Timely Crop Area Estimates from Landsat*

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ABSTRACT: To use Landsat for timely crop area estimates, a variety of technical and logistical problems were dealt with. Those discussed here include ground data collection and integration; handling missing, cloudy, or hazy data; signature extension for large areas; and the modification of existing statistical expansion procedures.

Results for three crop years (1980-82) in New Brunswick show that the Landsat-derived estimates for potato areas are more consistent and less prone to error than standard procedures. Much larger areas were analyzed for Canola-rapeseed, but with more variable accuracies. Accuracies are presented and results are discussed.

INTRODUCTION

STATISTICS CANADA and the Canada Centre for Remote Sensing began cooperative projects to evaluate, and then use, Landsat MSS data for crop area estimation in the 1980 crop year. Earlier publications have described the basic research (Ryerson *et al.*, 1979; Goodenough *et al*, 1980; Brown *et al.*, 1980), outlined 1980 results (Ryerson *et al.*, 1981a), compared Canadian and American methods (Ryerson *et al.*, 1981*b*), and presented the general approach (Ryerson *et al.*, 1982). A procedural manual has also been prepared (Ryerson *et al.*, 1983).

The present paper has two objectives: to discuss the types of technical problems encountered and solved in the use of satellite remote sensing for crop area estimation by a user agency; and to present, for the first time, all results from 1980 to 1982 in the various projects. The general conclusion from this set of projects is that to use satellite data effectively for provision of timely information there must be careful planning, built-in flexibility, and simplicity of method. The balance of this paper outlines the findings that have resulted in these conclusions.

The following section places these projects in the context of other work in the field. Technical questions are then addressed under the topics of ground data collection and verification, remote sensing methods, and statistical procedures. This is followed by the presentation of results.

BACKGROUND

The emphasis of this work is on the solution of problems involved in producing satellite-derived crop area estimates to meet rigid deadlines with limited manpower and budgetary resources.

While much has been learned about organization, data flows, and crop separability from the Large Area Crop Inventory Experiment (LACIE, 1979), and from the Agriculture and Resources Inventory Surveys through Aerospace Remote Sensing (AGRISTARS), most of these techniques are not directly applicable for Statistics Canada's needs. All of LACIE and much of the AGRISTARS work have focused on generating crop area estimates with multiple satellite acquisitions over a season for each location without benefit of ground data and usually in foreign countries (Hay, 1979; Crist and Malila, 1981).

Because of timeliness, cost, and cloud cover problems, multiple acquisitions are considered impractical for the purposes of Statistics Canada. However, because the agency's mandate is limited to domestic crop reporting, and because ground surveys are routinely conducted, ground data can be collected. This lessens the need for images at several time periods to definitively identify crops for further computer-assisted analysis.

The general approach developed in Canada is based in part on the United States Department of Agriculture's domestic crop reporting work now under AGRISTARS. (Hanuschak *et al.*, 1979.) Their approach requires only one satellite pass, although they have experimented with multitemporal applications (Mergerson, 1981).

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The major differences between the two methods are in the sampling design of the ground data collection and in the way in which the satellite data are regarded. While the Canadian work uses a weighted segment expansion, the USDA uses a direct expansion method. (Ryerson *et al.*, 1983; Houseman, 1975; Hanuschak, 1979.) The American statisticians regard satellite data as supplementary digital data, or numbers, from which statistical information can be extracted, while in Canada they are seen as digital images, which must be studied visually but which may also yield the same statistical information. This different perception relates to the varying orientation of those involved in developing both the estimation methods and the basic hardware. In Canada the hardware developments eventually used for crop area estimation have been driven by users in the environmental disciplines who are more comfortable, as a result of training in air photo interpretation, when dealing with images rather than with numbers. These users have worked closely with scientists in both government and industry in the design, manufacture, and use of such hardware. (Goodenough *et al.*, 1974; Economy *et al.*, 1974; Goodenough, 1979; Kourtz and Scott, 1978.) In the United States, the methods and hardware used by USDA were brought together by statisticians who did not have the same perceived need to study images visually. As a result of the different perception of satellite data in the American and Canadian domestic crop reporting programs, there are subtle differences in the respective methods with important implications in large-area applications.

