing Platforms and Limitations

Jackson (1984) and Moran *et al.* (1997) reported that the limitations of integrating remote sensing data into day-to-day agricultural management decisions were restricted spectral range, coarse spatial resolution, slow turn around time, and inadequate repeat coverage. Satellite-based sensors have fixed spectral bands that may not be applicable to precision agriculture and the spatial resolution may be too coarse to detect in field variability. High-resolution data collected via satellite, manned aircraft or ground-based sensors can be costly and time consuming to collect (Moran *et al.* 1997). The cost, feasibility, and length of time required to process multi-spectral images for real time crop management precludes implementation of this method by most, if not all, agricultural producers. In some instances, piloted flights are becoming increasing difficult to coordinate due to urban sprawl encroachment on agricultural lands.

In academia, the quality and specifications of the imagery are very precise (i.e., near solar noon, nadir images, number and length of spectral bands, and other sensors). Using high-resolution imagery from satellites forgoes the requirements and the risks associated with manned aircraft but have less flexibility in timing and historically slow delivery of images to the customer. Satellite imagery is available from numerous providers that vary in spectral, spatial and temporal resolutions. Regardless of the satellite platform/model, the spectral and spatial resolutions are set (i.e., no modifications can be made with respect to changing band or band widths).

In comparison to other available satellites, AVHRR and MODIS are available at no cost, pass every 1-2 days, and have set spectral bands with coarse spatial resolutions ranging from 0.25 km to 1 km. These data sets are useful for monitoring purposes as they generate continuous seasonal and year-to-year data. In contrast, very high-resolution satellite datasets are very costly. QuickBird satellite developed and operated by Digital-Globe provides 61-cm panchromatic and 2.44-m multispectral images at nadir at a cost of $10,000 per image. The incorporation of satellite data into farm management requires a maximum turn around time of several hours with coverage once a day and at a spatial resolution of 5 x 5 m (Jackson 1984, Moran 1994).

Moran (1994) reported numerous disadvantages reported in using SPOT, HRV, and Landsat TM satellite data for day-to-day irrigation management decisions. The study made an effort to acquire every possible SPOT and Landsat image for an entire growing season. Only 31% of the forecasted satellite data acquisition opportunities were realized. A majority of failures were due to weather conditions (i.e., cloud, cirrus, cumulus, and haze) or because of technical difficulties. (i.e., conflicts at the receiving station, the sensor view angle was of opposite sign with a view angle of +12º, programming errors, failure to order satellite data, sensor calibration, and atmospheric interference).

Curtis Ross, vice president of CAL MAR Soil Testing Labs in Remington, Ind., partnered with Purdue's School of Aeronautics and Astronautics, Center for Advanced Manufacturing, and Department of Aviation to design an electric RPV called "Crop Condor" (Campbell, 2005) at an estimated cost of $30,000. The Condor could be piloted to 60-100 meters above the ground to collect digital and multi-spectral images of approximately 0.16 km^2 (Campbell, 2005). Once the aerial tasks are completed the engine is turned off and the Condor glided into a cropped field. The Condor had the ability to stay aloft for approximately one hour, collecting data at a cruising speed of 400 km per hour (Campbell, 2005).

Brewster *et al.* (2002) conducted preliminary investigations on the implementation of hand launched RPVs for precision integrated pest management (PIPM). PIPM evaluates pest populations in smaller areas in order to establish management decisions and controls based on comprehensive information on the life cycles of pests and their interaction with the environment. This information, in combination with available pest control methods, may be used to control pest damage in a manner that is most economical to agricultural producers while minimizing exposure to human health and the environment. According to Brewster (2002), one of the challenges posed by PIPM is the dynamic nature of insect populations makes it difficult to map their distribution. PIPM units are dependent on the extent of an infestation (i.e., localized or entire field), spatial variability, temporal composition, and pest mobility. RPV remote sensing systems allow farm managers to gather spatially referenced pest information on their crop fields more efficiently than traditional ground-based scouting (Brewster *et al.*, 2002). Brewster and his team of researchers were successful in collecting video, red, and near infrared imagery. The acquired remote sensing data would be used to construct surrogate pest infestation maps.

