A Farmer’s Guide to
Remote Sensing
in Midwestern Agriculture
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Farmer’s Guide to Remote Sensing in Midwestern Agriculture is designed to be a how-to book on taking and interpreting farm field photographs. It provides many examples of what unique characteristics can be identified through aerial photos. The guide also explains how growers can use 35mm cameras and color film to record their own farm field images.

This guide is divided into four sections. Section 1 addresses the basics of remote sensing, how images are taken, and how aerial photos can be used to identify field characteristics. Section 2 provides aerial photo examples of what growers have observed in their fields such as weed patterns, insect damage, equipment patterns, tile lines and crop stand. Included are examples of different types of imagery such as color infrared.

Section 3 shows examples of aerial photography obtained from a county FSA office as well as other things to consider when ordering your own remote sensing. It also outlines how growers can take their own aerial photos. Section 4 provides more advanced examples of remote sensing used in conjunction with GPS and GIS and how they can be applied to detect such things as iron chlorosis, nitrogen deficiencies and soil organic matter.

This publication was prepared and supported in part with soybean checkoff dollars at the request of the Iowa Soybean Promotion Board (ISPB) of Directors primarily to help educate growers on the use of remote sensing for increased profitability of their farming operation.

This information is presented mainly through a vast compilation of aerial photographs collected by the Iowa Soybean Association (ISA) and with the cooperation of several other organizations. A number of the photographs were obtained as a result of various on-farm testing projects currently conducted with the ISA and ISPB and whose collaboration is gratefully acknowledged. As well, special recognition should go to Monsanto for both the sharing of information and the financial support to make this publication possible. Monsanto made certain data sets available that were created from research projects designed to help increase grower profitability. Finally, several universities and ARS units should be thanked for graciously contributing both imagery and support for this publication.

This publication was produced through a joint project between the Iowa Soybean Association (under the direction of Tracy Blackmer, Ph.D.) and the Laboratory for Applied Spatial Analysis at Southern Illinois University Edwardsville (Professor Randall Pearson, Ph.D. and Nancy Davis). Matt Nelson of the ISA also contributed his time to this publication by spending hours in the field (or up in the air) collecting and organizing the photographs seen in Section 2. Special thanks should go to the individuals who provided content feedback and editing expertise to make this publication a success.

From left to right (Randall Pearson, Nancy Davis, Matt Nelson, and Tracy Blackmer).
SECTION 1
Remote Sensing in Agriculture

What is the value of remotely sensed data collected over my field? .......................... 7
Do I need a GPS and a computer to use remotely sensed data? ................................. 8
What is the difference between Color and Color Infrared (CIR) photography? ............. 8
Can I use a handheld digital camera to collect imagery over my fields? ....................... 10
What is georeferenced imagery and why is it important? ....................................... 11
What are vegetative indices and how are they used? ........................................... 12
When would be the best time during the growing season to collect remotely sensed data over a field? .............................. 12
What does it cost to collect photography or digital imagery over a field? ................... 13
What are the different types of remote sensing that are available to me as a grower? .......... 14
What are the more advanced remote sensing technologies being used in agriculture? ........ 15-16
Glossary ............................................. 17-18

SECTION 2
Aerial Photographs Examples (B&W, Color, CIR, and Multi-spectral)

Weed detection ..................................... 20
Insect damage ..................................... 21
Tile lines ........................................ 22-23
Moisture stress ..................................... 24
Equipment patterns ................................ 25-30

SECTION 3
How to Collect Your Own Aerial Photography

FSA information .................................. 50-52
Taking your own Aerial Photography .................................................. 53-54
Ground vs. Aerial Views .................................................. 55-56
Resolution Variation .................................................. 57
Disposable Camera Test .................................................. 58

SECTION 4
Advanced Remote Sensing Applications for Agriculture

Remote Sensing of Soybeans to Map High PH Soils .................................................. 60
Mapping Soybean Chlorosis to predict N stress .................................................. 61
Predicting Soil Organic Matter Using Digital Imagery ........................................ 62
Vegetation Indices ............................................. 63
Integration of Remotely Sensed Imagery with Field Elevation Data .......................... 64
Satellites as an Imagery Source .................................................. 65
Remote Sensing satellites cover large areas on a regular schedule ......................... 66
Acknowledgements ............................................... 67
A Farmer’s Guide to Remote Sensing is designed to provide growers with a basic understanding of remote sensing and its frequent uses in field management. The following section focuses on answering questions related to the application and collection of remotely sensed data for midwestern agriculture. The answers to the questions are not intended to be overly technical, but are meant to provide practical information on the use and interpretation of aerial photography for the agricultural community.
Remote Sensing in Agriculture

General Overview

Photography has been used for aerial surveillance for well over a hundred years. In fact, in the mid 1800’s, cameras were strapped to everything from tethered balloons to carrier pigeons. While balloons and birds (Figure 1) enabled the collection of photographs from overhead, they certainly had their limitations in military conflicts. During World War I, airplanes quickly became the preferred mechanism of carrying cameras aloft. With this, the age of “remote sensing” was born.

Since this time, there have been considerable advancements in remote sensing technology such as color-infrared photography, digital cameras, thermal infrared sensors, and satellite imagery. Likewise, there is increasing use of these innovations in agriculture, both in research and farm management. These range from hybrid analysis and determining maturity ratings to organic matter mapping and pre-harvest yield estimates.

Accompanying these advancements, however, is a growing list of frequently asked questions by those interested in, or even currently using, remotely sensed data for field management decisions. For example, what is the best time of year to collect remotely sensed data? Do I need a GPS or a computer? Can I collect aerial photography with a digital camera and, if so, what are the settings? This section is designed to provide practical and informative answers to these and other questions about remote sensing as it is applied to agriculture.

What is the value of remotely sensed data collected over my field?

The view of an agricultural field is typically done from ground level, or at best, from the seat of farm machinery. While this ground level view of a field will never be replaced, the addition of a “bird’s eye” view can greatly enhance a grower’s ability to make informed management decisions about their field(s). More specifically, field knowledge coupled with an aerial view of the field, may provide a grower with a better understanding of factors potentially affecting crop yields. In fact, it is this view from above that often reveals problematic patterns in a field that would otherwise go undetected. Examples include planter skips, location of tile lines, herbicide overlap, magnitude of soil variation, and wide guess rows. Figure 2 shows an example of an aerial photograph taken during optimal soil moisture conditions that enables the identification of tile line placement.

Figure 1. Early remote sensing systems.

