SPATIAL WEED DISTRIBUTION DETERMINED BY GROUND COVER MEASUREMENTS

A Thesis submitted to the College of Graduate Studies and Research in Partial Fulfillment of the Requirements for the Degree of Master of Science in the Department of Agricultural and Bioresource Engineering

University of Saskatchewan
Saskatoon

By

Robert Joseph Baron

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ABSTRACT

A portable dual-camera video system was used to evaluate the potential for using total projected green cover as an indirect measure of weed infestations in a wheat crop during early growth stages. The video system would have applications in mapping weed infestations to assist precision farming operations.

The two cameras provided a real-time composite image of reflected light measured in red (640 nm), and near-infrared (860 nm) wavelengths. A simple ratio of reflected light intensity in each wavelength was used to isolate the growing plants from the background. Software was developed to automatically adjust for varying ambient light conditions and calculate the percentage of the image occupied by growing plants. Total green cover was measured at randomly selected sites prior to direct seeding wheat and at four growth stages following wheat emergence. The portion of green cover observed was compared to crop and weed dry matter at each location. Weed infestations at each location were estimated by measuring the total green cover and subtracting the projected green cover due to the crop alone. A minimum weed dry matter of 20 g/m^2 and 30 g/m^2 could be detected by the video system at the 3-leaf and 5-leaf growth stages, respectively. Weed dry matter less than 20 g/m^2 could not be detected reliably due to the variability of the wheat crop. Detection of weeds within the crop beyond the 5-leaf stage using this method was difficult due to crop canopy closure.

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1. INTRODUCTION

Many agricultural weeds grow in patches. Traditional farm practice in western Canada has been to treat entire fields as if the weed distributions were homogeneous. Typically, producers visually survey a field and choose a chemical control strategy dependent on the dominant weed species and an economic threshold. The whole field is sprayed with the same chemical mixture and rate. In modern reduced-tillage systems, herbicides are the dominant method of weed control. The potential exists to reduce input costs and environmental impact by identifying weed patches and applying herbicides to only those areas infested. Recent site-specific technologies, including the use of differentially corrected global positioning systems (DGPS), have enabled farmers to accurately spot-apply herbicides based on a pre-defined prescription map.

Defining the weed-infested areas to be treated by traditional field-scouting methods can be difficult and time consuming. Weed identification must happen early in the growing season so that weed competition can be reduced by appropriate control measures. Manual field scouting on many hectares is impossible to do in a timely fashion. An automated weed-mapping method could be used to collect spatial weed information in a timely manner, and at a fine resolution with perhaps better accuracy than current field-scouting methods. Once weed density is known, the producer could focus a ground investigation to decide the most appropriate herbicide and control action for that area.

The research project presented in this thesis investigated one approach for the real-time detection of weed infestations. The hypothesis was that the weed biomass at a given stage of crop growth can be indirectly determined by examining the portion of the projected ground area that is covered by green-growing plants and subtracting the portion of green expected from crop alone. A geo-referenced video imaging system could then be developed to determine the weed cover and weed biomass at a given location and ultimately be used to generate a weed biomass map. The weed biomass map could be used to develop prescriptions for spot spraying. Crop type, uniformity, stage of growth and row spacings were expected to be major variables affecting weed cover and weed biomass determination using the system developed.

2. REVIEW OF LITERATURE

2.1 Site Specific Weed Management

Many agricultural weeds are known to exist in patches. Patchy weed populations imply that portions of the field are weed-free while other areas have weeds occurring at various densities (Mortensen and Dieleman, 1998). With a large variation in weed occurrence, patch spraying based on the need for weed control may reduce treatment cost and herbicidal loading to the environment (Christensen et al., 1998). Lindquist et al. (1998) evaluated the economic importance of managing spatially heterogeneous weed populations and predicted an economic gain by not applying herbicides to an entire field. Tian et al. (1999) estimated that between 48% and 58% of herbicides could be saved by using their real-time weed detecting sprayer, using weed coverage between 0.5% and 1.5% as a threshold. Blackshaw et al. (1998a) performed tests to determine potential reductions in herbicide use and associated cost savings by utilizing the weed-sensing Detectspray sprayer to control weeds throughout the fallow season and to control weeds after crop harvest on the Canadian prairies. The Detectspray system gave comparable weed control to conventional broadcast spraying on 80% of the application dates and reduced glyphosate/dicamba use over the fallow season by 19% to 60%. Postharvest glyphosate use on quackgrass (*Agropyron repens* (L.) *Beauv.*) with the Detectspray was reduced 50% to 78% compared to broadcast applications, and clopyralid use on Canada thistle (*Cirsium arvense* (L.) Scop.) was reduced 71% to 80%. The Detectspray system was limited to use in fallow or post-harvest applications and cannot detect weeds within a crop canopy.

For some species of weeds, distributions are stable (Combellack and Miller, 1998; Mortensen and Dieleman, 1998; Wilson and Brain, 1991), and reasonably precise weed mapping preceding spraying may provide the necessary information to spot apply herbicides. Sampling may not need to be as extensive in subsequent years if weed distributions remain consistent. By mapping weed locations before spraying, increased safeguard distances around weed patches could help to ensure effective control and reduce seed spread (Combellack and Miller, 1998). Sprayers that detect weeds and actuate spray nozzles in real-time cannot provide the necessary safeguard distances around weed patches. Mapping weeds before application would allow these areas to be delineated.

Yield loss caused by weeds depends on the relative age or growth of crop and weeds (Cousens et al., 1987). Early detection and control of weeds is important to reduce yield loss. A weed detection system that identifies weeds at an early growth stage would be valuable.

2.2 Weed Mapping

Site-specific weed management requires knowledge of weed species density and location in the field. Weed maps have been created, (mainly for research purposes) by counting weed numbers within quadrats located at the intersection points on a uniform grid (Rew and Cousens, 2001a). Considerable areas of the field remained unsampled with discrete grid sampling. For example, if a 1-m^2 quadrat was placed on a 20-m by 20-m grid, only 0.25% of the field would actually be recorded (Rew and Cousens, 1998). There has been little consistency or validation of the choice of quadrat, grid sample size or interpolation technique used in most studies (Rew and Cousens, 2001b). Grid-sampling of production fields on a sufficiently small scale to obtain spatially dependant data may have limited usefulness because of time, cost and labour constraints (Clay et al., 1999). Christensen et al. (1998) suggested that 10 to 25 points per hectare were required to compile a useable weed map for patch spraying weeds in cereal crops. Interpolation methods such as kriging can be used to estimate weed density between sampled points and generate a weed map. The accuracy of weed maps generated from kriging sparse weed counts is questioned (Rew and Cousens, 2001a). Perimeter mapping of distinct weed patches is possible but suffers from similar inaccuracies (Rew and Cousens, 1998). Increasing the accuracy of the weed maps could be achieved by increasing sampling using an automated weed detection system.

The grid size of a map can affect the potential saving realized by patch spraying. When a large grid size is used (10-m by 10-m) and the presence of weeds is assessed for each cell, only a very small portion of the field will be classified as weed free. If every square millimetre could be evaluated for the presence of weeds, then much more of the field could be classified as weed-free. Using this principle, Wallinga et al. (1998) found that for an 18-m x 42.4-m test area, an idealized patch sprayer that detects and sprays all weeds with a spatial resolution (boom width) of 1.0-m would spray 41% of the amount of herbicide required for a whole-field application. Spraying with a finer spatial resolution of 0.5-m would give a further 26% reduction in herbicide use. This would conclude that a finer resolution would be necessary to achieve the greatest herbicide savings. A ground-based weed identification system, capable of mapping weed presence at a fine grid resolution could be used with a computerized sprayer of similar resolution to reduce herbicide use.

2.3 Imaging Methods For Plant Discrimination

Remote sensing offers a non-invasive and rapid method of generating weed maps required for computerized sprayers. Resolution is the main problem with remotely sensed weed data from satellites, as large patches must be present to be reliably detected (Felton and Nash, 1998). Satellite remote sensing applies to a few weed species at growth stages often too advanced for effective weed control. Better discrimination is achieved from aircraft. Lamb and Weedon (1998) used a four camera airborne digital imaging system to map weed patches in a fallow field with a 1-m^2 pixel size. An 87% classification was achieved when compared to ground truth data. Tian (2002) and Bajwa and Tian (2001) found that the correlation between aerial images and ground truth weed data was a function of the spatial resolution of the aerial system. Tian

(2002) used resolutions between 0.76 m/pixel and 4.5 m/pixel, with the 4.5 m/pixel resolution giving a better correlation due to increased averaging of the geographic error.

Ground-based weed detection systems have used either discrete sensors (Felton et al., 1991; Haggar et al., 1983; Christensen et. al., 1994) or video camera imaging (Robbins, 1998; Perez et al., 2000; Tian et al., 1999). Variations in spectral reflectance are used to distinguish growing plants from background soil and crop residue. In blue wavelengths, both soil and green vegetation reflect similar amounts of light but the reflectance of green vegetation rises sharply at wavelengths greater than 750 nm in the near-infrared (NIR) band (Haggar et al., 1984). Plants strongly absorb visible light in the red band and reflect in the near-infrared band. Haggar et al. (1983) could detect green vegetation independent of incident light intensities by using a ratio of red (650 nm) to near-infrared (750 nm) reflectance. Since then, several researchers have developed sensors to detect green material from the background using simple reflectance ratios and various normalized difference vegetation indices (Mayhew et al., 1984; Felton et al., 1991; Christensen et. al., 1994; Lamb and Weedon, 1998; Wang et al., 1999; Perez et al., 2000). Although Perez et al. (2000), Søgaard and Olsen (1999), Steward and Tian (1999), Adamsen et al. (1999) and others have tried to use standard red-green-blue (RGB) imaging, the best classifications occur when the near-infrared measurements are compared to either the red or green spectrums. Lamb and Weedon (1998) used a four-camera imaging system to map weeds in a fallow field and found that the best classification resulted from a simple normalized ratio of only red and NIR reflectance measurements.

2.3.1 Ratios and Normalized Difference Vegetation Indices

As described above, many ratios and vegetative indices have been used with imaging systems to discriminate growing plants from a background of soil, plant residue and rocks and to estimate crop growth characteristics. Vegetation indices have also been used successfully to reduce or eliminate the effects of variable illumination (Tian, 2002; Bajwa and Tian, 2002; Woebbecke et al., 1995).

Two of the most commonly used indices are the simple ratio or ratio vegetation index (RVI),

$$RVI = \frac{NIR}{RED} \quad , \qquad (2.1)$$

and the normalized difference vegetation index (NDVI),

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)}, \qquad (2.2)$$

where: *NIR* = reflectance within the infrared band (750 – 1350 nm) and

RED = reflectance within the visible red band (600 – 700 nm).

Vegetative indices such as the ratio vegetative index (RVI) showed a strong linear relationship with weed cover (Christensen et al., 1994). Wanjura and Hatfield (1987) found that the RVI was more sensitive to high levels of plant biomass and leaf area index (LAI) than the NDVI, but when the crops were small, the NDVI was a better estimator of LAI and ground cover.

Perry and Lautenschlarger (1984) reviewed many of the vegetation indices used and demonstrated their mathematical equivalence and that a decision made with one vegetative index could have been equally made with another.

2.3.2 Characteristics of Natural and Artificial Light

The discrimination of plant and other material by reflectance measurements can be affected by changes in the incident light, even when vegetation indices are used to reduce the effect. Blackshaw et al. (1998b) evaluated the commercial Detectspray system and found that weed detection was affected by changes in solar irradiance during the day. Factors affecting detection may include latitude, time of year, time of day and degree of cloudiness. Blackshaw et al. (1998b) also indicated that shadows cast by the spray boom or by tall crop have been reported to reduce weed detection accuracy. Haggar et al. (1983) indicated that radiance values by green grass did not differ with levels of cloud cover but were affected by time of day. Mayhew et al. (1984) found that solar angle, and thus time of day, can greatly affect reflectance measurements. Some researchers (Robbins, 1998; Wang et al., 1999) have used fluorescent or halogen-tungsten illumination units to provide consistent illumination when trying to discriminate weed species using reflectance. The fluorescent lights can give problems with image flickering (Robbins, 1998). The commercial Patchen system uses a light source from monochromatic light-emitting diodes (LEDs) that is modulated so that the artificial light can be separated from the natural light allowing the sensor to operate in a variety of conditions (Felton and Nash, 1998). Natural light can be used if a translucent diffuser is used on sunny days to reduce highlights and shadows (Perez et al., 2000), and if sensing is not attempted too soon after sunrise or before sunset (Blackshaw et al., 1998b).

2.3.3 Leaf Area and Biomass

Early tests by Haggar et al. (1984) and Mayhew et al. (1984) showed that the ratio of NIR (740-1000 nm) to red (630- 690 nm) radiation reflected from a grass canopy was closely related to biomass. Christensen et al. (1994) indicated a good correlation between a calculated relative reflectance index and leaf area in a spring barley crop. Wanjura and Hatfield (1987) also found strong relationships between several vegetative indices and crop biomass in four row crops. Weed biomass and leaf area can be indicators of weed competitiveness (Cousens et al., 1987). Haggar et al. (1984) found that leaf area index (LAI) followed a sigmoidal relationship when measured with a reflectance meter. At large LAI values, the reflectance meter could not detect the addition of more green material. At low LAI values, small plants could not be detected.

A charge-coupled device (CCD) grid sensor, as used in a video camera, may provide the necessary resolution to make accurate leaf area, biomass or weed density measurements. Paice et al. (1999) used a video system to capture images at 0.5 mm per pixel and indicated that image analysis may give a more accurate measurement of crop density than single sensor R/NIR radiometry. In addition to weed identification, reflectance measurements of weed leaf area may be used as a basis to apply other crop-protection products (Paice et al., 1999). Canopy growth analysis using reflectance detectors could provide an inexpensive method to monitor crop growth to provide both temporal and spatial data (Felton and Nash, 1998). Felton and Nash (1998) suggested that estimates of crop growth across a field during the season might be just as valuable as yield maps.

Distinguishing weeds within a crop canopy by reflectance alone can be a challenge. Christensen et al. (1994) discussed the feasibility of using infrared and red reflectance measurements to map the spatial distribution of weed vegetation at early growth stages. Preliminary studies showed that comparative measurements of a crop-weed mixture and a crop-free plot (measured in tramlines) could be used to estimate the relative weed cover. Using a discrete sensor with a circular field of view of 150-cm^2 in a spring barley crop, Christensen et al. (1994) observed a low correlation between the reflectance index used and weed density (r^2=0.25). The weed cover in this study was less than 2% of the total area, and weed variations were lost in the natural variations of the crop cover and soil background. Haggar et al. (1984), Mayhew et al. (1984) and Christensen et al. (1994) all used discrete sensors with a large field of view. Christensen et al. (1994) found that detection of small weed seedlings at their early growth stages required using a discrete sensor with a small target spot area approaching the size of a single weed seedling.

Photodetectors or cameras can be used to detect the weed as a “plant out of place” by observing only between crop rows. At the early stages of crop establishment, weeds are visible between the rows of many crops and may be detected. Tian (2002) hypothesized that weed patches are normally distributed across the inter-row and crop row area and that the weed density would be similar within a small area. He believed that the weed density within an inter-row area could be used to estimate the weed infestations in the crop row between plants. Perez et al. (2000) used a colour RGB camera to detect broadleaf weeds in between the rows of a cereal crop. The row positions were determined to reduce the number of objects to which the shape analysis was applied. Perez et al. (2000) found that although the number of weed seedlings was difficult to determine, image-processing techniques could be used to estimate the leaf area of the weeds versus the total leaf area of weeds and crop. Detection of crop rows by image analysis is not an easy task (Perez et al., 2000; Søgarrd and Olsen, 1999). Steward and Tian (1999) used a 3-CCD colour camera to observe weeds between the rows of a soybean crop under natural lighting conditions. An adaptive scanning algorithm (ASA) was developed to detect crop row edge positions. The ASA-determined weed densities were highly correlated with manual weed counts.

2.3.4 Summary of Literature

The review of the preceding literature suggested that:

- patch spraying of weeds is possible and may result in considerable reductions in herbicide use,
- an automated method of determining weed distributions is desired,
- the pixel resolution of an optical detector should be sufficient to distinguish individual weed plants at an early growth stage,
- ground-based video systems are capable of resolutions approaching single plants,
- many samples of weed density must be acquired in a field to generate a useful weed map,
- to realize the maximum reduction in herbicide use, weed mapping and subsequent spraying must occur at a fine spatial resolution,

- green growing plant material can be distinguished from crop residue and soil by comparing reflectance in the red (640-660 nm) and near-infrared (790-850 nm) spectra,
- ratio or normalized difference indices can be used with a fixed threshold to classify plant and non-plant areas with equal results,
- natural light should be adequate for simple green plant/other discrimination as long as an appropriate vegetation index is used and measurements are not taken too close to sunrise or sunset,
- the proportion of green cover can be related to plant biomass and leaf area, both indicators of weed competitiveness,
- challenges exist in establishing weed biomass within a variable crop and
- weeds detected between the rows can be an estimate of the weed population at that location.

The next chapters describe one ground-based imaging system that was developed using some of the principles described above and one method in which an imaging system could be used to map weed infestations to aid precision farming operations.

3. RESEARCH OBJECTIVES

The presence of weeds in a cereal crop field is often visible to the observer as with the Canada thistle in Figure 3.1A. Figure 3.1B, the binarized image showing only photosynthetically active plant material, shows that the weed patch is clearly visible and fills in the inter-row space between the seed rows.

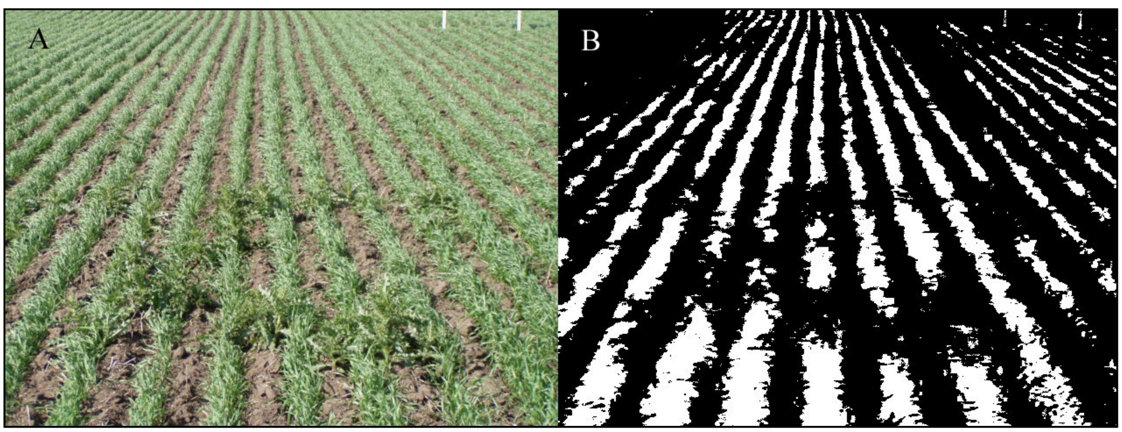

Figure 3-1 The image on the right (B) is a binarized version of the image on the left (A), and illustrates the potential to predict weed density within a crop using projected green area.

The objective of the research was to develop and test an imaging system to determine if in-crop weed densities can be indirectly estimated by the portion of green cover within a camera's field of view.

Specific objectives were to:

1. develop a portable video imaging system that can reliably determine the portion of the image occupied by green growing plants, by distinguishing between growing plants and a background of soil or crop residue,
2. determine the relationship between green cover, as determined by the above imaging system, and total plant dry matter for one cereal crop, at four growth stages,
3. compare green cover measurements with and without natural weeds, at four growth stages in a cereal crop at one fixed row spacing and
4. establish a procedure to evaluate the imaging system's ability to predict weed intensity within a cereal crop at four growth stages.

The field experiment attempted to answer the following qualitative research questions.

1. At what level (% weed cover and weed dry matter (g/m^2)) can weeds be distinguished within a cereal crop, using an image analysis procedure that analyzed only the projected green area in an image?
2. Does the ability of such a system to detect weeds change as the crop advances in growth stage?
3. What is the potential of using green cover measurements to predict spatial weed intensities?

The next sections describe the development and evaluation of an imaging system and field experiments used to meet the above objectives.

4. DESIGN AND DEVELOPMENT OF THE IMAGING SYSTEM

4.1 System Overview

A portable dual-camera video system was developed to measure the portion of the field of view occupied by green growing plants. The two cameras had overlapping fields of view that, when combined, provided a composite image with information in the red (640 nm) and near-infrared (860 nm) wavelengths. A computer was used to simultaneously capture the images, isolate the growing plants from the background by comparing the reflectance in the red and near-infrared wavelengths and store the data. A simple RVI ratio of NIR/RED was used to classify each pixel in the image as plant or non-plant. Software was written to capture and align the images, control the exposure settings and calculate the portion of the field of view occupied by growing plants. A global positioning system receiver with sub-meter accuracy was interfaced with the acquisition computer to also record the geographic location of each sample point.

4.2 Camera Description

Two nearly identical, commercially available, industrial black and white (B/W) video cameras were used to acquire the images. The RED camera (XC-ES50, Sony Corporation Tokyo, Japan) was chosen to gather images in red wavelengths while the NIR camera (XC-EI50 Sony Corporation, Tokyo, Japan) was chosen to gather images in NIR wavelengths. Both cameras utilized a ½-inch charge-coupled device (CCD) with an effective grid of 768 pixels horizontal and 495 pixels vertical. The NIR camera was identical to the RED camera but had increased sensitivity in the NIR wavelengths. The published response for each camera detector was plotted in Figure 4.1.

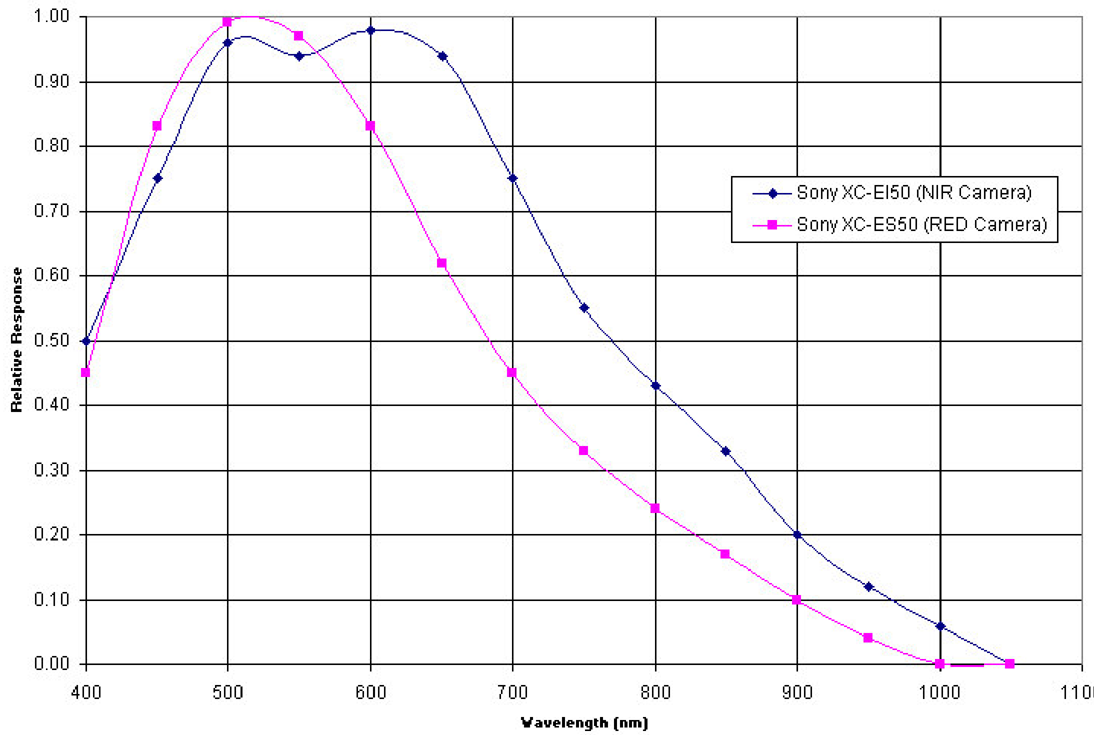

Figure 4-1 Spectral response characteristics of Sony XC-EI50 (NIR) and XC-ES50 (RED) video cameras (Sony Corp.)

Both cameras were equipped with an electronic shutter that could be varied from 1/100 to 1/10,000 of a second by setting dual inline package (DIP) switches on the rear of the camera. The DIP switches were used during the experiment to adjust the shutter of both cameras to account for large changes in natural light intensity that might saturate the camera's sensor.

Each camera was fitted with identical C-mount Cosmicar 6-mm lenses (Pentax Precision Co. Ltd., Golden, Co.). The lenses were equipped with manual focus and aperture rings. The wide-angle view of the 6-mm lens allowed the cameras to be placed less than one meter from the target. The 6-mm lens provided a 56° horizontal field of view and a 44° vertical field of view that resulted in a pixel that was 1.5 mm square (2.25 mm^2) at the 0.80-m nominal target distance. Some optical distortion near the edges of the field of view was observed as a result of the wide angle of view.

4.3 Filter Selection

Each camera lens was fitted with a filter to isolate a particular wavelength band. The RED camera was fitted with a narrow bandpass interference filter to capture red reflectance centred about 640 nm with a full width at half maximum bandwidth (FWHM) of 11.4 nm. The NIR camera was fitted with a long-pass filter with a cut-off wavelength of 830 nm. The infrared long-pass filter, combined with the decreased sensitivity of the CCD sensor above 900 nm, created an effective broad bandpass response centred about 860 nm for the NIR camera. The predicted camera response was determined by calculating the product of the camera's response specifications and the filter's transmittance specifications and was plotted in Figure 4.2.

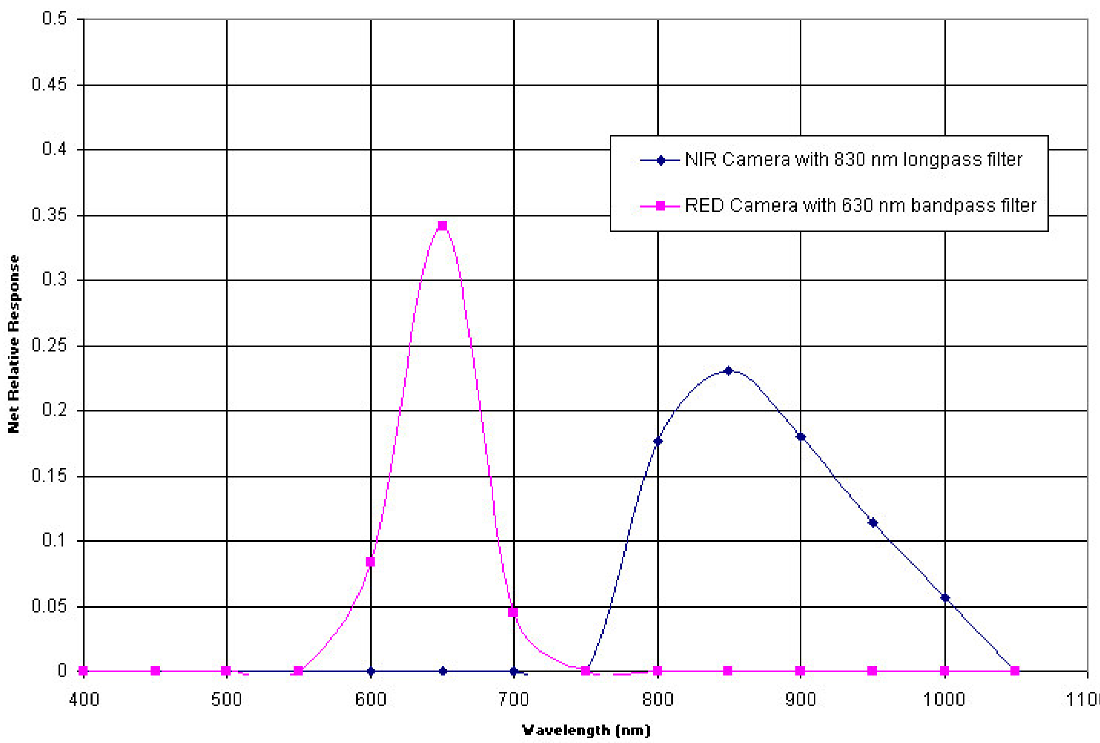

Figure 4-2 Net relative response of NIR and RED video cameras with selected filters

4.4 Video Capture Hardware

A multi-channel frame-grabber card (Meteor II/Multi-Channel, Matrox Electronic Systems Inc., Dorval, Quebec) was installed in a portable computer and used to capture the images from the video cameras. Two of the six monochrome video channels of the frame-grabber card were used to capture images from the cameras. The video signal of the RED camera was directed to the red band of the frame grabber. The video signal of the NIR camera was directed to the green band of the frame grabber and the blue band was left unconnected. In this way, the frame grabber treated the two black and white cameras as if they were one colour camera. To ensure simultaneous capture, both cameras were set to external synchronization and received horizontal and vertical digital synchronization signals from the image-capture card. The capture card operated as a master clock and supplied horizontal and vertical video TTL synchronization signals (HD/VD) to both cameras (Figure 4.3). The card was configured to provide a monochrome image of 640 by 480 pixels at 8-bit resolution from the analog video signals.

To access the functions of the frame grabber card, an image processing software library (Matrox Imaging Library 7.0 'MIL' and ActiveMIL 7.0, Matrox Electronic Systems, Dorval, Quebec) was used. ActiveMIL was a set of ActiveX (Microsoft Corporation, Redmond, Washington) controls that were based on the MIL to provide low-level video capture and processing subroutines that were called from within a Visual Basic (Microsoft Corporation, Redmond, Washington) main program.

