An Introduction to

Infrared AERIAL PHOTOGRAPHY

For many uses, this new technique is unsurpassed as a too for immediate and long-range planning in agriculture

INFRARED AERIAL PHOTOGRAPHY is a relatively recent development for use in the agricultural field. Stereoscopic coverage taken by means of correct film-and-filter combinations, from various altitudes up to 20,000 feet, provides information that can aid materially in:

- Crop yield forecasting
- Crop vigor determinations
- Crop deficiency determinations
- Evaluation of crop response to specific amendments
- Soil typing
- Soil suitability evaluations
- Water evaluations, especially in terms of water-logging
- Irrigation and drainage studies
- Nitrogen evaluations
- Other fertilizer evaluations
- Disease determinations during early stages of onset
- Detecting specific insect infestations during early stages of onset
- Weed infestation determinations
- Insecticide-pesticide response evaluations
- Seeding and test-plot studies
- Foreign contamination determinations
- Certain subsurface determinations
- Delineating specific, but fewer and more meaningful areas for soil sampling.

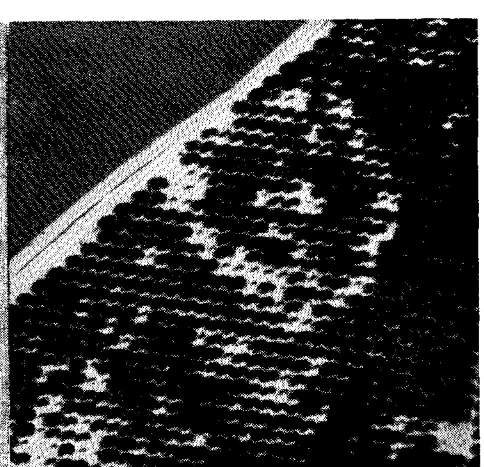
When correctly applied, the infrared aerial photography technique is probably unsurpassed as an immediate and long-range planning tool in agriculture.

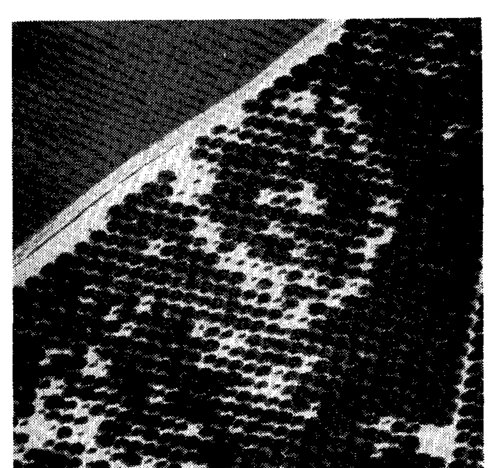
Aerial photographs have been used in the field of natural resources for many years. Conventional aerial photography based on panchromatic (black and white) film and a minus blue filter has been used to define old stream-beds, planting irregularities, cropping patterns, and acreage delineations, and for timber cruising or estimating and the measurement of outcroppings (*1*). These characteristics are more clearly distinguished when the eyes are at 6000 feet above terrain than when they are at six feet.

One reason for this is that broader

Vertical aerial photos of a plum orchard in northern California. Panchromatic film with a 25A filter; K-17 camera with 12-inch focal length. While individual trees can be determined, growth similarities and differences are slurred, and tree-vigor cannot be ascertained

You may be able to view these two photos and those opposite in stereo. Bring page up to eyes with space between pair centered between eyes. Move slowly away from eyes while concentrating on pictures.





