Hand Held Remote Sensing Instrumentation

Every substance emits, absorbs, transmits or reflects electromagnetic radiation in a manner characteristic of the substance. This is the underlying principle involved in all remote sensing. By measuring the quantity of radiation in each of the wavelengths, the characteristics of the substances can be defined (Pederson 1990). *Appendix 1* documents absorption bands which are specifically related to foliar chemical concentrations in plants.

Although, this principle may appear simple, choosing an instrument which can measure the quantity of radiation being emitted in each wavelength in a suitable fashion for your application can be more complicated. Selection criteria includes a variety of factors such as, what type of measurement is required (whole canopy or canopy component); wavelength resolution (spectroradiometer or multispectral radiometer); field of view (FOV); wavelength coverage (Visible/PAR 400-700 nm or full spectrum 350 nm - 2500 nm); and practical considerations, is the unit field portable and useable under remote working conditions (how heavy, battery life, memory capacity).

Measurement Theory

A key principle in remote sensing which is used in the development of spectral equipment is the Bi-directional Reflectance Distribution Function (BRDF). The Bidirectional Reflectance Distribution Function (BRDF) characterizes surface reflectance. Two directions are necessary in defining the function; (1) the source incidence direction in terms of zenith and azimuth angles (0i, oi) and (2) the view direction angles (0v, ov). Figure 1 shows a diagramatical representation of the incident and reflected radiation geometry for a vegetative surface.

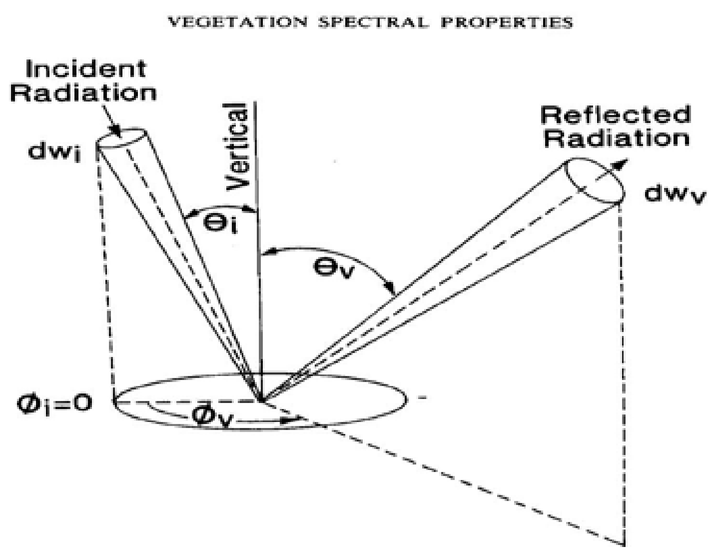

Figure 1. **The spectral properties of a vegetative surface demonstrating the principle of Bidirectional Reflectance Distribution Function (Walter-Shea and Biehl 1990).**

BRDF relates irradiance from a given direction incident on a surface to the reflected radiance in the viewing direction. BRDF is only a derivative of point values which are unable to be measured directly.

It is important to remember reflectance measurements are average values of BRDF over a specified interval not, absolute measures. (Walter-Shea & Biehl 1990).

Sources of Variability

In order to determine the reflectance or transmittance of a material, two measurements are required: the spectral response of a reference sample and that of the target material. The reflectance or transmittance is then calculated by dividing the spectral response of the target material by that of the reference sample (Curtiss and Goetz 1994). It then follows that all parameters which are common to both the target and the reference sample such as spectral irradiance of the illumination source and optical throughput of the instrument will cancel each other out. Hence, an inherent assumption that the illumination characteristics of the illumination source are the same for the reference and target materials.

Illumination characteristics are subject to rapid change (particularly natural sources) resulting in erroneous spectra. The magnitude of this error will be dependent upon the degree of variation in the illumination characteristics between the time the reference material and target are measured. Therefore, if reference measurements and target measurements are made simultaneously or at regular, short intervals under relatively constant illumination conditions the inherent error will be negligible if not canceled out completely.

Natural Illumination

Natural or ambient solar illumination is the most common source of illumination for spectral measurements made in the field. Under field conditions the target material is illuminated by three or more sources (Figure 2), each with its own spectral characteristics. (Curtiss and Ustin 1988).

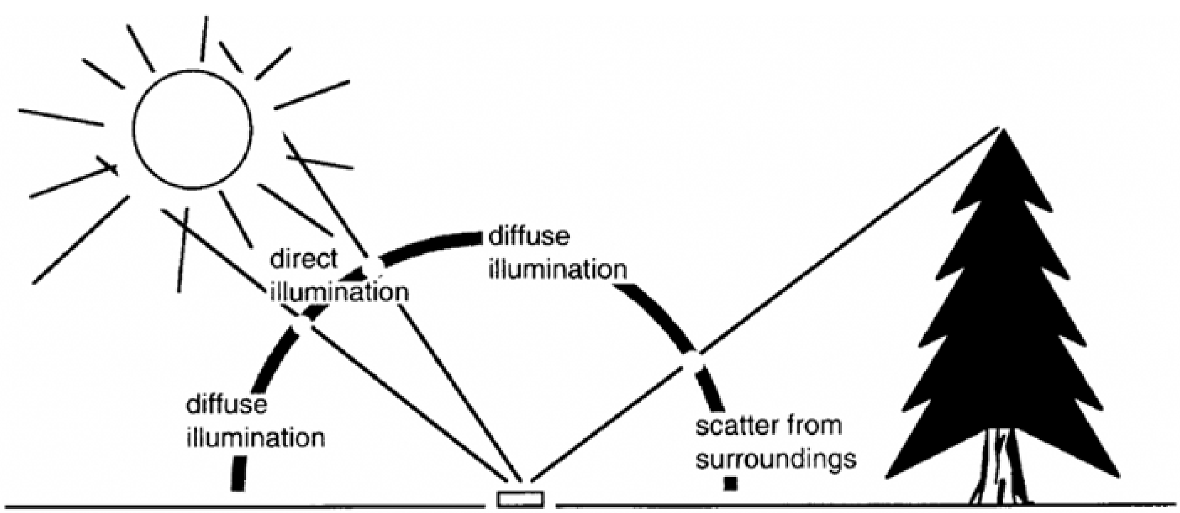

Figure 2. The three sources of natural illumination which effect spectral reflectance measurements

in the field.

