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A Guide to the Practical Use of Aerial Color-Infrared Photography in Agriculture

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Educational Circular 8

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The Conservation and Survey Division of the University of Nebraska is the agency designated by statute to investigate and interpret the geologically related natural resources of the state, to make available to the public the results of these investigations, and to assist in the development and conservation of these resources.

The division is authorized to enter into agreements with federal agencies to engage in cooperative surveys and investigations in the state. Publications of the division and the cooperating agencies are available from the Conservation and Survey Division, University of Nebraska, Lincoln, Nebraska 68588-0517.

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June 1988

Cover photo: Color-infrared photograph of an agricultural area in Clay County near Inland, Nebraska. Photo was taken Aug. 15, 1983, from about 6,000 feet above the ground. Scale is approximately 1:12,000.

Contents

Illustrations

Table

Factors for Converting English Units to the International System of Units (SI)

Multiply English Units	By	To obtain SI units
	Length	
inches	25.5	millimeters
feet or foot	.3048	meters
miles	.609	kilometers
	Area	
acres	4047	square meters
square miles	2.590	square kilometers
	Volume	
acre-feet	1233	cubic meters
	Flow	
gallons per minute	.00006309	cubic meters per second

Introduction

The use of aerial photography in agriculture might eventually be considered as important a management tool as any other farm tool. Obtaining a general view of cropland from aloft by aerial photography could possibly mean the difference between a successful harvest or a preventable crop failure.

Aerial photography has been used widely in the United States since the 1930s to assist land managers in the evaluation of agricultural resources. Determining the amount of land planted to specific crops has historically been an important activity of the U.S. Department of Agriculture, and aerial photography has long provided that agency with a cost-effective and timely means of obtaining such data.

In Nebraska, aerial photography also has been flown on a regular basis for about fifty years. Extensive collections of historical photographs are held by agencies such as the Conservation and Survey Division at the University of Nebraska–Lincoln and the USDA Agricultural Stabilization and Conservation Service and Soil Conservation Service.

Traditionally, black-and-white (or "panchromatic") aerial photography has been the most common information source. With this type of film, the various colors and patterns of the land surface are depicted as a series of gray tones ranging from white to black. Panchromatic film is still widely used for a multitude of agricultural applications despite the fact that, in some cases, it is difficult to distinguish between different types of vegetation.

Infrared film, available in both black-and-white and color formats, is a relatively recent development. Color-infrared (CIR) film, sometimes referred to as "false-color," is the most common form. It was originally developed by the military for detection of camouflage, a concept based on the ability to distinguish between real vegetation and surfaces that have been merely painted green or covered with freshly cut brush or green netting. With color-infrared photography, painted surfaces and dead or dying vegetation were easily discriminated from live, healthy vegetation, and it was not long before the many agricultural applications of CIR technology became apparent to the civilian community.

In fact, numerous private companies, some operating in Nebraska, have now evolved for the sole purpose of providing low-level aerial infrared photographic services to farmers. However, despite the significant interest in the film today, it seems that many misconceptions persist. A basic understanding of the film's capabilities and limitations should enhance the applications of color-infrared film to general agricultural problems, even for the casual user.

This brief report represents an attempt to provide both potential and current users of infrared film with a concise, relatively non-technical reference on the physical properties and practical applications of CIR aerial photography as it relates to agricultural management. The work treats only color-infrared film because the farming public seems most interested in this particular type of film.

Electromagnetic Energy

All life on this planet exists in a sea of electromagnetic radiation. Most of us are unaware that everything from cosmic and gamma rays to radio and television waves are always moving through our atmosphere. We tend not to notice the movement of these various forms of radiation because they are invisible. In fact, our eyes are sensitive to only a very small part of the total number of energy forms that continually bombard our environment.

Panchromatic and ordinary color film both record essentially what we see with the naked eye, but CIR film uses the light spectrum just beyond the sensitivity of the human eye. This portion of the spectrum is known as the "near-infrared" or "photographic-infrared" region (fig. 1).

One must be very careful not to be confused by the term "infrared." The thermal (or heat-emitting) properties of the terrain and vegetation are not recorded on CIR film.[1] This is a common misunderstanding on the part of the casual user of CIR imagery. With CIR film, one is measuring only the amount of near-infrared energy being reflected or absorbed by a given surface, not its temperature.

Vegetative Response to Solar Radiation

When solar radiation reaches a vegetative canopy such as a forested area or a field that is cropped, predictable interactions occur. In general, all vegetation tends to react to sunlight in a similar fashion, although some specific differences may be caused by variations in plant morphology and physiology, local soil type, and the climate of the growing area.

The study of the response of vegetation to solar radiation is relatively complex but is generalized for this brief discussion. Known biophysical interactions include the fact that a small amount of incoming light is reflected from the outer surface of the plant's leaves, while a greater amount is transmitted into the spongy mesophyll tissue in the leaf where the light rays are reflected back by the cell walls toward the light source.

The spectral character of the interactions varies according to the phenology of the plant (the relation between climate and periodic biological phenomena, such as flowering and fruiting). As a typical plant begins its life cycle and is exposed to sunlight, the amount of chlorophyll in the leaf increases for a time. Red and blue light tend to be absorbed by chlorophyll, while green light is reflected, which is why plants appear green to the human eye (fig. 2).

As the plant matures, the chlorophyll content begins to stabilize, as does the corresponding green reflectance; however, the reflectance of near-infrared light

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[1] CIR film will, in some cases, record emitted infrared energy from hot objects, but this occurs only when the temperature of the feature is extremely high. As a general rule, CIR film captures only the reflected infrared energy from a surface.

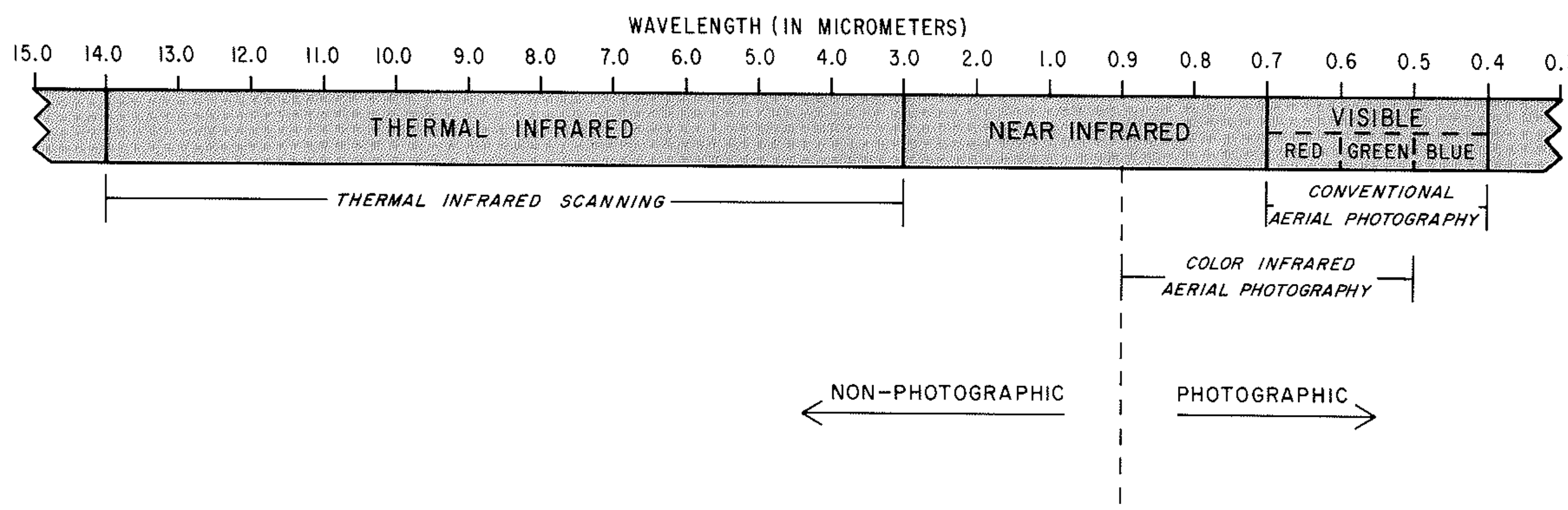

Fig. 1. A portion of the electromagnetic spectrum showing the visible and infrared regions.

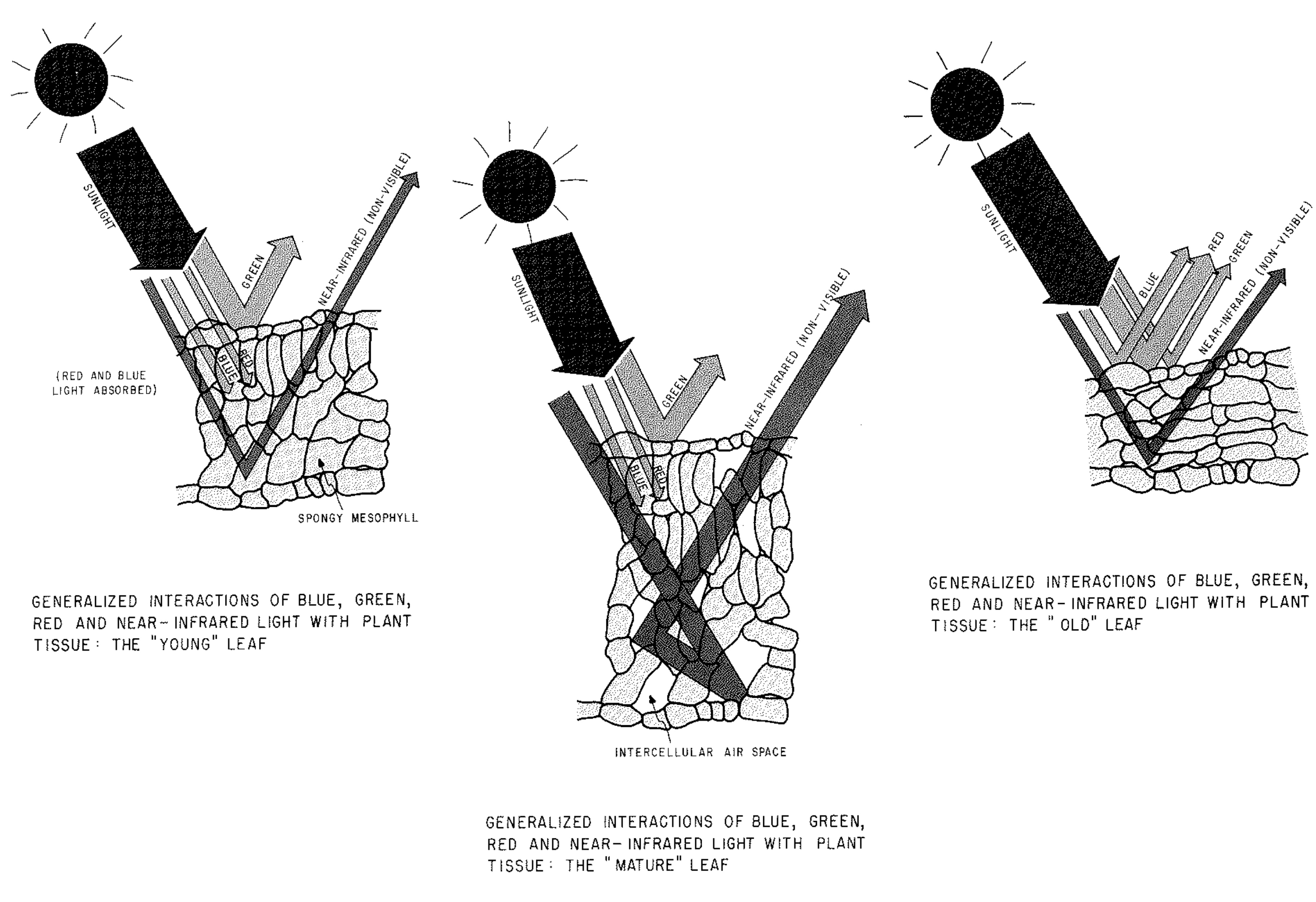

Fig. 2. Generalized spectral-reflectance characteristics of young, mature, and old vegetation.

increases proportional to the increasing number of cell walls and intercellular spaces and the total plant surface area (fig. 2). These reflectance characteristics remain relatively constant during the mature stage unless external influences such as severe weather or disease cause a change in the overall chemistry of the plant. The external factors may result in an eventual change in plant pigmentation, mesophyll structure, water content, or the surface condition of the plant (for example, leaf mold).

