Using Color Infrared (CIR) Imagery

A Guide for Understanding, Interpreting and Benefiting from CIR Imagery

Prepared for the North Carolina Geographic Information Coordinating Council

by the Statewide Mapping Advisory Committee,

Working Group for Orthophotography Planning

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Executive summary

A color infrared (CIR) image is a false color photograph (digital or film) that shows the reflected electromagnetic waves from an object accordingly:

- Near Infrared (NIR), which is invisible to the human eye, as red
- Green light as blue
- Red light as green

Although CIR photography can be used to photograph an object from any vantage point, this issue paper will focus on its use in aerial imagery. The usefulness of this photographic technology in aerial imagery is based on the science that most objects exhibit a neglible NIR reflectance, but actively growing plants exhibit a high NIR reflectance (~6x stronger than a plant's reflectance of visible green light) and stressed plants (either from disease or drought) exhibit a reduction in their NIR reflectance. Consequently, actively growing vegetation shows up prominently on an aerial image as bright red, stressed vegetation shows up as a darker red, and a non-vegetated area shows up as a color dependent on its material composition. In addition, there are subtle NIR reflectance differences between vegetation types (conifers vs. broadleaf trees and between species) that can aid in plant identification.

Although CIR photography was originally developed for the U.S. military in WWII to detect enemy camoflauged tanks, it is now used by government agencies (county, state, and federal) as well as the private sector and academia in numerous applications, such as the following:

- Crop and timber inventory and analysis in order to estimate yields
- Damage assessment to prioritize recovery efforts as after a forest fire or to verify insurance claims as after a hail storm on a field
- Impervious surface mapping in order to estimate stormwater run-off

As our society needs to be able to do more and more with decreasing resources and funds, the information derived from CIR imagery will become even more valuable for our society.

1. Introduction

Aerial imagery, whether it is panchromatic (gray scale), color, or **color infrared (CIR)** imagery, is based on the fact that each type of land cover absorbs a particular portion of the electromagnetic spectrum, transmits another portion, and reflects the remaining portion, which can be recorded with a passive imaging system (i.e. a film-based or digital camera).

The reasons for utilizing the tool of CIR imagery in addition to (or instead of) color imagery includes the following (Paine and Kiser, 2003 and Aronoff, 2005):

- CIR imagery has better penetration through atmospheric haze than normal color imagery, because the shorter, easily scattered wavelengths (i.e. blue and violet) are filtered out
- CIR's ability to detect how an object responds to Near infrared (NIR) light (i.e. absorbs, transmits, or reflects) can reveal such land cover conditions, which are undetectable on color imagery, as:
    - Stressed vegetation
    - Moist areas in fields
    - Plant identification (e.g. differentiate between hardwoods and conifers)

2. What is CIR imagery?

The most basic definition of CIR imagery, which will be built upon in this article, is that it is a form of *"multispectral data that includes part of the visible light spectrum as well as the near infrared…."* and *"…is especially useful for vegetation mapping."* (USDA Forest Service, 2008).

Photogrammetrists map land cover types using airborne passive imaging systems (i.e. film-based and digital cameras) that detect and record specific wavelength (λ) ranges of reflected solar radiation, which are sections of the electromagnetic spectrum (Figure 1).

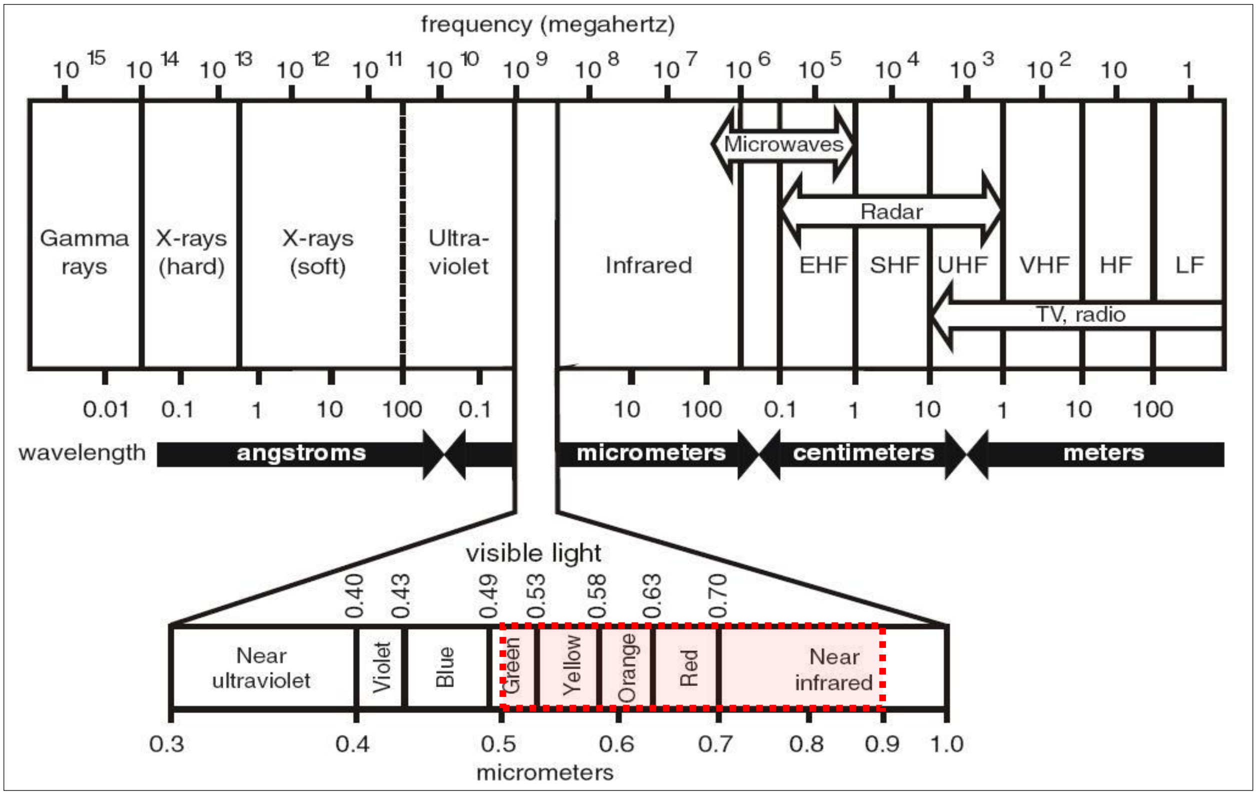


Figure 1. The electromagnetic spectrum (NASA, 2000) as divided into types of radiation by ranges of wavelength and frequency (waves per unit time) with the CIR section shown in red shading. Due to the order of magnitude difference in wavelength, the spectrum's wavelength axis is presented logarithmically using the meter (m) and the following meter-based units:

- **Centimeter (cm)** = 1×10^{-2} m
- **Micrometer** or **Micron (µm)** = 1×10^{-6} m
- **Angstrom (Å)** = 1×10^{-10} m

Wavelength can also be expressed in **nanometers (nm)**, which is 1×10^{-9} m. Thus,

- Visible light can be described as extending from 0.4 to 0.7 µm or from 400 to 700 nm
- CIR can be described as extending from 0.5 to 0.9 µm or from 500 to 900 nm

Although remote sensing specialists generally describe the electromagnetic spectrum in terms of wavelength instead of frequency, the conversion between the two forms is presented below:

Given: **Wavelength = λ** **Frequency = ν** **Speed of light = $c = 3 \times 10^{8}$ m/s**

