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Vegetable Crop Management with Remote Sensing

Repetitive aerial color infrared photography reveals important information concerning large potato and tomato crops.

Abstract: *Repetitive aerial photography with color infrared (ACIR) and black-and-white infrared (B&WIR) films was taken of potato and tomato fields in southwest Florida during the spring season of 1975. Color differences observed in the photographs revealed different levels of soil moisture in the fields, improper ditch arrangements, poor stands of plants, and areas where late blight (*Phytophthora infestans*) (Mont.)d.By and early blight (*Alternaria solani*) (Ell. & Mart.) Jones & Grout. were defoliating potato plants. Photographs of fields before planting also indicated areas where excessive rock formations existed which would make field preparation costly. Preplanting photographs also pinpointed areas with different water table levels.*

Introduction

Vegetable production is a major segment of the agricultural output of Lee, Hendry, and Collier counties of southwest Florida with a value of over 80 million dollars. Increased labor, fertilizer, and pesticide costs, plus increased environmental concern, have forced growers to search for improved methods of disease detection and evaluation over large cultivated land areas.

In the fast-growing field of remote sensing—acquiring information through the use of cameras and related devices such as radar and thermal infrared sensors operated from aircraft and spacecraft—several useful developments have taken place. Most of them are designed to give better and more timely resource information and, hence, lead to better resource management.

Remote sensing has been widely used in different fields ranging from archaeology to tax mapping. The detection of plant stress caused by nutrient deficiencies (Gausman, 1975), diseases (Blazquez, 1972; Colwell, 1960; Manzer and Cooper, 1967; Norman and Fritz, 1965; Watson and Hoyle, 1975), and water availability has been reported. Soil characteristics (Piech and Walker, 1975), moisture (Colwell, 1960), and rock outcrops (Myers, 1975) also have been detected.

The reluctance to utilize remote sensing in vegetable production may be because of a lack of communication between individuals experienced in remote sensing and those involved in production management. Apparently, the most useful technique tested in applying remote sensing to agriculture is aerial color infrared (ACIR) photography (Colwell, 1960) which detects differences which often cannot be detected visually, particularly incipient disease and nutrient deficiency symptoms (Blazquez, 1972; Colwell, 1960; Manzer and Cooper, 1967; Norman and Fritz, 1965; Watson and Hoyle, 1975). ACIR photographs are most valuable in monitoring a large crop area which is virtually impossible to inspect from the ground. The ease and efficiency of coverage is good and prob-

Florida Agricultural Experiment Stations Journal Series No. 859

Photogrammetric Engineering and Remote Sensing,
Vol. 47, No. 4, April 1981, pp. 543-547.

lem areas may be pinpointed for corroborative investigations on the ground. In addition, the photographs taken may be used later for comparative study and malady identification.

We report the findings of a combined aerial surveillance and ground inspection program of potato and tomato fields in southwest Florida that helped to pinpoint early stages of agricultural problems and monitor them throughout the growing season.

MATERIALS AND METHODS

Aerial photographs were made using two electric cameras: a 70-mm ELM Hasselblad and a 5-inch focal length K-24. Both were connected to an intervalometer and powered by the electrical system of a Cessna 172 aircraft. The two color films used were Eastman Kodak's Ektachrome MS Aerographic 2448 AC and Aerochrome Infrared 2443 (ACIR).* The two black-and-white films were Plus X Aerial 3401 (B&W) and Infrared Aerographic 2424 (B&WIR). Scales were 1:3000 and 1:1000, respectively. Most flights were made around 10:00 A.M. with full sunlight. The best exposure setting for ACIR was 1/300 sec. at *f*5.6 because it revealed the most ground detail and was, therefore, selected for most flights (Fritz, 1967). Haze filters were used with the Ektachrome MS AC film and a Wratten No. 12 with the ACIR 2443 film. Prints made from the B&W Plus X Aerial 3401 and the B&WIR 2424 films were combined and arranged into photomosaics. In addition, the best negatives were selected for making mylar positives which could be used with DuPont's mylar film 3774. Positives were then processed through a standard Thermofax copying machine to make blueprint type copies of either entire fields or selected problem areas.

* Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the University of Florida or the authors and does not imply its approval to the exclusion of other products that may also be suitable.