While early use of aerial photography was centered on military applications, its use in agriculture was not far behind. By the 1940’s, the USDA Soil Conservation Service was routinely collecting aerial photography primarily for the compilation of early soil surveys.
The important point here is that what a grower sees from an aerial photograph can have a significant impact on how he manages his fields. For instance, how effective are the tile lines at draining a field? Are there areas within the field that need additional tiling? Can historical cropping patterns be seen in the field or are there patterns that suggest soil compaction from farm machinery? When monitoring the crop, are there planter skips, is there uniformity in plant stand, or is there a pattern in the field suggesting herbicide overlap? In many instances, it is equipment or management-induced patterns that most surprise growers when they see aerial photographs of their fields. If surveyed, probably 80% of midwestern growers would identify equipment patterns as the number one problem that have gone unnoticed within their fields. Quite often, these yield-reducing problems (identified through remote sensing) are easily rectified through simple adjustments in management practices or equipment.

**Do I need a GPS and a computer to use remotely sensed data?**

The use of remotely sensed data does not require a GPS receiver or a computer. For many applications of remote sensing in agriculture, especially equipment related problems; a simple photographic print will suffice. Standard photographs (black and white, color, and color-infrared) often show patterns such as herbicide overlap or wide guess rows that are difficult to see from ground level. Quite often, the knowledge that these patterns (problems) exist is information enough to begin taking corrective measures. Figure 3 shows an example of downed corn due to greensnap. In this case, a GPS and a computer would add little additional value to the grower’s use of remote sensing. Instead, this raw oblique photograph enables a simple estimation of the percentage of the field that is affected.

While the above photograph demonstrates that remotely sensed data can be useful without owning a GPS unit or a computer, there are times when these high-tech tools provide significant value to a grower. An aerial photograph provides only the relative location of problems or conditions seen in a field. However, a GPS unit can provide a grower with the absolute location of these field conditions (either through field scouting or extracting coordinates from a georeferenced image). Additionally, there are computer software packages specifically designed for agricultural management that enable a grower to visualize and manipulate field data such as yield monitor or elevation data. This type of computer software can be a useful farm management tool. The value of integrating geographic (or georeferenced) data into farm management is discussed more in-depth later in this publication.

**What is the difference between Color and Color Infrared (CIR) photography?**

CIR photography is similar to color photography in that it measures light reflectance. While color film is designed to provide a picture that is somewhat consistent with what we see with our eyes, color infrared film provides a false-color image that utilizes wavelengths beyond human vision (near infrared). Color photography represents each wavelength of light by its true color (blue, green, and red); color infrared photography, on the other hand, represents each wavelength by a false color (green, red, and near infrared light are represented by blue, green, and red film colors). The photographs in Figure 4 show an example of this false color concept.

Notice how in the color infrared photograph, the green tractor takes on a blue appearance, while the similarly colored green vegetation (which has high near infrared reflectance) appears red. Simply
stated, a CIR photograph enables us to see near infrared reflectance by assigning the NIR a red color in photography. The value of the near infrared wave-band is in its ability to measure the amount of plant matter (crop biomass) in an agricultural field. A stressed or diseased plant (with less biomass) does not reflect as much near-infrared light as a healthy plant. Therefore, color-infrared photography may be used to detect subtle changes in crop health.

Figure 4. Color and color infrared photographs of farm equipment.

To emphasize this color versus false color difference, photographs were taken of the same soybean field using both color and color infrared film (Figure 5). The plants and trees in the color infrared photograph are displayed in shades of red depending upon the amount of plant structure (or measured near infrared reflectance). The healthy, green soybean plants range in color from magenta to deep red while the stressed, yellow plants (seen in the middle of the image) have very little near infrared reflectance and appear light pink. These ground level photos emphasize the visual differences between color and color infrared photography. Conversely, these color differences are equally dramatic in aerial photos acquired from several thousand feet overhead.

Figure 5. Color and color infrared photographs of the same soybean field.

Figure 6 shows an example of what a midwestern agricultural field looks like from both color and color infrared aerial photography. While the color differences are striking, the added complexity of an aerial perspective can make interpretation of both film types (especially color infrared) a bit challenging. For example, from the color photograph one can see significant differences in crop color due to variation in both crop stage and soil moisture. In this case, the use of a familiar color scheme coupled with pattern and texture makes this photograph fairly easy to interpret. However, unlike color photography where green indicates healthy vegetation and yellow indicates stressed or senescing areas, color infrared photography (typically used in crop analysis) indicates differences in crop health through varying shades of only one color (red). This unnatural monochromatic color scheme can be difficult for even the most experienced remote sensing users to interpret.
So, does a grower necessarily need color infrared photography for day-to-day field management? Probably not. Although it is often assumed that CIR photography is beneficial for agricultural management, 90% of the problems in a field can be identified through standard color photography. This is not to say that color infrared photography does not have value. In fact, it has been used extensively in agricultural research for analyses ranging from pre-harvest yield estimation to hybrid evaluation. The point here is that for the average grower, color aerial photography should be sufficient for most field management decisions.

Can I use a handheld digital camera to collect imagery over my fields?

One of the primary advantages to having a digital image rather than a photograph is that it allows for computer enhancement that can highlight specific aspects of a field that might not otherwise be noticed. At the most elementary level, digital imagery can be acquired through simply using a handheld digital camera or scanning an aerial photograph with a flatbed scanner. More advanced methods include the use of optical mechanical scanners and digital multi-camera systems. One caveat for collecting imagery with a digital camera is that there may be potential limitations to F-stop and shutter speeds settings that could cause motion blurring in the image.

Once an image is in digital format, simple computer enhancement techniques can add a great deal of clarity to the image enabling easier interpretation. The two primary techniques of enhancement include contrast stretching and spatial filtering. A contrast stretch involves identifying the lower and upper bounds of the data and applying a transformation (linear or histogram equalization) to force the data over the full range of possible values (0-255). The image in Figure 7 shows an example of a typical 35mm aerial photograph before and after a linear contrast stretch.

This photograph was taken on a hazy day, which caused the image to have a washed out appearance, and shows very little contrast. After enhancement, the photograph gains considerable value by making variation between and within the fields more obvious.
Spatial filters, on the other hand, are designed to enhance the tone or texture of objects in an image based on what is directly around them. More specifically, filters can be used to smooth an image to suppress noise (despeckle) or sharpen an image to accentuate detail. Figure 8 gives an example of an image with a sharpening filter (high pass) that brings out subtle patterns that were not easily seen in the original image.

Figure 8. Result of sharpening filter.

Does an image need to be georeferenced? When is it important to have georeferenced imagery?

