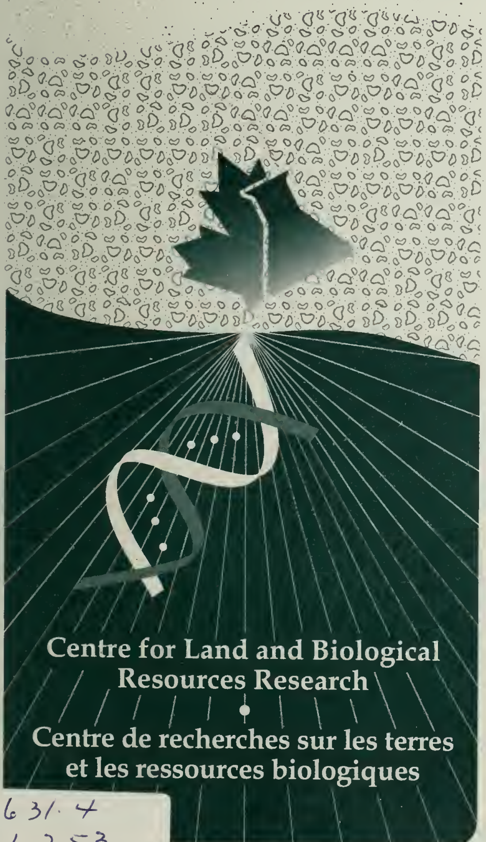
Agriculture and Agri-Food Canada
Research Branch

Agriculture et Agroalimentaire Canada
Direction générale de la recherche

A comparison of estimates of agricultural land use using satellite imagery and the Census of agriculture inventories



J.C. Hiley
Agriculture and Agri-Food Canada
and
A. Richard
Ducks Unlimited Canada

Centre for Land and Biological Resources Research
Research Branch, Agriculture and Agri-Food Canada
CLBRR Contribution No. 95-72

Canada

Citation

This publication may be cited as:

Hiley, J.C. and A. Richard. 1995. ***A comparison of estimates of agricultural land use using satellite imagery and Census of agriculture inventories.*** Edmonton: Agriculture and Agri-Food Canada. Centre for Land and Biological Resources Research Contribution No. 95-72. 53 pages.

Copies of this publication are available from:

Alberta Land Resource Unit
Centre for Land and Biological Resources Research
Agriculture and Agri-Food Canada
Suite 1295, Royal LePage Building
10130 - 103 Street
Edmonton, Alberta, Canada.
T5J 3N9

Telephone: (403) 495-4243
FAX: (403) 495-5344
Internet: HILEYJ@EM.AGR.CA

Summary

Very similar estimates of general agricultural land use are found between the satellite imagery and Census of Agriculture inventories for 2 regions within the County of Leduc, Alberta. The estimates, derived from a quarter section satellite inventory of land cover from a 1986 Thematic Mapper (TM) spring image and custom-processed farm headquarters data from the 1986 Census, are most similar for 9 landscapes in the Lake Edmonton Basin. A qualitative assessment of the estimates of total land system area as well as annually cultivated and uncultivated area shows generally small absolute and relative differences between the inventories. A quantitative assessment shows evidence of statistically significant associations (based on the Spearman Rank Correlation Coefficient, $p = 0.95$), with one exception. There may be significant differences in estimates of total land system area because of large differences in bigger land systems at the margin of extensive annual cultivation. There appears to be no statistically significant difference in the magnitude and direction of the estimates (using the Wilcoxon Matched-Pairs Signed-Ranks Test, $p = 0.95$).

Compared to the results for the Lake Edmonton Basin, larger differences between the inventories are found in a region where agriculture is a significant, but not always dominant, rural land use. The Morainal Areas region has 6 generally larger land systems with lower quality land resource for annual crop production and less extensive annual cultivation. The Census inventory shows more annually cultivated and less uncultivated area compared to the satellite inventory; however, there is evidence of statistically significant associations (Spearman Rank Correlation Coefficient, $p = 0.95$). There are insufficient cases to conduct a test of the magnitude and direction of differences in estimates between the inventories in this region.

The results provide new information for rural land use planning and land evaluation research. With respect to the former, a new and integrated rural land use database is now feasible for municipal planning, when relatively small differences are found between the inventories. The database contains not only the advantages of satellite inventories (i.e., summarizing data to quarter section, annual updates) but also the strengths of Census inventories (i.e., structural characteristics of farm-level production, economic data). An integrated database provides at least 2 significant benefits to municipal planning, one being a more complete description of rural agricultural production than is currently available. A second benefit is the opportunity to use the integrated database to develop a co-operative process when planning for multiple uses of the rural land base, as discussed in this study in the context of waterfowl habitat development in landscapes with extensive agricultural production.

Future land evaluation research will address the possibility of systematic biases within each inventory due, in part, to the land resource and land use characteristics of the land systems under study. The present research found that differences between the inventories are greater for landscapes in the Morainal Areas region, compared to land systems in the Lake Edmonton Basin. The larger land systems in the Morainal Areas region have lower quality land resources for annual crop production and less extensive annual cultivation. In general, Census estimates are higher for cultivated, and lower for uncultivated, area compared to the satellite inventory. These results may be associated with an increase in spectral confusion and mixed pixels in the satellite inventory. As well, it is hypothesized that farmers in this region may be reporting areas that they are cultivating in other land systems to the land system that contains their farm headquarters. Evaluation of these hypotheses will help to determine if more similar estimates can be derived from satellite imagery and Census of Agriculture inventories.

Acknowledgments

Several years have passed, all too quickly, between the formulation of the research objective and this publication. Over that time, the authors have benefited from interactions with many individuals. The following people are recognized for their continued support to this study: Gary Stewart and Gary Larson (Ducks Unlimited Canada); Wayne Pettapiece and Gerry Coen (Agriculture and Agri-Food Canada); and, Leon Marciak and Roger Andreiuk (Alberta Agriculture, Food and Rural Development).

The authors also express their appreciation to the following individuals for reviewing the study and providing many suggestions to improve the presentation of this research: Bob Clay (Ducks Unlimited Canada); Ted Huffman (Agriculture and Agri-Food Canada); and, Rob Rempel (Ontario Ministry of Natural Resources). Our thanks as well to Jane Horb (Ducks Unlimited Canada) and Pete Smith (Agriculture and Agri-Food Canada) for their excellent graphics support.

Table of Contents

List of Tables

List of Figures

List of Appendices

1.0 Introduction

1.1 Integrated Assessments for Rural Planning in Alberta

Integrated assessments of the rural resource base have become a valuable planning tool at the municipal level in Alberta. Integrated assessments link spatially referenced data to a landscape and provide descriptions of both the natural resource base and various uses of it. They have been used by officials in wildlife management, agriculture and municipal government to support policy and program development. Generally, these assessments are classified as either Broad Area Assessments (BAAs) or Small Area Assessments (SAAs) (Hiley and Huffman 1993). For example, SAAs have been used by municipal planners to inventory the location and distribution of wildlife habitats as well as to develop policies concerning the impact of local soil and water conservation issues on these habitats (MCPPP 1993). SAAs are subdivided into at least 2 groups on the basis of the type and source of land cover and land use data.

One group of SAAs are based on remote sensing information, typically satellite imagery, because this data source has several strengths in the inventory of rural land cover. These advantages include: cost-effectiveness over a large area; the large number of detailed observations; the complete coverage of a landscape; and, the repeated coverage every 16 days in the growing season, subject to the degree of cloud cover (Table 1).

Table 1. Characteristics of Land Cover and Use Data for Small Area Assessments (SAAs).

Data Characteristics	Group 1: Satellite Imagery	Group 2: Census of Agriculture
Type of Data	Land Cover and Generalized Land Use	Production Inventories and Management Practices
Typical Source	Satellite - Thematic Mapper	Statistics Canada
Base Unit	Pixel	Farm
Dimensions of Base Unit	30 Metre Square	128 Hectares (Average Farm Size in Black Soil Zone, Prairie Provinces)
Presentation Scales	1:25,000 to 1:500,000	1:250,000 to 1:5 Million
Update of Data	Every 16 Days in Growing Season	Once Every 5 Years

A second group of SAAs are based on the Census of Agriculture because of its benefits in the inventory of farm-level agricultural production. These advantages include: the availability of survey data on every farm reporting some income from the sale of agricultural products; an inventory of crops, livestock and machinery on each farm; reasonably detailed information on farm expenses and general information on income from the sale of agricultural products; regular updates of the information at 5 year intervals; and, the capability to customize the information to suit specific planning issues (Table 1).

With a recent advance in the reprocessing of Census data, policy makers and planners can now utilize both satellite and Census data sources within local landscapes, termed land systems. Previously, Census data were not available for land systems because of technical and procedural considerations in reprocessing this data source at the level of land systems. Recent research has produced a new technique, termed farm headquarters processing, that permits the efficient capture of Census data within landscapes appropriate for municipal planning (Hiley et al. 1994). With this technique, satellite and Census data can be produced for the same land system, leading to a more complete database on land cover and land use for local planning. However, the presentation of land cover and land use data from different sources for the same base unit raises a question about the similarity of estimates derived from satellite and Census inventories.

A systematic study of the satellite and Census inventories will determine the similarity of estimates of general land use derived from these sources. The inventories may provide dissimilar estimates for the following 3 reasons:

1. the inventories are derived from different sources of information (i.e., interpretation of satellite imagery compared to farmer-estimated values for the Census of Agriculture);
2. the dimensions of the base unit are dissimilar (i.e., estimates derived from 30 metre square pixel compared to approximately 128 hectares for an average farm); and,
3. the scope of the inventories are not identical (i.e., complete coverage from the satellite, only those lands in agricultural production for the Census).

Given such differences in the compilation of the inventories, there is a need to determine the similarity of estimates of rural land use within land systems of a municipality.