The first result of the different approach in Canada is that off-the-shelf (and hence lower cost) analysis hardware may be used. The methods have been adapted to the ARIES-II* systems already available in New Brunswick, Alberta, and Manitoba.

Because the analyses involve constant inspection of results on the video display of a small stand-alone system, and because the analyst does not require access to large, expensive general purpose computer systems, the methods are amenable to a range of applications with fewer cost limitations. To date, applications have included both large and small areas of intensively and extensively grown crops where timeliness, rapid processing, and ease of verification have been primary considerations. Similar procedures may also produce crop type maps or other outputs for any provincial, state, or national crop inventory program, depending upon the size of area, types of crops, and the availability of ground data. Furthermore, because we have attempted to design the procedures to rely on a number of separate systems operated by several trained individuals, the method is not based on a "single-thread system" or limited staff. An individual machine being out of service, or one or two key individuals being unavailable, should not halt the derivation of statistics, as can occur with a single, larger system. In addition, the work is spread out among more people and systems, alleviating potential bottlenecks. In this respect the distributed system used in some areas by USDA (but linked to one large computer) also serves to spread at least some of the human effort.

The last and perhaps most important implication associated with the difference between the Canadian and USDA approach is that the basic methodology proposed for Canada was sufficiently different that we could not use all of the experience gained in the USDA program. As a result, the potential problems involved in a large area application could not be specified, in spite of thorough attempts to do so. The following section addresses the problems encountered and the solutions adopted.

TECHNICAL PROBLEMS AND THEIR SOLUTION

INTRODUCTION

The problems faced included those of a technical nature concerning remote sensing and statistics, as well as related ones of project organization discussed elsewhere (Dobbins *et al.*, 1983).

Two factors identified by Dobbins *et al.* (1983) are of primary importance when considering problems in implementing remote sensing procedures for real-time analyses. First is the fact that there is a forward linkage between problems. If a problem (even a simple one) is not solved early in the project, it will have serious and perhaps even disastrous consequences relative to the solution of later problems. Second, problems encountered early in the project during the seven- to eight-month project planning phase may be important, but can usually be solved in a relaxed atmosphere. Those encountered in the so-called critical phase, which usually lasts only two weeks, are all important, no matter how trivial they may seem. Of interest, these same two factors have also been identified and addressed in the current crop reporting system at Statistics Canada described by MacCartney (1982).

To ensure that test conditions would mirror this critical phase, it was decided to attempt to provide a real-time estimate during the first year's test. This would demonstrate whether satellite data could be delivered and processed under tight time constraints. It was also hoped that any unexpected problems in methodology would be identified, leaving the fall and winter months available for correcting such problems so that methods would be better for the second year's application. Additionally, there was the challenge of producing more

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* Mention of or failure to mention commercial trade names does not necessarily imply endorsement or criticism by Statistics Canada or the Government of Canada.

timely and cost-effective estimates than previously had been produced using satellite data.

Although work had been done on both Canola-rapeseed (Brown *et al.*, 1980) and potatoes (Ryerson *et al.*, 1979; Mosher *et al.*, 1978), it was decided to apply the methods to potatoes first, because they are grown in a smaller, more localized area, allowing ready access by project staff for field checking.

Field checking, ground data collection, and integration provided the first of three sets of technical hurdles. The second was the modification of the basic method during the "real-time" application to potatoes in 1980. The methods had, therefore, been tested and were known to work when the Canola-rapeseed area analyses were begun in 1981. The Canola-rapeseed analyses provided the project team with yet another major technical problem—the sheer volume of data and associated logistical problems—discussed in more detail below.

GROUND DATA COLLECTION, INTEGRATION, AND VERIFICATION PROBLEMS

For the first application of the methods to potatoes, total area coverage of the 7 900 sq. km St. John Valley region (see Figure 1) was obtained from normal color aerial photography at about 1:60 000 scale. It was planned that this would be used (in conjunction with field checks) as the "true data" to verify the accuracy and area estimates provided by field enumerators working for the 1 July Statistics Canada Agricultural Enumerative Survey (AES), as well as by the Landsat MSS image analysis. To avoid "contamination," this was to be done after the Landsat analysis.