When the plant reaches the senescence or deterioration stage, the cell walls of the mesophyll tissue begin to dessicate and collapse, which results in a substantially reduced intercellular surface area and air space (fig. 2). The end result is a decrease in the level of green and near-infrared reflectance and an increase in reflectance of blue and red light. By making use of the impact of invisible near-infrared energy on sensitized film and by displaying vegetation in shades of red, it is sometimes possible to correlate the variations in tone with factors such as plant species, stage of maturity, plant vitality, and even the moisture content within leaves.

"Red" Vegetation on Color-infrared Film

Whereas panchromatic film yields gray tones and conventional color film produces colors resembling what we view with our eyes, CIR film renders healthy vegetation in bright red tones (fig. 3). This substitution of red for green vegetation is somewhat confusing and warrants further explanation. The red tone of healthy vegetation as seen on a CIR photo is perhaps best explained by comparing CIR to conventional color film. While normal color film contains emulsion surfaces sensitized to blue, green, and red, infrared film contains emulsions that react to green, red, and reflected infrared energy (fig. 4). [2]These emulsion sensitivities result in the unique capability of color-infrared film to provide the user with detailed information about growing vegetation. Because one emulsion layer is sensitive to green light and growing plants reflect intermediate amounts of green light, this aspect of the vegetation can be captured on the film. In addition, the red-sensitive emulsion layer provides information relating to the level of photosynthetic activity in plants because vegetation growing vigorously (at high photosynthetic levels) absorbs red light rather than reflecting it. Finally, the infrared-sensitive emulsion yields information relating to normal plant cell-wall numbers and shapes, and vigorously growing, healthy plants reflect high levels of infrared energy. If vegetation becomes stressed, the results can be captured by the color-infrared film, sometimes before the damage becomes apparent to the human eye.

During the development process for CIR film, yellow, magenta, and cyan dyes are assigned in combination to the green, red, and infrared-emulsion layers (fig. 4). The assignment of these particular dyes results in a "false-color" rendition in which blue images result from objects reflecting primarily green energy, green images from objects reflecting primarily red energy, and red images from objects reflecting primarily in the photographic-infrared portion of the electromagnetic spectrum (fig. 3). Thus, vigorously growing, healthy vegetation appears in a bright red or magenta tone on color-infrared film.

Although the explanation may seem involved and difficult for most to follow, another reference to figure 4 might serve to clear up the remaining confusion. Notice that both the dye layers and resulting colors are exactly the same for normal-color and color-infrared films. Only the film sensitivities differ, and the visual colors in that category are merely shifted one position to the left with the near-infrared sensitivity added with CIR film.

The Loss of Red Color with the Onset of Stress

Perhaps the best way to explain how vegetation loses its bright red CIR signature with the onset of stress is to compare stressed to healthy vegetation (figs. 5 and 6). As noted earlier, normal growing vegetation reflects a little red energy, a medium amount of green, and a large amount of near-infrared. Because CIR is a reversal film, the final film signature for vegetated areas is the result of the high-level near-infrared reflection being replaced by only a small amount of cyan dye, and the medium green reflectance being replaced by a medium amount of yellow dye. Most importantly though, the low red reflectance results in a large amount of magenta dye in the film composite. Therefore, healthy vegetation is red.

In the case of stressed vegetation, the low near-infrared reflectance is reversed to a high level of cyan dye, and the high red reflectance is reversed to a low level of magenta dye in the final composite (fig. 6). Hence, stressed vegetation is not red, but often tends toward cyan.

Agricultural Applications of Color-infrared Film

There are many documented examples where color-infrared film has been applied to agricultural problems. Detailed descriptions of these applications may be found in any of the several periodicals and books devoted to the subject of aerial photography (see list of references for further information). For the purposes of this abbreviated report, a few examples of these applications are organized under five general headings (table 1). Selected applications are discussed in succeeding paragraphs. It is hoped that these few illustrations are indicative of how color-infrared aerial photography may be used in day-to-day agricultural management decision-making.

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[2]Color-infrared film is also sensitive to blue light, but this is generally removed by using a minus-blue filter on the camera. Objects reflecting blue light tend to be imaged as black on CIR film (fig. 3).

Fig. 3. A comparison of normal-color and color-infrared photographs. Notice the specific CIR color reversals, for example, the red porch steps, the green car, the blue car, and the healthy vegetation. Compare these color reversals to figure 4.

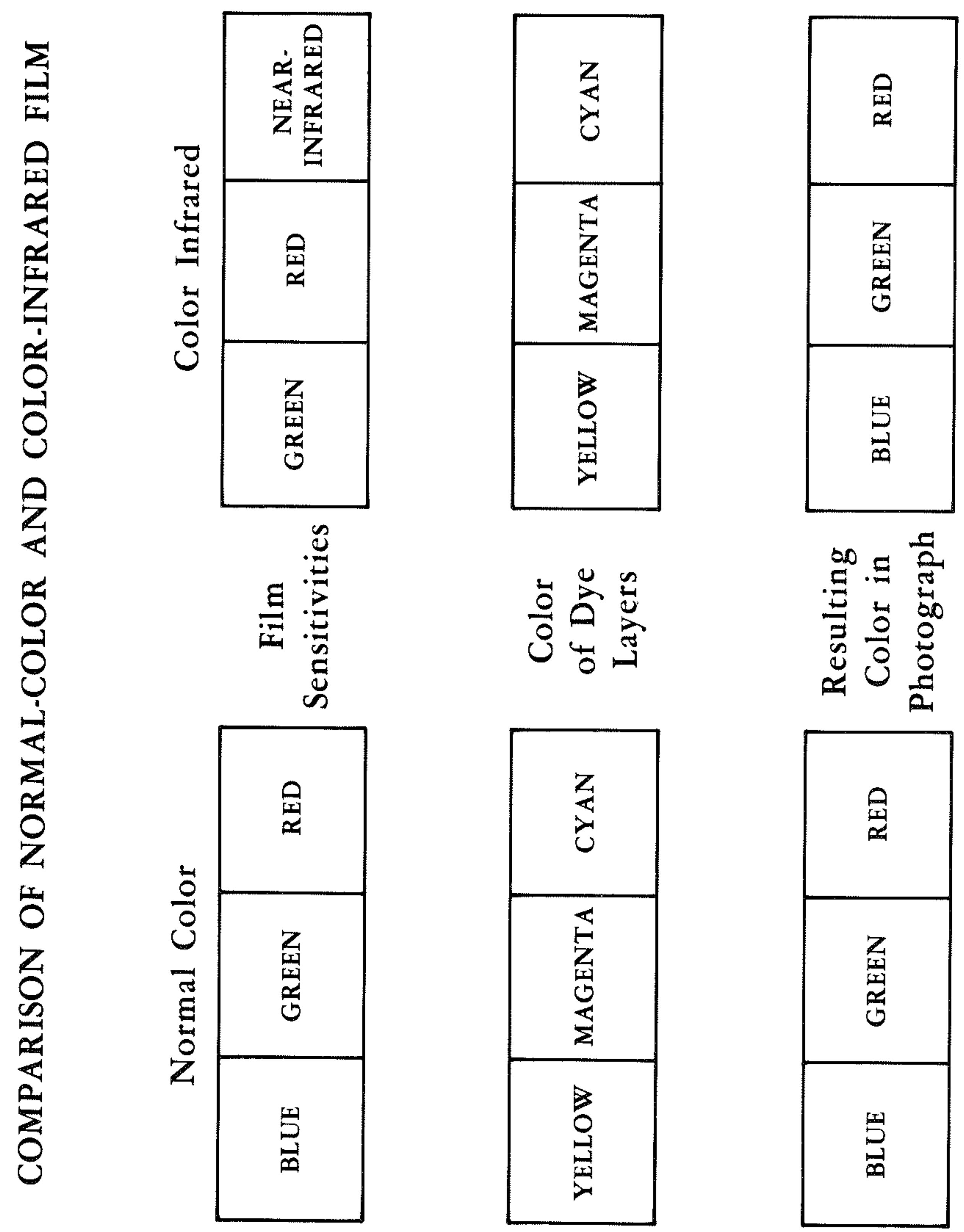

Fig. 4. Characteristics of normal-color and color-infrared film.

THE REFLECTANCE/DYE DENSITY RELATIONSHIP IN COLOR-INFRARED FILM:

HEALTHY VEGETATION

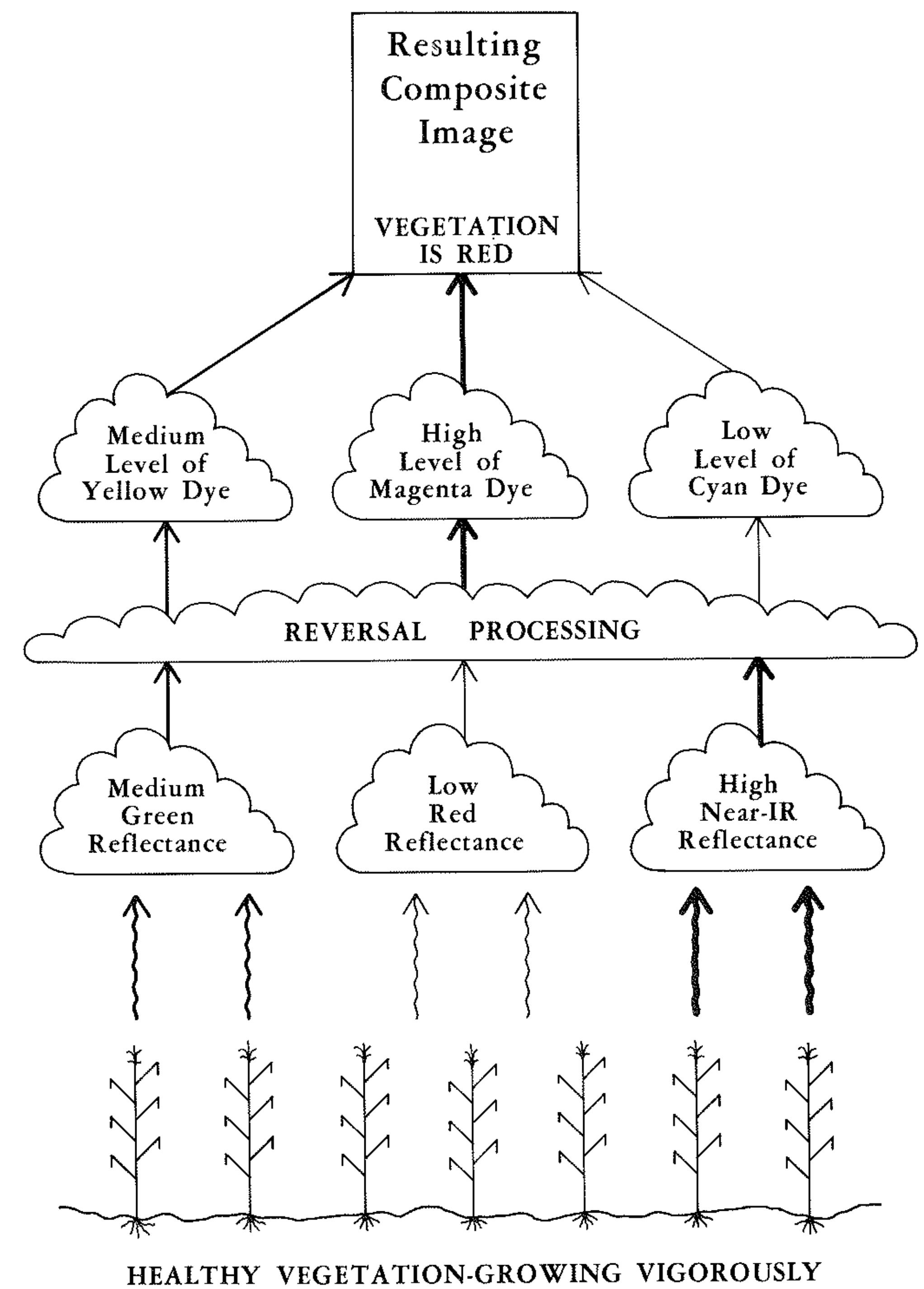

Fig. 5. The reflectance/dye-density relationship in color-infrared film: healthy vegetation.

THE REFLECTANCE/DYE DENSITY RELATIONSHIP IN COLOR-INFRARED FILM:

STRESSED VEGETATION

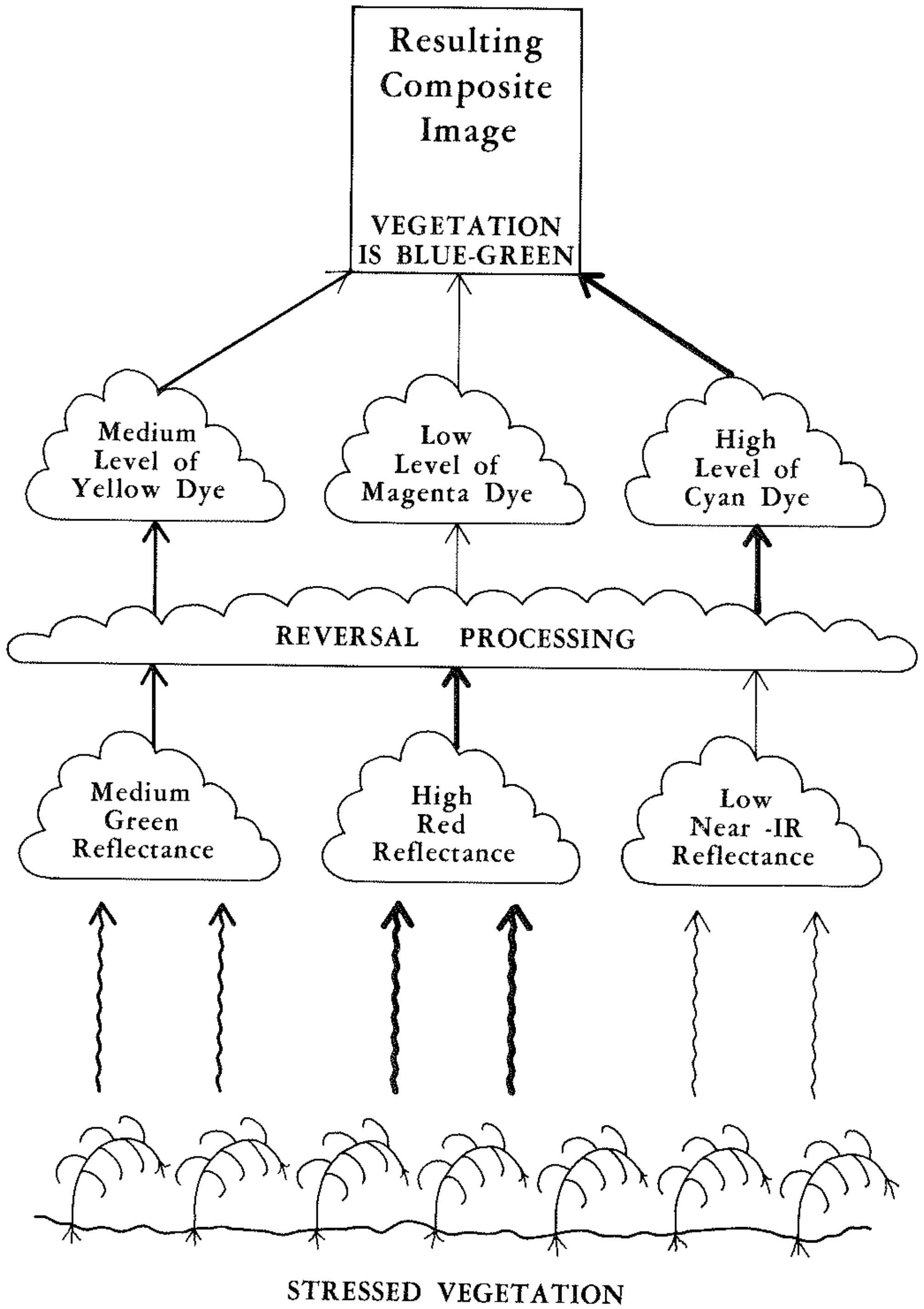

Fig. 6. The reflectance/dye-density relationship in color-infrared film: stressed vegetation.

Table 1. Representative applications of color-infrared aerial photography to agriculture

Crop Inventory and Analysis	***Crop Stresses***
Species identification	Weed infestation
Variety identification (some)	Insect infestation
Canopy biomass measurement	Disease
Yield estimation	Nutrient deficiency (some)
Overall crop condition	Moisture deficiency
	Uneven fertilizer application
	Pesticide misapplication
	Severe weather damage
Soils	***Water***
Classification	Irrigation effectiveness
Topsoil moisture	Drainage problems
Salinity	Feedlot runoff
Compaction	Sedimentation in water bodies
Early erosion detection	
Rangeland	
Overgrazing	
Carrying capacity	

Crop Inventory and Analysis

CIR aerial photography is used widely for general crop inventory and analysis. It is often important for a resource manager or agriculturalist to record and/or map the distribution of crop types within a certain study area; for example, a county or natural resources district. Of course, the scale and type of photography flown for inventory purposes is generally different than that acquired for monitoring one farm or a few particular fields. For regional crop surveys, workable scales are between 1:40,000 and 1:80,000 (sometimes even up to 1:120,000), while the film format is generally 9 inches by 9 inches.

One very important aid in the identification of crop types from aerial photography is the agroclimatic calendar, or more commonly, the crop calendar. A crop calendar summarizes the general planting, reproduction, and harvesting periods for crops located in specific growing areas. An example of a crop calendar for the Nebraska panhandle for five specific crops is shown in figure 7.

An understanding of the crop calendar for a particular area is critical to the correct identification of agricultural crops from CIR aerial photography. The interpreter must be aware that the photographic tone or specific color "signature" of a crop changes as its life-cycle stage changes. An example of the change in image signatures as seen at different points in time in southeastern Nebraska is illustrated in figure 8. Notice in figure 8 that the corn and wheat are easily distinguished by referring to the multi-date CIR imagery, but separating corn from milo or corn from soybeans is much more difficult.

Through an understanding of the crop calendar for a particular area, one can also plan the CIR aerial-photo missions for the maximum interpretive separation of crops on the resulting images. Critical points in the life-cycle of each crop can be identified and the air-photo mission planned accordingly.

While crop species are generally discernible to an experienced interpreter of multi-date CIR photography, differentiating crop varieties is much more difficult. For example, the area in figure 8 designated as wheat is actually made up of small plots representing many different varieties of that crop. Notice that it is possible, in some cases, to detect subtle differences in signature among the wheat plots.

Remote-sensing research has shown that sometimes it is possible to correlate the density of a crop canopy (biomass) as shown on CIR film with the eventual yield obtained from the field. Such research generally involves instrumentation for converting the film into a computer-readable format (digitizing) and subsequent statistical analysis by computer.

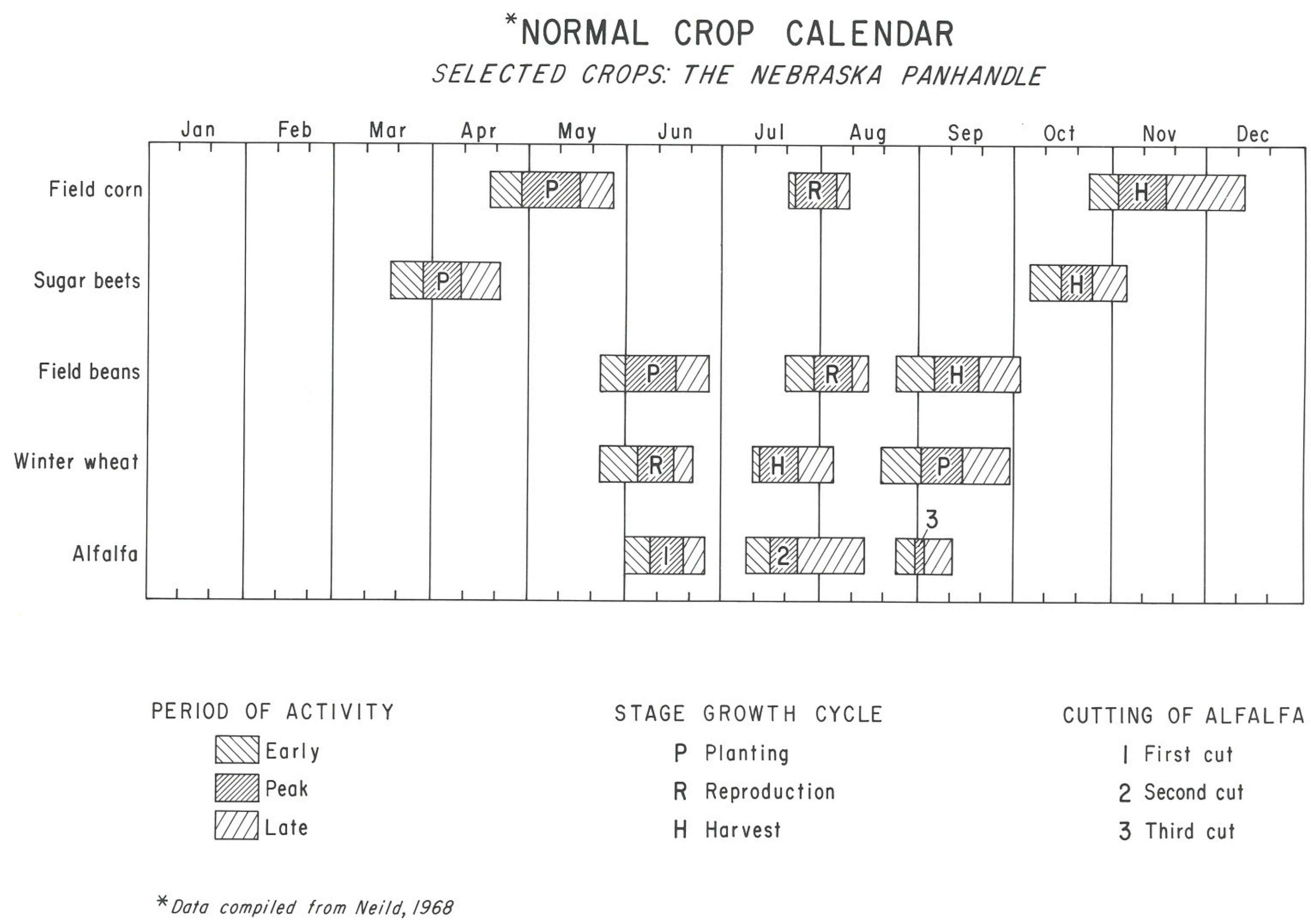

Fig. 7. The normal agroclimatic calendar for five selected crops grown in the Nebraska panhandle.