1.2 Study Objective

The objective of this research is to determine the similarity of estimates of general agricultural land use from satellite imagery and Census of Agriculture inventories.

2.0 Method

Three procedures are used to achieve the objective. The first procedure compiles data from the satellite and Census inventories within each land system in the County of Leduc, Alberta. The second procedure uses a generic land cover and land use classification to produce comparable estimates of general agricultural land use. The third procedure determines the similarity of these estimates of using a combination of qualitative and quantitative techniques. The steps associated with each procedure are presented in this section.

2.1 Procedure 1: Data Compilation by Land System

Satellite and Census of Agriculture estimates of general rural land use are compiled for each land system in the County of Leduc, Alberta in four steps (Figure 1). First, a map of the land systems within the county is derived by using standard procedures (Brierley et al. 1992) and a computerized quarter section database of soil survey and related land resource information, termed the Soil Inventory Database for Management and Planning (SIDMAP) (Hiley et al. 1986). The map summarizes the spatial distribution of 4 land resource characteristics, including agroclimate zone, texture of the parent material, topography and soil development, attributes that are indicative of the quality of the resource base for annual dryland crop production (ASAC 1987). In the second step, a file containing the Dominion Land Survey coordinates to the quarter section level for each land system is produced from the automated land systems map.

The third step produces a satellite inventory of general rural land use by quarter section using a single, classified Thematic Mapper (TM) from May 28, 1986 (Koeln et al. 1986). These data are summarized for each land system by matching legal locations with the file from the second step. In the final step, 1986 Census of Agriculture data (Statistics Canada 1986) by farm headquarters are compiled for each land system using a custom processing technique and the file from the second step (Hiley et al. 1994). The Census data for each land system are supplemented with an inventory of major non-agricultural land uses, as determined from the land ownership map for the municipality (Stewart, Weir and Co. 1982).

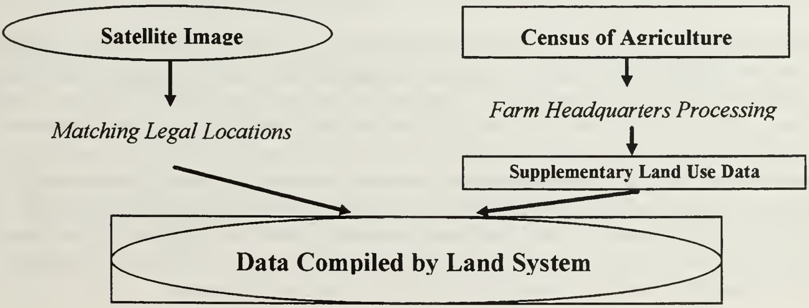


Figure 1. Overview of Procedure to Compile Data by Land System.

2.2 Procedure 2: Generic Land Cover and Use Classification

The second procedure develops a generic classification to produce comparable estimates of land cover and land use from the 2 inventories. A generic classification is required because the inventories use different, and not directly comparable, variables (Table 2). The classification contains 2 classes, annually cultivated and uncultivated area, that distinguish the permanence of vegetative cover within a land system. It was not possible to further define the generic classification because the satellite inventory was limited to a single image.

Table 2. Generic Land Cover and Land Use Classification.

Generic Classes	Satellite Variables	Census Variables
Annually Cultivated Area	- Annual Cropland	- Cropland less Tame Hay - Summerfallow
Uncultivated Area	- Grassland - Total Wetland - Wooded Land - Other (Urban, Industrial)	- Tame Hay - Improved Pasture - Other Improved Land - Unimproved Pasture - Wooded Land - Other Unimproved Land

2.3 Procedure 3: Data Analysis

The similarity of estimates from the 2 inventories is determined in 3 steps. In the first step, the decision is made to compare Census estimates to the satellite inventory. The decision to base the comparison on the satellite inventory is for convenience and does not imply that it is a more accurate inventory than the Census. Absolute differences are determined by subtracting Census estimates of total land system area as well as annually cultivated and uncultivated area from the satellite inventory. In the second step, relative differences are calculated by dividing absolute differences by the corresponding satellite estimate and multiplying by 100. The results of the first 2 steps are presented in graph and tabular form for qualitative assessment.

In the third step, the degree of similarity between the 2 inventories is quantitatively evaluated in 2 dimensions using a non-parametric approach. In one dimension, the statistical significance of the **association** between the inventories is measured by the Spearman Rank Correlation Coefficient (Siegel 1956). In the second dimension, the statistical significance of the **magnitude and direction of differences** between the inventories is measured by the Wilcoxon Matched-Pairs Signed-Ranks Test. Significance tests are conducted with a high degree of confidence ($p = 0.95$; $\alpha = .05$). A conservative interpretation of the results of the statistical analysis is taken in this study, with rejection of the null hypothesis leading to reserved judgment on the alternative hypothesis (Freund 1979). A cautious approach is advised under conditions of uncertainty, as is often the case with estimates of agricultural land use in natural landscapes.

3.0 Results

The County of Leduc contains 17 land systems, 10 of which are found within one region in the central part of the municipality. These land systems are part of the Lake Edmonton Basin, a level plain of Black Chernozemic soils with a slight heat limitation for annual dryland crop production (Figure 2) No land use data are available for Land System 3J because it extends beyond the boundary of the satellite image used in this study. The remaining land systems are contained within the Morainal Areas region which extends to the east and west of the Lake Edmonton Basin. This region is an hummocky upland of Gray Luvisolic soils with a moderate to severe heat limitation for annual cropping of cereal grains and oilseeds. No results are available for Land System 4A because it also extends beyond the limits of the satellite inventory.

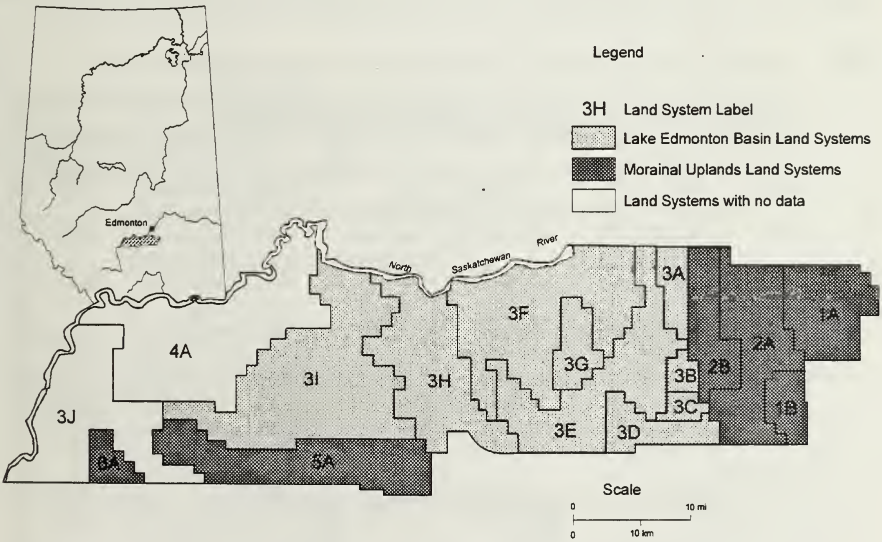


Figure 2. Study Area Location and Distribution of Land Systems in Study Area.

The results are presented in 2 subsections, representing the Lake Edmonton Basin and Morainal Areas. The first subsection describes the land resource characteristics for land systems in a region and is followed by an analysis of the degree of similarity in estimates of general agricultural land use .

3.1 Lake Edmonton Basin

3.1.1 Land Systems

From west to east, the land systems show a decrease in size and increase in the quality of land resources for annual crop production. The land systems are divided into 3 groups on the basis of total area, including small (Land Systems 3A, 3B and 3C), medium (Land Systems 3D and 3G) and large (Land Systems 3E, 3F, 3H, 3I and 3J) (Figure 2; Table 3) (see Glossary for the limits to these classes). The small to medium-sized land systems and 2 of the larger land systems (i.e., Land Systems 3E and 3F) are part of a medium textured plain of Black Chernozemic soils that has a slight heat limitation for annual crop production. The larger land systems to the west, Land Systems 3H, 3I and 3J, are part of a medium textured plain of Gray Luvisolic soils and have both a significant amount of poorly drained soils and a heat limitation to annual crop production.

Table 3. Resource Characteristics of Land Systems in the Lake Edmonton Basin.

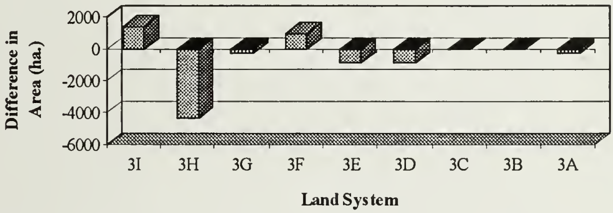
Land Syste		Land Resource Characteristics				
Identifier	*Size Range*	*Agroclimate Zone*	*Texture*	*Topography*	*Soil Development*	*Total Area (hectares)* [1]
3A	Small	2H	Medium	Plain	Black Chernozemic, some Solonetzic soils	3883
3B	Small	2H	Medium	Plain, some Hummocky area	Black Chernozemic, some Solonetzic soils	2589
3C	Small	2H	Medium	Plain	Black Chernozemic, some Dark Gray Chernozemic soils	2848
3D	Medium	2H	Medium	Plain	Black Chernozemic, some Solonetzic soils	9061
3E	Large	2H	Medium	Plain	Black Chernozemic	30289
3F	Large	2H	Medium	Plain	Black Chernozemic	39156
3G	Medium	2H	Medium	Plain	Black Chernozemic, some Solonetzic soils	8025
3H	Large	3H	Medium	Plain	Variable	28865
3I	Large	3H	Medium	Plain	Gray Luvisolic, some gleyed soils	54624
3J	Large	4H	Medium	Plain	Gray Luvisolic, some gleyed soils	36308

1 *Total area is calculated by the number of quarter sections by a constant size of 160 acres. This value is converted to a metric equivalent using a constant value of 0.4047 hectares per acre.*

3.1.2 General Agricultural Land Use

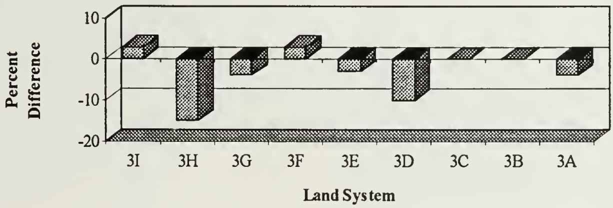
The satellite image shows that both land cover and field geometry vary within the region from west to east. In the western part, the image includes Land System 3H and shows extensive areas of uncultivated land (Figure 4). Fields with less vegetative cover, interpreted as cultivated land (black), are smaller and more irregularly shaped than the uncultivated areas. In the central and eastern parts of the region, spring vegetation is not extensive, an indication that annual cultivation is a dominant land use. The image, extending to Land Systems 3A and 3D in the east, shows that annually cultivated land (black) in large, rectangular fields (Figure 5).