Simpson *et al.* (2003) designed a low cost RPV for precision agriculture applications for a total cost of less than $1000. The project modified a commercially available sailplane, or glider, by installing a Jeti Phasor 45/3 electric motor and 40-3P Opto speed controller and a 12-cell, 2400 mAH battery pack (Simpson, 2003). Live video from a single board camera was transmitted from the plane to a ground station and was recorded on VHS video. The sensor platform also included digital 2.0 Mega pixel camera with the capacity to store 50 images. The RPV weighed 3.4 kg making it light enough to hand launch and was able to withstand "belly landings". The simplicity of the plane allowed for easy transport and on-site data review. In the event of an uncontrolled landing the sensors were not damaged and the plane could be repaired in the field with materials and components that were readily available from hobby shops.

Digital cameras have been used to quantify wheat senescence (Adamsen *et al.*, 1999), estimate flower numbers in Fendler's bladderpod plants (Adamsen *et al.*, 2000), determine canopy coverage in wheat (Lukina *et al.*, 1999) and soybeans (Purcell, 2000). Karcher and Richardson (2002) used digital image analysis software to determine the average hue, saturation, and brightness (HBS) in order to quantify turf color.

Vegetation Indices

Vegetation indices are designed to enhance the vegetation signal from measured spectral responses. Spectral vegetation indices are obtained by rationing, differencing, combining, or transforming spectral data to represent plant canopy characteristics such as percent canopy cover, leaf area index, phytomass, green weight, and dry weight (Jackson, 1984). One of these indices is the NDVI, which is the difference between the near infrared (NIR) band and the red band divided by the sum of the NIR and red bands, and its values typically range from 0 (bare soils) to 1.0 (full canopy) over agricultural covers (Equation 1). Although NDVI is not originally a nitrogen stress index, El Shikha (2003), showed that it gave a fairly good indication of nitrogen stress in Broccoli. An index such as the canopy chlorophyll concentration index (CCCI- Barnes *et al.*, 2000) would have been preferred; however, it requires the use of more advanced sensors that will significantly increase project costs.

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}$$ (Rouse *et al.*, 1974)

Equation 1

where ρ_{NIR} is reflectance in the near-infrared and ρ_{RED} is reflectance in the red.

The objectives of this research were to construct an inexpensive RPV platform from commercially available products, and to examine its ability to distinguish different plant densities under two nitrogen and two irrigation treatments.

MATERIALS AND METHODS

In this experiment, the project team assembled an “almost ready-to-fly” (ARTF) airplane kit with a removable and easily interchangeable sensor pod. The sensors and circuit board configurations were purchased from independent retailers and constructed in-house. The project team constructed a platform for a cost less than $4,000 (Table 1). This section was divided into two parts. Section I provided an overview of experiment’s objective, design, and treatments. Section II presented the RPV design, remote sensing image collection procedure, and an interpretation of the data collected.

I. Experiment Overview

The project coordinated three RPV flyovers in conjunction with an on-going experiment by USDA-Arid Land Agricultural Research Center (USDA-ALARC) at the University of Arizona’s Maricopa Agricultural Center

(MAC – 33° 04′_ N; 111° 58′_ W, 361 m MSL) located in Maricopa, Arizona, USA. The USDA-ALARC experiment had two primary remote sensing objectives. The first was to compare remotely sensed crop coefficients (NDVI K_{cb}) with calendar-based irrigation scheduling programs (FAO-56 K_{cb}) (Allen *et al.*, 1998). The second was to test the performance of several remotely sensed indices for crop status under various plant populations and nitrogen fertilization levels.

Table 1: System costs

Components	***Costs***
ARTF Kit	$109
Motor	$74
Propeller	$10
6-Channel Radio Transmitter	$150
Ground Support Kit	$20
Fuel (per gallon)	$15
Basic Platform Total	$378
Ground-Support and Payload	
Monitor (TV/VCR)	$100
Wireless Modem	$200
Laptop Computer	$1,000
Downward Looking Video Camera	$90
Forward Looking Video Camera	$90
Multi-Spectral Camera	$2,000
Batteries	$50
ATV Down Converter	$85
Ground Support Total	$3,615
Total Costs	$3,993