Georeferencing is the process of assigning map coordinates to a digital image and involves relating each pixel in the image to geographic coordinates (i.e., latitude/longitude). In many instances, such as the basic visual interpretation of aerial photography, the photograph does not necessarily need to be georeferenced. The photograph in Figure 9 shows a field with a sawtooth pattern that resulted from the lifting of equipment when moving in opposite directions. In many cases, it is the pattern that is most important for management decisions, not the absolute geographic location of where the pattern occurred.

Figure 9. Equipment pattern in agricultural field.

While it is not essential, georeferenced imagery is required for applications such as change detection over time (multi-date imagery) and the integration with GIS data layers (soil survey, yield monitor, elevation, etc.). The image in Figure 10 shows the integration of a digital soil survey with a georeferenced image of a field in central Iowa.

Figure 10. Integration of georeferenced imagery and digital soil survey.

Another important use for georeferenced imagery is for field scouting purposes. If, for example, an area on a photograph indicates crop stress (Figure 11), geographic coordinates can be extracted from the georeferenced image, entered into a GPS unit, and then used for “Go To” operations by field scouts. It should be noted that to georeference oblique or highly distorted photography/imagery, advanced image processing software is needed.
What are vegetative indices and how are they used in agriculture?

A common approach by researchers to assess the vegetative health within agricultural fields is the use of vegetative indices. Vegetative indices are calculated by mathematically manipulating (ratioing) near infrared versus red reflectance resulting in a numerical value that represents crop condition or crop health. For instance, the simplest vegetative index is the division of the near infrared spectral band by the red band. This ratio plays on the fact that healthy green vegetation has high near infrared reflectance and low red reflectance, thereby producing a numeric value (ratio) greater than one. Conversely, soil has a near equal reflectance in both the near infrared and red portions of the light spectrum and results in a ratio close to one. With this ratio, numbers greatly exceeding one indicate very healthy vegetation while low numbers equate to less healthy vegetation or less biomass.

The diagram in Figure 12 illustrates the process of ratioing two images. In this diagram, the near infrared image on the left is divided by the red image on the right resulting in a new image that highlights variation in vegetative health/amount. The new ratioed image is displayed with a rainbow color scheme that enhances this variation whereby red indicates the healthiest areas in the field (with the most biomass) and pink the least healthy. While this shows a simple vegetative index, other more complex indices include Normalized Difference Vegetative Index (NDVI), a Perpendicular Vegetative Index (PVI), and a Soil Adjusted Vegetative Index (SAVI). Each of these indices is specifically designed to adjust for field conditions such as soil variation and moisture.

When would be the best time during the growing season to collect remotely sensed data over a field?

Timing of remotely sensed data is dependent on a variety of factors, with the two most important being crop type and management objectives of the grower. These two factors alone can vary the timing of photograph acquisition by months. For instance, is the crop of interest corn, soybeans, wheat, or alfalfa? Is the grower interested in drought stress, ponding, equipment patterns, disease, pest, or irrigation problems? Or, does the grower simply want an aerial view of the field?

\[ \text{NDVI} = \frac{(\text{nir} - \text{red})}{(\text{nir} + \text{red})} \]
Even though the answer to the question of timing seems elusive, there are some general guidelines that can be used for the acquisition of remotely sensed data. First is the reality that a single acquisition of aerial photography may not be enough to tell the whole story of what is going on within an agricultural field. This idea of multiple dates of photography/imagery throughout the growing season is referred to as multi-temporal. By collecting and comparing photography through time, various patterns begin to reveal themselves. These patterns, in many instances, are not apparent in a single photograph.

The photographs in Figure 13 show this concept well. The three photographs are of a bare field in central Iowa taken at different times prior to planting. The first image in this series was taken when the field was relatively dry and the color variations correlate to changes in organic matter (OM) (darker colors relate to higher levels of OM). The second and third images in this series were acquired within a few days of a significant rainfall. The second image (taken one day after rainfall) shows the effect of tile lines within the field. The third image (taken three days after rainfall) shows areas that are retaining moisture. The point is, each image was taken within the period of a week and reveals significantly different conditions within the field.

![Figure 13. Time series of the same bare soil field.](image)

Probably the best advice for timing the acquisition of aerial photography over an agricultural crop is to pay attention to crop stage. For instance, with corn, unless the grower is attempting to identify a specific field condition, the collection of imagery just after planting, and, at the V12, Tasseling, and R4 stages, seems to be a good sequence for identifying unknown problems within a field. While crop stage is adequate for timing the general collection of remotely sensed imagery, there are certainly more precise times when one would want to collect data to address crop-specific problems.

**What does it cost to collect photography or digital imagery over a field?**

The cost of collecting remotely sensed data over an agricultural field can vary significantly. On the low end, collection of photography can be as simple as the use of a disposable 35mm camera taken from the window of a single engine aircraft. Figure 14 shows the results of such a configuration: a picture of a farm field in central Iowa taken with a 35mm camera from the window of a Cessna 172. For this economy method of collecting aerial photography, the cost of the film and one hour of air-time in the Cessna 172 (this includes pilot cost) averages approximately $100-$200. During a typical one-hour flight, a camera operator can easily collect photos of 3500 acres. One can see that the cost to collect photography under this scenario can be as little as 3 cents per acre. While this is certainly inexpensive, for many applications of remote sensing in agriculture, it may be all that is required.

![Figure 14. Low cost color aerial photograph.](image)

On the other end of the cost spectrum is the acquisition of digital multi-spectral imagery. These systems utilize multiple cameras, each equipped to capture specific wavebands of light. Once acquired, these data need additional image processing to assure that all bands of data are registered or aligned together (band-to-band registration). Figure 15 shows an image collected over central Iowa with a 4 band digital multi-spectral system (blue, green, red, near infrared) flown in a Cessna 210. The cost of the camera system, the extra requirements for advanced aircraft systems, and the cost of band-to-band registration, result in a cost of approximately 50 cents to several dollars per acre. While this is considerably...
more expensive than the simple photography method, multi-spectral data has the advantage over aerial photography in its ability to measure distinct spectral reflectance properties of crops. This data is typically employed in more advanced analyses such as vegetation indices, temporal comparative analysis, and management zone determination.

Figure 15. Multi-spectral digital image.

What are the different types of remote sensing that are available to me as a grower?

There are a variety of remote sensing resources readily available to today's grower. These include color photography, color infrared photography, and digital multi-spectral imagery. These data types are relatively easy to collect, low to moderately priced, and can typically be collected by a vendor with very little notice (weather permitting). While the value of the above data types has been discussed extensively in this document, there are other sources of data that may also be of value to the agricultural community. These include FSA Photography and USGS Digital Orthophoto Quadrangles (DOQ's).