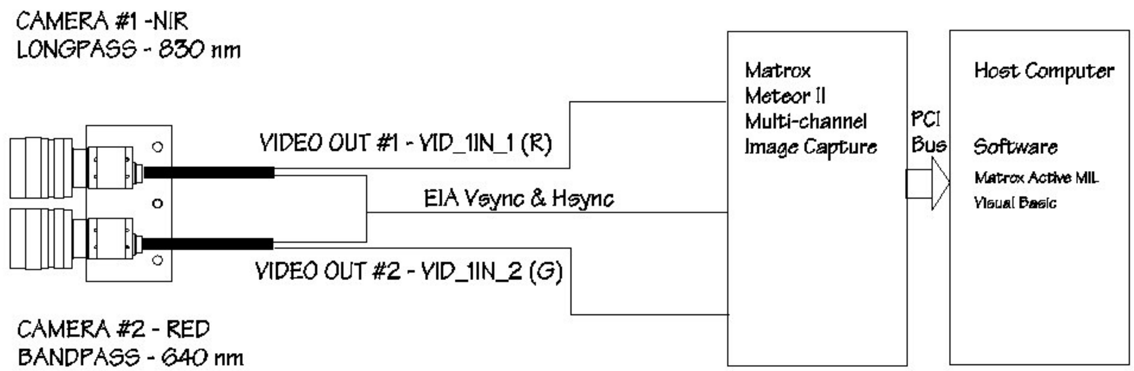

Figure 4-3 Camera and frame grabber card connections

4.5 Interfacing The Global Position Receiver

During data acquisition, the geographic location of each image site in the field was recorded. To accomplish this, a differentially corrected global positioning receiver (DGPS) (Trimble AgGPS 132, Trimble Navigation Ltd., Sunnyvale, CA) was interfaced to the image capture computer. The DGPS receiver was connected to a standard serial port on the computer. The DGPS receiver was set to send serial data out every second following the National Marine Electronics Association NMEA-0183 standard. Software was written to identify the NMEA-0183 RMC sentence, (Recommended Minimum Specific) and parse the string to extract the GPS status, longitude and latitude information. The DGPS location of each sampling point was saved in the program's data file along with the RED and NIR images, image parameters, camera settings, field notes and percent green observed in the image.

4.6 Camera Support And Mounts

The cameras were mounted parallel to each other 50-mm apart and aligned vertically on a common mount 800 mm above the ground (Figure 4.4). A rigid steel frame was used to ensure consistent camera-to-camera and camera-to-target distances. The base of the camera stand provided a square frame that was visible in the images and used to isolate the exact area of study (0.50 m by 0.50 m quadrat).

Figure 4-4 Dual camera mount maintained parallel line of sight.

Two crop rows at a spacing of 254 mm were visible within the field of view provided by the constant 800 mm target distance. Elastic cords were used to define the area of study in the field of view of the cameras (Figure 4.5). The precise alignment and isolation of the overlapping images was done by the image analysis software using the white elastic cords as a reference.

Figure 4-5 Typical area of study defined by elastic cords showing crop row and weeds.

A vehicle was used to shelter the computer terminal, support the camera frame and provide power to the computer through a DC to AC inverter. The test apparatus was mounted on a parallel linkage hitch system that hung cantilevered from the hitch of the vehicle (Figure 4.6). In the lowered position, the quadrat frame was at a constant height above the ground (50 mm). In the upper position the hitch allowed rapid and safe transport of the camera frame between sample points. All data were taken with the vehicle facing north to reduce shadows caused by the frame and the vehicle.

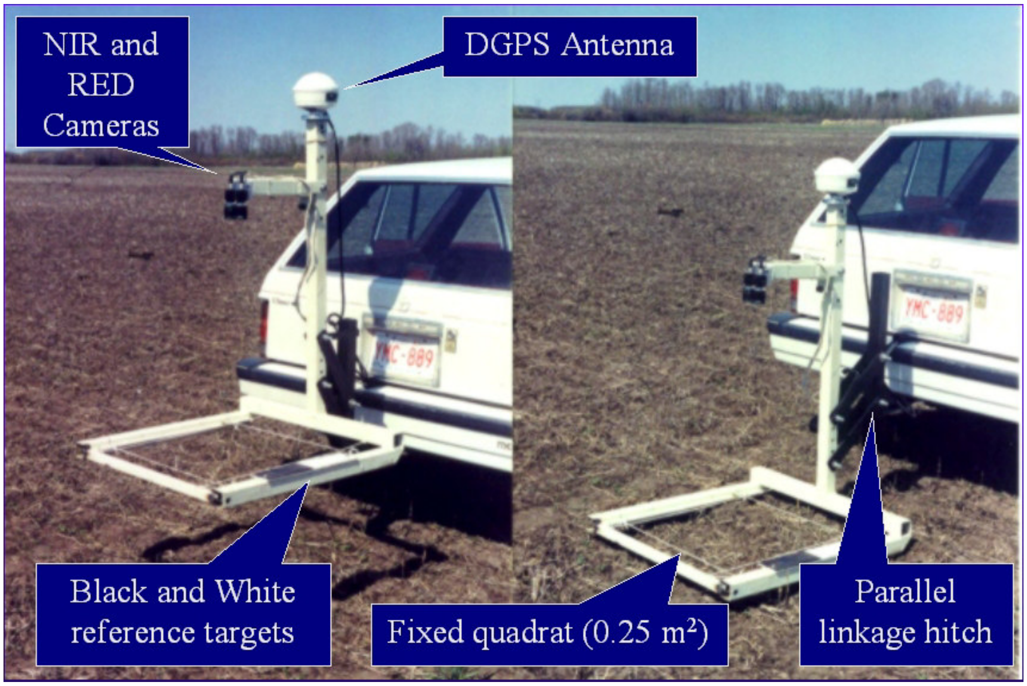

Figure 4-6 The dual camera imaging system and global positioning receiver used to acquire images within a consistent field of view defined by the rectangular frame

4.7 Exposure And Contrast Control

Natural sunlight was used to illuminate the plants in the field; therefore, a consistent method of controlling the camera exposures was required. Because a simple ratio of NIR/RED reflected light was used to detect plants, the relative exposure settings of the two cameras were most important to ensure consistency of the measurement. A reference card of consistent reflectance, simultaneously visible to both cameras, was used to automatically adjust the exposure parameters of the video capture card. The reference card had white and black regions.

The average pixel intensity of a sub image 20 by 60 pixels centred on each card region was calculated for both the white and black references and displayed on the main screen of the system software. The gain and the black and white reference voltages of the video capture card were automatically adjusted by the software to maintain the measured reflected light from the reference cards within constant limits. In this way, the system automatically responded to changes in light intensity and colour of the incident light from the sun. Because changes in digitization settings on the capture card affected both cameras, only the reference cards visible with the NIR camera were used to make adjustments to the digitizer. During daily set up, the reflected light measured on the black card of the RED camera was manually adjusted using the manual iris ring on the lens to read 5 units above the set reference level of the black card on the near-infrared image. This black level offset was required to allow the black reference level of the RED camera to be a set amount higher than the black level of the NIR camera thereby increasing the contrast of the RED image. The average pixel intensity limits were consistent during the entire experiment and are listed in Table 4.1. The software would not allow collection of image data if the reference exposures were outside the set tolerances.

Table 4.1 Digitizer levels of the black and white reference cards used by the software during automatic adjustment of exposure.

Reference card	Set level (Range 0-255)	Tolerance
Black (RED image)	30	+/- 3
White (RED image)	Not controlled	--
Black (NIR image)	25	+/- 3
White (NIR image)	245	+/- 3

4.8 Software

4.8.1 Overview

The program used to capture and process images (WeedArea6.exe) was written in Visual Basic 6.0 (Microsoft, Redmond, WA). The program simultaneously captured images from the two video cameras using the image-capture card. The captured images were manipulated to determine the percentage of area covered by growing plants in a defined area of interest. Figure 4.7 shows the main screen of the program that displayed the images and allowed the user to make measurements and adjustments.

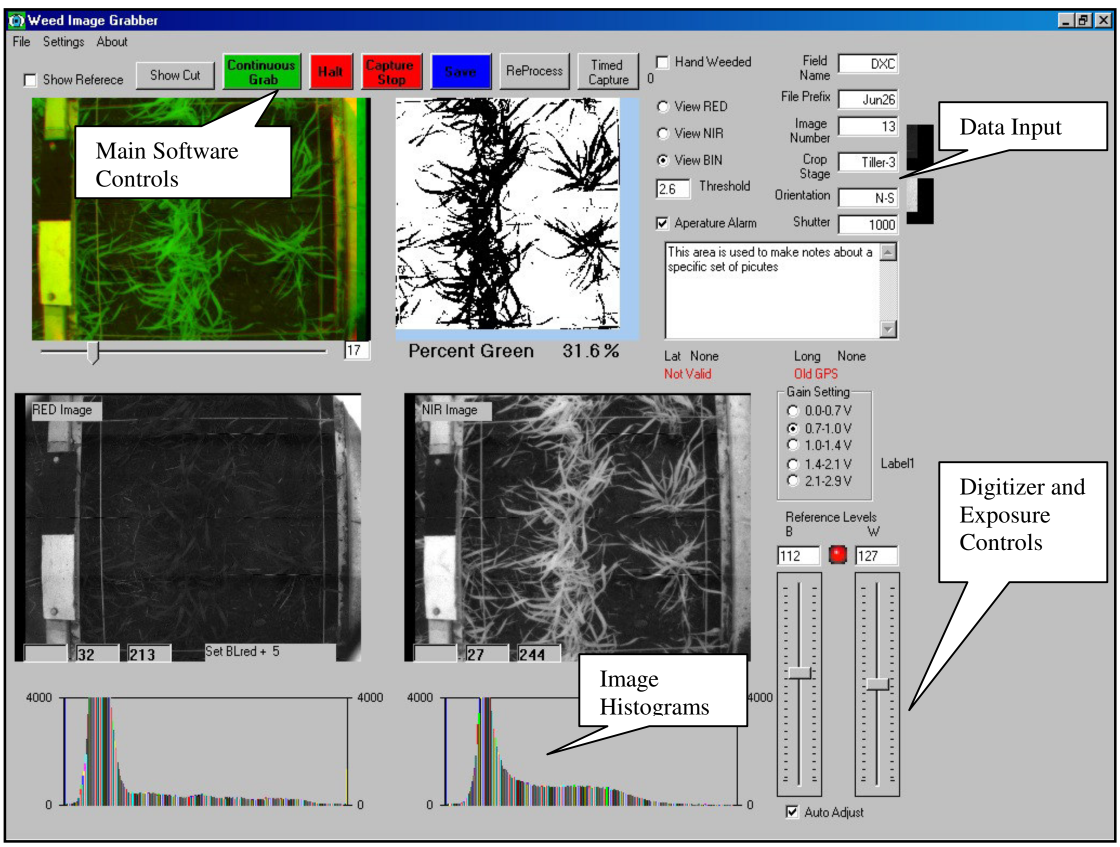

Figure 4-7 Main screen of the image acquisition program

The software provided the following functions.

- The software simultaneously grabbed an image from each camera and placed the image on a specific layer of a composite RGB image. The RED camera's image was copied to the red layer and the NIR camera's image was copied to the green layer. The blue layer remained black.

- The image was split into the RED and NIR components for processing and display.

- The image layers were combined using an adjustable horizontal and vertical offset to account for the physical separation of the two cameras. The user moved a software slider control to adjust the alignment so that the two images appeared as one. The combined image was displayed on the main screen.

- White and black reference cards were located within the field of view. The software determined the average intensity of the white and black reference regions by sampling a rectangle 20 by 60 pixels within each region on the card. The average intensity of each card was displayed and used to adjust digitizer settings.

- The program could be set to automatically adjust the video digitizer's black and white reference levels depending on the values measured from the reference cards. If the light intensity varied outside the range of the digitizer, the program allowed the user to choose a different gain setting.

- An area of interest matching the physical area delineated by elastic cords on the camera frame was isolated from the captured image. The area of interest was copied from the aligned image into a temporary image buffer. The NIR pixel values were divided by the corresponding pixel values on the RED layer. A binarization function was applied at a user-defined threshold to classify each pixel. An image was created that contained binary information, with growing plants displayed as black pixels and background material displayed as white pixels. A histogram function was applied to count the black and white pixels within the area of interest. The proportion of black pixels was determined and displayed on the main screen.

- The original RED and NIR images and the binary image were saved to a user-selected directory so that data could be reprocessed at a later date if necessary.

- The program scanned the serial port of the computer for GPS information and parsed the NMEA-0183 data stream into longitude, latitude and GPS status.

- The program allowed the user to save additional data related to the captured images. The information associated with an image was appended to a sequential text file each time a new image was stored. The documentation file included the image file names, date, time, field name, plant growth stage, image orientation, X and Y offsets, threshold, proportion green, size and location of the area of interest, camera shutter speed, digitizer gain setting, RED and NIR reference card readings, white and black digitizer reference settings, GPS status, longitude, latitude and user notes.

- The program included a function to reload stored images and reprocess with different thresholds and offset values.

- A save-settings function was provided to save default settings, so that once adjustments were made, the same settings were used each time the program was loaded. The variables saved were file prefix, field name, horizontal and vertical offsets, threshold levels, black and white reference levels, and location and size of the area of interest.

4.8.2 Program Flow

The programming language (Visual Basic 6.0, Microsoft, Redmond, WA) was an event based software development language used to write the image acquisition and processing software. Once started, the image processing program waited for a user prompt then initiated the appropriate subroutine. A prompt could be a start of the program, change of a control or press of a button. The program flow following each event in the image and data acquisition program WeedArea6.exe is described by the figures in this section. The actual program listing is contained in Appendix A with the variable definitions listed in Appendix B. Figure 4.8 shows the general flow and relationship between major program modules or subroutines. Timer1 was set to repeatedly capture images at a rate of one image per second.

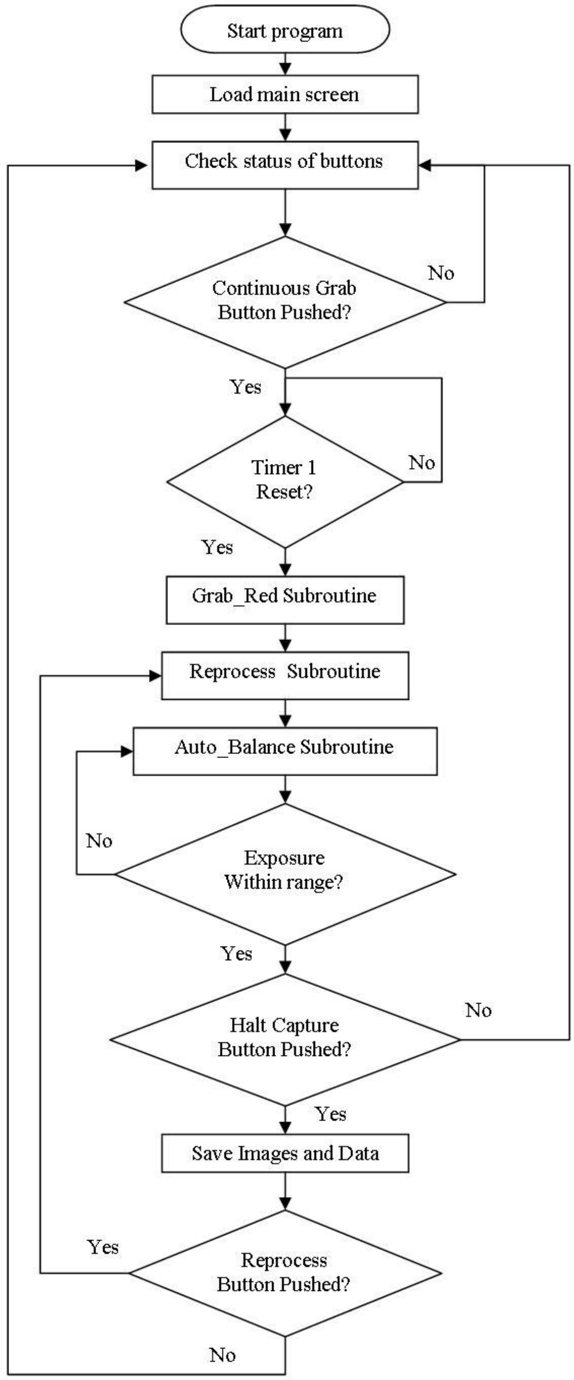

Figure 4-8 Flow chart describing start of program and relationships between program modules

When the program was first started, the program initialization module (Figure 4.9) was opened and commands were executed to initialize program variables and load the previously saved default values. The main program screen (Figure 4.7) would appear and wait for operator input.

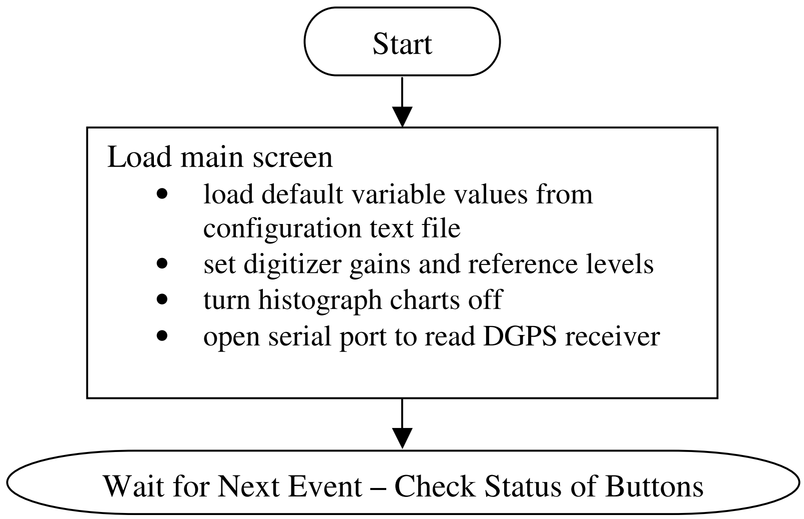

Figure 4-9 Program initialization module (Form1)

To start capturing images the user would press the "Continuous grab" button (Figure 4.7), starting the GrabRED subroutine (Figure 4.10). The GrabRED and Reprocess subroutines contained the main functions of the program, capturing and processing the images to return the portion of the area of interest occupied by pixels above the preset threshold of NIR/RED intensity. The Reprocess subroutine would make a call to the Auto_Balance subroutine to verify the exposure levels on the white and black reference cards (Figure 4.11). Once started, the program continued capturing images at a rate of one per second until the user pushed the "Capture_Halt" button. At this time, the program continued to cycle through the GrabRED, Reprocess and Auto_Balance subroutines until the Auto_Balance subroutine declared that an image with the correct exposure settings had been acquired. At this point, the user could save all the raw images and associated data.

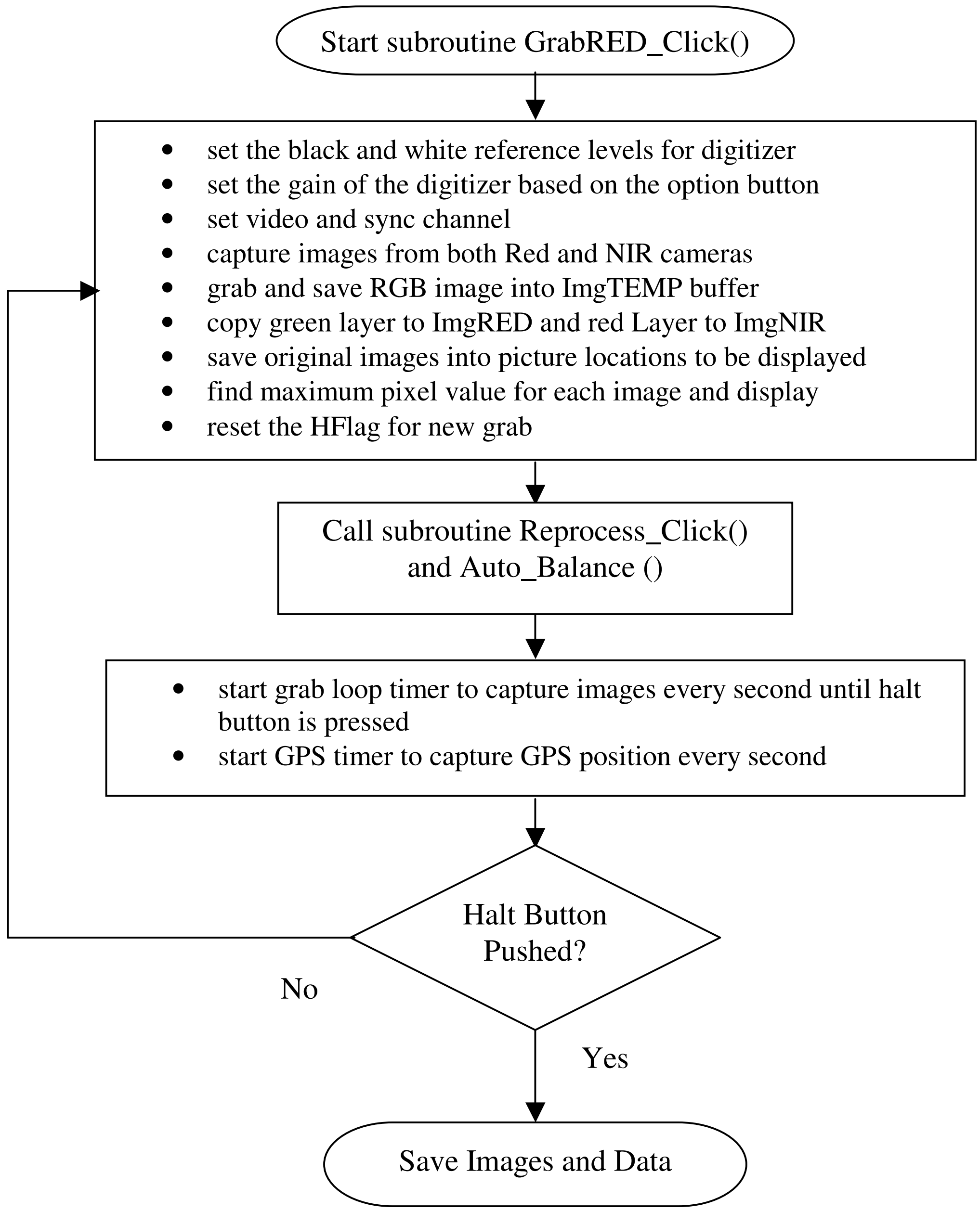

Figure 4-10 Program flow initiated when the continuous grab button was pressed on the main screen.

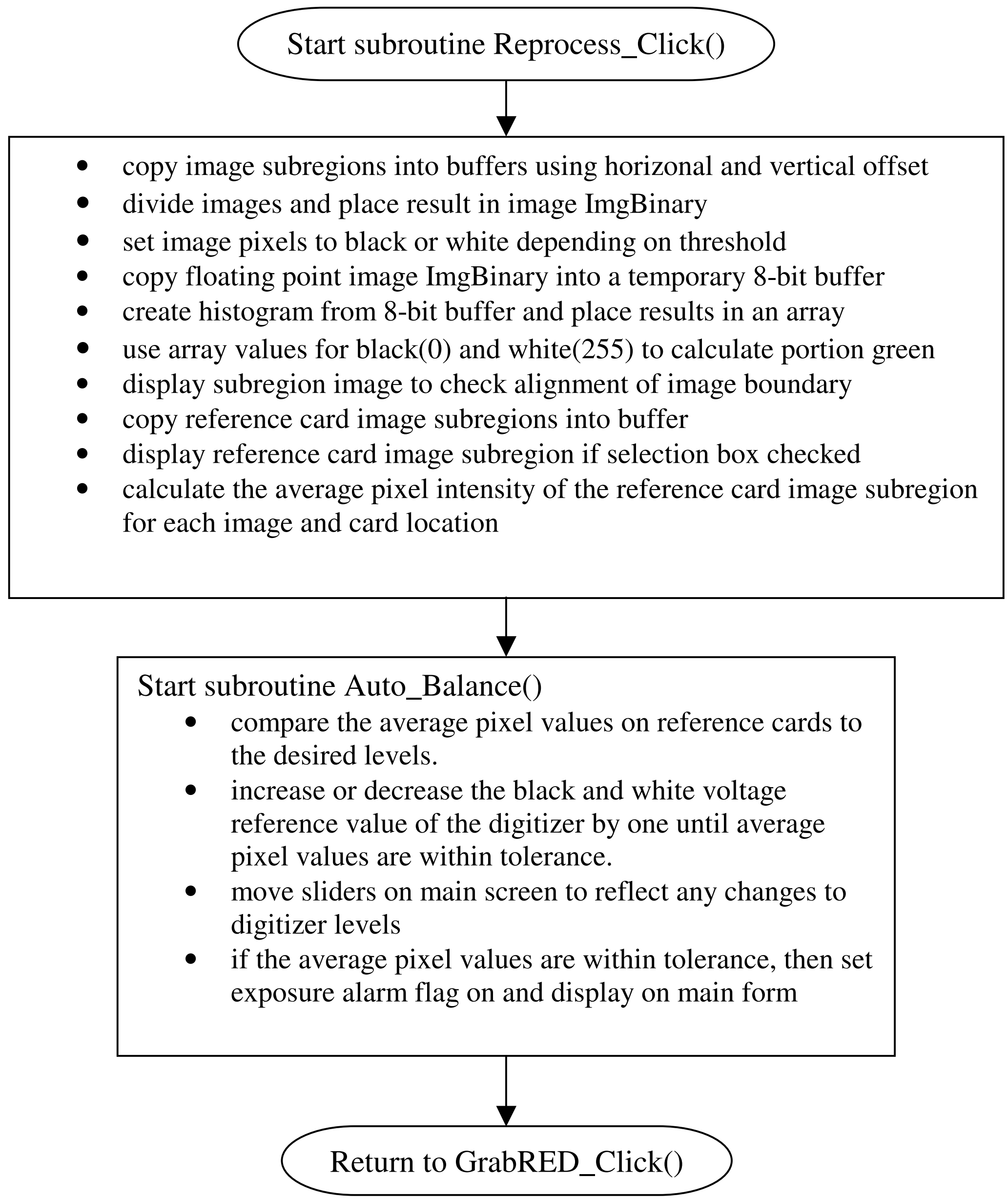

Figure 4-11 Flow of main image processing subroutines (Reprocess and Auto_Balance)

4.8.3 Matrox Active MIL Functions

Matrox Active MIL 7.0 imaging library functions performed many of the image processing tasks. These low-level functions were called from within the Visual Basic shell program described above. Images were stored in MIL image buffers (memory locations) and displayed in a display control window. The image buffers and MIL controls used in the program are listed and defined in Appendix C.

4.9 Preliminary Testing

4.9.1 Objectives Of Preliminary Tests

Preliminary tests were done during the summer of 2002 to verify the operation of the imaging system and refine the software and experimental procedures. The specific objectives of the preliminary tests were to:

- field test the imaging system and software,
- calibrate the image area and area coverage calculations,
- develop procedures that would provide consistent measurements of projected plant area in the varying conditions expected when using natural sunlight for illumination and
- determine the typical green cover for a cereal crop and the contribution of weeds to that green cover, and become acquainted with the typical variability in projected green area for a cereal crop and weeds.

4.9.2 Image Calibration

To verify the area calibration of the imaging system, cloth patterns of known area were placed on a consistent background in the field of view (Figure 4.12). The cloth was chosen to have a high reflectance in the NIR and low reflectance in the RED wavelengths under incandescent illumination, similar to the reflectance characteristics of plants. The cloth was cut into 16 rectangles of various sizes and measured with a caliper. Various proportions of the field of view were occupied by the rectangles by incrementally adding cloth pieces to the field of view. The portion of the field of view occupied by the fabric was calculated by the imaging system and compared to the known areas of the cloth patterns.

The area calibration done in the lab verified the imaging system's accuracy. The highly linear relationship (r^2=1.00) between the areas of the cloth patterns measured by the imaging system and the manually measured areas suggested low errors in the area measurement (Figure 4.13). Discrepancies between the areas measured by the imaging system and those measured manually, averaged +/- 0.09% with no measurement in error being more than 0.3%. The error in area calculation was considered insignificant relative to the error caused by the incorrect classification of pixels. The greater challenge was to maintain consistent portion-of-green readings under changing outdoor lighting conditions.

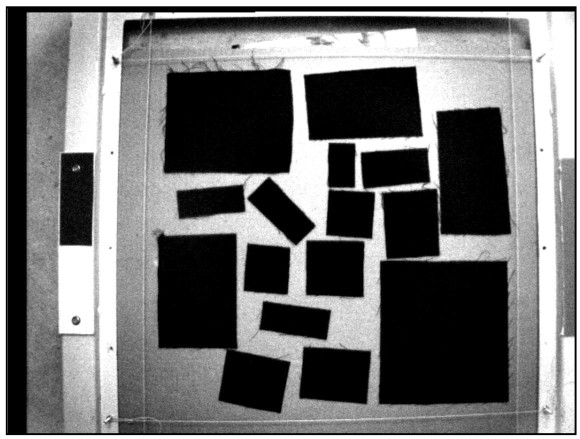

Figure 4-12 Fabric targets of known area were used to calibrate the portion of the field of view occupied by objects

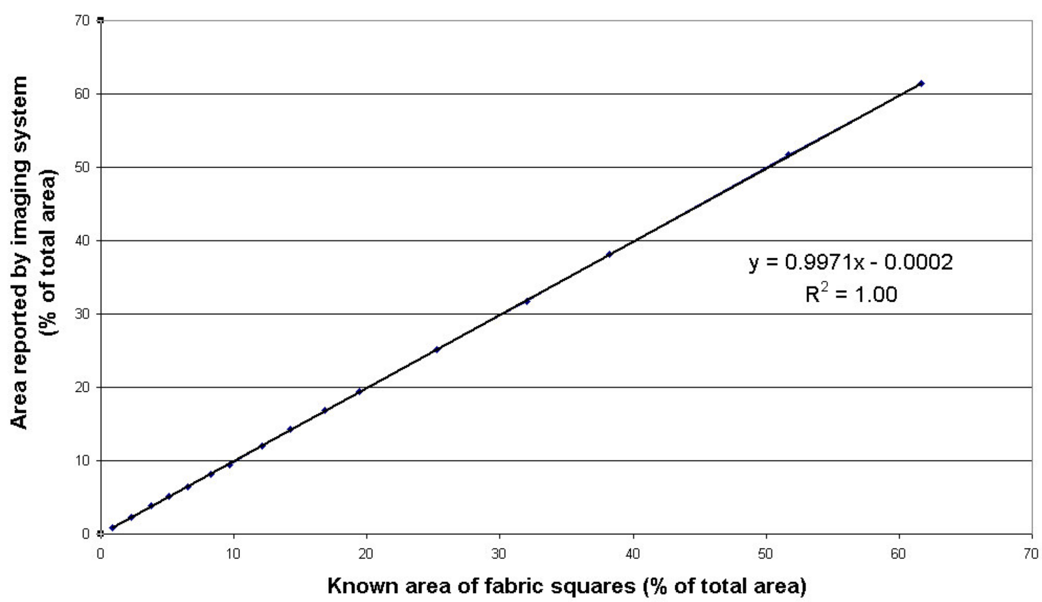

Figure 4-13 Calibration of the imaging system with fabric squares measured under incandescent lighting

4.9.3 System Stability Under Varying Light Conditions

The repeatability of measurement was tested by placing the camera frame at a single location within an oat field and calculating the percent green cover every 30 seconds over a two-hour period. The imaging system was allowed to automatically adjust the black and white voltage references during the test. If the imaging system performed well, the portion of the field of view occupied by plant material would remain relatively constant over the two-hour period.