Wheat (*Triticum aestivum* L., cv. Yecora Rojo) was sown into dry soil in a north-south orientation in a 2.5 ha field at the Maricopa Agricultural Center in 15 Dec., 2003. The soil was classified as a Casa Grande series with sandy loam to sandy clay loam textures (Post *et al.*, 1988). The experiment consisted of 12 different treatment combinations and 32 field plots (11.2 by 20 m each) (Figure 1). A wet and a dry bare soil plots, less than 50% of the treatment plot area, were included in the experiment too. Individual plots were surface irrigated via gated pipes with gated ports spaced at 1.0 m along each pipe. For the primary irrigation treatment, irrigations were scheduled based on basal crop coefficients (FAO-56 K_{cb}), which followed an unmodified table lookup procedure based on time of planting and expected length of the season. In the second irrigation treatment, irrigation was scheduled based on basal crop coefficient calculations as predicted using NDVI measurement. NDVI-based scheduling implemented near real time K_{cb} derived as a function of canopy NDVI as measured 2 to 3 times per week with an Exotech radiometer (MODEL PX-100) with TM red (665-675nm) and NIR (760-900nm) bands and a 15°_field of view (FOV). Treatments included three plant densities and two nitrogen fertilization rates.

There were five rows per meter and planting densities included: sparse (90 plants m^{-2}, single line planting); typical (164 plants m^{-2}, single-line planting) and dense (291 plants m^{-2}, double-line planting). Two levels of nitrogen were applied (in irrigation water): "high" at 150 kg N ha^{-1} (63 kg N / Feddan) and "low" at 93 kg N ha^{-1} (39 kg N / Feddan). The high nitrogen application rate was based on soil analysis and following locally recommended practices for wheat (Doerge *et al.*, 1991).

FSH	FTL	FDH	NTL		NDL	NTH	NTL	FTH
NDL	NTH	FTH	NDH		FSH	NSL	FTL	FSL
NTL	FTL	NSL	FSL		NDH	FTL	NTH	FDH
NSH	NTH	FDL	FTH		FDL	FTH	NSH	NTL

Irrigation Schedule	Canopy Density	N Treatments
F - FAO Irrigation Schedule	S - Sparse Canopy	H - High Nitrogen
N - NDVI Irrigation Schedule	T – Typical Canopy	L - Low Nitrogen
	D - Dense Canopy	

Figure 1: The experimental design included 12 different treatment combinations and 32 field plots.

II. RPV Platform and Flight Procedure

The aircraft was an ARTF kit, manufactured by World Models, Inc. (Figure 2). The study utilized an ARTF airplane powered by a 7.53 cubic centimeters (cc) and a 2-stroke glow fuel (nitro) engine, with a wingspan of 1.63 meters and wing area of 0.78 m^2. Its weight when un-fueled was 3.18 kg with a fuel and carrying capacity of 0.35 L and 0.34 kg, respectively. When fully loaded with the remote sensing package it weighs 3.87 kg (Figure 2). It is capable of flight durations of 30 minutes at a control range and frequency of 3.23 km and 72 MHz FM.

The ground support system consisted of a 33 cm video monitor, a video signal-receiving unit, and a voltage converter used to provide 12 VDC and 120 VAC 60Hz. The aircraft was equipped with downward and forward facing color charge couple device (CCD) NTSC video. The forward facing camera was installed in the wings for navigational purposes. The downward facing camera allowed for detailed ground observations. The system recorded all video sent from the RPV for later review. The RPV controls were installed on a separate power bus from the video transmission system. This eliminated any conducted or radiated interference on the flight control receiver. The battery systems for the receiver and video transmitter were capable of powering their individual systems for a 4 hours minimum. Digital images were collected with a DYCAM multi-spectral camera (FOV 30°) with spectral bands at 600 nm and 1100 nm, visible red and near infrared (NIR), respectively. The camera had a pixel resolution of 496 x 365. The DYCAM was stripped of the manufacturer's case and secured to the bottom of the fuselage in a balsawood casing. The images were saved on-board the camera and downloaded with RS-232 serial connection. The twelve 24-bit color, 8-bits per band images from the camera were evaluated with DYCAM software. Authors used the BRIV32 software which is free software that comes with the camera to calculate normalized difference vegetation index (NDVI). Using more sophisticated image processing software (ENVI, Imagine etc.) would increase the cost (i.e. hundreds to thousands of dollars per license a year) which opposes the objective of this study.