Parameters such as, solar elevation angle and atmospheric conditions will effect the overall intensity and spectral characteristics of direct solar illumination which, under normal conditions is the dominant source of illumination. Diffuse skylight illumination characteristically will contribute between 5-10% of the total illumination reaching a surface. At shorter wavelengths, diffuse skylight can contribute as much as 20-25% of the total (Curtiss and Goetz 1994).

The spectral characteristics of the illumination scattered off surrounding objects is determined by their reflectance characteristics. In the case of a forest clearing, as much as 20% of the illumination in the 750 -1200 nm wavelength range can be attributed to sunlight scattered off the surrounding forest canopy (Curtiss and Goetz 1994). Objects in the surrounding area e.g., the person taking the measurement and the instrument itself can effect the overall illumination of the target surface by obscuring portions of direct and diffuse solar illumination. Where possible these objects should be removed or their effect minimized.

The magnitude of both diffuse and scattered illumination from surrounding objects can be determined by the solid angle subtended by these sources when viewed from the reference frame of the target surface (Curtiss and Goetz 1994).

Artificial Illumination

Artificial Illumination (Figure 3) has a number of advantages over natural illumination. The use of artificial illumination allows (1) more control over illumination and viewing geometry; (2) more control over sample geometry; (3) measurements during non-optimal conditions (cloud cover or at night); and (4) measurement of reflectance and transmittance in the deep atmospheric absorption bands. Several problems with using artificial illumination include; (1) difficulty in maintaining a constant distance between the sample or reference and the light source when measuring a sample of irregular geometry; and (2) lights can "cook" vegetation samples (water loss, chlorophyll degradation). Alternatively, the light source can be either incorporated into the instrument (often precluding the use of solar illumination) or can be provided in the form of an optional accessory that mounts to the light collecting optics of the instrument.

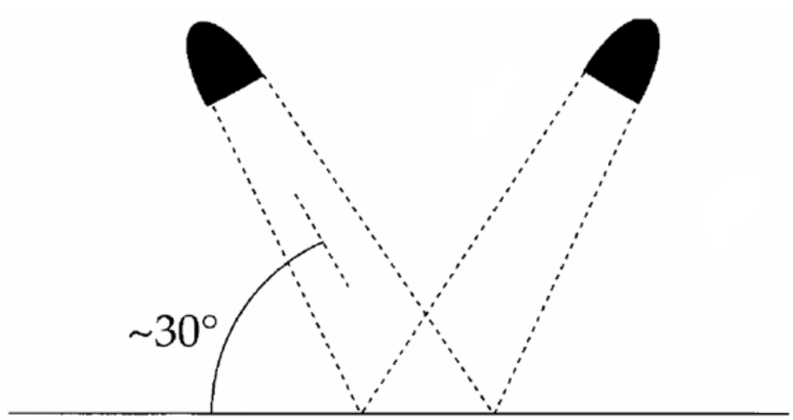

Figure 3. A typical lamp configuration for indoor illumination of samples.

Scene Variability

In addition to variations in illumination the scene or texture of a target can also effect the spectral measurement. A material or targets surface texture will effect the relative portion of the various sources of illumination. A rough surfaced target will accept a higher proportion of diffuse and scattered illumination than a smooth surfaced target.

Canopy variability is also an important parameter to be considered when making measurements. Some targets are very uniform such as some agricultural crops or leaves with few and small veins, others are more random such as forest canopies (Walter-Shea and Biehl 1990). In situations such as this it is important that the FOV of the instrument is large enough to include a representative portion of the canopy or leaf to ensure an accurate spectral reflectance that characterizes the target is achieved.

Wind can also be a serious source of error if the material such as a plant or plant canopy, moves during the time the spectrum is acquired. If a spectrum is slowly scanned, changes in the amount of shadow in the instrument FOV will result in erroneous "features" in the spectrum. Fast scanning instruments that can record measurements in 0.01 seconds will significantly reduce this source of error.

Spectroradiometers

Spectroradiometers are capable of recording measurements with a very high resolution of between 1-10 nm. They are commonly used in plant component, mineral or chemical applications that require measurements of precise wavelengths. The "FieldSpec" Spectroradiometer manufactured by Analytical Spectral Devices has a spectral resolution of 3 nm with a wavelength accuracy of +/- 1 nm.

The "FieldSpec" can measure radiance, irradiance, transmittance and absorbance. These factors can either be viewed in real time or saved to memory for latter processing using the customized data analysis software. Since, high resolution measurements can become quite voluminous, the FieldSpec provides the user with a facility to average scans and store a single measurement rather than all the raw scans. This is possible due to the small scan time of 0.1 second and the ability to average up to a maximum of 32,000 scans. However, if individual scans are required they can also be saved to memory.

Field of View (FOV)

The FieldSpec has a very flexible FOV due to the design of the interchangeable foreoptic sensor. For this reason there is no maximum limit to the range of FOV covered by the FieldSpec.

The bare fibers of the fiberoptic cable used in the manufacture of the FieldSpec have a 25^{o} acceptance angle when spliced. Therefore, the diameter of the spot covered is approximately 40% of the distance to the object. The FOV is determined by the foreoptic placed over the fibre. These range from 1^{o} to 8^{o} in the case of the FR. Using a 1^{o} foreoptic, the spot diameter is approximately 60% of the distance from the target.

The advantage to having such a flexible FOV is that with the same instrument a range of varying research projects are possible from; canopy component, such as leaves and pine needles to whole canopies of crops, grasslands and forests. However, if you wish to make use of the flexible FOV capacity of the FieldSpec a variety of foreoptics would need to be purchased and interchanged as required.

Detector

The FieldSpec Full Range (FR) model consists of three separate detectors (Figure 4) that are coupled in a unique way to combine radiation from the electromagnetic spectrum producing a very accurate and continuous spectral response between 350 nm to 2500 nm.

Inside the instrument, the fibre-optic bundle within the trifurcated cable is broken into three bundles each, consisting of 19 fibers. Each of the three bundles then delivers the collected light to the entrance slit of one of the three spectrometers.

The first detector uses a silicon photodiode array overlaid with an order separation filter and a concave fixed holographic reflective grating dispersion element. It measures the wavelength region from 350 nm to 1000 nm, called the Visible/Near Infrared (VNIR). The detector has 512 elements, each of which measures light within a narrow (1.4 nm) wavelength range.