Estimates of total land system area from the 2 data sources are quite similar. With the exception of Land System 3H, all estimates are within +/- 1000 hectares (Appendices 1 and 2; Figure 3), or +/- 5 percent (Appendix 2; Figure 4). In the case of Land System 3H, the Census estimate of total area is over 4000 hectares, or about 15% lower than the satellite inventory.



** - Positive values indicate Census estimates that are larger than the satellite inventory.*

Figure 3. Absolute Difference in Estimates of Total Area for Land Systems in the Lake Edmonton Basin.*



** - Positive values indicate Census estimates that are larger than the satellite inventory.*

Figure 4. Relative Difference in Estimates of Total Area for Land Systems in the Lake Edmonton Basin.*

Figure 5. Satellite Image of the Western Part of the Lake Edmonton Basin.

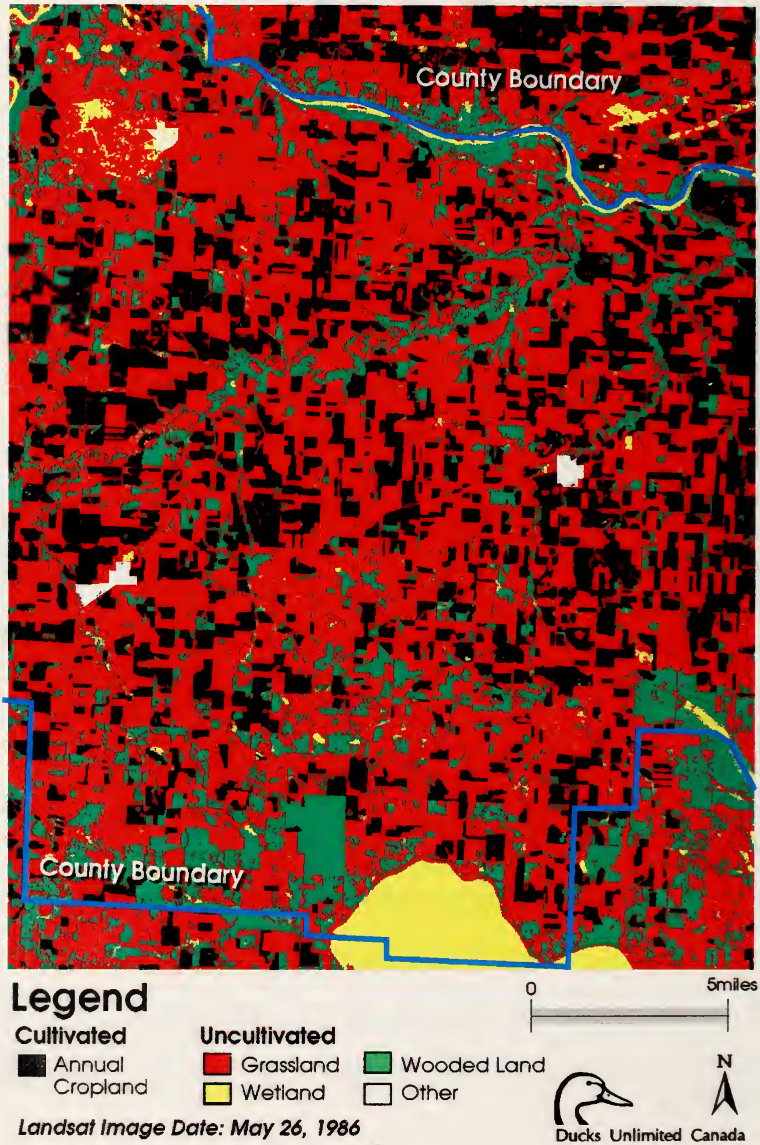
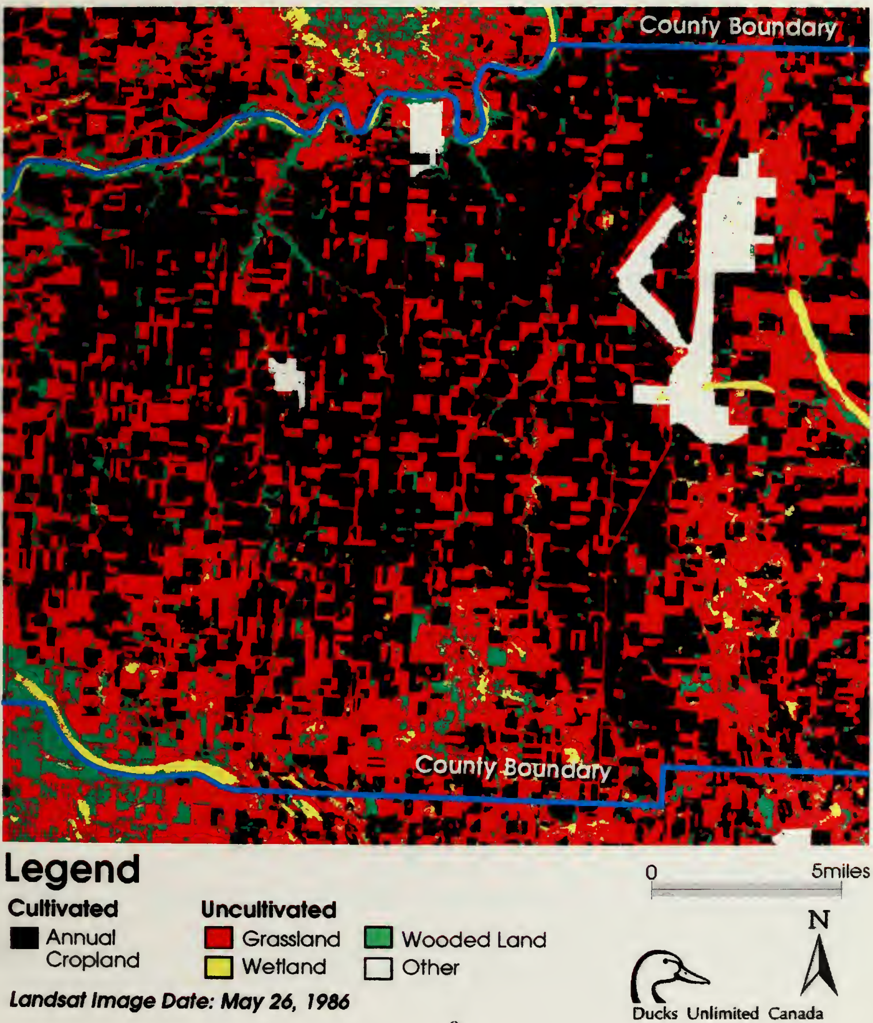


Figure 6. Satellite Image of the Central and Eastern Parts of the Lake Edmonton Basin.

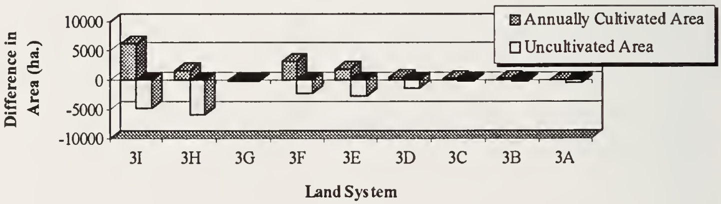


Based on the results of the statistical analyses, the following decisions are reached on the null hypotheses:

1. as **Rho** (calculated) is > **Rho** (critical), the null hypothesis that there is no statistically significant difference between the 2 inventories in estimates of total land system area is rejected and judgment is reserved on the alternative hypothesis (Appendix 3); and,
2. as **T** (calculated) is > **T** (critical), the null hypothesis that there is a statistically significant difference in the magnitude and direction of ranks between the 2 inventories in estimates of total land system area is not rejected (Appendix 4).

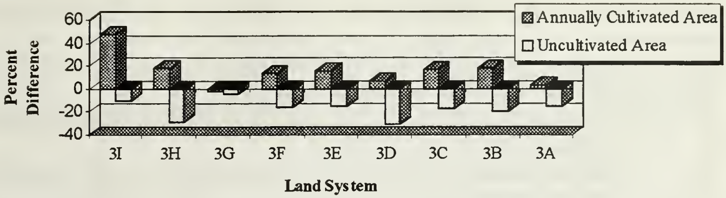
A small number of differences in the ranking of land systems, particularly in terms of the magnitude and direction of differences, is evidence of associated but distinguishable estimates. The estimates appear to be closely associated because no major differences are found in the ranks of land systems by estimated total land system area. However, the results for 3 large land systems in particular show differences in the magnitude and direction of estimates of total land system area. Larger Census estimates are found for Land Systems 3F and 3I, with differences of up to 1500 hectares. Conversely, smaller estimates from the Census are reported for Land System 3H, by over 4000 hectares.

