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EVALUATION OF REMOTE SENSING

IN CONTROL OF PINK BOLLWORM IN COTTON

(IMPERIAL, COACHELLA, PALO VERDE VALLEYS, CALIFORNIA)

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16. Abstract The main objective of this investigation is to evaluate the use of a satellite in monitoring the cotton production regulation program of the State of California as an aid in controlling pink bollworm infestation in the southern deserts of California. Color combined images of ERTS-1 multispectral images simulating color infrared are being used for crop identification. The status of each field (i.e., crop, bare, harvested, wet, plowed) is mapped from the imagery and is then compared to ground survey information taken at the time of ERTS-1 overflights. A computer analysis has been performed to compare field and satellite data to a crop calendar. Correlation to date has been 97% for field condition. Actual crop identification varies; cotton identification is only 63% due to lack of full season coverage.

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EVALUATION OF REMOTE SENSING IN CONTROL
OF PINK BOLLWORM IN COTTON

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Type III Final Report for Period July, 1972 - October, 1973

II

ACKNOWLEDGMENT

PREFACE

The objective of our study was to evaluate ERTS-1 imagery for the
identification and mapping of cotton fields in the southern deserts of
California. If successful in terms of accuracy, cost, and timeliness, a
new tool would be available to the State of California in its effort to
control pink bollworm infestation of cotton. Our investigation proved to
be less costly; accuracy was less than field mapping, but due to the facts
that a full cotton season was not available and time was needed for the
development and implementation of the computer system, timeliness was poor.
Data was received 45 to 60 days after a given satellite pass; a maximum of
two weeks delay is necessary if the program is to be successfully utilized.
Recommendations include increased resolution of ERTS-1 imagery, a longer
study period (at least one full cotton season), and imagery receipt no later
than two weeks after a satellite overpass.

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INTRODUCTION

The identification of crops from high altitude or space photography has been long considered important for such purposes as land use mapping, crop yield prediction, disease identification, control, and eradication, and crop inventory. The main objective of this investigation is to evaluate the use of satellite imagery in monitoring the cotton production regulation program of the State of California as an aid in controlling pink bollworm infestation in the southern deserts. It should be stressed that this is only the initial and most obvious objective. If the proposed investigation is successful, the potential of such a satellite monitoring program for agriculture is unlimited.

The three main agricultural areas in the southern deserts of California, the Imperial, Coachella and Palo Verde Valleys, are heavily infested with pink bollworm which affects both the quantity and quality of cotton produced. Therefore, the State of California has established regulations in an attempt to control the expansion in numbers and areal extent of the pink bollworm. The regulation (1) (Appendix I) states that all acreage to be planted to cotton must adhere to the following rules. Cotton may not be planted in the Coachella and Palo Verde Valleys until February 28, and February 15 in the Imperial Valley. By December 15, all cotton fields must be picked, all remaining plant material must be thoroughly shredded and subsequently plowed underground. Those fields must then be left fallow until the following February unless another crop besides cotton is to be planted in those fields. The "plowdown" procedure is to ensure that any pink bollworm in the larval or diapause state will have no cotton plant material on which to feed during the winter months.

The most immediate potential exists in the cooperative regulation of cotton production between California, Arizona, and Mexico. Substantial areas of cotton exist in the Arizona area bordering the southern California deserts and in the areas of Mexico bordering the southern California deserts. Both of these areas represent substantial sources of pink bollworm infection for California. Therefore, if the management system imposed upon cotton producers by the California Department of Agriculture is not successful, it will be imperative to determine whether the lack of success is due to the failure of growers in California to comply with the regulations or the fact that insects are entering the diapause in readily available sources of plant material in Mexico and Arizona and then spreading into the southern California area.

Another application of this research could be the extension of such a management system employing satellite monitoring to other crops in California and the rest of the United States. The use of chemical pesticides for the control of insects is coming under increasing criticism, and it is recognized by scientists the world over that other means of control must be utilized whenever possible. One means of control is that of pest management, i.e., the kind of improved management that we are attempting to develop in the cotton fields of the southern California deserts. There are many other instances of crop production in the United States, indeed the world, where insect control could be improved by removing a crop before an insect pest enters the diapause stage. Whenever such programs involve substantial acreages, the assurance that growers are cooperating in observing a regulatory schedule is imperative. The use of satellite sensing devices to provide such grower assurance could easily prove to be the simplest means of monitoring available.

Furthermore, the investigation might also play a significant role in averting a far greater disaster than the current pink bollworm threat to cotton crops in southern California. Although the California desert areas produce 80,000 acres of cotton annually, the State of California in its entirety produces over 900,000 acres of cotton, the bulk of which is concentrated in the San Joaquin Valley. It is a major effort of the Federal government, the California Department of Agriculture, and the University of California to ensure that pink bollworm does not spread into this area of cotton production. Although such a disaster has not occurred, pink bollworms have been found in the San Joaquin Valley and it may become necessary to implement the regulations that have been prepared but not yet practiced. It would become necessary to monitor the defoliation, plowdown and replanting dates for 900,000 acres of cotton rather than 80,000 acres. Obviously, it would be almost impossible to carry out such a massive management program without the development of some remote sensing system.

PROJECT HISTORY

Cotton is regulated by law in California in an attempt to control pink
bollworm. The insect is a serious pest in the southern deserts of California
because it affects both the quantity and quality of cotton produced. At
present, there are no effective chemical means of controlling the pink bollworm,
therefore regulations were established to provide a biological control. In
order to do this, it is necessary to break the insects' life cycle. The pink
bollworm is in the resting or diapause stage during the winter months; however
is still needs plant material for food. The regulations, therefore, for the
1972 growing season required that all cotton in the three valleys was to be
harvested, all remaining material plowed under, and all gin trash disposed of
by December 15. Cotton could not be planted until February 15 in the Imperial
Valley and February 28 in the Coachella and Palo Verde Valleys.