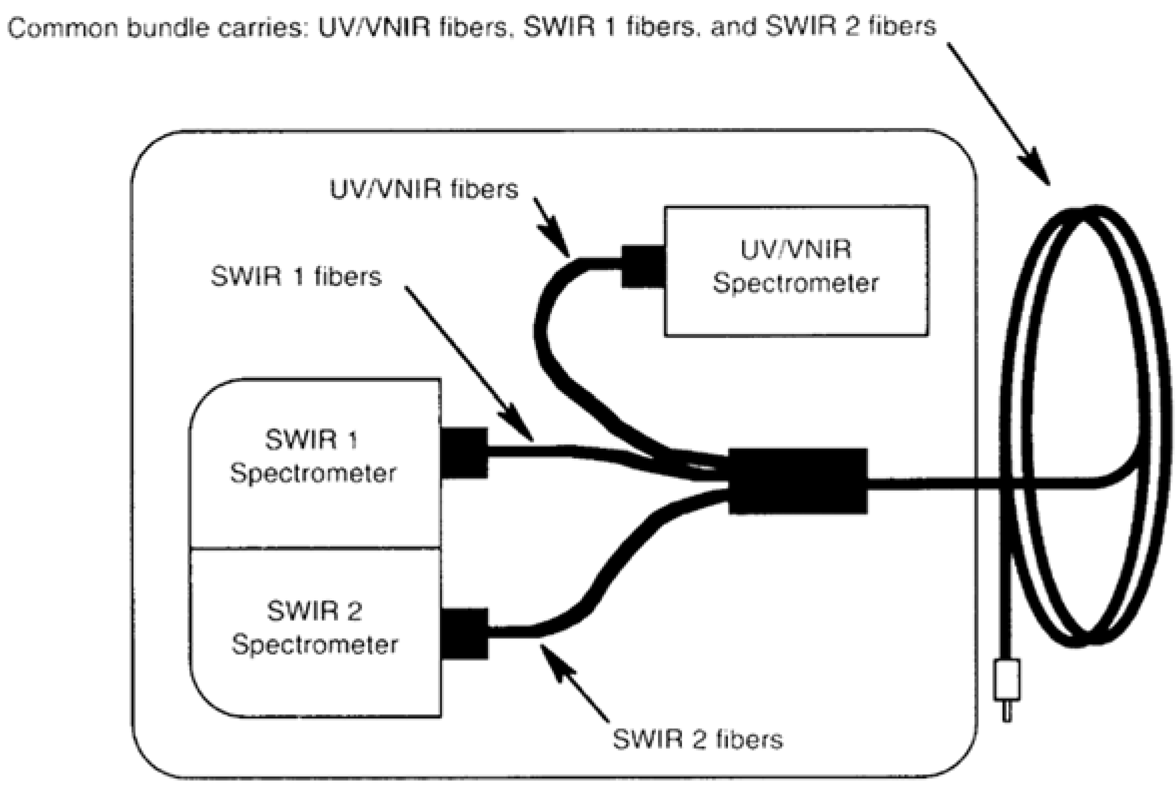

Figure 4. The FieldSpec FR consists of three spectrometers which receive light from a common trifurcated fibre optic bundle

An advantage of using the fixed grating detector is that it is capable of sampling all 512 elements simultaneously which allows for the very narrow wavelength range and superior accuracy. However, a disadvantage to the fixed grating is that the signal to noise ratio is fixed to the sampling interval and spectral resolution. Because of the rapid fall-off of energy of the solar spectrum in the 1000 nm to 2500 nm region narrow spectral sampling intervals are of limited value by comparison to an increased signal to noise ratio. Therefore, as the fixed grating has a rigid narrow sampling interval it cannot achieve a necessarily high SNR to be accurate in the longer wavelength so is replaced by scanning gratings.

The Short-Wave Infrared (SWIR), also called the Near-Infrared (NIR), portion of the spectrum is acquired with two scanning spectrometers. Each spectrometer consists of a fast scanning, concave holographic, reflective grating dispersion element and a thermoelectrically cooled ($-30^{o}C$) Indium-Gallium-Arsenide (InGAs) detector. The gratings are mounted to a common shaft that oscillates with a period of 200 milliseconds; each spectrometer has one detector which is exposed to different wavelengths of light as the grating oscillates. The first spectrometer (SWIR1) covers the wavelength region from 900 nm to 1850 nm and the second (SWIR2) covers the region from 1700 nm to 2500 nm. The controlling software automatically accounts for the overlap in the wavelength intervals by choosing a wavelength inside the overlap to switch from one spectrometer to the next. The sampling in each region is every 2 nm and the resolution varies between 10 and 11 nm, depending on the scan angle.

InGAs detectors are utilized in the SWIR spectrometers as they have superior high frequency response required for rapid scanning which traditional lead sulfide (PbS) detectors lack. InGAs detectors also dispense with the need for an optical chopper which PbS required. Overall, the development of a rapid scanning detector has seen the FieldSpec improve the Signal to noise ratio beyond that possible with a PbS array detector and with a spectral sampling interval that is less than one fifth the spectral resolution without compromising the SNR.

A disadvantage of scanning detectors is that due to their design they are not capable of measuring all wavelengths simultaneously as array detectors are. Which can result in errors due to changes in the target during measurement of the spectrum. However, the speed at which the rapid scanning designed detectors incorporated in the FieldSpec spectrometers scan and measure the target spectrum eliminates this error.

Each detector of the three spectrometers converts incident photons into electrons that are stored, or integrated until the detector is read out. At read out time, the photoelectric current for each detector is converted to a voltage and is digitized by a 16 bit analog to digital (A/D) converter. The resultant raw data or 16-bit digital numbers (DN's) corresponding to the output of each element in the detector array and each 2 nm sample of the SWIR spectra are then transferred directly to the computer's main memory using the enhanced parallel port on the Zeos computer.

Datalogger

In place of a standard datalogger for field data storage the FieldSpec utilizes a laptop computer. The computer is a Zeos notebook with an 80 Mb hard disk, 33 MHz, 2 Meg of RAM and floppy disk drive. The laptop is attached to the top of a weather-resistant case which encloses the detector and internal workings of the FieldSpec. Resulting in a field portable package that measures 35 x 29 x 13 cm in size, with an operational weight of 7 kg.

Battery

The batteries used in the FieldSpec are 4 Am hour 12 volt Nickel Cadmium (NiCad) rechargeable batteries. The discharge rate of the battery varies dependent upon the FieldSpec model used. However, for the Full Range (FR) the discharge time is approximately 3 hours of continuous field use and 5 hours for the Very Near Infrared (VNIR) model. They have a life expectancy of approximately 1000 charges. It is recommended that for remote work two battery packs are used as this will ensure a full days work.