To measure the changing incident solar radiant flux density, the output of a factory-calibrated pyranometer (LI-200SZ, Li-Cor Inc., Lincoln, Nebraska) was recorded at the same time as the images, and the values were saved to a data logger (CR10X, Campbell Scientific Inc., Logan, Utah)

The two-hour tests consisted of sessions during three times of day with each session at a single location within the field. Two of the session times corresponded to low sun angles in the morning and in the evening (18° to 38°), and one session centred around solar noon (sun angle 61°). In total, six two-hour sessions were recorded over three days.

The solar radiant flux density recorded during the field tests ranged from 100 to 875 W/m^2. When not controlling the exposure levels, the portion of the image occupied by green plants reported by the imaging system was unacceptable and ranged from 0 to 100% as incident light changed. Engaging the auto-exposure software routine resulted in a more consistent measurement of the portion of green in the field of view within +/- 2%.

During the course of the day, the cameras had to be adjusted for shutter speed and lens aperture to ensure that the images were not too dark or over-exposed. Every time the cameras were adjusted, the NIR/RED ratio and, ultimately, the percentage of pixels classified as plant were affected increasing or decreasing the portion of green in the field of view.

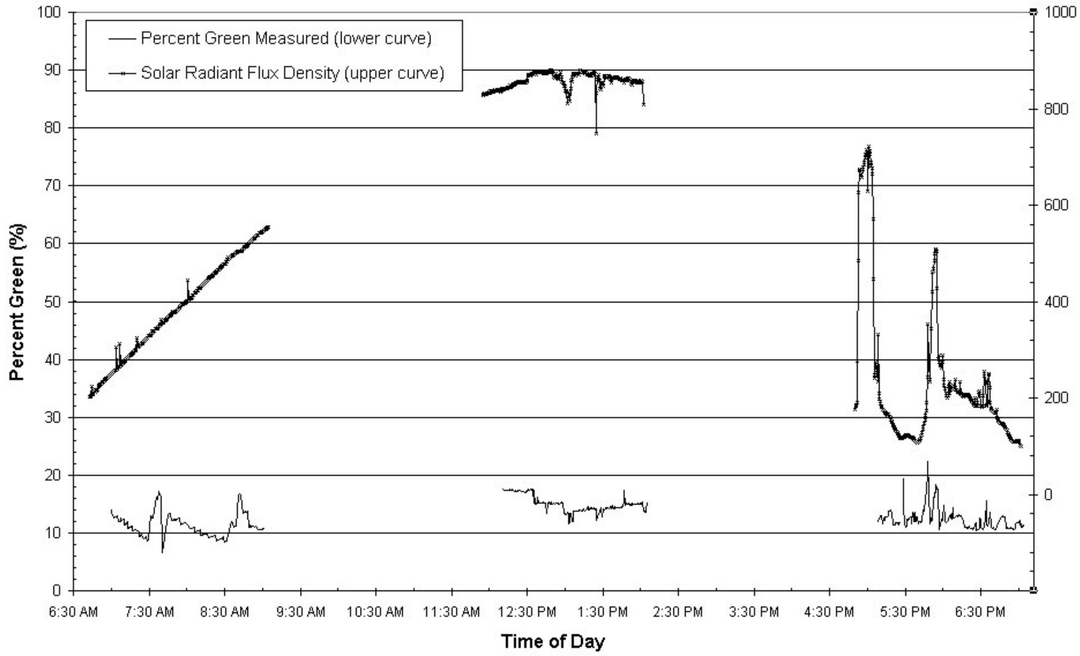

Figure 4-14 Variations in percent green readings at three times of day (June 13, 2002).

The automatic software control of the black and white reference levels maintained consistent exposure levels and reduced the effect on the NIR/RED ratios for each pixel. The system worked well when compared to the uncompensated system. Figure 4.14 provides an example of the percent green reported by the imaging system at one site during three two-hour sessions on June 13, 2002. The overall average percent green reported for the three sessions on that day was 12.9% with a standard deviation of 2.4%. Unfortunately, this did not meet the design repeatability target of +/- 2.0%.

Individually, the second session (Figure 4.14), centred about solar noon (1:07 p.m. Central Standard Time), appeared to provide a more consistent reading, with a standard deviation of 1.4% meeting the design target. Better consistency was also observed during the mid-day session at the other location (Session 6, Table 4.2). The inconsistency observed early in the morning or late at night might have been due to the low sun angle (18° to 38°) affecting the spectral power distribution of the incident light, which in turn affected the NIR/RED reflectance ratio. Saturation of the RED image was a consistent problem during morning and evening sessions. The automatic black and white reference control software was designed to correct the black reference level on both the cameras and the white reference level on only the NIR camera. Due to hardware limitations, the two white reference levels were simultaneously adjusted by one software control. Because the white reference level of the RED camera was slaved to adjustments of the white reference level of the NIR camera, saturation of the RED camera was common and could contribute to the variations in readings observed in the morning and evening sessions. The plotted steps apparent in the morning session (Figure 4.14) were the result of aperture changes to both cameras to prevent saturation of the CCD sensor. Long shadows were also more common during the morning and evening sessions, possibly affecting the classification of pixels. The exposure control appeared to adapt well to the drastic changes in incident light intensity caused by cloud cover during the evening session of Figure 4.14.

Table 4.2 Mean percent green and standard deviations measured during two-hour tests

Session	Day	Time	Location	Mean % Green	Maximum/ Minimum % Green	Standard Deviation (%)
1	1	17:51 to 19:06	A	10.9	12.1/9.8	0.6
2	2	07:00 to 09:01	B	11.2	17.2/6.5	2.0
3	2	12:10 to 14:05	B	15.0	17.6/11.5	1.4
4	2	17:08 to 19:04	B	12.3	22.3/10.4	1.9
5	3	07:00 to 09:00	C	23.3	29.8/17.1	2.6
6	3	11:42 to 13:33	C	22.0	24.1/18.3	1.0

Higher errors were observed in some field conditions as soil and residue were sometimes classified as plants, and reflective highlights on the plants were sometimes classified as non-plant. These erroneous pixels were visible as speckles within the binary image (Figure 4.15). To estimate the number of pixels incorrectly classified as plant, selected images were edited manually to remove obviously erroneous pixels (Figure 4.15). Typically the speckles accounted for less than 2% of the total image pixels. However, during the morning sessions, speckles were observed to contribute up to 6.9% of the total image area, greatly influencing the measurement of plant area. Increasing the NIR/RED threshold could have reduced the number of speckles. However, a consistent threshold setting of 3.3 was chosen for all preliminary field tests as it yielded the most consistent results.

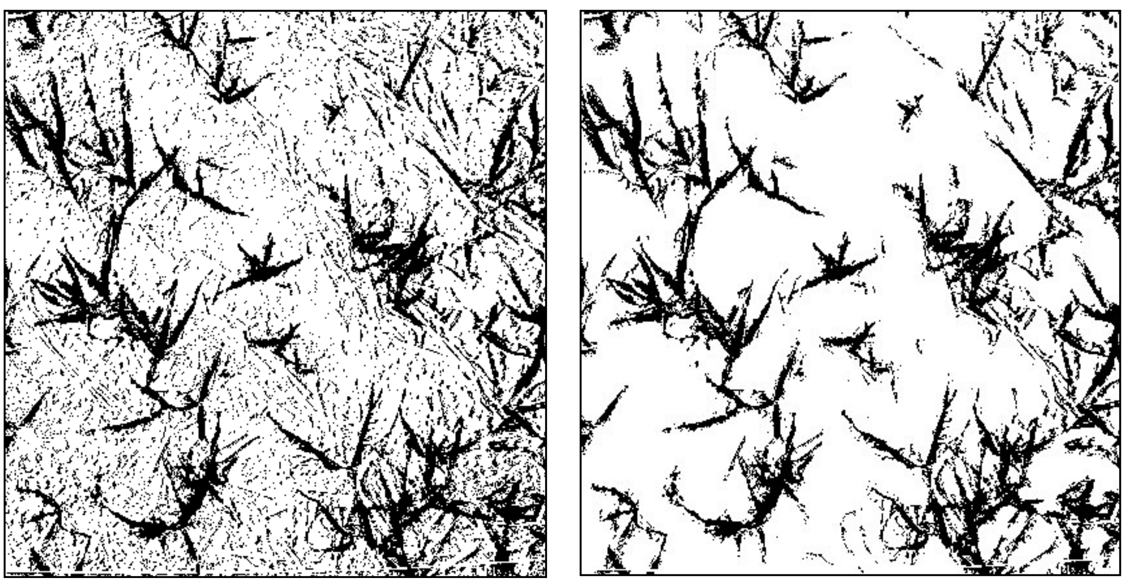

Figure 4-15 Severe classification errors of an unaltered image (25.2% green) on the left and an image with erroneous pixels manually removed (18.7% green) on the right

Classification errors were also caused by parallax distortions due to the physical separation of the two cameras. The images from the two cameras were overlapped to provide precise alignment (+/-1 pixel) on a plane 50 mm from the ground at the centre of the image. Leaves or soil above or below 50 mm in height were not perfectly aligned. The 6 mm focal length lenses also caused optical distortions at the outer edge of the image, affecting the RED to NIR pixel alignment.

To minimize misclassification of pixels, all subsequent green portion measurements were made between 10:00 a.m. and 4:00 p.m.

4.9.4 Evaluation of Proposed Experimental Procedure

A field test was done in the summer of 2002 to use the imaging system in field conditions in an effort to identify potential problems with the experimental technique proposed for the planned experiment in the summer of 2003. The one-day test also gave an indication of possible green cover variation, with and without weeds, that could be expected within the field of view.

The test field was direct-seeded to wheat in mid-June 2002 following a dry spring season. Herbicide was not applied prior to the test field to allow a weed population to establish. Weeds in the field included lamb's quarters (*Chenopodium album* L.), Canada thistle, wild buckwheat (*Polygonum convolvulus* L.), and redroot pigweed (*Amaranthus retroflexus* L.). Lamb's quarters was the predominant weed. On July 12, 2002 the wheat was at the 6-leaf stage and weeds were well established. The weeds were past the stage for effective herbicide control.

Green cover measurements were performed between 10:00 a.m. and 2:00 p.m. as these times were found to give the most consistent green cover measurements in the preliminary testing described in section 4.9.3. The sky was clear with only occasional clouds passing overhead.

Two images were taken at each of 30 random sites in the field and the portion of green cover was calculated using the video imaging system operating in its automatic white-balance mode. In this mode, the white and black video reference levels were adjusted based on the white and black target cards contained within the field of view. This method of exposure adjustment produced the most consistent green cover measurements under varying light conditions.

The first image was used to calculate the portion of green cover of the crop including all naturally occurring weeds within the field of view (0.5 meter by 0.5 meter). The second image was used to calculate the percent green cover immediately after the weeds were removed from the field of view and collected in brown paper bags. No attempt was made to identify the weed species within the test area. The difference in green cover between the two images was assumed to be the area within the field of view that was occupied by the weeds. All aboveground green weed material within the field of view was gathered and dried for 24 hours at 100 °C in a laboratory oven according to the ASAE standard for determining the moisture content of forages (ASAE S358.2 DEC99) to determine the dry mass of weeds at each test location. The test results are presented in Table 4.3.

The dry weed mass varied between 0.036 and 15.048 g/m^2 for the 30 test sites. The percent green cover, including all plants, varied from 10.6 to 46.5%. The average percent green cover was 27.3% for the crop including weeds and 24.0% for the crop with weeds removed. A paired t-test of the average results indicated a significant difference between the average green cover measurement with and without weeds ($p<0.001$), indicating that the presence of weeds did contribute to the overall green cover. The variability of green cover measured for the crop with weeds was high, with a coefficient of variation of 32%. This high variability would likely make identification of low weed densities within a crop by green cover measurement difficult.

The difference between green cover measurements with and without weeds present appeared to follow a linear relationship relative to the weed dry matter (r^2=0.84, Figure 4.16). However, the total green cover was highly variable (CV=32%) and was not related to the amount of weed dry matter (r^2=0.02, Figure 4.17), even though there appeared to be a general increase in green cover with increasing weed dry matter. For weed dry matter to be determined by total green cover, a more defined trend must exist. Variability of crop density greatly affected the ability of a simple imaging system to infer weed dry matter from green cover measurements alone. Obviously, more replication was necessary in a variety of fields and growing conditions to fully understand the green cover variability that existed at each stage of crop and weed growth.

Table 4.3 Percent green cover measured at 30 sites within the wheat field, sorted by increasing weed mass.

Site ID	With Weeds %Green	Without Weeds %Green	Difference %Green	Weed Dry Mass g/m^2
32/33	10.6%	10.5%	0.1%	0.036
17/18	24.9%	23.5%	1.4%	0.244
15/16	24.3%	24.3%	0.0%	0.304
13/14	15.4%	14.9%	0.5%	0.836
21/22	21.4%	19.8%	1.6%	0.960
5/6	32.5%	31.3%	1.2%	1.068
3/4	29.7%	28.8%	0.9%	1.164
56/57	18.7%	17.6%	1.1%	1.352
7/8	37.8%	35.8%	2.0%	1.664
46/47	27.2%	27.3%	-0.1%	1.868
52/53	36.3%	34.3%	2.0%	1.924
19/20	23.0%	20.8%	2.2%	2.372
42/43	25.9%	23.8%	2.1%	2.732
1/2	40.2%	37.6%	2.6%	3.364
54/55	35.9%	33.1%	2.8%	3.748
58/59	28.7%	23.4%	5.3%	4.020
38/39	30.1%	25.8%	4.3%	4.284
40/41	16.3%	13.9%	2.4%	4.508
23/24	24.2%	20.6%	3.6%	4.664
36/37	23.1%	17.5%	5.6%	5.224
9/10	29.9%	24.5%	5.4%	5.312
34/35	46.4%	43.1%	3.3%	5.800
30/31	18.9%	15.0%	3.9%	6.280
44/45	27.3%	22.5%	4.8%	7.152
11/12	46.5%	39.1%	7.4%	7.456
25/26	13.5%	9.2%	4.3%	7.956
48/49	28.8%	24.3%	4.5%	8.344
50/51	29.2%	24.3%	4.9%	8.908
60/61	23.2%	14.9%	8.3%	12.144
27/28	30.4%	17.0%	13.4%	15.048
Average	27.3%	23.9%		
Standard Deviation	8.8%	8.6%		
CV%	32.0%	35.7%		

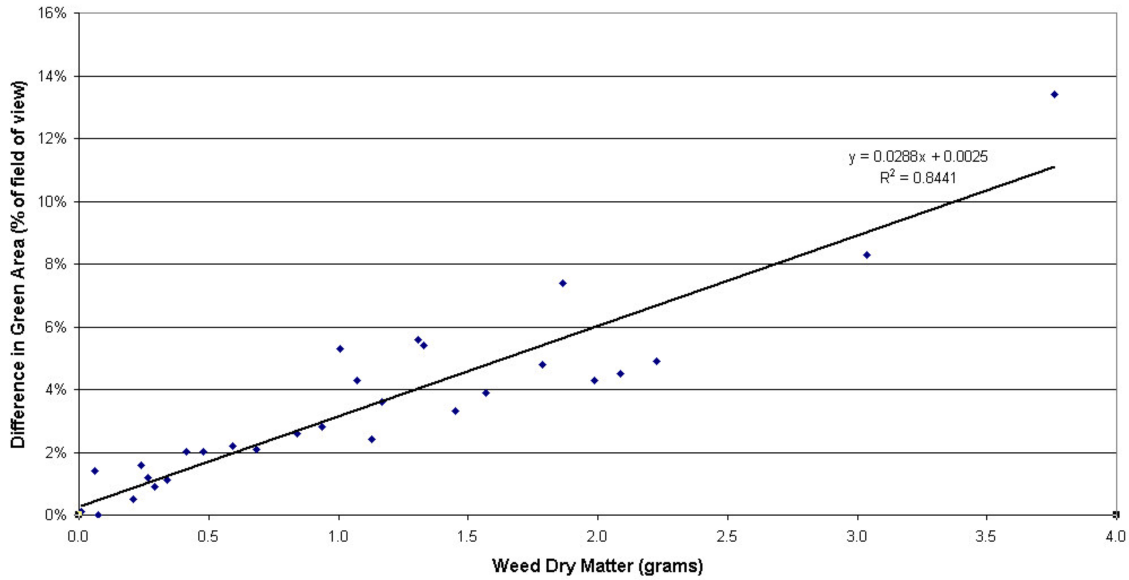

Figure 4-16 Linear relationship between change in green cover measurement (Percent green cover measured with weeds less percent green cover measured with weeds removed) and weed dry matter. Wheat at 6-leaf stage

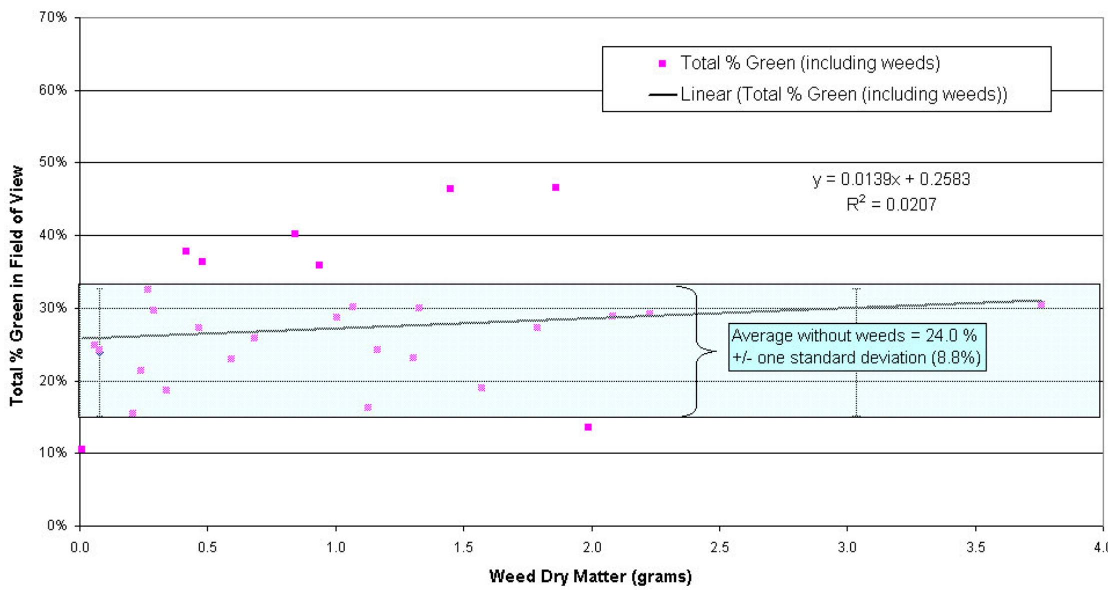

Figure 4-17 Total green cover as a function of weed dry matter. Band shows the average green cover of all images with weeds removed +/- one standard deviation.

The preliminary single data set suggested that:

- green cover measurements varied greatly within the single field and selected growth stage (C.V. = 32% in this case),
- weeds generally occupied less than 5% of the field of view even with the weeds at an advanced stage of growth and
- weed area, as inferred by the difference between the green cover with weeds and with weeds removed, may be related to the dry mass of the weeds removed.

4.9.5 Conclusions of the Preliminary Testing

An estimate of the projected area of green growing plants within a field of view under natural sunlight illumination was possible using the dual camera video imaging system described. A simple ratio of NIR/RED pixels was successfully used to classify green growing plants from a background of soil, crop residue and small stones. The automatic black and white reference system employed by this imaging system was capable of stabilizing percent green measurements even under widely changing ambient light conditions, typically within +/- 2%. Green cover measurements were most repeatable during the mid-day sessions. With the preliminary testing completed, a more complete experiment was planned for the summer of 2003 and is described in the next section.

5. THE FIELD EXPERIMENT

5.1 Introduction

A field experiment was planned to determine the relationship between green cover as measured by the imaging system and total plant dry matter for a wheat crop, and to compare green cover measurements with and without natural weeds at four growth stages in a cereal crop, and to establish a procedure for evaluating the imaging system's ability to predict weed intensity within a cereal crop at four growth stages. Through this investigation, the potential of using a ground-based video imaging system to map weed dry matter within a crop was evaluated.

5.2 Field Crop and Plot Selection

Three test plots were chosen on a level site near Vermilion, Alberta (Figure 5.1). The field had a loamy-sand textured soil and was located in the thin black soil zone of western Canada. Canola had been grown in the previous year. However, due to a drought in the 2002 growing season, the canola crop was thin and left little residue on the surface. The fields had been used to grow silage with minimal weed control in the years previous to 2002 so that significant weed populations were expected to establish under the conditions of the experiment.

The plots were located in a north-south orientation 27 m from the field boundary to eliminate edge effects and allow one pass of a sprayer on the outside round. A narrow plot shape was chosen to allow the plot to traverse a range of weed densities. Each plot was 27 m by 148 m, approximately 0.40 hectare in area.

The cereal crop chosen was a Prodigy hard red spring wheat (*Triticum aestivum* L.) and was seeded by the farmer in all five fields.

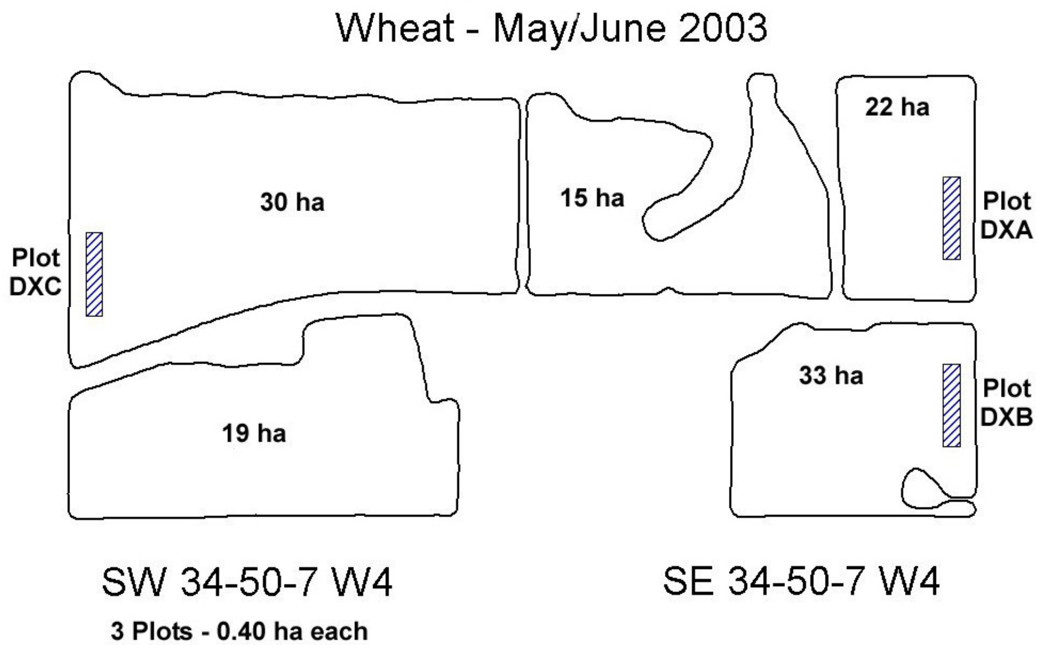

Figure 5-1 Location and orientation of test plots within the wheat fields

5.3 Pre-seeding Weed Profile

Weeds in the test fields included wild oat (*Avena fatua* L.), shepherd's purse (*Capsella bursa-pastoris* (L.) Medic.), lamb's quarters, Canada thistle, wild buckwheat, common groundsel (*Senecio vulgaris* L.), stinkweed (*Thlapsi arvense* L.), toad flax (*Linaria vulgaris* Hill.), dandelion (*Taraxacum officinale* Weber), stork's bill (*Erodium cicutarium* (L.) L'Her.), quackgrass and narrow-leaved hawk's beard (*Crepis tectorum* L.).

Each plot varied in weed population and severity. Each plot was visually assessed by an experienced field scout prior to seeding. A subjective rating system was used similar to the one described by Dorrance (1988). Weed infestations were ranked as light, medium or heavy depending on the plant populations, competitive characteristics of the weed, stage of weed growth and economic impact. The summary of weeds present in each plot is presented in Table 5.1 along with a relative visual rating of the severity of infestation.

Table 5.1 Pre-seeding weed levels in each plot determined by field scouting

	Pre-seeding weed infestation levels		
Weed Present	Plot DXA	Plot DXB	Plot DXC
dandelion	Heavy	None	Medium
narrow-leaf hawk's beard	Heavy	None	Heavy
stinkweed	Medium	None	Medium
lamb's quarters	Light	None	Light
canola (volunteer)	Light	Light	None
wild oat	Light	None	None
quackgrass	None	Medium	Medium
shepherd's purse	Light	None	Light
Canada thistle	Medium	Light	Medium
wild buckwheat	Light	None	None
common groundsel	Light	None	None
toad flax	None	None	Medium

None of the plots were sprayed before seeding, or during the test. The fields adjacent to the plots received a pre-seeding application of Roundup Transorb (glyphosate) at a rate of 666 g/ha on May 14, 2003. A post-emergent application of K2 (thifensulfuron methyl + tribenuron methyl + flucarbazone-sodium) at 17.4 g/ha and 2,4-D at 490 g/ha were also applied to the adjacent fields later in the growing season with the wheat at the 5-leaf stage. The herbicides were applied carefully to avoid drift onto the test plots.

The location of distinct weed patches was mapped using a DGPS backpack receiver (Figure 5.2) to provide an indication of the weed distribution throughout the plot. The weed maps were compared to weed densities measured by the imaging system and ground truth investigation. The maps of the pre-seeding weed patches are presented in section 6.5.

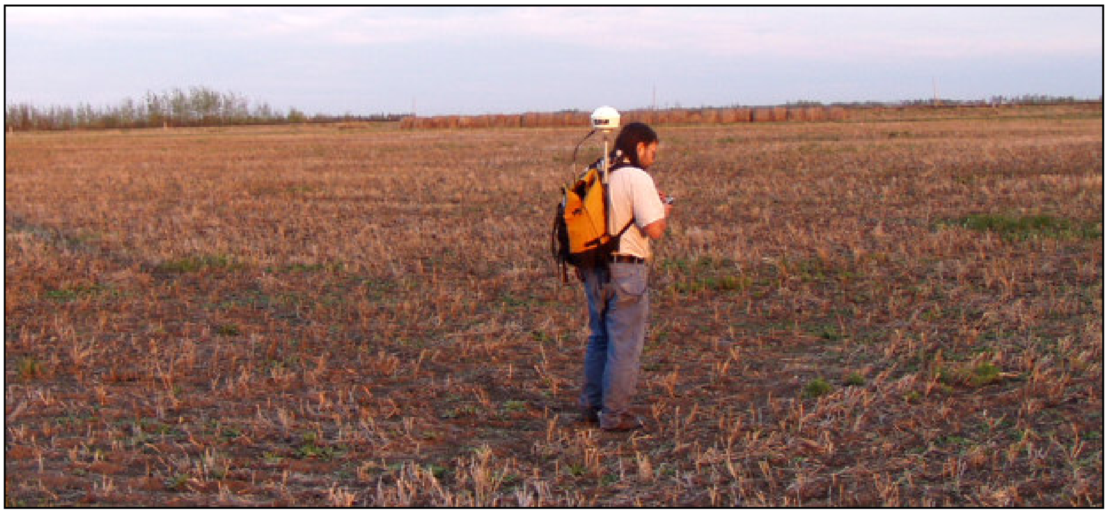

Figure 5-2 DGPS mapping of distinct weed patches before seeding

5.4 Seeding Equipment and Methods

The fields containing the plots were direct-seeded to wheat at 100 kg/ha with a Morris Maxim air hoe drill (Figure 5.3) on May 18 and 19, 2003. Seeding depth was nominally 5 cm. The test fields were direct-seeded into canola stubble with paired-row seed openers at 25-cm spacings, with a seed spread of approximately 8 cm that resulted in a seedbed utilization of approximately 30% (Figure 5.4). A fertilizer blend was applied below and between the seed rows at a rate of 28-22-6 (kg/ha, Nitrogen-Phosphorus-Potassium).

Figure 5-3 Morris Maxim air hoe drill used to seed the plots

Figure 5-4 Paired-row seed and fertilizer opener

5.5 Emerged Plant Population and Crop Uniformity

The emerged plant population was expected to affect the imaging system's ability to estimate weed density within the crop. To verify the seeding rate and plant population, crop plants were counted within a 0.25-m^2 quadrat, at 24 sample locations distributed within each plot, at the 2-tiller growth stage. The following results were obtained (Table 5.2).