In 1935, the USDA began a program of collecting photography over agricultural areas for the purpose of accurate field and farm measurements. This aerial photography program is now operated by the Aerial Photography Field Office (APFO) of the Farm Service Agency (FSA) and has both current and historical black and white photography available for most of the nation's major cropland areas.

For selected areas, color and color infrared photography are also available. Figure 16 shows an example of a black and white FSA photograph.

Figure 16. Example of FSA photograph.

These photographs are an excellent source for identifying historical cropping practices and field patterns, assessing soil variations within fields, and mapping tile lines. Individual photographs (1955 to present) may be purchased directly from FSA from the following website:


The price for FSA photography ranges from $5.00 to $70.00, depending on the size and type of photography requested.

Another source of information that is available to midwestern growers is the USGS Digital Orthophoto Quadrangles (DOQ's). In 1990, the USDA and the USGS jointly proposed the concept of a National Digital Orthophoto Program (NDOP). The primary goal of this program was to ensure the public availability of digital orthophotography. A DOQ is a computer-generated image of a black and white aerial photograph in which displacements caused by camera orientation and terrain have been removed. These images have been georeferenced and thus combine the characteristics of a black and white photograph with the geographic integrity of a map. This enables easy use within a farm management computer system. An example of a DOQ is given in Figure 17.
DOQ’s have applications in agriculture similar to those of FSA photography, and include mapping of field boundaries, delineation of drainage features, and the assessment of soil variation within a field. The USGS began to produce DOQ’s in 1991 and currently have nearly 50,000 available for distribution. Complete DOQ coverage of the conterminous United States under this program is expected by the year 2004. Thereafter, the DOQ’s will be updated on a 10-year cycle for most areas, and on a 5-year cycle in areas where land use change is more rapid. Individual photographs for Iowa may be downloaded directly from the Iowa State University website: http://ortho.gis.iastate.edu/doqqs.html.

What are the more advanced remote sensing technologies being used in agriculture?

Although aerial photography and digital imagery are the backbone of agricultural remote sensing at the farm level, there are other remote sensing technologies, such as satellite imagery, that have been used extensively within general agriculture for decades. Additionally, there are new and promising remote sensing technologies that are being researched for their potential in on-farm management. These include thermal infrared sensors, hyperspectral sensors, and Lidar.

**Satellite Imagery**

Historically, satellite imagery has been used for a variety of agricultural applications including crop type mapping, general crop condition assessment, and crop acreage estimation. Typically, these applications were used over large areas due to the limited spatial resolution (pixel size) of these early satellites. Finer spatial resolutions of more recent satellites, however, are now enabling within field assessment of problems such as drought stress, flooding, hail damage, and pest infestations. Figure 18 shows a broad area view of an agricultural area from satellite.

**Figure 18.** Subset of satellite image acquired over midwestern agricultural fields.

**Thermal Infrared Imagery**

Thermal infrared imagery is slowly making its way into agriculture with the primary use being the measurement of crop canopy temperature. Past research suggests that abnormally high canopy temperatures may directly relate to crop water stress. Figure 19 shows an example of thermal imagery acquired over a cotton field in Arizona. The red and yellow areas indicate higher canopy temperatures, which in turn, relate to areas of potential moisture stress.

**Figure 19.** Thermal image over Arizona cotton field. (Courtesy USDA, ARS)

While thermal imagery is being used extensively in monitoring high value crops such as cotton, melons, and citrus, the application in corn and soybeans has largely been limited to research.
Hyperspectral Sensors
The difference between multi-spectral sensors and hyperspectral sensors is the number (and width) of wavebands that are collected. Hyperspectral sensors collect between 10 and 400 narrow wavebands of digital information for every point on the ground, while multi-spectral sensors collect between 3 and 10 broad wavebands. The concept behind hyperspectral sensors is that specific information about an agricultural crop may be masked in the broad wavebands of multi-spectral systems. However, by using hundreds of narrow wavebands, researchers believe that specific diseases, pests, and crop deficiencies may be more easily and consistently recognized. Once a specific waveband, or a set of wavebands, is identified for a certain application, new, less expensive, multi-spectral sensors can be designed to target this application.

Lidar
Lidar, which stands for Light Detection and Ranging, is an active remote sensing system similar to RADAR. Lidar is being used in agriculture to gather precise elevation measurements on a field with accuracy to within six inches. These systems work by emitting laser light pulses toward a target. The time it takes for the laser light pulse to reach the target and return to the sensor determines the distance between the two. From this information a detailed terrain model can be developed for an agricultural field. This type of system is an improvement over GPS-based mapping because it is not limited by drastic differences in terrain and land cover. However, Lidar is significantly more expensive than GPS and therefore is probably cost-prohibitive for the most common field elevation mapping.
Glossary of Key Terms

Aperture Setting:
The size of the opening in a photographic lens that admits the light into a camera. The setting is represented by a numeric value (the f/stop). Film exposure is a function of f/stop and shutter speed.

F/Stop:
See aperture setting.

Band:
One layer of a multispectral image representing data values for a specific range of the electromagnetic spectrum; for example, the Near Infrared band.

Black and White Photography:
Standard panchromatic film type used for aerial photography.

Charge-Coupled Devices (CCD):
Two-dimensional detector devices capable of differentiating a substantially wider range of scene brightnesses than photographic film.

Color-Infrared Photography:
False color film is different from ordinary color film in that the three film layers are sensitive to green, red and infrared radiation instead of blue, green and red.

Color Photography:
Aerial photography using color rather than black and white panchromatic film.

Computer Enhancement:
The act of increasing or improving the value and quality of data with a computer (filtering, contrast stretching).

Contrast Stretching:
Expanding a measured range of digital numbers in an image to a larger range, to improve the contrast of the image for visual display.

Digital Camera:
A camera that uses a typical camera body and lens but records image data with charge-coupled devices (CCD) rather than film.

Digital Image:
An image where the property being measured has been converted from a continuous range of analogue values to a range expressed by a finite number of integers, usually recorded as numbers ranging from 0 to 255.

Geographic Coordinates:
A number that identifies a position on a map with respect to its geographic position on the earth’s surface. Example: Latitude/Longitude, Universal Transverse Mercator (UTM).

Georeference:
The process of registering or adjusting a digital image to a geographic coordinate system. The result is that the approximate geographic location for each pixel is known.

Global Positioning System (GPS):
A navigational system which uses a constellation of satellites for triangulating or calculating the geographic position of a receiver on or above the earth's surface.