(a) (b) (c)

Figure 2: RPV (World models, Inc.). Sensors included downward (a) and forward facing (b) cameras. The diameter of these cameras was about 2.5 cm. The DYCAM multi-sectral camera (c) was stripped of its manufacturer casing and secured in a constructed bulsa wood box. The RPV with all the sensors installed (d).

Field percent canopy cover (plant canopy width as a percent of bed width) was measured for all the plots and data were compared to NDVI data from both DYCAM and hand-held radiometer. The hand-held radiometer and field measurements of percent canopy cover were considered as ground truthing for the RPV (i.e. DYCAM). Soil adjusted vegetation index (SAVI), which eliminate the effect of soil background, was calculated too. Because SAVI was very similar to NDVI, authors choose to present NDVI only in this paper. The SAVI works better than NDVI if significant differences in the soil texture exist, which was not the case in this experiment. Explicitly, the difference would be pronounced when monitoring bigger areas.

The project performed over flights on three different dates to collect multi-spectral aerial images of the study site at an altitude of about 150 m above ground level. The flyovers were conducted on days of year (DOY) 57, 71, and 113. The plane took-off and landed along the southern boundary of the study site, against prevailing wind directions. Upon takeoff, the platform was capable of flying half-hour intervals. The project performed two flyovers per experiment date, generally collecting 2-4 reliable images.

Project personnel were able to assemble the platform, set-up and calibrate the ground-support system, and collect and download the images in less than 3-hours. The use of laptop computers allowed the images to be downloaded and reviewed upon the completion of each flight.

RESULTS AND DISCUSSION

NDVI and Canopy Percent Cover

Digital and NDVI images of the field for days of year (DOY) 57, 71, and 113 are presented in Figure 3 and Figure 4. As expected, the plots with typical or dense canopies in combination with high nitrogen achieved the highest NDVI values, ranging from 0.576 to 0.765 (i.e., dark blue in Figure 4).

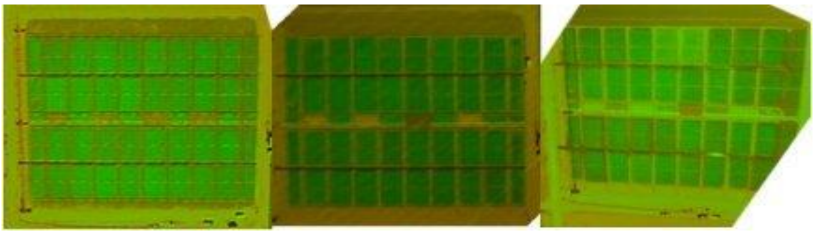

Figure 3: DYCAM digital images for days of year (DOY) 57, 71, and 113, from left to right respectively.

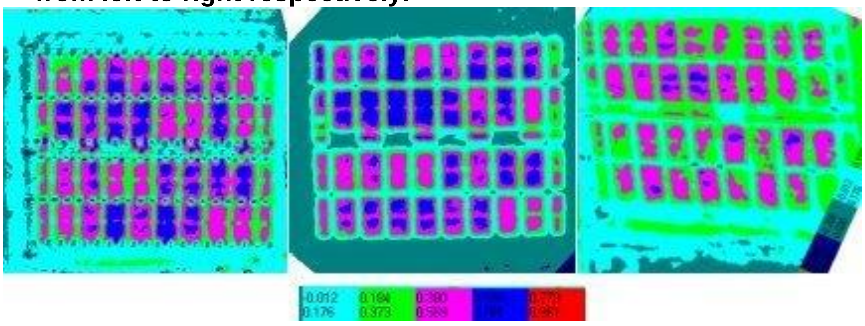

Figure 4: NDVI images differentiating plant densities for DOY 57, 71, and 113, from left to right respectively. Dark blue colors indicate healthy crop conditions that occurred early in the season (DOY 57 and 71). Senescence and irrigation ceased later in the season in preparation for harvest (DOY 113 - marked increase in stressed vegetation as indicated by green and pink colors).

The image collected on DOY 113 was near the end of the season and the field was no longer being irrigated results in NDVI values ranging from 0.184 through 0.373. In all three images bare soil had the lowest NDVI values ranging from 0 to 0.176 (i.e., light blue in Figure 4).

