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Monitoring conservation tillage practices using Landsat multispectral data

Stephen D. DeGloria, Sharon L. Wall, Andrew S. Benson, and Michael L. Whiting

ABSTRACT: Manual interpretation of film products acquired by satellite remote sensing was used to estimate the land area under dryland grain production and to monitor the land area and spread of conservation tillage practices over a 5-year period in the central coast region of California. Using 35mm positive transparency enlargements projected onto and registered with a mapping base, the area of conventionally tilled and conservation-tilled land was correctly mapped with an overall classification accuracy of 80.8%. Due to variable cultivation practices and inadequate satellite coverage over certain areas, however, the commission error for mapping the conservation tillage area was 71%. With improved satellite data acquisitions and proper training, this satellite-based system could be adopted for mapping and monitoring lands under conventional and conservation tillage practices.

MORE hectares of agricultural land in California are devoted to small grains than to all other crops (*10*). These grains, primarily wheat, barley, and oats, are grown on both level terrain, generally under irrigation, and on upland slopes, generally using dryland farming practices. Because of the high susceptibility of the upland soils to erosion and the success that midwestern grain farmers have had with conservation tillage, such practices are becoming an integral part of dryland grain production in the central coast region of California (*6*).

In 1982 this region was designated by the U.S. Department of Agriculture as a national targeted area. As a targeted area, local farmers are working with resource conservation districts; Soil Conservation Service, Agriculture Stabilization and Conservation Service, and Cooperative Extension Service personnel; and agricultural commissioners to modify and develop equipment and techniques for conservation tillage. In California conservation tillage is defined as any small grain tillage and planting system that maintains at least 30% residue cover (1,700 kg/ha) after planting to reduce soil erosion by water and wind.

Because conservation tillage had been included as a practice in the 1980 Agricultural Conservation Program, the area planted using this practice was well known. But the extent to which conservation tillage has spread as a result of other farmers' direct observation of the success of program participants or through locally sponsored demonstrations and workshops was undocumented. Estimating the extent of conservation tillage and monitoring its spread was difficult over such a large area because of limited road access and the fact that some farmers were practicing conservation tillage without SCS assistance or ASCS cost-share payments.

Remotely sensed data acquired by aircraft and spacecraft have been used to map, inventory, and monitor a variety of grain land and crop residue conditions for many years (*1, 2, 3, 7, 8, 11*). Remote sensing can provide data that often are unobtainable, in a practical sense, using any other method. The operational use of remote sensing data is based on two important assumptions: a tested and documented technique exists to perform the required task and adequately trained personnel are available.

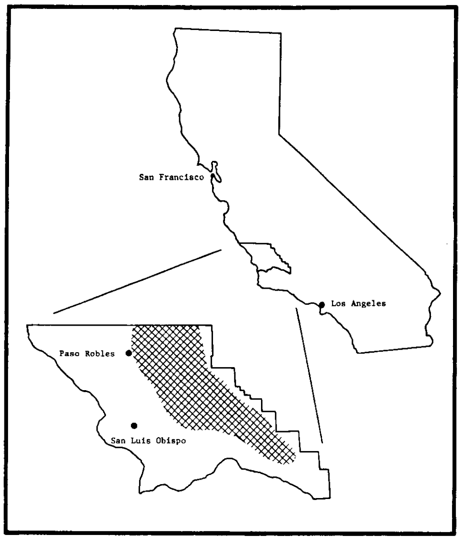

Figure 1. Location of the study area and the principal dryland grain production area within San Luis Obispo County, California.

Based on the need to monitor conservation tillage and encouraged by the success of previous remote sensing studies in mapping irrigated and nonirrigated grain land, we conducted a trial (a) to determine the degree to which dryland grain fields can be mapped using Landsat multispectral scanner film products and (b) to develop an inexpensive, rapid, and reliable method to estimate and monitor the extent and spread of conservation tillage in the central coast dryland grain region (5).

Study area and methods

Our study focused on San Luis Obispo County, which lies within the central coast region of California (Figure 1). This region has been a leading producer of dryland grain since the 1880s. It includes about 162,000 hectares of dryland grain in both San Luis Obispo and southeastern Monterey Counties.