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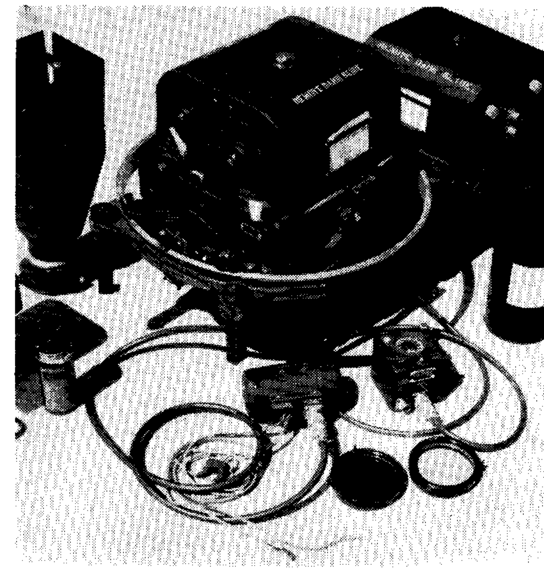
Left: Cessna 182 modified for aerial photography. Below: Equipment used for infrared aerial photography (left to right): View finder, K-17 aerial camera in mount, can of aerial film. In front are power supply and intervalometer.



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air scope permits the viewer to see and evaluate more similarities and differences at one time. And since even the slowest aircraft flies too rapidly to permit detailed examination of an area, correct aerial photography—which can be examined stereoscopically and at leisure by the photo interpreter—becomes a superior tool for such studies.

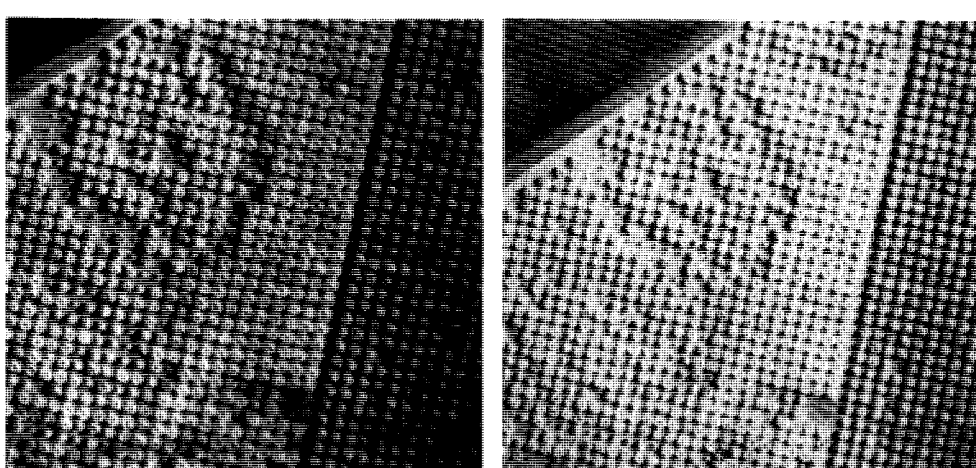
However, maximum utility of panchromatic or Ektachrome (color) films is limited by their spectral confines. These films are limited to the visible spectrum—wavelengths of about 0.4 to about 0.7 microns. Ektachrome (color) ground photography of the visible spectrum has been used effectively in the determination of normal growth, and in the diagnosis of various mineral deficiencies in plants (5).

Infrared radiation is the band of electromagnetic wavelengths lying between the extreme of the visible spectrum (about 0.7 microns) and the shortest microwaves (about 1,000 microns). All bodies not at absolute zero in temperature radiate in this range. Infrared radiation is sometimes incorrectly called "heat radiation" because warm bodies emit the radiation and bodies which absorb radiation are warmed. However, the radiation itself is not "heat."

The visible spectrum (0.3–0.7 microns) permits the human eye to differentiate approximately 20,000 variations of color from red to violet, and approximately 2000 variations from black to white. Since the visible spectrum has a range of approximately 300 millimicrons within which 20,000 variations of color can be determined, the eye can distinguish approximately 70 variations per millimicron. The infrared range (near, middle, far) from 700 millimicrons to 1 million millimicrons should therefore, mathematically, permit approximately 70 million variations that theoretically can be read, if correct instrumentation can be made available.