$\lambda = c/\nu$ **$\nu = c/\lambda$**

Thus, the frequency equivalent of the wavelength range for CIR, which extends from 0.5 to 0.9 µm, would be 6.0×10^{8} to $3.\overline{3} \times 10^{8}$ MHz:

Given: **1 wave per second = 1 Hz = 1×10^{-6} MHz**

$\nu_{\text{CIR range beginning}} = (3 \times 10^{8}\ \text{m/s})/(0.5 \times 10^{-6}\ \text{m}) = 6.0 \times 10^{14}\ \text{Hz} = 6.0 \times 10^{8}\ \text{MHz}$

$\nu_{\text{CIR range ending}} = (3 \times 10^{8}\ \text{m/s})/(0.9 \times 10^{-6}\ \text{m}) = 3.\overline{3} \times 10^{14}\ \text{Hz} = 3.\overline{3} \times 10^{8}\ \text{MHz}$

CIR uses reflected solar radiation in the 0.5 to 0.9 µm range (500 to 900 nm), which encompasses portions of the following electromagnetic spectrum sections (Figure 1):

- **Visible light**: The electromagnetic spectrum section from 0.4 to 0.7 µm (400 to 700 nm), which the human eye can detect as the colors from violet through red (Figure 1).

  Note: CIR filters out blue wavelengths for a crisper image (Figures 1, 2, 3, and 4).

- **Near Infrared (NIR)**: The electromagnetic spectrum section that extends beyond red from 0.7 to 1.0 µm (700 to 1000 nm), which the human eye can not detect.

  Note: CIR filters out the longer wavelength range of NIR from 0.9 to 1.0 µm (900 to 1000 nm) due to the decrease in atmospheric transmission or conversely the increase in absorption in this wavelength range (Figure 2).

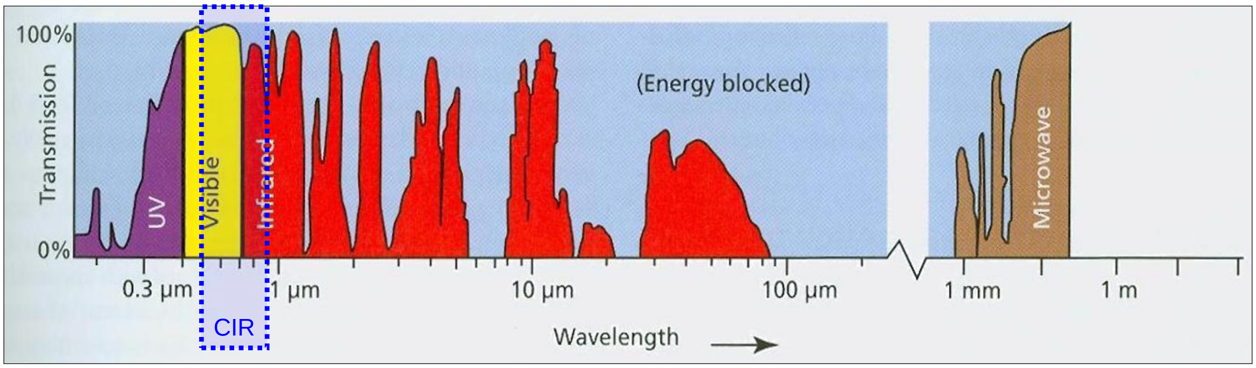


Figure 2. The atmospheric transmission across the portion of the electromagnetic spectrum from UV to microwave showing wavelength ranges of:

- High transmission as peaks, which are termed "atmospheric windows" and are utilized in remote sensing
- Low transmission or high absorption as valleys, which are filtered out in remote sensing

The spectrum ranges are color-code with UV in purple, visible light in yellow, infrared in red, and microwave in tan (Aronoff, 2005).

The atmospheric transmission across the CIR range is shown in the blue shaded box.

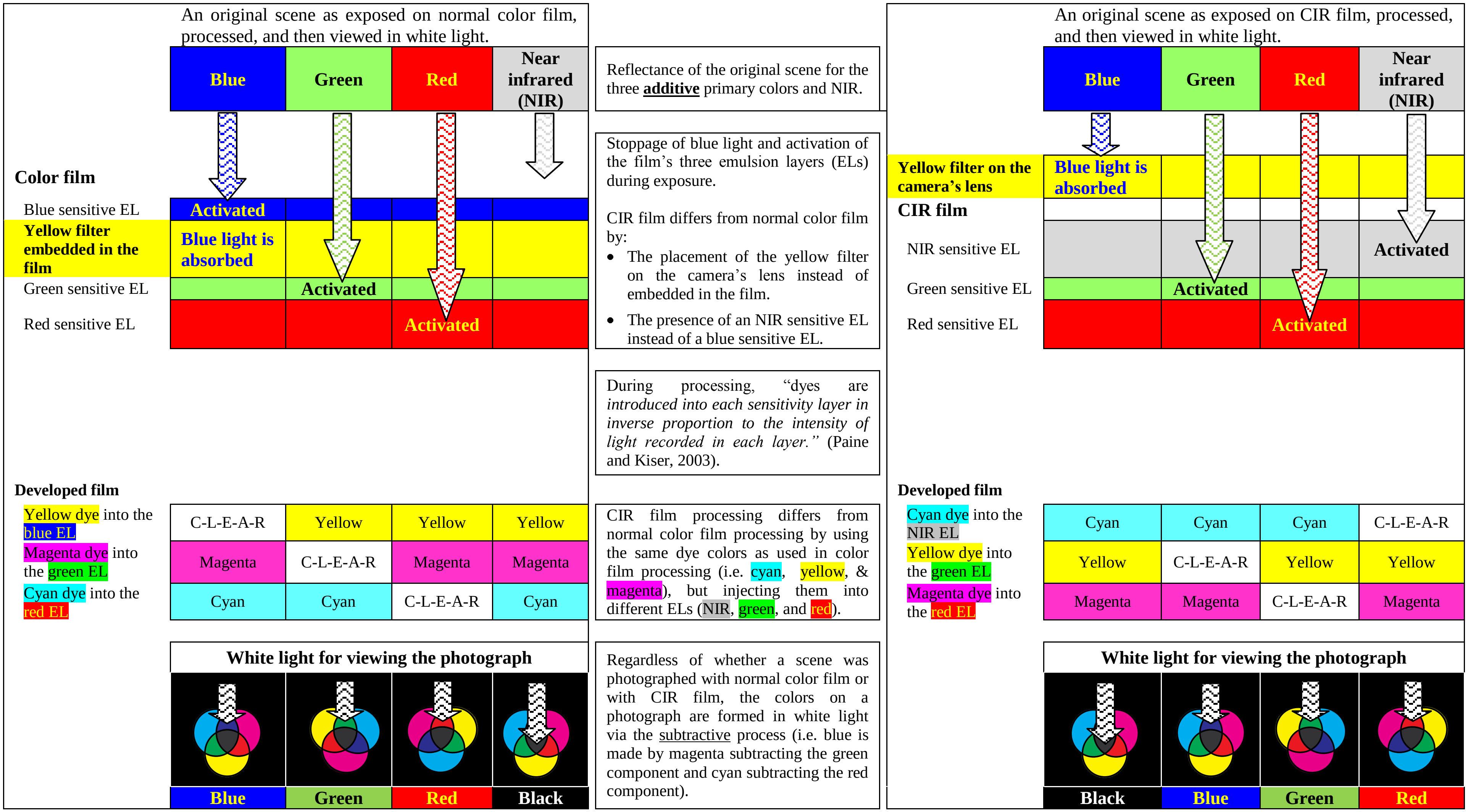
3. Why was CIR film developed?

