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Application of low altitude remote sensing (LARS) platform for monitoring crop growth and weed infestation in a soybean plantation

Grianggai Samseemoung · Peeyush Soni · Hemantha P. W. Jayasuriya · Vilas M. Salokhe

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Abstract Crop growth and weed infestation in a soybean field were monitored by processing low altitude remote sensing (LARS) images taken from crane-mounted and unmanned radio controlled helicopter-mounted platforms. Images were taken for comparison between true color (R–G–B) and color-infrared (NIR) digital cameras acquired at different heights above ground. All LARS images were processed to estimate vegetation-indices for distinguishing stages of crop growth and estimating weed density. LARS images from the two platforms (low-dynamic and high-dynamic) were evaluated. It was found that crane-mounted RGB and NIR platforms resulted in better quality images at lower altitudes (<10 m). This makes the crane-mounted platform an attractive option in terms of specific low altitude applications at an inexpensive cost. Helicopter-mounted RGBH and NIRH images were found suitable at altitudes >10 m. Comparison of NDVICH and NDVIH images showed that NDVI values at 28 DAG (days after germination) exhibited a strong relationship with altitudes used to capture images ($R^2$ of 0.75 for NDVICH and 0.79 for NDVIH). However, high altitudes (>10 m) decreased NDVI values for both systems. Higher $R^2$ values ($\geq 0.7$) were also obtained between indices estimated from crane- and helicopter-mounted images with those obtained using an on-ground spectrometer, which showed an adequate suitability of the proposed LARS platform systems for crop growth and weed infestation detection. Further, chlorophyll content was well

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correlated with the indices from these images with high $R^2$ values (>0.75) for 7, 14, 21 and 28 DAG.

**Keywords** Crop growth monitoring · Weed detection · Crane-mounted image acquisition · Helicopter-mounted image acquisition · NDVI

**Introduction**

Many researchers (Meyer 1998; Stafford and Benloch 1997; Tillet et al. 1996; James et al. 1996; Chaisattapagon and Zhang 1995; Tangwongkit et al. 2006; Samseemoung et al. 2011) have employed image processing techniques for crop and weed recognition and evaluation. As the first step of the image processing technique, they tend to separate plants from soil. Segmentation is done using visible color information or reflection intensity in near-infrared wavelengths. Information on variable light conditions should be taken into account to achieve good segmentation and classification (Tian et al. 1999). In the second step, attempts are made to recognize shape, texture and color properties of the plants and to use this information for classification of plants into species or crop/weed categories. For detection of weed patches, a number of remote sensing techniques such as satellites, balloons, aeroplanes, helicopters and low altitude systems have been investigated (Swain and Jayasuriya 2007). Satellite remote sensing has successfully demonstrated its applications for within-field monitoring (Stafford 2000) but is still not free from its limitations, which mainly include higher temporal resolution due to longer satellite re-visit times, cloud cover, total cost, poor spatial resolution and lack of proper techniques and facilities to process imagery for agricultural applications (Steven 1993). Adoption of satellite based remote sensing for precision agriculture (PA) is also influenced by the perceived risk of yield reduction (Kim and Chavas 2003; Koundouri et al. 2006). The perceived risk could include timely availability of good quality images, availability of support technology and uncertainties in terms of crop yield and net return.

Better image quality with greater detail is the basic requirement in PA applications to facilitate robust analysis and reliable results. Some of these systems can probably be organized on a near real-time basis to acquire and distribute images to relevant users. The need for a simple, near real-time image data acquisition system as a substitute to satellite-based remote sensing for application on smaller areas has been strongly advocated. However, more elaboration is required on the available methods of low altitude remote sensing (LARS) and their comparative performance. Therefore, this study was conducted to explore the prospects of low (tractor-mounted) and high (unmanned radio-controlled helicopter-mounted) dynamic data acquisition systems with emphasis on acquisition of aerial photography suitable for PA applications in small farms of developing countries. The percentage of greenness, weeds and the normalized difference vegetation index (NDVI) were obtained at different altitudes and compared for their relative performance.

**Hardware and system configuration in LARS systems**

In the low-dynamic mode of image data acquisition (tractor driven crane-attachment), the tractor speed was maintained constant and low to avoid excessive jerks during image acquisition. In the high-dynamic mode of image data acquisition (helicopter-mounted platform), a commercially available unmanned helicopter was selected. The helicopter weighed approximately 6 kg with a payload capacity of 5 kg and was flown by a skilled
operator with a radio transmitter functioning at a frequency of 42 MHz and with a range of 1–2 km radius. Figure 1 depicts the main components of both LARS platforms used in the study.