Table 5.2 Emerged plant population at the 2-tiller growth stage in each plot

Plot	Average plants/m^2	Standard Deviation plants/m^2	Coefficient of Variation
DXA	243	57	24%
DXB	223	54	24%
DXC	231	45	19%

A series of paired t-tests were used to determine that the average emerged plant density was the same among all fields ($p>0.25$).

To evaluate the crop uniformity among the plots, plant dry matter was measured and found to be similar among all three fields at this growth stage (Table 5.3).

Table 5.3 Average crop dry matter at the 2-tiller growth stage in each plot

Plot	Average Crop Dry Matter g/m^2	Standard Deviation g/m^2	Coefficient of Variation
DXA	40.1	15.1	38%
DXB	41.4	15.3	37%
DXC	37.0	14.9	40%

5.6 Image Collection

Images were captured and data were collected in each plot prior to direct seeding and at four subsequent growth stages. The growth stages selected for the wheat crop were pre-seeding, 2 to 3-leaf, 5-leaf, 2-tiller, and 3-tiller. Two images were taken at each of 24 randomly distributed sites in each plot and the portion of green cover was calculated using the video imaging system. The first image was used to calculate the portion of green cover of the crop including all naturally occurring weeds within the field of view. The second image was used to calculate the percent green cover immediately after the weeds were manually removed from the field of view and collected.

All images were collected between 10:00 a.m. and 4:30 p.m. local time to minimize the errors due to the low sun angle as observed in the preliminary testing. Avoiding the low sun angle also reduced the amount of shadow cast by the camera frame. Images for all plots were recorded over two consecutive days at each growth stage. A hand-held digital colour camera was used to take colour photographs of each sample point for future reference and as a visual indicator of the weed intensity at each point.

5.7 Dry Matter Measurements

All aboveground green weed material within the field of view was gathered and dried for 24 hours at 100 ºC in a laboratory oven according to the ASAE standard for determining the moisture content of forages (ASAE S358.2 DEC99). The mass of the dry matter was measured to the nearest 1/1000 of a gram. Weed dry matter (g/m^2) was used to quantify the weed intensity at each sample point. No attempt was made to identify the weed varieties within the test area. The aboveground crop material was collected separately and similarly dried. Sampling points at subsequent growth stages were selected to avoid previously harvested areas. Image information and dry matter data are tabulated in Appendix D.

5.8 Data Analysis

Although all plots were prepared and treated exactly the same, they were not considered experimental replicates but rather three independent test fields. The portion of green in the field of view of each of the 24 sample points was plotted relative to weed dry matter for each field. Linear regression lines were fit to the data to indicate trends. Generally, the portion of green in the field of view increased with increased weed dry matter. The average green cover and standard deviation due to the crop were calculated and used in the determination of a minimum detectable weed mass (m_{dw}) for each field and growth stage. The minimum detectable weed mass was defined as the point where the regression line of total green area intersected the average area covered by the crop alone plus two standard deviations (s).

To illustrate the potential for spatial weed mapping using green cover measurements, the percent green cover greater than the m_{dw} threshold was plotted and visually compared to perimeter maps of weed patches estimated by ground observations.

6. RESULTS AND DISCUSSION

6.1 Relationship between projected green area and plant biomass

One of the objectives of the field experiment was to determine the relationship between the portion of an image occupied by green growing plants and the aboveground plant dry matter. Figure 6.1 shows all the data points, and illustrates the relationship observed between projected green cover (gc) and plant dry matter (dm) using the total percent green (crop+weed) for all fields and growth stages. A rectangular hyperbola was used to estimate the trend,

$$gc = \frac{0.8249dm}{1+\frac{0.8249dm}{144.76}} \qquad r^2=0.879, \qquad (6.1)$$

with the constants estimated using Statistica (Statsoft Inc., Tulsa, Ok.). As expected, the relationship was fairly linear at low green cover values and reached a level plateau at high biomass values as the crop canopy closed.

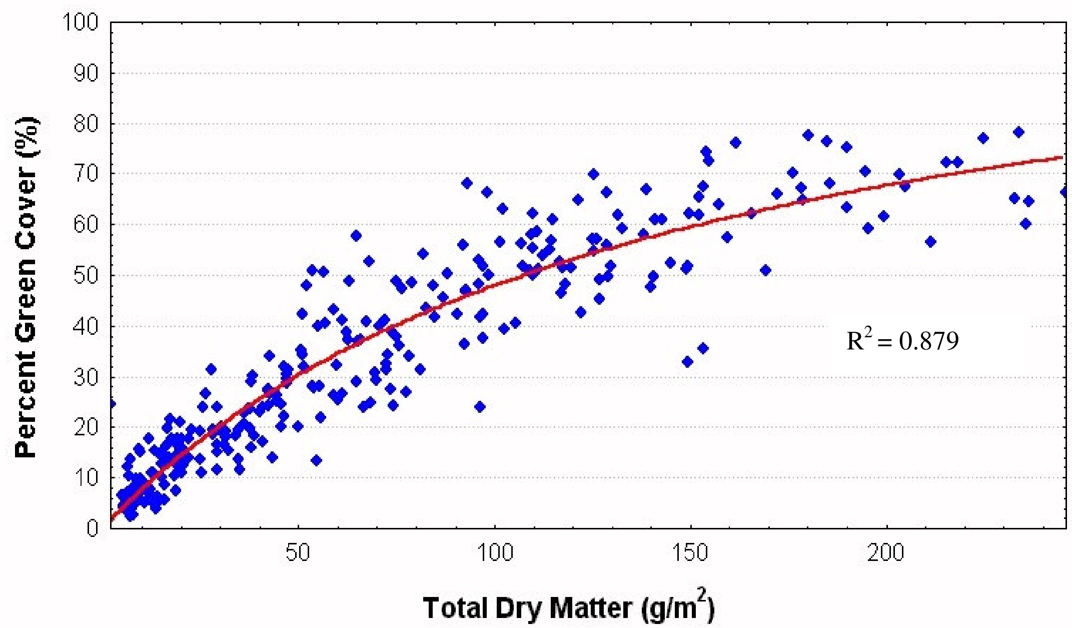

Figure 6-1 The observed relationship between percent green cover and aboveground plant biomass for all field and growth stages. The rectangular hyperbola of Equation 6.1 illustrates the trend.

6.2 Crop Biomass

The average crop dry matter collected from the 24 sample points within each plot and growth stage is plotted in Figure 6.2. As expected, the crop dry matter increased as the growth stage progressed. Although some the plots had different crop dry matter at the 2 to 3-leaf and 5-leaf stage, by the time the crop progressed to the 2-tiller stage, the crop had evened out and the crop dry matter among plots were not significantly different ($p>0.05$, multiple paired t-test).

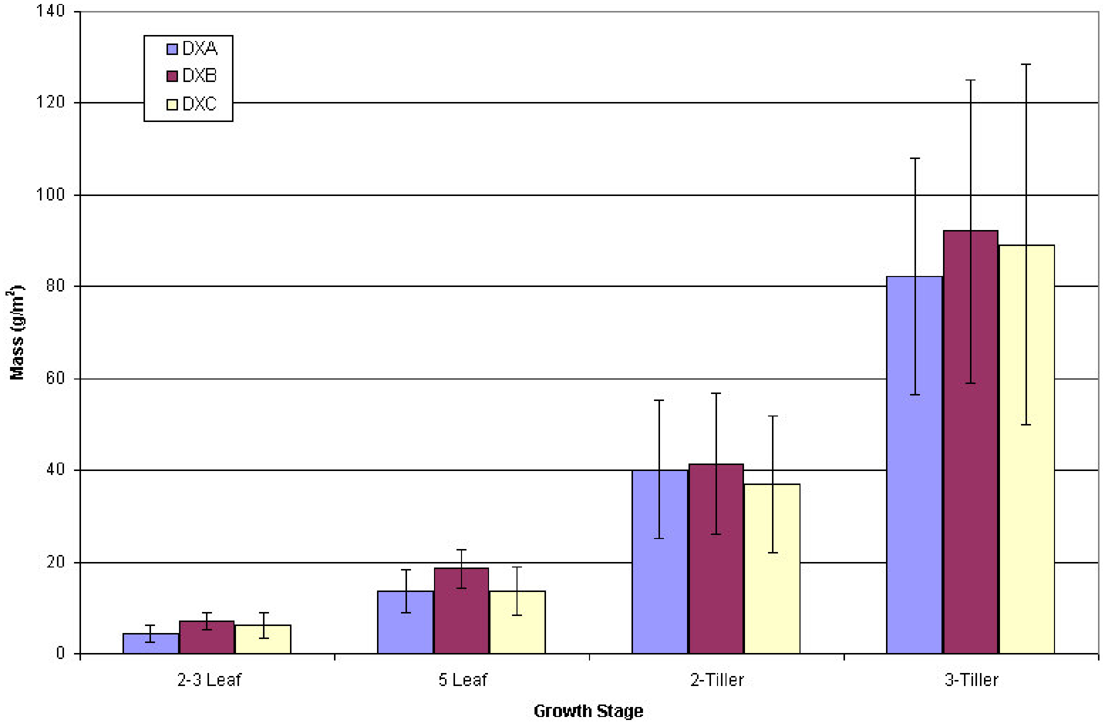

Figure 6-2 Crop dry matter averages for each plot and growth stage. Each bar is the average of 24 measurements. Error bars show +/- one standard deviation.

6.3 Weed Biomass

The plots varied considerably in their weed profile and intensity. Prior to seeding, plot DXA had weed dry matter similar to DXB or DXC, but the weeds quickly grew and took over the crop (Figure 6.3). At the 3-tiller growth stage, the average weed dry matter (105 g/m^2, Figure 6.3) in plot DXA exceeded the average crop dry matter (82 g/m^2, Figure 6.2). Plot DXB was the least weedy field. The average weed dry matter of plot DXB reached 17 g/m^2 at the 3-tiller growth stage. Plot DXB also had the highest average crop biomass at all growth stages, likely due to the decreased weed competition.

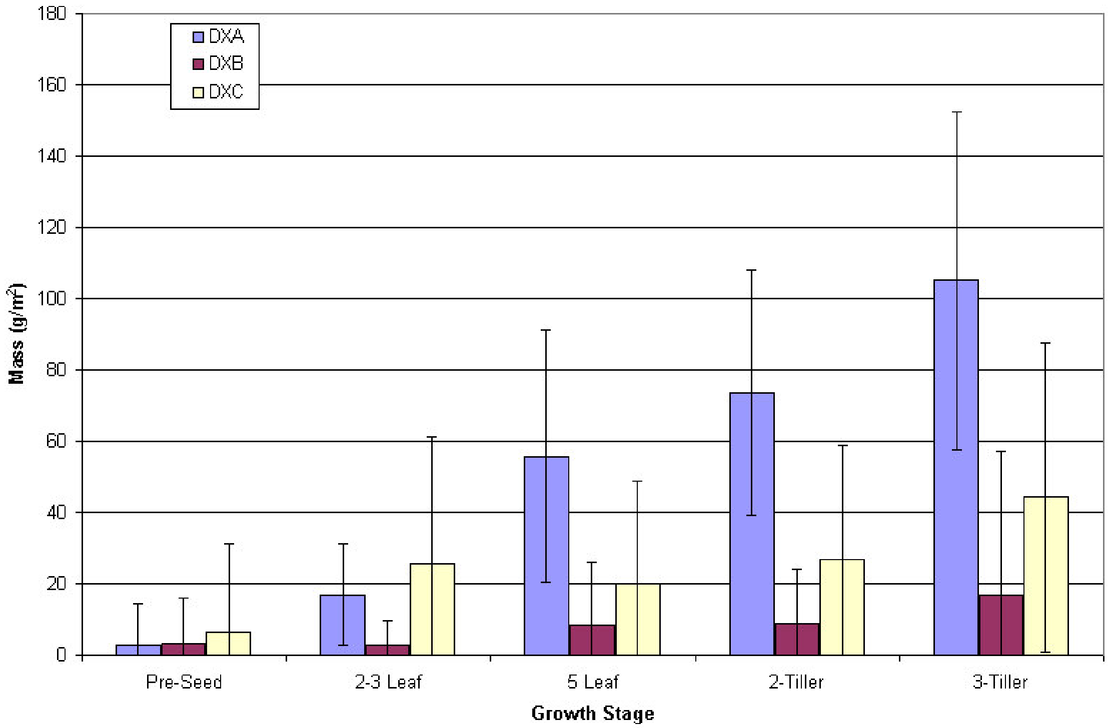

Figure 6-3 Weed dry matter averages for each plot and growth stage. Each bar is the average of 24 measurements. Error bars show +/- one standard deviation.

6.4 Minimum Detectable Weed Mass

For each plot and growth stage, the total green area and the area of crop cover (without weeds) were plotted relative to the dry weed mass (Figures 6.4 to 6.15). Generally, as the total weed mass increased, the total green area was observed to similarly increase. At early growth stages, the portion of green crop alone was fairly consistent (Figures 6.4, 6.6, 6.7, and 6.8). To compare the ability of the imaging system to detect weed dry matter at each plot and growth stage, a minimum detectable weed mass (m_{dw}) was defined as the point where the regression line of total green area intersected the average area covered by the crop alone plus two standard deviations (*s*). By selecting a threshold of two standard deviations above the average green cover, any weed area identified would have a green cover above 95% of all observations expected from crop alone if the variation in green cover was normally distributed. Figure 6.7 of plot DXA at the 5-leaf stage ideally illustrates the concept. For the case described by Figure 6.7, the average green cover for the crop alone was 18.2% with a standard deviation of 5.6%. In this case, the upper threshold of the portion of the area covered by the crop alone was:

$$18.2\% + (2 \times 5.6\%) = 29.4\% . \qquad (6.2)$$

Any observation above 29.4% green cover was considered to contain weeds above a minimum detectable level. The regression equation for the total percent green line for plot DXA at the 5-leaf growth stage is given in Equation 6.3,

$$y = 0.3855x + 24.41 \qquad (6.3)$$

where: y = percent green in the field of view (%) and

x = weed dry matter (g/m^2).

For the situation in Figure 6.7, the minimum detectable weed mass was 12.9 g/m^2 as calculated by substituting the upper threshold number determined in Equation 6.2 into the regression equation for the total percent green line for plot DXA at the 5-leaf growth stage, (Equation 6.3), and solving for the corresponding weed dry matter. The substitution

$$\frac{29.4\% - 24.41\%}{0.3855(\% \cdot m^2 / g)} = 12.9 g / m^2 \qquad (6.4)$$

concludes the calculation of m_{dw} for the conditions in Figure 6.7. The calculation of m_{dw} was repeated for all plots and growth stages, and is summarized in Table 6.1 and plotted for each growth stage in Figure 6.16.

The minimum detectable weed mass varied greatly depending on the crop variability and growth stage. The m_{dw} was easily determined at early growth stages, but as the crop developed, the m_{dw} became very large or indeterminate as at the 3-tiller growth stage (Figures 6.13 to 6.15).

The coefficient of determination (r^2) of the total green cover line in Figures 6-4 to 6-15 was also an indicator of field conditions that would result in better predictions of weed mass. Relationships with a high r^2 values resulted in better m_{dw} predictions.

Using total green cover for the prediction of weed intensities may not work for all fields and growth stages. Figure 6.10 illustrates the difficulties determining m_{dw} as the crop and weeds grew. At the 2-tiller growth stage, the relationship between total green cover and weed mass was not strong (r^2=0.22), and the crop green cover was affected by competitive weed growth as can be observed by the negative slope of the crop green cover line. As the crop grew, the crop canopy closed in and saturated the field of view. The average total green cover (crop+weed) was 55% with only a 17% coefficient of variation. It appeared that at the 2 and 3-tiller growth stages, the total green cover was relatively constant, comprised either of crop or weed. As weed mass increased, the portion of green crop decreased, likely due to excessive competition between crop and weed.

Plot DXB had very low weed intensities throughout the test that made it difficult to calculate the m_{dw} at the 2 to 3-leaf growth stage. By the 5-leaf growth stage, DXB displayed characteristics similar to the other fields. By the 2-tiller growth stage, none of the field data permitted a reasonable determination of m_{dw}.

Table 6.1 The minimum detectable weed mass (m_{dw}) and coefficient of determination (r^2) of the total green cover line calculated for each plot in wheat at 4 growth stages.

Growth Stage	**Plot**	**Average weed dry matter (g/m^2)**	**Average green cover (crop only) (%)**	***Standard Dev.* green cover (crop only) (%)**	**Total % Green line r^2**	**Minimum detectable weed dry matter (g/m^2)**
2 to 3-leaf	DXA	16.94	2.4	1.2	0.772	4.1
	DXB	2.90	6.7	2.0	0.152	20.0
	DXC	25.53	6.1	3.4	0.884	15.9
5-leaf	DXA	55.75	18.2	5.6	0.761	12.9
	DXB	8.55	14.5	2.7	0.845	10.4
	DXC	19.82	14.1	5.7	0.540	29.5
2-tiller	DXA	73.70	27.3	9.2	0.221	1.9
	DXB	8.84	22.8	5.0	0.139	52.9
	DXC	26.62	24.2	9.1	0.209	93.5
3-tiller	DXA	105.02	38.9	9.8	0.094	Negative[1]
	DXB	16.84	39.0	11.6	0.048	308.7
	DXC	44.31	45.4	15.3	0.001	Negative[1]

[1] Negative numbers indicate that no minimum weed mass could be determined using the stated criteria.

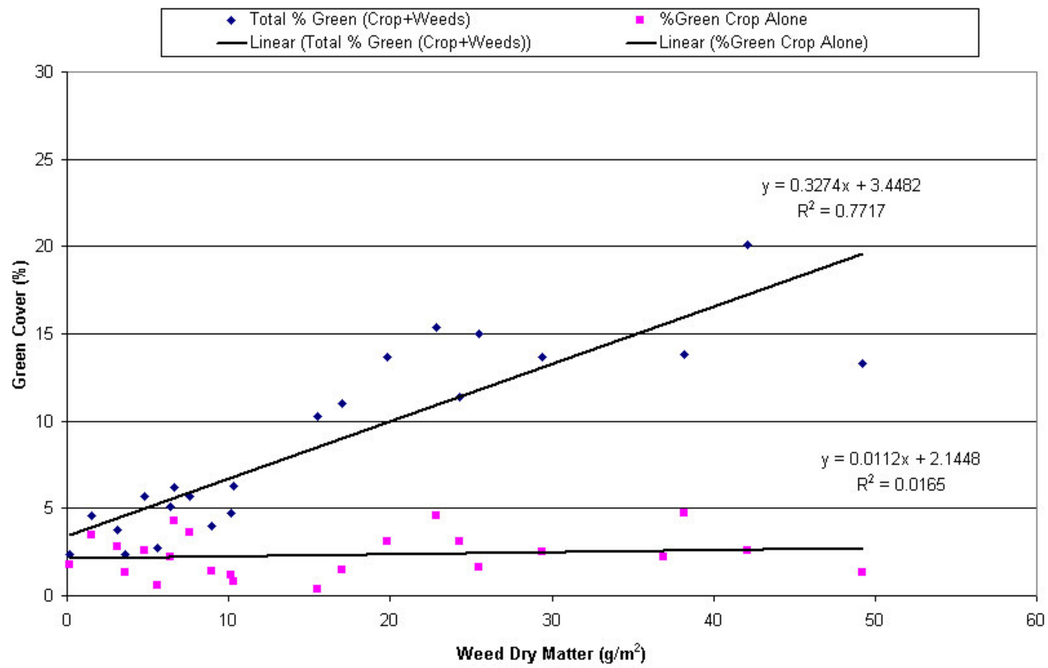

Figure 6-4 The percent green cover observed as a function of weed dry matter for wheat at the 3-leaf growth stage for plot DXA (m_{dw}= 4.1 g/m^2).

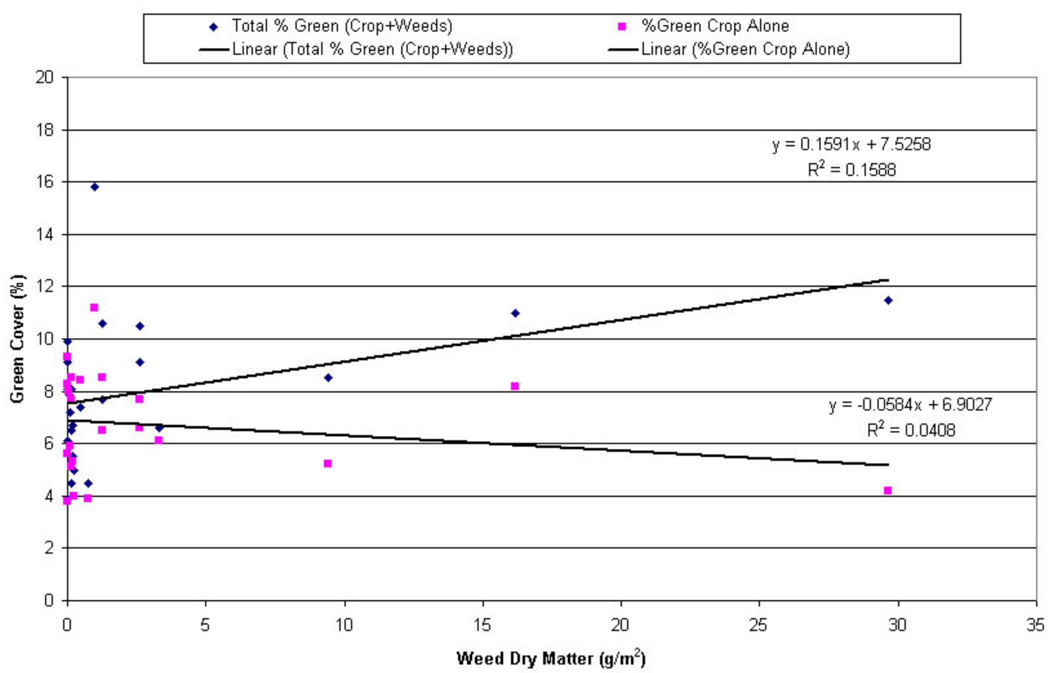

Figure 6-5 The percent green cover observed as a function of weed dry matter for wheat at the 3-leaf growth stage for plot DXB (m_{dw}= 20.0 g/m^2). Plot DXB had a very low weed intensity making determination of m_{dw} difficult.

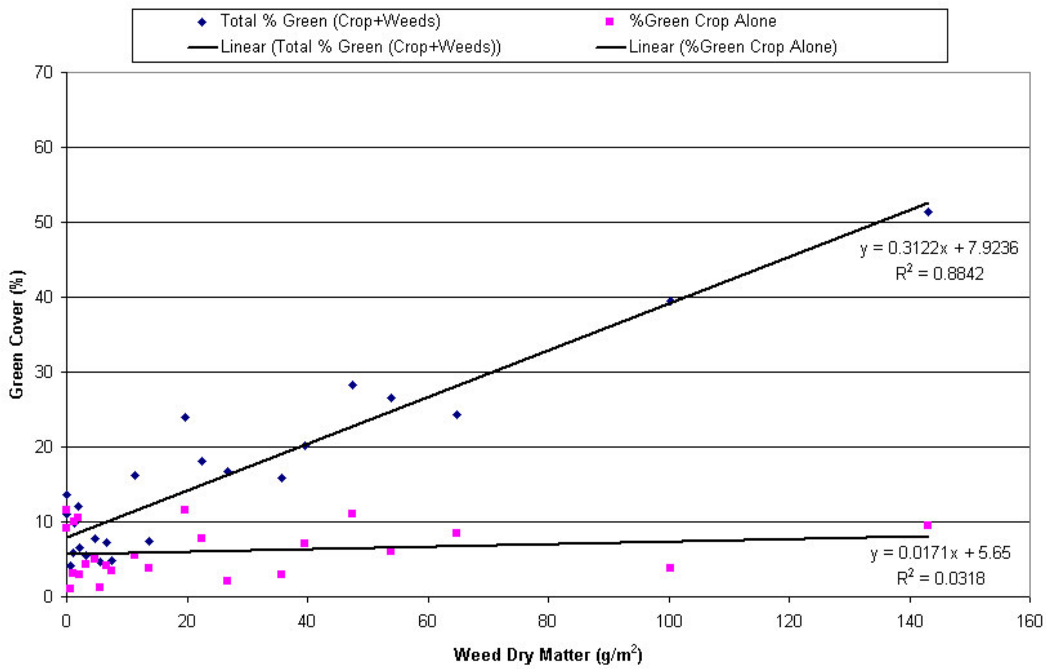

Figure 6-6 The percent green cover observed as a function of weed dry matter for wheat at the 3-leaf growth stage for plot DXC (m_{dw}= 15.9 g/m^2).

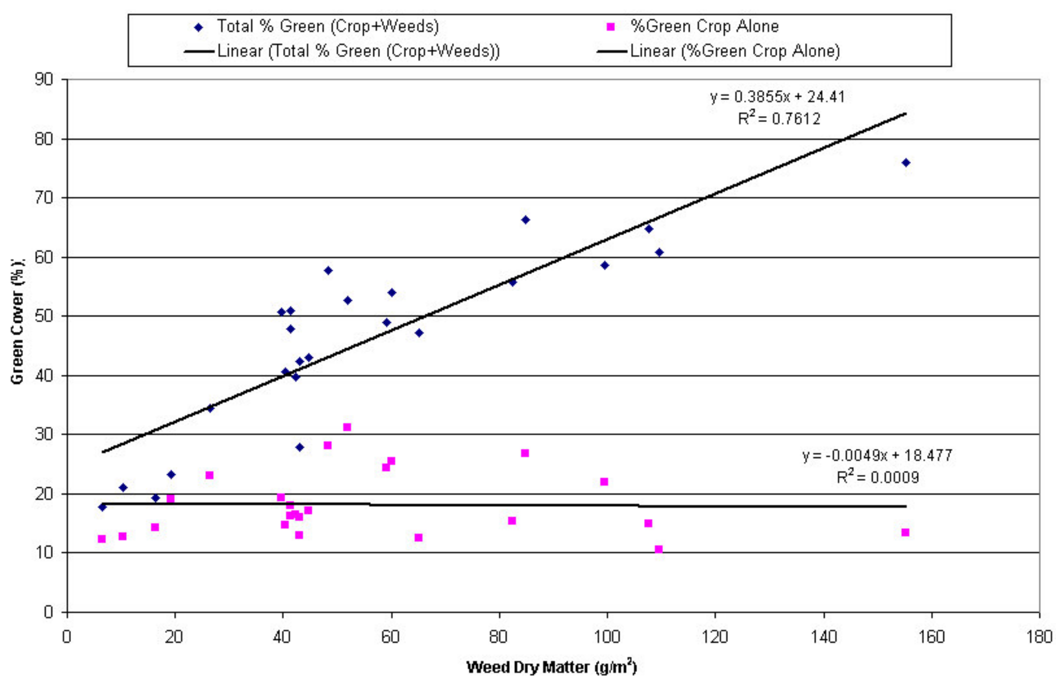

Figure 6-7 The percent green cover observed as a function of weed dry matter for wheat at the 5-leaf growth stage for plot DXA (m_{dw}= 12.9 g/m^2).

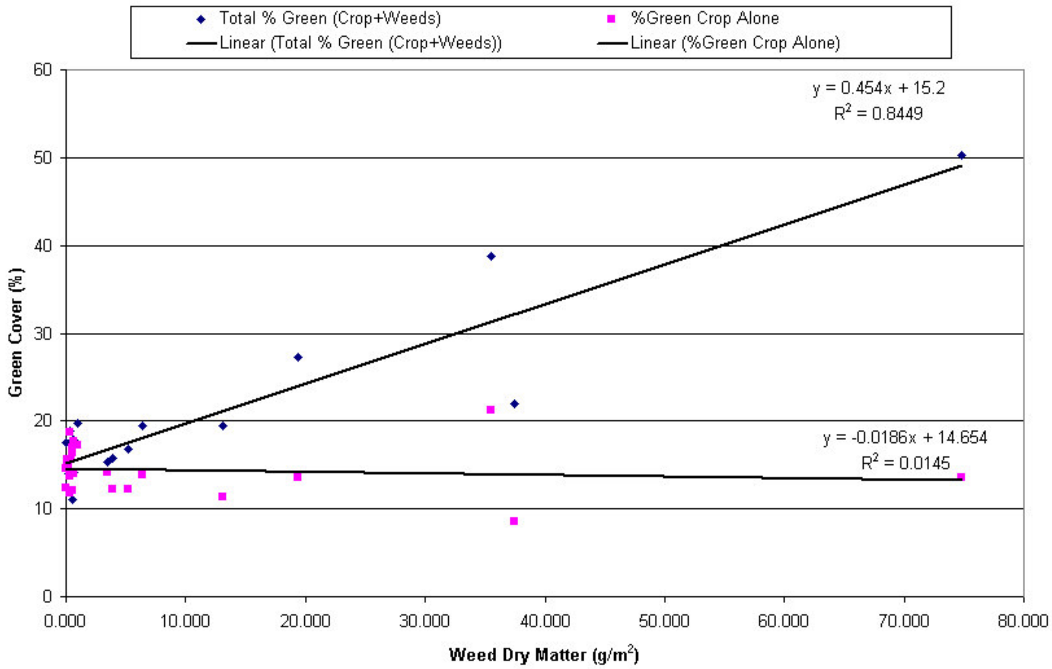

Figure 6-8 The percent green cover observed as a function of weed dry matter for wheat at the 5-leaf growth stage for plot DXB (m_{dw}= 10.4 g/m^2).