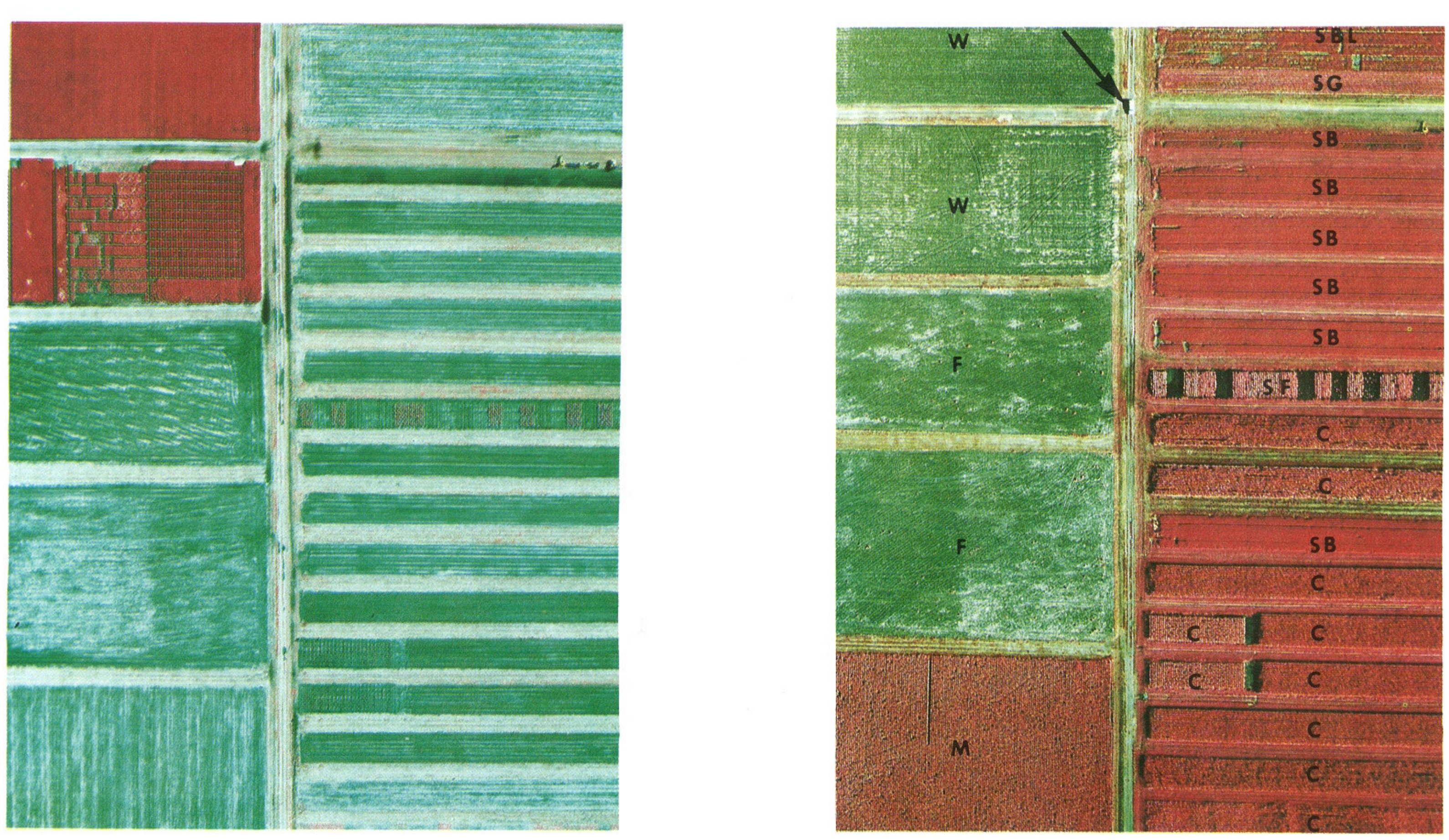

Fig. 8. Aerial color-infrared photographs of the University of Nebraska South Central Research and Extension Center, near Clay Center, Nebraska, taken on June 15, 1983 (left) and August 15, 1983 (right). Notice how the CIR tone of the fields has changed through the growing season (from June 15 to August 15). The specific crops are identified as follows: "W" = winter wheat; "F" = summer fallow; "M" = milo; "SBL" = late-planted soybeans; "SG" = silage sorghum; "SB" = soybeans; "SF" = sunflowers; "C" = corn. Some variations in signatures are apparent between and among fields of the same crop, for example, in the case of corn (lower right). These variations generally indicate cropping experiments. A good example is the two small corn fields (lower center) that are planted in north-south rows while the other corn plots are planted in east-west rows. The arrow on the August 15 image points to a parked car, which may be used as a reference for scale.

Crop Stresses

CIR aerial photography has attracted the most attention as a means of interpreting crop stress. As noted earlier, it is possible under certain conditions to detect some types of crop stresses on CIR film, sometimes before the stress is visible to the naked eye. Considerable scientific discussion has been devoted to the length of this "pre-visual" interpretation period; some claims even exceed a week. But such claims seem dubious at best, and a much more realistic estimate would be a few to several hours. Hence, the "turn-around time" between the photographic exposure and the viewing of the images is critical. For practical use, one needs to be able to view the photography almost immediately, in "near real-time." This timeliness is one of the biggest problems when attempting to use aerial CIR images in to discern crop stress.

In other situations, the plant stress might be visible to the viewer as he stands in the field, but the CIR photo can still contribute to good crop management by enhancing the interpretation (by allowing a view of near-infrared plant reflectance) and/or allowing one to accurately delineate the affected area on the aerial photograph. With regard to the latter, it is then relatively easy to map out the specific area of a field that is affected by the particular problem.

Crops can be stressed by numerous environmental pressures. Lack of moisture, probably the most apparent and common vegetative stress associated with cropland agriculture leads, as noted earlier, to the collapse of the cell walls and a corresponding decrease in the amount of near-infrared reflectance. Thus, drought conditions dessicate dryland crops, the result of which can be detected on CIR film (figs. 2 and 9).

Insects often attack plant tissues, leading either to a reduction in the density of leaf cover or a decrease in a plant's ability to transport water and nutrients. In both cases, the level of near-infrared reflection is reduced, and the damaged areas generally contrast sharply with areas of normal vegetation on the CIR imagery.

By studying sequential CIR photos, the diffusion of an infection or pest can be detected and monitored with ease. Perhaps one photo taken every two or three days might provide information about the dynamics and behavior of a particular disease or insect. Such analysis could lead to the development of preventive measures or procedures. The aerial photos could also be used to guide treatment within the field before the entire crop is lost, again, if they can be obtained and processed in a timely manner.

One of the easiest management errors to detect with CIR film is uneven fertilizer application. Portions of the field that have received proper amounts of nutritional supplements contrast sharply with those that have not (fig. 10). Of course, excess fertilizer will severely damage or kill a crop; these areas are also apparent on CIR images.

The use of CIR aerial photographs to evaluate crop damage due to severe weather is an application that is increasing. Some insurance companies have begun to investigate the use of CIR images in computing their weather-related financial adjustments to farmers. Damaged portions of a field will possess a CIR signature that varies from that of the unaffected areas (fig. 11).

Soils

Traditionally, black-and-white aerial photographs have been used for soils mapping, especially by the U.S. Department of Agriculture Soil Conservation Service. Panchromatic film and its processing are less expensive than natural-color and color-infrared films. However, color differences between vegetation and soil and subtle variations in soil moisture and vegetation vigor are more readily detected using color-infrared film, compared with black-and-white film. For this reason, color-infrared photography is preferred over black-and-white photography in the analysis of crop-soil relationships.

As discussed in preceding sections, variations in crop signature on color-infrared photography may be attributed to several causes, including moisture stress, blight, or stage of physiological development. However, these variations might also indicate differences in soil properties (for example, texture, salinity, or internal drainage).

In general, if we assume that we have a constant situation and a uniformly non-vegetated soil, light-toned areas on the air photos tend to be located on relatively high topographic positions, which tend to be low in moisture content, coarse in soil texture, and low in organic content. Dark-toned areas on CIR images tend to possess the opposite characteristics. Experience has shown, though, that these conditions are true only in an ideal environment. In the real world, these variables and others form a complex system that makes the interpretation process difficult. A few examples are given in the following paragraphs.

Texture

Rarely is a field uniform in soil texture and structure. When water reaches a field, either in the form of precipitation or irrigation, it infiltrates at a variable rate according to the texture and structure of the soil. A high infiltration rate in coarse-textured soils may result in excessive water intake, while finer textured soils with lower infiltration rates will receive lesser amounts of water. The implication of these variations in infiltration rates is that moisture stress could occur in both cases, one from excessive internal drainage and the other from high surface runoff. If the field has received a sufficient amount of water and variations in crop signature occur, one of the possible causes for moisture stress may be traced to differences in soil texture and structure and the effects these two variables have on the infiltration rate (fig. 12).

Differences in soil texture can be estimated by the sharpness of the boundary between the lighter and darker toned areas on an aerial photograph. Fine textured soils generally will have gradual gradations between light and dark tones while coarser textured soils usually will have sharper gradations. These variations in tonal transition are the result of differences in capillary action occurring in soils with different textures.