Figure 5 demonstrates the change in the NDVI for three planting densities during the growing season. The histograms represent NDVI averaged for nitrogen (high and low) and irrigation (FAO- and N-based) treatments. Histograms distinguished plant density (i.e., dense, typical and sparse). The highest NDVI values were associated with the dense followed by the typical then the sparse treatments. Relatively lower NDVI values were observed in DOY 113 due to senescence that changes plant color to yellow. Digital images collected on this date indicated that some of the plots were in senescence.

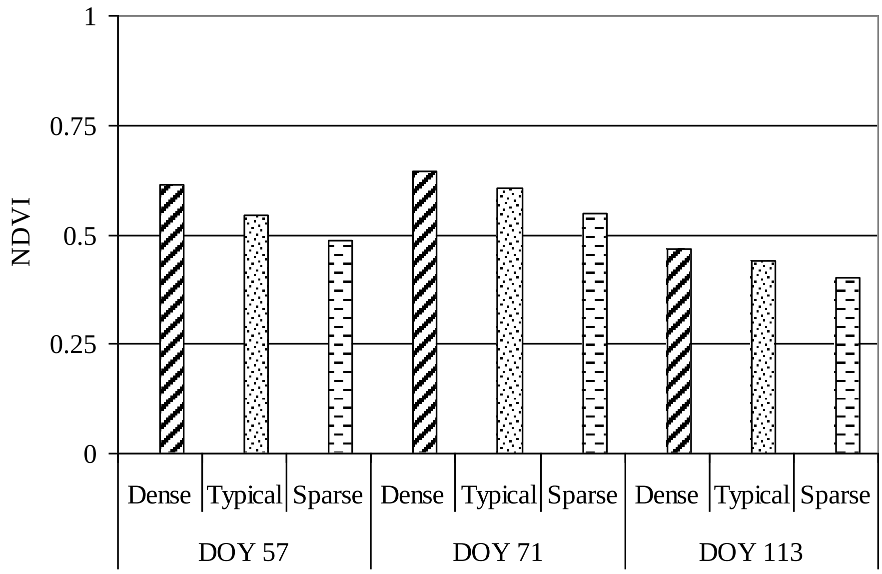

Figure 5: Average NDVI for different plant densities during the growing season.

Correlation of NDVI from DYCAM to that of Exotech for FAO- and NDVI- based (N-based) irrigation schedules were provided in figure 6. The lowest NDVI values (<0.2) represent bare soil. DYCAM data were highly correlated (R^2>0.93) to Exotech until DOY 71 (average %cover ≈75%) but Exotech data were relatively higher than DYCAM. The disparity could be attributed to the dissimilarity of field of view, band width and spatial resolution of the two sensors. R^2 values decrease (0.8 and 0.85 for FAO- and N-based irrigation, relatively) for DOY 113 due to plant senescence resulting in wilting and loss of green color. Except for DOY113, the FAO- resulted in higher R^2 and better correlations than the N-based irrigation. The NDVI from the DYCAM (DYC) were correlated to both Exotech (Exo) and percent canopy cover (%cover) (Fig. 7). Generally, DYCAM and Exotech data were highly correlated. The lowest correlations (r=0.4) were associated with the FAO-based irrigation (DOY 113). Both DYCAM and Exotech were highly correlated to percent canopy cover (r=0.83-0.91) up until DOY 71.