Census estimates are consistently higher for annually cultivated land and lower for uncultivated land relative to the satellite inventory, with larger differences noted in the larger land systems. In the case of annually cultivated land, the Census estimates are generally higher by 2000 hectares (Appendix 5; Figure 7), or about 20% (Appendix 5; Figure 8). The largest difference is recorded for Land System 3I, an area of gleyed soils intermixed with Gray Luvisolic soils. The Census estimate for annually cultivated area is about 6000 hectares larger for this land system.



* - *Positive values indicate Census estimates that are larger than the satellite inventory.*

Figure 7. Absolute Difference in Estimates of General Land Use for Land Systems in the Lake Edmonton Basin.*



** - Positive values indicate Census estimates that are larger than the satellite inventory.*

Figure 8. Relative Difference in Estimates of General Land Use for Land Systems in the Lake Edmonton Basin.*

Census estimates are lower for uncultivated area by about the same amount that they are larger for annually cultivated land. Census estimates are generally about 2000 hectares (Appendix 6; Figure 7), or 20% (Appendix 6; Figure 8) lower, compared to the satellite inventory. Larger absolute differences are found in 2 land systems. Land System 3H is a large area of variable soil development and a difference of 6000 hectares, or 30%, is recorded. Land System 3I, also a large area of lower quality land resources, shows a Census estimate that is nearly 5000 hectares (about 10%) lower for uncultivated area and 6000 hectares (approximately 60%) higher or annually cultivated area.

The statistical analyses provide similar results for both annually cultivated and uncultivated area and indicate that:

1. as **Rho** (calculated) is > **Rho** (critical), the null hypotheses that there are no statistically significant difference between the 2 inventories in estimates of annually cultivated and uncultivated area are rejected and judgment is reserved on the alternative hypotheses (Appendices 7 and 8); and,
2. as **T** (calculated) is > **T** (critical), the null hypotheses that there are no statistically significant differences in the magnitude and direction of ranks between the 2 inventories in estimates of annually cultivated and uncultivated area are rejected and judgment reserved on the alternative hypotheses (Appendices 9 and 10).

Although the estimates of annually cultivated and uncultivated area appear to be closely associated, some differences are noted in the type of land use and size of the land system. In the case of annually cultivated area, the 4 cases with differences in ranks are in the small to medium-sized land systems (i.e., Land Systems 3B, 3C, 3D and 3G). Conversely, the 2 land systems with different ranks of uncultivated area are both larger units (i.e., Land Systems 3E and 3H).

By way of summary, the comparison shows, in terms of total land system area, that:

1. estimates are generally within +/- 1000 hectares, or +/- 5%;
2. there may be a statistically significant association;
3. differences in the ranking of land systems by total land system area may be statistically significant; and,
4. larger differences are found in large land systems with lower quality land resources for annual crop production.

With respect to estimates of annually cultivated and uncultivated area, the comparison shows that:

1. estimates are generally within 2000 hectares, or 20%, for both annually cultivated and uncultivated area;
2. Census estimates for annually cultivated area are generally higher;
3. Census estimates for uncultivated area tend to be lower;
4. despite the results noted in Points 2 and 3, there is evidence of statistically significant associations between the inventories;
5. there appears to be no statistically significant differences in the ranking of land systems by annually cultivated or uncultivated area;
6. differences in the ranking of land systems by extent of annually cultivated area occur in smaller land systems with better quality land resources for annual crop production; and,
7. differences in the ranking of land systems by extent of uncultivated area occur in larger land systems with lower quality land resources.

3.2 Morainal Areas

3.2.1 Land Systems

This area contains 7 land systems, 3 to the west of the Lake Edmonton Basin and 4 to the east of it. In the west, Land Systems 4A, 5A and 6A are part of medium textured, hummocky upland of Gray Luvisolic soils that has a severe heat limitation for annual crop production (Figure 2; Table 4). Land System 4A is a large unit that contains a significant amount of soils developed under conditions of forest-grassland transition. Land System 5A is also a large unit with variable topography and Land System 6A is a small unit with low quality land resources for annual crop production.

Table 4. Resource Characteristics of Land Systems in the Morainal Areas.

Land System		Land Resource Characteristics				
Identifier	*Size Range*	*Agroclimate Zone*	*Texture*	*Topography*	*Soil Development*	*Total Area (hectares)*[1]
1A	Large	3H	Medium	Plain, some variable topography	Dark Gray Chernozemic, so Gray Luvisolic an Solonetzic soils	16827
1B	Medium	2H	Medium	Plain	Black Solonetzic gleyed soils	5825
2A	Large	3H	Medium	Hummocky	Dark Gray Chernozemic	23558
2B	Large	3H	Medium	Hummocky	Black Chernozem	11391
4A	Large	4H	Medium	Hummocky	Gray Luvisolic, some Dark Gray Chernozemic	47440
5A	Large	4H	Medium	Variable	Gray Luvisolic	26665
6A	Small	4H	Medium	Hummocky	Gray Luvisolic	4142

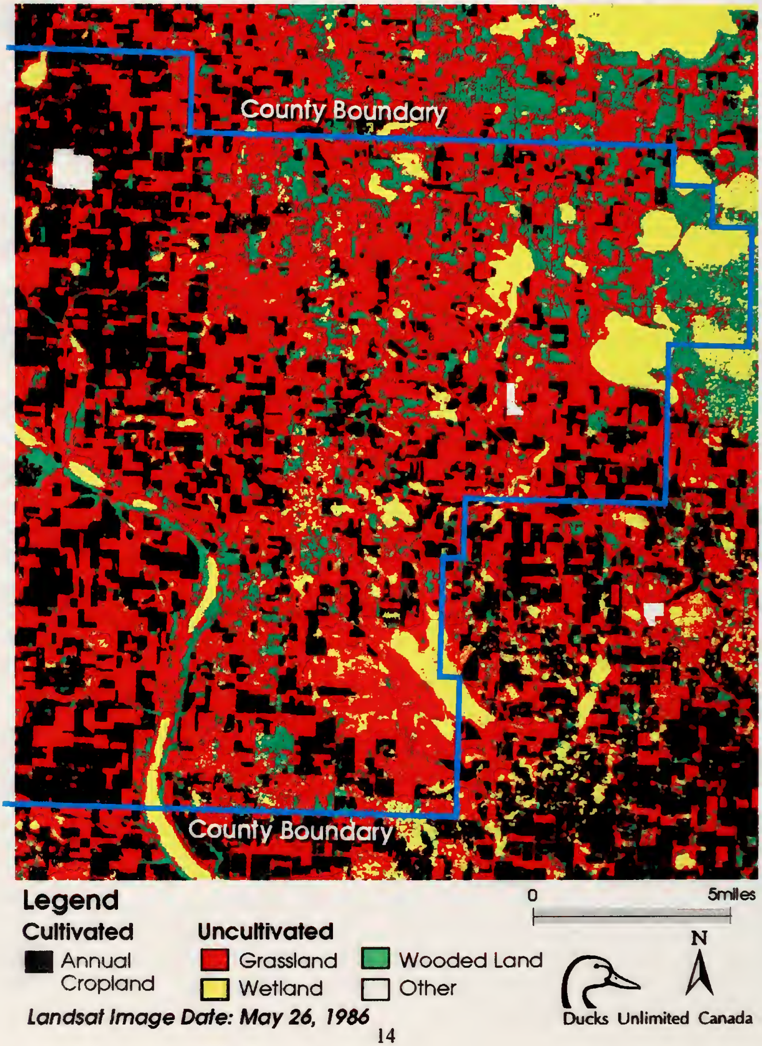
1 *Total area is calculated by the number of quarter sections by a constant size of 160 acres. This value is converted to a metric equivalent using a constant value of 0.4047 hectares per acre.*

The 4 land systems in the east are part of an hummocky upland with a moderate heat limitation for annual crop production and show differences in most land resource characteristics. Both Land Systems 1A and 1B are part of a medium textured plain of variable soil development. Land System 1A is a large unit with a significant amount of variable topography and soils developed near or under forest conditions. Land System 1B, a medium-sized unit with a slight heat limitation for annual crop production, is characterized by soils of the Solonetzic Order, a significant amount of poorly drained or gleyed soils and a slight heat limitation for annual crop production. Land System 2A is a large area with soils developed under a combination of grassland and forest conditions. Land System 2B is a medium-sized unit with soils developed under grassland conditions.

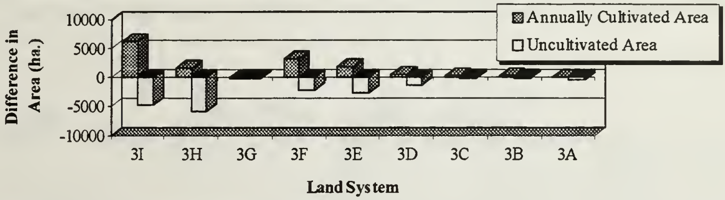
3.2.2 General Agricultural Land Use

The satellite image shows variation in the type and extent of land cover classes as well as field size and shape in the eastern part of the Morainal Areas region. Land System 1A has extensive areas interpreted as grassland (red) and forested (green), with the latter in large, generally rectangular blocks (Figure 9). A large water body consisting of open water and peripheral marsh vegetation (yellow) is evident in Land System 1B, as is the extensive area of grassland land (red). Annually cultivated land (black) is more evident in Land System 2A and occurs in generally rectangular fields. Land System 2B shows more annually cultivated area and uncultivated areas appear to be managed in generally rectangular fields.

Figure 9. Satellite Image of the Eastern Part of the Morainal Areas.