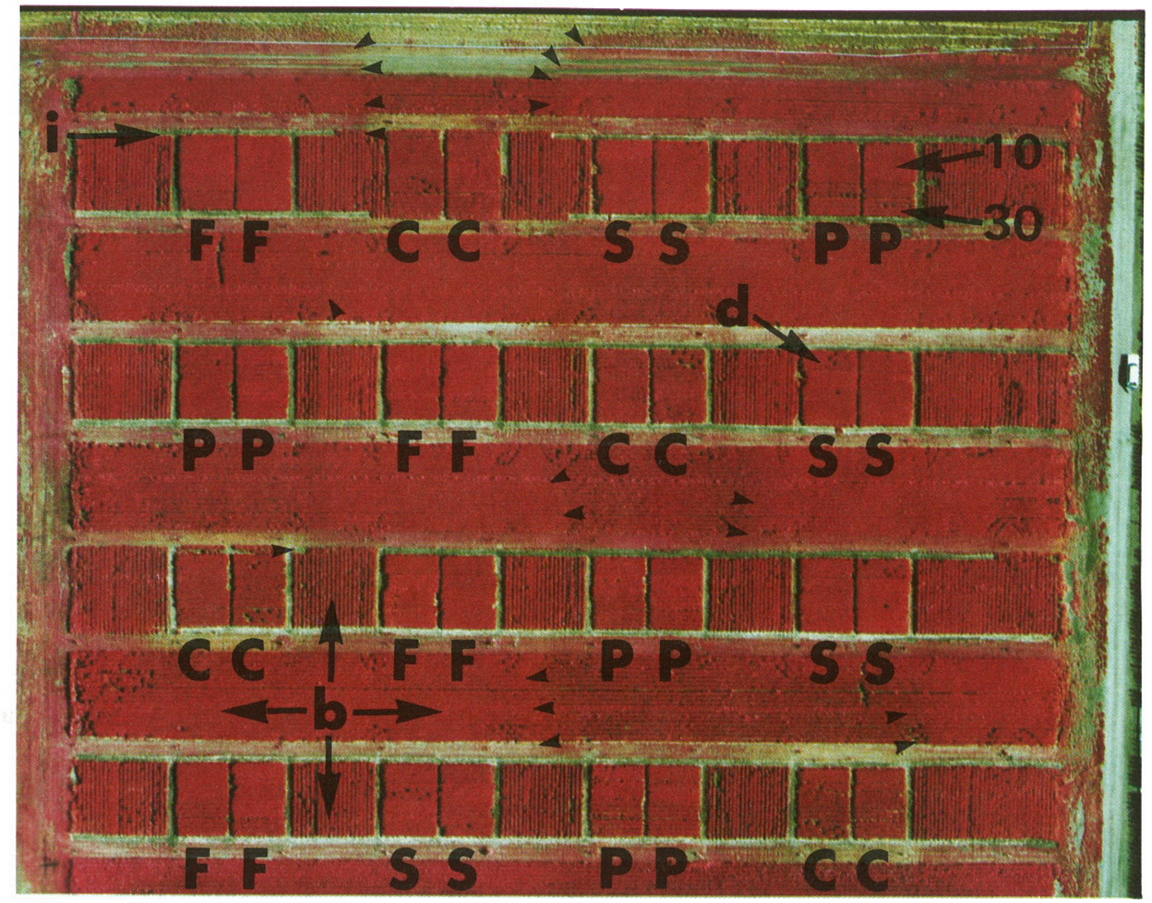

Fig. 9. Soybean irrigation experiment at the NU South Central Research and Extension Center, Clay Center, Nebraska. Date of photograph is Aug. 15, 1983. For reference, the irrigation treatments are labeled (plots shown above corresponding letters): "CC" = check (no irrigation water applied during the growing season); "FF" = flowering (9.2 inches of water applied, beginning at flowering); "PP" = pod elongation (6.2 inches applied, beginning at pod elongation); and "SS" = scheduled (13.7 inches applied, based on soil-moisture depletion). All other areas are bulk soybeans (see areas marked "b"). The irrigation pipes and sprinklers are located in the horizontal rows, such as the one labeled "i," and the small arrows show the edge of a sprayer pattern. The "10" and "30" refer to row spacing in inches; half of each plot is planted with 10-inch rows and half with 30-inch rows. The "d" highlights one of the areas of destructive sampling.

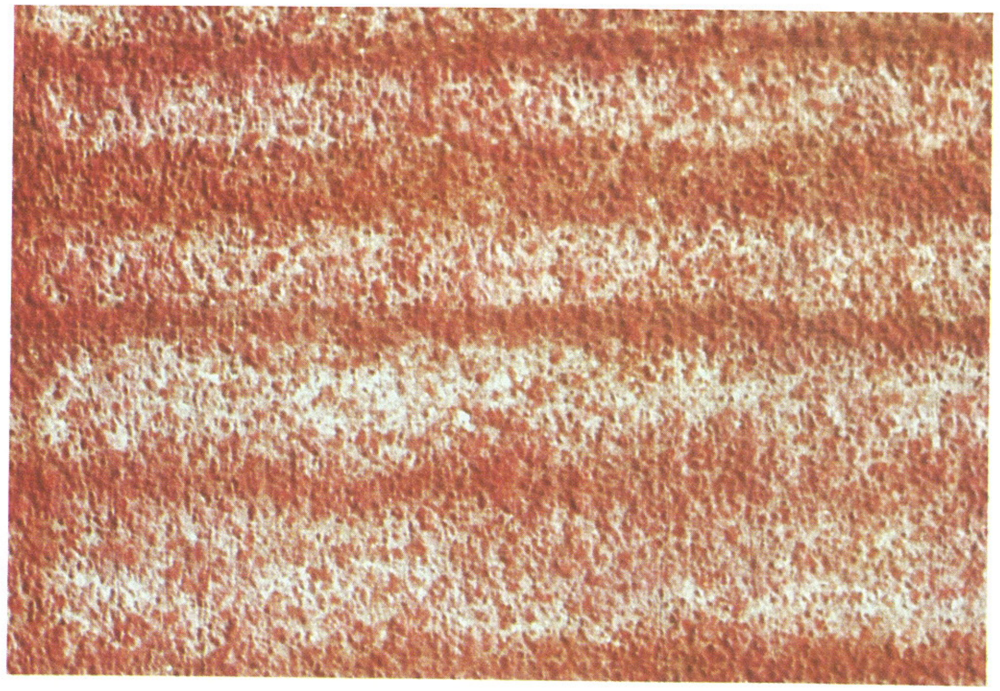

Fig. 10. Uneven fertilizer application in a pasture. The darker stripes are areas where the fertilizer has stimulated good growth of the rangeland.

Fig. 11. Lodging of wheat due to high winds. The light tones delineate areas of damage.

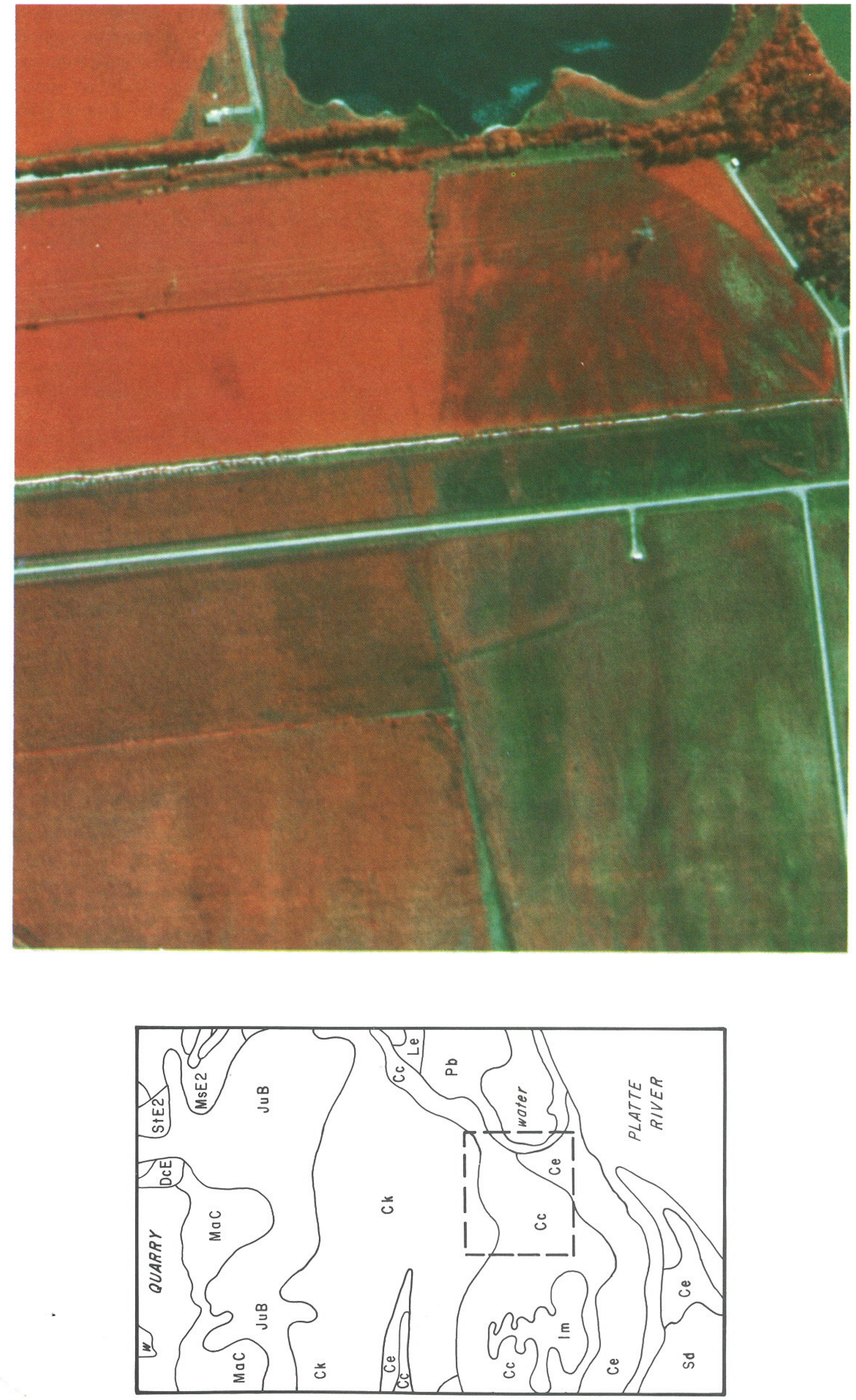

Fig. 12. Differences in soil texture may be indirectly observed through variations in crop vigor. On this late-August color-infrared photograph, the effects from the highly permeable Cass fine sandy loam soil (indicated by "Cc" on the map to the left) can be seen beside the less permeable Colo and Kennebec soil (Ck). The bright red signature of the Colo and Kennebec soil indicates that it has a higher water-availability capacity relative to the Cass soils, which are underlying crops that have a less vigorous growth (purplish-blue color).

Permeability

Besides the variations found in soil texture on the surface of the soil, there are differences in texture within the vertical profile of a soil. For example, a field may a have a relatively homogeneous texture on the surface but have variable textures in different parts of the field below the surface. The infiltration rate is regulated by the least permeable layer in the vertical profile.

In the early stages of normal crop growth, little variation in crop signature may be noticed on color-infrared aerial photography, assuming that all other variables affecting crop development are equal. However, as the plant roots move deeper into the profile, where soil texture differences are present, variations in crop signature begin to develop. For example, in semi-arid regions such as western Nebraska, claypans or hardpans are found just below the surface. As root development progresses downward, the claypan or hardpan impedes root penetration and causes lateral root development. During drought, when the available moisture in the upper layers of the soil is below the wilting point of plants, moisture stress becomes evident in the vegetation (as indicated by a pale pink signature on the photographs of the affected vegetation). Plant roots that are able to penetrate deeper into the profile may find more available water and appear less stressed on the color-infrared photography (relatively brighter red than vegetation on the claypan or hardpan soils).

