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Crop identification in the Netherlands by means of aerial false-color film

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Summary

In this publication it is pointed out that identification of crops by means of aerial false-color film is not possible by means of differences in color. The identification must be based primarily on differences in structure between the crops, and on the cultivation characteristics of the crops. An identification table is valid only for a specified area and time of the year. An identification table for the major crops grown in the Netherlands polder areas is presented.

Introduction

Though aerial photography was mentioned already nearly half a century ago as a method for making disease surveys in agricultural crops (Neblette, 1927), it was the declassification of the infrared-sensitive film material ('camouflage detection film') that caused a revival of interest in this way of surveying. Colwell (1956), and later Brenchley (Brenchley and Dadd, 1962; Brenchley, 1964, 1968a, 1968b, 1968c), promoted the use of infrared-sensitive film for the detection of diseases and the study of their dispersal. In recent years, the non-military application of infrared-sensitive film developed rapidly under the stimulus of civil space research (Zadoks, 1970). The Laboratory of Phytopathology was interested in the application of aerial photography with false-coler film to research on the epidemiology of plant, especially of potato late blight and wheat rusts. The first difficulty to overcome in studying diseases by means of false-color film was the identification of the various crops. Colwell (1956) produced a 'Dichotomous key for the aerial photo identification of healthy and diseased cereal crops growing on or near University Farm, Davis, California'. Philpotts and Wallen (1969) described a dozen important crops and other kinds of soil cover, of which beans and soybeans were mentioned also for their phytopathological interest (bacterial blight). This paper only deals with crop identification. Descriptions of the image of the major crops on false-color film are presented; a di(tri)chotomous key for the identification of these crops has been prepared from the descriptions.

Materials and methods

Technical data

Imagery was obtained from 7 flights, carried out in 3 successive years during June, July and August, 1968 (3 flights), 1969 (1 flight) and 1970 (3 flights). Except one, all flights were carried out above the Lake Yssel polders in the centre of the Netherlands. The 1968 flights were test flights, needed to obtain information on the suitability of various photographic materials, the time of the day, the wheather conditions, photo scale, and size of the film. The following choice was made for the 1969 and 1970 flights:

Film material	: Kodak Ektachrome IR Aero film type 8443-119-21.
Filters	: Wratten 12 and Wild sandwich filter.
Camera	: Wild RC 8-507.
Object-lens	: Wild UAG 432.
Photo scale	: 1:4,000 (Meyer and Calpouzos, 1968).
Film size	: 23 × 23 cm diapositive.
Time of the day	: between 11h00 and 13h00 (Manzer and Cooper, 1967).
Weather conditions:	: clear weather with bright sunlight, or alternatively totally covered with light continuous cloud cover.

Ektachrome IR Aero film

As in the case of the normal color film, the IR Aero film type 8443 has 3 light-sensitive film layers (Fritz, 1967). The optimal sensitivity of the layers in this film has, however, been shifted to the longer wave-lengths; green (yellow-forming layer after processing), red (magenta-forming layer) and infrared (cyan-forming layer). All 3 layers are more or less sensitive to the blue part of the spectrum, which must be eliminated by a yellow Wratten 12 or 15 filter.

As infrared radiation penetrates easier through the atmosphere than visible light, the IR Aero film is particularly suitable for aerial photography. The light reflection of the so-called photographic or near IR radiation (wave-length 700-960 nm) by crops in comparison with that of their surroundings, and the change in IR reflection in case of an irregularity, is an asset of IR Aero film for agricultural usage.

Color rendition

Colors as reproduced on IR false-color film depend on:
- the quantity and composition of the radiation received by the crop;
- the angle of light incidence, or altitude of the sun;
- the visible light reflected by the object;
- the IR radiation reflected by the object;
- the orientation of the leaves;
- the filter used;
- the exposure time;
- the situation of the airplane relative to the object in question;
- the weather conditions;
- the conditions during storage and processing of the film.

The handling and processing of IR false-color film may face the photo-interpreter with surprises with respect to color rendition. Color rendition may vary between and within films, and even between and within photographs of a single film. Therefore, color alone does not provide a useful criterion for identification, unless references in the form of standard color screens have been laid out in the field and photographed. These were, however, not yet available.