Image data acquisition system and other signal receiver sensor

The system platform consisted of a true color (R–G–B) digital camera (Canon Inc., Thailand) and a color-infrared (NIR) digital camera (G–R–NIR) (ADC Tetracam Inc., USA) with wireless trigger control (Jelsoft Enterprises Ltd., USA), an altitude sensor
(Seagull Wireless Dashboard Flight System FCC 900 MHz version; Jelsoft Enterprises Ltd., USA), an illumination sensor (two channels with central bands at 660 and 730 nm; Skye Instruments, UK), a computer central processing unit (CPU), control software (Research Systems, Inc., USA) and a specifically developed data acquisition system. The specifically developed software provided image orientation correction, geo-referencing and NDVI analysis.

The SKR 1800 illumination sensor measured prevailing sunlight intensity. The illumination sensor was attached to a data logger (SpectroSense-2; Skye Instruments, UK). The wireless altitude sensor was used to measure and control the altitude of the LARS platform to acquire images from a constant altitude.

An ASD FieldSpec® spectrometer (ASD Inc., USA), with 350–2 500 nm spectral range and 3 nm spectral resolution in the red band (R) and 10 nm in the near-infrared (NIR) band (Table 1) was used to estimate crop spectral reflectance at ground level by using R (650 nm) and NIR (800 nm) spectral bands. The RS³ application software (ASD Inc., USA) was used for real-time operation during field data acquisition. A leaf chlorophyll meter (Minolta SPAD 502; Konica Minolta Sensing Inc., Japan) (Table 1) was used to measure the average chlorophyll content (expressed as SPAD values) of soybean crop leaves during the experiment for calibration and ground truthing. The units for the Minolta SPAD-502 leaf chlorophyll meter can be described by the equation (Markwell et al. 1995);

\[
Chl \, \mu mol \, m^{-2} = 10^{0.783M}
\]

where \( M \) is the leaf chlorophyll meter reading (digital number) and \( Chl \) is the chlorophyll content in \( \mu mol \, m^{-2} \).

Materials and methods

Experimental set up and field preparation

The experimental site was located at the Asian Institute of Technology (AIT), Thailand (14.03°N, 100.61°E). The soybean crop was transplanted in a 40-m \( \times \) 40-m area with 0.5-m row spacing. Ground-truth points were marked at a spacing of 5 m \( \times \) 5 m. Weeds were allowed to grow between the soybean rows. Images were taken with the true color digital camera (R–G–B) and the NIR digital camera (G–R–NIR) at 7, 14, 21 and 28 days after germination (DAG) in the soybean field. Figure 2 shows images of soybean crop growth.

Soil physical and chemical properties at the experimental site are shown in Table 2. About 25–30 kg of NPK: 20-20-0 fertilizer was applied per rai (1 ha = 6.25 rai).

Monitoring crop growth and weed infestation

Combinations of two camera types (NIR digital photography, true color RGB digital photography) and two levels of platform stability (low and high dynamic) were used to compare their relative performance in terms of percentage of greenness and weed density. Vegetation indices were calculated using ENVI 4.2 software from the images acquired at three heights above ground (5, 10 and 15 m). Results from low and high dynamic image data acquisition systems were compared in terms of image processing quality.
<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
<th>Feature</th>
<th>Value</th>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image size resolution</td>
<td>1280 × 1024 (10.1 Mpixels)</td>
<td>Image size resolution</td>
<td>1280 × 1024 (1.3 Mpixel)</td>
<td>FOV</td>
<td>18° (1.5 m fiber optic)</td>
</tr>
<tr>
<td>Object dimension at M.O.D.</td>
<td>10.6 × 8.0 cm</td>
<td>Pixel size</td>
<td>0.0007 × Altitude</td>
<td>Spectral range</td>
<td>350-2,500 nm</td>
</tr>
<tr>
<td>Spectral bands</td>
<td>R-G-B</td>
<td>Spectral bands</td>
<td>G-R-NIR</td>
<td>Software</td>
<td>RS³ application</td>
</tr>
<tr>
<td>Lens type</td>
<td>C-mounted</td>
<td>Lens type</td>
<td>C-mounted</td>
<td>Spectral resolution</td>
<td>3 nm @ 700 nm 10 nm @ 1,400/2,100 nm</td>
</tr>
<tr>
<td>Lens</td>
<td>18 mm</td>
<td>Lens</td>
<td>8.5 mm</td>
<td>Sampling interval</td>
<td>1.4 nm @ 350-1,050 nm</td>
</tr>
<tr>
<td>Mostly used with</td>
<td>Light aircrafts, general</td>
<td>Mostly used with</td>
<td>Land vehicles, light aircrafts</td>
<td>Weight</td>
<td>12 lbs or 5.2 kg</td>
</tr>
<tr>
<td>Triggering</td>
<td>Manual/Cable switch trigger-ing</td>
<td>Manual/Cable switch trigger-ing</td>
<td>Manual/Cable switch trigger-ing</td>
<td>Accuracy</td>
<td>Within ± 1.0 SPAD unit reading</td>
</tr>
</tbody>
</table>