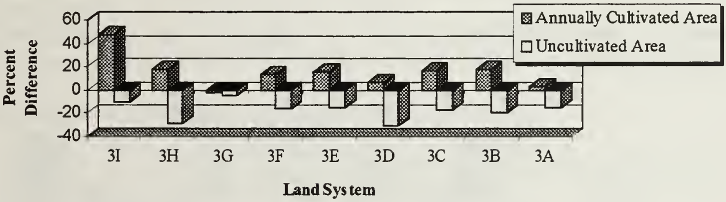


Comparison of the estimates of total land system area shows that the inventories provide similar information. Except for Land System 5A, estimates are within +/- 1500 hectares (Appendices 1 and 11; Figure 10) or +/- 15% (Appendix 11; Figure 11). Land System 5A, a large area of variable topography and lower quality land resources for annual crop production, reports a Census estimate that is 5000 hectares, or almost 20%, lower.



- Positive values indicate Census estimates that are larger than the satellite inventory.

Figure 10. Absolute Difference in Estimates of Total Area for Land Systems in the Morainal Areas.*



** - Positive values indicate Census estimates that are larger than the satellite inventory.*

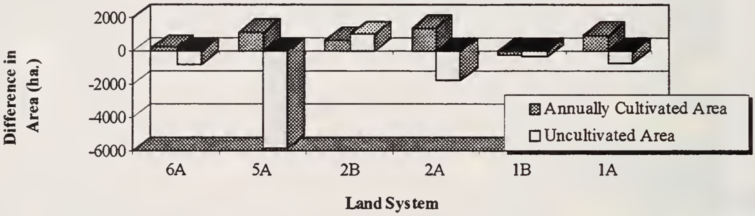
Figure 11. Relative Difference in Estimates of Total Area for Land Systems in the Morainal Areas.*

The following decisions are reached on the null hypotheses:

1. as **Rho** (calculated) is > **Rho** (critical), the null hypothesis that there is no statistically significant difference between the 2 inventories in estimates of total land system area is rejected and judgment is reserved on the alternative hypothesis (Appendix 12); and,
2. there are insufficient cases to conduct a Wilcoxon Matched-Pairs Signed-Ranks test.

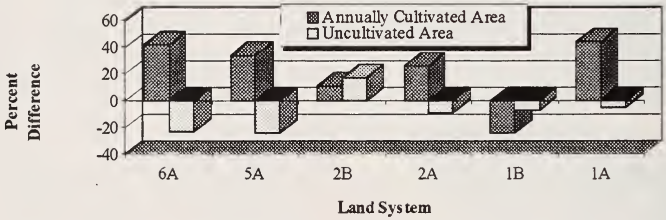
The results of the statistical analysis indicate that a statistically significant association may exist between the 2 inventories. Small differences in the ranking of land systems by total area are found in 2 of 6 cases (Appendix 12). In these 2 cases, both land systems are large units with variable topography.

Census estimates tend to be higher for annually cultivated area and lower for uncultivated area, relative to the satellite inventory. Census estimates of annually cultivated area are 2000 hectares (Appendix 13; Figure 12) or about 40% higher (Appendix 13; Figure 13). In the case of Land System 1B, a medium-sized plain of Solonetzic and gleyed soils, Census estimates are slightly lower in absolute terms but, given the small area of annually cultivated land estimated from the satellite image (just over a 1000 hectares), nearly 30% lower on a percentage basis.



** - Positive values indicate Census estimates that are larger than the satellite inventory.*

Figure 12. Absolute Difference in Estimates of General Land Use for Land Systems in the Morainal Areas.*



** - Positive values indicate Census estimates that are larger than the satellite inventory.*

Figure 13. Relative Difference in Estimates of General Land Use for Land Systems in the Morainal Areas.*

Lower estimates of uncultivated area are reported by the Census in 5 of 6 cases, relative to the satellite inventory. Generally, the Census estimates this area by up to 2000 hectares (Appendix 14; Figure 12) or about 20% (Appendix 14; Figure 13), relative to the satellite inventory. In the case of Land System 5A, the Census estimates for uncultivated area by almost 6000 hectares or about 25%, lower. Conversely, higher Census estimates of uncultivated area are found in Land System 2B by about 1000 hectares or nearly 20%.

The statistical analyses provide similar results for both annually cultivated and uncultivated area and indicate that:

1. as **Rho** (calculated) is > **Rho** (critical), the null hypotheses that there are no statistically significant difference between the 2 inventories in estimates of annually cultivated and uncultivated area are rejected and judgment is reserved on the alternative hypotheses (Appendices 15 and 16); and,
2. there are insufficient observations to conduct a Wilcoxon Matched-Pairs Signed-Ranks test.

The analysis shows that a statistically significant association may exist between the inventories with respect to estimates of annually cultivated and uncultivated area. Two differences in the ranking of land systems by extent of annually cultivated area are found, those being Land Systems 2A and 2B (Appendix 15), both land systems characterized by hummocky topography. No differences are found in the ranking of land systems by extent of uncultivated area (Appendix 16).

To summarize, the comparison shows that:

1. estimates are within +/- 1500 hectares, or +/- 15%;
2. a statistically significant association may exist between the inventories; and,
3. differences occur in large land systems with hummocky or variable topography.

In terms of annually cultivated and uncultivated area, the results show that:

1. the estimates are generally within 2000 hectares, or 40%, for annually cultivated area and about 2000 hectares, or 25% lower, for uncultivated area;
2. Census estimates for annually cultivated area tend to be larger;
3. Census estimates for uncultivated area tend to be lower;
4. statistically significant associations between the 2 inventories may exist; and,
5. differences in the ranking of land systems by extent of annually cultivated area occur in medium to large size land systems with hummocky topography.

4.0 Discussion

The results show that the satellite imagery and Census of Agriculture inventories can provide similar estimates of general agricultural land use within a land system. The estimates are very similar for land systems in the Lake Edmonton Basin, whether in terms of total land system area (i.e., +/- 1000 hectares; +/- 5 %), annually cultivated area (2000 hectares; 20%) and uncultivated area (2000 hectares; 20%). There is also evidence of statistically significant associations between the inventories and no statistically significant difference in the magnitude and direction of estimates at the 95% confidence level. Similar estimates of general agricultural land use provides justification for the integration of data from the inventories into a more complete database for rural planning, as discussed in the first subsection.

The comparison also shows that differences in estimates of general agricultural land use do occur between the satellite imagery and Census inventories. Larger differences in estimates are found for larger land systems in both regions that have lower quality land resources and less extensive annual crop production. For instance, for land systems in the Morainal Areas region compared to the Lake Edmonton Basin, larger differences are reported for total land system (+/- 1500 hectares; +/- 15%), annually cultivated area (40%) and uncultivated area (25%). These results indicate that land resource and land use characteristics may have differential affects on the satellite and Census inventories, as discussed in the second subsection.

4.1 An Integrated Database for Rural Land Use Planning

Rural planners use satellite and Census inventories to define and describe areas of similar land use, or regions, within a municipality. Planners take a regional approach because it helps them to develop and adapt policies to the particular land use patterns within a municipality. An integrated land use database, based on the strengths of satellite imagery and Census of Agriculture inventories, would provide at least 2 benefits to the planning community, including:

1. a more complete description of agricultural land use in landscapes appropriate to municipal planning; and,
2. the opportunity to develop a more co-operative rural planning process.

These potential benefits are described in this subsection in the context of a current rural planning issue, that being the assessment of rural landscapes for waterfowl habitat in areas of extensive annual crop production.

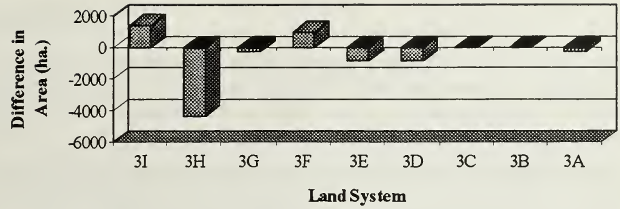
Waterfowl habitat planners presently use an effective planning process to design and target treatment programs to broad landscapes. They use a model, termed the 'Computer Planning Tool (CPT)', to measure the benefit/cost ratio of a suite of habitat treatments within a large area (Conchatre et al. 1987). For a specific landscape, the model allows planners to examine potential increases in the mallard population in response to changes in upland nesting habitats. It essentially determines the incremental costs of alternative land management scenarios relative to the expected incremental increase in waterfowl production. Planners use information from the CPT in conjunction with other information sources not only to design treatment programs suited to the particular characteristics of a broad landscape but also to allocate finite program expenditures to those projects with the highest relative biological and economic returns. However, application of the model and planning process to smaller landscapes has been restricted in part because the specific land use data required to run the CPT has not been consistently available at this scale. An integrated database, using satellite and Census inventories by land system, could address these current limitations in the availability of specific land use data for habitat planning in a municipality.

An integrated database could help habitat planners assess the relative returns from, and most likely locations for, different treatment programs within relatively small landscapes in a municipality. The Census provides a refined breakdown of the various types of land uses, information that is of assistance in running the CPT. Planners can use Census data on, for example, the extent of uncultivated land in terms of hay as well as improved and unimproved pasture, in the CPT. Model output would help to determine both the treatments with the highest benefit/cost ratio (i.e., largest incremental increase in waterfowl production per dollar expended) and the types of uncultivated land associated with each treatment. Planners could then use the satellite inventory to determine, with a high degree of accuracy, the spatial distribution of uncultivated land within a particular land system. Staff could then be directed to specific locations within a land system to verify the type of uncultivated land and the treatment programs most suited to it. A more complete description of the land resource and land use characteristics of interest to habitat planners is not the only benefit of an integrated database. Further research may indicate additional opportunities for co-operation between habitat and agricultural resource planners.