Approximately 900,000 acres of cotton are grown annually in California.
All cotton in the southern deserts is monitored by ground survey teams which
is an expensive and time consuming process. Although the San Joaquin Valley
produces almost 90% of the cotton in California, it has not yet been seriously
affected by the pink bollworm. However, the insect has been found in this
area and it is imperative that a more efficient and economical means of
monitoring cotton be provided.

As pointed out by Johnson (1969) (2), the only viable means for identifying
crops, given present technology, would be sequential photography. The Earth
Resources Technology Satellite (ERTS) launched in July, 1972 provided
photography for a given area every 18 days. A multispectral scanner (MSS)
operating in four spectral bands (.5 – .6 µm, .6 – .7 µm, .7 – .8 µm, .8 –
1.1 µm; green, red, and two infrared bands, bands 4, 5, 6, 7, respectively)
was used to obtain the imaginery.

The study sites for our project are the southern deserts of California. Our purpose was to determine whether or not cotton in the Imperial, Coachella, and Palo Verde Valleys could be identified (Fig. 1, 2). Because cotton is regulated by law in California in an attempt to control pink bollworm, and because these areas are essentially cloud-free throughout the year, it was felt these areas would provide a good test for crop identification using sequential photography.

Two basic methods were used to identify cotton fields. In the Imperial Valley, the imagery, which was combined to simulate color infrared (CIR), was mapped every 36 days and each field was classified as bare, wet, plowed, harvested, or cropped. At the time of the ERTS overflight, a field survey was conducted. The information obtained from the imagery in addition to field size, time of year, and the crop calendar for the Imperial Valley (3) (Appendix IV) were then fed to a computer which determined what crops would most likely be in a given field at a particular time. The data were then checked against the field survey for accuracy. After one year of study, it was found that the accuracy for field condition identification of a given field on a given date is 92%. After four consecutive dates, the accuracy rises to 97% for field condition identification. Computer identification accuracy for specific crops varied, e.g. sugar beets, 82%, cotton, 63%.

In the Coachella and Palo Verde Valleys, all fields which were bare in March were mapped. Cotton is not planted in these areas until February 28 and would not begin to appear on the imagery until May or June. The imagery was mapped again in May to determine which fields showed a crop. A field survey of the two valleys was conducted in August to determine the accuracy of the crop mapping. The results were poor; approximately 50% of the fields mapped from the imagery were correctly identified. The same method was used in the Imperial Valley as a check. The accuracy was only 33%.

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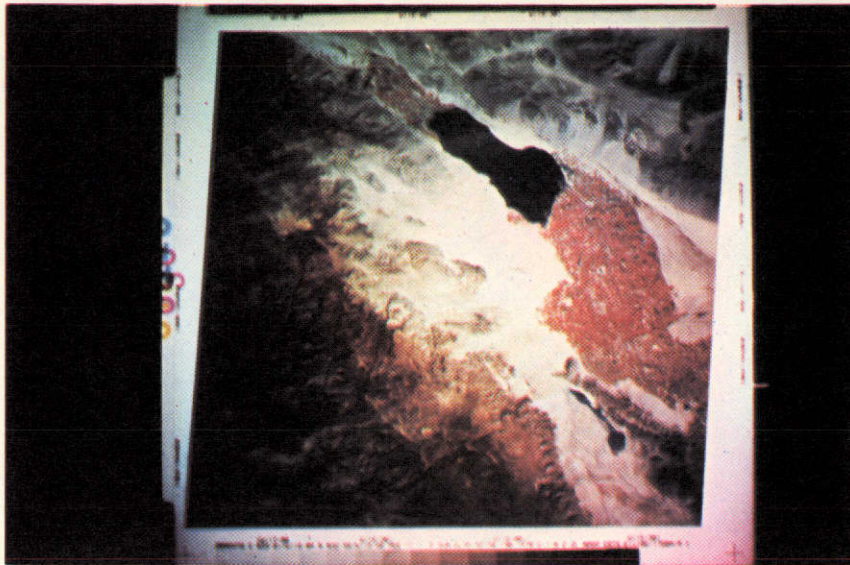
Figure 1. Imperial and Coachella Valleys (ERTS-1 CIR photograph). The Coachella Valley is located north of the Salton Sea (large black area) and the Imperial Valley to the south.
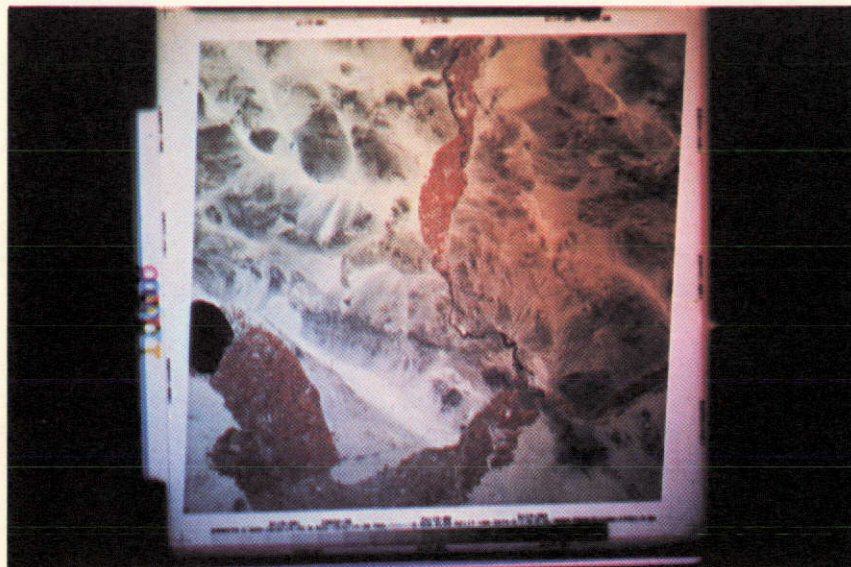
Figure 2. The Palo Verde Valley (ERTS-1 CIR photograph) is located in the upper center. The Imperial Valley is seen on the left.