As claimed by respective manufacturer
Fig. 2 Stages of soybean crop growth in the experimental field: a 7 DAG, b 14 DAG, c 21 DAG, d 28 DAG

<table>
<thead>
<tr>
<th>Soil sampling depth (cm)</th>
<th>pH</th>
<th>Soil composition</th>
<th>Organic matter (%)</th>
<th>Particle density (g/cm³)</th>
<th>Bulk density (g/cm³)</th>
<th>Moisture content (% dry basis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>4.7</td>
<td>15</td>
<td>30</td>
<td>55</td>
<td>1.54</td>
<td>2.42</td>
</tr>
</tbody>
</table>

Image data acquisition and processing

Healthy plants with high chlorophyll content have high reflectance in the NIR band; therefore, they appear red in the composite image. The NIR band (displayed as red) and the visible red band (displayed as green) were compared after plotting them on a scatter plot in MATLAB displaying one point per pixel, with its X-coordinate determined by its value in the red band and Y-coordinate by its value in the NIR band. From the scatter plot it was observed that the ratio of NIR to red could be used to locate pixels containing dense vegetation.

The technique of combining plot-based NIR and RGB digital camera images was used in this research. To detect weed density and crop growth in the soybean field, image processing and analysis software (IPAS) was developed in MATLAB. The IPAS used image processing techniques to process and analyze for weeds and crop position. In the first step, the visible bands taken from true color digital images are loaded into IPAS. This true color image was transformed into a grayscale image before it was converted into a
Fig. 3 Flowchart of IPAS steps

black and white color image (binary format). Then, the perimeter of the dilated binary image was delineated. In the final step, the crop and weeds are differentiated from the soil (color segmentation by using k-means cluster). Only weeds were separated; the program counted the pixels-of-interest between crop rows spaced at 0.5 m in an image. The weed positions and extent were recognized in the field and weed status and application maps were created for further management actions.

The images acquired by the LARS platform were linked to data from a GPS receiver, a digital magnetic compass and an altitude sensor. Images may have large GPS error if a low precision GPS receiver is used. This problem was addressed by combining frames of each image using a mark with the coordinate (Xi, Yi). A program was developed to mask and trim the excess areas beyond the ground margins. Altitude correction for the images was done beforehand.

The true ground coordinates were used for the reference points to combine all images into a matrix. Steps of processing are outlined in Fig. 3.
Fig. 4  a Amount of wood chips observed in a frame of 1 m² area for image processing calibration; b–d A color image at 5, 10 and 15 m, respectively; e–g A color-IR image at 5, 10 and 15 m, respectively

Image calibration

To calibrate the image processing methodology, the percentage of wood chips collected in a 1-m² area at different heights (5, 10 and 15 m) were computed for all combinations of image data acquisition systems (marked in Fig. 4). Results of image quality from low- and high-dynamic modes of image data acquisition systems were compared.

Ground truthing measurements

Ground truthing was done using a spectrometer (18° FOV) and SPAD-502 chlorophyll meter. Measurements were simultaneously taken with the helicopter-mounted and crane-mounted LARSs, at (i) three altitude (i.e. 5, 10 and 15 m), and at (ii) four crop-growth stages (i.e. 7, 14, 21 and 28 DAG).