Light Reflectance:
Light that is not transmitted or absorbed by a surface body. This is what cameras measure when taking a picture.

Multi-date Imagery:
Images of the same area taken at different times (i.e., different days, different seasons, or different years). Multi-date imagery is typically used in change detection analyses.

Monochromatic Color Scheme:
A color scheme having or consisting of one color or hue.

Normalized Difference Vegetation Index (NDVI):
An index calculated from reflectance’s measured in the visible and near infrared channels. NDVI is calculated as: (NIR-R)/(NIR+R).

Oblique Photography:
Photography in which the optical axis of the camera is not perpendicular to the terrain. If the horizon is present in the image, it is referred to as high oblique.

Perpendicular Vegetative Index (PVI):
A vegetation index that assumes that the reflectance in the NIR and red varies with increasing vegetation density (such as leaf area index) and that these variations are parallel to the soil baseline. Therefore, the perpendicular distance from the baseline in a NIR-red plot determines the vegetation density.
**Plant Biomass:**
The total mass of living matter in a given plant.

**Ratioing:**
An image prepared by processing digital multi-spectral data as follows: for each pixel, the value for one band is divided by, subtracted from, or added to that of another band. Ratioed images are used for applications ranging from vegetation indices to mineral identification.

**Remote Sensing:**
The acquisition of information about an object, without being in physical contact with that object.

**Senescence:**
The latter stages of a plant’s life.

**Shutter Speed:**
The shutter speed is the length of time the "shutter," which covers the CCD (charge coupled device), allows light onto the CCD.

**Soil Adjusted Vegetative Index (SAVI):**
A vegetation index that accounts for, and minimizes, the effect of soil background conditions.

**Spatial Filtering:**
An image enhancement method that modifies pixel values based on the values of the surrounding pixels, with the objective of enhancing areas of high or low spatial frequency.

**Vegetative Indices:**
Mathematical quantities that are sensitive indicators of the presence and condition of healthy green vegetation.

**Wavelength:**
The distance between one peak or crest of a wave of light and the next corresponding peak or crest.
Section 2

Aerial Photograph Examples

This section focuses on showing actual examples of what growers have seen on their fields. It is easy to list the types of patterns or problems that can be detected in crop production fields, but this section focuses on actual examples. Examining the different examples and explanations will also help better understanding your own pictures. In section 2, you can see that all of these images can be utilized without using a GPS or even a computer. To further benefit growers, section 2 contains a number of comparisons allowing growers to better understand the differences between the timing or types of imagery. There are a number of comparisons provided that allow growers to compare color and color-infrared images. There are also a number of comparisons showing a time sequence of the same field.
Weed Detection

The image above shows a center pivot with the faint red color representing crop canopy and the brighter red color being areas of heavy weed growth.

The field above is a pasture that has weeds with yellow flowers which can be seen from the air.

The brown areas are dead weeds after being sprayed. The whiter regions of the field are lighter soils with less crop growth.

The bottom portion of this image shows light green striping from left to right which is probably due to driving too wide during a herbicide application.
Insect Damage

The whitish pattern (mostly in the top half of the image) is from lodged corn resulting from corn root worm damage. Photo courtesy of USDA ARS, Lincoln, NE.

This image shows a corn field with corn lodged from infestation of grape colapsis. The faint left-right striping is the result of different N rates.

Same as photo at left but taken with CIR photography. Photo courtesy of USDA ARS, Lincoln, NE.

This is a trial showing soybean aphid damage in stripes patterned in an s’ shape. The striped pattern resulted from varying aphid control from pesticide test strips. Cloud shadow present in lower left.
Lighter colored linear patterns in this field indicate tile lines.

Recently laid tiles are responsible for the pattern in this field.

The patterns in this field are a combination of tillage and tile lines. Also, power lines are apparent in this field.

The patterns in these fields show a difference in growth resulting from differential drainage due to tile lines. There are trees in lower left hand corner.
Tile Lines

This is the bare soil image of a field.

This is the bare soil image of the same field collected two years later.

This is the same field shortly after a rainfall. The lighter shades are faster drying areas (immediately over the lines).

This image was taken shortly after the one to the left. Notice the difference in the soil patterns with varying drying conditions.
Moisture Stress

Light brown areas indicate where crop died early due to severe moisture stress (both corn and soybeans).

Notice the moisture stress evident in both crops in this photograph.

Drought pattern in the same corn and soybean fields at left photographed two weeks later.

This image shows areas that have been affected by drought. Note the pattern detail (this is much finer than a yield monitor could generate).
Equipment Patterns

The dotted pattern represents a planter malfunction resulting in skips in the plant population.

Notice the tractor in the field and the color difference in the soil before and after the soil has been worked.

The streaks in this field represent areas where manure was applied to the surface.

The circular patterns result from a center pivot. The lighter areas represent soils with less organic matter and the dark wavy line is a drainage way.
This image shows how many different observations can be made with a single image. Notice the crop differences, equipment patterns, and waterways.

The east-west striping in the top half represents nitrogen application error. The lower half of the image shows some cultivator blight from narrow guess rows. Photo courtesy of Alfred Blackmer, Iowa State University Agronomy Department.

This photo shows recently worked soil in portions of the field.

The cross-hatching seen in the bottom portion of this photograph represents equipment patterns from multiple operations.
Equipment Patterns

The pattern in the top field represents an anhydrous ammonia application error. Photo courtesy of Alfred Blackmer, Iowa State University, Agronomy Department.

Notice the general growth pattern differences as well as the cross hatching which represents old plow patterns.

The above image shows soybean iron chlorosis (appearing yellow from high pH), two directions of equipment patterns, and wet spots that appear darker.

The north-south striping in this field is management-induced and shows a major impact on crop growth.
The light colored streaks are due to an anhydrous nurse tank running low.

White dots in field represent combine residue from combine stops. The dark areas represent low-lying wet areas in the field.

The saw-tooth pattern in this photo represents lifting of equipment when moving in opposite directions causing an apparent offset.

This image shows patterns that are not consistent with the row direction.
The east-west strips represent wide guess rows resulting from planter marker error. In the bottom field, the corn was drowned out and replanted to beans.

The above image is a soybean field with iron chlorosis and wheel traffic patterns with planter gaps near the headlands. The mottled pattern is from the wind.

The east-west strips indicate wide guess rows. Notice the drowned out area on the west end of the field. Also, thin clouds can be seen in the center of the image.

The photograph above shows weeds present in the missing corn canopy.
Equipment Patterns

Notice low wet (dry in this image) areas in the field and the multiple directions of wheel traffic.