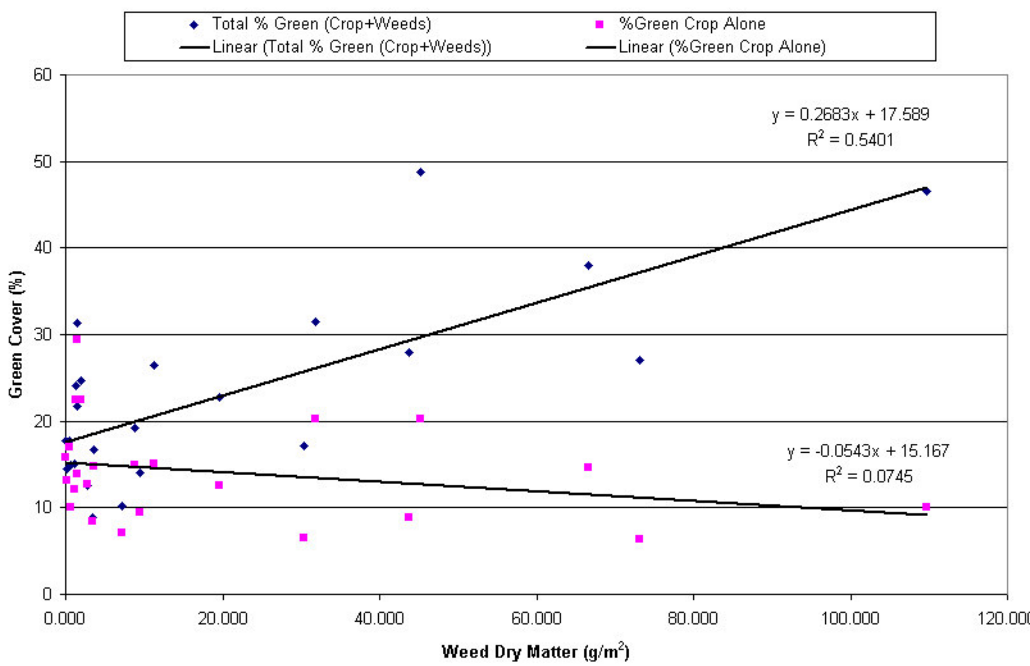

Figure 6-9 The percent green cover observed as a function of weed dry matter for wheat at the 5-leaf growth stage for plot DXC (m_{dw}= 29.5 g/m^2). Weed competition started to have an effect on the crop, decreasing the percent green at high weed intensities.

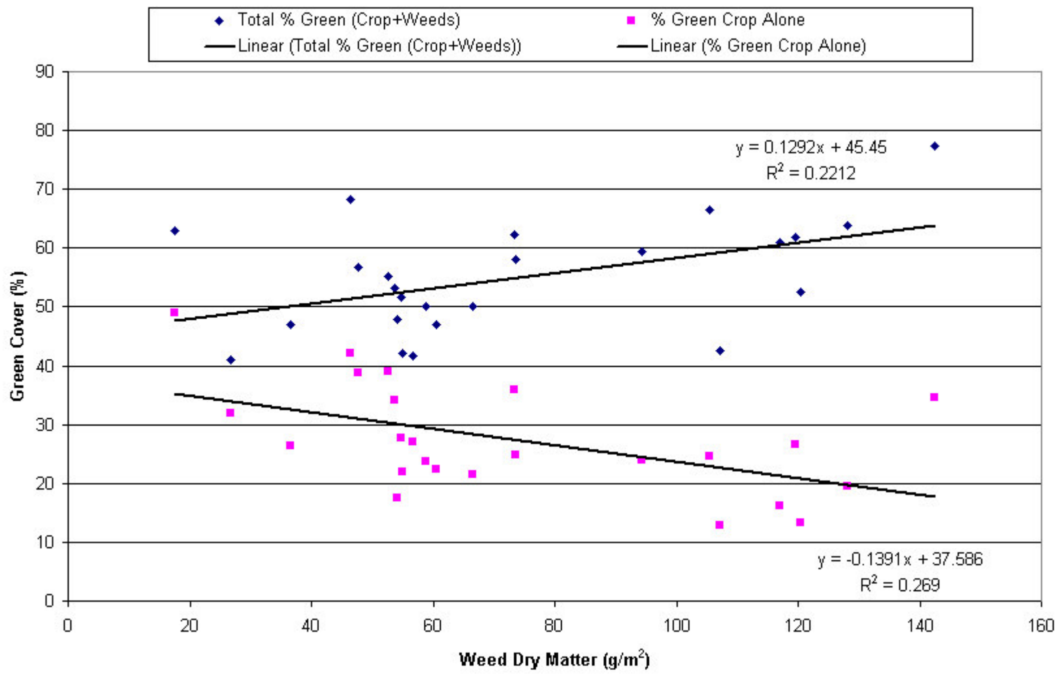

Figure 6-10 The portion of green cover observed as a function of weed dry matter for wheat at the 2-tiller growth stage for plot DXA (m_{dw}= 1.9 g/m^2). Crop canopy was near saturation and the crop growth was reduced at high weed intensities causing m_{dw} to be poorly defined.

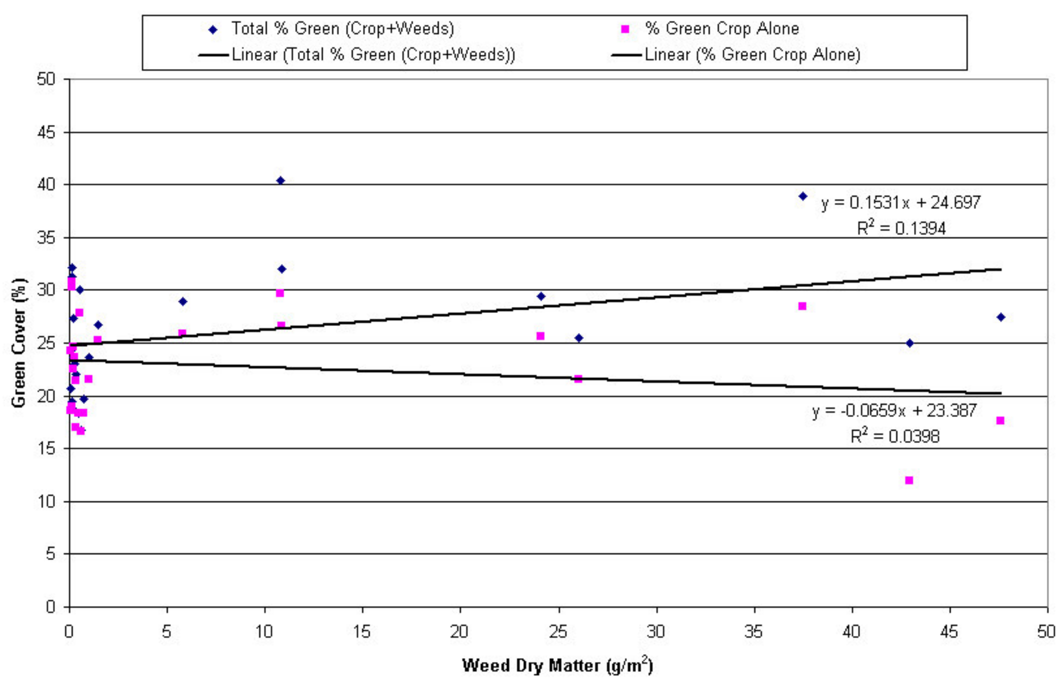

Figure 6-11 The percent green cover observed as a function of weed dry matter for wheat at the 2-tiller growth stage for plot DXB (m_{dw}= 52.9 g/m^2). M_{dw} poorly defined.

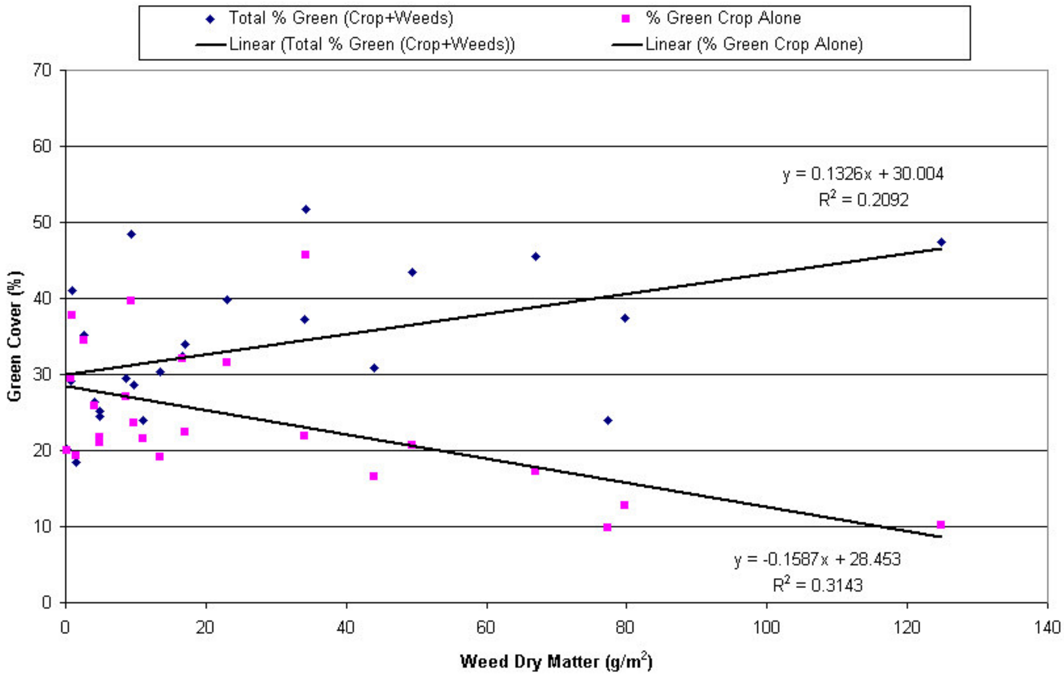

Figure 6-12 The percent green cover observed as a function of weed dry matter for wheat at the 2-tiller growth stage for plot DXC (m_{dw}= 93.5 g/m^2). Severe competition due to high weed intensities was observed.

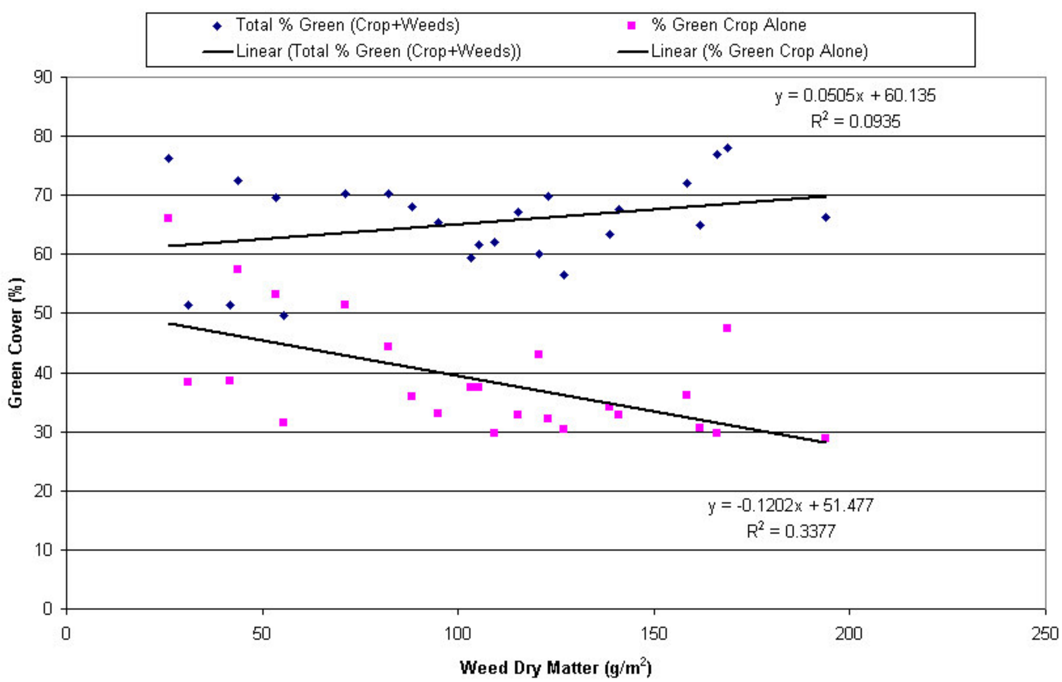

Figure 6-13 The percent green cover observed as a function of weed dry matter for wheat at the 3-tiller growth stage for plot DXA (m_{dw} was indeterminate (negative)). Crop canopy was at saturation with high weed intensities severely affecting crop.

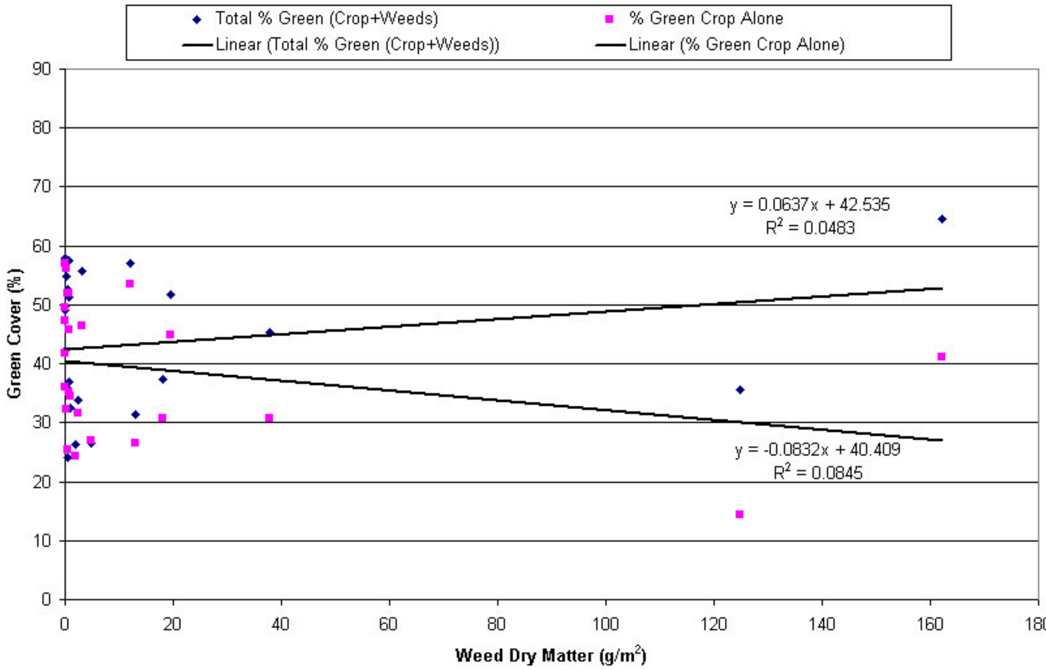

Figure 6-14 The percent green cover observed as a function of weed dry matter for wheat at the 3-tiller growth stage for plot DXB (m_{dw}= 308.7 g/m^2). M_{dw} too high to be practical.

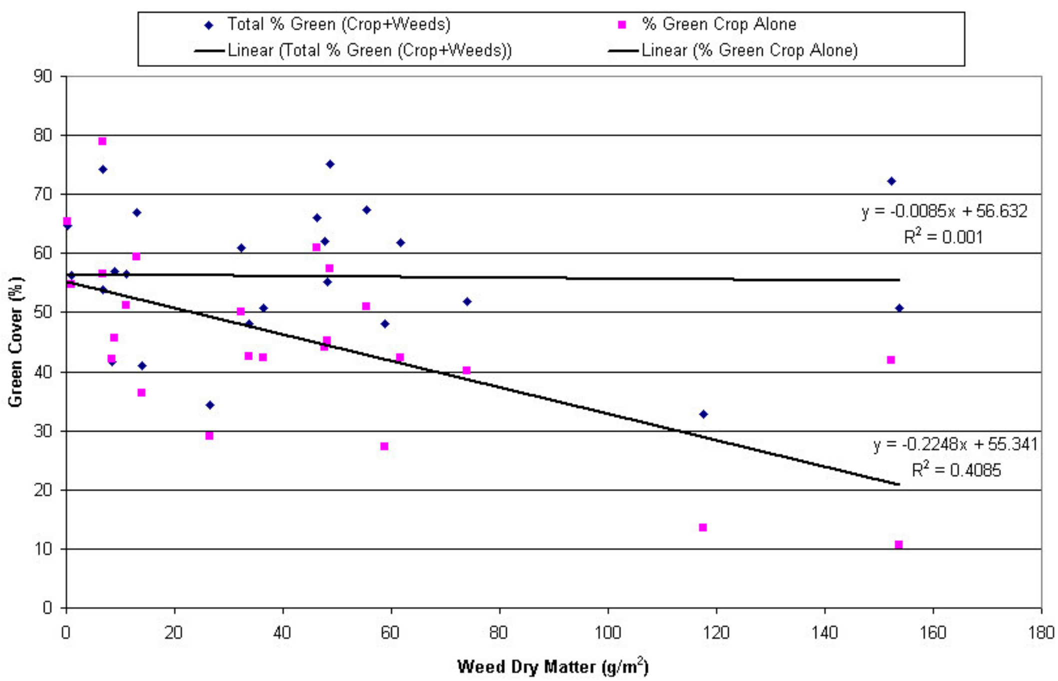

Figure 6-15 - The percent green cover observed as a function of weed dry matter for wheat at the 3-tiller growth stage for plot DXC (mdw was indeterminate (negative)). Crop canopy was at saturation with high weed intensities severely affecting crop.

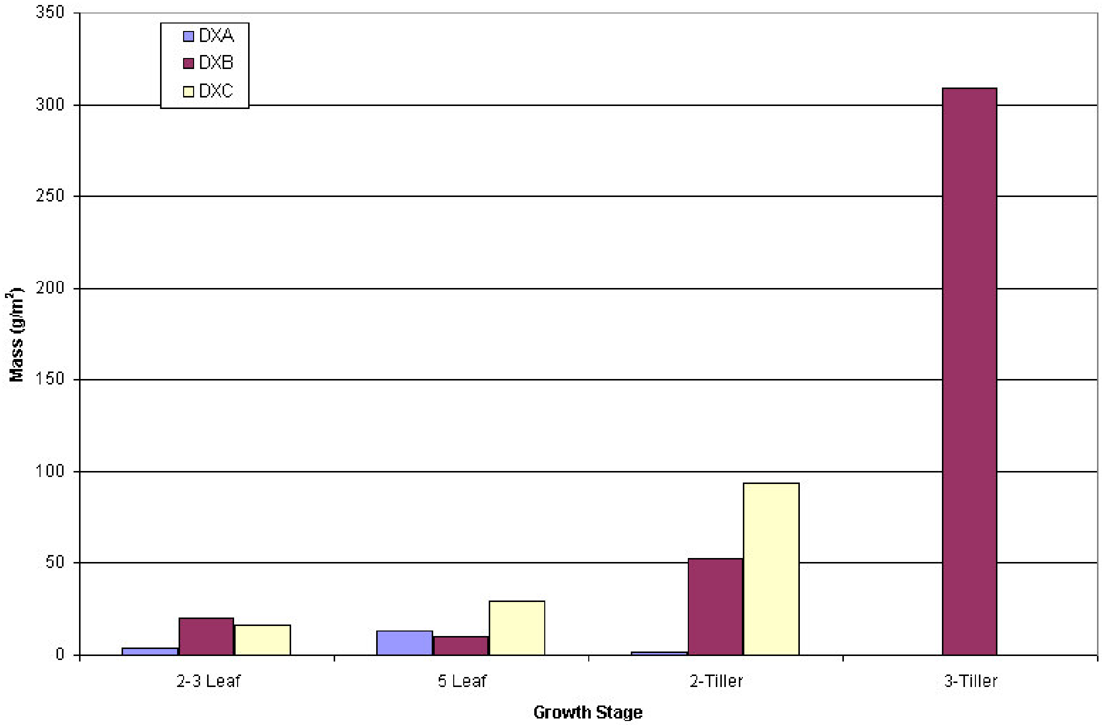

Figure 6-16 Minimum detectable weed dry matter (m_{dw}) determined for each plot and growth stage.

6.5 Spatial distribution of weeds mapped by the imaging system

To demonstrate how an imaging system like the one described in this report could be used to map weed intensities, a number of maps were generated from the DGPS location data for each sample point. Figure 6.17 shows the approximate distribution of weeds prior to seeding, mapped with a DGPS receiver and visually delineating distinct weed patches. Superimposed on each map is the location of each pre-seeding image measurement with the size of each dot in proportion to the percent green cover measured at each location. All of the points with the highest percent green cover were in proximity to the visually mapped weed areas. This relationship between green cover and weed areas was expected since no crop was present and all green cover could be classified as weed.

To illustrate the potential for spatial weed mapping using green cover measurements within a crop, the percent green cover above the m_{dw} threshold for each plot at the 5-leaf growth stage was plotted and visually compared to perimeter maps of weed patches estimated by ground observations at the conclusion of the field tests (2-tiller growth stage). The 5-leaf growth stage was the latest stage at which m_{dw} could be reliably determined. Using the DGPS location of each sample point, a 2-m interpolated grid weed map was generated using the inverse distance-weighting algorithm in ArcView 3.2 (ESRI, Redlands, California). Figures 6.18, 6.19 and 6.20 illustrate the similarities observed between the weed dry matter estimated by the imaging system and the boundaries of the distinct weed patches delineated by field scouting. Although weeds were found throughout the plots at the 2-tiller stage, patterns of weed distribution are visible in both the map derived from field scouting and the map generated from green cover data. Areas with low weed densities, such as the small patch in the northwest corner of plot DXA were visible in both maps (Figure 6.18).

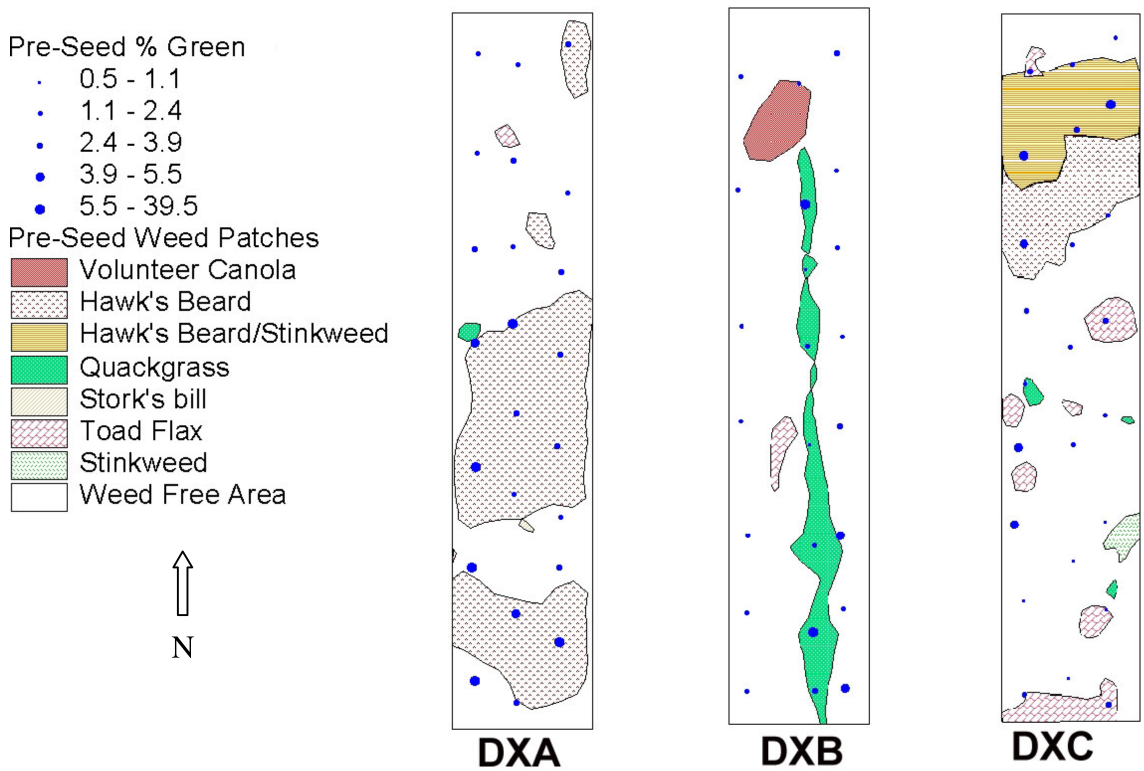

Figure 6-17 Pre-seeding observations of spatial weed distributions in each plot. The dots represent image sample points with the size of the dot being proportional to the percent green cover measured by the imaging system at that point.

High weed intensities were predicted in the centre and lower half of plot DXA (Figure 6.18), the northwest corner and east-centre of plot DXB (Figure 6.19), and at two locations in plot DXC (Figure 6.20).

The similarities between the weed distribution predicted by the imaging system and the actual observed weed distribution were a visual check, and were not scientifically evaluated in this experiment. The potential to create accurate weed maps from spatial green cover data will require further investigation.

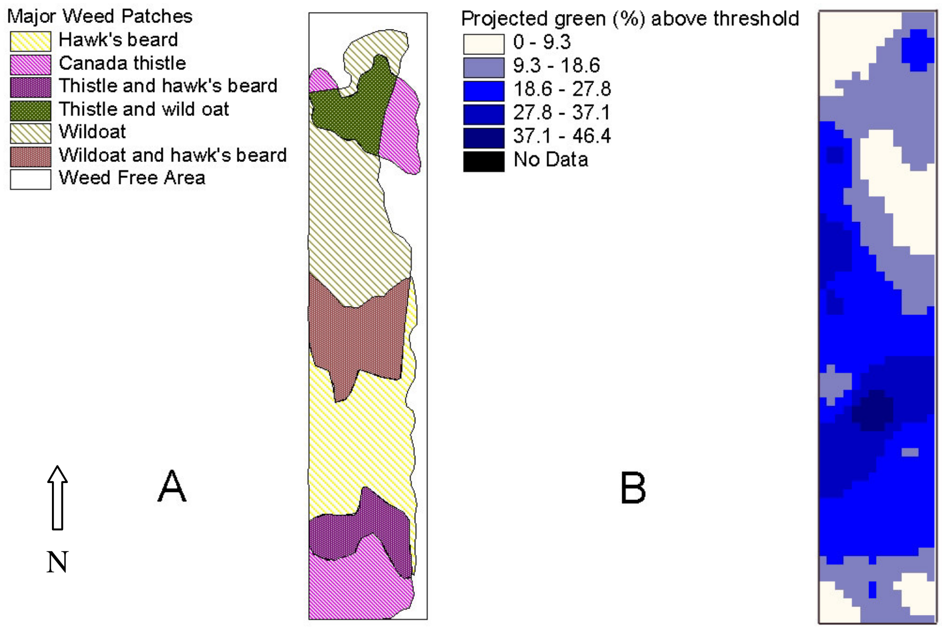

Figure 6-18 Comparison of data derived from manual scouting and from the imaging system for plot DXA. Image A delineates the major weed patches and was determined by ground observation at the 2-tiller growth stage. Image B is an interpolated 2-m grid of estimated weed dry matter generated using the percent green above the m_{dw} threshold at the 5-leaf stage.

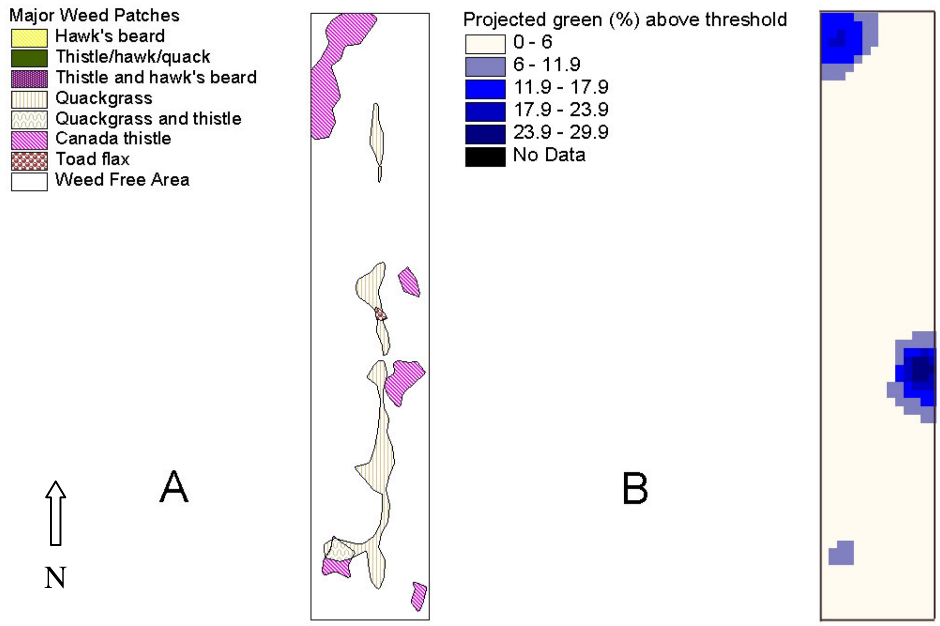

Figure 6-19 Comparison of data derived from manual scouting and from the imaging system for plot DXB. Image A delineates the major weed patches and was determined by ground observation at the 2-tiller growth stage. Image B is an interpolated 2-m grid of estimated weed dry matter generated using the percent green above the m_{dw} threshold at the 5-leaf stage.