The poor results obtained from the bare field method and the variability

of specific crop identification were due in large part, we feel, to the poor

resolution of the ERTS-1 imagery and because two incomplete seasons, July

to December, 1972, and March to May, 1973, are hardly adequate to determine

the usefulness of the system. At the minimum, one full year covering the

entire cotton season is needed in order to obtain meaningful results. Three

years would be preferable in order to minimize factors affecting identification

such as weather, crop conditions, and operator inexperience. We feel strongly

that our computer system and sequential photography are capable of identifying

crops with great accuracy, but only if they are supported with better camera

systems and a minimum study period of one to three full years of the entire

cotton season.

PROJECT SYSTEMS AND RESULTS

Base maps.

The first requirement for our study was a set of base maps for each of

the three valleys to be studied. A base map of the Imperial Valley had already

been prepared by Claude Johnson, Department of Earth Sciences, Geography,

University of California, Riverside. The scale of the map is 1:63,360. Base

maps for the Coachella and Palo Verde Valleys were obtained from the Agri-

cultural Commissioner's office in each valley. The respective scales are

1:36,115 and 1:31,680. All base maps were transferred onto opaque acetate

for mapping purposes. It should be noted here that a base map prepared from

a USGS topographic map can be overlaid directly onto a ERTS-1 image with

little distortion (Fig. 3).

Underflight imagery.

The U-2 underflight imagery because of its high resolution, was used

to update field lines on all maps. It was also extremely useful as a check

on information mapped from the ERTS-1 images. Although the color balance

on the U-2 photography varied, it nonetheless proved very useful in detecting

the various stages of cotton plowdown (Fig. 4) which were not visible on

the ERTS-1 images. The U-2 imagery was not studied intensively as to its

full value for our study. We believe that results for both the "bare field"

and crop calendar method would have been better had we utilized it, primarily

because of the high resolution.

Color images.

In order to obtain information for our project, it was important to

have color images. The first method used was the Diazochrome process in which

bands 4, 5, and 7 from the multispectral scanner (MSS) were copied to yellow,

magenta, and cyan respectively, then superimposed to simulate CIR. This is

an adequate "first look" procedure, but the colors vary considerably from one

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Figure 3. Planimetric base map drawn from a USGS Topographic Sheet superimposed on an ERTS-1 CIR photograph.
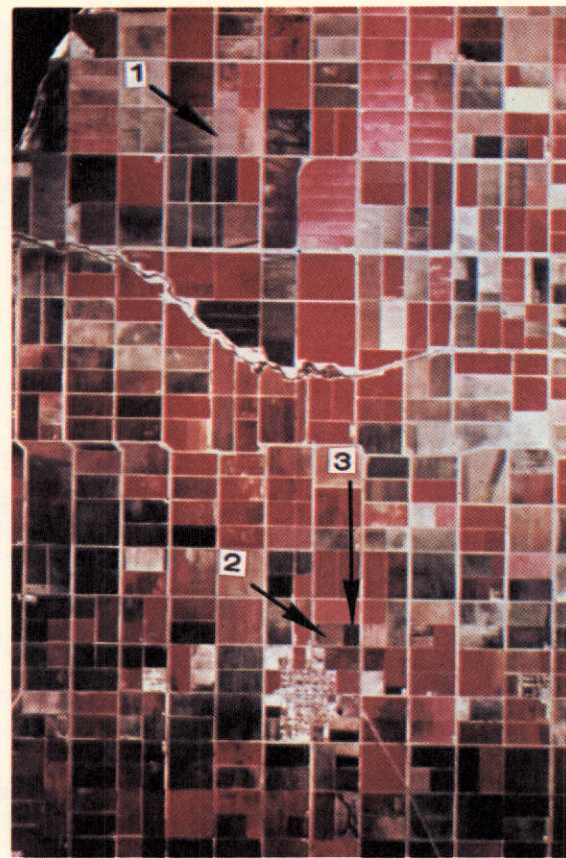
Figure 4. Stages of cotton plowdown shown on U-2 CIR photograph. (1) A defoliated an/or picked cotton field. (2) Field with shredded cotton material. (3) Field being plowed down.

pass to another and do change over time.

The Department of Earth Sciences, Geography, University of California, Riverside, received an International Imaging Systems (I^2S) optical color combiner in January, 1973. Through their cooperation, we were able to obtain high quality, CIR photographs. The photographs are 35mm slides of the images projected onto the viewing screen of the color combiner.

Information mapping.

In order to map information, the slides are projected onto a clear plate glass "window" on which had been placed on opaque acetate base map of the area. By using this method, the operator can then map the information directly from the back of the window and not interfere with the projected image (Fig. 5). Since the projector and "window" are both movable, this allows the image to be projected at any scale needed for mapping.
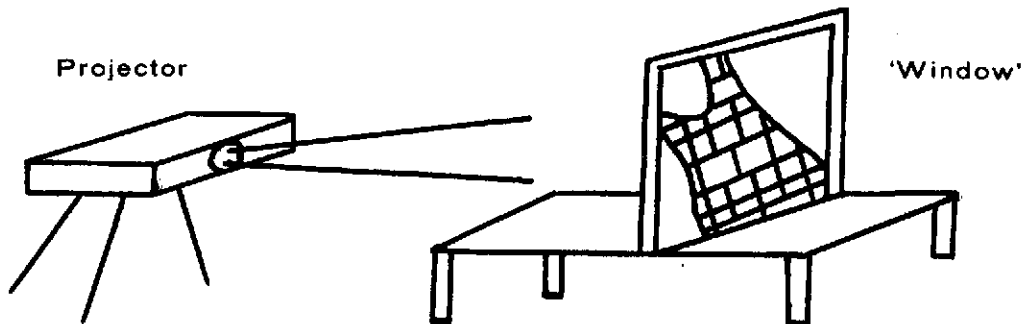
Figure 5. Apparatus used for mapping from ERTS-1 imagery.