The battery for the FieldSpec comes in a separate battery pack that weighs 2.2 kg and is worn either in fanny pack around the waist or in a shoulder pack. An AC power adapter is used to charge the battery pack which automatically fully discharges itself prior to charging. This feature eliminates the memory effect associated with recharging non-discharged NiCad batteries.

The Zeos notebook computer has a separate AC power adapter and is charged whenever it is connected, although it will charge more quickly when the computer is not turned on and being used.

Measurement Technique and Calibration

Measurements taken with the FieldSpec spectroradiometer require a reference measurement from a white reference such as Spectralon and the unknown target material. This is necessary because it is only possible to measure the intensity of a light field. By calculating the ratio of the raw spectrum of the unknown material to that of the known reference, the characteristics of the instrument and light source are canceled out, resulting in a spectrum which is the ratio of the reflectance or transmittance of the unknown relative to the reference sample. In order to calculate this ratio correctly the FieldSpec must first correct the raw spectra to eliminate the Dark Current.

Incoming photons from an object being measured create thermal electrons that add a definable quantity of current to the output current of the detector resulting in a phenomenon known as Dark Current. This is a property of the detector which varies with temperature and, for the VNIR spectrometer, integration time. The addition of the dark current signal to the true signal from the light field results in spectral amplitude values that are offset, thus the dark current at each channel must be subtracted from the total signal at that channel if an accurate result is to be obtained.

The software facilitates the correction of raw data for dark current however, the user must make an assessment as to how often a new dark current reading is necessary in order to maintain a specified level of accuracy.

The raw data coming back from the spectrometer consists of a set of data points, one from each channel of the instrument. Each channel covers a specific wavelength and relates to a data point. The process of identifying the wavelength of each instrument channel is called a wavelength calibration. This calibration is done at the factory, and the FieldSpec software automatically interpolates the incoming raw data to a consistent wavelength range (350 to 2500 nm) before displaying it for the user. Re-calibration of the instrument, if required, must be done at the factory by ASD engineers.

Because the calibration of each instrument is unique, each instrument has been assigned both a number which identifies the particular instrument and a number which identifies which calibration is currently being used.

The instrument's ID number is used to locate its description in the initialization file. This information is stored in the text file "ASD.INI" and is required for the software to run the instrument. Without the ASD.INI file or if this file is corrupted or lost the FieldSpec will be disabled.

Software

The FieldSpec operating software is DOS based with pull-down menus and "click-on-button" screens. Data is stored in binary format to minimize storage space and can be converted to ASCII text files using the included PortSpec and S-table programs for export to associated analysis programs.

The configuration of the instrument involves a combination of interrelated parameters. Because this configuration is so crucial to the quality of the spectral data, the FieldSpec FR software provides a mechanism to select an optimal instrument configuration. Optimization must be performed before the data from the spectrometer will be useful.

Optimization of the VNIR portion of the instrument involves taking a VNIR dark current measurement and adjusting the VNIR integration time to maximize the amount of signal without saturation. The software can then adjust parameters of the analog circuitry in the SWIR spectrometers, called the "Gain" and "offset" to match the SWIR detector's analog signal to the input voltage range of the A/D converter. The gain determines the amplitude of the incoming spectrum; the offset is used to set the base line.

No spectrum is perfect - there is always a certain amount of random noise from the detectors, variations in the experimental environment, and other sources. A way to reduce this noise is to take several spectra and use their average rather than any of the individual spectra themselves. If the noise is truly random, then the noise decreases with the square root of the number of samples. Spectrum averaging decreases random noise at the cost of time to complete a measurement. The FieldSpec software allows the selection of any number of samples to make up a single final spectrum, from one sample to 32,000.

Data is saved to either the notebooks hard disk or floppy disk drives. Each set of spectra is saved to a specified data directory and given a basename to distinguish a set of spectra from subsequent data sets. The software adds a sequential 3 digit numbering system to each files basename to identify each file. Additional descriptive information such as current date and time, the current instrument setup (integration time, attached foreoptic, etc) and the user's comment will also be saved with each spectra.

During the setup procedure, the user will specify how many spectra will be saved in the current set, the time interval between saves and the set number for the first file.

Applications

The FieldSpec Spectroradiometer is capable of quantitative measurements of radiance, irradiance, reflectance or transmittance of any material whether it is geological, vegetative or anthroprogenic in nature.

The most common area that has embraced and applied field spectroscopy is the remote sensing industry. Field spectroscopy has been used for aircraft and satellite sensor calibrations, development of remote sensing data exploitation methods, remote sensing feasibility studies and geologic mapping.

In addition to remote sensing applications, field spectrometers are used to make direct material identifications in the field rather than collecting samples for later laboratory analysis. This has been of significant benefit to mineral exploration and mining companies with savings in time and expensive laboratory testing.

In the food, agriculture, pharmaceutical, polymer, cosmetics, environmental, textile, and medical fields, portable NIR analysis finds a wide range of applications. There are still many unknown applications waiting to be discovered and with the maturity of this technique more people will use portable NIR analyzers for convenience and flexibility.

One of the most rapid advances of the NIR technology is within the food industry. NIR has been used for quality determination of a range of produce from cereal products to fresh fruit. Typical applications in cereals such as wheat, corn, soybeans and rice have been to determine grain moisture content, protein content, starch levels and grain hardness.

In Japan extensive work has been conducted using NIR to develop methods of determining fruit and vegetable maturity, firmness, and quantify surface defects.

Specific research into fruits such as peaches, Japanese pears, apples, tomatoes, strawberries and Satsuma oranges have developed non-destructive techniques for determining Brix levels (sugar contents). The method involves interactance measurements and subsequent second derivative and normalized second derivative regression analysis of the spectra.

Multispectral Radiometer

Multispectral radiometers are specifically designed to reduce the large volume of data collected by spectroradiometers by collecting measurements from a specified number of broad wavelength bands. The Cropscan multispectral radiometer system (MSR) consists of a set of paired narrow band interference filters housed within a aluminum case which is held aloft a target via a telescoping pole and connected by cabling to a datalogger controller (DLC).

The MSR system has the capacity to accept near simultaneous inputs of incident and reflected radiation and convert them to a millivolt signal for subsequent analog to digital (A/D) measurement conversion and storage by the datalogger.