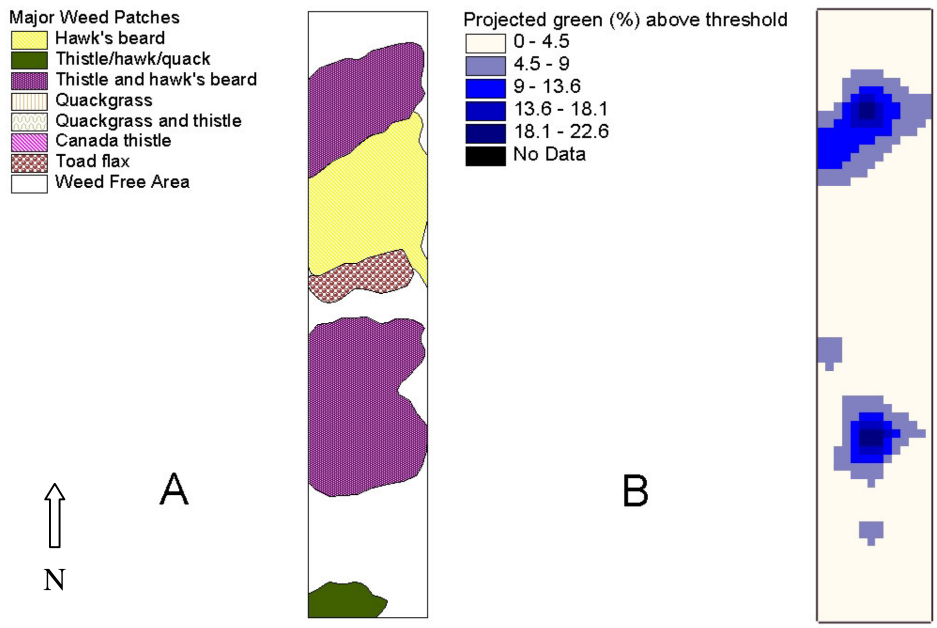

Figure 6-20 Comparison of data derived from manual scouting and from the imaging system for plot DXC. Image A delineates the major weed patches and was determined by ground observation at the 2-tiller growth stage. Image B is an interpolated 2-m grid of estimated weed dry matter generated using the percent green above the m_{dw} threshold at the 5-leaf stage.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 The Imaging System

The two-camera imaging system developed for this field experiment was capable of classifying plant from background material and determining the portion of the field of view occupied by growing plants. If threshold settings remained constant, changes in the portion of projected green area were detectable and useful in evaluating the field experiment's objectives. Changes in ambient light continued to have an effect on the imaging system's stability. The unavoidable problem of parallax affected the overlap of images from the two-camera system and the classification of pixels. Using two cameras/lenses with independent manual iris rings was time consuming and created problems balancing the exposure of the two cameras. These problems can be eliminated in future experiments by using a specially designed multispectral 3-CCD camera utilizing one lens with filters for red, near-infrared and green wavelengths, similar to the ones manufactured by Redlake (San Diego, CA) and used in remote sensing applications. The cost of such a camera for this initial investigation was prohibitively expensive. If more work is to be done in this area, a single camera system should be considered.

7.2 The Field Experiment

Plant dry matter was found to be related to the projected green cover measured by the imaging system, especially at early growth stages. Measurements of total projected green cover using a ground-based imaging system had potential to estimate the spatial weed dry matter within a wheat crop in certain situations. The best estimates of weed dry matter were achieved at early growth stages when the crop cover did not exceed 30% of the area in the field of view. The increase in projected green cover caused by small weed populations was masked within the variability of the crop. However, if the weed density was high, the additional projected green cover could be attributed to the weeds. At the 2-leaf growth stage in wheat, weed dry matter of 20 g/m^2 could be detected in all 3 plots. At the 5-leaf growth stage, weed dry matter of 30 g/m^2 could be detected in all 3 plots. Once the crop began to tiller and the crop canopy began to close, the ability to detect weeds by projected green cover was reduced, requiring a weed dry matter of 100 g/m^2 or more to be detected. Because most chemical post emergent weed control is done between the 3-leaf and 6-leaf stage in wheat, weed detection at the advanced growth stages may not be necessary.

These tests were done on relatively uniform crop stands with small plots and on flat ground. More investigation is necessary to evaluate the potential of using projected green cover as an estimate of weed infestations across an entire field, in different crops and at different row spacings.

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APPENDIX A – SOFTWARE LISTING

```
'  This program captures images from two cameras attached to the
'  Matrox Meteor II/MC card.  Each source image was displayed on the
'  Screen.  The two B/W images are combined into one colour image with
'  the information from each camera on the Red and Green bands.
'  The program then classifies pixels as plant or not depending on a
'  Ratio of NIR/RED.  The percent of pixels classified as plant is
'  Calculated.  The program also provides data logging of image
   information and GPS location of images.
'  ** Robert Baron May 10 2003 **

Private Sub About2_Click()
 ' Display the About Screen
 About.Show
End Sub

Private Sub Capture_Click()
' Stops Grab loop when Capture Stop button was pushed
' only if Black and White reference levels are in the correct zone.
   CapFlag = 1
End Sub

Private Sub Command1_Click()
 ' Toggle Timer2 on or off
 ' Timer2 was used to capture images and process them at a regular
interval\
 ' Then save the information to disk
    If TFlag = 0 Then
    Timer2.Enabled = True
    TFlag = 1
    Else
    Timer2.Enabled = False
    TFlag = 0
    End If
End Sub

Private Sub Form_Load()
'   Load defaults from configuration file when program was started and
save in
'   appropriate locations

    'Sets location for configuration file to the application path
    ' ChDir "d:\BaronVB\VB2003"
    ' ChDir App.Path

    Open "d:\BaronVB\VB2003\Weedefaults.txt" For Input As #1

    Input #1, Nm, FNm
    Input #1, XR, YR, XN, YN
    Input #1, a, B, C, D, E, F
    Input #1, XX, YY, ImgX, ImgY, XRef, YRef, BL, WL, Tol, Logfile
    Input #1, BLdiff, Grow
    FileName.Text = Nm
    FldName.Text = FNm
```

```
    Growthstage.Text = Grow
    Threshold.Text = a: Shutter.Text = B: NormNIR.Text = C:
NormRED.Text = D
    BLevel.Text = E: WLevel.Text = F
    XRED.Text = XR: YRED.Text = YR
    XNIR.Text = XN: YNIR.Text = YN
    Slider1.Value = YR
    Slider2.Value = XN
    Slider3.Value = BLevel
    Slider4.Value = WLevel
    'Turn Graphs off at start of program
    HistRED.Visible = False: HistNIR.Visible = False

    Close #1
    ' Open Com1 Port to read GPS Receiver
    GPSComm1.PortOpen = True
    Label16.Caption = "Set BLred + " + Str(BLdiff)

End Sub
```

Private Sub GPSTimer_Timer()

```
' Data array holds each line of GPS data
' Data2 array holds each element of each line
   Dim data() As String
   Dim data2() As String
   Dim i As Integer

' Read data from Com1 input buffer and display
inputstring = GPSComm1.Input

' Split data into lines
data() = Split(inputstring, Chr$(13) + Chr$(10))

' Test data for Recommended Minimum NMEA sentence
For i = LBound(data()) To UBound(data())
 testvar = data(i)
 data2() = Split(testvar, ",")
' Added to prevent nulls in Data2 array
 If testvar = "" Then GoTo 200
' Added to deal with partial read of $GPRMC sentence
 If data2(0) = "$GPRMC" And UBound(data2()) > 5 Then GoTo 100
 GPSvalid.Caption = "Not Valid": GoTo 200
100 GPSvalid.Caption = "Valid"

' Test NMEA sentence for valid GPS data
    If data2(2) = "A" Then GoTo 150
    GPSCurrent.Caption = "Old GPS Position": GoTo 160
150 GPSCurrent.Caption = "Current GPS Position"

' Calculate lat and long in decimal degrees
' Lat in position 3 and Long in position 5 of the NMEA sentence
160 latdeg = Val(Left(data2(3), 2)) + Val(Right(data2(3), 9) / 60)
    Latlabel.Caption = latdeg
    longdeg = Val(Left(data2(5), 3)) + Val(Right(data2(5), 9) / 60)
```

```
    LongLabel.Caption = -longdeg
200 Next

End Sub
```

Private Sub GrabRED_Click()

```
 ' DigRED - Digitizer for RED/NIR Cameras on Channel 0
 ' Grab from Both Red and NIR Cameras in a loop

 ' Sets the Black and White Reference Level for Digitizer
    DigRED.BlackReference = Val(BLevel.Text)
    DigRED.WhiteReference = Val(WLevel.Text)

' Sets the Gain of the Digitizer based on the option buttons
        If Option1.Value = "True" Then
        DigRED.InputGain = digGain3
        'DigNIR.InputGain = digGain3
        Else
        If Option2.Value = "True" Then
        DigRED.InputGain = digGain2
        'DigNIR.InputGain = digGain2
        Else
        If Option3.Value = "True" Then
        DigRED.InputGain = digGain1
        'DigNIR.InputGain = digGain1
        Else
        If Option4.Value = "True" Then
        DigRED.InputGain = digGain0
        'DigNIR.InputGain = digGain0
        Else
        If Option5.Value = "True" Then
        DigRED.InputGain = digGain4
        'DigNIR.InputGain = digGain4
        Else

        End If: End If: End If: End If: End If

        Label13.Caption = DigRED.InputGain

     ' Sets channel and sync channel
     DigRED.SignalChannel = digCh0
     DigRED.SyncChannel = digCh0
     ' Grab and Save Image into ImgTEMP
     DigRED.ImageName = "ImgTEMP"
     DigRED.Grab

     'Copy Green layer to ImgRED and RED Layer to ImgNIR
     ImgRED.Copy ImgTEMP, imGreen
     ImgNIR.Copy ImgTEMP, imRed
     'Save Original Images into Picture locations for future save
     PicRED.Picture = ImgRED.Picture
     PicNIR.Picture = ImgNIR.Picture
```

```
' Find Maximum pixel value and display
     ImageProcessing4.Source1 = ImgRED
     ImageProcessing4.FindExtremes False, True
     MaxRED = ImageProcessing4.Results(1)

' Find Maximum pixel value and display
    ImageProcessing4.Source1 = ImgNIR
    ImageProcessing4.FindExtremes False, True
    MaxNIR = ImageProcessing4.Results(1)

    'Reset HFlag for new grab
    Hflag = 0

 ' Goto Image Processing Subroutine
    Reprocess_Click

' Start grab loop to capture repeatedly until halt button was hit
   Timer1.Enabled = True

' Start GPS timer to capture GPS position every 1 sec
    GPSTimer.Enabled = True

End Sub
```

Private Sub Exit_Click()

```
'End When selected and close GPS on Com1
    GPSComm1.PortOpen = False
    End
End Sub
```

Private Sub Halt_Click()

```
' Stops Grab loop when Halt button was pushed
   Timer1.Enabled = False
   'Halt flag used in reprocessing routine to save grabbed grey levels
   Hflag = 1

' Stop GPS logging
    GPSTimer.Enabled = False
    ' GPSvalid.Caption = "Not Valid"
    ' GPSCurrent.Caption = "Old GPS Position"

End Sub
```

Private Sub Load_Click()

```
' Load Images from File for Processing
    CommonDialog1.DialogTitle = "Pick only the BIN file!"

    ' Opens Standard Windows Dialog
    CommonDialog1.ShowOpen

    'ImgBinary.Picture = LoadPicture(CommonDialog1.FileName)
    'Loads all three images into appropriate buffers
    DispBinary.ImageName = "ImgBinary"
    FnameBin = CommonDialog1.FileName
    L = Len(FnameBin)
```

```
    Fname = Left(FnameBin, L - 7)
    ImgRED.Picture = LoadPicture(Fname + "RED.bmp")
    DispRED.ImageName = "ImgRED"
    ImgNIR.Picture = LoadPicture(Fname + "NIR.bmp")
    DispNIR.ImageName = "ImgNIR"
End Sub
```

Private Sub Mask_Click()

```
' Shows Form for setting the cut dimensions and location
   Frame.Show
End Sub
```

Private Sub Normalize_Click()

```
' *** Not used in Current Version
'Normalize Pictures to Set Grey Value on Test Square
'Normalize RED
    'ImgTemp2.Copy ImgRED, imAllBands 'Convert to Floating point image
for processing
    'ImageProcessing3.Source1 = ImgTemp2

    ' Normalize by adding or subtracting difference between( Normalize
Value)-(Grey Reading)
    DiffRED = Val(NormRED.Text) - Val(MaxRED.Caption)
    ImageProcessing3.Source1 = ImgRED
    ImageProcessing3.Source2 = Abs(DiffRED)
    ImageProcessing3.Destination1 = ImgRED
      If DiffRED > 0 Then
        ImageProcessing3.Add True
      Else
        ImageProcessing3.Subtract False, True
      End If

'Normalize NIR
    'ImgTemp2.Copy ImgNIR, imAllBands 'Convert to Floating point image
for processing
    'ImageProcessing3.Source1 = ImgTemp2
    DiffNIR = Val(NormNIR.Text) - Val(MaxNIR.Caption)
    ImageProcessing3.Source1 = ImgNIR
    ImageProcessing3.Source2 = Abs(DiffNIR)
    ImageProcessing3.Destination1 = ImgNIR
      If DiffNIR > 0 Then
        ImageProcessing3.Add True
      Else
        ImageProcessing3.Subtract False, True
      End If

    ' Reprocess using the Normailized Images
    Reprocess_Click
End Sub
```

Private Sub Histogram()

```
 ' Draw the histograms of the RED and NIR image at the bottom of the
screen
```

```
    PAverage.Source1 = ImgRED
    PAverage.Destination1 = ImgRED
    PAverage.Histogram
    PAverage.Results.Get impValues, IntenseRED

    ' Sets vertical scale of graph
    HistRED.Plot.Axis(VtChAxisIdY).ValueScale.Auto = False
    HistRED.Plot.Axis(VtChAxisIdY).ValueScale.Maximum = 4000
    HistRED.ChartData = IntenseRED

    PAverage.Source1 = ImgNIRClip
    PAverage.Destination1 = ImgNIRClip
    PAverage.Histogram
    PAverage.Results.Get impValues, IntenseNIR
    HistNIR.Plot.Axis(VtChAxisIdY).ValueScale.Auto = False
    HistNIR.Plot.Axis(VtChAxisIdY).ValueScale.Maximum = 4000
    HistNIR.ChartData = IntenseNIR

    'Make graphs visible
    HistRED.Visible = True: HistNIR.Visible = True

End Sub
```

Private Sub Reprocess_Click()

```
' Main Image Processing Routine
' Combine each camera into bands on colour image with offset
' Reads offset from slider locations

    'Automatically adjust Black and White Reference Levels
    'Process if check box set for auto
    'If AutoAdjust.Value = 1 Then
    '    Auto_Balance
    'Else: End If

    ImgCombine.Clear
    XRED = Val(XRED.Text): YRED = Val(YRED.Text)
    XNIR = Val(XNIR.Text): YNIR = Val(YNIR.Text)
    ImgCombine.CopyRegion ImgNIR, imAllBands, 0, 0, imGreen, XNIR,
YNIR, 640, 480
    ImgCombine.CopyRegion ImgRED, imAllBands, 0, 0, imRed, XRED, YRED,
640, 480

'       Clips subregions from each image into buffers
'       Divides the two images
'       Binarize image to given threshold

    'Sets ImgBinary and Tempbuffer image to Cut image size
    ImgBinary.Free
    ImgBinary.SizeX = ImgX: ImgBinary.SizeY = ImgY
    ImgBinary.Allocate

    Tempbuffer.Free
    Tempbuffer.SizeX = ImgX: Tempbuffer.SizeY = ImgY
    Tempbuffer.Allocate
```

```
'   Copy image regions for analysis using offset

    ImgREDClip.CopyRegion ImgRED, imAllBands, XNIR + XX, YNIR + YY,
imAllBands, 0, 0, ImgX, ImgY
    ImgNIRClip.CopyRegion ImgNIR, imAllBands, XRED + XX, YRED + YY,
imAllBands, 0, 0, ImgX, ImgY

'   Divide images and place result in image ImgBinary
'   Note: ImgBinary has properties changed to 32 bit floating point
    ImageProcessing1.Source1 = ImgNIRClip
    ImageProcessing1.Source2 = ImgREDClip

    ImageProcessing1.Destination1 = ImgBinary
    ImageProcessing1.Divide

         '   ImageProcessing1.Source1 = ImgBinary
         '   ImageProcessing1.Source2 = 20
         '   ImageProcessing1.Multiply
         '   Temp2.Copy ImgBinary, imAllBands
         '   PicComp.Picture = Temp2.Picture

'   Set image pixels to black or white depending on threshold
    ImageProcessing2.Source1 = ImgBinary
    ImageProcessing2.Destination1 = Tempbuffer
    ImageProcessing2.Binarize impLessThan, Val(Threshold.Text)

'   Copy floating point image ImgBinary into a temporary 8-Bit buffer
'   Create histogram form 8-bit buffer and place results in an array
'   Use array values for black(0) and white(255) to calculate % green
    ImageProcessing4.Source1 = Tempbuffer
    ImageProcessing4.Destination1 = Tempbuffer
    ImageProcessing4.Histogram
    ImageProcessing4.Results.Get impValues, Resultarray
    Greenlabel.Caption = Int(Resultarray(0) / (Resultarray(255) +
Resultarray(0)) * 1000) / 10

    'Select which image to display - Helps to check alignment of cut
        If VBIN.Value = "True" Then
        DispBinary.ImageName = "Tempbuffer"
        Else
        If VRED.Value = "True" Then
        DispBinary.ImageName = "ImgREDClip"
        Else
        If VNIR.Value = "True" Then
        DispBinary.ImageName = "ImgNIRClip"
        Else
        End If: End If: End If

    'Saves Binary image to Picture Buffer to be saved later
    PicBin.Picture = Tempbuffer.Picture

' Locate areas on mask to measure incident radiation
' Size of white and black reference images
    XA = 20: YA = 60
```

```
    GraphicContext2.Image = ImgCombine
    GraphicContext2.DrawingRegion.CenterX = XX + XNIR + XRED - XRef
    GraphicContext2.DrawingRegion.CenterY = YY + ImgY / 2 + YNIR +
YRED - YRef
    GraphicContext2.DrawingRegion.SizeX = XA
    GraphicContext2.DrawingRegion.SizeY = YA

    ' Display location of test areas for alignment if box checked
      If ShowRef.Value = 1 Then
        GraphicContext2.Rectangle True
        Else: End If
    GraphicContext2.DrawingRegion.CenterX = XX + XNIR + XRED - XRef
    GraphicContext2.DrawingRegion.CenterY = YY + ImgY / 2 + YNIR +
YRED + YRef
    GraphicContext2.DrawingRegion.SizeX = XA
    GraphicContext2.DrawingRegion.SizeY = YA
      If ShowRef.Value = 1 Then
        GraphicContext2.Rectangle True
        Else: End If

 'Copy Black test square into temorary buffer and calulate the average
 'Average Pixel intensity for the NIR Black Card

    BLRef.CopyRegion ImgCombine, imGreen, XX + XNIR + XRED - XRef - XA
/ 2, YY + ImgY / 2 + YNIR + YRED - YA / 2 - YRef, imAllBands, 0, 0,
XA, YA
    PAverage.Source1 = BLRef
    PAverage.Destination1 = BLRef
    PAverage.Histogram
    PAverage.Results.Get impValues, Intense
      tot = 0
      For i = 0 To 255
        tot = tot + Intense(i) * i
      Next i
    BLNIR.Caption = Int(tot / (XA * YA))
    '   GoTo 10 ' Bypass for diagnostics
 'Now calulate the average pixel intensity for the RED Black Card
    'Process the left 50 by 50 pixel square
    BLRef.CopyRegion ImgCombine, imRed, XX + XNIR + XRED - XRef - XA /
2, YY + ImgY / 2 + YNIR + YRED - YA / 2 - YRef, imAllBands, 0, 0, XA,
YA
    PAverage.Source1 = BLRef
    PAverage.Destination1 = BLRef
    PAverage.Histogram
    PAverage.Results.Get impValues, Intense
      tot = 0
      For i = 0 To 255
        tot = tot + Intense(i) * i
      Next i
    BLRED.Caption = Int(tot / (XA * YA))
10 ' Continue
'Calculate the average pixel intensity for the NIR White Card
    WLRef.CopyRegion ImgCombine, imGreen, XX + XNIR + XRED - XRef - XA
/ 2, YY + ImgY / 2 + YNIR + YRED + -YA / 2 + YRef, imAllBands, 0, 0,
XA, YA
```

```
    PAverage.Source1 = WLRef
    PAverage.Destination1 = WLRef
    PAverage.Histogram
    PAverage.Results.Get impValues, Intense
      tot = 0
      For i = 0 To 255
        tot = tot + Intense(i) * i
      Next i
    WLNIR.Caption = Int(tot / (XA * YA))
    '    GoTo 20 ' Bypass for diagnostics
 'Calculate the average pixel intensity for the RED White Card
    WLRef.CopyRegion ImgCombine, imRed, XX + XNIR + XRED - XRef - XA /
2, YY + ImgY / 2 + YNIR + YRED + -YA / 2 + YRef, imAllBands, 0, 0, XA,
YA
    PAverage.Source1 = WLRef
    PAverage.Destination1 = WLRef
    PAverage.Histogram
    PAverage.Results.Get impValues, Intense
      tot = 0
      For i = 0 To 255
        tot = tot + Intense(i) * i
      Next i
    WLRED.Caption = Int(tot / (XA * YA))
20 ' Continue
    If Hflag = 0 Then
     '   GreyRED = MaxRED.Caption
    '  GreyNIR = MaxNIR.Caption
    Else: End If
    ' Call Histogram subroutine to display histogram of RED and NIR
images
    Histogram

    'Automatically adjust Black and White Reference Levels
    'Process if check box set for auto
    If AutoAdjust.Value = 1 Then
        Auto_Balance
    Else: End If

    ' Check to see if Aperature alarm was clicked
    ' If clicked produce a beep when BlackLevel in each picture is
    ' within desired level (typically +10 on red)
    If AppAlarm.Value = 1 Then
      If Val(BLRED.Caption) = Val(BLNIR.Caption) + BLdiff Then
      Beep
      Else: End If
    Else: End If

    If Timer2.Enabled = True Then
        Command1.BackColor = &HFFFF&
        Else
        Command1.BackColor = &H8000000F
        End If
End Sub
```

```
Private Sub Auto_Balance()
' Sets the black and white voltage reference levels for the digitizer

    BLNIR = Val(BLNIR.Caption)
    WLNIR = Val(WLNIR.Caption)
    BLRED = Val(BLRED.Caption)

  If BLNIR > (BL - Tol) And BLNIR < (BL + Tol) Then GoTo 30 ' Skip if
in range
  If BLNIR > BL Then
    If BLevel = 255 Then GoTo 10
    BLevel = BLevel + 1 ' Increase Black level if required
10  Else
        If BLevel = 1 Then GoTo 20
        BLevel = BLevel - 1 ' Decrease Black level if required
20  End If

30 'Continue
  If WLNIR > (WL - Tol) And WLNIR < (WL + Tol) Then GoTo 50
  If WLNIR > WL Then
    If WLevel = 255 Then GoTo 40
    WLevel = WLevel + 1 ' Increase White level if required
40  Else
    If WLevel = 1 Then GoTo 50
    WLevel = WLevel - 1
50 'Continue
  End If
  ' Set sliders to new value
  Slider3.Value = BLevel
  Slider4.Value = WLevel

  'Check to see if values are within tolerance level and turn light on
  If (BL - Tol) < BLNIR And BLNIR < (BL + Tol) And (WL - Tol) < WLNIR
And WLNIR < (WL + Tol) And (BL + BLdiff - Tol) < BLRED And BLRED < (BL
+ BLdiff + Tol) Then
    LED.Visible = True

    'Log 'Calls Log subroutine for diagnostics
    Else
    LED.Visible = False
    End If

End Sub


Private Sub S_Binary_Click()

'Save Aligned Divided Image to file
 CommonDialog1.ShowSave
 SavePicture PicComp.Picture, CommonDialog1.FileName

End Sub

Private Sub S_Comp_Click()
```

```
'Save Aligned Composite Image to file
 PicComp.Picture = ImgCombine.Picture
 CommonDialog1.ShowSave
 SavePicture PicComp.Picture, CommonDialog1.FileName

End Sub
```

Private Sub Save_As_Click()

```
 ' Save Images into predefined files with appropriate codes

 ' If Hand Weeded Box was checked then add a W to the file name
 If Check1.Value = 1 Then
    WW$ = "W"
    Else: WW$ = ""
    End If

  'Sets up error handling for Cancel Button
  CommonDialog1.CancelError = True

' Save Red image
  FnameRED = ImgNumber.Text + WW$ + FileName.Text + "_RED.bmp"
  CommonDialog1.FileName = FnameRED
  On Error GoTo 100
  CommonDialog1.ShowSave
  SavePicture PicRED.Picture, CommonDialog1.FileName
  'FnameRED = CommonDialog1.FileName
100 Resume Next ' Cancel Error handling and Skip Save

' Save NIR image
  FnameNIR = ImgNumber.Text + WW$ + FileName.Text + "_NIR.bmp"
  CommonDialog1.FileName = FnameNIR
  On Error GoTo 200
  CommonDialog1.ShowSave
  SavePicture PicNIR.Picture, CommonDialog1.FileName
  'FnameNIR = CommonDialog1.FileName
200 Resume Next ' Cancel Error handling and Skip Save

' Save Binary image
  FnameBin = ImgNumber.Text + WW$ + FileName.Text + "_BIN.bmp"
  CommonDialog1.FileName = FnameBin
  On Error GoTo 300
  CommonDialog1.ShowSave
  SavePicture PicBin.Picture, CommonDialog1.FileName
  'FnameBin = CommonDialog1.FileName

  ' Automatically Increment File Number
  ImgNumber.Text = Val(ImgNumber.Text) + 1

  ' Append Data for Image to the Data file
  N = CStr(Now) ' Current time and data as a string variable
  LF = Logfile + ".txt"
  Open LF For Append As #2
  Write #2, N; FnameRED; FnameNIR; FnameBin; FldName.Text;
Growthstage.Text; Orientation.Text;
```

```
  Write #2, Notes.Text; YRED.Text; XNIR.Text; Threshold.Text;
Greenlabel.Caption; XX; YY; ImgX;
  Write #2, ImgY; Shutter.Text; DigRED.InputGain; BLRED.Caption;
WLRED.Caption; BLNIR.Caption; WLNIR.Caption;
  Write #2, BLevel.Text; WLevel.Text; Latlabel.Caption;
LongLabel.Caption; GPSCurrent.Caption

  Close #2
    ' Reset GPS caption and notes field
    GPSvalid.Caption = "Not Valid"
    GPSCurrent.Caption = "Old GPS Position"
    Notes.Text = "Enter Notes"
300 Resume Next ' Cancel Error handling and Skip Save
End Sub
```

Private Sub Save_Click()

```
' Direct to save subroutine when save button was hit
    Save_As_Click
End Sub
```

Private Sub Save_Setting_Click()

```
' Save calibration settings to be loaded next time program was started
    ' ChDir App.Path ' Sets directory to application path
    ' ChDir "d:\BaronVB\VB2003"
    Open "d:\BaronVB\VB2003\Weedefaults.txt" For Output As #1
    Print #1, FileName.Text
    Print #1, FldName.Text
    Print #1, XRED, YRED, XNIR, YNIR
    Print #1, Val(Threshold.Text), Val(Shutter.Text),
Val(NormNIR.Text), Val(NormRED.Text), Val(BLevel.Text),
Val(WLevel.Text)
    Print #1, XX, YY, ImgX, ImgY, XRef, YRef, BL, WL, Tol, Logfile
    Print #1, BLdiff, Growthstage.Text
    Close #1
End Sub
```

Private Sub Show_Cut_Click()

```
' Display the cut area as a rectangle over the combined image
    GraphicContext1.Image = ImgCombine
    GraphicContext1.DrawingRegion.CenterX = XX + (0.5 * ImgX) + XNIR +
XRED
    GraphicContext1.DrawingRegion.CenterY = YY + (0.5 * ImgY) + YNIR +
YRED
    GraphicContext1.DrawingRegion.SizeX = ImgX
    GraphicContext1.DrawingRegion.SizeY = ImgY
    ' Draw rectange  with fill set to false
    GraphicContext1.Rectangle False

End Sub
```

Private Sub Slider1_Click()

```
' Update Calibration when slider was moved Vertical
 YRED.Text = Slider1.Value
 Combine_Click
End Sub
```

```
Private Sub Slider2_Click()
' Update Calibration when slider was moved Horizontal
 XNIR.Text = Slider2.Value
 Combine_Click
End Sub

Private Sub Combine_Click()
' Combine each camera into bands on colour image with offset
    XRED = Val(XRED.Text): YRED = Val(YRED.Text)
    XNIR = Val(XNIR.Text): YNIR = Val(YNIR.Text)
    ImgCombine.CopyRegion ImgNIR, imAllBands, 0, 0, imGreen, XNIR,
YNIR, 640, 480
    ImgCombine.CopyRegion ImgRED, imAllBands, 0, 0, imRed, XRED, YRED,
640, 480
End Sub

Private Sub Slider3_Click()
' Update Black reference level when slider was moved.
  BLevel.Text = Slider3.Value
End Sub

Private Sub Slider4_Click()
' Update White reference level when slider was moved.
  WLevel.Text = Slider4.Value
End Sub

Private Sub Timer1_Timer()
  'Direct to Grab image repeatedly at 500 ms intervals
  'Stopp timer only if capture halt button pushed, levels in range and
  'GPS data were valid

  If CapFlag = 1 And LED.Visible = True And GPSvalid.Caption = "Valid"
Then
   CapFlag = 0
   Timer1.Enabled = False
    'Halt flag used in reprocessing routine to save grabbed grey
levels
        If T2Flag = 1 Then
        Log
        T2Flag = 0
        GrabRED_Click
        Else: End If
    Hflag = 1
    GoTo 10
  Else: End If

  GrabRED_Click
10 'Continue
End Sub

Private Sub Timer2_Timer()
 ' Capture image and save exposure information to file for diagnostics
 CapFlag = 1
 T2Flag = 1
```

```
End Sub
```

Private Sub Log()

```
' Used for diagnostics records information when ever levels are in the
correct zone
 LF = Logfile + ".txt"
 Open LF For Append As #3
    N = CStr(Now)
    Write #3, N; BLevel.Text; WLevel.Text; Greenlabel.Caption;
BLRED.Caption; WLRED.Caption; BLNIR.Caption; WLNIR.Caption;
Threshold.Text; DigRED.InputGain
    Close #3
    Logcount.Caption = Val(Logcount.Caption) + 1
End Sub
```

'Variable Assigments

```
Public Resultarray(0 To 255) As Long
Public Intense(0 To 255) As Long
Public IntenseRED(0 To 255) As Long
Public IntenseNIR(0 To 255) As Long
    Public ImgX As Double
    Public ImgY As Double
    Public XX As Integer
    Public YY As Integer
    Public XRef As Integer
    Public YRef As Integer
    Public BL As Integer
    Public WL As Integer
    Public Tol As Integer
    Public CapFlag As Integer
    Public T2Flag As Integer
Public FlagC As Integer
    Public XRED As Integer
    Public YRED As Integer
    Public XNIR As Integer
    Public YNIR As Integer
    Public Hflag As Integer
    Public TFlag As Integer
    Public GreyRED As Integer
    Public GreyNIR As Integer
    Public BLdiff As Integer
Public Logfile As String
```

APPENDIX B – VARIABLE DEFINITIONS

Public Variables

FlagC as Integer
GreyNIR as Integer – Average pixel intensity of grey card in NIR image
GreyRED as Integer – Average pixel intensity of grey card in RED image
Hflag as Integer – Set to 1 when halt button pushed
ImgX as Double – Width of Area of Interest (pixels)
ImgY as Double – Height of Area of Interest (pixels)
Intense (255) as Long – Array to store results of binary histogram function
IntenseRED (255) as Long – Array to store RED histogram
IntenseNIR (255) as Long – Array to store NIR histogram
Resultarray (255) as Long – Array to store results of histogram function
Tflag as Integer – Timer flag set during automatic capture
XNIR as Integer – X offset of NIR image
XRED as Integer– X offset of RED image
XX as Integer – X coordinate of upper left corner of area of interest
YNIR as Integer– Y offset of NIR image
YRED as Integer– Y offset of RED image
YY as Integer – Y coordinate of upper left corner of area of interest

Private Variables

A as Integer – Temporary variable for threshold
B as Integer – Temporary variable for shutter speed
C as Integer – Temporary variable for RED normalization
D as Integer – Temporary variable for NIR normalization
DiffRED - Difference between grey level and RED normailation
DiffNIR- Difference between grey level and NIR normailation
E as Integer – Temporary variable for black reference level
F as integer - Temporary variable for white reference level
Fname as String – Temporary variable for file name prefix
FnameBin as String – Binary file name
FnameNIR as String – NIR image file name
FnameRED as String – RED image file name
FNm as String – Field name
I as integer – Temporary counter
L as Integer – Temporary variable for string length
N as String – Date and time of image save
Nm as String – File prefix
Tot as integer – Accumulates pixel values during averaging operations
WW$ as String – Contained "W" if images were flagged as hand weeded
XN as Integer – X offset on NIR image
XR as Integer – X offset on Red image
YN as Integer – Y offset on NIR image
YR as Integer – Y offset on Red image

Text Box Storage Locations

BLevel.text – Black reference level
FileName.text – Prefix for file name
FldName.text – Field name
Growthstage.text – Text describing growth stage
ImgNumber.text – Image number for file name
NormRED.text – Normalization level for RED image
NormNIR.text – Normalization level for NIR image
Notes.text – User notes
Orientation.text – Text describing image orientation
Shutter.text - Shutter speed of camera
Threshold.text – Threshold number
Wlevel.text – White reference level
XNIR.text – X offset of NIR image
XRED.text – X offset of RED image
YNIR.text – Y offset of NIR image
YRED.text – Y offset of RED image

Special Control Properties Set

DigRED	Format	Rs170ROB.dcf (Custom camera definition file)
	Gain	M_GAIN2(0.7-1.0Vpp)
ImgRED	Number of Bands	1
	Unsigned 8-bit	
	Size 640 by 480	
ImgNIR	Number of Bands	1
	Unsigned 8-bit	
	Size 640 by 480	
ImgCombine	Can Grab	False
	Number of Bands	3
	Unsigned 8-bit	
	Size 850 by 494	
ImgREDClip	Can Grab	False
	Number of Bands	1
	Unsigned 8-bit	
	Size 900 by 700	

ImgNIRClip	Can Grab	False
	Number of Bands	1
	Unsigned 8-bit	
	Size 900 by 700	
ImgBinary	Can Grab	False
	Number of Bands	1
	32-bit Floating Point	
Tempbuffer	Number of Bands	1
	Unsigned 8-bit	
ImgTemp	Number of Bands	3
	Unsigned 8-bit	
Temp2	Number of Bands	1
	Unsigned 8-bit	
ImgTemp2	Number of Bands	1
	32-bit Floating Point	
Timer1	Interval 500 ms	

APPENDIX C – IMAGE BUFFERS AND CONTROLS USED IN SOFTWARE

The following **image buffers** were allocated in the program.