Two methods were used to identify cotton fields in the Imperial, Coachella, and Palo Verde Valleys. The "bare field" method was used in all three valleys and the detailed crop calendar method accounting for all crops was used in Imperial Valley.

"Bare field" method.

The "bare field" method is based on the theory that no cotton remains in any field after December 15 and cannot be planted until February 15 in the

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Imperial Valley and February 28 in the Coachella and Palo Verde Valleys. Therefore, all bare fields evident in January and February photography could potentially be cotton fields and would be mapped as such. Irrigation would begin in late February and early March and cotton would begin to appear on the imagery in April. Although such crops as sorghum, sudan grass, tomatoes, corn, and onions are planted about the same time as cotton, these crops would mature more rapidly and be harvested long before cotton, thereby eliminating these fields.

Unfortunately, the winter of 1972-73 was an extremely wet one and not all cotton was plowed under by December 15. Also, fields which would normally have shown bare in January and February often looked irrigated and heavy weed growth made fields look cropped when they actually were not. The rains also delayed the planting of cotton, so some fields did not show a crop until midsummer and were not mapped as cotton.

Rather than using January and February photography, it was decided that the March imagery would be mapped for bare fields. These were then checked against May photography in order to determine which fields had begun to show a crop. Since there was no photography after May 23, all bare fields which had become cropped were assumed to be cotton since there was no way to eliminate the other crops previously mentioned. A field survey of all three valleys was conducted in August to check the accuracy of the maps made from ERTS-1 imagery.

The results were as follows. In the Coachella Valley, no fields which were predicted to be cotton were cotton. The Imperial Valley was better with a 33% accuracy. Fifty percent accuracy was achieved in the Palo Verde Valley. The results are poor and hardly meaningful because there was no imagery after May 23 and a full cotton season was not available for study.

Crop calendar method.

The Imperial Valley was studied in cooperation with the Department
of Earth Sciences, Geography, University of California, Riverside. The
method used was based on the crop calendar for all crops grown in the
valley. The ERTS-1 imagery was mapped every 36 days (alternate passes of
the satellite) and field surveys were conducted in the valley at 36 day
intervals to coincide with the ERTS-1 passes. Mapping consisted of classify-
ing each field according to its conditions, i.e., bare, wet, plowed,
harvested, or cropped. Using the color combined CIR photographs, the
respective colors for each of the above conditions were white, blue or
dark lavendar, gray brown or light lavendar, yellow, and red. Differenti-
ation between wet and plowed was often a problem and heavy weed growth
due to the rains also caused problems in classifying cropped fields.

The information obtained from the photography in addition to field
size, time of year, and the crop calendar for the valley, were then given
to a computer which determined statistically which crop(s) was (were) most
likely to be in a given field at a particular time. This information was
then checked against the field survey data for accuracy. The correlation
for field condition over four 36 day cycles has been 97%; crop identification
accuracy varies from 82% for sugar beets to 63% for cotton. The low accuracy
for cotton is due to the fact that a full cotton season could not be
studied and the result should not be considered meaningful.

See Appendix III for a detailed explanation of the computer system
designed for crop identification.

COST ESTIMATE

From the table, it is obvious that both time and cost for the ERTS-1 investigation was less than the field surveys conducted by the agricultural commissioners in terms of actual time spent for field and photographic mapping. Approximately $40.00 was spent on computer time to obtain field condition and crop identification for the four dates used. Even if a full year's coverage were used, the money spent for computer time would not significantly affect the cost savings provided using the ERTS-1 system.

Table I. Cost estimates of ERTS-1 investigation and agricultural commissioners field surveys.

	Man hours		Cost	
	ERTS-1	Ag. Comm.	ERTS-1	Ag. Comm.
Imperial	161	320	$ 846.00	$1,800.00
Coachella	15	120	90.00	600.00
Palo Verde	15	N.D.*	90.00	N.D.*
	191 hours	440 hours	$1,026.00	$2,400.00

* N.D. – no data

SIGNIFICANT RESULTS

The results obtained from the "bare field" method are obviously poor:
0% accuracy for the Coachella Valley, 33% and 50% respectively for the Imperial
and Palo Verde Valleys. There are, however, some mitigating circumstances.
Foremost is the fact that neither the 1972 or 1973 photography provided an
entire cotton season to study. Cotton fields on the 1972 imagery were located
using information obtained from the various agricultural commissioners. There
was no accurate way of identifying cotton fields on the 1973 imagery because
a full cotton season was not available to study and there was no way to
eliminate those crops which appear at the same time as cotton but are harvested
earlier. In addition, the heavy winter rains delayed the plow down and
planting of cotton and caused problems in attempts to map irrigated and
cropped fields. Because of weather conditions such as this, it is only
logical that a study such as this should be carried out over a period of
years in order to minimize the effects of such conditions. Also, because no
imagery was received after May 23, 1973, there were no means to eliminate
other crops which were planted at the same time as cotton, but would be
harvested before cotton. Again this shows the necessity for a longer study
period, or at least a minimum of one full cotton season.

The computer results were extremely good: 97% accuracy in identification
of field condition after four consecutive dates. Actual crop identification
varied from 82% accuracy for sugar beets to 63% for cotton. Only four
consecutive 36 day cycles, August 26, October 1, November 6, and December 12,
1972, were used. This was due in part to the time needed to develop and
implement the computer identification program and because it was felt that
this half of the cotton season, which included the plow down, would give the
most accurate results. It should be noted, however, that if a full cotton

season had been available for analysis, the accuracy for crop identification would no doubt be greater.