CIR film, which was originally called "camouflage-detection film" was developed for the military during World War II as a means to differentiate camouflaged tanks from the surrounding vegetation. On a CIR photograph, healthy green vegetation appears red, but camouflage painted equipment and cut vegetation appears as blue-green. Eventually during World War II, CIR fooling materials (paint and fabric) were developed, which made CIR film less useful for military surveillance (USDA Forest Service, 2011 and USDI U.S. Geological Survey, 2011).

4. How does CIR photography record NIR?

CIR film or CIR digital sensors are composed of the following sensitive layers: green, red, and NIR instead of the following sensitive layers as in normal color film or digital sensors: blue, green, and red (Aronoff, 2005 and Paine and Kiser, 2003). For a detailed comparison between normal color film photography and CIR film photography, please peruse the following diagram (Figure 3):

Figure 3. A comparison of normal color photography vs. CIR photography at film exposure, development, and viewing the resulting photograph (Paine and Kiser, 2003).



Basically, CIR photography (film-based or digital) does the following (Figure 4):

- Filters out blue light, which makes blue objects appear black
- Shifts:
    - Green reflected light to blue
    - Red reflected light to green
- Shows NIR as red

Actual (reflected) color of an object	Blue	Green	Red	Near Infrared
False (shifted) color on a CIR image	Black	Blue	Green	Red

Figure 4. A chart showing how an object's actual (reflected) color would appear on a CIR image (Minnesota Geospatial Information Office, 2011).

5. Why does green vegetation appear on a CIR image as red instead of as blue?

Before that question can be answered, we must understand that when solar energy hits a surface (e.g. a leaf) that *"the energy is either absorbed, transmitted, or reflected in accordance with the Law of Conservation of Energy."* (McCloy, 1995):

Given:

E = Spectral energy

$E_{i,,\lambda}$ = Incident spectral energy at a given wavelength

$E_{a,,\lambda}$ = Absorptance spectral energy at a given wavelength

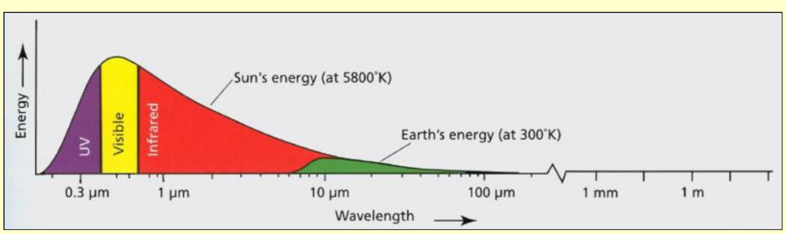
$E_{r,,\lambda}$ = Reflectance spectral energy at a given wavelength

$E_{t,,\lambda}$ = Transmittance spectral energy at a given wavelength

$$E_{i,\lambda} = E_{a,\lambda} + E_{r,\lambda} + E_{t,\lambda} = E_{i,\lambda}(a_\lambda + r_\lambda + t_\lambda)$$

In other words, the sum of the absorptance, reflectance, and transmittance spectral energy must equal the incident spectral energy at any given wavelength.

Note: The amount of spectral energy across the electromagnetic spectrum is not constant nor linearly correlated to wavelength, but has a skewed bell shaped curve (Figure 5):



- Increases steeply through the short wavelengths sections (X-ray to UV)
- Peaks in the visible light section at 0.5 µm (green light)
- Gradually decreases through the long wavelengths sections (IR)

Figure 5. Theoretical emission curves of blackbody sources at different temperatures (Aronoff, 2005):

- The sun's emission curve, which is color-coded in purple for UV, yellow for visible, and red for infrared, approximates a blackbody at 5,800°K (5,527°C or 9,980°F).
- An emission curve, which is color-coded in green, for a blackbody at 300°K (27°C or 80°F), which is the approximate temperature of many naturally occurring objects on the Earth. The thermal IR band is used to estimate the temperature of earth's features.

Therefore, in order for scientists to study how an object (e.g. a leaf) responds (i.e. absorptance, reflectance, and transmittance) to light across the spectrum, which has varying amounts of spectral energy at each wavelength, they do the following:

1. Normalize the spectral energy [i.e. set the energy at each wavelength to 1 (i.e. 100%)]
2. Use the following formula for absorptance, reflectance, and transmittance (McCloy, 1995):

   $a_{\lambda} + r_{\lambda} + t_{\lambda} = 1$
3. Plot the results (Figure 6):

Although each species would have a unique graph with minor variations due to an individual's growing conditions and genetic variation, the general trends shown on Figure 6 can be used to explain why green vegetation appears red on CIR imagery. As light enters a plant leaf and is reflected and scattered by cell walls, the chlorophyll in the chloroplast organelles:

- Selectively absorb (dashed line) nearly all the visible light energy (~90%), which is used in photosynthesis
- Transmit (dotted line) a negligible amount of visible light energy
- Reflect (solid line) a small percentage from <u>all</u> wavelengths of visible light, but reflect a slightly higher percentage (~7 to 12%) from the green wavelengths, which makes leaves appear green to the naked eye.

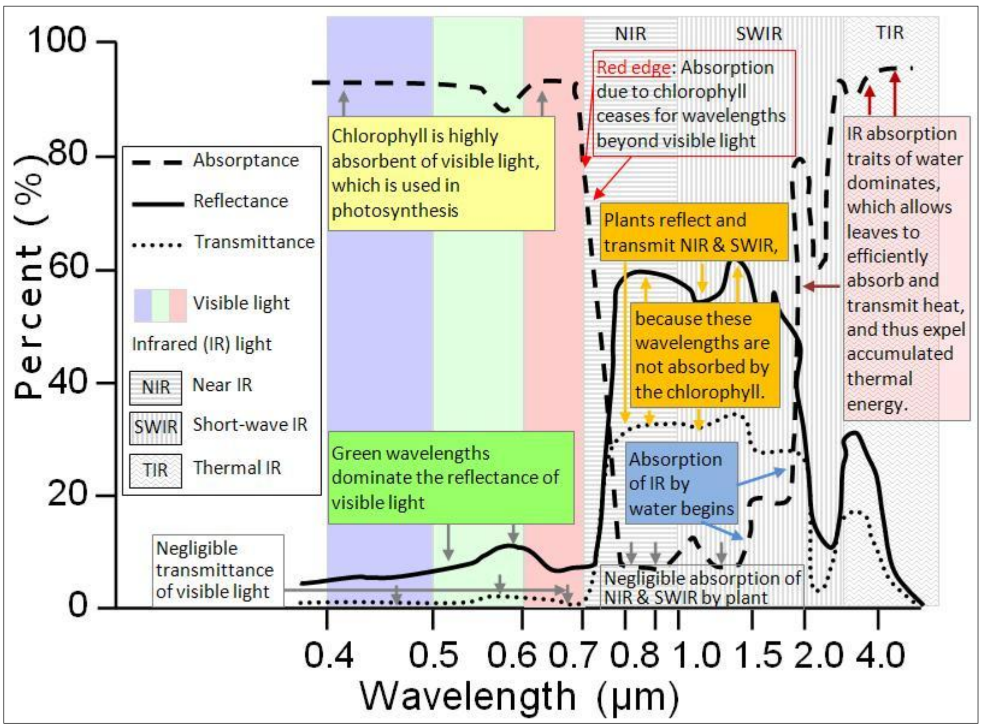


Figure 6. The percent absorptance (dashed line), reflectance (solid line), and transmittance (dotted line) of *Raphiolepis ovata* (Indian hawthorn) across the electromagnetic spectrum from 0.4 to 4.0 µm (McCloy, 1995).