Generally, the enumerator's interview-based estimate for potatoes in an AES segment was more highly correlated to the air photo (or true) estimate than was the satellite estimate (Ryerson *et al.*, 1981*a*). Errors and inconsistencies between the ground data and satellite measures were found for potatoes and subsequently verified in the field. Subsequent modification of interviewer instructions resulted in virtually no problems being encountered in 1981 and 1982.

In the second application, for Canola-rapeseed in the 104 900 sq. km Peace River District and 37 750 sq. km Crop District 4a in Alberta (see Figure 1), air photo coverage for calibration and checks on the satellite and ground data were obtained for only a subsample of the Farm Enumerative Survey (FES) segments. Only twenty segments covered by aerial photography contained Canola-rapeseed. In the Peace River District there were many inconsistencies between the field data and the satellite images. There were six reasons for these inconsistencies:

- Twelve crops had to be identified and then mapped on the enlarged copies of older air photos by the FES enumerators (compared to two crops in New Brunswick);
- The major crop of interest (Canola-rapeseed) is not the dominant crop grown in the region, as is the case with potatoes in New Brunswick;
- For some segments, older aerial photography was used to produce copies of poor quality and tonal contrast for the ground work. In New Brunswick,

FIG. 1. Regions of Canada used for crop area estimation with Landsat, 1980-1982.

where the land base is relatively stable, older photography is not a problem. However, in the rapidly changing Peace River District (Ryerson *et al.*, 1982*b*), this resulted in understandable confusion when the boundaries of new fields had to be outlined on what were forested areas on the old photographs. This was further complicated by dark copies for some segments;

- The weather in 1981 resulted in delayed seeding and/or fields with highly variable crop conditions. In some cases, farmers with a poor crop ploughed their fields down after the ground enumeration but before the Landsat pass, resulting in confusion (from the apparent errors and inconsistencies) when attempting to integrate ground data collected earlier in the season into the analyses of satellite data acquired later;
- A number of respondent refusals were encountered, with the majority being for segments containing the crop of interest; and
- The whole ground data effort was further hampered by a private courier's loss of all display materials assembled for the FES enumerator training. In addition, the project leader from Statistics Canada changed. Given the difficulties faced by the field staff, it is perhaps surprising that the data were so consistent and, for the most part, that they remained usable for the project.

To solve the various problems mentioned above, specific remedial actions were taken:

- Enumerator training materials have been improved by editing the text, incorporating better, less complex visuals for the training sessions, as well as preparing a set of cartoons to summarize how the methods should be applied in the field. These are documented in Ryerson *et al.* (1983);
- To assist the interviewers in obtaining a response, colorful brochures on remote sensing have been supplied to all respondents in the remote sensing sample in the Alberta projects (courtesy of the Alberta Center for Remote Sensing). Special brochures on the projects have also recently been prepared jointly by the Canada Centre for Remote Sensing (CCRS) and Statistics Canada;
- To reduce errors in ground data, the survey questionnaires and annotated enlarged copies of the photographs undergo a parallel quality control phase to check for inconsistencies or problems before image analysis commences. This is particularly important where refusals are encountered, because they tend to disrupt work by making the affected segments less useful for training and more work to process. Those problems found after analysis begins are also verified with the questionnaires or other ancillary sources. Other field work inconsistencies have been resolved by local cooperators who visit specific problem segments and determine the true situation;
- Steps have been taken to ensure that all data arrive at the appropriate time for both the analysis and estimation processes. All segments containing the target crop were identified and made readily retrievable before image processing on a master analysis map used to plan training and signature extension. For future years, areas of refusal and no-contact will also be noted on the master analysis map to further streamline the work.

An additional factor, of course, is that the enumerators and the training staff have gained from the first year's experience, as have those involved in the image analysis.

REMOTE SENSING RELATED PROBLEMS

The key feature in the solution of remote sensing related problems in both the potato and Canola-rapeseed projects has been flexibility. To arrive at an operational approach, we cannot remain committed to only one procedure. With the exception of the requirement to be able to see, and interactively modify, classification results, the project team has collectively maintained an open mind on implementing procedural changes. As the need for a change became apparent, it was discussed by the entire team (when possible) and implemented if beneficial to meeting the project's objectives.