The cost estimate has shown that there is a definite advantage to using ERTS-1 information. Lower cost, less time, and equivalent accuracy to field mapping are significant factors in "selling" this type of system to a user. We have achieved lower cost and less time. We believe we can achieve equivalent accuracy. The most significant factor, however, is timeliness. The delay of 45 to 60 days in receiving imagery makes this program of virtually no practical use. For agricultural management, particularly pest management, two weeks is the absolute maximum delay which will provide useful data and results.

By color combining bands 4, 5, and 7 of the MSS to simulate color infrared, we obtained the best color contrasts were for field condition identification which are vital for actual crop identification. Also necessary are field size, time of year, and a crop calendar for the study area.

CONCLUSION

Pink bollworm infestation in the southern deserts of California is of serious proportions. The costs of surveying cotton fields are such that the agricultural commissioner of the Imperial Valley has eliminated the survey for the valley. The sequential coverage provided by ERTS-1 is shown to be useful in our study to identify and map cotton fields. Although the accuracy for cotton field identification is only 63%, we feel that with at least a full cotton season available for analysis we can achieve equivalent accuracy to field mapping. We have achieved the ability to identify and map cotton fields in less time and with less cost.

The planimetry of the ERTS-1 imagery is such that a base map prepared from USGS topographic map can be superimposed on the image with almost perfect accuracy. As such, a base map can be drawn directly from ERTS-1 imagery eliminating the need for tedious cartographic work. High flight imagery such as the U-2, if available, can be used for updating field lines which do change and which are not always seen on ERTS-1 imagery. Greater resolution of the ERTS-1 imagery would eliminate the need for high flight photography.

We have found that color combining bands 4, 5, and 7 from the MSS to simulate color infrared provide the best color contrasts for field condition identification which is vital to actual crop identification. In addition, field size, time of year, and a crop calendar of the area to be studied must be available for crop identification.

There are three recommendations which we feel will not only improve our results, but will make crop inventory and management a practical application. First, the camera system must be improved, especially with regard to resolution. Second, a longer study period is needed to minimize such factors as weather, crop conditions, and operator inexperience. At least one full cotton season

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is vital to the success of the study. Third, but most important, imagery must be received by the user no more than two weeks after the pass is made. All three recommendations are necessary if the project is to succeed, but only timeliness will prove its worth.

APPENDIX I

Cotton Regulations

CALIFORNIA DEPARTMENT OF AGRICULTURE

1220 N Street
Sacramento
95814

NOTICE OF PROPOSED CHANGES IN THE REGULATIONS
OF THE CALIFORNIA DEPARTMENT OF AGRICULTURE
Pertaining to Pink Bollworm Host-Free District
and Host-Free Period

Notice is hereby given that the California Department of Agriculture, pursuant to the authority vested by sections 407, 5322 and 5781 of the Agricultural Code of California, and to implement, interpret, and make specific sections 5322 and 5781-5784 of the Agricultural Code, proposes to amend regulations in Title 3 of the California Administrative Code as follows:

Amends section 3595 to establish six host-free districts instead of five, and in most host-free districts changes the dates for the host-free periods. Terminology and other changes are also proposed to clarify and strengthen this regulation and its provisions.

A complete copy of the proposed regulation may be obtained on request from Special Services, Division of Plant Industry, California Department of Agriculture, 1220 N Street, Sacramento, California 95814.

Notice is also given that any person interested may present statements or arguments in writing relevant to the action proposed to the California Department of Agriculture at or before 4:30 o'clock p.m. on the 30th day of May, 1972. The California Department of Agriculture, on its own motion or at the instance of any interested person, may thereafter adopt the above proposals substantially as above set forth without further notice.

CALIFORNIA
DEPARTMENT OF AGRICULTURE

Dated   MAY 1 2 1972

_____
Director

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MAY 22 1972

3595. <u>Pink Bollworm Host-Free Districts and Host-Free Periods.</u>

(a) <u>Proclamation.</u> The Director of Agriculture finds that infestation of pink bollworm in cotton growing areas of California presents a threat of further spread of pink bollworm and that it is impracticable to eradicate said pest or to prevent its continuing spread unless the provisions of this regulation are required and enforced.

(b) <u>Definitions.</u> The following definitions are applicable to this section.

(1) <u>Pest.</u> Pink bollworm (<u>Pectinophora gossypiella</u>)

(2) <u>Hosts.</u> Cotton (<u>Gossypium</u>) and okra (<u>Hibiscus esculentus</u>), kenaf (<u>Hibiscus cannibinus</u>) plants and parts thereof, or any other plant which by investigation is shown to be capable of sustaining pink bollworm in any stage of development.

(c) <u>Host-Free Districts.</u> The following areas are declared pink bollworm host-free districts.

(1) <u>District 1.</u> The entire Counties of Riverside and San Diego, except the Palo Verde Valley described in District 3.

(2) <u>District 2.</u> The entire County of Imperial, except the Palo Verde Valley described in District 3.

(3) <u>District 3.</u> The Palo Verde Valley in Riverside County, including the area located east of Range 14 East and a projection of that line: and that portion of Palo Verde Valley in Imperial County lying east of the east line of Township 20 East and north of the third Standard Parallel South S.B.B.M.

(4) <u>District 4.</u> The entire Counties of Fresno, Kings, Kern, San Benito and Tulare.

(5) <u>District 5.</u> The entire Counties of Madera and Merced.

(6) <u>District 6.</u> The entire Counties of Inyo, San Bernardino and Los Angeles.

(d) <u>Host-Free Periods.</u>

(1) The host-free period for District 1 shall be that portion of each year beginning on December 15 and continuing through February 28, provided, however, planting of commercial okra may begin on February 1.