Incoming or reflected irradiance is first bandpass filtered with interference type filters. The irradiance that passes through the filter then strikes the surface of a photodiode and is converted into an electrical current. This current is converted into an electrical voltage by integrated electronic amplifiers and is conducted by a cable through analog multiplexers to the analog-to-digital converter of the DLC.

Use of the radiometer is based on the BRDF principle. It assumes that the irradiance flux density of the incident on the up facing sensor is equal to the irradiance flux density incident on the target surface. Given that the illumination source is a long, equi-distance from both the radiometer and the target surface then, the assumption is justified.

Field of View (FOV)

The instrument field of view (FOV) is an important consideration in selecting an instrument in agricultural research applications. This is particularly true when using a multispectral waveband radiometer as the FOV must be large enough to contain a representative sample of the target being measured. The photodiode sensors used in the Cropscan have a fixed 28^{o} FOV which was chosen as it is the most flexible, single FOV setting that is best suited to agricultural research, in general.

The diameter of the field of view is one half the height of the radiometer over the target or approximately 50% of the distance from the target (Figure 5). The data acquired represents the average reflection from the area sampled. Theoretically, the greater the distance from the canopy, the more valid the reflectance data.

To acquire data from smaller plots using a fixed FOV of 28^{o} the radiometer may be lowered so that the diameter of the FOV is less. Under these circumstances the number of sub-samples measured per plot should be increased to offset the reduction in distance from the canopy and hence, maximize the accuracy of the data.

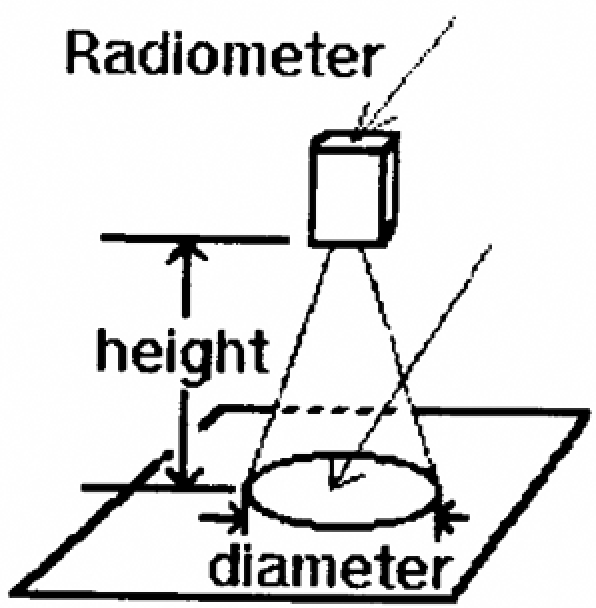

Figure 5. The diameter of the FOV is half the height of the Radiometer above the target.

Datalogger

The Datalogger Controller (DLC) used in the Cropscan Multispectral Radiometer systems is essentially a single board computer. It consists of a low power microprocessor (Intel 80C31), parallel I/O circuit (82C55), counter/timer (82C54), program memory (EPROM) and data storage memory (RAM). It's I/O section consists of an RS232 communication channel, real time clock/calendar, an analog to digital conversion system with 16 channels of input, 4 digital inputs, 8 digital outputs, and an RS485 expansion port. *Appendix 2* details the technical specifications of the Cropscan.

The main function of the controller is to operate as a 16 channel digital voltmeter that can measure voltages from 0.000 to +4.095 volts. Each channel provides a 12 bit digital reading of the analog voltage giving a 0.001 volt resolution corresponding to 1 of 4096.

The DLC has a simple control-orientated BASIC interpreter implemented within the firmware and DLC operating program resident in EPROM. This allows the DLC to function either as a non-dedicated datalogger capable of logging any type of single ended or differential sensors or, as a dedicated logger for exclusive use with the MSR system by uploading the MSR program to the EPROM.

The DLC has only one internal power source essentially with no back up system. A large capacitor will provide sufficient power to the DLC for a maximum of two hours. This facilitates the maintenance of data stored in RAM whilst the batteries are exchanged however, after this time all data and the MSR program will be lost from the EPROM. The DLC will then revert to the simple control-orientated BASIC program which runs the logger. If this occurs the MSR program must be reloaded either from disk/PC or memory card.

Battery

The Cropscan requires a power source capable of providing a voltage range of between +7.0 VDC minimum to +13.0 VDC maximum and an average maximum 100 mA current with 200 mA surges of less than 1 second. This is achieved by utilizing an 8 cell pack of rechargeable NiCad AA size batteries for internal use or a 12 volt rechargeable lead acid battery for external power. Sensors can obtain +5 volts power and ground from the terminal board that is attached to the Data Acquisition Connector.

The DLC drains current from the battery for each function it performs even when the DLC is idle on standby. The amount of current each function drains is as follows;

During Communication - 120 mA

During Scan -60 mA

During Standby - 1 mA

The expected battery life for a 1.2 Ahr battery at 1 Scan/minute with 1 upload/day is approximately 60 days. Although, under normal research conditions the expected battery life is approximately 4.5 hours of continual use and uploading.

If the battery falls below 8.6 volts, a warning BEEP and message appears on the CT100 display. The batteries should then be charged for about 12 hours by plugging in the AC-to-DC 12 volt converter.

Nickel Cadmium or NiCad batteries as they are known have been successful rechargeable battery for many years. However, they are plagued by the inherent characteristic of possessing a "memory" and if they are not cyclically discharged and recharged correctly the battery life will be reduced to an unusable limit.

The continual evolution of battery technology has seen the recent development of a new Nickel Metal Hydride (NiMH) rechargeable battery. These batteries have approximately twice the capacity of NiCad batteries and do not have the recharge memory effect. NiMH batteries will therefore not require full discharge/charge cycles and with the increased capacity will allow for more remote site applications of the Cropscan.

Measurement Techniques and Calibration

The Cropscan facilitates two methods of measuring reflectance to allow greater flexibility in experimental design. Reflectance can be measured with either downward facing sensors only or with both upward and downward facing sensors. To ensure accurate measurements three associated methods of system calibration are necessary.

The required method of calibration will depend upon the necessary configuration of the Cropscan to satisfy any specific application.

Down Sensors Only

When downward facing sensors only are used a white standard card with a known spectral reflectance must be used as a measurement reference. The frequency of white standard reference readings will depend on the rate of change of the solar irradiance at your location, time of day and your tolerance of solar irradiance change between white standard readings.