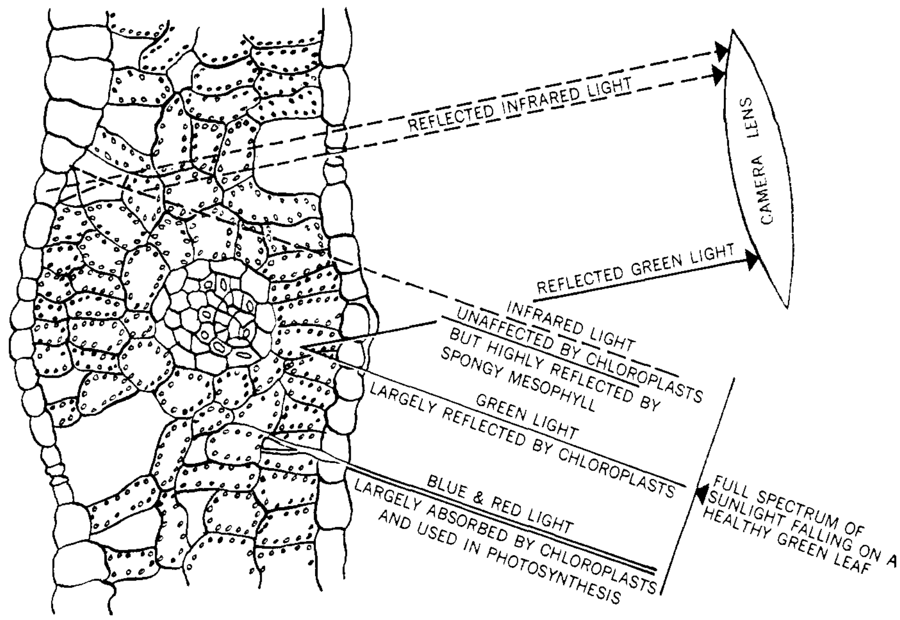
Our present concern is with the part of the near infrared extending roughly from 700 to 1000 millimicrons—hence permitting a mathematical differentiation of some 20,000 variations which can be used diagnostically.

As techniques and instrumentation develop, it should be possible to move upward on the invisible spectrum, eliminating film entirely.



Vertical aerial photos of a plum orchard in northern California. Infrared film with 89A filter; K-17 camera with 12-inch focal length. Note clarity of individual trees and varying tonal differences. Stereoscopic examination will reveal several trees, in the center of the area, gradually dying back. Transplants appear with marked clarity. Trees with fairly identical growth, vigor, and conformation are easily noted

As early as 1890 spectrophotometric data were published for healthy leaves, showing their high reflectance of green and infrared light, and their strong absorption of blue and red light. In 1947 Eames and MacDaniels (*4*) compiled a schematic drawing of a cross-section of a healthy leaf showing that certain wavelengths are largely absorbed while others are reflected to a high degree, either by the chloroplasts or by the spongy mesophyll tissue. The blue light and red light of the visible spectrum are largely absorbed by the chloroplasts and used in photosynthesis. The green is largely reflected by the chloroplasts, with reflectivity of approximately 40%. Infrared is unaffected by the chloroplasts, but is highly reflected by the spongy mesophyll tissue, with reflectivity of about 80%. (See diagram on this page.)



Infrared reflectance of healthy vegetation, as a norm, has been established in a number of instances. Variation from this reflectance norm, in many cases, then becomes diagnostic (*2*).

When plants undergo stresses of many kinds—deficiencies, excesses, disease—one of the first parts of the plant (grasses, trees, vegetation) to be affected is the spongy mesophyll, through collapse or plugging. This change occurs long before the green color begins to fade. Since infrared is highly reflected by the spongy mesophyll, and relatively unreflected from the cuticle on the upper surface, changes in the structure or composition of the spongy mesophyll affect the manner in which the infrared light is reflected. So, even while the plant continues to look "normal" to the human eye of the expert on the ground, infrared will pick up many "abnormalities" from altitudes of 10,000 feet and more.

Since there are now available films that are sensitive to the segment of the infrared band between approximately 700 and 1,000 millimicrons in wavelength, and a choice of numerous light-filters, a different and additional dimension has been added to aerial photography as an evaluative tool in agriculture.