(2) The host-free period for District 2 shall be that portion of each year beginning on December 15 and continuing through February 15.

(3) The host-free period for District 3 shall be that portion of each year beginning on December 15 and continuing through March 15.

(4) The host-free period for District 4 shall be that portion of each year beginning on December 15 and continuing through March 15.

(5) The host-free period for District 5 shall be that portion of each year beginning on December 15 and continuing through March 15.

(6) The host-free period for District 6 shall be that portion of each year beginning on December 15 and continuing through March 15.

(e) Prohibitions. During the host-free period planting, growing, cultivating or maintenance in any manner of any cotton plant or plants or parts thereof in a state or condition capable of sustaining or continuing pink bollworm, in any stage, or the maintenance of unharvested fruits of okra beyond the marketable stage of maturity as fresh, edible okra, or the planting, growing, cultivating, or maintenance of any plant, including kenaf, capable of sustaining pink bollworm in any stage is prohibited within a host-free district during a host-free period.

Any and all cotton plants or parts thereof, okra fruits as defined above, or any other host plant, including kenaf, capable of sustaining the pink bollworm in any stage within any host-free district during a host-free period are a public nuisance subject to abatement pursuant to section 5782 of the Agricultural Code.

The remains of any cotton plants or parts thereof which have not been destroyed as required in subsection (f) is prohibited and constitute a public nuisance subject to abatement pursuant to section 5782 of the Agricultural Code.

(f) Control Methods. Before the beginning of the host-free period residue of cotton plants or parts thereof or other host plants or parts thereof remaining in any field within a district shall be destroyed to the satisfaction of the Agricultural Commissioner in accordance with the following method:

(1) Shredding. All such residue shall be shredded by a power driven shredding device.

(2) Tillage. Following shredding as required above, the land on which any cotton plants were growing during the preceding season shall be tilled in such a manner that all stubs are completely uprooted.

(g) Requirement for further planting. No crop shall be planted on ground where cotton or other host plants were growing during the preceding season until that ground has been brought into compliance as required by subsection (f), to the satisfaction of the Agricultural Commissioner. This prohibition applies whether or not the new crop is planted before or after the beginning of the host-free period for the district. Any crop planted in a field not in compliance is subject to abatement in order to bring the field into compliance.

APPENDIX II

Variable Crop and Field Conditions

There are several crops and field conditions that can and were confused with cotton in the Imperial, Coachella, and Palo Verde Valleys. These are listed below as well as the times they can be eliminated.

Palo Verde	Coachella	Imperial	
sorghum	sorghum	alfalfa	stubble
alfalfa	plowed fields	sudan grass	harvested fields
melons		sorghum	wet leach fields
weeds		asparagus	plowed fields
plowed fields		melons	abandoned fields
		rye	

sorghum – can be eliminated between August and October

sudan – can be eliminated between August and October

melons – fall melons, planted in summer after cotton has matured

melons – spring melons, harvested in June after most cotton has matured

rye – generally a cover crop for alfalfa

alfalfa – can be eliminated only after cotton is harvested or if it is

      known that the field is alfalfa and will remain so

asparagus – can be eliminated only after cotton is harvested

abandoned – can be eliminated at first field check

weeds – difficult to eliminate especially if rains are heavy

wet leach – some can be eliminated with first field check, but can occur

      during the whole season and may cause problems

stubble and harvested – usually are grain or grass crops; probably showed

      this year due to heavy rains (wet ground made color

      identification difficult); cotton can be planted through

      June and a recently harvested field could look like an

      emergent cotton field.

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APPENDIX III

Computer Method Discussion

MONITORING CROP CHANGES IN THE IMPERIAL VALLEY FROM ERTS-1.

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UNIVERSITY OF CALIFORNIA, RIVERSIDE

Sequential satellite imagery can provide sufficient data to determine specific field conditions with 97% accuracy. Techniques being developed at the University of California, Riverside, utilize the color infrared returns from an ERTS-1 color combined image of multispectral bands 4, 5, and 7. Combining the interpretation procedures of the imagery with a computerized program that compares the data to the actual crop calendar of the region, each field of 20 acres or more can be monitored over a minimum of four sequential 36 day cycles and subsequently identified by the computer as to the most probable crop that is growing within that field.

ERTS-1 images of 1972 of 26 August, 1 October, 6 November, and 12 December were interpreted for the experiment and results compared to approximately 10% of the total field population (biased sample) that had been ground surveyed. The results discussed in this report are based on this comparison. Although the ground survey fields were biased by accessibility to hard surfaced roads, the percentage breakdown by total number of crops by field and by acreage are almost identical to the Imperial Irrigation Report percentage breakdown of crops growing as of December 31, 1972 (4) (Appendix V). Only four sequential 36 day cycles were used due to the time needed to develop the computer program and because the four fall dates were more likely to provide better field condition information for cotton than the spring and summer dates.

Initial work with specific crop identification involved field condition data from four 36 day cycles between August 26 to December 12, 1972. From the 8,000 plus fields in the Imperial Valley, 1,164 fields were studied, and their data used to test different approaches to crop identification. The 1,164

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fields used were specifically selected because ground truth surveys were available for these fields, thus making it possible to check tentative conclusions about the crop growing in any one field, and facilitating perfection of the crop identification process. A computer card was made for each field, and each time more imagery was received, the condition of each field was coded and punched on the card.

The Imperial Valley Crop Calendar (3) (Appendix IV) was used as a guide; however, it was found that the field condition code sequences obtained from ERTS-1 imagery differed from the idealized crop calendar because of the extremely wet fall and winter in the Imperial Valley in 1972. Therefore, it was necessary to depart from the idealized crop calendar. In order to devise a system for crop identification applicable to the time period in question, we examined carefully the code sequences of the sample field, and recorded them. Then we matched each field's code sequence, ground truth, and acreage. This allowed us to note several trends in the data, and to determine which crops would fit any particular sequence. Two significant things were noted at this time: (1) for any one sequence, crops varied if the field in question was over 80 acres or 80 acres or less, because field crops are more common in fields of over 80 acres, and (2) some crops could not be positively identified from only four periods because of similar code sequences and acreage sizes as other crops.