A relatively impermeable layer may also cause too much moisture to be retained in the upper layers of the soil profile, resulting in a perched water table. This condition is more harmful to vegetation than situations where moisture stress occurs. As the air pores in the soil fill with water, less and less oxygen is available to plant roots. The anaerobic condition that develops encourages root diseases and molds (for example, Phytophthera root rot). An oxygen-free environment in the soil can kill plant roots in a few hours and the entire plant in a few days.

Detection of poorly drained soils on color-infrared aerial photographs depends on soil color and crop response. In poorly drained areas, soils are generally darker than the surrounding, better drained soils. The dark tones are indicative of relatively higher concentrations of soil moisture (fig. 13). In naturally poorly drained areas, the dark tones may also indicate the buildup of organic matter.

Compaction

Soil compaction, generally a result of intensive agriculture, is also apparent on aerial CIR photos. With compaction, the natural structure of the soil breaks down through repeated cultivation and the pressure exerted by heavy farm equipment. Soil compaction impedes water infiltration and root penetration, reduces pore space and, ultimately, crop yields (fig. 14).

Salinity

The effects of soil salinity are observable on aerial photography by the presence of limited and poor vegetative growth in areas adjacent to healthy vegetation. Usually, white "slick" spots are also found throughout the affected area. In moderately saline environments, plants are not usually killed but will exhibit an abnormal, dull red or purple color on color-infrared photographs (fig. 15).

Cut and Fill

Cut-and-fill areas, a result of land leveling, can cause problems resulting from compaction and a lack of nutrients. Heavy earth-moving equipment rearranges the soil profile and compacts the soil surface, reducing permeability and soil pore space. Fill spots create a greater problem than cut areas because of the accompanying deterioration of soil structure. (CIR signatures relating to permeability and compaction are described in previous paragraphs.)

In places where the topsoil is removed, the readily available source of non-mobile nutrients (for example, phosphorous) also is taken away. If nutrient compensation is not made on the cut area, crop yields will probably be lower than the yields from uncut areas due to stunted plant growth and a reduction in crop population. The signature on the CIR imagery will be a light red to pinkish-gray, a result of relatively low biomass per unit area of soil surface.

Rill and Inter-rill Erosion

Color-infrared photography also is used to analyze conditions influencing cropland erosion. Crop management (for example, crop selection and rotation method) and conservation practices (for example, placement of terraces and grass waterways on steep slopes) provide information that can be used in the estimation of potential soil loss attributed to rill and inter-rill erosion. Early season photography is useful in the identification of erosion-control structures (fig. 16), while sequential photography during the growing season assists in the interpretation of crop types and the subsequent type of plant residue on the fields during the fall. Season-to-season aerial coverage provides information relating to crop-rotation practices, an important element in estimating the potential for soil erosion (figs. 17 and 18).

Through systematic interpretation of the various elements of the landscape (for example, topography, drainage patterns, vegetation, and photo tone and color), the aerial-photo analyst can identify different terrain conditions. In complex areas, though, the interpreter should not make unsupported decisions about terrain conditions and should consult other information sources, such as soil surveys, to supplement interpretations.

Water

Although CIR film was designed, and is usually used,

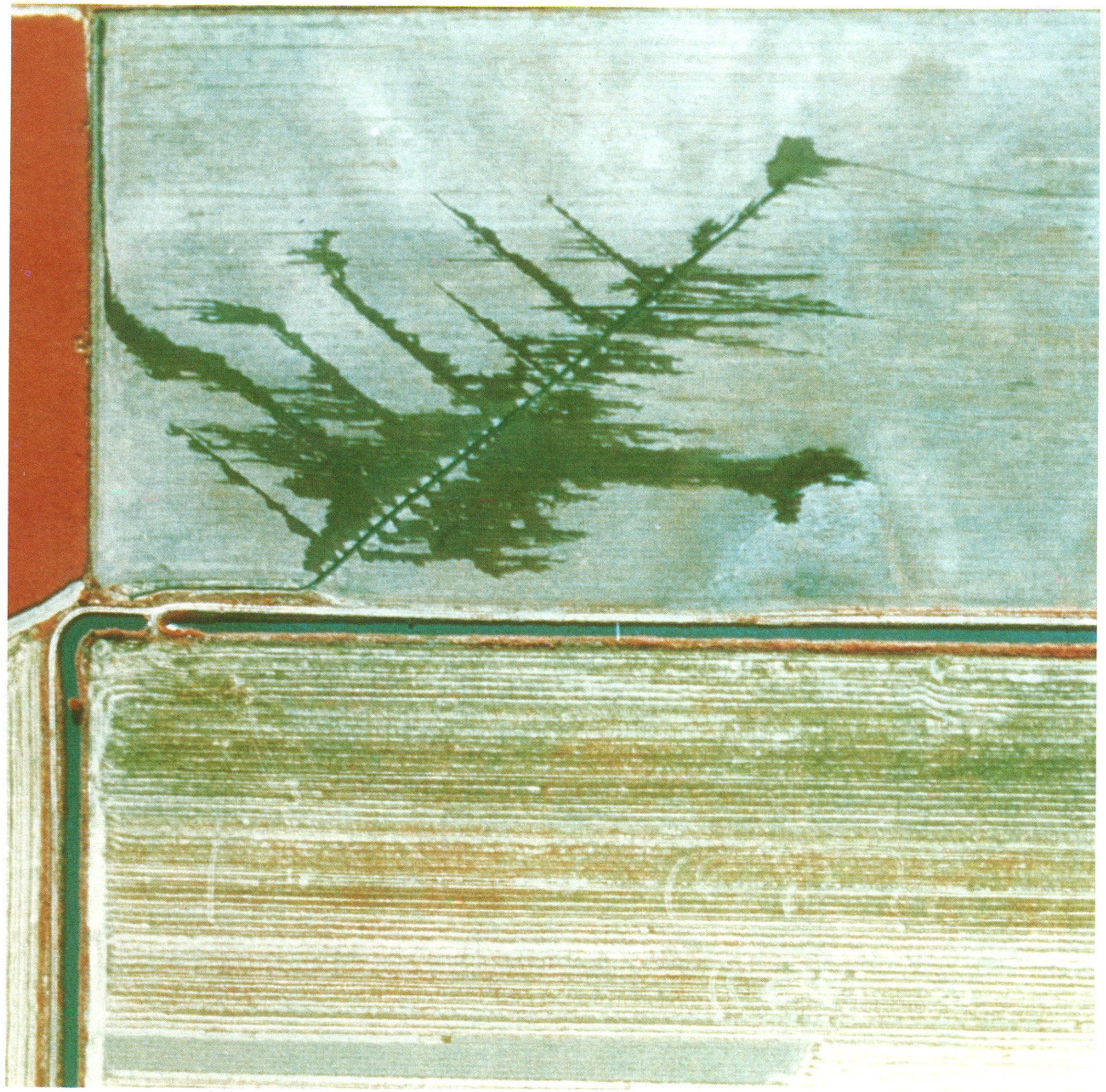

Fig. 13. The dark green areas in the field indicate relatively moist conditions in the soil. The linear pattern is caused by tile drains located immediately below the soil's surface.

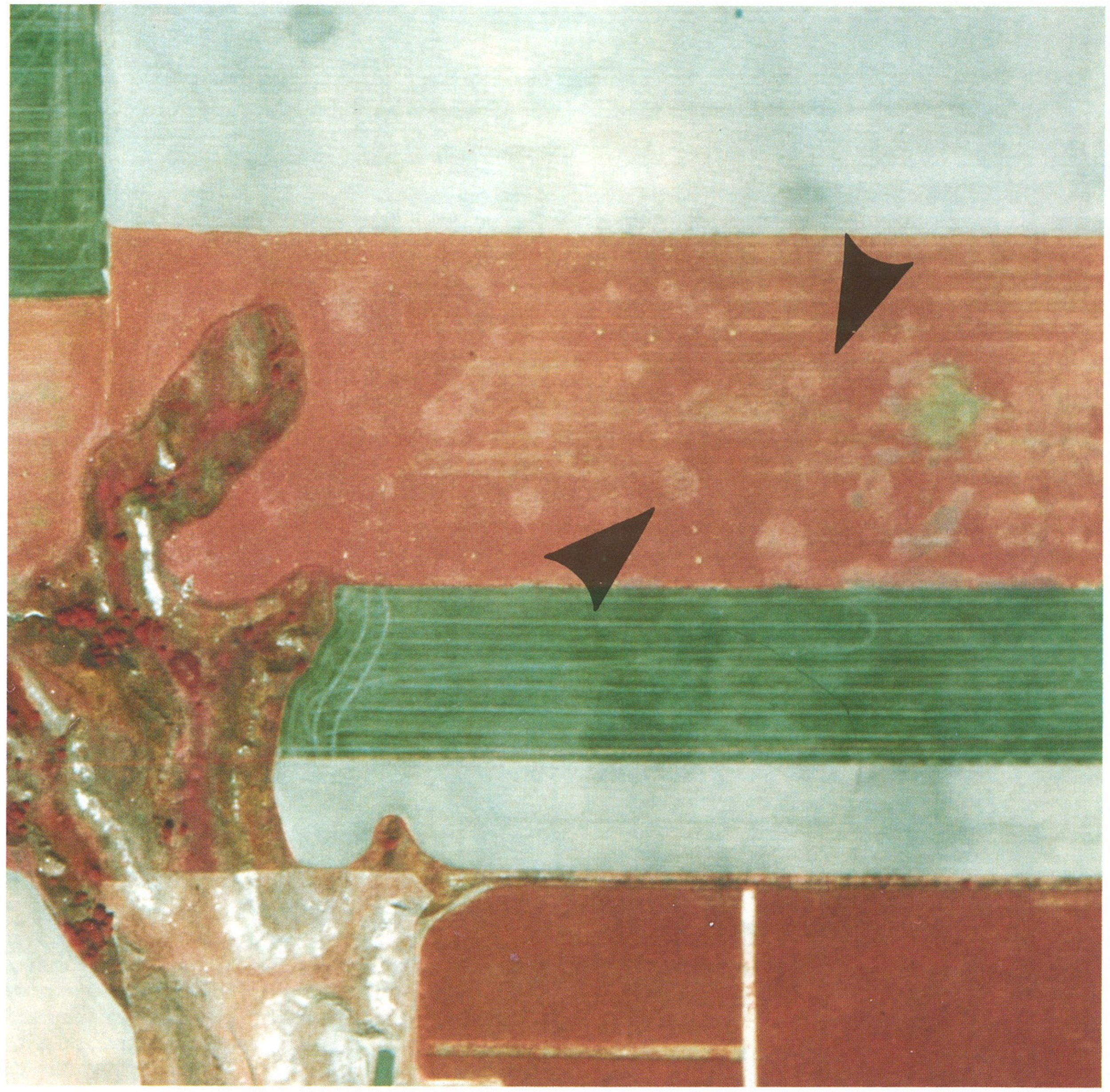

Fig. 14. Compaction marks are identified by their ellipsoidal and circular shapes. Relatively poor plant vigor is reflected by the pink-gray tones in the compacted portions of the field.