Color contrasts, however, are the strong points of this type of film in comparison with conventional color film. The contrast-producing property of the false-color film is due to the registration of the IR radiation in the wave-lengths between 700 and about 960 nm, invisible to the human eye. The reflection of IR radiation by living plant tissue

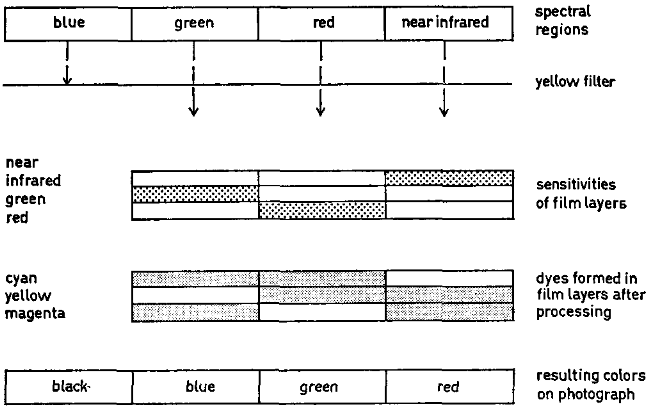

Fig. 1. Color rendition by Ektachrome IR Aero film type 8443. Resulting colors are formed by subtractive mixing of dyes of remaining layers (Anon., 1968).

is considerable; it depends on the plant or crop observed, but will be about 50 %, and often more (Gates et al., 1965).

Both quantity and composition of the spectral reflectance of plants and crops depend on several factors, such as:

- the anatomical structure of the leaves at the top of the canopy;
- the spatial arrangement of the leaves;
- the growth stage or stage of ripening of the crop (age);
- the water balance of the plants;
- the state of health and fertilization;
- the presence of pigments (chlorophyll, carotene, anthocyans, etc);
- pests and diseases.

Excluding the factors which can be controlled, the colors on the IR false-color film will be formed by the reflected visible light and near-infrared radiation.

The colors formed on the false-color film are the result of substractive mixing of three dyes (cyan, yellow and magenta), which remain after processing (Fig. 1).

Prediction of the colors or changes in color as they probably appear on the film is possible with some knowledge of the IR reflection by Fig. 2. It is the so-called CIE (Commission Internationale de l'Eclairage) chromaticity diagram, used internationally to specify colors. This CIE system is valuable because it provides a scientific standard for the measurement of colors. It describes the following terms: dominant wave-length (hue), luminous reflectance (brightness), and excitation purety (saturation) (Anon., 1953). Fig. 2 shows a horseshoe-shaped line representing the position of the pure colors of the spectrum and a more triangular form representing the colors as they can be produced by mixing the colors of the sensitive layers on the false-color film. The straight line closing the horsehoe shows the position of the magenta/purple colors, which are complementary to the green colors of the spectrum. Color formation can be predicted as follows. Start from the 'illuminant point' for the standard light source, which is equivalent to daylight, and go in a straight line over a chosen point on the triangular form (sensitivity of film layers: infrared, green and red) towards the horseshoe-line (blue), (green) and (red), and you will find the color appearing on the film.

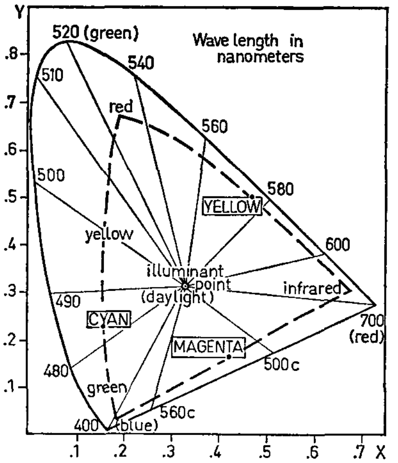

Fig. 2. CIE chromaticity diagram. CYAN, etc. = dyes formed in Kodak Ektachrome Aero film layer; green, etc. = sensitivity of the film layer (undeveloped film); (red), etc. = color as formed on developed film;
The outer solid line represents the position of the pure colors of the spectrum.
The inner broken line represents the colors as they can be produced by mixing the three color layers of the Kodak Ektachrome Aero film.
See for further explanation: Anon. (1953).

Means of crop identification

Color

Looking at IR false-color film, the layman would expect the identification of crops on such films to be based first of all on differences in color. This is not so. Color differences can be used as means of identification, but rank second only and serve to complete the observations of the structure and texture of the crop image, and, foremost, of the agricultural aspects of the crop.