After the visible light section, the absorption line between 0.7 – 0.8 µm plummets from ~90% absorptance to ~7% absorptance, which is referred to as the "red edge" as absorption due to chlorophyll ceases and only absorption due to the leaf's structure remains. Since the plant leaf can only absorb a negligible amount of NIR and must follow the Conservation of Energy law, the remaining amount of spectral energy must either be reflected (~60%) or transmitted (~33%). Consequently, if a CIR sensor (film or digital) recorded the reflected energy from the plant leaf, the leaf would show up as red on the CIR image instead of as blue, because the reflectance percentage of NIR (~60%) was ~6 times greater than the reflectance percentage of green light (~10%).

6. CIR collection methods: past and present

CIR imagery can be collected by either a film-based camera or a digital camera. For remote sensing applications of the earth's surface, a passive imaging system's platform is typically either a fixed-wing aircraft or a satellite. A satellite platform would use a digital collection system while an aircraft platform could be equipped with either a digital collection system or a film collection system.

One distinct advantage of a digital collection system is its ability to collect panchromatic, color, and CIR imagery in a single pass over a project area, which means that there would be no time difference between the three exposure types and that the exposure types would be taken from the same position (Figure 7).

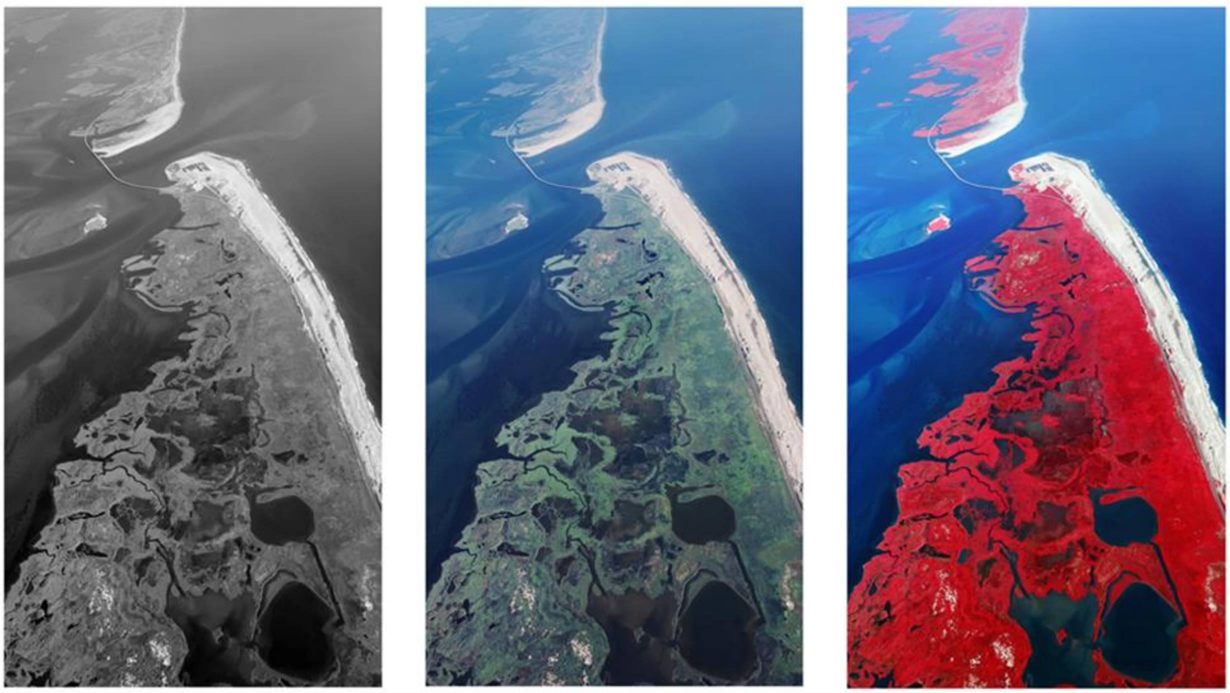


Figure 7. A comparison of panchromatic (left image), color (middle image), and CIR (right image) of North Carolina's Oregon Inlet from the north end of Pea Island looking north. CIR imagery depicts clear, blue water as black, since water absorbs NIR wavelength energy. Water with varying amounts of suspended particles appears in CIR imagery as shades of blue, because suspended particles reflect a very small amount more of green light than clear water does. Photo source: NCDOT Photogrammetry Unit. The three images were acquired in one pass on 10 August 2010 with an Intergraph Digital Mapping Camera.

In contrast, a film-based collection system requires one pass per exposure type, which means that each exposure type would be acquired at a different time and from a different position on each pass. Consequently, a digital system would require considerably less airplane fuel and flight support labor than a film-based system. Due to all these advantages of a digital system over a film-based system, digital systems are used almost exclusively now. This switch from film-based to digital-based systems occurred during the first decade of the 21st century as documented by the usage statistics from the National Agriculture Imagery Program (NAIP) (Figure 8).

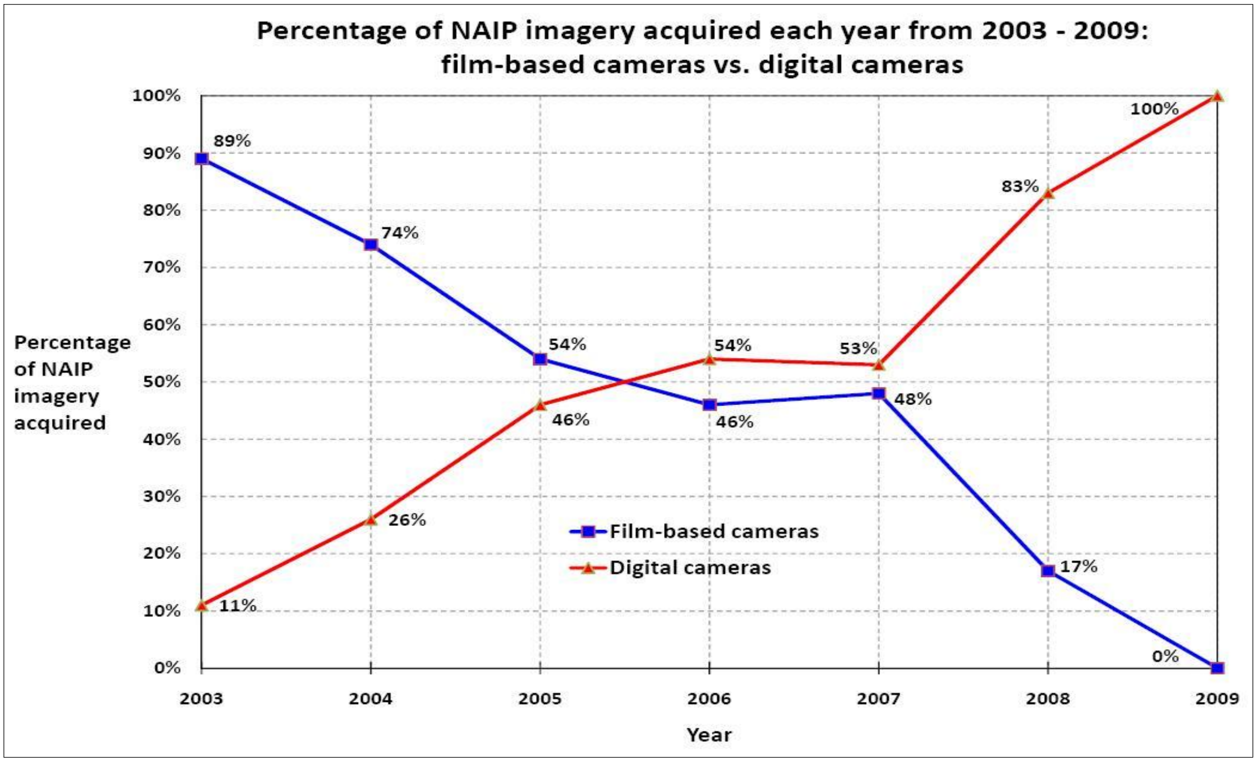
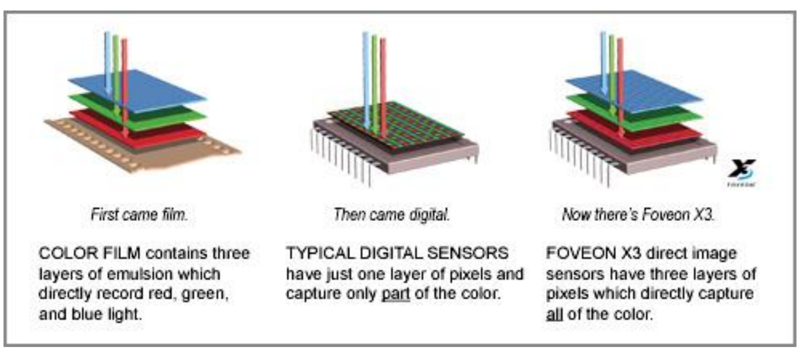