Complementary information from satellite imagery and Census inventories provides an opportunity for greater co-operation between waterfowl habitat and agricultural resource planners. The inventories discussed in this study are important, but not exclusive, databases in habitat and agricultural land use planning. There may be other databases that are mutually beneficial to both groups as they examine different uses of the same rural resource base. In addition, the habitat planning process described above, in that it can be strongly influenced by present agricultural land use, is of interest to agricultural planners. An examination of the databases and planning processes used by these planning groups could produce more beneficial linkages in the future.

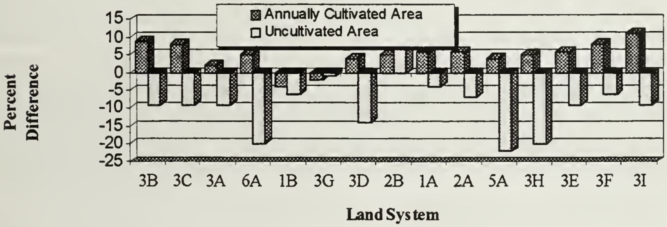
4.2 Future Research

Three patterns are noted in a examination of estimates of annually cultivated and uncultivated area by size of the land system, patterns that may be related to the land resource and land use characteristics of the land systems. The first pattern noted is a larger absolute differences between the inventories in estimates of general agricultural land use for larger land systems (Appendix 17; Figure 14). As discussed in the Results section, the larger land systems in the municipality have similar land resource and land use characteristics, including lower quality land resources and less extensive annual cultivation, compared to the smaller land systems. The second pattern is a trend to a consistent relative difference in estimates of annually cultivated area, at about 10% (Appendix 17; Figure 15). The third pattern is variability between the inventories in absolute and relative estimates of uncultivated area (Appendix 17; Figures 15, 16). At least 3 research hypotheses may help to determine whether these patterns indicate the affect of land resource and land use characteristics on the satellite imagery and Census inventories and, therefore, the similarity of estimates of general agricultural land use from them.



** - Positive values indicate Census estimates that are larger than the satellite inventory.*

Figure 14. Absolute Differences in Estimates of General Land Use by Size of Land System.*



** - Positive values indicate Census estimates that are larger than the satellite inventory.*

Figure 15. Relative Difference in Estimates of General Land Use by Size of Land System.*

The first research hypothesis concerns spectral confusion in the satellite data, a factor that may be associated with the size, land resource and land use characteristics of land systems. Spectral confusion is the result of variation in spectral response within a uniform land cover class. For instance, a field of wheat may have different spectral responses, depending on the general conditions at planting, variation in factors that either positively or negatively effect the growth of the crop, date of imagery and so forth. It is hypothesized that spectral confusion may be greater in land systems with lower quality land resources for annual crop production. These units show more variability not only in the land resource characteristics that define them but also in the spatial distribution of those characteristics, compared to the smaller land systems of the Lake Edmonton Basin. These characteristics effect crop growth, and by extension, the spectral response expected from fields within the land systems. Future research, through comparative studies of the variability in spectral response as related to different land systems and land cover classes, will test the validity of this hypothesis.

The second research hypothesis concerns mixed pixels, a factor that is also affected by the size as well as resource and land use characteristics of land system. A mixed pixel is produced when more than one land cover type is located within the area on the ground being sensed by the detector (Lillesand and Keifer 1994). For instance, a mixed pixel will result from sensing the boundary between cultivated and uncultivated areas. For a given ground resolution cell size, the number of mixed pixels varies with the complexity, size and geometry of different land cover types (Pitts and Badhwar 1980; Cihlar 1988). In this study, more variation in field size, shape and cover class is found in the larger land systems with lower quality land resources. Future research, using higher resolution satellite imagery, be used to test this hypothesis that less regularity in the geometry of fields in larger land systems is contributing to increase in the number of mixed pixels.

The third research hypothesis concerns the potential for a bias in the reporting of total farm area in land systems with lower quality land resources. The farm headquarters processing technique assigns all of the production information that a farmer reports on a Census questionnaire to the location of the main farm buildings. The technique will not bias estimates of general agricultural land use, relative to the satellite inventory, when the majority of farmers have most of their land base within a land system. However, large differences between the inventories in estimates of the total area, as well as variation in estimates of uncultivated area, are found in large land systems with lower quality land resources. It is hypothesized that farmers in land systems with lower quality land resources may be working, and reporting, more land outside of the unit to the farm headquarters, relative to farmers in the smaller land systems of the Lake Edmonton Basin.

Due to the confidentiality of Census data, it is not possible to directly test this hypothesis. However, future research may refine existing, and provide new, techniques to indicate land systems susceptible to this potential bias. In this study, the comparative analysis of estimates from different inventories is one technique to identify possible discrepancies related to the Census processing technique. As well, a comparison of total farm area to the total land system area has been used in this context (Hiley et al. 1994). Further study is required to determine if a number of Census variables may be used to indicate production systems that typically use land at some distance from the farm headquarters. For example, unconfined beef cattle operations may use grazing lands outside of a land system. This type of livestock operation can be identified by a number of Census variables, including the extent of uncultivated area, the number of farms reporting beef cattle, the type of beef cattle and the total number of beef cattle. Other sources of data may also be referenced, such as a land ownership maps and local expertise, to determine the prevalence of these types of operations in land systems with lower quality land resources and the extent to which lands outside of a land system are consistently used for these production systems.

5.0 Conclusions

Overall, very similar estimates of general land use are found between the satellite and Census of Agriculture inventories for land systems in the County of Leduc, Alberta. The estimates are very similar because:

1. generally small absolute and relative differences are noted in total land system area as well as cultivated and uncultivated area;
2. there is evidence of a number of statistically significant associations between the 2 inventories; and,
3. there is no evidence of statistically significant differences in the magnitude and direction of estimates of annually cultivated and uncultivated area for land systems in the Lake Edmonton Basin.

A number of specific conclusions are reached, including:

1. the estimates are very similar in a region where the land resources are generally homogeneous, of high quality for annual crop production and have been extensively cultivated on an annual basis;
2. the estimates are less similar in land systems that have lower quality land resources and extensive areas of uncultivated land;
3. the estimates may not be identical due to a 'margin of error' associated with technical factors of each inventory;
4. the inventories provide estimates that are within +/- 3000 hectares (+/- 15%) for total land system area, 2000 hectares (20 to 40%) for annually cultivated area and 2000 hectares (25%) for uncultivated area;
5. systematic differences in estimates of annually cultivated and uncultivated area may be related to spectral confusion and mixed pixels in the satellite inventory; and,
6. less systematic differences in estimates of general agricultural land use may be related to the farm headquarters processing technique used to assign Census data to land systems.

6.0 References Cited

Agriculture Canada. 1976. ***Glossary of terms in soil science.*** Ottawa: Agriculture Canada, Research Branch. Publication 1459, revised. 44 pages.

Alberta Soils Advisory Committee. 1987. ***Land capability classification for arable agriculture in Alberta (1987).*** W.W. Pettapiece (ed.). Edmonton: Alberta Agriculture. 103 pages, 1 map.

Brierley, J. A., J. Kwiatkowski and L.C. Marciak. 1992. ***Land systems within the County of Stettler, Alberta.*** Edmonton: Agriculture Canada and Alberta Agriculture. Centre for Land and Biological Resources Research Contribution No. 92-205. 55 pages.

Cihlar, J. 1988. *Area measurements of agricultural fields from satellite images.* ***Canadian Journal of Remote Sensing.*** Vol. 14, No. 2, December, 1988. pp. 110-116.

Conchatre, M., B. Kazmerik, W. Cowan, J. Nelson, B. Wark and R. Wishart. 1987 ***North American waterfowl management plan computer planning tool (CPT); a users' manual.*** Winnipeg: Ducks Unlimited Canada. 33 pages.

Dangermond, J. 1992. *What is a geographic information system (GIS)?* ***in*** Geographic Information Systems (GIS) and Mapping - Practices and Standards, ***ASTM SPP 1126.*** Philadelphia: American Society for Testing and Materials. pp. 11-17.

Freund, J.E. 1979. ***Modern elementary statistics (fifth edition).*** Englewood Cliffs, N.J.: Prentice-Hall, Inc. 510 pages.

Hiley, J.C., G.T. Patterson, G.K. Peterson, W.W. Pettapiece and R.L. Wehrhahn. 1986. ***SIDMAP: Soil inventory database for management and planning: development, applications and evaluation.*** Edmonton: University of Alberta. Alberta Institute of Pedology No. M-86-1. 25 pages.

------- and E.C. Huffman. 1993. A *land use analysis and monitoring system to assess soil quality.* in D.F. Acton (ed.). ***A program to assess and monitor soil quality in Canada: final report.*** Ottawa: Agriculture Canada. Centre for Land and Biological Resources Research Contribution No. 93-49. 155 pages.

------- , L.C. Marciak, D.L. Beever and C.R. King. 1994. ***Agricultural production profiles of land systems within the County of Stettler, Alberta.*** Edmonton: Agriculture and Agri-Food Canada and Alberta Agriculture, Food and Rural Development. Land and Biological Resources Research Centre Cont. No. 94-34. 55 pages.

Holland, S.S. 1976. ***Landforms of British Columbia, a physiographic outline.*** Vancouver: British Columbia Department of Mines and Petroleum Resources. Bulletin 48. 138 pages.

Koeln, G.T., P. Caldwell, D.E. Wesley and J.E. Jacobson. 1986. *Inventory of wetlands with LANDSAT's thematic mapper.* in **Proceedings** of the 10th Canadian Symposium on Satellite. Edmonton: Alberta. pages 153-162.

Lillesand, T.M. and R.W. Kiefer. 1994. ***Satellite and image interpretation third edition.*** New York: J. Wiley and Sons, Inc. 750 pages.