We designed a mapping and monitoring system to estimate the land area for five cover type classes on an annual basis over a 5-year period. The system involved photointerpretation of enlarged Landsat film products reproduced on 35mm color transparencies and projected onto base maps at a scale of 1:63,360. The cover type classes included (1) land on which conventionally tilled dryland grain crops were being grown in any given year (G), (2) land with a stubble residue cover during the winter months (S), (3) land previously cropped but which was fallow during the current year (F), (4) land farmed with some form of conservation tillage (C), and (5) all other land on which a dryland grain crop was not being produced (N).

We used data from Landsat Multispectral Scanner (MSS) color composite film products, California Department of Water Resources (DWR) land use maps, U.S. Geological Survey topographic quadrangles, and field data from the SCS, ASCS, and San Luis Obispo County annual agricultural reports. Optimizing the Landsat interpretation process based on cropping practices required at least two images per year. The images had to be so spaced in time to cover the study area during both the fall-winter and winter-spring periods of the growing season. Given the size and orientation of the study area with respect to the placement of the satellite orbits, three scenes were required to cover the entire county on any given acquisition date. We, thus, needed at least 30 images.

Stephen D. DeGloria, Sharon L. Wall, and Andrew S. Benson are staff consultants with the Resource Survey Institute, P.O. Box 423, Benicia, California 94510. Michael L. Whiting is a resource inventory specialist with the Soil Conservation Service, U.S. Department of Agriculture, 2121-C 2nd Street, Davis, California 95616-5475.

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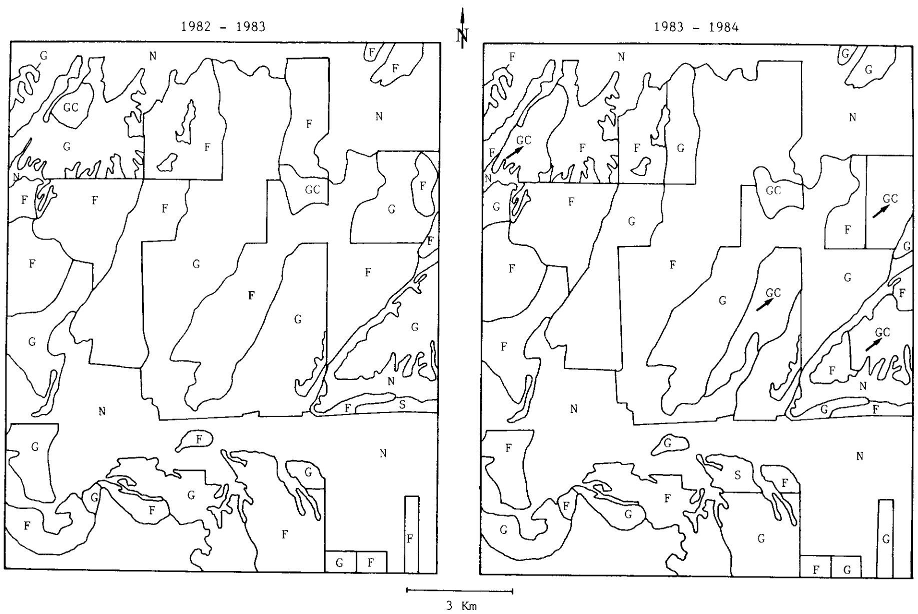

Figure 2. Examples of the map products illustrating the increase in acreage devoted to conservation tillage (arrows) over a 2-year period for the Shandon, California, topographic quadrangle. G = grain, conventional till; GC = grain, conservation till; F = fallow; S = grain stubble; N = nongrain land.

We used USGS 7½-minute quadrangles (1:24,000-scale). Seventy-eight map sheets were required to cover the county, 58 of which contained dry farmed grain land. The original map sheets were reduced to a mapping scale of 1:63,360 and reproduced on both mylar and sepia material. Using rear projection, MSS images were projected on these materials and annotations made directly on mylar or sepia. We verified the classification and mapping accuracy of the maps produced over the 5-year period with field data provided by SCS, ASCS, and county annual reports.

We enlarged the original Landsat color positive transparencies using a conventional copy camera, film, and a latitude/longitude grid overlaid on the transparency. Each slide was labeled and catalogued with the date of acquisition, Landsat path/row, and DWR row and column numbers of the four 7½-minute quadrangles that corresponded to the area pictured on each slide.