Steps were taken to incorporate the above two findings into a computer program designed to automatically identify crops from the input data. The first step was to divide fields with a certain sequence into fields with over 80 acres and fields with 80 acres or less. The second step was to establish "weights" relating to the proability of a particular crop growing under any code sequence. The weights were obtained by computing percentages of different crops in each code sequence. For example, a very common code is 1 1 1 1,

indicating that the crop in that field was identified on ERTS-1 imagery as growing during each of the four periods considered. We determined that for fields of over 80 acres for that code sequence the weighted values are:

Alfalfa 92   Sugar Beets 3   Cotton 3   Barley 2

Using only four cycles, uncertainty of identification for some sequences results, for example if the sequence is 1 1 1 2, with 80 acres or less, the identification and weights are:

Alfalfa 40   Cotton 38   Sorghum 13   Sudan Grass 6   Lettuce 3

In this case, the addition of more code sequences would permit definite identification of the crop.

In the process of reviewing the fields and determining the weights, it became apparent that some codes fit no known crops. We designed the computer program to note all the fields with code sequences other than those of known crops. The irregular code sequences can then be checked to determine if human error in initial interpretation of the imagery occurred, and if so, the error can be corrected, and the code identified. Another possibility with an irregular crop code is that a new crop is being grown, such as was the case with Alicia grass. In a few cases, data was not obtainable from the imagery for certain fields. The crops in these fields, obviously, could not be identified.

With the system outlined above, using only four periods, accuracy of specific crop identification varies. It is not usually possible to state for certain that one particular crop is growing in a field because several crops may have the same code sequence, and four time periods are enough for only preliminary identification of the crop growing in any one field. Our findings suggest that overall, an 81% accuracy can be expected if one accepts the two highest weights of any code sequence. With more sequential imagery interpretation, positive identification of a crop can be anticipated.

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The system being developed shows great promise of achieving the objective of more than 90% accuracy of crop inventory for a given agricultural region. The experiment utilized only four 36 day cycles. Many more fields could have been identified if the cycles were extended to at least 6 time frames. More importantly, the system operating throughout the entire year would have the advantage of knowing the previous crop. In the Imperial Valley the previous crop is a great aid to identification and inventory procedures because there are restraints on crop rotation. Sugar beets for example must be planted before cotton has been picked. Therefore, sugar beets cannot follow a cotton crop. Watermelons cannot be planted in the same field for a five-year period. Factors such as the above can be very useful in developing an automated crop inventory system. Future investigations should consider performing the task on a year around basis.

APPENDIX IV

Imperial Valley Crop Calendar

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Field Crops	Planting date	Harvest date
Alfalfa	Oct. 1–Nov. 15	All year
Barley–pasture	Sep. 20–Oct. 15	Dec. 15–Feb. 15
Barley–grain	Dec. 1–Jan. 30	Apr. 15–June 1
Sugar beets	Sep. 1–Sep. 30	Apr. 15–July 1
Field corn	Feb. 15–Mar. 15	July 1–Aug. 1
Cotton	Mar. 15–Apr. 1	Nov. 15–Dec. 15
Flax	Dec. 1–Dec. 15	May 15–June 1
Bermuda grass	Sep. 1–Oct. 15	Apr. 15–Oct. 15
	Mar. 15–Apr. 15	Apr. 15–Oct. 15
Ryegrass–annual	Sep. 1–Oct. 1	Jan. 1–June 1
Oats	Dec. 1–Dec. 15	Apr. 15–June 1
Sesbania	May 15–Aug. 1	July 15–Oct. 15
Grain sorghum	Mar. 1–July 15	June 15–Dec. 15
Forage sorghum	Mar. 1–July 15	June 15–Dec. 15
Wheat	Dec. 15–Jan. 1	May 1–June 1
Safflower	Dec. 1–Jan. 30	June 1–July 1

Vegetable Crops	Planting date	Harvest date
Asparagus	March	Feb. 1–Apr. 15
Broccoli	Sep. 1–Oct. 15	Feb. 1–Apr. 1
Cabbage	Sep. 1–Oct. 15	Jan. 1–Apr. 1
Cantaloupe–fall	Aug. 1	Oct. 15–frost
Cantaloupe–spring	Dec.–Mar. 1	May 10–June 15
Carrots	Sept. 1–Dec. 15	Nov. 15–June 1
Cauliflower	Sep. 7–Oct. 15	Jan. 1–Apr. 1
Corn, sweet	Jan. 15–Feb. 15	May 1–June 1
Cucumber–fall	Aug. 1	Oct. 15–frost
Cucumber–spring	Dec. 1–Feb. 15	Apr. 1–June 1
Garlic	Sept. 15–Oct. 1	May 1–July 1
Lettuce	Sept. 1–Dec. 1	Nov. 30–Apr. 1
Melons–other	Same as cantaloupe	
Pumpkins, squash	Aug. 1–30	Oct. 15–Dec.
	Dec. 1–30	Mar. 20–May 30
Tomatoes	Dec. 1–Jan. 15	Apr. 1–July 15
Watermelons	Jan.–Feb.	May 5–June 15

APPENDIX V

Imperial Valley Crop Report

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IMPERIAL IRRIGATION DISTRICT

ANNUAL INVENTORY OF AREAS RECEIVING WATER

YEARS 1972, 1971, 1970

Note: This survey and annual inventory revises and supersedes previous reports.