ImgBinary – A 32-bit, floating-point image used for division during image processing.
ImgCombine – Stored the false-colour image of the combined and aligned NIR and RED images.
ImgNIR – Stored the NIR black and white image.
ImgNIRClip – Stored the NIR image of the area of interest.
ImgRED – Stored the RED black and white image.
ImgREDClip – Stored the RED image of the area of interest.
ImgTemp – Unaligned RGB image used during capture.
ImgTemp2 – A 32-bit, floating-point image used for multiplication during normalization.
Tempbuffer –Stored the binary image of the area of interest.
Temp2 – Location for sub-image of reference card.

Image controls are used to allocate and operate on image buffers. The following Active MIL controls were used in the program

ImgBinary.Allocate – Allocated the resources of the image control
ImgBinary.Free – Freed the resources of the image control.
ImgBinary.SizeX – Set the image width.
ImgBinary.SizeY – Set the image height.
ImgCombine.Clear – Removed information from the buffer.
ImgCombine.CopyRegion – Copied data from a region of a source image into the specified region of a target image.
ImgRED.copy – Used to copy images from one buffer to another.
ImgRED.Picture – Loaded saved image into the buffer.

The following **Display Controls** were used in the program.

DispBinary – Displayed the binary image on the form. Can be switched to show the area of interest of any image.
DispCombine – Displayed the aligned composite image. Used during the alignment procedure and to display a rectangle showing the area of interest.
Display1 – Temporary display used to show the reference card sub-images.
DispNIR – Displayed the NIR black and white image.
DispRED – Displayed the RED black and white image.

DigRED was a **Digitizer Control** that manipulated and controlled the digitizer section of the imaging board and allowed acquisition commands to be sent to the imaging board.

DigRED.BlackReference – Set black reference level of the digitizer board.
DigRED.Grab – Grabbed image from digitizer board into image buffer.
DigRED.ImageName – Set the name of the destination image for grab operation.
DigRED.SignalChannel – Set video signal channel of the digitizer board.
DigRED.SyncChannel – Set the synchronization channel to be used.
DigRED.WhiteReference – Set white reference level of the digitizer board.

Image Processing Controls include a variety of image processing capabilities.

ImageProcessing1.Divide – Used to perform a point-to-point division of the NIR image by the RED image and store the results in a new image buffer.
ImageProcessing2.Binarize – Performed a point-to-point binary thesholding operation on the image.
ImageProcessing3.Multiply – Used to multiply the image by a constant. Used during the normalization subroutine to adjust the brightness of the image.
ImageProcessing4.FindExtremes – Determined the maximum pixel intensity of the image.
ImageProcessing4.Historgram – Generated the intensity histogram of the binary image.
PAverage.Histogram – Generated the intensity histogram of the reference cards and used to calculate the average intensity for the reference cards.

Graphic Context Controls are used to draw graphic objects on an image

GraphicContext1.DrawingRegion – Defined the location of a square that was drawn showing the area of interest on the image.
GraphicContext1.Rectangle – Drew the rectangle on the image
GraphicContext2.Rectangle – Drew a rectangle showing the location of the grey card in the image.

APPENDIX D – FIELD TEST DATA

Table D-1 Pre-seed summary data, May 11, 2003

Field Code	Image	Green %(System)	Weed Dry Matter (g)	Weed Dry Matter (g/m^2)	Latitude	Longitude
DXA	1	6.2	2.348	9.392	53.35487018	-110.932442
DXA	2	3.7	0.219	0.876	53.3550063	-110.9324441
DXA	3	2.2	0.412	1.648	53.35509745	-110.9324408
DXA	4	3.9	1.888	7.552	53.35522697	-110.9324486
DXA	5	3.3	0.239	0.956	53.35539402	-110.9324403
DXA	6	3.2	0.071	0.284	53.35554358	-110.9324362
DXA	7	1.5	0.064	0.256	53.35568587	-110.9324188
DXA	8	3.2	0.199	0.796	53.35595745	-110.932413
DXA	9	2.3	0.000	0.000	53.35592045	-110.9325681
DXA	10	3.2	0.497	1.988	53.35574562	-110.9325801
DXA	11	2.4	0.474	1.896	53.35558872	-110.9325838
DXA	12	6.8	2.560	10.240	53.35544927	-110.9325853
DXA	13	3	0.077	0.308	53.3552872	-110.9325728
DXA	14	2.3	0.110	0.440	53.35513778	-110.9325832
DXA	15	4.1	0.527	2.108	53.35492133	-110.9325768
DXA	16	2.5	0.211	0.844	53.3547597	-110.9325748
DXA	17	9.1	3.212	12.848	53.35479893	-110.9327014
DXA	18	6	0.856	3.424	53.35500572	-110.932709
DXA	19	7.8	1.798	7.192	53.35518928	-110.9326986
DXA	20	4	0.269	1.076	53.35541467	-110.9326988
DXA	21	3.8	0.331	1.324	53.35558433	-110.9326997
DXA	22	2.2	0.135	0.540	53.35575953	-110.9326921
DXA	23	1.3	0.244	0.976	53.35593963	-110.9326888
DXC	100	2	0.280	1.120	53.35388307	-110.9554659
DXC	101	0.5	0.058	0.232	53.35405838	-110.9554672
DXC	102	5.2	2.108	8.432	53.3541974	-110.9554952
DXC	103	5.5	0.448	1.792	53.35434075	-110.9554843
DXC	104	2.4	0.048	0.192	53.35445772	-110.9554625
DXC	105	3.1	0.113	0.452	53.35459177	-110.9554553
DXC	106	5.4	1.433	5.732	53.35471527	-110.955465
DXC	107	39.5	15.450	61.800	53.35487893	-110.9554639
DXC	108	2.7	0.842	3.368	53.35503437	-110.9554436
DXC	109	2.1	0.342	1.368	53.35504582	-110.9553154
DXC	110	3.1	1.712	6.848	53.35492548	-110.9553024
DXC	111	1.4	0.094	0.376	53.35471318	-110.9553157
DXC	112	1.6	0.000	0.000	53.35452335	-110.9553226
DXC	113	1.9	1.006	4.024	53.35434597	-110.9553135
DXC	114	0.5	0.000	0.000	53.35413365	-110.9553104
DXC	115	0.5	0.122	0.488	53.35391435	-110.9553281
DXC	116	3.5	0.050	0.200	53.35386608	-110.9552056
DXC	117	1.1	0.027	0.108	53.35404233	-110.9552117
DXC	118	0.5	0.067	0.268	53.35420377	-110.9552148

Field Code	Image	Green % (System)	Weed Dry Matter (g)	Weed Dry Matter (g/m^2)	Latitude	Longitude
DXC	119	1.7	1.312	5.248	53.35439945	-110.9552171
DXC	120	3.9	3.278	13.112	53.35457223	-110.9552121
DXC	121	1.7	0.000	0.000	53.3547665	-110.9552076
DXC	122	23	8.657	34.628	53.35497325	-110.9551967
DXC	123	1.8	0.072	0.288	53.3550948	-110.9551841
DXB	1	5.4	1.055	4.220	53.35182105	-110.9324175
DXB	2	1.6	0.045	0.180	53.35196622	-110.9324234
DXB	3	4.5	1.559	6.236	53.35209985	-110.9324313
DXB	4	2.9	0.845	3.380	53.35229965	-110.9324307
DXB	5	1.3	0.029	0.116	53.35246157	-110.9324264
DXB	6	1.4	0.280	1.120	53.35262448	-110.9324392
DXB	7	2.3	0.559	2.236	53.35276472	-110.9324439
DXB	8	2.5	0.393	1.572	53.35298092	-110.9324409
DXB	9	3.2	0.922	3.688	53.35181708	-110.9325087
DXB	10	5.8	2.811	11.244	53.35192478	-110.9325134
DXB	11	1.3	0.065	0.260	53.35208303	-110.9325117
DXB	12	0.8	0.031	0.124	53.35226847	-110.9325226
DXB	13	2	0.210	0.840	53.35244388	-110.9325328
DXB	14	1	0.032	0.128	53.35258542	-110.9325341
DXB	15	13.1	6.563	26.252	53.35270333	-110.9325368
DXB	16	1.9	0.295	1.180	53.3529248	-110.932558
DXB	17	1.5	0.397	1.588	53.35181508	-110.9327163
DXB	18	1.9	0.429	1.716	53.35196038	-110.9327184
DXB	19	2.1	0.410	1.640	53.35210007	-110.9327148
DXB	20	1.6	0.156	0.624	53.3523084	-110.9327363
DXB	21	1.2	0.131	0.524	53.35248058	-110.9327348
DXB	22	1.4	0.348	1.392	53.35273065	-110.9327442
DXB	23	2.1	0.648	2.592	53.35293752	-110.9327349

Table D-2 Plot DXA summary image data 2 to 3-leaf stage, June 7, 2003

Field Code	Image Number	Image Code	Total Green % 2-Camera System	Weed Dry Matter (g)	Weed Dry Matter (g/m^2)	Latitude	Longitude	Image Number	Image Code	Crop Only Green % 2-Camera System	Crop Dry Matter (g)	Crop Dry Matter (g/m^2)	Total DM (g) Weed+Crop	Change in % Green Weed-Crop 2-Camera System
DXA	1	W	2.4	0.045	0.180	53.35473567	-110.9324394	2	C	1.8		0.000		0.6
DXA	3	W	5.7	1.895	7.580	53.35485565	-110.9324360	4	C	3.6	2.035	8.140	3.930	2.1
DXA	5	W	4.7	2.534	10.136	53.35501425	-110.9324378	6	C	1.2	0.897	3.588	3.431	3.5
DXA	7	W		9.226	36.904			8	C	2.2	0.822	3.288	10.048	
DXA	9	W	6.2	1.665	6.660	53.35537942	-110.9324206	10	C	4.3	1.319	5.276	2.984	1.9
DXA	11	W	2.7	1.391	5.564	53.35555473	-110.9324237	12	C	0.6	0.582	2.328	1.973	2.1
DXA	13	W	15.0	6.376	25.504	53.35567888	-110.9324186	14	C	1.6	0.885	3.540	7.261	13.4
DXA	15	W	5.1	1.594	6.376	53.35590160	-110.9324086	16	C	2.2	1.113	4.452	2.707	2.9
DXA	17	W	4.0	2.228	8.912	53.35594763	-110.9325505	18	C	1.4	1.125	4.500	3.353	2.6
DXA	19	W	15.4	5.719	22.876	53.35579625	-110.9325611	20	C	4.6	2.307	9.228	8.026	10.8
DXA	21	W	2.4	0.905	3.620	53.35564813	-110.9325546	22	C	1.3	0.818	3.272	1.723	1.1
DXA	23	W	6.3	2.571	10.284	53.35543505	-110.9325676	24	C	0.8	0.953	3.812	3.524	5.5
DXA	25	W	13.3	12.311	49.244	53.35531605	-110.9325512	26	C	1.3	1.348	5.392	13.659	12.0
DXA	27	W	10.3	3.868	15.472	53.35517580	-110.9325532	28	C	0.4	0.659	2.636	4.527	9.9
DXA	29	W	11.0	4.261	17.044	53.35501312	-110.9325521	30	C	1.5	0.732	2.928	4.993	9.5
DXA	31	W	11.4	6.067	24.268	53.35479508	-110.9325466	32	C	3.1	1.199	4.796	7.266	8.3
DXA	33	W	4.6	0.383	1.532	53.35476990	-110.9327079	34	C	3.5	1.394	5.576	1.777	1.1
DXA	35	W	5.5			53.35493677	-110.9327115	36	C	3.3	1.229	4.916	1.229	2.2
DXA	37	W	20.1	10.52	42.080	53.35508942	-110.9327106	38	C	2.6	0.879	3.516	11.399	17.5
DXA	39	W	13.8	9.544	38.176	53.35524750	-110.9327006	40	C	4.7	1.308	5.232	10.852	9.1
DXA	41	W	5.7	1.197	4.788	53.35542677	-110.9326905	42	C	2.6	1.235	4.940	2.432	3.1
DXA	43	W	13.7	7.348	29.392	53.35558177	-110.9326953	44	C	2.5	1.272	5.088	8.620	11.2
DXA	45	W	13.7	4.958	19.832	53.35574398	-110.9327066	46	C	3.1	1.224	4.896	6.182	10.6
DXA	47	W	3.8	0.769	3.076	53.35595655	-110.9326982	48	C	2.8	1.071	4.284	1.840	1.0
		Average	8.557	Average	16.935				Average	2.4		4.401		
		Sd	5.107	sd	14.267				sd	1.2		1.824		

Table D-3 Plot DXB summary image data 2 to 3-leaf stage, June 7, 2003

Field Code	Image Number	Image Code	Total Green % 2-Camera System	Weed Dry Matter (g)	Weed Dry Matter (g/m^2)	Latitude	Longitude	Image Number	Image Code	Crop Only Green % 2-Camera System	Crop Dry Matter (g)	Crop Dry Matter (g/m^2)	Total DM (g) Weed+Crop	Change in % Green Weed-Crop 2-Camera System
DXB	49	W	10.5	0.656	2.624	53.35181928	-110.9324100	50	C	7.7	1.046	4.184	1.702	2.8
DXB	51	W	5.0	0.055	0.220	53.35196213	-110.9324159	52	C	4.0	1.564	6.256	1.619	1.0
DXB	53	W	4.5	0.040	0.160	53.35213497	-110.9324229	54	C	5.1	1.859	7.436	1.899	-0.6
DXB	55	W	11.5	7.413	29.652	53.35232847	-110.9324267	56	C	4.2	1.363	5.452	8.776	7.3
DXB	57	W	8.5	2.349	9.396	53.35247695	-110.9324297	58	C	5.2	1.554	6.216	3.903	3.3
DXB	59	W	8.1	0.037	0.148	53.35263558	-110.9324299	60	C	8.5	2.139	8.556	2.176	-0.4
DXB	61	W	6.7	0.052	0.208	53.35283618	-110.9324367	62	C	5.3	1.517	6.068	1.569	1.4
DXB	63	W	7.2	0.019	0.076	53.35298205	-110.9324375	64	C	5.9	1.524	6.096	1.543	1.3
DXB	65	W	15.8	0.243	0.972	53.35180297	-110.9325391	66	C	11.2	2.031	8.124	2.274	4.6
DXB	67	W	9.1	0.000	0.000	53.35196958	-110.9325398	68	C	9.3	2.283	9.132	2.283	-0.2
DXB	69	W	9.9	0.002	0.008	53.35216877	-110.9325467	70	C	8.3	2.161	8.644	2.163	1.6
DXB	71	W	10.6	0.320	1.280	53.35236833	-110.9325354	72	C	8.5	2.962	11.848	3.282	2.1
DXB	73	W	7.4	0.112	0.448	53.35251673	-110.9325392	74	C	8.4	1.867	7.468	1.979	-1.0
DXB	75	W	9.1	0.649	2.596	53.35271117	-110.9325381	76	C	6.6	1.782	7.128	2.431	2.5
DXB	77	W	6.5	0.040	0.160	53.35285847	-110.9325448	78	C	7.7	1.177	4.708	1.217	-1.2
DXB	79	W	11.0	4.046	16.184	53.35303632	-110.9325340	80	C	8.2	2.225	8.900	6.271	2.8
DXB	81	W	7.9	0.010	0.040	53.35181140	-110.9327102	82	C	8.0	1.944	7.776	1.954	-0.1
DXB	83	W	4.5	0.186	0.744	53.35196112	-110.9327157	84	C	3.9	1.159	4.636	1.345	0.6
DXB	85	W	5.5	0.042	0.168	53.35215028	-110.9327256	86	C	5.3	1.523	6.092	1.565	0.2
DXB	87	W	8.1	0.004	0.016	53.35235758	-110.9327240	88	C	8.3	2.280	9.120	2.284	-0.2
DXB	89	W	3.9	0.000	0.000	53.35250938	-110.9327183	90	C	3.8	1.426	5.704	1.426	0.1
DXB	91	W	7.7	0.312	1.248	53.35251288	-110.9327340	92	C	6.5	1.592	6.368	1.904	1.2
DXB	93	W	6.6	0.823	3.292	53.35283970	-110.9327243	94	C	6.1	2.216	8.864	3.039	0.5
DXB	95	W	6.1	0.000	0.000	53.35300902	-110.9327272	96	C	5.6	1.881	7.524	1.881	0.5
		Average	7.988	Average	2.902				Average	6.7		7.179		
		sd	2.707	sd	6.779				sd	2.0		1.787		

Table D-4 Plot DXC summary image data 2 to 3-leaf stage, June 7, 2003

Field Code	Image Number	Image Code	Total Green % 2-Camera System	Weed Dry Matter (g)	Weed Dry Matter (g/m^2)	Latitude	Longitude	Image Number	Image Code	Crop Only Green % 2-Camera System	Crop Dry Matter (g)	Crop Dry Matter (g/m^2)	Total DM (g) Weed+Crop	Change in % Green Weed-Crop 2-Camera System
DXC	1	W	12.0	0.494	1.976	53.35389698	-110.9554772	2	C	10.5	1.092	4.368	1.586	1.5
DXC	3	W	13.7	0.000	0.000	53.35402270	-110.9554914	4	C	11.5	1.724	6.896	1.724	2.2
DXC	5	W	28.2	11.875	47.500	53.35417682	-110.9554931	6	C	11.1	1.521	6.084	13.396	17.1
DXC	7	W	23.9	4.897	19.588	53.35435633	-110.9554979	8	C	11.6	2.383	9.532	7.280	12.3
DXC	9	W	9.9	0.299	1.196	53.35452162	-110.9554948	10	C	10.0	2.071	8.284	2.370	-0.1
DXC	11	W	18.1	5.616	22.464	53.35466900	-110.9555005	12	C	7.8	2.228	8.912	7.844	10.3
DXC	13	W	7.4	3.415	13.660	53.35481533	-110.9555064	14	C	3.8	1.266	5.064	4.681	3.6
DXC	15	W	51.3	35.760	143.040	53.35497528	-110.9554983	16	C	9.4	1.493	5.972	37.253	41.9
DXC	17	W	11.1	0.000	0.000	53.35392705	-110.9553648	18	C	9.1	3.157	12.628	3.157	2.0
DXC	19	W	24.3	16.184	64.736	53.35409028	-110.9553692	20	C	8.5	2.388	9.552	18.572	15.8
DXC	21	W	16.2	2.857	11.428	53.35425062	-110.9553655	22	C	5.6	1.186	4.744	4.043	10.6
DXC	23	W	7.7	1.199	4.796	53.35444355	-110.9553580	24	C	5.0	1.871	7.484	3.070	2.7
DXC	25	W	4.6	1.392	5.568	53.35461142	-110.9553652	26	C	1.2	0.551	2.204	1.943	3.4
DXC	27	W	26.6	13.461	53.844	53.35480855	-110.9553628	28	C	6.1	1.843	7.372	15.304	20.5
DXC	29	W	39.5	25.065	100.260	53.35501342	-110.9553587	30	C	3.8	0.596	2.384	25.661	35.7
DXC	31	W	5.5	0.786	3.144	53.35392520	-110.9552359	32	C	4.3	1.388	5.552	2.174	1.2
DXC	33	W	7.3	1.651	6.604	53.35407998	-110.9552158	34	C	4.2	0.865	3.460	2.516	3.1
DXC	35	W	16.7	6.668	26.672	53.35420708	-110.9552244	36	C	2.1	1.040	4.160	7.708	14.6
DXC	37	W	6.5	0.520	2.080	53.35435718	-110.9552121	38	C	2.9	1.439	5.756	1.959	3.6
DXC	39	W	5.8	0.258	1.032	53.35453318	-110.9552152	40	C	3.1	1.520	6.080	1.778	2.7
DXC	41	W	4.9	1.883	7.532	53.35467177	-110.9552119	42	C	3.4	1.290	5.160	3.173	1.5
DXC	43	W	15.9	8.906	35.624	53.35488265	-110.9552011	44	C	2.9	0.587	2.348	9.493	13.0
DXC	45	W	20.2	9.883	39.532	53.35497232	-110.9551949	46	C	7.1	2.547	10.188	12.430	13.1
DXC	47	W	4.2	0.150	0.600	53.35508157	-110.9551937	48	C	1.1	1.120	4.480	1.270	3.1
		Average	15.896	Average	25.537				Average	6.1		6.194		
		sd	11.816	sd	35.589				sd	3.4		2.665		

Table D-5 Plot DXA summary image data 5-leaf stage, June 13, 2003

Field Code	Image Number	Image Code	Total Green % 2-Camera System	Weed Dry Matter (g)	Weed Dry Matter (g/m^2)	Latitude	Longitude	Image Number	Image Code	Crop Only Green % 2-Camera System	Crop Dry Matter (g)	Crop Dry Matter (g/m^2)	Total DM (g/m^2) Weed+Crop	Change in % Green Weed-Crop 2-Camera System
DXA	1	W	34.4	6.633	26.532	53.3547873166667	-110.9324392833	2	C	23	6.073	24.292	50.824	11.4
DXA	3	W	54.1	14.994	59.976	53.3549222000000	-110.9324370333	4	C	25.4	5.488	21.952	81.928	28.7
DXA	5	W	47.3	16.310	65.240	53.3550780833333	-110.9324403500	6	C	12.5	2.773	11.092	76.332	34.8
DXA	7	W	60.9	27.410	109.640	53.3552258500000	-110.9324379667	8	C	10.6	1.300	5.200	114.840	50.3
DXA	9	W	47.8	10.326	41.304	53.3553862833333	-110.9324337333	10	C	16.3	2.705	10.820	52.124	31.5
DXA	11	W	27.8	10.726	42.904	53.3555685000000	-110.9324272333	12	C	13	2.748	10.992	53.896	14.8
DXA	13	W	43.1	11.201	44.804	53.3557382500000	-110.9324326833	14	C	17.1	3.504	14.016	58.820	26.0
DXA	15	W	52.7	12.970	51.880	53.3559459666667	-110.9324327833	16	C	31.1	4.073	16.292	68.172	21.6
DXA	17	W	48.9	14.760	59.040	53.3547827166667	-110.9325713667	18	C	24.4	3.987	15.948	74.988	24.5
DXA	19	W	55.8	20.620	82.480	53.3549757500000	-110.9325746333	20	C	15.4	2.341	9.364	91.844	40.4
DXA	21	W	75.9	38.810	155.240	53.3551738666667	-110.9325786667	22	C	13.3	1.594	6.376	161.616	62.6
DXA	23	W	50.6	9.923	39.692	53.3553982000000	-110.9325554667	24	C	19.3	4.211	16.844	56.536	31.3
DXA	25	W	40.6	10.081	40.324	53.3555637000000	-110.9325560667	26	C	14.7	4.131	16.524	56.848	25.9
DXA	27	W	17.7	1.624	6.496	53.3557165333333	-110.9325578500	28	C	12.2	3.426	13.704	20.200	5.5
DXA	29	W	39.8	10.574	42.296	53.3558537500000	-110.9325546833	30	C	16.5	3.121	12.484	54.780	23.3
DXA	31	W	19.3	4.069	16.276	53.3560096833333	-110.9325617000	32	C	14.2	3.797	15.188	31.464	5.1
DXA	33	W	23.2	4.810	19.240	53.3547360833333	-110.9327204667	34	C	19.2	5.211	20.844	40.084	4.0
DXA	35	W	50.9	10.327	41.308	53.3548850833333	-110.9327126667	36	C	18.1	3.047	12.188	53.496	32.8
DXA	37	W	64.7	26.890	107.560	53.3550592666667	-110.9327158500	38	C	14.9	3.446	13.784	121.344	49.8
DXA	39	W	42.4	10.758	43.032	53.3552190500000	-110.9327088333	40	C	16.1	1.988	7.952	50.984	26.3
DXA	41	W	57.8	12.065	48.260	53.3553998000000	-110.9327052667	42	C	28.1	4.119	16.476	64.736	29.7
DXA	43	W	66.2	21.200	84.800	53.3555294833333	-110.9327164000	44	C	26.7	3.334	13.336	98.136	39.5
DXA	45	W	58.7	24.870	99.480	53.3557204000000	-110.9327117333	46	C	22	2.883	11.532	111.012	36.7
DXA	47	W	21.1	2.574	10.296	53.3559701166667	-110.9327147833	48	C	12.8	2.321	9.284	19.580	8.3
				Average	55.754				Average	18.2		13.604		
				sd	35.463				sd	5.6		4.658		