For spectrometer measurements in the soybean field, a 40-m × 40-m area was selected with 0.5-m row spacing. The operator was positioned between crop rows to measure reflectance. Measurement height was between 1.5 and 2.0 m. As a result, the projection at the level of measurement was circular with a radius of 0.2–0.5 m. The spectral reflectance between the rows was calculated using reflected target radiance divided by the irradiances of a Spectralon (ASD Inc., USA) white panel.

Results

Calibration and performance of image acquisition and processing systems

Results of the processed images acquired from different systems at three altitudes are summarized in Table 3. At low-altitude (5 m), NIR digital photography (G–R-NIR) mounted on the crane-attachment LARS (NIRC) recognized the highest percentage of wood chips (82.9 %) as compared to other image acquisition systems where its values with NIRH, RGBC, and RGBH were 80.3, 69.0 and 65.9 %, respectively. Thus it is evidently shown that NIRC could be regarded as an appropriate system for low-altitude image acquisition. The quality of image acquisition decreased as the altitude was raised from 10
Table 3  Comparative performance of RGBC, RGBH, NIRC, NIRH image acquisition systems

<table>
<thead>
<tr>
<th>Altitude (m)</th>
<th>Labor force (amount of wood chips/m²) (%)</th>
<th>RGBC (%)</th>
<th>NIRC (%)</th>
<th>RGBH (%)</th>
<th>NIRH (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>70 (100)</td>
<td>69.04</td>
<td>82.86</td>
<td>65.89</td>
<td>80.33</td>
</tr>
<tr>
<td>10</td>
<td>70 (100)</td>
<td>71.43</td>
<td>73.80</td>
<td>61.86</td>
<td>70.07</td>
</tr>
<tr>
<td>15</td>
<td>70 (100)</td>
<td>68.57</td>
<td>74.76</td>
<td>51.02</td>
<td>72.97</td>
</tr>
</tbody>
</table>

Average illumination during observations: Red 1,650 μmol m⁻² s⁻¹ and NIR 1,050 μmol m⁻² s⁻¹ at 12:00 h

Table 4  Effect of illumination (recorded with SKR 1800) on NDVI

<table>
<thead>
<tr>
<th>Experiment No.</th>
<th>Illumination (μmol m⁻² s⁻¹)</th>
<th>Reflectance index value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Red</td>
<td>NIR</td>
</tr>
<tr>
<td>1</td>
<td>1,867</td>
<td>1,107</td>
</tr>
<tr>
<td>2</td>
<td>1,859</td>
<td>1,210</td>
</tr>
<tr>
<td>3</td>
<td>1,797</td>
<td>986</td>
</tr>
</tbody>
</table>

to 15 m. The percentage of wood chips detected from NIRC, NIRH, RGBC and RGBH systems were decreased with increasing altitude; it was in range 73.8–74.7, 70.1–72.9, 68.6–71.4 and 51.0–61.9 %, respectively. Therefore, NIRC still remained suitable for LARS for altitudes 5–15 m.

To minimize the error due to fluctuation in sunlight illumination, the reflectance indices (ratio of two spectral band values) were used in place of individual spectral band values (Table 4). The variation of NDVI remained insignificant with change in sunlight illumination. Thus, the images can be taken with the LARS at any time of the day, without significantly compromising the final reflectance index value. Figures 5 and 6 show the segmented image data from RGB and NIR digital photography taken from low-dynamic and high-dynamic LARS platforms.

Discussion

Estimation of percentage of greenness

Four replications of image data taken at different altitudes and type of image data acquisition systems were analyzed using analysis of variance (ANOVA) (Table 5) of image data obtained indicated that the main and interaction effects of low-dynamic image acquisition on tractor driven crane-attachment and high-dynamic image acquisition on helicopter-mounted LARS platform were significantly different (p < 0.05).

Effect of altitude on estimation accuracy

Average values of percent greenness obtained from twelve-replications across three altitudes (5, 10 and 15 m) using four combinations of image data acquisition systems (RGBC, NIRC, RGBH and NIRH) are presented in Fig. 7. Performance of the RGBC image data
acquisition system remained higher than 30% of the greenness invariably across the three altitudes. It could be a suitable system to reference the quality in the visible-region of the spectra. In addition, the RGBC, RGBH and NIRH at low-altitude (15 m) also obtained a high percentage of greenness (>30%); however, there were no significant differences among them. The percentage of greenness obtained with the high-dynamic system (helicopter-mounted; RGBH and NIRH) was better in the near-infrared region when the altitude increased. Thus, the near-infrared application seems suitable with the helicopter-mounted platform at low to medium altitudes.