The above image shows patterns of possible herbicide overlap (overlapping rows and headlands) and poor stand. Notice a cloud shadow at right edge of field.

This photo shows three sources of variability including soil variability, compaction from tillage (diagonal pattern), and streaks running with the rows.

This photo shows both field variability (high pH) and herbicide overlaps (north-south streaks and headlands).
Crop Stand

The photo shows areas of downed corn in the field. From this photograph, it is possible to estimate the percentage of affected plants.

A corn field with greensnap damage. This photo shows the differences in amount of greensnap damage between the two hybrids in a split planter trial.

This image shows the severity of greensnap. It would make a difference which side of the field you checked if you assessed this field from the ground.

This aerial photograph shows corn that lodged just prior to harvest after some strong winds presided.
Conservation Structures

This CIR image shows terraces in corn and soybeans.

This color photo shows terraces in corn and soybean fields.

This image shows terraces in a bare soil field.

This photo shows buffer strips in a field. Also notice the north-south power lines through the middle of the field.
Field Variation - Color vs CIR

This color infrared photograph shows an identical pattern of soil type and soil moisture to that of the color photograph at right.

This color photo shows variation in both soil types and soil moisture.

This color infrared photo shows variation in plant biomass. The image was taken 20 days prior to the color photograph at right.

This color photograph shows a senescing corn canopy as related to the variability shown in bare soil photos above.

Photos this page courtesy of Alfred Blackmer, Iowa State University, Department of Agronomy.
Field Variation

The effects of soil variation and an old stream channel can be seen in this photo.

This photo shows differences in crop growth due to soil variation.

This image shows a field with two rates of N applied in alternating strips. Notice the non-uniform differences.

This photo shows differences in crop growth due to soil variation.
Field Variation

This image shows drowned out corn with replant as well as poor plant stand on the knolls.

This photo shows replant and areas that should have been replanted.

This photo shows a major area of replant due to drowned out spots.

This image shows extensive replant in corn (bright red).
Field Variation

Same field as color photograph to the right but taken with color-infrared photography. Photo courtesy of USDA ARS, Lincoln, NE.

Late season image acquired at about 50% senescence. The crop variation pattern matches that of soil. Photo courtesy of USDA ARS, Lincoln, NE.

This photo shows poor stand throughout the corn field.

The poor stand in this soybean field was the result of a bad seed lot.
Field Variation

Ground level photo of chlorotic areas from the photograph on the right.

Notice the soybean chlorosis from high pH and the wheel traffic patterns through the chlorotic areas as shown from the air and the ground (photo at left).

The photo above shows drowned areas, chlorosis (high pH), and equipment patterns (diagonal, north-south and east-west stripes).

The above photo shows two soybean varieties and two major replant areas.
Field Variation – Time Series

This field and the subsequent three images show soil variability and its effect on crop growth.

This image was taken just prior to tasseling.

This image was taken around milk to dough stage. The soil patterns are still present.

This image was taken when the corn was between waist and chest high.

This image was taken just prior to tasseling.
Field Variation – Time Series

This image shows soil variation, water ponding, and early weed detection (shown by the faint red). Compare this image to the other three on this page.

In this image, both corn (right side) and soybean (left side) fields have established canopy. The corn has multiple hybrids resulting in a striping effect.

This image shows a change in the canopy from the previous flight for both corn and soybeans.

Even at the end of the season, the canopy variation still reflects variability in soils for both crops.
This image shows the ground recently tilled in fields that were planted to corn. The light colored soybean fields have not been tilled and show less soil variability.

This image shows the differences in reflectance for corn and soybean canopies. The corn field is in the center with soybeans adjacent to it (right and upper-left).

This image was collected at an optimal time to show early corn growth differences but was collected too early to detect soybean differences.

In this image you can start to see some of the corn hybrids senescing but the soybean fields still show full canopy.
Field Variation – Time Series

Light blue areas in field indicate less growth (more bare soil).

Notice that later in the season, areas that had less early-season growth now show the most vegetative growth (these areas will probably be lower yielding).

This bare soil image shows major soil variation and ponding (standing water). The impacts of standing water can be seen in the image of this field taken later in the season (at right) and identifies areas of potential yield loss.

Canopy growth is variable due to the amount of standing water earlier in the season. Also, the drowned out areas were replanted to beans.
Field Variation – Time Series

Notice soil variability in this image and how it influences the crop in the following pictures.

Notice how this image collected at tasseling time shows less variation than earlier and later images.

Notice the subtle variation in the center of this corn field and how it relates back to the soil variability in the bare soil photo.

The variation in the crop seen on this image can be related back to the soil variation apparent in the initial bare soil image.
This photo shows light green stripes where management injured the crop. In addition, greensnap (the light brown areas), is also evident in the field.

This image of a corn field shows a circular area of crop stress (lack of water) around the center pivot that resulted from a clogged nozzle. The light green linear pattern in the field is from nitrogen treatments. Photo courtesy of USDA-ARS, Lincoln, NE.

This photo shows areas of low plant populations, planter gaps, and also where the anhydrous ammonia applicator ran out (in the bottom wedge of the field).

The small bright areas in this field are the result of water ponding and planting around tile inlets.
Notice the creek in the bottom portion of this photo is white. This is due to sun glint.

Remote sensing ag fields wouldn’t be complete without a picture of a crop circle.

A corn maze with the Iowa State University Cyclone logo.

The mottled pattern in this field is due to the effect of wind moving the leaves throughout the canopy. Also, there is the shadow of the plane in the upper left hand corner of the image.
This field shows a split-planter trial (hybrid strips alternating across the field). Also present are buffer strips and spots where there is poor stand.

In the lower left hand corner, there is an airplane shadow and a halo around the plane.

This image shows corn, CRP, pasture, and a recently planted field with grass waterways.

Notice the sun glint on the ponded portions of the field. The darker region on the right is a cloud shadow.
The brown areas in this aerial photograph represent areas of sudden death syndrome (SDS) in soybeans.

This photo shows the ground view where SDS was detected in the field below.

This color photograph shows areas of SDS as well as lightning strikes.

Same field at left but photographed using color infrared.

Images on this page courtesy of Dr. Harlan Palm, Department of Agronomy, University of Missouri.
Below is an aerial photograph of a field with the yellow areas matching actual soybean cyst nematode samples shown below the image.
The image above was created by mosaicing a large number of scenes together. By looking at the broader picture, field by field comparisons can be made. Also notice the pattern across fields where the glacier came from the top left corner to the lower right corner. Image courtesy of Geovantage.
Section 3

How to Collect Your Own Aerial Photography

This section focuses on growers obtaining their own imagery. Although there are a number of commercial services available, the exact source and areas served change so rapidly, we chose not to focus on these services. Government sources of photographs are available through the FSA office that growers can obtain for their specific fields. We have provided examples of government data from a single field so growers can examine the options available to them. In addition, most growers can collect their own imagery relatively inexpensively by working with a local pilot for a small fee. We provide written instructions on how to set the camera and some examples of other factors that affect when and how to take the pictures.
FSA Information

Below are examples of aerial photography available from the county FSA office focusing on the same quarter section over a 20-year period.