The first difficulty encountered was using CCRS geometrically corrected Digital Image Correction System (DICS) data to give full but not duplicative coverage. It was found that there was often overlap from one DICS image to another, in east-west as well as north-south. The overlapping edge does serve to prove correct line-up of scenes, but it must be removed to avoid double counting. This was done by manually deleting all classifications in the overlap zone after the adjacent scenes had been displayed as abutting video displays. The problem of avoiding double counting is more severe (but expected) with the Standard System Corrected data because the imagery does not easily overlay, edges are not simple straight lines, and many more pixels are involved. Details on areas analyzed from any given tape were recorded on the Master Analysis Maps.

Other related bookkeeping/organizational problems included keeping track of images received and areas under cloud (for which other data were required). The last of the organizational problems noted here is the organization of disk storage of the images to be analyzed. Special forms and procedures were developed to ensure the smooth flow of data to the disk before analysis sessions to allow for maximum throughput during sessions. (The fastest processing of any one DICS scene with nine subscenes (total 1200 by 1500 pixels) was just over ½ hour—the scene contained no segments or new training data.)

In the USDA crop area estimation work upon which the initial stages of these projects were based, a maximum likelihood decision rule (MLDR) classifier was used. The original methods proposed by the background research team here were similar. A number of representative training sets were to be chosen to generate a "truthfile," and then these were to be applied to the data in a batch processing mode with an MLDR classifier on the CCRS Image Analysis System (CIAS).

The plan was to make use of the most advanced classifier available and to use a large number of training sets. However, the methods did not work. It was hard to select and locate representative training data in the small fields. For this reason, a number of iterations would have been required, and the classifier was slow (several hours versus several minutes), because the specialized array processor on the system was not functioning. The only alternative, given the tight deadline and limited system time available, was to redesign the procedures around the simple parallelepiped classifier. This redesign was accomplished within 24 hours by the project scientists. Using these procedures (Ryerson *et al.*, 1982; Ryerson *et al.*, 1983) we can now process the entire New Brunswick potato belt (2700 km^2) in under eight hours on the CIAS. Using a small ARIES-II system in a test mode, the same area was covered in less time using digital data which were not geometrically corrected. (ARIES-II systems are now the basis for all image analysis.) As noted by Dobbins *et al.* (1983), the planning required to lead up to the eight-hour session requires considerably more time than the session itself.

Other general operational problems associated with remote sensing that were solved include segment location for training the classifier, training data selection, implementing the parallelepiped classification, and classification evaluation. These procedures are described in detail elsewhere (Ryerson *et al.*, 1982).

In addition, after the second year, it was found that prelocating all ground segments and then overlaying them on the real-time satellite data was difficult and often inaccurate. A contract was let to provide for more accurate overlay and near-automatic calculation of areas in each segment. The software was available just after the third year's results became available. Unfortunately, changes in data prices have resulted in abandoning DICS data. All segment location was then to be performed in real time during analysis because the data source and the software cannot work with standard system-corrected data.

More specific analysis problems included handling missing or unacceptable segment data as well as areas without training data.

Because some clouds or haze always seem to be in the scenes of interest, methods have also been developed to handle isolated areas of cloud, cloud shadow, and haze. Misclassified but isolated pixels have also been dealt with under specific analysis problems.*

Segment data may be missing because of cloud, cloud shadow, haze, or forest fire smoke. In such cases the segment was ignored. Ground data may also be rendered obsolete by poor weather—for example, fields may have been ploughed under after enumeration because of poor germination. Questions about the veracity of ground data were assessed by the project staff. Depending upon the result of this assessment, segments were deleted, changes were made to correct the segments, or they were further refined by local cooperators. This procedure of rendering ground data obsolete may also result in the ground data being made unrepresentative of the situation at the time of data capture. Any such changes, however, were only made after careful consideration involving the statisticians.