Figure 8. The percentage of NAIP imagery acquired from 2003 - 2009 by film-based cameras vs. digital cameras (USDA Forest Service, 2009).

QUESTION: If digital sensor technology [i.e. the Charge-Coupled Device (CCD) chip design of a checkerboard array of light absorbing pixels] had been available since the 1970s, what happened in the early 2000s to precipitate the change in remote sensing from film-based cameras to digital cameras?

ANSWER: The Foveon X3 chip design was released in 2002. This new chip design was a technological breakthrough for digital sensors (Foveon, Inc., 2011; Newsweek, 2002; Paine and Kiser, 2003), because it overcame the inherent design flaws of an array by utilizing three light absorbing layers that mimicked the emulsion layers in film (Figure 9), which did the following:



- Improved resolution
- Reduced file size
- Eliminated interpolation errors

Figure 9. The Foveon X3 light detector design (right image) as compared to film (left image) and Charge-Coupled Device (CCD) detectors (center image). The Foveon X3 detector has three light absorbing pixel layers embedded into silicon, which are similar to the emulsion layers in film, and can capture 100% of the light. In contrast, the single layer CCD checkerboard array of light absorbing pixels captures only 25% of the blue light, 50% of the green light, and 25% of the red light, which can cause rainbow artifacts as the camera interpolates for the light that it did not capture.
Note: The images and explanations are for normal color photography (i.e. blue, green, and red light) instead of for CIR photography (i.e. green, red, and NIR). Photo source: Foveon

7. Interpretation of CIR imagery

Aerial imagery can be interpreted by photogrammetrists, remote sensing analysts, or GIS specialists based on the following principles or traits (Aronoff, 2005; Paine and Kiser, 2003):

- **Association**: Spatial interrelationships between features (e.g. sports fields with schools)
- **Tone or color**:
  - If black and white, then tone (brightness)
  - If color, then hue, saturation, and brightness
- **Pattern**: Distinctive arrangements of features
- **Shadow**: Reveal the outline of a feature
- **Shape**: Outline of a feature (distinct vs. indistinct boundaries)
- **Site**: Feature's position with respect to topography and drainage
- **Size**: Dimensions of a feature (relative vs. absolute size)
- **Texture**: Variation in tone over a surface, which is created by surface irregularities that create microshadows

As for interpreting CIR imagery, photogrammetrists would still use all of the preceding principles, but would utilize a color classification or key based on:

- NIR reflectance curves (Figure 10)
- Generalized CIR color representations (Inset box on the next page)
- Adjustments for time of year, weather, and/or local conditions

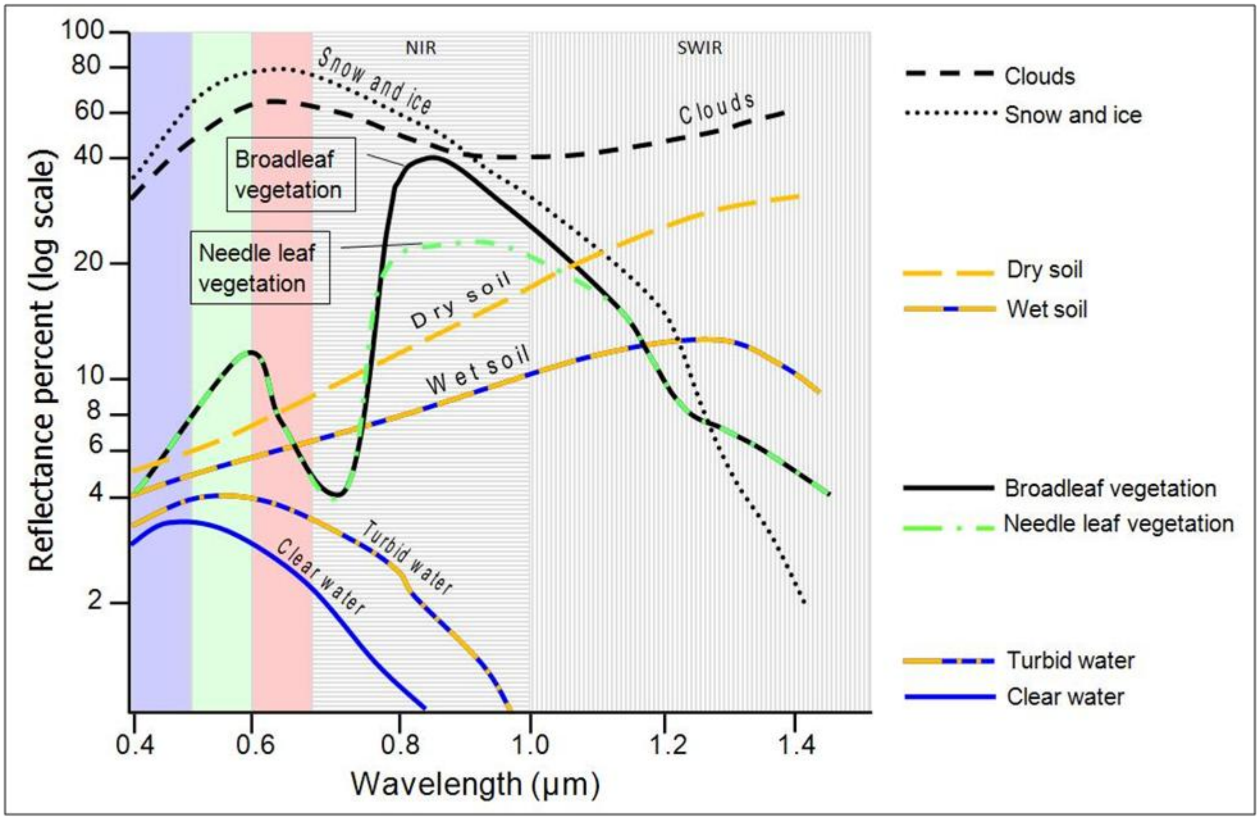


Figure 10. Spectral reflectance curves for the following paired landcover types (Aronoff, 2005):
- Clouds vs. Snow & ice
- Broadleaf vegetation vs. Needle leaf vegetation
- Dry soil vs. Wet soil
- Turbid water vs. Clear water

Generalized CIR color representations

The following is a listing of what each color on a CIR image could indicate or generally represent (USDI United States Geological Survey, 2011; Minnesota Geospatial Information Office, 2011):

- **Intense bright red:**

  Vigorously growing, dense vegetation that is producing a large amount of chlorophyll.