At some locations, the irradiance change can range from approximately 1% per hour near solar noon to about 47% per hour at 60^{o} sunangle. If your reference accuracy requirement is 1% then you would only need to take a white reference reading 2 or 3 times per hour around solar noon with increasing frequency per hour up to once per minute approaching 60^{o} sunangle (Cropscan 1993).

In applications where the flux density of sunlight varies significantly from canopy to ground, targets such as forests and green houses this method should be used. To make regular white reference measurements under these conditions a white reference card of known spectral reflectance should be positioned horizontally in the field at an open site which receives good constant sunlight. Readings should be taken periodically and immediately before a plot is read.

When the Cropscan is configured to use only downward facing sensors percent Reflectance is calculated as:

Reflectance (%) = Down Units / White Standard Units x White Standard Reflectance x 100

Up and Down Sensors

One of either two calibration methods are used when both up and down sensors are used. The first makes use of an opal glass and is called the Two Point method (2-Pt.Up/Dn). The second makes use of a white standard reference card and is called the White Standard Up/Down method (WhiteStd.Up/Dn).

When the Cropscan is configured to use either of the following calibration methods Percent Reflectance is calculated as follows;

Reflectance (%) = Down Units / Up units x 100

Two Point Method

This calibration is based on the following assumptions;

(i) Both sets of sensors are viewing the same irradiation intensity provided by the sun illuminating the standard opal glass diffuser.

(ii) each sensor response is linear over the operating range.

This method of calibration has several advantages. It is convenient. It may be carried out in the field anytime provided sunlight conditions are ideal. The reason being that calibration coefficients generated for each channel by this method are stored in the Calibration constants table. They will remain with the program until they are changed by re-calibration or manual editing.

When performing this calibration care must be demonstrated when turning the radiometer upside down. The downward facing sensors should be covered with the opal glass prior to facing them towards the sun to avoid overexposure.

White Standard Up & Down

This method requires the use of a white standard for which the spectral reflectance is known. The standard along with a table of reflectance values at 2 nm intervals from 460 to 1800 nm is required. Before this method can be implemented the reflectance values corresponding to the peak wavelengths of each of the radiometers filters must be entered into the calibration constants table in the WhiteSt. column for the down sensors.

The calibration is applied to both the up and down sensors but, the white standard does not have to be taken into the field and constantly be used as a reference. This calibration is only necessary once or twice a season.

Basic Models

MSR87

Consists of eight (8) matched sets of filtered silicon photodiodes which act as light transducers. Each photodiode has a 25-30 nanometer bandwidth which has a centered reflectance peak (Figure 6) at the following wavelengths along the electromagnetic spectrum;

460 nm - Blue

510 nm - Green

560 nm - Yellowish Green

610 nm - Reddish Orange

660 nm - Red

710 nm - Deep Red

760 nm - Near Infrared

810 nm - Near Infrared

The MSR87 utilizes Silicon photodiodes as they exhibit excellent linearity with respect to irradiance intensity between 460 nm and 1000 nm. Silicon photodiodes exhibit temperature sensitivity however, this can be corrected for by applying temperature sensitivity calibrations when processing the data. This is done automatically when the POSTPROC program is used.

An opal glass covers the upward facing sensors and acts as a cosine transmitting diffuser. This ensures that irradiance is transmitted to the photodiode with an intensity that varies with the cosine of the angle of incidence.

Reflectance (%)

Clear glass is used to cover the downward facing sensors. It is assumed that the surface from which the reflectance is to be measured exhibits lambertian reflectance properties. In that the radiant intensity of the reflected irradiance from a lambertian surface varies with the cosine of the angle of incidence of the irradiance.

The cosine properties for both upward and downward facing sensors allows the Cropscan to inherently correct for varying angles of irradiance. The cosine diffusing property of the opal glass, though not perfect, is quite good in the visible and Near Infrared (460-1200 nm) regions.

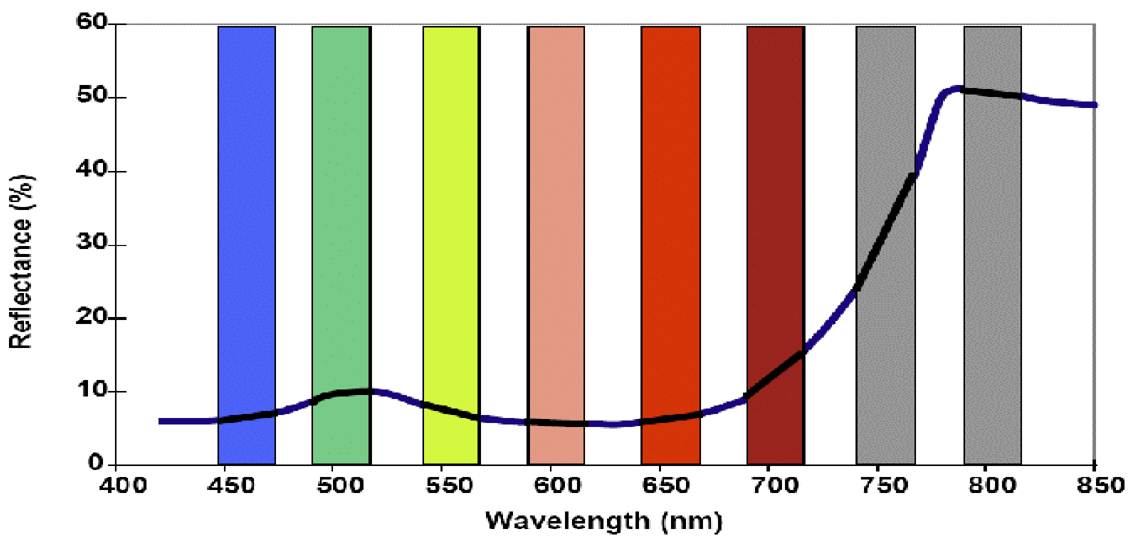

Figure 6. A typical green vegetation reflectance spectrum superimposed over the spectral bands covered by the MSR87

MSR16

The MSR16 was specifically designed to allow users flexibility of measurement and the ability to personally configure their radiometer with a personalised range of sensors. The MSR16 head can accommodate up to 16 matched sets of filtered photodiodes which act as light transducers. Each photodiode typically has a 25-30 nanometer bandwidth which has a centered reflectance peak at the specified wavelengths along the electromagnetic spectrum (Figure 7). However, if requested by a user a sensor can have a narrower or broader band width for any particular wavelength they choose up to a maximum of 1750 nm.

