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Evaluation of Simulated SPOT Imagery for the Interpretation of Agricultural Resources in California*

Abstract: *Simulated SPOT data were acquired over a diverse agricultural site in the Central Valley of California for assessing the potential utility of these data for discriminating multiple crop types and agronomic conditions. Ground data and low altitude oblique photography were acquired coincidently with the SPOT data acquisition. Ground data included crop type, percent crop canopy and crop residue cover, canopy and crop residue height, irrigation and cultivation practices, and dominant land use for selected individual fields and tracts. The range in field size is from <1.0 hectare to >80 hectares. Analysis of the "P" site data set in image format has yielded the following significant results: (1) the panchromatic data sampled to 10 m IFOV pixels permit the definition of inter- and intra-field boundaries, road networks, and water distribution systems; and (2) the multispectral data sampled to 20 m IFOV pixels permit (i) the discrimination of selected crop canopies having less than 20% ground cover, and (ii) the discrimination of within-field variability due to irrigation and fertilization practices, soil type, and type and degree of harvesting practices.*

Introduction

The management of agricultural lands requires timely and accurate information on the type, amount, availability, and condition of the food and fiber being produced on those lands. For many years, satellite remote sensing has provided the means for collecting spectral data over large land areas in support of these renewable resource inventory and monitoring information needs. The use of satellite data in the inventory process requires that data utilization requires that technological issues be addressed in concert with those of a sociological and educational nature. This will serve to broaden the marketplace, with direct benefits accruing to those hoping to capitalize on the use of Earth satellite data for renewable and non-renewable resource surveys.

Technically, an Earth observation system must be able to assist in the quantification of the type, amount, location, condition, and trend of plant and soil resources in either spatial (maps) or tabular (estimates) formats. Important temporal and spectral satellite technology (1) be implementable by the user agency and value-added industry, (2) provide consistent information within user-specified limits of performance, and (3) be cost-competitive with other alternatives. In addition, the use of satellite data also requires that the users, or clients, (1) have both a personal and organizational interest in the data, (2) be aware of the data's advantages and limitations, and (3) have a level of expertise to properly test, evaluate, and utilize the data for meeting the organization's information needs. Thus, satellite features of an agricultural scene which must be quantified with the aid of remotely sensed data include (Hay, 1980; Odenweller and Johnson, 1984; Horvath *et al.*, 1982)

- the date in the growing season when a crop canopy becomes spectrally detectable ("spectral emergence"),
- the date in the growing season when the crop has reached a maximum vegetative indicator value,
- the value of the vegetative indicator at this time,
- the length of the growing season,
- the rate at which a crop progresses from "spectral emergence" to this maximum vegetative indicator value, and

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- the rate at which a crop progresses from the maximum vegetative indicator value to senescence, or minimum vegetative indicator value.

Economically, an Earth observation satellite system must implement robust data acquisition, management, and marketing strategies to insure (1) the timeliness of data acqusition, (2) the availability and suitability of data products, and (3) that data products are competitively priced with respect to products derived from other Earth observation systems. The Earth observation satellite system which employs the necessary technological advances and marketing strategies, within a rigorously defined global sampling strategy optimized for quantifying these spectral and temporal features, will be in a strong position to provide direct benefits to the world agricultural survey and agricultural production communities.

Based on the desire to enhance spectral data acquisitions from space, the French government is developing an Earth observation satellite system called SPOT (Système Probatoire d'Observation de la Terre). The major attributes of this satellite system are shown in Table 1.

The sensors on the satellite will employ multispectral linear array technology for sensing reflected visible and near-infrared solar radiation in nadir, off-nadir, and stereoscopic imaging modes. The design objectives of the system are to provide image products, in digital or film formats, for assisting resource survey operations.

During 1983, simulated SPOT data were acquired for selected sites on a global basis to (1) enable users to evaluate SPOT data within their application field, (2) provide the value-added industry an opportunity for product development, and (3) serve as an aid to SPOT IMAGE Corporation in perceiving and responding to the needs of the U.S. user community. Qualitative analysis of simulated SPOT data acquired for two sites in California have been investigated by this author for use in agricultural and forest inventory and resource information systems. The primary objective for the present agricultural analysis was to investigate the degree to which the characteristics of tone and texture can be used in the interpretation of simulated SPOT image products for discriminating crop types, relative crop canopy cover, small fields and boundaries, and within-field variability of canopy and soil surface properties.