Flights were made over potatoes (*Solanum tuberosum* L.) planted in two fields with mixed Immokalee (white color) and Myakka (dark color) fine sands. A total of eight flights were made over other potato fields with similar but unmixed soil in the surrounding areas during the season. Although it was not possible to photograph all areas on every flight, it was possible to fly twice over the same mixed soil areas before planting, while planting was in progress, and after the plants were growing.

Ground observations of problem areas first detected by aerial photographs were made weekly in association with visits to weather stations involved in monitoring the weather and diseases (Blazquez, 1975).

Disease observations were estimated by the Brown, Barratt, and Horsfall method (Brown *et al.*, 1968). Three transects, one-third of an acre each, were walked through the field area where the disease conditions were first observed. One transect was walked through the center, the other two on the outer borders of the disease area. The percent disease per acre (% dis/A) was then estimated by integrating the results of the three transects.

Soil moisture determinations were made by percent dry weight from samples taken at 25 cm from irrigated areas, marginal areas with faulty irrigation, and dry areas where plants were not growing.

Areas with faulty irrigation, first detected by ACIR, were sampled three times during the experiment: (1) before planting; (2) half way through the growing season; and (3) after harvest when crop debris had been removed (Table 1). Seepage irrigation is a standard practice in southwest Florida and consists of a rim ditch surrounding the field with secondary ditches interconnecting two sides of the rim ditch (Figure 1).

Conferences were held with production managers and their field assistants to discuss the ability and accuracy of aerial photographs in pinpointing irrigation and disease problems at an early stage. Copies of photographs were given to assistants for

TABLE 1. PERCENT SOIL MOISTURE FOUND AT DRY AREAS (NO POTATO PLANTS), MARGINAL AREAS (UNTHRIFTY POTATO PLANTS), AND WET AREAS (HEALTHY POTATO PLANTS) OF FIELD 1 NORTH-SOUTH POTATO FIELD TAKEN BEFORE PLANTING, HALF-WAY DURING THE GROWING SEASON, AND AFTER THE CROP HAD BEEN HARVESTED AND BEFORE THE RAINY SEASON

	% soil moisture (mean of 4 replicates) Dates taken		
Location	5 October	15 December	2 April
Healthy area	12.2 a*	10.4 a	9.0 a
Marginal area—East	7.0 a	9.6 ab	8.0 ab
Marginal area—West	9.0 ab	6.2 b	5.6 b
Dry area	2.0 c	2.4 c	3.0 c

* Means followed by a common letter are not statistically significant at the 5% probability level according to Duncan's multiple range test.

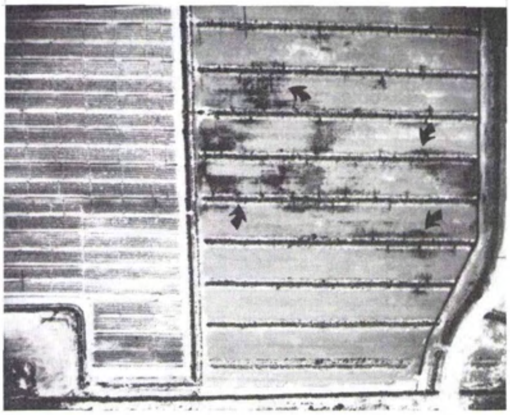
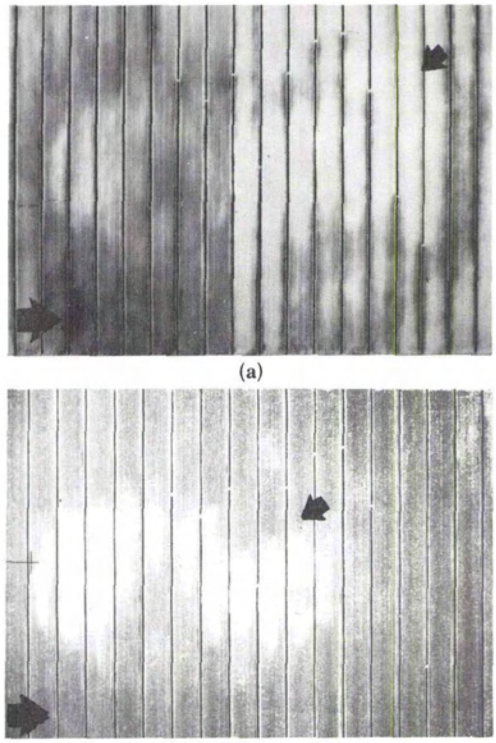


FIG. 1. Black-and-white copy of ACIR photograph showing seepage irrigation in potato fields in southwest Florida. The rim ditch surrounding the field with secondary ditches has blockages which resulted in irregular irrigation (dark areas).