Photodiodes used in the MSR16 with wavelengths above 1000 nm are made from germanium as germanium photodiodes exhibit excellent linearity with respect to irradiance intensity between the limits of 1000 nm and 1650 nm. Germanium, as with silicon photodiodes exhibits temperature sensitivity. This is again corrected for using temperature sensitivity calibration data for each sensor which is done using the POSTPROC program.

As the MSR16 commonly deals with longer wavelengths which are more susceptible to cosine diffusion opal glass is replaced with Styrene as a cosine transmitting diffuser because of its superior light diffusing properties. However, there is no known material that provides high quality transmission diffusion for wavelengths above 1200 nm. To minimize this effect Cropscan provides cosine response calibration data with each upward facing MSR16 module and includes the cosine correction facility in the POSTPROC program.

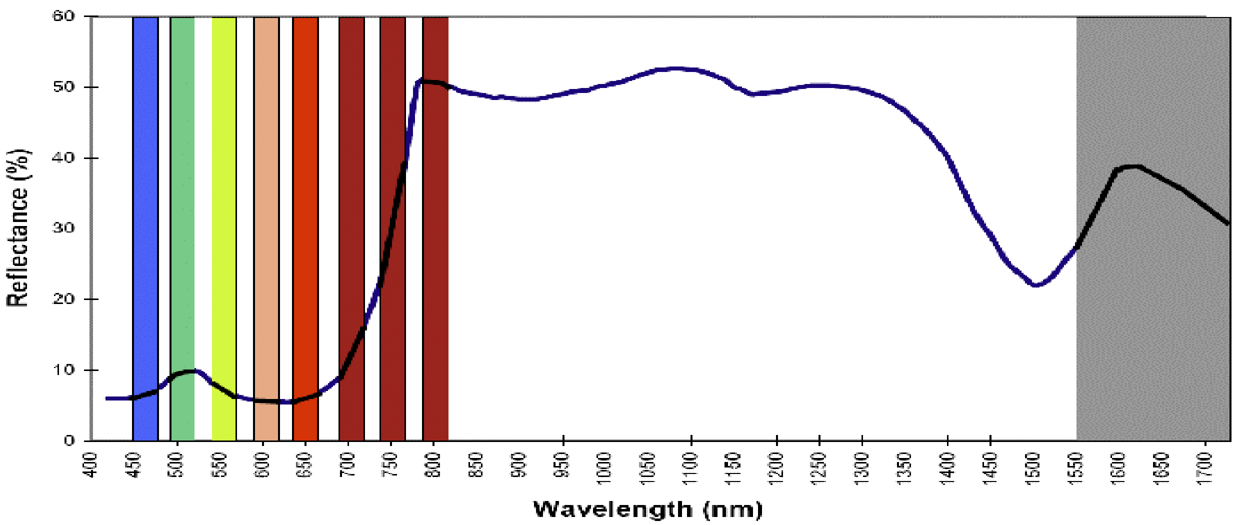

Figure 7. A typical green vegetation reflectance spectrum superimposed over the spectral bands covered by the MSR16.

MSR5

The MSR5 is the latest addition to the Cropscan range. It provides the remote sensing community with a hand held multispectral radiometer capable of measuring reflectance data in the same wavebands as the Landsat Thematic Mapper satellite (Figure 8).

The MSR5 consists of five (5) matched sets of filtered silicon and germanium photodiodes which act as light transducers. Each photodiode has a different bandwidth which correlates to the first five wavelengths covered by the TM Mapper satellite.

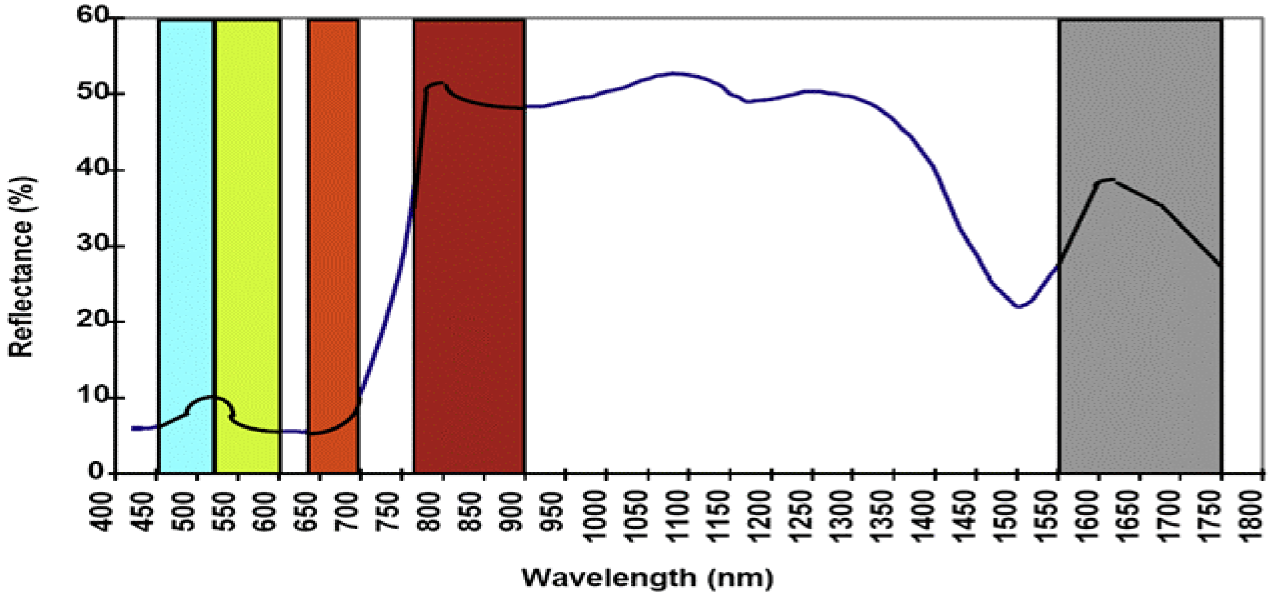

Figure 8. A typical green vegetation reflectance spectrum superimposed over the MSR5 spectral bands.

Software

The Cropscan has customized datalogger firmware and measurement and analysis software. The DLC operating system is written in BASIC programming language and is resident in EPROM. Several unique BASIC extensions have been written to support DLC operations to make the system completely autonomous.

The MSR Program diskette contains the MSR operating system program, MSR utility programs, analysis programs, MSR data files, examples of output from analysis of MSR data and DLC user manual examples.