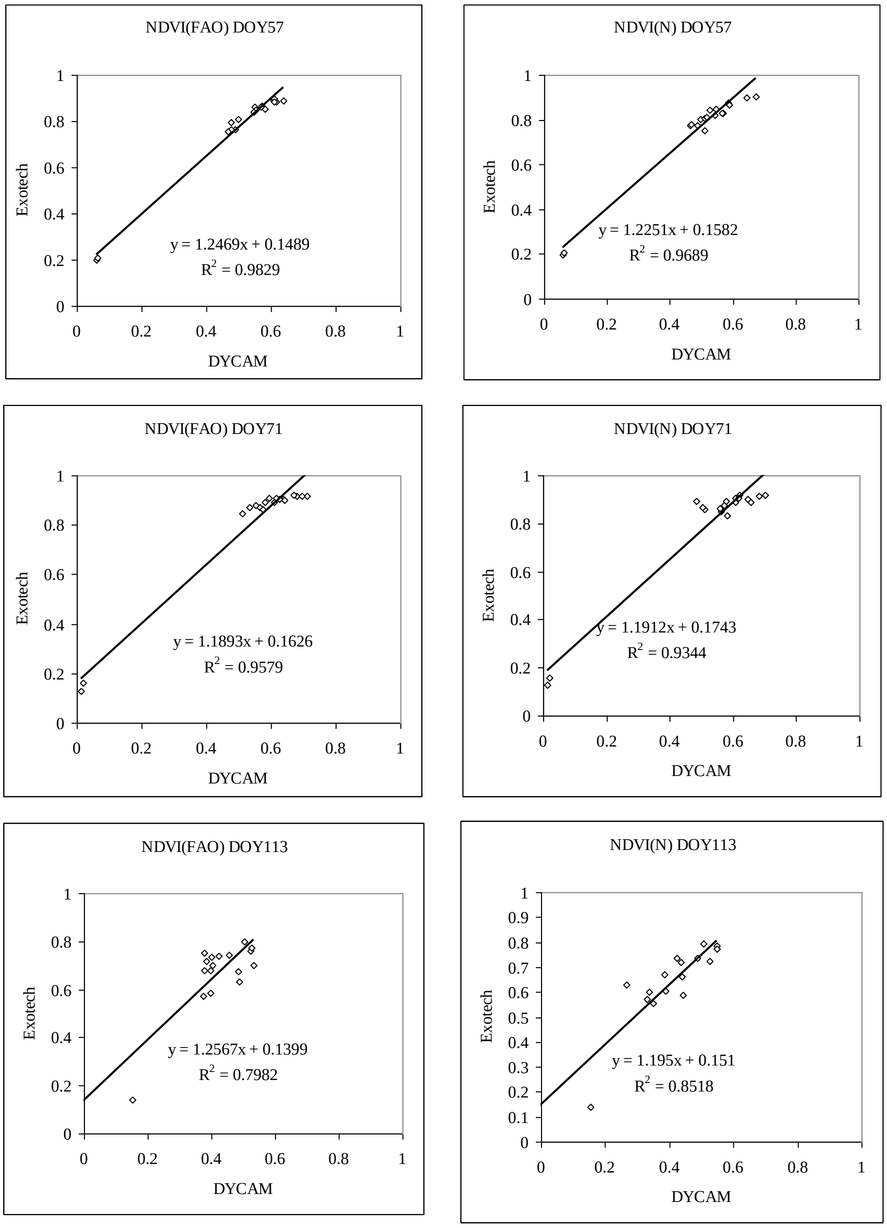

Figure 6: NDVI of the DYCAM as correlated to NDVI of the Exotech for the FAO- and N-based irrigation treatments.

For DOY 113, poor correlations were attained between the DYCAM and percent canopy cover. Exotech had low correlation coefficients to percent cover in DOY 113 too, which again could be attributed to senescence. At such a stage, the relation between NDVI and percent canopy cover fails due to the fact that NDVI measures greenness of plants. It can be used as a measure of percent cover only before senescence.

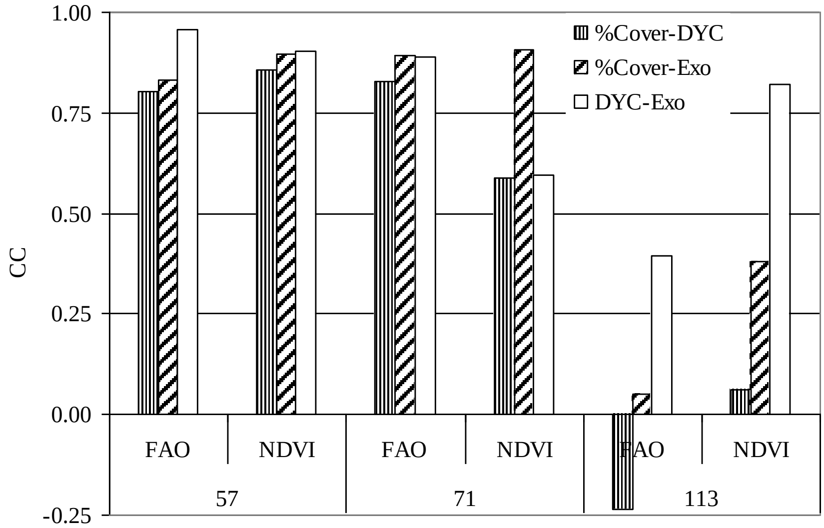

Figure 7: Correlation coefficient (CC) of NDVI from DYCAM (DYC) and Exotech (Exo) to percent canopy cover (%cover).