Each living and leaf-bearing crop reflects the photographically active IR radiation and will appear in a purple or red color on the false-color film. (The intensity of the purple or red depends on factors discussed below and above).

The color differences help the photo-interpreter to get an idea of:

– The distinction between crops or other vegetation and their surroundings. Water reflects hardly and IR radiation and appears as dark gray or black, and sometimes as blue or purplish depending on the presence of algae or pollution in the water; aquatic plants reflect IR radiation and are clearly distinguishable against their dark background. Green non-living objects, unlike green plants, hardly ever reflect IR radiation.

– The soil cover. Soil has little IR albedo and appears on the IR picture as black to greenish. The color depends on humidity, organic matter content, etc.

– Ripening of crops. A ripe crop remains visible but is colorless or brown on the IR picture.

– Irregularities within the crop, caused e.g. by pests or diseases. Damaged plants or plant parts reflect the IR radiation in another way than healthy plants, so that color differences will become visible on the photograph. When leaves fall or when the crop is ripening, the soil will become visible through the crop canopy. The gray to black tones of the soil will dominate.

– The presence of anthocyans, carotenes, etc. Plants possessing anthocyans in their leaves will appear on the IR false-color film with a color between yellow and red.

Cultivation characteristics (general)

In 1956, Colwell published a key for the identification of healthy and diseased cereals. He made good use of cultivation characteristics of these cereals. Philpotts and Wallen (1969) also separate the crops in a few big groups with the help of general knowledge of plant-growing techniques.

Trees. Trees are easy to distinguish from annual crops. The size of the individual plants and the distance between the plants are important for this distinction, and they are related to each other in a man-made perennial vegetation. A tree plantation is differentiated from a natural tree vegetation by its regularity: planting system, planting distances, equal sizes of tree tops, etc.

Annual crops. These crops are often cultivated in specific ways.. We can distinguish:
– *Drill culture:* crops planted or shown in rows. Visibility of rows remains till the end of the growing season, or fades away progressively, according to the distance between the drills and the size of the individual plants within the crop. The occasionally visible light striation in these fields on aerial photographs is sometimes the result of mechanical sowing.
– *Bel culture.* When crops are grown on beds, the beds nearly always remain visible, because a rather broad strip of ground is left open between the beds as a path (on these strips weeds sometimes can be found: high IR reflection!). !Example: flower bulbs are grown in this way in the Netherlands.
– *Ridge culture:* a technique of cultivation employed especially in the tropical countries and comparable with bed culture.

Other ways of cultivation, like broad-cast seeding, supposedly give their own typical image on an aerial photograph. Many of these ways of cultivation are specific for a particular region or country. Knowledge of the local cultivation systems seems to be a necessary condition for the identification of crops.

Cultivation characteristics (specific)

The identification table (Table 1) is based on the cultivation characteristics seen in the central polder area of the Netherlands. Here also there are specific regional characteristics. This polder area, where farming meets the highest standards of modern agriculture, shows great regularity. It is a recently reclaimed and developed region with a limited assortment of crops. The farm lots are rectangular and measure about 800 × 300 m, so that on aerial photographs a good image formation and survey is obtainable. In this region there are no important differences in altitude that can influence photo-interpretation and crop identification.

Structure and texture

The structure and texture of a crop as seen on the aerial photograph rank second in importance for the identification of a crop. In the identification table (Table 1) a few unusual terms have been employed, comparing the impression caused by crops to those given by some tissues when observed by the unaided eye.

Stereo image

The stereo-image completes the data gathered either by the unaided eye or by use of magnifier glasses.
For the identification it is important:
- to distinguish between short and tall crops;
- to see if the soil is completely covered or if open spots occur frequently;
- to identify phenomena like 'lodging', 'diseased patches' where the crop collapsed, etc.;
- to distinguish weeds from crops. This is not always possible by color differences.

In vegetation studies, differences in height are more important than absolute heights. These differences can be measured with some experience with the aid of a parallax bar (stereometer). Height differences of 15 to 20 cm can be determined without difficulty on pictures at a scale 1:4.000. The stereoscope is not an indispensable instrument in identifying crops on aerial photographs, but the interpreter can identify planting rows, flowering, irregularities, etc. more accurately with than without a stereoscope.