MCPPP (Municipal Conservation Planning Pilot Project). 1993. ***County of Stettler, Alberta, municipal soil and water conservation plan.*** Edmonton: Agriculture Canada and Alberta Agriculture, Food and Rural Development. 124 pages.

Pitts, D.E. and G. Badhwar. 1980. *Field size, length and width distributions based on LACIE ground truth data.* ***Remote Sensing of the Environment.*** 10:201-213 (1980).

Siegel, S. 1956. ***Non-parametric statistics for the behavioural sciences.*** New York: McGraw-Hill. 156 pages.

Statistics Canada. 1986. ***Agriculture: Alberta Catalogue 96-111.*** Ottawa: Ministry of Supply and Services. 216 pages.

Stewart, Weir and Co. 1982. ***Land ownership map of the County of Leduc.*** Edmonton: Stewart, Weir and Co. 1 map.

7.0 Glossary of Terms

Agroclimate zone - A classification for general agricultural assessments following a recognized system in Alberta (Alberta Soils Advisory Committee 1987). The classification is based on heat and moisture factors affecting dryland crop production.

Biophysical landscape unit - A land unit defined on the basis of characteristics that affect biological production. They are based on the land resource characteristics of agroclimate zone, texture of the parent material, topography and soil development.

Characteristic - A concept that describes one aspect of an object under study. For example, topography is a characteristic of a biophysical landscape unit.

Chernozemic - A grassland and parkland soil developed under semi-arid conditions. See Agriculture Canada (1976) for a formal definition.

Cropland - A variable derived from the Census. It refers to the total area of: crops seeded or to be seeded in 1986; tree fruits; cultivated berries, grapes, vegetables, sod and nursery products for sale; and, summerfallow.

Cultivated Area - A variable derived from the Census and satellite inventories. In this study it is equal to the area of cropland less the area of tame hay. In the satellite inventory, it is equal to the area of annually cultivated land, as represented by areas with very little vegetation.

Extensive - Having a wide extent. In this study, it is an adjective to describe the area of different land uses.

Geographic information system (GIS) - A set of computer hardware, software and geographic data designed to efficiently capture, store, update, manipulate, analyze and display geographically referenced information (Dangermond 1992).

Gleyed - A soil developed under saturated conditions for some period of each year. See Agriculture Canada (1976) for a formal definition.

Hummocky - A complex pattern of bowl shaped depressions (or 'kettles') and irregular to conical hills (or 'knobs'). See Agriculture Canada (1976) for a formal definition.

Large land system - a land system with a total area of greater than 10,000 hectares.

Luvisolic - A soil developed under forested conditions. See Agriculture Canada (1976) for a formal definition.

Medium texture - Intermediate class between fine and coarse texture (usually referring to parent material). It includes the following textural classes: very fine sandy loam; loam silt; and, silt. See Brierley et al. (1992) for a formal definition.

Medium-sized land system - a land system with a total area between 5,000 and 10,000 hectares.

Mixed Pixel - Pixels containing more than one cover type (Lillesand and Kiefer 1994).

Parent material - The unconsolidated and more or less chemically weathered mineral or organic matter from which the solum of a soil is developed by pedogenic processes (Agriculture Canada 1976).

Physiographic region (district) - A physiographic subdivision based upon the recognition of areas of similar landforms (Holland 1976).

Pixel - a 2 dimensional array of discrete picture elements, generally containing a record of the relative intensity of energy returning to a sensor (Lillesand and Kiefer 1994).

Small land system - a land system with a total area of less than 5,000 hectares.

Soil zone - A large geographic area with similar soil characteristics due to the influences of climate, vegetation and topography. For example, soils in the Black soil zone have more organic matter, and a darker colour, than soils in the Dark Brown soil zone. These differences in natural organic matter levels are influenced by the greater biological activity in the former zone.

Solonetzic - A poor quality grassland and parkland soil. It is affected by the accumulation of sodium salts in the root zone. See Agriculture Canada (1976) for a formal definition.

Total farm area - A variable derived from both inventories. In the Census inventory it includes the sum of: summerfallow; improved pasture; other improved land; unimproved land for pasture, grazing or hay; woodland; and, other improved land. In the satellite inventory, it is the sum of all lands assigned to a land system.

Uncultivated area - A variable derived from both inventories. In the Census inventory it includes the sum of: other improved land; unimproved land for pasture, grazing or hay; woodland; and, other improved land. In the satellite inventory, it is the sum of all lands interpreted as uncultivated, as presented in Table 2.

8.0 Appendices

Appendix 1. Estimates of Total Land System Area Using Census and Land Ownership Inventories.

Land System	Data Source		Total Area
	Census (hectares)	Ownership Map (hectares)	(hectares)
1A	13095	4026	17121
1B	4112	1153	5265
2A	20574	2678	23252
2B	12220	839	13059
3A	2823	774	3597
3B	2579	28	2607
3C	2820	16	2836
3D	8242	0	8242
3E	26043	3624	29667
3F	36441	3313	39754
3G	7762	0	7762
3H	24110	647	24757
3I	52652	3818	56470
5A	18651	3495	22146
6A	2944	388	3332
Total	235056	24800	259856

Appendix 2. Lake Edmonton Basin - Estimates of Total Area for Land Systems in the Lake Edmonton Basin.

Land System	Data Source		Difference	
	Census (hectares)	Satellite (hectares)	Hectares	Percent
3A	3597	3892	-295	4
3B	2607	2611	-4	0
3C	2836	2859	-23	0
3D	8242	9146	-904	-10
3E	29667	30531	-864	-3
3F	39754	38757	997	3
3G	7761	8050	-289	-4
3H	24747	29076	-4329	-15
3I	56470	55078	1392	3
Total	175682	180005	-4323	-2

Appendix 3. Spearman Rank Correlation Coefficient for Lake Edmonton Basin - Total Land System Area.

1. Hypotheses to be Tested.

Null Hypothesis- there is no statistically significant association between the 2 inventories in estimates of total land system area.

Alternative Hypothesis- there is a statistically significant association between the 2 inventories.

2. Calculation of Spearman Rank Correlation Coefficient (Rho)

Land System	**Ranking by Data Source**		**$(\text{Difference})^2$**
	Census	Satellite	**$(d)^2$**
3A	[illegible]	3	0
3B	1	[illegible]	0
3C	2	2	0
3D	5	5	0
3E	7	7	0
3F	8	8	0
3G	4	4	0
3H	6	6	0
3I	9	9	0
		Total	0

Rho $= 1 - (6 * (\mathbf{d})^2) / N^3 - N$ where $N = 9$
$= 1.000$

3. Test of the Significance of **Rho**

Degree of confidence $= 0.05$
Rho (calculated) $= 1.000$
N $= 9$
Rho (critical) $= 0.600$

4. Decision Concerning Spearman Rank Correlation Coefficient

As **Rho** (calculated) is > **Rho** (critical), the null hypothesis is rejected and judgment is reserved on the alternative hypothesis.

Appendix 4. Wilcoxon Matched-Pairs Signed-Ranks Test for Lake Edmonton Basin - Comparison of Total Land System Area.

1. Hypotheses to be Tested.

Null Hypothesis- there is a statistically significant difference in the magnitude and direction of ranks between the 2 data sources.

Alternative Hypothesis- there is not a statistically significant difference between the 2 data sources.

2. Calculation of Wilcoxon Matched-Pairs Signed-Ranks (**T**) Statistic.

Land System	Difference (hectares)	Rank	Sign	Sum of Ranks with Less Frequent Sign
3B	4	1	-	0
3C	23	2	-	0
3G	289	3	-	0
3A	295	4	-	0
3E	864	5	-	0
3D	904	6	-	0
3F	997	7	+	7
3I	1392	8	+	8
3H	4329	9	-	0
			T	15

3. Test of the Significance of **T**

Degree of confidence = 0.05
T (calculated) = 15
N = 9
T (critical) = 6

4. Decision Concerning Wilcoxon Matched-Pairs Signed-Ranks Statistic.

As **T** (calculated) is > **T** (critical), the null hypothesis is not rejected.

Appendix 5. Lake Edmonton Basin - Estimates of Annually Cultivated Area.

Land System	Data Source		Difference	
	Census (hectares)	Satellite (hectares)	Hectares	Percent
3A	1661	1615	46	3
3B	1592	1348	244	18
3C	1584	1358	226	17
3D	5423	5049	374	7
3E	14067	12149	1918	16
3F	28240	25075	3165	13
3G	5354	5521	-167	-3
3H	10146	8561	1585	18
3I	19317	13170	6147	47
Total	87383	73846	13537	18

Appendix 6. Lake Edmonton Basin - Estimates of Uncultivated Area.

Land System	Data Source		Difference	
	Census (hectares)	Satellite (hectares)	Hectares	Percent
3A	1936	2282	-346	-15
3B	1016	1263	-247	-20
3C	1252	1502	-250	-17
3D	2819	4097	-1278	-31
3E	15600	18382	-2782	-15
3F	11514	13682	-2168	-16
3G	2408	2528	-120	-5
3H	14601	20515	-5914	-29
3I	37153	41907	-4754	-11
Total	88299	106159	-17860	-17

Appendix 7. Spearman Rank Correlation Coefficient for Lake Edmonton Basin - Comparison of Annually Cultivated Land.

1. Hypotheses to be Tested.

Null Hypothesis- there is no statistically significant association between the 2 data sources in estimates of annually cultivated area.

Alternative Hypothesis- there is a statistically significant association between the 2 data sources.