Experimental Methods

The United States SPOT Simulation Campaign acquired multispectral and panchromatic data over 61 sites nationwide using the Daedalus AADS 1268 multispectral scanner on-board a Learjet 25-C platform. Simultaneous acquisition of stereo aerial photography (60 percent forward overlap) was acquired for each site using a Zeiss RMK A 15/23 metric camera with a 153-mm (6-in.) focal length lens. The film type used was Kodak Aerochrome Infrared Film, Type 2443; the resolving power of this film is 63 lpr/mm (1000:1, high contrast ratio targets) and 32 lpr/mm (1.6:1, low contrast ratio targets) (Slama, 1980).

Study Site Description

SPOT Simulation Campaign Site #76 is located in Yolo County, California, near the City of Davis (Figure 1). Agronomically, the area has intensive cultivation of a variety of crops on Land Capability Class I soils. The class rating is based on five of the 13 criteria used to assign soil units to a capability class in California; namely, effective rooting depth (>120 cm), surface texture (loams), permeability (0.5 to 1.5 cm/hr), profile available water holding capacity (>20 cm), and slope (0 to 2 percent) (Klingebiel and Montgomery, 1973). Other characteristics of the site are summarized in Table 2. This area was selected because of the diverse cropping practices, resulting in fields with large variations in percent plant cover, irrigation practice, boundary conditions, and area. This high proportion of small fields provides adequate opportunities to evaluate the usefulness of the 10-metre ground resolution of the SPOT film products.

Data Set Description

The simulated SPOT data were acquired as a "P"

Table 1. Major Attributes of the SPOT Satellite System (CNES, 1984)

Systeme Probatoire d'Observation de la Terre (SPOT)

- Pointable, high resolution visible (HRV) imaging sensors (across-track ±27°)
- Stereoscopic imaging
- Multispectral (visible, near-infrared), 20-m ground IFOV pixels
- Panchromatic, 10-m ground IFOV pixels
- 60-km swath width, each sensor
- 117-km swath width, both sensors (3-km overlap)
- 98.7° orbital inclination
- 832-km orbital altitude
- 26-day repeat cycle
- 10:30 acquisition, local solar time
- Direct X-band telemetry (50M bits/s), or tape recorders

FIG. 1. Location of the U.S. SPOT Simulation Campaign sites investigated by the University of California—Berkeley.

site for this agricultural study area on 24 June 1983. In support of this acquisition, field data were collected for a number of fields in the overpass area on 1 July 1983. Aerial oblique photography was also acquired from a light aircraft using a two-35-mm camera system exposing both color and color infrared film for identifying ground cover conditions of areas not ground surveyed. The simulated SPOT data set purchased from SPOT IMAGE Corporation is summarized in Table 3. The fields surveyed within the simulated SPOT data acquisition area are shown in Figure 2 and the legend for identifying these fields is shown in Table 4.

INTERPRETATION METHOD

Data analysis was limited to a qualitative evaluation of the combined panchromatic-multispectral image product generated at 10-metre ground IFOV pixels. The simulated SPOT product is shown with the simultaneously acquired Zeiss aerial photograph in Plate 1. The SPOT film product was evaluated in comparison to the aerial photograph using traditional manual photointerpretation techniques for determining the extent to which SPOT data in a film product mode can be used to (1) discriminate agricultural cover types, (2) detect fields with less than 20 percent crop canopy cover, (3) detect and measure small fields (less than five hectares), (4) delineate and update field and cultural boundaries commonly required on land survey maps, and (5) discriminate between cover type variations resulting from irrigation, fertilization, and harvesting practices.

RESULTS AND DISCUSSION

Based on visual inspection of the simulated SPOT film products with the Zeiss aerial photography, several significant features of the agricultural scene can

TABLE 2. CHARACTERISTICS OF SITE #76, YOLO COUNTY AT DAVIS, CALIFORNIA DURING THE 1983 U.S. SPOT SIMULATION CAMPAIGN

• Location:	Yolo County California (N38° 35′, W121° 45′)
• Elevation Range of Site:	11 to 18 m above mean sea level
• Field Size Range:	<1.0 to >80 hectares
• Major Cover Types:	Tomatoes, corn, alfalfa, irrigated pasture, orchard/vineyard, grain stubble, bare soil, specialty/experimental crops
• Land Capability Class:	I (Klingebiel and Montgomery, 1973)