Description of crops

Potatoes. The rows are easy to distinguish with the naked eye all over the field, and up till the end of the growing season. The headlands are often obviously separated from the mainfields by a one-drill wide path. Even without this path the distinction is obvious, because the rows are clearly visible (headlands do not occur in all regions!). Wheel-tracks are often visible between the rows; this depends on the date of the last spray previous to the date of the photo-shot. Potato crops killed by herbicide spraying at lifting time are olive-green to orange-brown. The rows are less clearly distinguishable than before, because the potato leaves shriveled away and only the dead haulms remain.

Beets. The coarse-shaped beet leaves give to the field the aspect of a tufted carpet ('carpet-like structure'). This aspect is caused by little red and rose color shades, as seen under the stereoscope. Rows are not always visible, but this depends on sowing density. Missing plants give conspicuous open spots in the field, like angular specks. Such open spots occur frequently in beet fields. When segments of the rows are not sown, these open spots occur as thin stripes, running parallel to the rows.

Cereals (fall-sown and spring-sown wheat and barley). The structure of all cereal fields shows a very fine striation, at times but not often corresponding with the rows. In the latter case striation often occurs in perpendicular direction. This striation depends mainly on the way of tillage of the fields. Though this is difficult to establish stereoscopically, the impression exists that in wheat the ears cause a slight striation, when they are 'lined up' (perhaps by the wind). Lodging points are always lighter in tone, and they have clear-cut boundaries; they are 'cloud-shaped', or protracted in shape and orientated in the same direction as the rows (overdosage nitrogen!). The various kinds of cereals cannot as yet be readily differentiated without local knowledge. A differential characteristic is the ripening time. The normal order is: rye - barley - wheat - oats. The rapid decline of the IR reflection is, of course, visible only at the end of the growing season.

Meadows. Meadows show a very irregular structure. No striation is visible. Blotches of different colors and color tones are intermingled, due to differences in grazing intensity, the occurrence of different kinds of weeds, and hay-making procedures. Colors within the field may vary between red and rose and may shade off into gray tones by the local disappearance of grass, due to treading of cattle (drinking-places or milking-places). Presence of drinking-places and milking-places and of cattle are evidence of meadows on aerial photographs. Differences in color between meadows are due to differences in the IR reflection, which in turn depends on the grass-sod of the pastures (hay cut or not, grazing intensity, fertilizing practice, etc.).

Fallow. Fallow land reflects little IR radiation when no weeds are present Consequently we see a gray or black color. Different tones between black and gray correspond with moisture contents of the upper layer of the soil (moist soil gives a dark-gray to black, dry soil a light-gray color). The patterns in the field can be an indication for the way of tillage, but also for the variation in soil types. Weed infestations on fallow land are visible as irregularities in the IR reflection, due to the irregular distribution of weeds over the field.

Flower bulbs. In the case of flower bulbs the soil coverage is low and the underground comes through. The cultivation method of flower bulbs is, however the best means of identification. Flower bulb beds are narrow (1 m) and alternate with wide paths. Stereoscoping is hardly a help in studying flower bulb fields, as the relative height differences between bulb varieties are too slight.

Cabbage. Cabbage is very difficult to identify; it is more important in horticultural than in agricultural areas. This crop may be confused with beets, but cabbage fields are usually smaller than beet fields. The planting density also is different (cabbage fields are less densely planted than beet fields). Each cabbage species has his own specific spectral signature, not only in the IR spectrum, but also in the visible light. Red cabbage must be singled out, however; the effect of red anthocyans in red cabbage on false-color film manifests itself by a shift to orange on the photograph. Flowering in cabbage can change the whole aspect of the field. Stereoscoping does not lead to a more rapid identification.

Onion. The cultivation of onions in the polders is not extensive; fields are relatively small. Onions do not have a big mass of foliage, and the leaves are situated in a nearly vertical position; therefore soil coverage of this crop is slight. In general the color of the soil dominates. A red haze of reflected IR radiation lies over the gray or green hue of the soil. Confusion with a weeds fallow is possible, but an onion field is obviously a managed field. This manifests itself in a very fine striation. It is not clear whether this striation is due to the onion rows or to the way of tilling in the field. The stereoscopic image gives no further elucidation.