(a)

(b)

FIG. 2. Black-and-white copy of ACIR photographs delineating different soil moisture patterns in Field 1. (a) Before planting photograph showing where soil moisture is high (large arrow) and light areas outlining low moisture and dry areas (small arrow). (b) After the potato plants had grown covering bare ground, the same areas could be delineated in the ACIR photograph.

better ground identification of problem areas in individual fields and for monitoring the increase or decrease of the specific problems.

RESULTS

FIELD 1. NORTH-SOUTH POTATO FIELD

Color infrared and black-and-white photographs of a potato field before planting revealed irregular patterns of dark and light soil areas not clearly distinguished from ground observations. Preliminary ground determinations indicated that the dark areas represented portions of the field where excessive water had saturated part of the soil (nearly 20 percent soil moisture) whereas very light areas delineated sections of the field which had little or no moisture (2 percent to 6 percent) (Figure 2a). The color infrared photographs consistently gave higher contrasts between the dark (12 percent to 20 percent) areas and the light (2 percent to 6 percent soil moisture) areas, greatly improving the ability of the photo interpreter to discern the areas. Whereas the differences were more readily seen in the color infrared film, black-and-white prints of the field also revealed the areas with excessive moisture. Only large differences in soil moisture were detected, and efforts to detect small differences were erratic and inconclusive (Figure 2).

Subsequent aerial photographs of the same field continued to reveal the excessively dark (12 percent to 20 percent soil moisture) soil areas clearly. Ektachrome ACIR film was satisfactory for detecting dry areas (2 percent soil moisture) where potato plants had not developed as well as the improper blocking of side ditches by dikes (Figure 1). Sequential photographs were more accurate in delineating the clearly dry from the wet areas. It was also possible to detect gradual changes in plant growth because the plants developed well in areas which were properly irrigated (12 percent to 20 percent soil moisture) and sparsely where the soil was not evenly moistened.

After the crop had been harvested, black-and-white photographs of the same field indicated the soil moisture patterns detected in the preplanting photography had not changed significantly and, in general, were quite similar to the irregular patterns before the field was planted in the previous season.

No diseases were detected in this field during the entire surveillance.

FIELD 2. EAST-WEST POTATO FIELD

Surveillance of this field before planting was not possible due to aircraft scheduling, but post-planting repetitive surveillance was carried out. Aerial photographs with ACIR and BWIR showed similar soil moisture patterns as the north-south field.

Late blight (*P. infestans* (Mont) d. By) was detected by photographs at an early stage (5% dis/A) in this field (Figure 3) and its spread was monitored in subsequent photographs. Ground observations confirmed the disease location and subsequent spread. The disease was more consistently observed on the wetter areas of the field at the 25 percent to 35 percent level of disease/A. Sequential ACIR photography showed that Maneb (1½ lb/A) fungicide applications halted the spread of the disease to other areas in the field.

Soil moisture problems were detected as large dry areas (3 to 5 percent soil moisture) in the repetitive ACIR surveillance.

Greater losses of potato acreage were detected between the combination of very dry areas (2 percent soil moisture) and areas defoliated by late blight (25 percent level of disease/A) (Figure 3) than by any other feature. In dry areas (+ diseased), nearly 90 percent of the crop was lost.

FIELD 3. TOMATO FIELD

Aerial photographic surveillance of a 1,500-acre field was made with ACIR, the B&WIR, and Plus X B&W Aerial 3401 films to determine the best available combination to use in following the progress of growing tomatoes (*Lycopersicon esculentum* Mill.).

ACIR photographs of a pasture covering the area to be planted later to tomatoes revealed irregular soil moisture patterns as well as an area currently planted with staked tomatoes. In the south central part of field B, the ditches had overflowed while they had not in the northern area of the field. Water was standing in the lowest areas of field 3A.