Cost Analysis

The efficiency, reliability and flexibility of RPVs are greater than the airborne or satellite platforms simply because their deployment is as needed and can easily be directed to the location of interest. Satellite sensor failures in contrast are not easily repairable, resulting in information gaps. In comparison, sensors on-board manned aircraft may be tended to during flight, and RPV adjustments are made upon retrieval. Free-flying satellites are costly, ranging from \$50-\$100 million, and with the exception of course resolution images, the cost of data is approximately \$1000 per scene with delivery times ranging from weeks to months. The system cost for the Imaging Science Subsystem (ISS) was in the range of \$30 million but has an advantage over free flying satellites in that the data is available at no cost with “immediate” delivery.

A generalized comparison of the developed platform to three similar ones developed by other universities was performed (Table 2). The comparison included: efficiency, reliability, flexibility, system and data costs, frequency of data collection, risk of inadequate and/or faulty data, operational problems, ease of analyses, and ease of data acquisition.

As shown by Table 2, Virginia Tech (VT), Purdue University (2005), and the University of Kentucky (UK) have performed similar remote sensing experiments in precision agriculture utilizing inexpensive RPV platforms. In comparing the UK and the UA, both universities purchased commercially available airplane kits and video cameras. VT implemented multi-spectral cameras to identify areas of crop stress due to pest infestation while the UA used normalized difference vegetation indices (NDVI) to distinguish different plant densities. VT and Purdue installed electric engines to minimize platform vibration, thereby, providing better quality images. Purdue, in contrast to the other universities partnered with a private company to design the most expensive platform with the estimated of cost of $30,000 (Campbell, 2005).

Table 2: A comparison between RPV designs from the University of Arizona, Virginia Tech, Purdue University, and the University of Kentucky.

RPV Specifications	**University of Arizona**	**Virginia Tech**	**Purdue University**	**University of Kentucky**
Airframe	**Almost-ready-to-fly kit**	**Custom built**	**Custom built**	**Almost-ready-to-fly kit**
Weight (kg)	3.87	Not available	8.1	1.95
Wing span (m)	1.63	0.9	3	Not available
Engine size Cubic centimeter (cc)	7.53	16.4	Not available	45-3 Motor/ 40-3P Opto Controller
Powered	Nitro fuelled	Not available	Electric	Electric
Flight Time (minutes)	30	30	60	7
Platform weight (kg)	3.87	0.57	8.16	3.4
Carrying capacity (kg)	0.34	Not available	1.13	0.45
Max flight speed (km/hr)	72	72	60	40
Flight Control	Piloted	Piloted w/ altitude hold and wing leveler	Piloted	Piloted
Max flying altitude (m)	240	140	305	300
Telemetry radius (km)	3.23	1.4	0.80	0.45
Imagery	Forward and downward facing CCD NTSC video, Red-NIR camera	Forward facing video camera, downward facing RBG and NIR video cameras	Color and infrared cameras	2.0 mega pixel camera
Estimated Platform Cost	$4,000	$12,000	$30,000	$1,000 (airplane only)

The reasonable cost of all three platforms demonstrates the feasibility of integrating RPVs into the real time precision agriculture management in academia and commercial farming applications. The RPV platform developed by The University of Arizona seams reasonable and can be developed at much less cost. Its estimated cost even included the cost of a laptop computer required for the operation of the system; however the other three systems did not include the laptop in their cost.

Conclusion

RPVs systems with commercially available products provide farm managers with a safe, innovative, and cost effective method of obtaining remote sensing information. The cost, accessibility, and the ability to perform multiple missions provide some possible advantages over satellites and airplanes. The RPV platform and ground support equipment could be easily transported in a mid-size car and assembled within 30 minutes upon arrival.