Effect of LARS platform stability on greenness estimation accuracy

When the low-dynamic and high-dynamic effects of LARS platform stability on the accuracy of image data acquisition systems at different altitudes were estimated, it was found that both image data acquisition systems on the tractor driven crane-attachment were suitable. Color-infrared (NIR) digital photography with the helicopter-mounted LARS...
Table 5 Variation of greenness and weed density with reference to the field test

<table>
<thead>
<tr>
<th>Altitude (m)</th>
<th>Type of image data acquisition systems</th>
<th>Percent variation of greenness (%)</th>
<th>Percent variation of weed density (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>RGB_C</td>
<td>36.24a</td>
<td>26.38a</td>
</tr>
<tr>
<td></td>
<td>NIR_C</td>
<td>51.44c</td>
<td>37.06c</td>
</tr>
<tr>
<td></td>
<td>RGB_H</td>
<td>30.73a</td>
<td>11.65a</td>
</tr>
<tr>
<td></td>
<td>NIR_H</td>
<td>34.68a</td>
<td>20.30a</td>
</tr>
<tr>
<td>10</td>
<td>RGB_C</td>
<td>36.02a</td>
<td>29.64b</td>
</tr>
<tr>
<td></td>
<td>NIR_C</td>
<td>58.81d</td>
<td>37.70f</td>
</tr>
<tr>
<td></td>
<td>RGB_H</td>
<td>32.42c</td>
<td>11.26f</td>
</tr>
<tr>
<td></td>
<td>NIR_H</td>
<td>38.18b</td>
<td>24.91b</td>
</tr>
<tr>
<td>15</td>
<td>RGB_C</td>
<td>42.59b</td>
<td>32.53f</td>
</tr>
<tr>
<td></td>
<td>NIR_C</td>
<td>63.50d</td>
<td>39.11f</td>
</tr>
<tr>
<td></td>
<td>RGB_H</td>
<td>28.27a</td>
<td>10.21f</td>
</tr>
<tr>
<td></td>
<td>NIR_H</td>
<td>31.94a</td>
<td>23.74f</td>
</tr>
</tbody>
</table>

Means for each characteristics followed by same superscript letter are not significantly different at $p < 0.05$ by Duncan’s Multiple Range test. (Average illumination during observations: Red 1,650 μmol m$^{-2}$ s$^{-1}$ and NIR 1,050 μmol m$^{-2}$ s$^{-1}$ at 12:00 h)

Fig. 7 Percent variation of greenness with altitude as compared to low-dynamic (crane-mounted; RGB_C and NIR_C) and high-dynamic (helicopter-mounted; RGB_H and NIR_H) effect.

platform and high-dynamic image data acquisition system could be suitable as altitude increased.

Estimation of percentage of weeds

The percentage of weeds detected is summarized in Fig. 8 for different low altitude aerial photography systems in terms of low-dynamic and high-dynamic image acquisition systems before weed control in crops grown in wide rows. Analysis of variance (ANOVA) of image data obtained indicated that the main and interaction effects of low-dynamic and high-dynamic image acquisition systems were significant different ($p < 0.05$).
Effect of altitude on estimation accuracy

Average values of percent weed recognized from 12-replications across three altitudes (5, 10 and 15 m) using four combinations of image data acquisition systems (RGBC, NIRC, RGBH and NIRH) are presented in Fig. 8. Images taken from low-dynamic (a tractor driven crane-mounted) RGBC and NIRC were not significantly different ($p < 0.05$) for all altitudes; and moreover, their performance was in the range of 25% weed detection. In contrast, the near-infrared system (NIRH) performed significantly better ($p < 0.05$) at all altitudes in the case of the high-dynamic (helicopter-mounted) image acquisition system.

Effect of LARS platform stability on weed estimation accuracy

When the estimation accuracy of the LARS platform stability was evaluated in terms of percentage of weeds, it was found that both the RGB and NIR digital photography on tractor driven crane-attachment could be suitable at all altitudes tested. For the helicopter-mounted image data acquisition system, the NIR digital photography was better than RGB.

Relationship between reflectance vegetation indices, crop growth and altitudes

Data obtained for NDVIC (NDVI based on crane-mounted images) and NDVIH (NDVI based on helicopter-mounted LARS images) (Table 6) were plotted for different altitudes and DAG; generally a negative correlation with altitude is shown in Fig. 9. The NDVI values taken 28 DAG showed a strong correlation with altitude, attaining coefficients of determination ($R^2$) of 0.75 for NDVIC and 0.79 for NDVIH, respectively.