Interpreters were trained to recognize the five land cover type classes on the various Landsat products for each period of the small-grain-growing season. The labeled slides for a 5-year sequence by path/row were projected onto the reduced map sheets on sepia material using the rear projection system. The image was scale-matched and registered to the map base prior to interpretation. Fields were labeled with one of the four grain land classes; remaining land within the map sheet was labeled or assumed to be nongrain land. The area of each map unit representing one of the four grain land cover classes was estimated on 290 map sheets using a coordinate digitizer.

We produced both tabular and graphic output from the area summation procedure. These results were compared to published and unpublished estimates of total land area in the county, total area of grain land, and total area of grain land under some form of conservation tillage. We determined classification accuracy using SCS-provided ground data for the 1983-1984 growing season and ASCS and county data from farmer acreage reports for 1980-1984. The nature of field data were such that 2 x 2 error matrices were constructed to indicate whether the map unit was interpreted as conventionally tilled grain (G) or fallow (F) for any given year.

Results and discussion

Figure 2 shows examples of the maps produced. These two maps represent the last 2 years of a 5-year interpretation sequence in which five classes were mapped for each of 5 years and from which acreage estimates by class were estimated using a coordinate digitizer. Figure 2 shows the Shandon, California, 7½-minute topographic quadrangle, which had the highest rate of conversion to conservation tillage in a 2-year period of all the quadrangles mapped. Table 1 shows the area of grain land estimated from Landsat image interpretation on an annual basis. The annual summaries for each class compared favorably with published data (*4*). The mean area of total grain land for the county was 119,585 ha, which includes conventionally tilled and conservation-tilled grain land left fallow or as stubble on an annual basis. This total underestimated that reported elsewhere by 10-16% (*9* and personal communication from B. Desonia, SCS, Paso Robles, Calif.).

We compared the total area of actively growing grain for a given year under conventional or conservation tillage (G and C) to county annual reports (*4*) in which the area of production and production values are tabulated by crop and crop group. Under the field crop group, barley, wheat, and grain hay are tabulated separately. We summed these values to make direct comparisons with the Landsat-interpreted dryland grain classes. The proportion of irrigated barley and wheat included in the county agricultural reports was insignificant, less than 0.5% (*4*). We included the grain hay category because the multitemporal spectral signature and agronomic practices are similar to wheat and barley, and as such it would have been labeled as dryland grain by the Landsat interpreter. Also, some wheat and barley fields may have been cut for hay under the Payment-in-Kind Program.

Table 2 shows the comparison between these county-reported and Landsat-derived totals. The relatively large underestimate for Landsat-derived totals in 1980 (−14.4%) and 1982 (−9.3%) was due in part to inadequate Landsat coverage; no images were available for spring 1980 or spring 1982.

We sampled independent data points

Table 1. Annual summary of grain land area by class for the San Luis Obispo County study area, derived from Landsat image interpretation.

	Grain Land Area (ha)				
Year	Grain(G)	Stubble(S)	Fallow(F)	Conservation(C)	Total
1979-1980	55,953	4,198	60,838	0	120,989
1980-1981	65,382	761	57,789	0	123,932
1981-1982	59,841	4,924	54,656	278	119,699
1982-1983	52,055	646	62,000	2,292	116,993
1983-1984	48,898	1,412	60,357	5,647	116,314
Mean	56,426	2,388	59,128		119,585

throughout the study area to assess the classification accuracy of the map units generated using Landsat interpretation and to determine the type and magnitude of interpretation errors. These randomly located sample points were placed within individual fields on several map sheets. We tabulated the Landsat-derived map unit label for each of the 5 years. In addition, the actual farming practice occurring on that field was extracted from the ASCS farm operator reports for the same 5 years that these operators were under various government support programs. We tabulated a total of 120 sample points for the 5-year period. From these sample-point data we constructed error matrices and calculated percent correct identifications and percent commission errors for individual classes, individual years, and the 5-year period.

The overall classification accuracy for the 5-year period was 80.8%. The classification errors resulted from several independent and interrelated factors:

► Limited or poor quality satellite acquisitions during important biological growth states were the principal reasons for low percent correct values and high percent commission error values during 1979.

► Fields in which volunteer vegetation, either weeds or volunteer grain, followed the grain crop caused interpretation errors. Interpreters identified such fields as grain when in reality the field was "fallow" with volunteer vegetation present.