Many of the images contained no Canola-rapeseed training fields. For these, training fields within the same satellite path on the same day were used. Where there were no training fields for all of the imagery acquired on one pass or date, imagery was interpreted visually to identify training sites using information on the crop's phenology. This visual interpretation was done for two images of 29. These two images were known to contain less than one percent of the crop of interest in the region.

A variety of methods based on clear lakes (Ahern *et al.*, 1977) and time-consuming recalculations of spectral values are available to correct for thin haze and other factors such as thin smoke or jet vapor trails, which affect the variability of a crop's signature over an image. The method developed here is based upon the subjective assessment of the effect of haze on both the displayed image and crop classification on that image. Areas of haze (often a jet vapor trail) appear as somewhat brighter, frequently elongated features. Usually, haze is not visible, but its faint effect on the ground beneath it or on the crop classifications is. The same effect is also seen at the edges of clouds. Where clouds are associated with haze, the haze is treated with the clouds, as below. Here the correction for haze is done after the initial classification of the subscene. For the most part, preliminary classification of normally bright Canola/rapeseed fields in non-hazy areas results in rectangular or square field areas being classified. In the presence of haze, the regularity and relationship of the classified Canola fields to the survey pattern decreases somewhat and the area classified increases dramatically. A sudden local increase in area classified as Canola/rapeseed was also used as a clue to the presence of haze. The edge of the haze area is determined by the local change in classification and the general brightening of the image. Rather than correct for the haze, the classification of the crop under the haze is modified. This is done by visually following the variability of rapeseed fields into the haze to locate a "normal-hazy" field (which is usually in a subset of what has already been classified). This field is trained on and the re-

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* More detail on the specific analysis problems discussed in the next five paragraphs was presented previously in Ryerson *et al.* (1982). It is presented here for continuity of the discussion.

sult checked against the general pattern in the non-hazy area and against fields visually interpreted as "normal-hazy" Canola-rapeseed. When an acceptable classification within the haze is obtained, usually after further modification, the previous non-hazy classification is deleted within the haze and the new classification is inserted in its place. Areas can then be recorded for the whole scene for both normal and hazy areas.

Eight of 29 DICS scenes in the Peace River Area contained cloud. Using the USDA criteria employed by Hanuschak *et al.* (1979), whole counties under the cloud would be removed. Because the Crop District is the primary reporting base, subsets could not be deleted very easily. An alternate method (Ryerson *et al.*, 1981*a*) was therefore used to impute under isolated cloudy areas using the percentage of crop in areas similar to those covered by cloud as representative of the crop under the cloud, under cloud shadow, and under associated haze.

One of the problems with classification of Landsat data in the large fields found in western Canada is the "salt-and-pepper" effect caused by single pixels either incorrectly classified as the crop, or cells missed within fields. The net effect is to have pixels randomly confused with the crop, and voids in fields that often (but not always) should be fully classified fields. Although it could be assumed that such pixels would be accounted for by the regression estimator, it was decided to reduce the noise to permit production of acceptable crop type maps as a by-product. The result is a spatially tighter classification with no isolated single cells—and fewer voids within fields. To assess the result of the filter, the classification is stored as two theme files, but only one is filtered. In the Peace River region the filter typically resulted in a ten to 20 percent reduction in area classified. Subsequent analyses show no significant difference in resulting crop areas using either the filtered or unfiltered results for any of the areas in western Canada.

Several other situations have required technical responses in terms of the remote sensing methodologies. The first of these is the required movement of the methods from the federal government subsidized CCRS Image Analysis System (Goodenough, 1979) to either a cost recovery or cooperative venture elsewhere. The presence of only DIPIX ARIES II installations in four of the five project provinces determined that this would be the system used. Of New Brunswick, Alberta, Manitoba, Ontario, and Prince Edward Island, only the last does not have an ARIES II system (it has no system). It was found that the general steps in the analysis could be performed equally well on the smaller ARIES II system, with some improvements in interactive capabilities and somewhat slower classifications because of the size of system used. The major changes came in the type of classification used (fast thresholding followed by maximum likelihood on ARIES versus parallelipiped on CIAS), and the way in which haze was handled.