Flax. Flax can be confused with cereals. The risk of confusion is not too great because the flax area is rather small. The only distinction with cereals is the sharpness of the image. A flax field gives a more hazy and woolly impression than a wheat or barley field. Striation can exist. The ripening and harvesting of flax takes place before those of cereals. The image of a flax field can change instantaneously at flowering time: flowers then dominate the scene. The color of the flowers is either blue or white. The spectral reflectance of the whole field changes, so that the identification meets with considerable trouble. White flowers will appear as white on the false-color photograph (white on

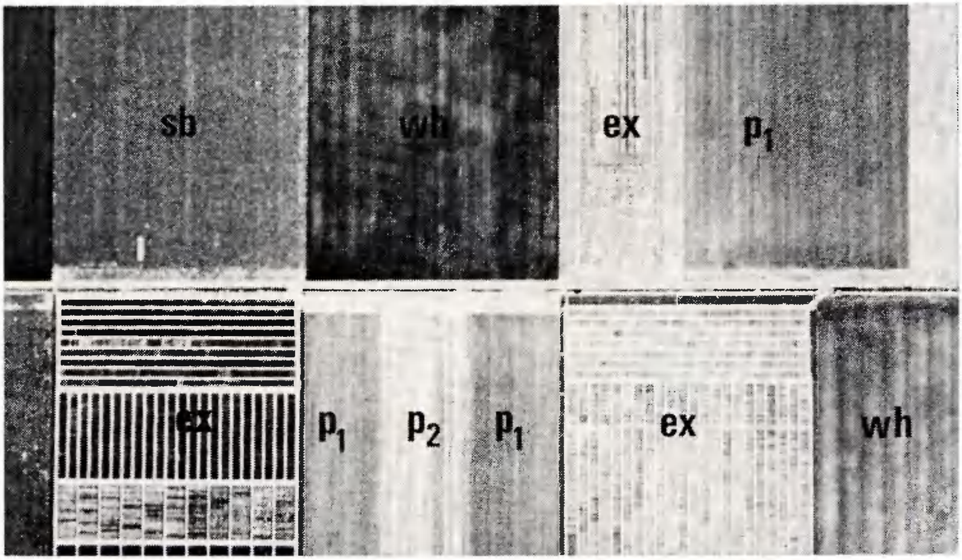

Fig. 3. Aerial photograph of an experiment farm in the North East Polder taken on 8 July 1971. (Photo KLM Aerocarto; scale 1:4,000.) wh = wheat; sb = sugar-beets; m = meadow; o = oats; p_1 = potatoes; p_2 = lifted potato field; ex = experiment field.