Suitability of reflectance vegetation indices

A spectrometer was used to estimate the crop reflectance at the ground level. The vegetation NDVI index was calculated from ground-level spectrometer reflectance values. Figure 10a shows the correlation between NDVISpectro (spectrometer-based NDVI values) and NDVIC (NDVI based on crane-mounted images) at different DAG. The NDVIC was found to be proportional to that of NDVISpectro with $R^2$ of 0.72, 0.78, 0.81 and 0.90.
Table 6 Variation of reflectance indices with crop growth

<table>
<thead>
<tr>
<th>Days after germination (DAGs)</th>
<th>Reflectance index value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(NDVI$_{Specu}$)</td>
</tr>
<tr>
<td>7 DAGs</td>
<td>0.7883$^{b}$</td>
</tr>
<tr>
<td>14 DAGs</td>
<td>0.8586$^{b}$</td>
</tr>
<tr>
<td>21 DAGs</td>
<td>0.8576$^{b}$</td>
</tr>
<tr>
<td>28 DAGs</td>
<td>0.9236$^{c}$</td>
</tr>
</tbody>
</table>

Means for each characteristic followed by same superscript letter are not significantly different at $p < 0.05$ by Duncan’s Multiple Range test. (Average illumination during observations: Red 1,650 $\mu$mol m$^{-2}$ s$^{-1}$ and NIR 1,050 $\mu$mol m$^{-2}$ s$^{-1}$ at 12.00 h).

Fig. 9 Variation of reflectance indices with altitude: a crane-mounted; b helicopter-mounted
for 7, 14, 21 and 28-day old soybean crop, respectively. Figure 10b shows that the NDVIH (NDVI based on helicopter-mounted LARS images) is proportional to the NDVISpectro with $R^2$ of 0.70, 0.74, 0.79 and 0.77, respectively. Thus, the higher $R^2$ values (≈0.7) for indices estimated from crane-mounted images (NDVIC) and from helicopter-mounted LARS images (NDVIH) with indices obtained from the ground spectrometer reading (NDVISpectro) confirm the suitability of the proposed LARS system for crop growth and weed detection studies.

The SPAD 502 meter readings of soybean leaf greenness were converted into chlorophyll content (μmol m$^{-2}$) for different DAGs. The estimated indices NDVIC and NDVIH obtained from image reflectance values were compared with the variation of the chlorophyll content. From Fig. 11, it is evident that the chlorophyll content can be related using the indices from crane-mounted and helicopter-mounted LARS images with $R^2$ higher than 0.75 for 7, 14, 21 and 28-day old soybean crop, respectively. A similar result (with $R^2$
Fig. 11  Relationship between the reflectance indices and SPAD 502 meter readings: a crane-mounted; b helicopter-mounted

≈0.75) has also been reported by Hunt et al. (2005) for spinach crop grown under greenhouse conditions.

Conclusions

In this research, crop growth and weed density were monitored in a soybean field using LARS platforms. Performance of the LARS image data acquisition system mounted on a tractor driven crane-attachment (image data acquisition with low-dynamic effect) and on an unmanned radio-controlled helicopter (image data acquisition with high-dynamic effect) was compared. The LARS image data acquisition system captured images from heights <20 m while operated from the ground via wireless remote control. The quality of image processing results at different heights with the developed image data acquisition
systems was found acceptable. Percent greenness in terms of crop growth at different heights, with both types of image data acquisition systems was successfully calculated. Eventually, the coefficients of determination (R²) as established between the NDVIC, NDVIH, NDVISpectro and chlorophyll content (μmol m⁻²) were evaluated and found acceptable enough to testify the applicability of tractor driven crane-attached and helicopter-mounted LARS systems. Application of the LARS images and image processing techniques may successfully overcome challenges when considering the setting time required and high cost for acquiring and processing of the crop growth and weeds images for real-time or near-real-time applications most commonly referred under PA applications. Vegetation indices (VIs) and band ratios obtained through these LARS platforms are able to reasonably represent crop and weed parameters for crop monitoring. However, more work is necessary to make low-cost systems that are also less complicated in terms of affordability and acceptability of unskilled farmers of developing countries.

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