Each photograph is from a 35mm slide that was collected each year during the summer.
Each photograph covers two sections.
These can be helpful for identifying historical patterns in a field, particularly when assessing the potential of new fields.
FSA Information
FSA Information

Below are examples of aerial photography available from the FSA that have been archived since the 1950s in most areas. The photographs were collected over the same field from 1955 to 2000.
How to Collect Your Own Aerial Photography

Selecting an Airplane
Most airports have planes and pilots that can be hired to collect arial photography for around $75 to $200 an hour. The cost of flight time can be minimized by selecting an airport as close to the field or fields of interest as possible. In this instance most growers can expect to collect all of their fields in about an hour or less. If possible, locating a pilot with a plane designed for capturing aerial photography is best. These planes typically have a hole in the bottom so pictures can be easily taken directly over the field instead of through a side window. If taking pictures out of the side window is the only option, then finding a plane with wings mounted above the window will make it easier to collect unobstructed photographs. Airplanes with a window that will open will permit you to get better pictures. If you bring along a screwdriver, you can unhook the window bracket that will let you open the window wider and get a better range to adjust your camera. Once the plane is airborne, the air current will hold the window open even though the bracket is disconnected.

Camera and Altitude Settings
Most 35mm film cameras will work for taking aerial photographs. It is important to note that the automatic settings on cameras do not work well for aerial photographs. Usually the focus control should be set on infinity and the shutter speed should be set manually. The two most important features on a camera are the type of lens and shutter speed setting. While there are many different types of lenses, an adjustable lens makes it easier to focus on the field of interest without having to change the altitude of the aircraft. As well, for an adjustable lens, distortion decreases with increased aircraft altitude. However, at higher altitudes, the increased haze of the atmosphere can cause a foggy or blurry appearance in the image. An ultraviolet (UV) filter will help reduce the impact of haze on the images. As a general rule, fly lower (3,500 feet) on hazy summer days and fly 5,000 to 7,000 feet on clear days. With this in mind, the typical camera can collect an 80-acre field at an altitude of 3,000 feet or 160-acres at 6,000 feet above ground level.

The second most important component for collecting aerial photog-raphy is the camera’s shutter speed. Because of the rapid forward motion of the aircraft, a fast shutter speed is necessary to minimize motion, blur. However, shutter speed is also determined by film type. A film speed of ASA 200 works well for most conditions. Film speeds of ASA 100 or less are sensitive to motion blur while film speeds of ASA 400 or greater can appear grainy. Films with an ASA of 100 or lower may not work with fast shutter speeds when sunlight is somewhat limited. Films with an ASA of 400 or higher will appear grainier, but may be required if collecting images under the clouds.
Timing of Collection Soil variation.
Soil variation in a field is best detected when there is very little crop residue on the surface and soil moisture is optimum. Crop residue is usually minimal just after planting while soil moisture is optimum 2 to 4 days after a rainfall. Also, a good time to collect aerial photographs for assessing soil variability is immediately after performing a tillage operation.

Crop Stand.
The best time to detect differences in early growth is usually when there is enough crop canopy to cover the soil. This can be difficult to determine as seen in the examples of ground to air photos in Section 2. In general, the timing for corn in 30 inch rows is usually when the crop is 3 feet tall and for 30 inch soybeans about two feet tall (earlier for narrower rows).

The next best time for collecting imagery (of corn) is just before tasselling. This particular timing of acquisition is after rapid nutrient uptake by the plant and when there is a high amount of crop biomass (ground cover), but prior to tasselling and pollen shed.

A late stage for acquisition for corn is late dough to early dent stage. At this time the plant is starting to senesce and crop variability seen on an image can often be related to differences in yield. A map of soybeans during senescence is also useful but is more difficult to obtain. This is due to the fact that senescence occurs over a narrower time period and varies with different maturities, whereas corn has a much wider window of opportunity.

Useful things to bring on an aerial trip.

- A camera - preferably one with an adjustable lens.
- Several roles of film.
- A map to show the pilot the fields of interest.
- A note pad to take any interesting notes.
- A screw driver to remove the bracket for the side window.
- A wide, closeable plastic bag in case you get airsick.
Ground vs. Aerial View

This shows the windshield view of 30 inch row-spaced corn. Although you can see a lot of green plants, soil is still showing through the crop.

This photograph is an aerial view of the same field to the left taken on the same day. Notice how you see mostly soil differences as compared to plant differences.

This shows the windshield view of 30 inch row-spaced corn (little to no soil shows through the crop). To the right is an aerial perspective of the same field.

This shows the aerial view of the field to the left taken on the same day. In this photograph, variations in crop growth/stand are now visible. Cloud shadow can be seen in the upper right portion of the photograph.
This is a ground shot of a soybean field. The bare soil is still apparent in this field.

This shows the windshield view of both 30-inch and 15-inch row-spaced soybeans. The 30-inch rows still show a lot of bare soil through the plants—especially on the knolls.

This shows the aerial view of the field to the left taken on the same day. Notice that within the 30-inch rows of soybeans, the soil is more visible than the crop.

This photograph is the field at left taken on the same day. Although plants can be seen at ground (field) level, there is not enough canopy coverage for the crop to be noticeable from the air.
Resolution Variation

Often digital imagery is available in different resolutions. Particularly, satellites offer a wide range of resolutions. The same image is shown as a 1, 5, 10, and 20m resolution to illustrate the differences.
The two pictures at the bottom of the page compare a picture collected with a normal 35mm camera to one collected with a disposable camera. The lighter colored areas are corn that was flattened after a wind storm. Notice there is not much difference between the two images. A camera with an adjustable lens will make it easier to focus the picture on the field of interest. Also, images that will be blown up will have better quality if collected with a better lens.
This section focuses on more advanced examples of remote sensing. These examples show what can be done with more expensive and advanced imagery using computers and GIS. These are by no means the full extent of what is possible or even available today. These examples do show some of the possibilities of what can be done with more effort and expense.
Remote sensing of soybeans to map high-pH soils

Soybean plants grow poorly and show chlorosis (i.e., yellow leaves) when grown on "calcareous" soils, which have pH values above 7.5 and an abundance of carbonates. Calcareous soils have been very difficult to map because they often occur in complex spatial patterns within fields. Remote sensing of the spatial patterns of stress on soybean plants offers a new approach to mapping calcareous areas within fields. Degrees of plant stress are used to define areas that should be sampled separately, and soil testing is used to characterize soil pH and carbonate content for each of these areas.