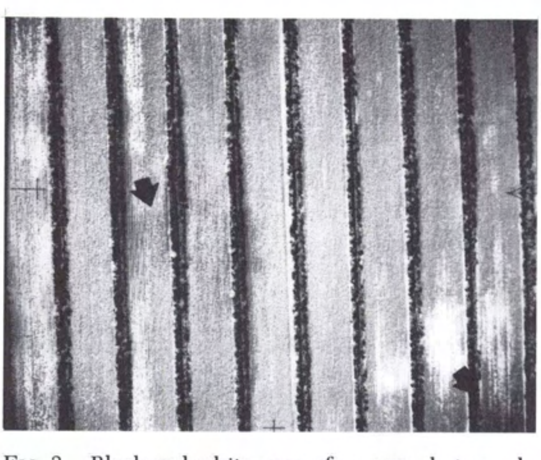


FIG. 3. Black-and-white copy of an ACIR photograph of potato field No. 2 outlining dry (white) and wet (dark) areas where plants developed poorly. A late blight (phytophthora infestans (Mont.) d. By.) diseased group of plants developed in a wet area (black area).

There was a difference in moisture patterns in the ACIR photographs; however, it was not possible to relate the calculated percent of soil moisture from samples taken to moisture patterns in either the pasture areas or the tomato areas in the ACIR photography. Changes in pasture growth were likewise treated, and ground measurements were made because the purpose of the research was to pinpoint problematic areas rather than to determine the cause of the problem. In the more moist areas, pasture grasses appeared quite lush and healthy, while in the dry areas, the grass was desiccated. Three patterns were discernible in the ACIR photographs. The first was a wet area in the south central and western ends of the field where the pattern was irregular but appeared to flow to the southwest and delineated dry pasture areas. The second was a distinct discoloration found mostly in areas used for pasture purposes. The third was found to represent rock outcroppings below the soil surface. These formations were detected in the eastern end of the field. A number of side ditches were observed in the adjacent area with heavy rock formations. The rock outcroppings were visible in ACIR and indicated to the field manager. They were not as clearly visible from oblique photographs or ground observations, although their depths varied from 0.1 to 0.9 m.

Enlarged prints were made of the most promising areas for tomato growing, and copies were distributed to the field supervisors for verification of the photo-interpretation.

Ground observations corroborated the location of rock outcroppings in one of the prospective tomato fields. They appeared as lighter colored irregular patches and small circular spots in the grassy areas surrounding them. While it was possible to locate and quantify the outcroppings, it was not possible to determine the depth with any degree of accuracy because the outcroppings ranged from 0.1 to 0.9 m with a mean of 0.44 m.

DISCUSSION

Remote sensing, and particularly aerial photography, has been used for 30 years for agricultural programs in the United States. However, only a small part of the information obtained has been used, and it was not fully understood that agricultural aerial photography very rapidly becomes outdated. Plant growth changes due to plant stress (insects, disease, nutrition), irrigation, and pollution are frequent and play important roles in plant development. Repetitive aerial photography must be made due to the frequency of these changes.

The results obtained in the north-south field indicated that light areas in the ACIR photographs were areas of the field that were dry (2 percent to 3 percent soil moisture) before planting and remained dry throughout the growing season. The areas in the ACIR photography which appeared dark before the planting were wet (above 50 percent soil moisture). The potato crop did not show any stress due to excessive water in those areas and grew well.

These results indicate aerial photography with ACIR film has the capability of detecting changes from 5 percent to 50 percent in soil moisture. Detection of late blight in the east-west potato field followed a pattern previously determined and again showed that the disease was easily detected with ACIR (Blazquez, 1972).

The capability of ACIR to detect rock outcroppings has been reported previously (Colwell, 1960; Myers, 1975). ACIR photographs of the prospective tomato field located rock outcroppings in the western part of the field so that ground verification could be used to determine their depth and estimate the cost of removal. ACIR photography located and quantified the problem areas, but additional investigation will be required to determine if the cost of removal of outcroppings can be determined with ACIR.

The aerial photographic experiments carried out in the three fields showed that repetitive aerial photographic surveillance with color and black-and-white infrared films were instrumental in pinpointing specific problems. It has shown it may be a valuable tool in vegetable crop management.

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(Received 12 November 1977; revised and accepted 19 September 1980)