- **Light red, magenta, or pink:**

  Vegetation that is not producing a large amount of chlorophyll:

  - Mature stands of evergreens (Figure 9 shows that evergreens reflect less NIR than broadleaf vegetation)
  - Agricultural fields nearing the end of the growing season

- **White, blue, green, or tan**
  - Soils

    A soil's appearance on CIR imagery can indicate its composition (i.e. its percentage of sand, silt, and clay):

    - Sandy soils: white, gray, or light tan
    - Clayey soils: tans or blue-greens

      Note: Soil moisture and/or organic matter can darken a soil's hue on CIR imagery (Figure 10 shows that moisture reduces a soil's reflectance in both visible light as well as NIR)

  - Unhealthy - dead vegetation: light pink to shades of green or tan

    Note: *"If plant density becomes low enough the faint reds may be overcome by the tones of the soil on which the plants are growing."* (USDI United States Geological Survey, 2011)

  - Sediment-laden water: pale or light blue
  - Buildings and manmade materials such as concrete and dry gravel: white to light blue. Thus, if a building is obscured by vegetation on a standard color aerial image, its size and shape may be discernable on a CIR image.

- **Dark blue to black**
  - Asphalt roads: dark blue to black.
  - Water: shades of blue to black depending on its clarity and/or depth. Generally, the clearer the water, the darker the color. (Figure 10 shows that turbidity increases water's reflectance in both visible light as well as NIR)

    Note: Shallow streams often display the colors associated with the materials in their stream beds. Thus, if the stream bed is made of sand, the color will appear white or very light tan due to the high reflective property of sand.

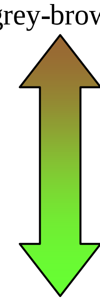
The United States Department of Agriculture (USDA) Forest Service (1995) even states that *"Color must be dealt with in relative terms..."* because CIR photography is not consistent enough to describe a species or type based *"...in precise hue, value, and chroma terms."* The Forest Service elaborated that color photography and CIR photography in particular are affected by the following factors:

- Film batch and printing process
- Season
- Shadow
- Slope exposure
- Sun angle and light intensity

Although digital photography eliminates inconsistencies related to film, the other factors still render the goal of describing a species or type using absolute color descriptions unattainable. Yet, *"...relative colors* [between species] *remain consistent and can be relied upon"* (USDA FS, 1995). Consequently, the USDA FS (1995) recommends identifying tree species on CIR imagery using the following parameters:

- Relative color: Gray brown to green for softwoods and pink to orange for hardwoods (Table 1)
- Color intensity: Soft to intense strength/concentration/saturation (Table 2)
- Texture: Soft (even) to well-defined (open, broken, and/or uneven) canopy (Table 3)

Table 1. The relative color (color range) of New England tree species on CIR photography showing (USDA FS 1995):
- Softwoods (excluding hemlock) ranging from grey-brown to green
- Hardwoods (including hemlock) ranging from pink to orange

Softwood species (excluding Hemlock)	**Color range**
• White pine	grey-brown
• Red pine	
• Pitch pine	
• Balsam fir	
• Red spruce	
• Black spruce	
• Tamarack	
• dead stem	green

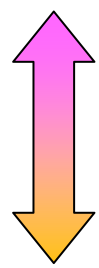
Hardwood species (including Hemlock)	**Color range**
• Hemlock	pink
• Beech	
• White oak	
• Sugar maple	
• Red maple	
• Aspen	
• White birch	
• Red oak	orange

Table 2. The relative color intensity (strength/concentration/saturation) of New England tree species on CIR photography (USDA FS 1995).

Softwood species	**Color intensity (strength/concentration/saturation)**	**Hardwood species**
• Hemlock	soft color	• White birch
• White pine		• Yellow birch
• Balsam fir		• Beech
• Pitch pine		• Aspen
• Tamarack		• Sugar maple
• Black spruce		• Red maple
• Red pine		• White oak
• Red spruce		• Red oak
• Atlantic white cedar	intense color	

Table 3. The relative texture of the crowns of New England tree species on photography near the scale of 1:6000 (USDA FS 1995).

Softwood species	**Texture**	**Hardwood species**
• Hemlock	soft	• White birch
• White pine		• Beech
• Pitch pine		• Aspen
• Red pine		• Yellow birch
• Tamarack		• Red maple
• Balsam fir		• White oak
• Black spruce		• Sugar maple
• Red spruce		• Red oak
• Atlantic white cedar	Well-defined	

8. Benefits of CIR imagery

CIR imagery has great value in analysis and classification. CIR is most often used in such vegetation studies as:

- Area of vegetation
- Types of vegetation
- Health of vegetation
- Submerged vegetation mapping
- Damage assessment
- Vegetated vs. non-vegetated areas

8.1. Area of vegetation

One of the major uses of CIR is determining area of vegetation, which can be used in forestry (Figure 11) as well as agriculture/land management, facility management, parks and recreation management, and utility management. CIR can also be used in local planning to represent vegetated areas in relation to structures, transportation, and natural features.

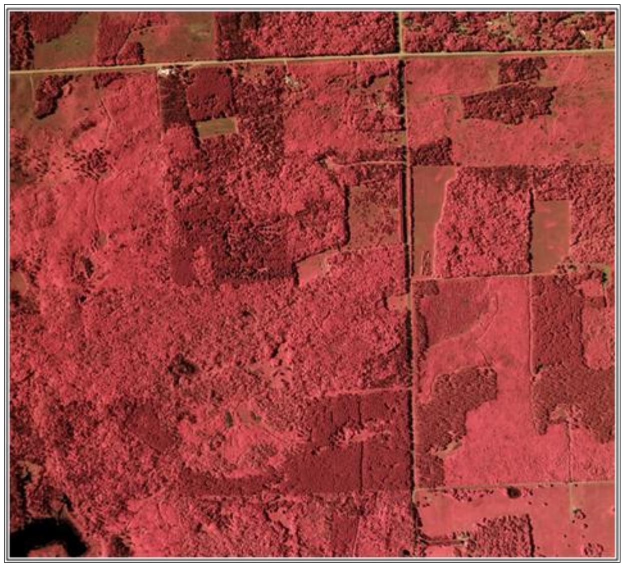


Figure 11. A CIR aerial image of a forested area in Minnesota showing how CIR can be used to determine the forested acreage of various tree species:

- Dark red areas: White spruce
- Medium red areas: Red Pine
- Lighter pink areas: Aspen, Maple and Oak

Photo source: Cirrus Digital Systems.

Basically, red areas on a CIR image show vegetated areas on the landscape, which is an incredible management tool. In addition, the texture, pattern, and shape of a feature can also be utilized to help identify cultivated and non-cultivated areas.

CIR imagery can also show the location of structures and roads in relation to vegetation, which can help to manage crops while taking into consideration the location of non-cultivated vegetation and/or how non-cultivated vegetation spreads into cultivated fields.