Copy these programs and files to your hard disk in a directory named \MSR. This will allow you operate the system and practice using the programs on example data.

The MSR program facilitates the viewing in real-time of irradiance values and recording of reflectance measurements. Reflectance measurements are downloaded to a PC in raw millivolt configuration, (denoted by the **.MV** extension) using the Retrieve program. The POSTProcess program is used to process raw millivolt data and convert it to Reflectance figures (denoted by **.rfl** extension) for the respective wavelength bands. The conversion is completed using the configuration and calibration constants for the sensors which are contained within the DLC. The processed data is formatted with text and commas so it can be exported into databases, spreadsheets or analysised using the Cropscan analysis programs. A complete explanation of the functions of all Cropscan programs are given in Appendix 3.

Batch Processing

PC batch files can be created to sequence the Retrieve, PREPRO, POSTPROC, and VIEW programs. The parameters (filenames) can either be explicitly specified or can be made as batch file substitution variables. Using substitution variables provides flexibility for managing data file naming. Batch files can be created with most any ASCII text editor or PC DOS's line editor.

Example:

To automatically retrieve data from a locally (Com port 1) attached DLC, clear DLC memory, perform percent reflectance calculations on the data, and view the results, but specify filename, the batch file could be written as follows;

```
RETRIEVE 1 %1.MV Y Y

POSTPROC %1.MV  N

VIEW %1.RFL
```

The %1 represents a substitution parameter that is obtained from the DOS prompt line following GET %RFL. At the PC DOS prompt you only need to type GET %RFL followed by the desired data filename (without an extension). For example GET%RFL ABC123 and then press enter. The data would be retrieved, processed, and the percent reflectance output displayed for your viewing.

More elaborate batch files capable of exporting reflectance data to a spreadsheet are also possible but would need to be modified to the specific experiment.

Software Compatibility

The MSR Program is compatible with both IBM compatible PC's and MacIntosh computers. Computer hardware requirements are 386, 33 MHz processor (or higher) with 200 Meg hard disk and 2 Meg of RAM.

Although, the MSR program is a DOS program written in BASIC programming language an icon file and program interface file (PIF) are included to allow Microsoft Windows users to launch the Cropscan Menu program under a DOS session.

The PIF file sets up the MSRMENU DOS session so it will run in the background and will receive 30% of the CPU while in the background. For the Cropscan DOS session to run as a background session, Microsoft Windows must be running in the 386 Enhanced mode. If your windows is not running in Enhanced mode you should not switch away from the session during data or configuration transfers.

Stand-Alone/Remote Operation

The MSR system can be configured to operate in an unattended stand-alone mode for routine unattended measurements in remote locations. However, the system does require a special weather proof enclosure. Radiometer measurements and readings of any type of sensor including weather station sensors can be made at any specified period. The system can be reached remotely for data retrieval or operational changes using modems and a telephone connection.

To configure the MSR it must be first calibrated using the MSR.bas program. The resultant calibration file must be retrieved and stored for latter use by the PREPROC program. This program will be required to format the data for subsequent POSTPROCessing as the MSR can only be operated as a standalone unit using the DLC BASIC program.

Applications

Percent reflection of radiation of various wavelengths is influenced by any condition that influences the normal growth of plants. Stress of any kind can significantly alter the percent reflection from a plant canopy within specific wavelengths. The Near Infrared (NIR) bands of 750-900 nm are particularly useful for detecting and estimating the severity of foliar disease on plants. Longer wavelengths in the NIR are useful for estimating biochemical content of plants (Pederson 1990).

The Cropscan has been trialed very successfully in experiments for measuring severity of foliar disease and their effects on crop yield and quality. The radiometer has proven to be a more efficient and accurate means of estimating severity of crop disease than conventional visual rating methods and, is more effective for estimating yield loss through different levels of disease stress than the traditional plot combine method. The radiometer has also been used for estimating the efficacy of different rates and timing of fungicide application and for screening of experimental fungicides in field trials.

In a more practical sense the Cropscan's ability to record near simultaneous inputs of incident and reflected radiation allows the measurement of reflectance data even when sun angles or light conditions are less than ideal. This feature increases the operating range of the Cropscan to include normally unsatisfactory cloudy or overcast conditions.

All of these factors combine to make the Cropscan a very accurate, and flexible instrument capable of broadscale applications within the field of plant sciences. Appendix 3 provides a list of suggested applications which the Cropscan has been used in.

Case Studies

Barley

Experiments in Europe and North America have used the Cropscan in great detail to examine crop trials of herbicide, fertilizer and fungicide applications. An experiment conducted to test severity of foliar diseases of barley and their effects on yield and quality were very successful.

Another trial to compare fungicide treatments for the control of spot blotch in barley was also successful. In this slide a favourable plant response to the fungicide treatment is evident with a significant increase in reflectance in the Near Infrared (NIR) regions 760, 810, and 850 nm.

Wheat and Lupins

In Western Australia the Cropscan has been used to develop simple indices derived from spectral data to describe photosynthetically active tissue in a plant canopy that will accurately determine plant biomass production. This application is being used by wheat and lupin plant breeders to decrease the time taken to develop new varieties.

The technique uses a relationship between the Normalized Difference Vegetation Index (NDVI), defined as (NIR - R/NIR + R), where NIR is the reflectance at 813 nm and R is reflectance at 613 nm and, the Green Area Index (GAI). As GAI and dry matter production increases, reflectance in the red (R) part of the spectrum decreases, but that in the near infrared (NIR) increases; thus the value of NDVI increases to approach a maximum value of 1.

The results of the trial show that the Cropscan was very sensitive to GAI and dry matter production in the early stages of growth, provided a good surrogate measure of GAI throughout the season and was potentially useful for ranking trial plots. Future work is proposed to investigate the role of other spectral indices to predict canopy characteristics and dry matter production by crops.

Cotton

The Cropscan has been used by agricultural consultants in the Namoi valley of N.S.W in Australia to ground truth aerial videography data of cotton fields. The Cropscan data was first trialed against aerial video data in the NIR wavelength of 800 nm to confirm a direct correlation between the two instruments. Once, the relationship was established the Cropscan was successfully used in variety trials for plant response due to soil variations, waterlogging, plant populations and disease.

ICT International Pty Ltd
PO Box 503, Armidale NSW 2350, Australia
Ph: [61] 2-6772-6770 Fax: [61] 2-6772-7616
sales@ictinternational.com.au
www.ictinternational.com.au