► Cooler or dryer climatic conditions contributed to interpretation errors when the canopy cover was insufficient to be imaged by the MSS sensor or the available satellite acquisitions were limited.

We used field data extracted from SCS cooperator records, field sheets, and photo enlargements of 45 individual fields for 1983-1984 to evaluate the accuracy of conservation tillage areas mapped during that year using the Landsat method. These data indicate several significant results. SCS estimated that 4,029 ha were in conservation tillage in the county. The Landsat-derived estimate was 5,647 ha, an apparent 40.2% overestimation (Table 2). But a field-by-field comparison of the percentage of the 4,029 SCS hectares correctly classified by the Landsat interpreter is more important. Based on SCS cooperator data, 1,636 ha (40.6%) of the SCS area were mapped correctly using the Landsat system. Thus, by subtraction, 4,010 ha were incorrectly included in the conservation tillage class, a commission error of 71%. The rate of high commission errors could have resulted from several factors:

Table 2. Comparison of areal estimates of land in grain production derived from Landsat image interpretation (G + GC) and those published in the County of San Luis Obispo (CSLO) annual agricultural reports.

	Grain Land Area (ha)		
Year	*CSLO Report*	*Landsat*	*Percent*
1980	65,382	55,953	− 14.4
1981	68,826	65,382	− 5.0
1982	66,317	60,119	− 9.3
1983	56,235	54,347	− 3.4
1984	56,559	54,544	− 3.6

► There were more dryland grain fields under conventional, annual tillage systems than anticipated.

► Fields conventionally tilled during 1983 were in volunteer vegetation, thus giving them the appearance of a grain field during 1984.

► Not all conservation tillage fields have been recorded by the SCS.

► Some reduced-till fields have the appearance of fallow fields during certain Landsat acquisitions.

Of these factors, the confusion caused by volunteer grain is significant. Identification of such land will be difficult without additional information on agronomic practices or unique spectral characteristics that could aid the interpreter. Until such information is available, the reliability of the Landsat method to estimate the extent and spread of conservation tillage practices remains in question.

Conclusions and recommendations

Based on the relative success of this project, we offer the following conclusions and recommendations:

► Manual interpretation of Landsat imagery can be used to inventory dryland grain in the central coast area on an annual basis if proper acquisitions are available.

► Landsat imagery offers an inexpensive, rapid method to monitor the spread of conservation tillage practices. But the reliability of the method needs to be improved by developing means to identify accurately those fields in which volunteer vegetation is present.

► Before the Landsat method is adopted on an operational basis, our cost and accuracy data must be compared to the cost and accuracy of current SCS methods used to map dryland grain and changes in land area under conservation tillage practices.

► Given somewhat favorable cost and accuracy comparisons to conventional methods, SCS should implement a Landsat-based system to map annually the amount of dryland grain and to monitor areal changes in conservation tillage practices.

► This system would best be implemented using field office personnel who have had appropriate training in photointerpretation and measurement methods and who are knowledgeable about local grain production systems.

► Our approach of using the manual interpretation of image products instead of computer-assisted interpretation and analysis is a valid one. Manual interpretation reduces overall costs and generates acceptable classification accuracies. Given the requirements and allowable costs to develop such a monitoring system and the sparse distribution of the features of interest, we would not have achieved the relative success documented here using a digital data processing approach.

We believe SCS should evaluate the need for map products, such as those we generated, to estimate the extent of dryland grain and to monitor conservation tillage adoption. Numerous sampling-based strategies, as opposed to mapping-based, are available to generate tabular areal estimates and associated sampling errors on an annual basis. But these procedures do not provide a map product illustrating the physical location of the fields.

If a map product is not required, then we recommend future efforts be directed toward developing a sampling-based system in which individual sample units or plots are interpreted and expanded to generate county- or region-wide estimates. If management goals require map products, however, a system similar to the one developed here would be required.

Independent of the estimation and monitoring system selected, additional research is needed to develop the accuracy assessment component of the inventory system. We had to rely heavily on historical data that were in a format that was difficult and, therefore, expensive to obtain. An operational inventory system employing Landsat imagery would require large-scale, small-format aerial photography acquired at optimal times during the growing season along specified transects, along with limited field work, to minimize reliance on cumbersome and perhaps statistically biased field data.

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