Some of the problems associated with gas powered planes were the vibrations from the engine that sometimes blur the images. Fortunately, some of the deficiencies associated with internal combustion engines can be addressed by operating electric powered models. Electric motors reduce platform vibrations, which may damage delicate sensors, by allowing the pilot to turn off the engine in flight.

Furthermore, commercially available digital cameras with CCD arrays in conjunction with image analysis software may be used with RPVs as affordable means for the scientific community to analyze vegetation color and health. There is a considerable cost advantage of integrating high quality digital camera versus scientific grade radiometers. Using digital cameras with high resolution would result in broader application of the RPVs toward precision agriculture. They can be used for quantifying senescence, flower numbers and to determine the average hue, saturation, and brightness (HBS) to quantify turf color. This is not to say that RPVs will replace the information collected from satellites and manned aircraft, but will compliment traditional remote sensing crop management practices that are becoming more reliant on real-time data processing. This study demonstrates the potential of RPVs as a tool for the real-time management of crop health in precision agriculture research and commercial applications.

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إستخدام الطائرات ذات التحكم عن بعد للأغراض الزراعية

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أجريت العديد من الأبحاث علي إستخدام الأقمار الصناعية و التصوير الجوي لمتابعة حالة النبات. تبين وجود معوقات لإستخدام هذه النظم للأغراض الزراعية مثل التكلفة العالية و الدقة المتمثلة في أصغر وحدة مساحة يمكن قياسها و أصغر مدة زمنية بين كل صورتين متتالين. مما تطلب إستحداث نظم أخري أبسط و أقل التكلفة.

تم إجراء هذا البحث لدراسة إستخدام منظومة مكونة من نموذج مصغرة لطائرة (4 كجم تقريباً) ذات تحكم عن بعد لمراقبة نسبة الغطاء النباتي بحقل زراعي من خلال قياس ما يسمي بمعيار الخضرة ذو لفرق العياري. تم تزويد هذه الطائرة بكاميرامن نوع "داي كام" ذات فلترين عند طول موجي 600 و 1100 نانومتر و الممثلين للمنطقتين الحمراء و القريبة من تحت الحمراء من الطيف الكهرومغناطيسي.

شملت التجربة 12 معاملة من المياه، النيتروجين، و كثافة الزراعة. تمثلت معاملات المياه في إستخدام طريقتين لحساب معامل المحصول: طريقة منظمة الأغذية و الزراعة (FAO) مقارنة بطريقة أخري تعتمد علي الإستشعار عن بعد. أما معاملات النيتروجين فتمثلت في إضافة معدلين نيتروجين: 150 كجم نيتروجين/هكتار (63 كجم نيتروجين/فدان) و 93 كجم نيتروجين/هكتار (39 كجم نيتروجين/فدان). أما معاملات كثافة الزراعة فكانت: خفيفة (90 نبات /متر- زراعة علي سطر واحد)، شائعة (تقليدية) (164 نبات /متر- زراعة علي سطر واحد) و كثيفة (291 نبات /متر- زراعة علي سطرين).

تم تطيير الطائرة للتصوير ثلاث مرات خلال الموسم علي إرتفاع 150 متر تقريباً مع مقارنة النتائج مع مثيلتها من راديوميتر يدوي أيضاً مع القياسات الحقلية للغطاء النباتي. بينت النتائج وجود إرتباط عالي في أول يومين لمعيار الخضرة ذو الفرق العياري المحسوب من الداي كام مع المحسوب من الراديوميتر اليدوي ايضاً مع القياسات الحقلية للغطاء النباتي. بينما كان الإرتباط غير معنوي في اليوم الثالث و ذلك لدخول النبات في مرحلة النضج و ما ينتج عنها من إصفرار للأوراق. و من المعلوم أن معيار الخضرة ذو الفرق العياري يقيس خضرة النبات و بالتالي فإنه لا يمكن إستخدامه كمؤشر للغطاء النباتي بعد إصفرار النباتات و القرب من الحصاد.

مما سبق يتضح إمكانية إستخدام الطائرات ذات التحكم عن بعد في المتابعة اليومية للنمو الخضري و حالة النبات بصورة إقتصادية للمزارع و الباحث.