2. Calculation of Spearman Rank Correlation Coefficient (**Rho**)

Land System	**Ranking by Data Source**		**(Difference)^2**
	Census	Satellite	**(d)^2**
3A	3	4	0
3B	2	1	1
3C	1	2	1
3D	5	4	1
3E	7	7	0
3F	9	4	0
3G	4	5	1
3H	6	6	0
3I	8	8	0
		Total	4

Rho $= 1 - (6 * (\mathbf{d})^2) / N^3 - N$ where $N = 9$
$= 0.97$

3. Test of the Significance of **Rho**

Degree of confidence = 0.05
Rho (calculated) = 0.97
N = 9
Rho (critical) = 0.600

4. Decision Concerning Spearman Rank Correlation Coefficient

As **Rho** (calculated) is > **Rho** (critical), the null hypothesis is rejected and judgment is reserved on the alternative hypothesis.

Appendix 8. Spearman Rank Correlation Coefficient for Lake Edmonton Basin - Comparison of Uncultivated Area.

1. Hypotheses to be Tested.

Null Hypothesis- there is no statistically significant association between the 2 data sources in estimates of total land system area.

Alternative Hypothesis- there is a statistically significant association between the 2 data sources.

2. Calculation of Spearman Rank Correlation Coefficient (**Rho**)

Land System	**Ranking by Data Source**		**(Difference)^2**
	Census	Satellite	**(d)^2**
3A	3	3	0
3B	1	1	0
3C	2	2	0
3D	5	5	0
3E	8	7	1
3F	6	6	0
3G	4	4	0
3H	7	8	1
3I	9	9	0
		Total	2

Rho $= 1 - (6 * (\mathbf{d})^2) / N^3 - N$ where $N = 9$
$= 0.983$

3. Test of the Significance of **Rho**

Degree of confidence = 0.05
Rho (calculated) = 0.983
N = 9
Rho (critical) = 0.600

4. Decision Concerning Spearman Rank Correlation Coefficient

As **Rho** (calculated) is > **Rho** (critical), the null hypothesis is rejected and judgment is reserved on the alternative hypothesis.

Appendix 9. Wilcoxon Matched-Pairs Signed-Ranks Test for Lake Edmonton Basin - Comparison of Annually Cultivated Area.

1. Hypotheses to be Tested.

Null Hypothesis- there is a statistically significant difference in the magnitude and direction of ranks between the 2 data sources.

Alternative Hypothesis- there is not a statistically significant difference between the 2 data sources.

2. Calculation of Wilcoxon Matched-Pairs Signed-Ranks (T) Statistic.

Land System	Difference (hectares)	Rank	Sign	Sum of Ranks with Less Frequent Sign
3A	46	1	+	0
3G	167	2	-	2
3C	226	4	+	0
3B	244	4	+	0
3D	374	5	+	0
3H	1585	6	+	0
3E	1918	7	+	0
3F	3165	8	+	0
3I	6147	9	+	0
			T	2

3. Test of the Significance of **T**

Degree of confidence = 0.05
T (calculated) = 2
N = 9
T (critical) = 6

4. Decision Concerning Wilcoxon Matched-Pairs Signed-Ranks Statistic.

As **T** (calculated) is < **T** (critical), the null hypothesis is rejected and judgment is reserved on the alternative hypothesis.

Appendix 10. Wilcoxon Matched-Pairs Signed-Ranks Test for Lake Edmonton Basin - Comparison of Uncultivated Area.

1. Hypotheses to be Tested.

Null Hypothesis- there is a statistically significant difference in the magnitude and direction of ranks between the 2 data sources.

Alternative Hypothesis- there is not a statistically significant difference between the 2 data sources.

2. Calculation of Wilcoxon Matched-Pairs Signed-Ranks (**T**) Statistic.

Land System	Difference (hectares)	Rank	Sign	Sum of Ranks with Less Frequent Sign
3G	120	1	-	0
3B	247	2	-	0
3C	250	3	-	0
3A	346	4	-	0
3D	1278	5	-	0
3F	2168	5	-	0
3E	2782	7	-	0
3I	4754	8	-	0
3H	5914	9	-	0
			T	0

3. Test of the Significance of **T**

Degree of confidence = 0.05
T (calculated) = 0
N = 9
T (critical) = 6

4. Decision Concerning Wilcoxon Matched-Pairs Signed-Ranks Statistic.

As **T** (calculated) is < **T** (critical), the null hypothesis is rejected and judgment is reserved on the alternative hypothesis.

Appendix 11. Morainal Areas - Estimates of Total Land System Area.

Land System	Data Source		Difference	
	Census (hectares)	Satellite (hectares)	Hectares	Percent
1A	17120	16895	225	1
1B	5265	5867	-602	-10
2A	23252	23632	-380	-2
2B	13058	11446	1612	14
5A	22146	26859	-4749	-18
6A	3332	3941	-609	-15
Total	84174	88639	-4465	-5

Appendix 12. Spearman Rank Correlation Coefficient for Morainal Areas - Comparison of Total Land System Area.

1. Hypotheses to be Tested.

Null Hypothesis- there is no statistically significant association between the 2 data sources in estimates of total land system area.

Alternative Hypothesis- there is a statistically significant association between the 2 data sources.

2. Calculation of Spearman Rank Correlation Coefficient (**Rho**).

Land System	**Ranking by Data Source**		**(Difference)^2**
	Census	Satellite	**(d)^2**
1A	4	4	0
1B	2	2	0
2A	6	5	1
2B	3	3	0
5A	5	6	1
6A	1	1	0
		Total	2

Rho $= 1 - (6 * (\mathbf{d})^2) / N^3 - N$ where $N = 6$
$= 0.943$

3. Test of the Significance of **Rho**

Degree of confidence = 0.05
Rho (calculated) = 0.943
N = 6
Rho (critical) = 0.828

4. Decision Concerning Spearman Rank Correlation Coefficient

As **Rho** (calculated) is > **Rho** (critical), the null hypothesis is rejected and judgment is reserved on the alternative hypothesis.

Appendix 13. Morainal Areas - Estimates of Annually Cultivated Area.

Land System	Data Source		Difference	
	Census (hectares)	Satellite (hectares)	Hectares	Percent
1B	3060	2122	938	44
1B	783	1034	-251	-24
2A	6583	5223	1360	26
2B	6126	5514	612	11
5A	4304	3210	1094	34
6A	653	460	193	42
Total	21510	17565	3945	22

Appendix 14. Morainal Areas - Estimates of Uncultivated Area.

Land System	Data Source		Difference	
	Census (hectares)	Satellite (hectares)	Hectares	Percent
1A	14060	14773	-713	-5
1B	4482	4832	-350	-7
2A	16669	18409	-1740	-9
2B	6932	5931	1001	17
5A	17842	23649	-5807	-24
6A	2679	3480	-801	-23
Total	62664	71074	-8410	-12

Appendix 15. Spearman Rank Correlation Coefficient for Morainal Areas - Comparison of Annually Cultivated Area.

1. Hypotheses to be Tested.

Null Hypothesis- there is no statistically significant association between the 2 data sources in estimates of total land system area.

Alternative Hypothesis- there is a statistically significant association between the 2 data sources.

2. Calculation of Spearman Rank Correlation Coefficient (**Rho**).

Land System	**Ranking by Data Source**		**$(\text{Difference})^2$**
	Census	Satellite	$(\mathbf{d})^2$
1A	3	3	0
1B	2	2	0
2A	6	5	1
2B	5	6	1
5A	4	4	0
6A	1	1	0
		Total	2

Rho $= 1 - (6 * (\mathbf{d})^2) / N^3 - N$ where N = 6
$= 0.983$

3. Test of the Significance of **Rho**

Degree of confidence = 0.05
Rho (calculated) = 0.983
N = 6
Rho (critical) = 0.828

4. Decision Concerning Spearman Rank Correlation Coefficient

As **Rho** (calculated) is > **Rho** (critical), the null hypothesis is rejected and judgment is reserved on the alternative hypothesis.

Appendix 16. Spearman Rank Correlation Coefficient for Morainal Areas - Comparison of Uncultivated Area.

1. Hypotheses to be Tested.

Null Hypothesis- there is no statistically significant association between the 2 data sources in estimates of total land system area.

Alternative Hypothesis- there is a statistically significant association between the 2 data sources.

2. Calculation of Spearman Rank Correlation Coefficient (**Rho**).

Land System	**Ranking by Data Source**		**(Difference)** ^{2}
	Census	Satellite	$(\mathbf{d})^2$
1A	4	4	0
1B	2	2	0
2A	5	5	0
2B	3	3	0
5A	6	6	0
6A	1	1	0
		Total	0

Rho $= 1 - (6 * (\mathbf{d})^2) / N^3 - N$ where N = 6
$= 1.000$

3. Test of the Significance of **Rho**

Degree of confidence = 0.05
Rho (calculated) = 1.000
N = 6
Rho (critical) = 0.828

4. Decision Concerning Spearman Rank Correlation Coefficient

As **Rho** (calculated) is > **Rho** (critical), the null hypothesis is rejected and judgment is reserved on the alternative hypothesis.

Appendix 17. Absolute and Relative Differences in Estimates of Total Area and General Land Use by Size of Land System.

Land System	Total Area	Absolute Difference		Relative Difference	
		Cultivated Area	Uncultivated Area	Cultivated Area	Uncultivated Area
	hectares	hectares	hectares	percent	percent
3B	2611	244	-247	9	-9
3C	2859	226	-250	8	-9
3A	3892	46	-346	2	-9
6A	3941	193	-801	5	-20
1B	5867	-251	-350	-4	-6
3G	8050	-167	-120	-2	-1
3D	9146	374	-1278	4	-14
2B	11446	612	1001	5	9
1A	16895	938	-713	6	-4
2A	23632	1360	-1740	6	-7
5A	26859	1094	-5807	4	-22
3H	29076	1585	-5914	5	-20
3E	30531	1918	-2782	6	-9
3F	38757	3165	-2168	8	-6
3I	55078	6147	-4754	11	-9