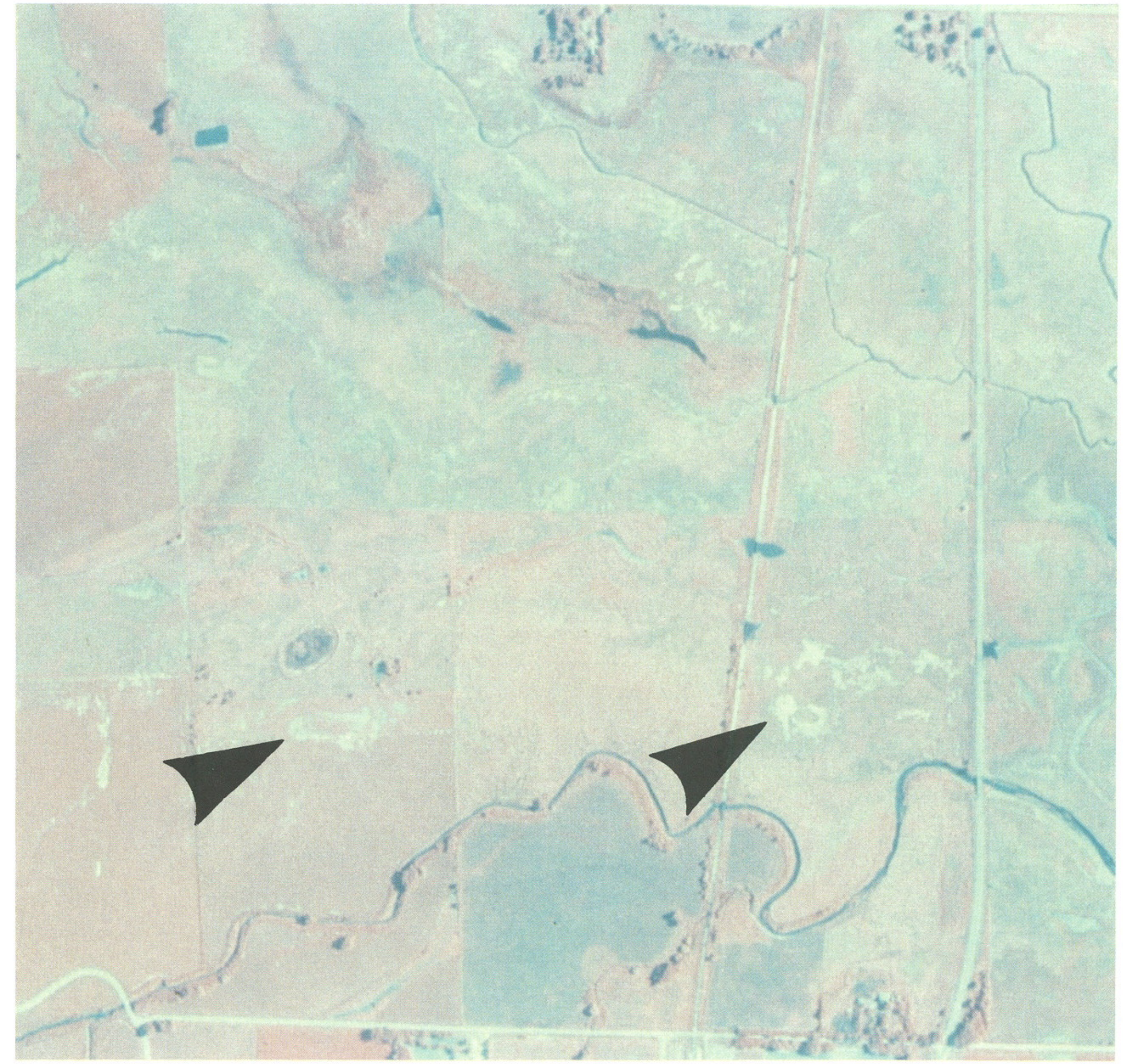

Fig. 15. Vegetation on moderately saline soil exhibits a light purplish-red signature, while more vigorous vegetation on non-saline soils contrasts with the presence of "slick" spots among the low vigor vegetation.

Fig. 16. Grass waterways form deep red "fingers" on the landscape in early spring. Slight variations in topography, such as terraces, may be delineated by the differences in soil moisture (light gray: dry; dark gray: wet).

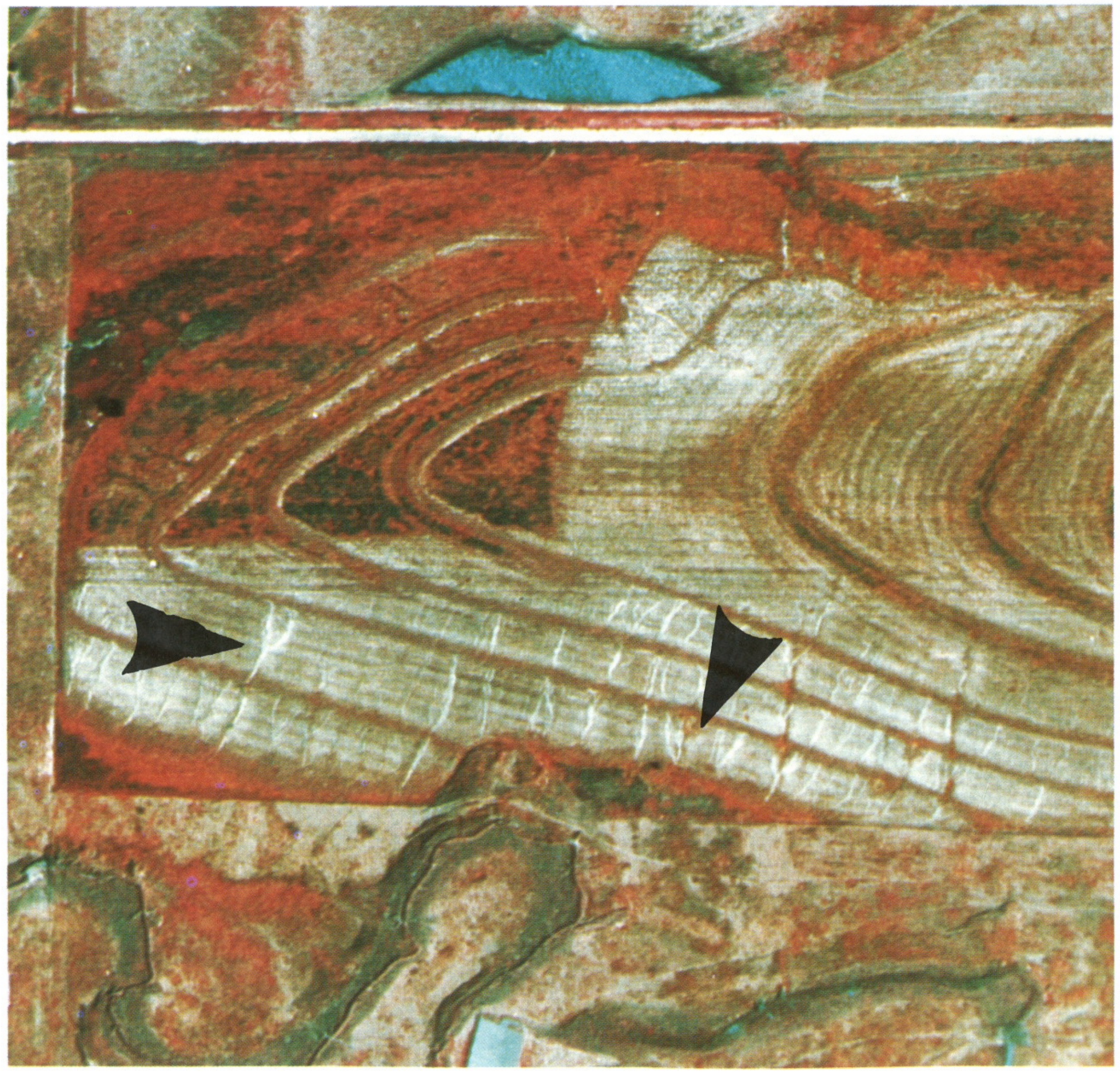

Fig. 17. Evidence of rill erosion on terraces can be observed on this photograph. The sharp contrast between vegetation and soil may be caused by many things, such as water erosion on slopes.

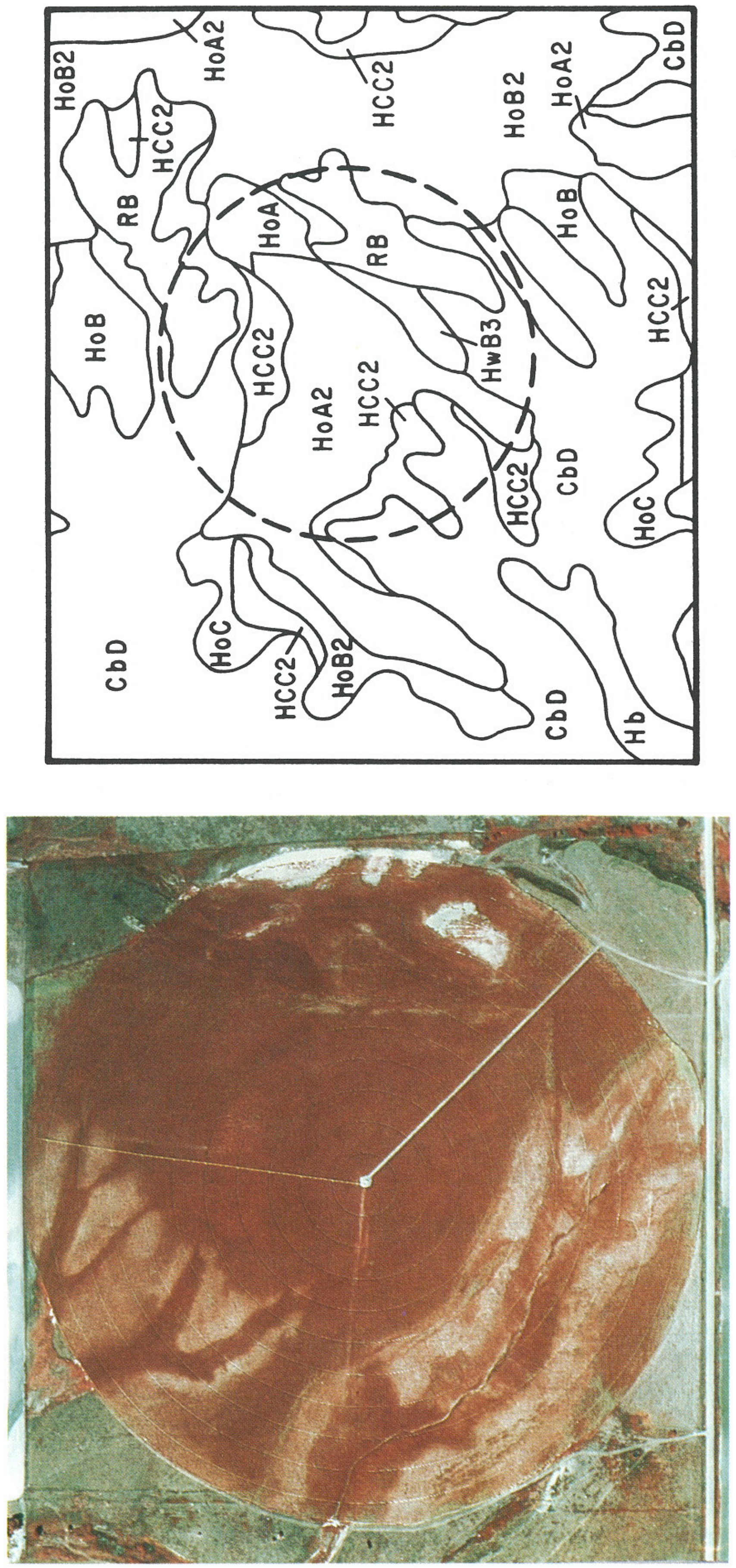

Fig. 18. The effects of eroded soil on crop vigor are evident on this photograph. The deep red color of the center-pivot-irrigated corn is underlain by Holdrege silt loam soils (HoA and HoA2). The light pink areas belong to the eroded soil complex, Holdrege-Coly (HCC2) and rough, broken land (RB).