This additional dimension permits clearer definition of areas of vegetation stresses, especially those resulting from such sources as water stress, mineral deficiencies or excesses, poor drainage, insect infestation, and others. Since water, on infrared film, appears as a black tone, moisture content on or under certain surfaces can be determined quantitatively with a distinct degree of accuracy.

It may be possible, as an extension of the work of Wallace (*5*), to measure—qualitatively and quantitatively—numerous aspects of soil mineral fertility, and specific lacks of fertility, through correct infrared aerial photography.

Since clearer definition becomes possible with infrared, area similarities and differences can be determined with a higher degree of accuracy than before. This permits greater refinement in selecting soil-sample locations, to the point that considerably fewer samples are needed for the data desired.

Infrared photography, because of its different and additional dimension, makes it possible for the analyst to extract data not at all available from films sensitive only to the visible band. Infrared can be more definitive at higher altitudes—with attendant cost savings—than the latter films. Infrared also permits more meaningful data to be extracted in a given time period than either pan or Ektachrome films (*3*).

It should be noted that infrared aerial photography is a tool, and that a subsequent percentage of ground-checking is an organic part of this tool. Norms, patterns, or keys must be checked with care in order that data extracted from the photographs be accurate. Where reference keys do not exist, new ones can often be established. This can be a lengthy, and sometimes expensive, process.

Various photogrammetry scales have been used for analytical purposes in agriculture. Since stereo coverage is essential for the analyst to extract data, the photos should have a 70% overlap and a 30% sidelap, so that each image point appears on at least two adjoining photos. At a scale of 1:7200, for example, the 9 in. by 9 in. contact print will cover 670 acres; a stereo pair will cover 187 acres. At a scale of 1:10,000 the contact print will cover 1290 acres; a stereo pair will cover 521 acres. At a scale of 1:20,000 the contact print will cover 5172 acres; a stereo pair will cover 1450 acres.

Since the cost per photo-exposure-and-print is the same for almost all altitudes, it can be seen that the higher the altitude, the lower the per-acre cost, for photography. Of course, for certain purposes the upper limit for photography may be a scale of 1:5000 or 1:7200.

Normally one can calculate photography costs at around $10 per exposure, assuming that the target area is fairly substantial in size, and not too distant from the home base of the aircraft.

Analytical costs, however, vary with the amount of time involved, the extent of ground-checking needed, and the subsidiary laboratory costs that may be involved. Jobs can range from $0.03 to $3.00 and more per acre, depending on what is required.

A brief example will demonstrate the use of infrared aerial photography in plant disease detection and in crop yield estimation, just two of its many applications in agriculture.

Oak root fungus (*Armillaria mellea*) is a debilitating disease that can affect tree growth and yield for several years before it is normally detected by the ground observer. When it is suspected, roots are examined by exposing them in an attempt to find the fungus growth. By that time the infection is fairly intense, and effective measures are difficult to take.

Early recognition of tree debilitation in an area where oak root fungus is suspected can be of value. While at this time little can be done to halt the spread of *Armillaria mellea* in certain orchard crops, early recognition can hasten a decision to remove the susceptible crop and to replace it with another that is *Armillaria* resistant. Such action can, in the long run, effect economic savings of substantial size.

The area involved in this example is planted to plums, which are not generally resistant to *Armillaria mellea*. Adjacent areas are in pears, which normally are resistant to *Armillaria*.

While preliminary examination of ordinary high-altitude photographs indicated an area of suspicion, nothing definitive could have been stated regarding infestation. Detailed examination of panchromatic films, exposed at lower altitude, was not conclusive, since tree vigor and debilitation could not be defined.

However, detailed examination of infrared films of the area, taken at a scale of 1:5000, did permit tree vigor and debilitation determinations, as well as transplant determinations.

When the evaluation of each tree was transferred to a data sheet, the ring formation characteristic of *Armillaria mellea* emerged. The transplants, representing in number approximately 7% of the unit's planting capacity, were mainly within the characteristic ring.

Since orchard trees are transplanted to replace non-bearing units, and since the area was in plums which are susceptible to *Armillaria*, and since the transplants were of uniform age, *Armillaria mellea* was immediately suspected. Subsequent root examination proved the existence of the infestation.