TABLE 3. DESCRIPTION OF THE "P" SITE DATA SET FOR THE 1983 SPOT SIMULATION SITE #76

Simulated SPOT Data Set Description

- Acquisition Period: 6/24/83 (22:38-22:41 GMT)
- Ground Area Coverage: 5 × 12km
- Panchromatic data sampled to 10m IFOV pixels (CCT)
- Multispectral data sampled to 20m IFOV pixels (CCT)
- False color composite print (10m + 20m) at 1:24,000 scale
- Panchromatic Black & White print at 1:24,000 scale
- Black & White transparencies of each spectral band
- 9 × 9 in. color infrared photographs acquired simultaneously
- Flight log, topographic maps, and auxiliary information

be discriminated. In terms of cover type discrimination, each crop type in the area has unique tone and texture characteristics. Variations of within-field tone result from uneven canopy cover and soil moisture effects. Variable canopy cover results from poor soil conditions, non-uniform crop growth stages within a given field, and improper management practices. The high spatial resolution of the SPOT film product permits the discrimination of these variable canopy cover conditions, as well as the unique tone signatures of orchard crops due to the size and arrangement of the trees. The mature orchards cast larger shadows which are detectable on the SPOT film products and contribute to the rougher image texture characteristics of orchard crops.

As stated earlier, detecting the presence of a crop canopy early in the growing season (date of "spectral emergence") is important to agricultural survey operations and crop spectral-temporal profile modeling activities. Tomato plant canopies with less than 20 percent cover on both light (dry) soil and dark (wet) soil backgrounds are detectable. These fields are in the lower portion of the film products shown in Plate 1.

Several boundary conditions are also discernible on the film product. These include (1) intra-field boundaries resulting from irrigation, cultivation, and harvesting activities; (2) inter-field boundaries independent of the contrast between fields, resulting from the unique tone signatures of roads, canals, and other structures which separate fields by ownership or agronomic practice; and (3) boundaries between cultivated fields and native vegetation areas in which the contrast between a uniform tone signature within the cropped or fallow field is in sharp contrast to the variable tone signature in the nature vegetation areas. Other agricultural scene characteristics which can be detected on the film products include (1) areas within fields being irrigated where the familiar gradation of light to dark image tones indicative of dry to wet soils results from sprinkler irrigation systems progressing across a field; (2) depression areas within fields where water accumulated resulting in areas of high soil moisture and dark tone signature on the film products; and (3) poor soil conditions within fields where salt-affected soils cause non-uniform canopy cover and a blotching appearance to fallow and cropped fields. Small grain fields being harvested are quite

FIG. 2. Location and identification of fields ground survey within Site #76 during the 1983 SPOT Simulation Campaign on 1 July 1983. The legend for the field labels is shown in Table 4.

TABLE 4. LEGEND USED FOR THE GROUND SURVEY OF AGRICULTURAL FIELDS WITHIN SITE #76 DURING THE 1983 SPOT SIMULATION CAMPAIGN

	Field Survey Legend		
Cover Type	Plant Height (cm)	Percent Cover	Comments
Tomatoes (T)			
T1	0-10	0-10	irrigated & dry
T2	10-20	10-30	irrigated
T3	20-40	30-60	dry
Corn (C)			
C1	10-50	15-20	irrigated
C2	50-90	20-70	
Alfalfa (A)			
A	15	75	irrigated
Pasture (P)			
P	15-20	95	irrigated
Grain Stubble (G)			
G1	15-25	100	dry
G2	25-36	100	dry
Bare Soil (S)			
S1	n/a	n/a	dry bare soil, disked
S2	n/a	n/a	grain stubble, plowed

obvious on the film product due to the high radiance of the grain stubble in comparison to the standing mature grain. Unharvested grain appears as a dark yellow tone with a nearly smooth texture based on the vertical dominance of the grain stems. Harvested grain appears as a pale yellow to white tone with a very smooth texture based on the horizontal dominance of the dry crop residue material. These fields are located throughout the film products presented in Plate 1, and have quite obvious tone signatures.

In summary, the simulated SPOT panchromatic and multispectral film products permit the detection and identification of intra- and inter-field boundaries and road networks. This will be extremely valuable for updating existing agricultural land survey maps or for conducting thematic mapping activities in new areas where high altitude aerial photography is unavailable. The multispectral film product also permits the discrimination of crop canopies of low percent cover (less than 20 percent), and within-field variability due to irrigation and harvesting practices.