to enhance interpretations related to vegetative canopies, it does facilitate some interpretations related to surface water. Because near-infrared energy tends to be absorbed by water rather than reflected, wet spots in fields can be identified easily by their dark tones on a CIR air photo (fig. 13). For example, from an environmental-control standpoint, the extent and direction of feedlot runoff can be identified either because of the increased vegetative vigor in the path of the runoff or the variable, often unusual color of the polluted water running from the feedlot. Variations in turbidity and alkalinity, although not necessarily related to agricultural activities, are visible on CIR imagery (fig. 19). Also, areas under irrigation that are receiving little or no water, because of clogged sprinkler nozzles, for example, can be detected on the CIR photos.

Rangeland

The quality of rangeland and pastureland can be monitored and evaluated at regular intervals with ease by using aerial CIR photos. Because the film is recording the density of the vegetative canopy (or biomass), the CIR film signature for grassland areas is especially useful from a management standpoint. Overgrazing causes stress on rangeland grasses, and its CIR signature contrasts with the more vigorously growing pastures (fig. 19). Areas where the vegetation has either been reduced to a dangerous level or removed completely can be identified quickly.

Don't Expect Too Much!

A word of caution should be given to the novice interpreter and a reminder given to the experienced analyst of color-infrared photography. When one studies a photograph and identifies a unique feature, as indicated by certain color tones or patterns, the specific reason for that anomaly cannot always be discovered solely from the photography. The aerial photo is only a tool to aid in locating potential agricultural problems. It is only by field-checks and detailed analysis of those sites that have been identified on the color-infrared photograph that one can ultimately determine the actual nature of the anomaly. Thus, color-infrared photography alone does not provide answers to problems, but it reduces the time spent looking for the extent of the problem and increases the amount of time that can be spent seeking solutions.

At the same time, color-infrared photography has considerable potential as tool for agricultural management. Continued in-field research under controlled conditions no doubt will increase our understanding of CIR imagery and increase its use in Nebraska.

Recently, one of the newest technological developments involving remote sensing of reflected infrared energy has been the use of airborne video imaging. This technique is based on the use of a video-camera system instead of the conventional framing camera for acquiring aerial imagery. With airborne video imaging, color-infrared images can be produced in real time, which makes flight-line navigation relatively easy, thereby reducing image-acquisition error. Another advantage is the electronic format of the data, which is compatible with computers. At the same time, however, some disadvantages exist with this kind of imaging, including the fact that spatial (ground) resolution is not quite as good as aerial photography. Nevertheless, airborne video imaging has become very popular.

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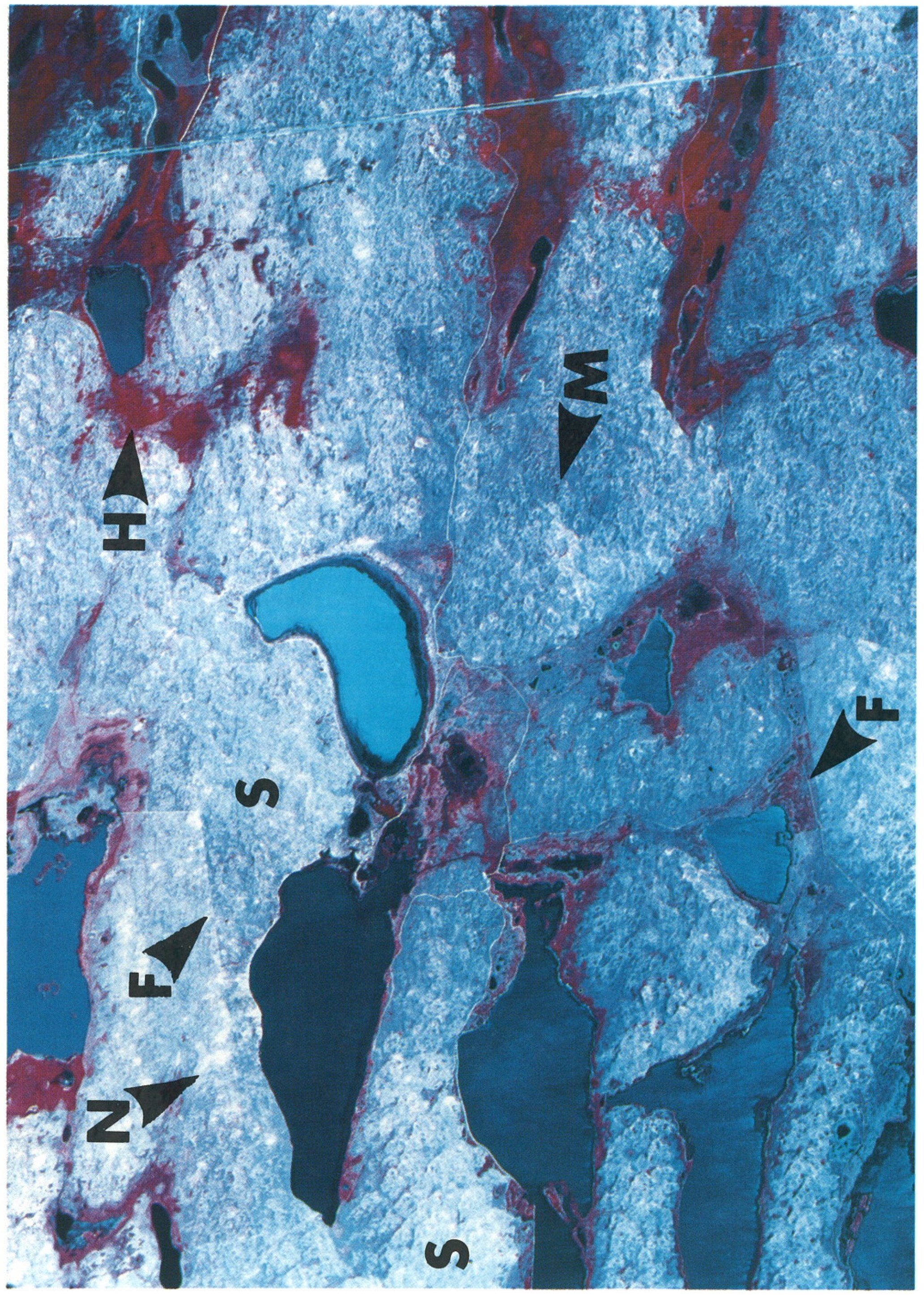

Fig. 19. Variations in vegetation density in the Nebraska Sand Hills, Garden County. The darkest red tones on this photo are associated with heavily vegetated marshes and wet meadows (H); medium reds depict rangeland areas with moderately dense grasses (M); and very light reddish-pink areas represent sparse vegetative communities (S). White areas are deflation hollows (blowouts) with no vegetative cover (N). Notice both the fenceline contrasts (F) and the various tonal signatures exhibited by the lakes.

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Appendix
Sources of Color-infrared Imagery

Federal Sources of Aerial Imagery

Agency	Comments
User Services Earth Resources Observational Systems (EROS) Data Center Sioux Falls, S.D. 57198 Phone: (605) 594-6511	Serves primarily as a distribution center for aerial and satellite imagery, especially that collected by NASA and the U.S. Department of Interior. Holdings include black-and-white, natural-color and color-infrared aerial photography.
Aerial Photography Field Office Administrative Services Division Agricultural Stabilization and Conservation Service 2505 Parley's Way Salt Lake City, UT 84109 Phone: (801) 524-5856	Maintains a collection of aerial photography of U.S. cropland from mid-1930s to present. Coverage is in black and white and has sufficient overlap for stereo interpretation. Photography is flown periodically for cropland inventories that are used in various federal programs.
Cartographic Division Soil Conservation Service, USDA Federal Building Wyattsville, MD 20782 Phone: (301) 436-8187	SCS has similar holdings to that of ASCS. However, the photography is not updated as often because the imagery is used for soil mapping.
U.S. Army Corps of Engineers Omaha District Remote Sensing Coordinator 7410 USPO and Courthouse 215 N. 17th St. Omaha, NE 68102 Phone: (402) 221-4021	Coverage is generally of areas over which the corps has jurisdiction, such as navigable waterways and wetlands. Color-infrared photography is available, as well as black and white. The collection is a result of imagery needs for specific projects and is not flown on a regular basis.
Remote Sensing Branch Environmental Monitoring Systems Laboratory Environmental Protection Agency P.O. Box 15027 Las Vegas, NV 89114	This center provides remote sensing assistance to the EPA for environmental monitoring. Because the agency is relatively new, aerial photography coverage may be limited.
Cartographic Archives Division National Archives and Records Service General Service Administration Washington, D.C. 10408 Phone: (202) 523-3006	This archive collection is of various aerial photography projects conducted during the 1930s and 1940s. All holdings are black and white.
National Cartographic Information Center U.S. Geological Survey 507 National Center Reston, VA 22092 Phone: (703) 860-6045	NCIC maintains a collection of aerial photographs that is used as a source for compiling maps. This agency will direct the inquirer to the original source or holder of the photography.

State Sources of Aerial Imagery

Conservation and Survey Division
Institute of Agriculture and Natural Resources
113 Nebraska Hall
University of Nebraska–Lincoln
Phone: (402) 472-3471

Direct Sources of Imagery: Private Companies

Agricultural Technology Company
206 E. First St.
Box 529
McCook, NE 69001
Phone: (308) 345-6570

Criterion Photoworks
119 E. 4th St.
Minden, NE 68959
Phone: (308) 832-2100

Horizons, Inc.
P.O. Box 3134
Rapid City, SD 57709

Hoskins-Western-Sonderegger, Inc.
825 J St.
Lincoln, NE 68508
Phone: (402) 475-4241

Kucera and Associates, Inc.
4690 Monaco Parkway
Denver, CO 80216
Phone: (303) 388-9289

Mid-Nebraska Aerial Photography
Box 1773
Kearney, NE 68847
Phone: (308) 234-9325

R & D Aerographics, Inc.
1411 W. Eisenhower Blvd.
Loveland, CO
80537 Phone: (303) 669-7900

EC-8
$12.00

Conservation and Survey Division
Institute of Agriculture and Natural Resources
University of Nebraska–Lincoln