Without infrared photography tree vigor could not have been determined in this instance, and meaningful data could not have been extracted.

It may be of interest that one of the general recommendations for restraining *Armillaria* is to lower the pH as far as possible consistent with the acidity-tolerance of existing trees. The pH of the soil samples taken within this *Armillaria* area was higher than that of 12 other samples from adjacent areas.

Can relationships be established between the health of certain crops and pH? If so, can such determinations be made through infrared aerial photography? If the answer to the first question is yes, the answer to the second probably would be yes, also. Gross determinations of subsurface pH through infrared aerial photography can be of great value.

The same photographs and data sheets used in detecting plant disease can be used for yield forecasting.

From the infrared photographs each tree is evaluated in terms of age and vigor, and the total area in terms of cultural practices. Plums in that part of the country are usually planted 75 trees per acre; an acreage determination (using any of several methods) from the prints showed that this particular orchard block had 14.4 acres. A tree-space count, again from the prints, showed 1097 trees, for an average of 76 trees per acre. This cannot be considered crowding; the area, then, was in good potential production.

However, approximately 10% of the tree spaces were non-productive, giving expectation of a "normal" yield reduction of 10%.

Further examination of the individual trees on the infrared photographs indicated that 70% of the bearing trees were in full maturity, while 30% were either too young or too old for maximum bearing.

Hence, projecting a full yield from the 70% of mature trees, plus an estimated yield of 75% from the too-young or too-old trees, minus any yield from the 10% that were not at all productive, the following relationship can be employed:

$XY = AB + AC$, in percentage, where
X is the estimated yield in percentage for a given crop;
Y is the percentage of normal expectation of a given crop in a given area for a given year. This Y factor must be established through study of available records for the crop under previously recorded conditions, through correlation with photography flown during prior seasons, through ground observations of a sampling of the area, and through other pertinent criteria.
XY, therefore, is the estimated yield of a particular crop, for a given year, at the time of photography. Subsequent abnormal weather or infestation conditions must be reckoned with before final forecasting, of course.
A is the total area capacity, minus blanks, in percentage;
B is the percentage of trees bearing an estimated 100% capacity;
C is the percentage of trees bearing at a percentage of capacity.

Hence, when a normal yield—in tons, bales, hundredweight—is multiplied by XY, a yield forecast can be made with a strong measure of accuracy.

The same general method can be used in forecasting yields in other orchard crops, cotton, potatoes, rangeland, and other crops, by gridding the photographs and considering each grid the equivalent of a tree-space.

The implications of a new tool often are more important than the mechanics of its use. Heretofore, and even today, agricultural production has been considered the personal preserve of the farmer and farmer-group. Despite monumental and costly surpluses in this country, most of the world still lives in intimacy with hunger. Population pressures are such that some 90,000 persons are added onto this planet, daily. Earth's arable acres, meanwhile, remain fairly constant in number.

It is about time that a correct inventory of our planet's bearing capacity were taken. Infrared aerial photography would be a major tool in such a project.

It has been estimated that for more than 95% of the world's population, cereal grains are the main source of food energy. Probably more time, effort, and money have been expended in cereal crop research than for any other aspect of agriculture. Yet today in this country and in other parts of the world, heretofore resistant strains of cereals are giving up the ghost and being wiped out by new strains of pathogens to which the hosts are not resistant.

As more than one researcher has pointed out (*4*), if nature can put virulence into pathogens faster than man can put resistance into crop plants, it may soon become necessary to use fungicides on really extensive acreages of basic food crops that are subject to wide-spread disease epidemics. In such an event, aerial photography flown to the proper specifications should be very useful in selecting areas in which fungicides might be most profitably applied.

Water, in this country and indeed all over the world, is becoming an increasingly critical problem, and its proper utilization is of concern to advanced planners in the agricultural field. Here again correct aerial photography can be a valuable tool in taking inventory and in preparing recommendations for maximum utilization.

If we are to use efficiently all that we possess, we must first know the extent of our possessions. Infrared aerial photography can help determine this extent.

Literature Cited

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