Table D-6 Plot DXB summary image data 5-leaf stage, June 13, 2003

Field Code	Image Number	Image Code	Total Green % 2-Camera System	Weed Dry Matter (g)	Weed Dry Matter (g/m^2)	Latitude	Longitude	Image Number	Image Code	Crop Only Green % 2-Camera System	Crop Dry Matter (g)	Crop Dry Matter (g/m^2)	Total DM (g/m^2) Weed+Crop	Change in % Green Weed-Crop 2-Camera System
DXB	1	W	14	0.046	0.184	53.3517925500000	-110.9324094833	2	C	14.8	4.174	16.696	16.880	-0.8
DXB	3	W	11	0.146	0.584	53.3519225833333	-110.9324147833	4	C	12.1	3.068	12.272	12.856	-1.1
DXB	5	W	15.4	0.025	0.100	53.3521115333333	-110.9324147667	6	C	15.5	3.281	13.124	13.224	-0.1
DXB	7	W	50.2	18.689	74.756	53.3523021166667	-110.9324178833	8	C	13.5	3.267	13.068	87.824	36.7
DXB	9	W	17.8	0.145	0.580	53.3524311500000	-110.9324174167	10	C	17	4.270	17.080	17.660	0.8
DXB	11	W	14	0.071	0.284	53.3525572000000	-110.9324179833	12	C	13.7	4.501	18.004	18.288	0.3
DXB	13	W	19.7	0.242	0.968	53.3527921500000	-110.9324317500	14	C	17.2	3.843	15.372	16.340	2.5
DXB	15	W	17.5	0.010	0.040	53.3529782333333	-110.9324308000	16	C	14.6	4.564	18.256	18.296	2.9
DXB	17	W	19.4	1.594	6.376	53.3517897500000	-110.9325584000	18	C	13.8	4.066	16.264	22.640	5.6
DXB	19	W	16.8	1.304	5.216	53.3519923500000	-110.9325637833	20	C	12.3	3.315	13.260	18.476	4.5
DXB	21	W	12.5	0.005	0.020	53.3521441166667	-110.9325622167	22	C	12.4	5.150	20.600	20.620	0.1
DXB	23	W	15.4	0.879	3.516	53.3523140333333	-110.9325654167	24	C	14.2	4.288	17.152	20.668	1.2
DXB	25	W	15.6	0.102	0.408	53.3524583833333	-110.9325650833	26	C	15.6	4.793	19.172	19.580	0.0
DXB	27	W	17.1	0.139	0.556	53.3525906000000	-110.9325674667	28	C	16.3	4.668	18.672	19.228	0.8
DXB	29	W	17.9	0.159	0.636	53.3527489500000	-110.9325763333	30	C	17.7	5.357	21.428	22.064	0.2
DXB	31	W	15.8	0.974	3.896	53.3529327000000	-110.9325665167	32	C	12.2	4.119	16.476	20.372	3.6
DXB	33	W	15.3	0.033	0.132	53.3517958833333	-110.9326852833	34	C	15.7	4.926	19.704	19.836	-0.4
DXB	35	W	27.3	4.855	19.420	53.3519029500000	-110.9326913333	36	C	13.5	5.737	22.948	42.368	13.8
DXB	37	W	22	9.356	37.424	53.3520699000000	-110.9326946333	38	C	8.6	4.568	18.272	55.696	13.4
DXB	39	W	14.1	0.175	0.700	53.3522973166667	-110.9326890833	40	C	14	4.833	19.332	20.032	0.1
DXB	41	W	12.1	0.080	0.320	53.3524593166667	-110.9326953000	42	C	11.8	4.753	19.012	19.332	0.3
DXB	43	W	18.9	0.094	0.376	53.3526420833333	-110.9326981667	44	C	18.7	7.544	30.176	30.552	0.2
DXB	45	W	19.4	3.269	13.076	53.3528023666667	-110.9326969000	46	C	11.4	5.424	21.696	34.772	8.0
DXB	47	W	38.7	8.875	35.500	53.3530077000000	-110.9326993667	48	C	21.3	6.675	26.700	62.200	17.4
				Average	8.545				Average	14.5		18.531		
				sd	17.624				sd	2.7		4.172		

Table D-7 Plot DXC summary image data 5-leaf stage, June 13, 2003

Field Code	Image Number	Image Code	Total Green % 2-Camera System	Weed Dry Matter (g)	Weed Dry Matter (g/m^2)	Latitude	Longitude	Image Number	Image Code	Crop Only Green % 2-Camera System	Crop Dry Matter (g)	Crop Dry Matter (g/m^2)	Total DM (g/m^2) Weed+Crop	Change in % Green Weed-Crop 2-Camera System
DXC	49	W	14.5	0.059	0.236	53.3539665000000	-110.9554838167	50	C	13.2	3.624	14.496	14.732	1.3
DXC	51	W	12.6	0.678	2.712	53.3540942166667	-110.9554818500	52	C	12.7	3.117	12.468	15.180	-0.1
DXC	53	W	26.5	2.801	11.204	53.3542452166667	-110.9554836667	54	C	15.1	3.806	15.224	26.428	11.4
DXC	55	W	31.5	7.971	31.884	53.3544229833333	-110.9554870667	56	C	20.3	3.869	15.476	47.360	11.2
DXC	57	W	21.7	0.367	1.468	53.3545584833333	-110.9554919667	58	C	13.9	3.933	15.732	17.200	7.8
DXC	59	W	8.8	0.873	3.492	53.3546962666667	-110.9554909667	60	C	8.4	1.831	7.324	10.816	0.4
DXC	61	W	38	16.636	66.544	53.3548489000000	-110.9554899667	62	C	14.7	2.055	8.220	74.764	23.3
DXC	63	W	27	18.286	73.144	53.3549675166667	-110.9554868167	64	C	6.4	1.040	4.160	77.304	20.6
DXC	65	W	17.7	0.000	0.000	53.3551123666667	-110.9554859333	66	C	15.8	2.916	11.664	11.664	1.9
DXC	67	W	15.1	0.267	1.068	53.3538840166667	-110.9553432833	68	C	12.1	2.099	8.396	9.464	3.0
DXC	69	W	31.4	0.384	1.536	53.3540242833333	-110.9553399833	70	C	29.4	6.508	26.032	27.568	2.0
DXC	71	W	48.8	11.317	45.268	53.3542305333333	-110.9553397000	72	C	20.3	4.438	17.752	63.020	28.5
DXC	73	W	24.7	0.484	1.936	53.3543952500000	-110.9553475667	74	C	22.4				2.3
DXC	75	W	15	0.148	0.592	53.3545329166667	-110.9553561833	76	C	10	3.586	14.344	14.936	5.0
DXC	77	W	22.7	4.917	19.668	53.3547104000000	-110.9553640667	78	C	12.5	4.117	16.468	36.136	10.2
DXC	79	W	46.5	27.420	109.680	53.3549301500000	-110.9553624000	80	C	10	1.815	7.260	116.940	36.5
DXC	81	W	24.1	0.311	1.244	53.3550785000000	-110.9553627333	82	C	22.4	6.069	24.276	25.520	1.7
DXC	83	W	10.2	1.790	7.160	53.3538746000000	-110.9552438833	84	C	7.1	1.940	7.760	14.920	3.1
DXC	85	W	19.2	2.219	8.876	53.3540039166667	-110.9552372167	86	C	15	3.952	15.808	24.684	4.2
DXC	87	W	14	2.352	9.408	53.3541748000000	-110.9552265667	88	C	9.4	3.154	12.616	22.024	4.6
DXC	89	W	16.7	0.917	3.668	53.3543428333333	-110.9552240333	90	C	14.8	3.924	15.696	19.364	1.9
DXC	91	W	17.2	7.596	30.384	53.3545669833333	-110.9552160333	92	C	6.5	2.615	10.460	40.844	10.7
DXC	93	W	17.8	0.141	0.564	53.3548193000000	-110.9552082500	94	C	17	4.609	18.436	19.000	0.8
DXC	95	W	28	10.956	43.824	53.3550300333333	-110.9552017667	96	C	8.8	2.909	11.636	55.460	19.2
				Average	19.815				Average	14.1		13.552		
				sd	28.794				sd	5.7		5.297		

Table D-8 Plot DXA summary image data 2-tiller stage, June 19, 2003

Field Code	Image Number	Image Code	Total Green % 2-Camera System	Weed Dry Matter (g)	Weed Dry Matter (g/m2)	Latitude	Longitude	Image Number	Image Code	Crop Only Green % 2-Camera System	Crop Dry Matter (g)	Crop Dry Matter (g/m2)	Total DM (g/m2) Weed+Crop	Change in % Green Weed-Crop 2-Camera System
DXA	1	W	53.1	13.440	53.760	53.35473273	-110.9324602	2	C	34.2	10.540	42.160	95.920	18.9
DXA	3	W	62.2	18.360	73.440	53.35484365	-110.9324542	4	C	36	9.050	36.200	109.640	26.2
DXA	5	W	68.2	11.580	46.320	53.35497365	-110.9324531	6	C	42.1	11.650	46.600	92.920	26.1
DXA	7	W	77.4	35.590	142.360	53.35518380	-110.9324509	8	C	34.5	9.500	38.000	180.360	42.9
DXA	9	W	66.4	26.350	105.400	53.35538605	-110.9324513	10	C	24.6	5.776	23.104	128.504	41.8
DXA	11	W	46.9	15.130	60.520	53.35552923	-110.9324507	12	C	22.5	8.038	32.152	92.672	24.4
DXA	13	W	63.8	32.050	128.200	53.35566920	-110.9324498	14	C	19.6	7.270	29.080	157.280	44.2
DXA	15	W	47.8	13.510	54.040	53.35593078	-110.9324593	16	C	17.6	7.600	30.400	84.440	30.2
DXA	17	W	51.7	13.680	54.720	53.35476022	-110.9325835	18	C	27.6	10.580	42.320	97.040	24.1
DXA	19	W	59.3	23.560	94.240	53.35494525	-110.9325723	20	C	24	9.580	38.320	132.560	35.3
DXA	21	W	61.8	29.880	119.520	53.35514800	-110.9325696	22	C	26.5	8.200	32.800	152.320	35.3
DXA	23	W	42.2	13.740	54.960	53.35532705	-110.9325555	24	C	22	10.480	41.920	96.880	20.2
DXA	25	W	58.1	18.390	73.560	53.35545800	-110.9325494	26	C	24.9	9.00	36.000	109.560	33.2
DXA	27	W	60.9	29.260	117.040	53.35557955	-110.9325506	28	C	16.2	6.446	25.784	142.824	44.7
DXA	29	W	50.1	14.710	58.840	53.35576747	-110.9325536	30	C	23.8	12.750	51.000	109.840	26.3
DXA	31	W	40.9	6.660	26.640	53.35592822	-110.9325547	32	C	32	10.140	40.560	67.200	8.9
DXA	33	W	62.9	4.360	17.440	53.35474072	-110.9327182	34	C	49	21.150	84.600	102.040	13.9
DXA	35	W	56.7	11.940	47.760	53.35488265	-110.9327140	36	C	38.7	16.690	66.760	114.520	18.0
DXA	37	W	52.5	30.130	120.520	53.35504710	-110.9327035	38	C	13.2	6.120	24.480	145.000	39.3
DXA	39	W	50	16.640	66.560	53.35522158	-110.9326988	40	C	21.6	7.970	31.880	98.440	28.4
DXA	41	W	42.5	26.780	107.120	53.35544402	-110.9326934	42	C	12.9	3.780	15.120	122.240	29.6
DXA	43	W	41.6	14.190	56.760	53.35558108	-110.9326956	44	C	27	9.870	39.480	96.240	14.6
DXA	45	W	47.1	9.150	36.600	53.35573348	-110.9326997	46	C	26.4	14.020	56.080	92.680	20.7
DXA	47	W	55.3	13.140	52.560	53.35588467	-110.9327009	48	C	39.1	14.310	57.240	109.800	16.2
			55.0	Average	73.703				Average	27.3		40.085		
			9.5	sd	34.422				sd	9.2		15.058		

Table D-9 Plot DXB summary image data 2-tiller stage, June 19, 2003

Field Code	Image Number	Image Code	Total Green % 2-Camera System	Weed Dry Matter (g)	Weed Dry Matter (g/m2)	Latitude	Longitude	Image Number	Image Code	Crop Only Green % 2-Camera System	Crop Dry Matter (g)	Crop Dry Matter (g/m2)	Total DM (g/m2) Weed+Crop	Change in % Green Weed-Crop 2-Camera System
DXB	49	W	22.1	0.084	0.336	53.35183252	-110.9327813	50	C	21.4	11.460	45.840	46.176	0.7
DXB	51	W	23	0.059	0.236	53.35196475	-110.9327389	52	C	23.7	9.070	36.280	36.516	-0.7
DXB	53	W	19.5	0.027	0.108	53.35213770	-110.9327446	54	C	19	7.020	28.080	28.188	0.5
DXB	55	W	23.6	0.252	1.008	53.35229613	-110.9327461	56	C	21.5	9.140	36.560	37.568	2.1
DXB	57	W	18.3	0.114	0.456	53.35244935	-110.9327477	58	C	18.3	9.510	38.040	38.496	0.0
DXB	59	W	38.9	9.370	37.480	53.35265620	-110.9327512	60	C	28.4	9.110	36.440	73.920	10.5
DXB	61	W	40.4	2.699	10.796	53.35282170	-110.9327513	62	C	29.7	23.690	94.760	105.556	10.7
DXB	63	W	32.1	0.026	0.104	53.35300700	-110.9327507	64	C	30.8	11.530	46.120	46.224	1.3
DXB	65	W	26.7	0.366	1.464	53.35177842	-110.9325563	66	C	25.3	10.260	41.040	42.504	1.4
DXB	67	W	19.7	0.181	0.724	53.35196617	-110.9325639	68	C	18.3	9.240	36.960	37.684	1.4
DXB	69	W	16.7	0.144	0.576	53.35213578	-110.9325654	70	C	16.6	7.190	28.760	29.336	0.1
DXB	71	W	30.1	0.133	0.532	53.35228458	-110.9325694	72	C	27.8	9.410	37.640	38.172	2.3
DXB	73	W	27.4	0.058	0.232	53.35247120	-110.9325849	74	C	24.6	10.520	42.080	42.312	2.8
DXB	75	W	32	2.720	10.880	53.35275905	-110.9325903	76	C	26.6	10.120	40.480	51.360	5.4
DXB	77	W	25	10.730	42.920	53.35290515	-110.9325883	78	C	11.9	6.330	25.320	68.240	13.1
DXB	79	W	24.2	0.009	0.036	53.35306577	-110.9325873	80	C	24.3	10.510	42.040	42.076	-0.1
DXB	81	W	27.5	11.900	47.600	53.35180913	-110.9324131	82	C	17.6	6.490	25.960	73.560	9.9
DXB	83	W	18.5	0.078	0.312	53.35191887	-110.9324116	84	C	17	6.960	27.840	28.152	1.5
DXB	85	W	23.6	0.050	0.200	53.35207102	-110.9324119	86	C	22.5	9.270	37.080	37.280	1.1
DXB	87	W	29	1.450	5.800	53.35230057	-110.9324221	88	C	25.9	14.750	59.000	64.800	3.1
DXB	89	W	25.5	6.500	26.000	53.35249535	-110.9324201	90	C	21.6	8.530	34.120	60.120	3.9
DXB	91	W	20.7	0.023	0.092	53.35262792	-110.9324227	92	C	18.6	9.010	36.040	36.132	2.1
DXB	93	W	29.4	6.030	24.120	53.35288130	-110.9323975	94	C	25.6	11.400	45.600	69.720	3.8
DXB	95	W	31.3	0.030	0.120	53.35302375	-110.9323807	96	C	30.3	18.070	72.280	72.400	1.0
				Average	8.839				Average	22.8		41.432		
				sd	14.991				sd	5.0		15.337		

Table D-10 Plot DXC summary image data 2-tiller stage, June 19, 2003

Field Code	Image Number	Image Code	Total Green % 2-Camera System	Weed Dry Matter (g)	Weed Dry Matter (g/m2)	Latitude	Longitude	Image Number	Image Code	Crop Only Green % 2-Camera System	Crop Dry Matter (g)	Crop Dry Matter (g/m2)	Total DM (g/m2) Weed+Crop	Change in % Green Weed-Crop 2-Camera System
DXC	1	W	35.2	0.648	2.592	53.3539203	-110.9554842	2	C	34.5	12.040	48.160	50.752	0.7
DXC	3	W	41.1	0.222	0.888	53.3540649	-110.9554799	4	C	37.8	15.070	60.280	61.168	3.3
DXC	5	W	43.5	12.340	49.360	53.35419062	-110.9554749	6	C	20.7	8.270	33.080	82.440	22.8
DXC	7	W	37.3	8.520	34.080	53.35434617	-110.9554696	8	C	21.9	7.980	31.920	66.000	15.4
DXC	9	W	33.9	4.251	17.004	53.3544925	-110.9554709	10	C	22.5	6.410	25.640	42.644	11.4
DXC	11	W	24.5	1.207	4.828	53.35463327	-110.9554664	12	C	21.7	10.130	40.520	45.348	2.8
DXC	13	W	26.4	1.011	4.044	53.35480667	-110.9554673	14	C	25.9	10.060	40.240	44.284	0.5
DXC	15	W	47.5	31.190	124.760	53.35495425	-110.9554603	16	C	10.1	3.819	15.276	140.036	37.4
DXC	17	W	28.7	2.430	9.720	53.35507353	-110.9553228	18	C	23.7	9.300	37.200	46.920	5.0
DXC	19	W	23.9	19.320	77.280	53.35497298	-110.9553145	20	C	9.8	4.790	19.160	96.440	14.1
DXC	21	W	29.5	2.139	8.556	53.35480165	-110.9553137	22	C	27	9.610	38.440	46.996	2.5
DXC	23	W	18.4	0.369	1.476	53.35465715	-110.9553115	24	C	19.3	8.100	32.400	33.876	-0.9
DXC	25	W	20.1	0.026	0.104	53.35448358	-110.9553089	26	C	20	7.550	30.200	30.304	0.1
DXC	27	W	45.5	16.750	67.000	53.3543241	-110.9553105	28	C	17.2	4.970	19.880	86.880	28.3
DXC	29	W	30.4	3.380	13.520	53.35413502	-110.9553262	30	C	19.1	8.360	33.440	46.960	11.3
DXC	31	W	48.4	2.351	9.404	53.353918	-110.9553303	32	C	39.7	17.400	69.600	79.004	8.7
DXC	33	W	32.4	4.167	16.668	53.35388652	-110.9552066	34	C	32	10.740	42.960	59.628	0.4
DXC	35	W	51.8	8.570	34.280	53.35401583	-110.9552033	36	C	45.7	18.270	73.080	107.360	6.1
DXC	37	W	29.1	0.193	0.772	53.35416472	-110.9552191	38	C	29.5	9.250	37.000	37.772	-0.4
DXC	39	W	39.9	5.750	23.000	53.35431922	-110.9552221	40	C	31.6	11.860	47.440	70.440	8.3
DXC	41	W	25.1	1.220	4.880	53.3545036	-110.9552217	42	C	21.1	9.910	39.640	44.520	4.0
DXC	43	W	23.9	2.773	11.092	53.35467813	-110.9552188	44	C	21.5	7.380	29.520	40.612	2.4
DXC	45	W	30.8	11.000	44.000	53.35487155	-110.9552158	46	C	16.5	6.340	25.360	69.360	14.3
DXC	47	W	37.5	19.910	79.640	53.35500025	-110.9552112	48	C	12.7	4.320	17.280	96.920	24.8
				Average	26.623				Average	24.2		36.988		
				sd	32.167				sd	9.1		14.922		

Table D-11 Plot DXA summary image data 3-tiller stage, June 26, 2003

Field Code	Image Number	Image Code	Total Green % 2-Camera System	Weed Dry Matter (g)	Weed Dry Matter (g/m2)	Latitude	Longitude	Image Number	Image Code	Crop Only Green % 2-Camera System	Crop Dry Matter (g)	Crop Dry Matter (g/m2)	Total DM (g/m2) Weed+Crop	Change in % Green Weed-Crop 2-Camera System
DXA	1	W	72.5	10.920	43.680	53.35476580	-110.9325414	2	C	57.4	27.790	111.160	154.840	15.1
DXA	3	W	62.1	27.320	109.280	53.35490355	-110.9324433	4	C	29.6	14.130	56.520	165.800	32.5
DXA	5	W	69.7	13.390	53.560	53.35506758	-110.9324387	6	C	53.1	17.930	71.720	125.280	16.6
DXA	7	W	76.9	41.550	166.200	53.35527447	-110.9324294	8	C	29.7	14.630	58.520	224.720	47.2
DXA	9	W	67.1	28.830	115.320	53.35543853	-110.9324238	10	C	32.9	15.720	62.880	178.200	34.2
DXA	11	W	63.4	34.680	138.720	53.35558797	-110.9324202	12	C	34.2	12.800	51.200	189.920	29.2
DXA	13	W	66.3	48.470	193.880	53.35574650	-110.9324211	14	C	28.9	13.000	52.000	245.880	37.4
DXA	15	W	51.4	10.420	41.680	53.35595155	-110.9324080	16	C	38.5	18.910	75.640	117.320	12.9
DXA	17	W	78.1	42.230	168.920	53.35477475	-110.9325449	18	C	47.5	16.250	65.000	233.920	30.6
DXA	19	W	72.1	39.600	158.400	53.35493300	-110.9325454	20	C	36.1	15.000	60.000	218.400	36.0
DXA	21	W	65.4	23.740	94.960	53.35513870	-110.9325340	22	C	33	14.300	57.200	152.160	32.4
DXA	23	W	67.6	35.230	140.920	53.35532485	-110.9325223	24	C	32.7	16.000	64.000	204.920	34.9
DXA	25	W	69.8	30.750	123.000	53.35546513	-110.9325221	26	C	32.2	20.070	80.280	203.280	37.6
DXA	27	W	70.3	20.580	82.320	53.35560405	-110.9325155	28	C	44.4	28.120	112.480	194.800	25.9
DXA	29	W	59.3	25.810	103.240	53.35574863	-110.9325140	30	C	37.5	23.050	92.200	195.440	21.8
DXA	31	W	51.5	7.790	31.160	53.35594137	-110.9325072	32	C	38.4	22.130	88.520	119.680	13.1
DXA	33	W	76.2	6.530	26.120	53.35479593	-110.9326886	34	C	66	39.720	158.880	185.000	10.2
DXA	35	W	70.2	17.780	71.120	53.35497085	-110.9326810	36	C	51.5	26.310	105.240	176.360	18.7
DXA	37	W	49.6	13.840	55.360	53.35514887	-110.9326751	38	C	31.4	21.310	85.240	140.600	18.2
DXA	39	W	68	22.070	88.280	53.35534233	-110.9326609	40	C	35.9	24.340	97.360	185.640	32.1
DXA	41	W	65	40.410	161.640	53.35550405	-110.9326653	42	C	30.7	17.820	71.280	232.920	34.3
DXA	43	W	60	30.180	120.720	53.35564773	-110.9326644	44	C	43.1	28.770	115.080	235.800	16.9
DXA	45	W	56.5	31.710	126.840	53.35579035	-110.9326663	46	C	30.4	21.170	84.680	211.520	26.1
DXA	47	W	61.6	26.290	105.160	53.35596817	-110.9326670	48	C	37.5	23.590	94.360	199.520	24.1
			65.4	Average	105.020				Average	38.9		82.143		
			7.9	sd	47.544				sd	9.8		25.764		

Table D-12 Plot DXB summary image data 3-tiller stage, June 26, 2003

Field Code	Image Number	Image Code	Total Green % 2-Camera System	Weed Dry Matter (g)	Weed Dry Matter (g/m2)	Latitude	Longitude	Image Number	Image Code	Crop Only Green % 2-Camera System	Crop Dry Matter (g)	Crop Dry Matter (g/m2)	Total DM (g/m2) Weed+Crop	Change in % Green Weed-Crop 2-Camera System
DXB	49	W	57.1	3.003	12.012	53.35179395	-110.9323930	50	C	53.5	28.520	114.080	126.092	3.6
DXB	51	W	32.6	0.220	0.880	53.35193695	-110.9323910	52	C	34.4	17.890	71.560	72.440	-1.8
DXB	53	W	54.8	0.047	0.188	53.35209462	-110.9323955	54	C	56.2	31.330	125.320	125.508	-1.4
DXB	55	W	52.7	0.140	0.560	53.35230182	-110.9323953	56	C	51.9	29.010	116.040	116.600	0.8
DXB	57	W	57.4	0.160	0.640	53.35243973	-110.9323977	58	C	52	39.710	158.840	159.480	5.4
DXB	59	W	36	0.070	0.280	53.35261620	-110.9324020	60	C	32.3	18.870	75.480	75.760	3.7
DXB	61	W	57.9	0.000	0.000	53.35277955	-110.9324054	62	C	57.1	34.500	138.000	138.000	0.8
DXB	63	W	49.1	0.001	0.004	53.35295838	-110.9324004	64	C	49.5	31.740	126.960	126.964	-0.4
DXB	65	W	37.4	4.510	18.040	53.35182727	-110.9325315	66	C	30.7	11.100	44.400	62.440	6.7
DXB	67	W	26.4	0.472	1.888	53.35200360	-110.9325376	68	C	24.4	14.260	57.040	58.928	2.0
DXB	69	W	24	0.121	0.484	53.35215122	-110.9325381	70	C	25.4	16.550	66.200	66.684	-1.4
DXB	71	W	36.9	0.192	0.768	53.35231275	-110.9325343	72	C	35.1	16.100	64.400	65.168	1.8
DXB	73	W	31.4	3.273	13.092	53.35249097	-110.9325372	74	C	26.6	16.990	67.960	81.052	4.8
DXB	75	W	49.8	0.022	0.088	53.35276010	-110.9325350	76	C	47.3	32.190	128.760	128.848	2.5
DXB	77	W	55.8	0.754	3.016	53.35290688	-110.9325268	78	C	46.5	31.420	125.680	128.696	9.3
DXB	79	W	45.3	9.430	37.720	53.35290812	-110.9325254	80	C	30.7	22.300	89.200	126.920	14.6
DXB	81	W	33.9	0.605	2.420	53.35178833	-110.9326770	82	C	31.7	18.980	75.920	78.340	2.2
DXB	83	W	35.6	31.220	124.880	53.35192063	-110.9326857	84	C	14.4	7.120	28.480	153.360	21.2
DXB	85	W	26.5	1.180	4.720	53.35210645	-110.9326854	86	C	26.9	14.080	56.320	61.040	-0.4
DXB	87	W	42.3	0.015	0.060	53.35231002	-110.9326899	88	C	41.7	22.660	90.640	90.700	0.6
DXB	89	W	51.2	0.180	0.720	53.35247725	-110.9326932	90	C	45.8	27.660	110.640	111.360	5.4
DXB	91	W	51.7	4.860	19.440	53.35268707	-110.9326946	92	C	44.8	27.610	110.440	129.880	6.9
DXB	93	W	36.3	0.000	0.000	53.35290058	-110.9326917	94	C	36.1	23.110	92.440	92.440	0.2
DXB	95	W	64.5	40.550	162.200	53.35303987	-110.9326900	96	C	41.2	18.570	74.280	236.480	23.3
			43.6	Average	16.838				Average	39.0		92.045		
			11.7	sd	40.425				sd	11.6		33.120		

Table D-13 Plot DXC summary image data 3-tiller stage, June 26, 2003

Field Code	Image Number	Image Code	Total Green % 2-Camera System	Weed Dry Matter (g)	Weed Dry Matter (g/m2)	Latitude	Longitude	Image Number	Image Code	Crop Only Green % 2-Camera System	Crop Dry Matter (g)	Crop Dry Matter (g/m2)	Total DM (g/m2) Weed+Crop	Change in % Green Weed-Crop 2-Camera System
DXC	1	W	41.6	2.113	8.452	53.35387175	-110.9552456	2	C	42.2	19.060	76.240	84.692	-0.6
DXC	3	W	51.9	18.500	74.000	53.3540226	-110.9552341	4	C	40.2	18.860	75.440	149.440	11.7
DXC	5	W	48.1	14.670	58.680	53.35421088	-110.9552273	6	C	27.2	9.280	37.120	95.800	20.9
DXC	7	W	55.1	12.030	48.120	53.3543859	-110.9552337	8	C	45.2	16.530	66.120	114.240	9.9
DXC	9	W	61.9	15.420	61.680	53.35459122	-110.9552355	10	C	42.4	17.510	70.040	131.720	19.5
DXC	11	W	41.1	3.500	14.000	53.35474112	-110.9552328	12	C	36.4	14.470	57.880	71.880	4.7
DXC	13	W	34.3	6.609	26.436	53.35491208	-110.9552256	14	C	29	11.550	46.200	72.636	5.3
DXC	15	W	50.8	38.460	153.840	53.35502973	-110.9552182	16	C	10.7	3.820	15.280	169.120	40.1
DXC	17	W	67	3.229	12.916	53.35386692	-110.9552904	18	C	59.4	31.510	126.040	138.956	7.6
DXC	19	W	74.2	1.671	6.684	53.35400445	-110.9552951	20	C	78.9	36.870	147.480	154.164	-4.7
DXC	21	W	62.1	11.900	47.600	53.3541854	-110.9552821	22	C	44.2	25.490	101.960	149.560	17.9
DXC	23	W	60.9	8.100	32.400	53.35435125	-110.9552824	24	C	50	27.120	108.480	140.880	10.9
DXC	25	W	56.3	0.230	0.920	53.35451042	-110.9552836	26	C	54.8	26.470	105.880	106.800	1.5
DXC	27	W	50.8	9.110	36.440	53.35465538	-110.9552803	28	C	42.4	18.180	72.720	109.160	8.4
DXC	29	W	56.5	2.767	11.068	53.35481167	-110.9552816	30	C	51.1	22.600	90.400	101.468	5.4
DXC	31	W	72.2	38.090	152.360	53.35387223	-110.9554301	32	C	41.9	15.720	62.880	215.240	30.3
DXC	33	W	64.7	0.061	0.244	53.35399725	-110.9554202	34	C	65.3	44.610	178.440	178.684	-0.6
DXC	35	W	75.2	12.190	48.760	53.3541345	-110.9554196	36	C	57.4	35.350	141.400	190.160	17.8
DXC	37	W	67.5	13.830	55.320	53.35429215	-110.9554199	38	C	50.9	24.510	98.040	153.360	16.6
DXC	39	W	66.1	11.570	46.280	53.35442115	-110.9554229	40	C	61	31.440	125.760	172.040	5.1
DXC	41	W	53.8	1.696	6.784	53.35454795	-110.955427	42	C	56.6	26.390	105.560	112.344	-2.8
DXC	43	W	48.1	8.460	33.840	53.35469863	-110.9554375	44	C	42.6	21.070	84.280	118.120	5.5
DXC	45	W	32.9	29.390	117.560	53.35487128	-110.955433	46	C	13.6	7.900	31.600	149.160	19.3
DXC	47	W	57	2.245	8.980	53.35506645	-110.9554298	48	C	45.7	29.000	116.000	124.980	11.3
				Average	44.307				Average	45.4		89.218		
				sd	43.450				sd	15.3		39.136		