A secondary benefit of changing systems is related to the Landsat price increases proposed at the time of writing. Working with the DIPIX System's capability made the use of system-corrected data (in place of DICS) easier than it had been on the CIAS. Using system-corrected in place of DICS data in eastern Canada will reduce costs by 50 percent for rush delivery. Even at the proposed new costs, the methods are still economic for potatoes in eastern Canada, while development and improvement in costs and throughput aimed at multiple crop area estimation are continuing in the West.

The third area of change to the remote sensing methods evolved from the requirements of the statisticians generating the estimates. This is discussed in the section below.

STATISTICAL PROBLEMS

The statistical problems which had to be dealt with included estimating around and under clouds, as well as "normal" problems for statisticians, such as handling refusals and very large (or specified) farms. When clouds cover large parts of the target region, the use of satellite information is limited to the cloud-free region. Thus, two different estimates have to be produced: one for the cloud-free region and one for the cloudy region. A method for dealing with isolated clouds or cloudy areas was given above. The following considers only large areas of either cloud or missing satellite data.

To produce an estimate for the cloud-free region (or area of missing satellite data), we must determine for each stratum how many enumerative areas and how many sampled segments belong to the cloud-free region. When this operation is done, we determine the new weights for each segment and then estimate the total acreage of crop(s) of interest in the cloud-free region. It can happen that in some strata, just one (or no) sampled segment is in the cloud-free region. When this occurs, strata should be grouped together to form new strata with a minimum of two sampled segments in order to allow variance estimation. Grouping should be such that the new strata are as homogeneous as possible according to the variable to be estimated and so that the strata grouped together have weighting factors as similar as possible.

There are two alternative methods of estimating for large cloudy or missing regions. The first is to expand the cloud-free region estimate to the target region level using the census enumerative area total. This method assumes that the cloudy region accounts for the same percentage of total acreage as was the case in the census year. Such a technique is applicable if the cloudy region is not very important for the crop involved or if there are insufficient ground data to produce an accurate estimate for the cloudy area. This approach was used in the most southeasterly region of the Alberta Peace River District, where the total Canola-rapeseed area usually amounts to only a hundred hectares, and for which there were no satellite data in 1982.

A second method is to use the ground data to produce the cloudy area estimate. This method is recommended if the cloudy area is important, if there is sufficient ground data, or if the ground survey design is efficient enough to produce an accurate estimate for the crop of interest. In 1982, this method was used in the most southerly 20 percent of the St. John Valley potato belt.

A further major problem related to the specified farms—large farms interviewed separately because of their size and importance. Because many of these will have land in a number of segments, it is easier for both Statistics Canada and farm operator to reply to one all-inclusive interview. Information gathered this way is not included in the normal survey, but is added later to arrive at the regional or provincial totals. For satellite analysis this has certain implications. First, land farmed by the specified operators must be excluded from the segment sums generated by the satellite analyses. Second, the total area of the crop of interest grown on the specified farms must be known within the regions that have been analyzed by the satellite, in order to avoid double counting. Analyses become even more complicated under large cloudy regions that include specified farms growing the crops of interest. These farms, their areas of the crops of interest, and the location of these areas of the crops of interest must all be known or imputed to make effective use of the methods presented here.

Another constraint is the ground survey design. The surveys used, the Agricultural Enumerative Survey (AES) and the Farm Expenditure Survey (FES), now combined in the National Farm Survey (NFS), are multiple purpose surveys and are not necessarily designed for the crop(s) in which the user is interested. (While potatoes are a major consideration in the sample design for New Brunswick and PEI, Canola-rapeseed is not as important in the sample design for provinces where this crop is grown.) However, the use of satellite information as an auxiliary variable and the use of a ratio or regression estimate should compensate to a certain extent for the possible deficiency of the design.

An additional problem concerns zero segments—segments not enumerated and known to be nonagricultural. These are usually not considered in the satellite work. The remote sensing response to the zero segment problem takes one of two directions depending upon the area being analyzed. In most cases errors of classification have tended to follow borders between fields, forest types, or any two other features. This results in a thin, linear expression of pixel misclassification. In western Canada this error can be removed through post classification filtering, as discussed above. In eastern Canada the fields are too small to allow this—a filter would remove accurate results as well as errors. In addition, the major source of error in the New Brunswick potato work appears in forest clear cuts now regrowing. To remove the error, forested areas outside of the developed agricultural lands are simply deleted. Errors inside the developed lands are still noticeable, but are minor and tend to be reflected within the segments analyzed, because many of these contain forested tracts.