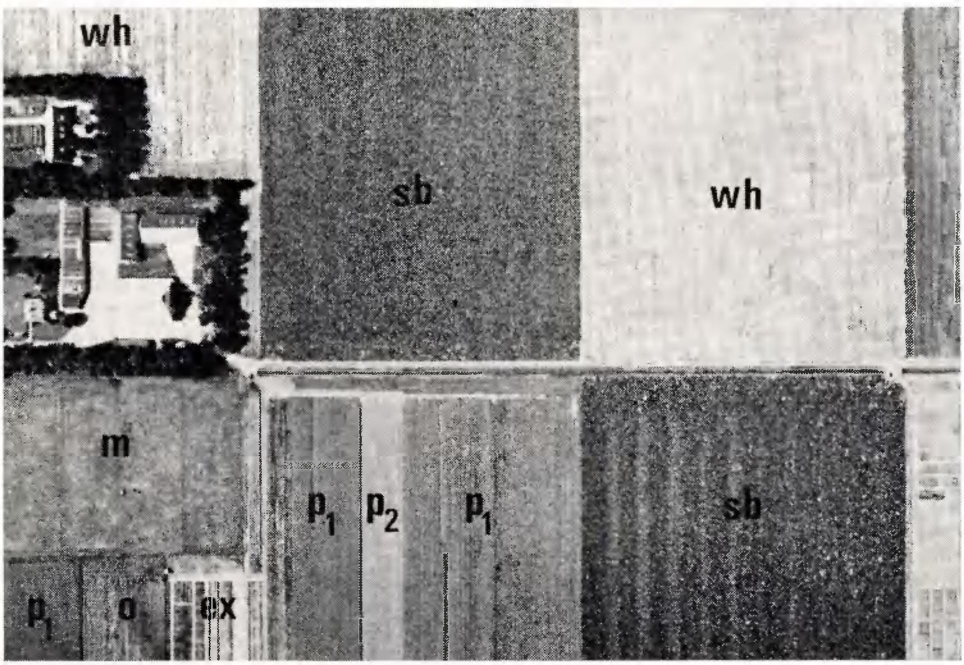

Fig. 4. Aerial photograph of an experiment farm in the North East Polder taken on 30 July 1970. (Photo KLM Aerocarto; scale 1:4,000.)
Wheat nearly mature; lodging visible as light. 'cloud-shaped spots. For legenda, see Fig. 3.

false-color changes into blue-green, IR reflection gives a red color, and together they will appear as white). Blue flowers do not show up so easily (blue changes into black, because it is filtered out by the yellow filter, IR reflection gives a red color, together they will appear as red).

Table 1. Key for the identification of some important crops on aerial photographs made with IR false-color film in the Lake Yssel Polders (the Netherlands).

Scale: 1:4,000
Time: June and July
Place: Lake Yssel Polders (the Netherlands)
Film: Kodak Ektachrome IR Aero Film type 8443

1a	Rows visible		2
b	Rows not visible		4
2a	Rows visible all over the field		3
b	Rows visible in some places only	cereals	
3a	Structure of the field dense and fine; main field and headland well separated from each other; color differences visible over great surfaces; end of rows characterized by irregular start or stop of planting machines	potatoes	
b	Structure of the field close and coarse ('carpet-like structure'); main field and headland adjoining without separation; open spots often visible between the rows, or perpendicular to the rows between main field and headland	beets	
c	Spotted and irregular red to rose over a gray or green background; no headland; fields often small	cabbage	
4a	Plant beds visible	flower bulbs	
b	No plant beds visible		5
5a	Fine parallel striation in longitudinal and/or transversal direction (not similar to plant beds or rows)		6
b	No striation of any kind visible (except wheel-tracks)		9
6a	Field of a uniform gray to green	fallow	
b	Field not of a uniform gray to green		7
7a	Field of a uniform red to rose; striation mostly in one direction only	flax	
b	Field mixed red to rose and gray to green		8
8a	Fine regular striation visible in one direction or in two perpendicular directions; fields gray/green, sometimes with red haze or covered with slight, sometimes woollij red or rose spots	onions	
b	Irregular striation in two perpendicular directions; color shades all over the field	cereals	
9a	Field of a uniform gray to green	fallow	
b	Field not of a uniform gray to green		10
10a	Structure woolly; color red to rose	flax	
b	Structure coarse and close ('carpet-like structure'), see 3b	beets	
c	Structureless; irregular spots gray/green and red; cattle often visible	meadows	

Rows: Clearly visible plant rows. Easily visible under the stereoscope, especially at the ends of the fields (for example potatoes).
Beds: More or less broad strips of crop separated by broad paths. On these paths weeds may grow (high and patchy IR reflection).
Striation: Possible in one or more directions. This striation is very fine and has nothing to do with plant rows; it is caused by a regular three-dimensional structure of the crop, sometimes enforced by wind.

Cultivars

There may be a way to distinguish different cultivars of crops form each other, but this will not be very easy, for it will than be necessary to utilize differences in color (characteristic IR reflection combined with the reflection of the visible light = characteristic spectral reflectance) on the false-color photograph. There are several objections to this. As pointed out before, the colors of the different photographs can differ by many causes. Even photographs of one and the same run are not comparable. Color differences between cultivars are mainly differences in red and magenta (the human eye is not very reliable in this part of the spectrum), but these small differences are often also differences normally present between the photographs of one and the same run. Cultivar identification will be easier, when at the moment of photographing the crop is flowering (flax) or ripening (cereals), or when obvious differences occur in leaf shape or plant structure.

Identification table (Table 1)

With the help of the false-color photographs made in 1968, 1969 and 1970, and concurrent collection of local data, an identification table has been produced. This table relates to the situation in the Netherlands, particularly in the Lake Ysselpolders, in the months of June and July. As stated before, the structure of the crop and its way of cultivation are more important in the identification procedure then differences in color. The procedure will certainly differ between areas and between countries, so that the validity of the identification is to be restricted always to a specified geographic area as well as to a specified historical period.

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