CIR can be used to map and place utilities (power lines and pipes), roads, and rail lines. CIR also lets you know if a utility right-of-way (ROW) is being maintained in a way that will keep that utility functioning properly.

8.2. Types of vegetation

CIR aerial imagery can also be used to differentiate types of vegetation by following the strategies outlined in the "Interpretation of CIR imagery" section as well as taking into account how a plant species' NIR reflectance changes throughout the year as with agriculture crops during their growing season (Figures 12).

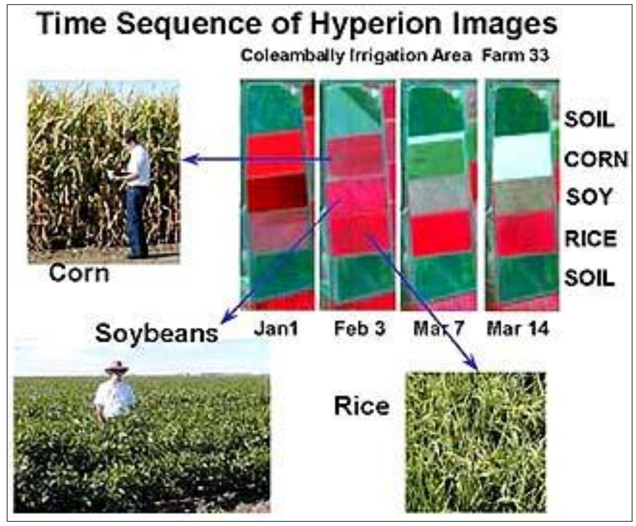


Figure 12: A CIR satellite image showing three crop fields (corn, soybean, and rice) and two fields of bare soil at four dates during the growing season at the Coleambally agriculture test area in Australia.

Photo source: NASA

Thus, an experienced photointerpreter could analyze a CIR image of an agriculture region (Figure 13) and identify and determine acreage:

- Specific crops and their stage of growth and health
- Bare fields and fields that were recently planted
- Grassland, scrubland, and wetland areas
- Agriculture run-off pathways
- Impervious surfaces

Figure 13. A CIR aerial image showing different crops at various states of growth and health.
Photo source: _______________.

A photointerpretter could likewise examine Figure 14 and identify wetlands and natural areas (non-patterned and irregular bounded red and reddish green areas), bare soil (green fields), planted crops (red fields), and the health of each of these land covers as well as man-made structures (e.g. deep water ship channel levees and roads). Consequently, CIR can be used to estimate:

Figure 14. A CIR aerial image of agricultural fields along the Sacramento River in California showing:

- Deep water ship channel levees
- Agriculture fields, wetlands, and scrublands
- Vegetative health

Photo source: Aerial Archives

- Crop yields
- Run-off and erosion
- Crop diseases
- Fertilizer and irrigation needs

Thus, CIR can be an invaluable assessment tool.

8.3. Health of vegetation

CIR imagery can be used to assess the health of vegetation due to reduced reflectance of NIR in stressed or unhealthy plants (Figure 15). Paine and Kiser (2003) stated that this loss of NIR reflectance in stressed or unhealthy plants could be due to many factors, but that one of the main factors is damaged cellular structure (e.g. plugged or collapsed of spongy mesophyll cells).

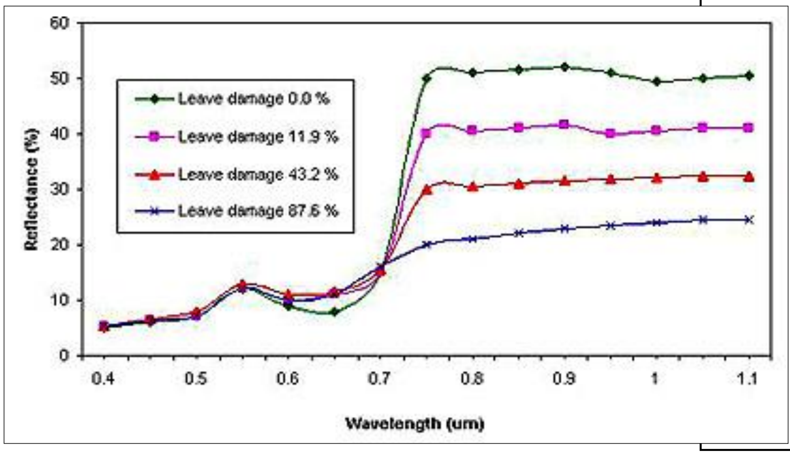


Figure 15. Reflectance curves of soybeans at increasing levels of leaf damage stress (NASA, 2010):

- 0% leaf damage (green line with diamond markers)
- 11.9% leaf damage (magenta line with square markers)
- 43.2% leaf damage (red line with triangle markers)
- 87.6% leaf damage (blue line with "X" markers)

Photo source: NASA

For example, a CIR image of a Lodgepole pine forest in Canada shows (Figure 16):

- Healthy trees in red
- Trees damaged by a beetle infestation in blue-green

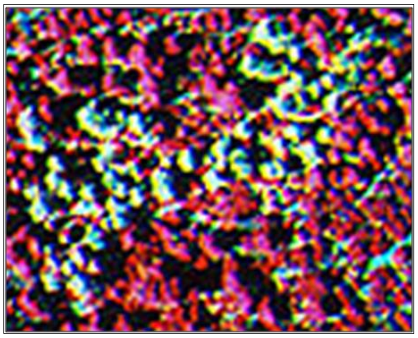


Figure 16. A Lodgepole pine forest in Canada showing healthy trees in red and Mountain Pine Beetle (MPB) infested trees in blue-green.

Photo source: NASA, 2010

In addition to using CIR imagery to assess the health of crops and forests, CIR imagery can also be used to show the health of vegetated areas in an urban environment, which can be a valuable decision making tool for land use, land management, and the health of a city or town as a whole. For example, Figure 17 shows how CIR imagery can be used to assess the vegetative health and species composition of a salt marsh bordering a river running through an urban environment. The importance of such information is due to the fact that the river is the Guadalupe River and that the marsh filters storm water run-off before it enters the San Fransico Bay. Urban planners, floodplain managers, and riparian restorationists could use this information coupled with elevation information in riparian maintenance efforts to slow storm water run-off in order to absorb:

- Pollutants to minimize polluting the bay
- Water to minimize flooding

Figure 17. A CIR aerial image showing the health of salt marsh vegetation bordering the Guadalupe River running through the urban environment of Alviso, California. This picture also shows a passenger plane that had just taken off from the San Jose International Airport. Photo source: Cirrus Digital Systems.

8.4. Submerged vegetation mapping

Although near infrared light is absorbed in only a few decimeters of water (Lillesand and Keifer, 2000), CIR aerial imagery is very useful at mapping submerged vegetation that floats near the surface, such as a kelp forest (Figure 18) due to its strong reflectance of red and near-infrared light (Horning et al, 2010). This ability to map kelp can serve as an indicator of the ecosystem's health (i.e. diseases, pollution, storm damage).

Figure 18. A CIR aerial image of Monterey Peninsula in California showing the offshore kelp beds in the bay and the golf course fairways on the hillsides.

Photo source: Cirrus Digital Systems.

8.5. Damage assessment

CIR imagery can be a great tool for assessing damage, such as showing burned areas from a forest fire (Figure 19). This information can be used to tally the acreage burned, identify areas most prone to erosion, and prioritize revegetation efforts.