Although a number of problems were encountered, they were largely solved. The basic procedures for potatoes in New Brunswick have been developed to the point that all methodologies and associated computer programs have been transferred from the research statisticians of the Institutional and Agricultural Survey Methods Division to the economists and support staff of the Crops Section for routine application within Statistics Canada.

RESULTS

The results of various projects are given in Table 1. Results in the regions where the agricultural land base is stable, and where both field and analysis staff have experience, are quite acceptable. Those for the potato area estimation in New Brunswick appear to be more accurate relative to the reported crop areas than do those for Canola-rapeseed in the rapidly expanding Peace River District. Indeed, the 1981 Landsat-based estimate of 53,827 acres available in September of 1981 was found to be only 34 acres off the 1981 Census of Agriculture's results eventually released in June of 1982. After the release of the census data, the published estimate was revised as indicated in Table 1. However, the 1982 accuracy is quite acceptable for Crop District 4a where the land base is relatively unchanging, and where we have two years of experience.

The discrepancies are primarily related to the sampling errors caused by rapid expansion of the agricultural base, inadequate sample size (especially in 1981), and the lack of experience and problems in ground data collection in the Peace River District. It should be noted that the satellite estimate is close to that of the FES, but neither is close to the reported or census crop area.

The results in the Peace River Region have led to the evaluation of Landsat for updating the agricultural land base, which in turn is used to update stratification (Gregory Geoscience, 1983). A similar approach is used operationally to update land-use maps for the June Enumerative Survey in the USDA (Costanzo, 1983).

TABLE 1. 1980, 1981, AND 1982 ESTIMATES OF THE POTATO AREA IN NEW BRUNSWICK

	1980 Estimates (Acres)			1981 Estimates (Acres)			1982 Estimates (Acres)	
	Test Region	New Brunswick	C.V. (%)	Test Region	New Brunswick	C.V. (%)	Test Region	New Brunswick
Ratio Estimate	49,504	51,524	5.5	55,628	57,898	5.4	55,264	57,964
Regression Estimate	49,115	51,119	5.5	51,717	*53,827*	5.5	52,533	55,233
Statistics Canada:								
Published Estimate	—	52,000	—	—	53,000[1]	—	—	54,000
1981 Census of Agriculture	—	—	—	—	*53,793*	—	—	—

Note: The coefficient of variation (c.v.) of an estimate is calculated as:

$$\text{C.V. } \% \; \frac{\text{Variance of Estimate}}{\text{Estimate}} \times 100\%$$

1981 AND 1982 ESTIMATES OF CANOLA-RAPESEED

Estimate	1981	C.V.	1982	C.V.
Census B.C. Peace	60,470			
FES B.C. Peace[2]	50,916	29.9	Cloud	
Landsat B.C. Peace	51.603	31.2		
Crop Rep. B.C. Peace	63,000			
Census Alta. Peace	468,800		—	
Crop Rep. Alta. Peace[4]	506,900		527,200	
Landsat Ratio	367,000[5]		412,793	12.5
Landsat Regression[3]	292,605	6.3	389,969	11.9
Landsat 4a.	215,822		287,011	6.0
Crop Rep. 4a	244,300		284,500	
Landsat[5]			196,488	5.5
Crop Rep.[5]			248,200	

[1] Revised to 54,000 after Census.

[2] The Landsat estimate was based on the FES.

[3] The estimate is based on weighted expansion using 1976 Census data—which is judged out of date.

[4] This value is based on change ratios.

[5] This estimate is based on an unweighted direct expansion.

With the new stratification based on the 1981 Census, better field data collection, and better quality control at all stages, the results in the Peace River Region and in other crop districts should improve in subsequent years.

At this stage, the work with potatoes is considered operational, while the region used for Canola-rapeseed estimation is being expanded to include three crop districts in southern Manitoba. In addition, developmental work has begun on the application of these same methods to fallow and grain in addition to oilseeds in the Manitoba study.

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