Photos courtesy of Rogovska and Blackmer, Iowa State University Department of Agronomy.
Recent field-scale studies have shown that deficiencies of nitrogen often show up in complex spatial patterns within cornfields. An example of this problem is revealed above in an aerial photograph of a cornfield in 1999. Fertilizer nitrogen had been applied in many strips in the spring and fall, and these strips can be seen only in areas where large losses of the fall-applied resulted in nitrogen-deficient corn. The complex spatial pattern of nitrogen losses could not be explained until remote sensing of the soybeans the next year revealed unexpected areas of high-pH soils. Additional studies showed that the high soil pH resulted in relatively rapid conversion of the fertilizer to nitrate, which was lost during spring rainfalls.

*Photos courtesy of Rogovska and Blackmer, Iowa State University Department of Agronomy.*
Historically, the measurement of organic matter within a field was performed on a few spot locations and extrapolated either across the entire field or, at the very least, to an entire region of the field. For the most part, this gave the grower a general idea of the percent organic matter for that field / area which ultimately affected everything from cation exchange capacity (CEC) to the amount of pre-emergent herbicide he might use. More recently, the use of GPS in soil sampling, combined with GIS technology and remote sensing, has enabled more detailed maps of soil characteristics such as percent organic matter. By relating soil organic matter (collected with GPS) to reflectance values obtained from digital aerial imagery, a regression equation can be calculated that enables the creation of a digital organic matter map that can be integrated into any farm level GIS. This method of using remotely sensed imagery for point extrapolation is often far superior to that of simple point to point interpolation that is somewhat standard in the industry.

The percentage of organic matter decreases as the red reflectance of plants increases (and appears lighter).
A common approach used by researchers to assess vegetative health within agricultural fields is the calculation of vegetative indices. These indices are calculated by mathematically manipulating (or ratioing) the near infrared reflectance in a digital image with the red reflectance resulting in a new thematic (or indexed) image. This index image is comprised of numerical values that represent the relative condition of a crop, i.e. plant biomass. The diagram below illustrates the process of ratioing two digital images using the Normalized Difference Vegetation Index (NDVI) equation. The output of this process is an image showing the variation of plant condition throughout the field whereby red indicates areas that are the healthiest (most biomass) and pink the least healthy.
This manual provides a variety of examples on how the use of aerial imagery can be used by a grower to gain insight into the crop variation often associated with agricultural fields. However, when looking at aerial photography of an agricultural area, the topographic properties of a given field are all but impossible to visualize. The image to the left shows this concept well. The dark areas within this field represent areas that are not well drained. Quite often, the assumption is that wet areas are the low lying parts of a field while the dryer, better drained areas are found at the higher elevations.

The integration of elevation data with the aerial image (shown below), proves that this assumption is not always true. While some of the moisture retention areas are, in fact, located in the low lying area of the field, in many instances, the wet areas are at the higher elevations (note arrows) as well as along the side-slopes where water is seeping to the surface. This three-dimensional perspective can be invaluable for assessing the influence that topography and slope have on agricultural productivity within a field.
Satellites as an Imagery Source

Satellite imagery has been used in agriculture since the first Landsat satellite was launched in 1972. Today, several commercial systems serve this market with resolutions ranging from 2-100 feet and revisit times ranging from every other day to every 16 days. The turnaround time for imagery varies depending upon the source, but some offer processed imagery as soon as 48 hours after collection time.

**Color Infrared Reference (CIR)**

Provides geographic context and some degree of soil variation. This information can be enhanced as done in the example to the right.

**Soil Zone Index (SZI)**

May 25, 2000, SE of Ames, IA

MeSoil Zone Index Map shows variations in the calibrated reflectance of surface soils and residue, if any. This map can be used to assess variation in organic matter content and making different types of zone maps.

**Green Vegetation Index (GVI)**

July 2, 2000, SE of Ames, IA

Green Vegetation Index (GVI) Map assesses quantitatively the green biomass status of a crop canopy. GVI is designed to not be affected by variations in soil-background brightness (moisture, organic matter).

**ScoutAide™ (SA) GVI Change**

July 2, 2000, SE of Ames, IA

ScoutAide! Map shows the weekly rate of change of GVI between two dates. This map can be used to assess which portions of a field have changed since the last image.

Examples provided by

**DigitalGlobe AgroWatch**

![Color Infrared Map](image1.png)

![Soil Zone Index Map](image2.png)

![Green Vegetation Index Map](image3.png)

![ScoutAide! Map](image4.png)
Remote Sensing Satellites Cover Large Areas on a Regular Schedule

Satellites are designed to repetitively collect imagery over large areas. Covering large areas is critical for users who wish to manage individual fields or distant farms with the same level of precision. Receiving calibrated imagery within 48 hours of collection allows growers to assess the severity and extent of variation in a field.

The Green Vegetation Index examples on the top row show the progression of corn and soybean fields through early August. The greater the Green Vegetation index the denser the crop. The June 15 image shows the distinct variation and greater canopy density of corn compared to adjacent soybean fields. Notice the differences between the early and late planted soybean fields in the upper left on June 24 and that the late planted beans fully caught up by July 11. In the second row, notice the correlation between soil characteristics and rate of plant growth (ScoutAid™ Change Map) as well as vegetative density (Green Vegetation Index). These soybeans growing on the darker soil at the bottom center do not grow as fast early in the season (see the change map) but catch up with the rest of the field by early August. The production practice on the dark soil at the top center resulted in the fastest growing, densest corn early in the year.
Acknowledgements:

The Iowa Soybean Association wishes to acknowledge and thank a variety of Individuals and institutions providing expertise in the development of this publication. These include:

Monsanto for both their financial support and their sharing of example imagery.

The different sponsors listed on Page 3 for their financial support.

The following people for their contributions:

John Ahlrichs, Digital Globe.
Dr. Alfred M. Blackmer, Department of Agronomy, Iowa State University.
Dr. Harlan Palm, Department of Agronomy, University of Missouri.
Dr. James Schepers, USDA-ARS, Lincoln, Nebraska.
Dr. Greg Tylka, Department of Plant Pathology, Iowa State University

The Iowa Soybean Promotion Board and the Iowa Soybean Association for their support.

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