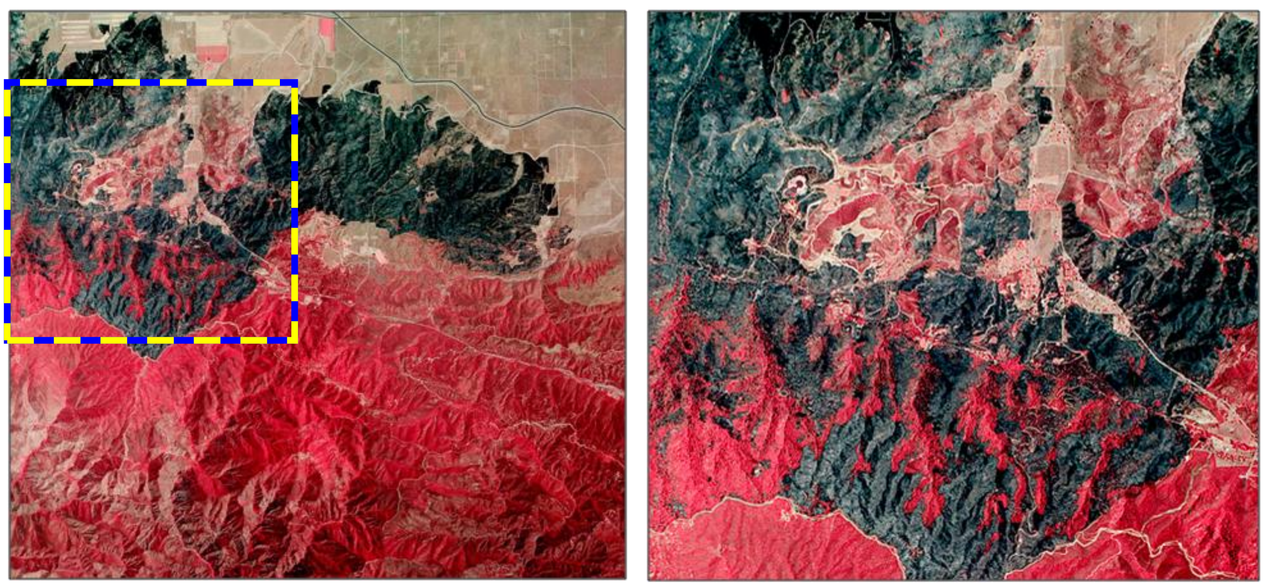


Figure 19. A CIR aerial image of Angeles National Forest in California showing pine fire damage in black. Zoomed-in inset shows spared ridges that would be seed sources for natural restoration. Photo source: Cirrus Digital Systems.

In addition, CIR can also be used to assess storm damage (e.g. hail and wind) on crops (Erickson, 2000). Insurance adjusters could use the information from this non-destructive and non-labor intensive assessment technique to process claims expeditiously.

8.6. Non-vegetated areas

CIR imagery can be used to distinguish built features and non-pervious surfaces (e.g. roads, buildings, and parking lots) from vegetated lands. This information can be used to help predict storm water run-off and its effects on flooding and waste water treatment facilities. For example, Figure 20 shows a CIR aerial image of agriculture lands near Sacramento, California with the fields clearly visible as bright pink rectangles/polygons bordered by gray roads and the residential developments as little maizes of roads built upon former fields. In addition, the image clearly shows:

- Transportation networks as gray and dark gray lines
- Manmade boundaries (roads or just a change in land cover) for the various development types (e.g. agriculture, residential, airport, schools, industry, and commerce)
- Rivers, streams, and canals as black ribbons
- Vegetated yards as pink dots in the residential development maizes

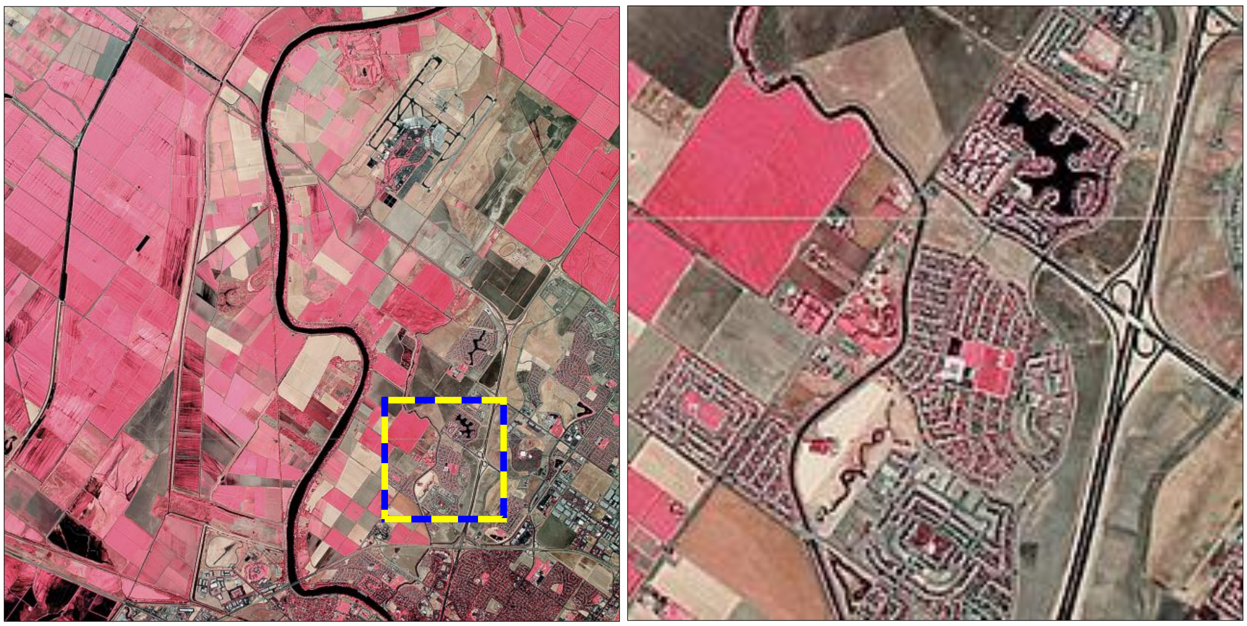


Figure 20. A CIR aerial image near Sacramento, California showing the interface of agriculture lands (pink fields in the left image) and residential developments built on former fields (zoomed-in inset).
Photo source: Cirrus Digital Systems.

9. Uses of CIR imagery

Due to CIR imagery's ability to display an object's reflectivity (or conversely its absorption) of infrared light with specific colors, CIR imagery is an incredibly valuable tool for or to indicate:

- **Crop inventory and analysis**, since CIR can be used to indicate the health, density, and classification of vegetation
- **Soil mapping**, since CIR can show subtle differences in vegetative growth and soil moisture across a field
- **Wet spots in fields**, since water absorbs NIR energy these bodies show up as dark spots on CIR imagery
- **Irrigation and waste run-off**, since CIR can detect differences in plant growth and vigor
- **Impervious surface mapping**, which is important for predicting surface water run-off, since buildings, roads, gravel, and concrete are easily differentiated from other surface types on CIR imagery.
- **Tree canopy,** particularly in urban areas where tree canopy is related to storm water management costs, carbon storage, and other environmental benefits.

Remote sensing and GIS specialists in local governments, private business, and educational institutions are continually evaluating CIR imagery as a tool for more and more applications. For example, in Wake County, CIR imagery is used by county remote sensing and GIS specialists for:

- Impervious surface extraction
- Basic tree canopy cover mapping
- Land Cover classification:
  - Tree cover (coniferous/deciduous)
  - Impervious surfaces
  - Grass
  - Bare ground
  - Water

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