I CROP SURVEY

GARDEN CROPS	A C R E S			FIELD CROPS	A C R E S		
	1972	1971	1970		1972	1971	1970
Blackeyed Peas	-	154	-	Alfalfa	178 625	180 708	175 293
Broccoli	434	507	712	Alfalfa (Seed)	212	1 899	2 170
Broccoli (Seed)	16	-	-	Alicia Grass	1 466	80·	-
Cabbage	466	990	664	Barley	48 393	61 815	57 385
Carrots	4 821	4 044	4 690	Bermuda Grass	2 201	2 360	1 318
Carrots (Seed)	3	25	-	Bermuda Grass (Seed)	-	-	55
Cauliflower	46	40	10	Clover	-	-	50
Cauliflower (Seed)	13	20	1	Cotton	30 563	32 713	34 708
Cucumbers	258	78	383	Flax	36	15	920
Ear Corn	136	317	580	Oats	1 252	1 229	1 380
Endive	9	-	17	Peas (Cattle Feed)	-	5	-
Fava Beans	-	-	50	Rape	292	-	1 684
Garlic	185	148	223	Rice	-	-	1
Herbs, Mixed	13	12	-	Rye Grass	30 082	26 537	21 217
Lettuce	39 585	36 725	47 753	Rye Grass (Seed)	-	145	-
Lettuce (Seed)	10	-	-	Safflower	1 022	357	-
Lettuce, Romaine	367	280	268	Sesbania	-	30	38
Lima Beans	-	45	-	Sorghum, Grain	50 744	49 487	57 635
Melons				Sorghum, Silage	855	1 520	1 152
Cantaloupes	12 612*	8 307	7 445	Sudan Grass	9 361	7 784	7 762
Cantaloupes (Seed)	20	-	-	Sugar Beets	67 100	65 352	63 348
Crenshaw	64	90	130	Wheat	50 804	39 925	62 352
Melons, Mixed	254	514	397	Totals	473 008	471 961	488 468
Watermelons	3 130	2 909	3 204				
Mustard	799	415	108	PERMANENT CROPS			
Okra	13	39	11	Apricots	15	-	-
Onions	3 819	4 226	3 942	Asparagus	4 789	4 255	3 681
Onions (Seed)	980	826	709	Citrus			
Pumpkins	60	-	-	Citrus, Mixed	464	486	374
Pumpkins (Seed)	20	-	-	Grapefruit	567	561	566
Rapini	136	-	144	Lemons	685	480	487
Sesame	30	-	-	Limes	7	7	-
Squash	948	742	796	Oranges	564	727	744
Squash (Seed)	72	71	-	Tangerines	366	498	433
Squash, Banana	-	70	5	Dates	80	91	91
Tomatoes	2 213	1 959	2 915	Duck Ponds (Feed)	6 617	6 394	6 304
Turnips	40	68	-	Fish Farms	426	526	332
Vegetables, Mixed	184	204	32	Fruit, Mixed	35	26	2
Vegetables, Mixed (Seed)	9	-	6	Ornamental Shrubs	5	5	5
Water Lillies	20	20	16	Pasture, Permanent	840	540	1 097
Totals	71 785	63 845	75 211	Peaches	37	-	-
				Pecans	54	77	100
				Totals	15 551	14 673	14 216
				Total Acres of Crops	560 344	550 479	577 895

NOTE: Crops are listed for the year in which they are predominantly harvested.
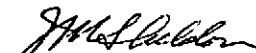*Cantaloupe acreage for 1972 taken from Imperial County Agricultural Commissioner's Office

S U M M A R Y

	1972		1971		1970	
No. of Farm Accounts Reported		4 904		4 907		4 971
No. of Owner-Operated Farm Accounts Reported	(41.4%)	2 029	(41.4%)	2 030	(44.5%)	2 213
No. of Tenant-Operated Farm Accounts Reported	(58.6%)	2 875	(58.6%)	2 877	(55.5%)	2 758
Average Area of Farm Accounts in Acres		98.97		98.72		97.73

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	ACRES		
	1972	**1971**	**1970**
Field Crops	473 008	471 961	488 468
Garden Crops	71 785	63 845	75 211
Permanent Crops	15 551	14 673	14 216
Total Acres of Crops	560 344	550 479	577 895
Total Duplicate Crops	116 833	110 473	142 244
Total Net Acres in Crop	443 511	440 006	435 651
Area Being Reclaimed: Leached	1 202	1 777	1 685
Net Area Irrigated	444 713	441 783	437 336
Area Farmable but not Farmed During Year (Fallow Land)	30 176	32 269	37 891
Total Area Farmable	474 889	474 052	475 227
Area of Farms in Homes, Feed Lots, Corrals, Cotton Gins, Experimental Farms, and Industrial Areas	13 638	13 352	13 598
Area in Cities, Towns, Airports, Cemeteries, Fairgrounds, Golf Courses, Recreational Parks and Lakes, and Rural Schools, Less Area Being Farmed	12 704	12 632	12 544
Total Area Receiving Water	501 231	500 036	501 369
Area in Drains, Canals, Rivers, Railroads, and Roads	71 565	71 629	71 596
Area Below -230 Salton Sea Reserve Boundary and Area covered by Salton Sea, Less Area Receiving Water	36 032	36 033	36 257
Area in Imperial Unit not Entitled to Water	63 933	63 933	63 933
Undeveloped Area of Imperial, West Mesa, East Mesa, and Pilot Knob Units	302 312	303 442	301 278
Total Acreage Included - All Units	975 073	975 073	974 433
*Acreage Not Included - All Units	87 217	87 217	87 857
Total Gross Acreage Within District Boundaries	1 062 290	1 062 290	1 062 290

IMPERIAL IRRIGATION DISTRICT

J. M. SHELDON, Manager
Water Department

*Acreage Within District Boundaries that is not included in District.

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