CONCLUSIONS AND RECOMMENDATIONS

The SPOT satellite system has many attributes which can directly benefit the agricultural survey and production communities. The major attributes include multispectral data acquisition, high spatial resolution, and off-nadir viewing, allowing site "revisits" which are important during critical plant growth stages if previous orbital paths were obscured by clouds. The SPOT system is a valuable addition to, not a replacement for, the suite of Earth observation sensors in use or planned for agricultural survey. Because of the long repeat cycle (26-day), this author strongly recommends that a global scene sampling strategy be developed to optimize the usefulness of the off-nadir (across track) viewing so crops can be spectrally sampled during these important plant growth stages, thus improving our ability to survey and monitor food and fiber production on a global basis.

In terms of global acquisition, processing, and marketing strategies, I recommend that (1) acquisition of SPOT data be based on the needs of both the global ecological and resource mapping communities and the individual entrepreneur; (2) processing and marketing of high quality film products be given as much emphasis as digital products in that this author predicts the highest proportion of users will be those who perform manual interpretation of standard or "enhanced" film products and integrate these interpretations in polygon or attribute form into geo-referenced resource information systems; and (3) marketing of data products include a strong educational component for developing among users or clients an understanding of the physical and physiological principles involved in remote sensing, the advantages and limitations of the SPOT system, and the application of the appropriate level of remote sensing technology to help solve resource related problems.

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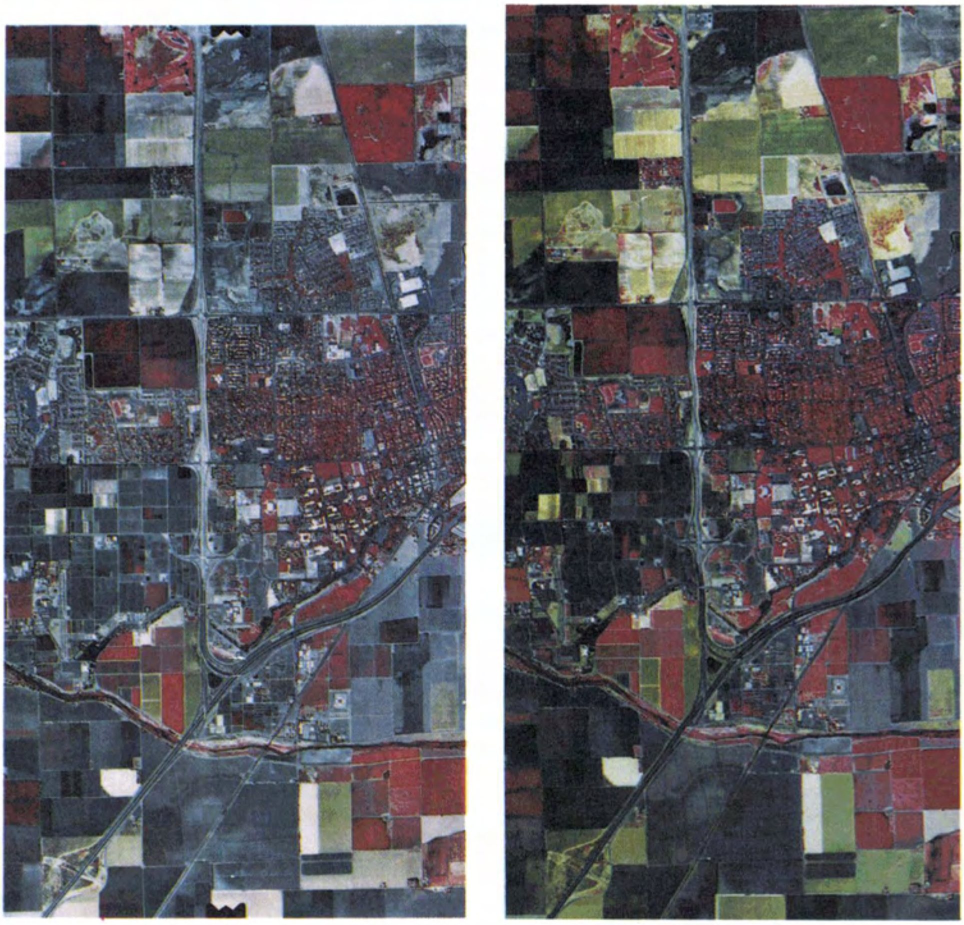

PLATE 1. Portion of the combined high resolution panchromatic and lower resolution multispectral image (right) and the same area as photographed by the Zeiss metric camera (left).

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