REMOTE SENSING FOR RESOURCES MANAGEMENT: TO ASSESS POST-HARVEST GROUND COVER CONDITIONS IN THE SOUTH INTERLAKE REGION OF MANITOBA

by

© Joan Simonton

A Practicum Submitted in
Fulfillment of the Requirements for the Degree
Master of Natural Resource Management

The Natural Resources Institute
University of Manitoba, Winnipeg, Manitoba
June 30, 1988

ISBN 0-315-47844-6

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ABSTRACT

Remote sensing provides a means of obtaining accurate and timely information on the location, extent, and condition of the agricultural land base. This study assessed the value of remote sensing techniques in providing reliable, and detailed distribution patterns and area values for post-harvest ground cover conditions in the South Interlake region of Manitoba.

The methodology used involved a series of stages based on a computer classification of an October 20, 1986 Landsat 5 TM image in conjunction with ancillary data on soil texture criteria and field measurements and observations collected two weeks prior. 42.14% of the study area was classified as crop residue, 63.96% of which was classified as having 33%-66% crop residue cover, 25.74% as 0%-33% crop residue cover or bare soil, and 10.3% as 67%-100% crop residue cover or stubble. The results of the classification revealed that the crop residue cover types of interest were spectrally separable, and that the information generated (thematic maps and area values) will serve as a basis for future monitoring and management of the agriculture land in the South Interlake.

ACKNOWLEDGEMENTS

I would like to thank the members of my committee for their time, insightful comments, and direction: Mr. Bryan Yusishen, South Interlake Land Management Association; Mr. Floyd Wilson, South Interlake Land Management Association; Mr. Hartley Pokrant, Manitoba Remote Sensing Centre; Dr. Carl Shaykewich, Department of Soil Science, University of Manitoba; and Dr. Walter Henson, Director of the Natural Resources Institute.

My sincere thanks are extended to the staff at the Manitoba Remote Sensing Centre for all their time, support, and guidance.

Financial support was provided by both the South Interlake Land Management Association (SILMA) and the Natural Resources Institute and is acknowledged with gratitude.

I express my appreciation to the Faculty and Staff of the Natural Resources Institute for their guidance throughout the two year practicum process. A special thanks to my fellow students for their support, understanding and friendships.

Finally, I thank my best friend and husband, Dave, whose encouragement and moral and financial support made this process that much easier.

ACRONYMS USED IN TEXT

ARIES	Applied Resource Image Exploitation System
CCRS	Canadian Centre for Remote Sensing
CCT	Computer Compatible Tape
EMS	Electromagnetic Spectrum
ERTS	Earth Resources Technology Satellite
HRV	High Resolution Visible
IFOV	Instantaneous Field Of View
IR	Infrared
LACIE	Large Area Crop Inventory Experiment
LANDSAT	Earth Observation Satellite
MDA	Manitoba Department of Agriculture
MRSC	Manitoba Remote Sensing Centre
MSS	Multispectral Scanner
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmosphere Administration
PFRA	Prairie Farm Rehabilitation Administration
SILMA	South Interlake Land Management Association
SPOT	Systeme Probatoire d'Obersvation de la Terre
TM	Thematic Mapper

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CHAPTER I

INTRODUCTION

1.1 PREAMBLE

In its report, Soil at Risk 1984, the Standing Committee on Agriculture expressed their concerns for soil degradation and its direct effects on the agriculture industry. The Senate Committee called soil erosion "the most serious agricultural crisis" in Canadian history. The Committee concluded that Canada risked the permanent loss of a large portion of its agricultural capability if a major committment to conserving the soil was not made immediately by all levels of government. Farming practices on the Canadian Prairies, for decades, have stressed short-term health and maintenance of the land. As a result, prairie soils now face a number of serious threats: erosion, salinity, and organic matter loss.

Soil erosion reduces the natural productivity of Prairie farmland. In Western Canada 5.2 million hectares or fourteen per cent of the improved farmland in the region have lost large amounts of topsoil because of erosion. If losses continue at the same rate, an additional 1.1 million hectares could be affected by the year 2008 (Anderson et. al., 1984). One of the major causes of erosion is excess tillage of farmland. Intensive cultivation in the fall to apply herbicides and fertilizers or to speed spring planting makes soil prone to wind and water erosion. Controlling erosion means protecting soil from the destructive effects of wind and water.

One of the most promising techniques developed to reduce wind and water erosion and for preserving soil organic matter is conservation tillage (Soils at Risk, 1984). Conservation tillage is a planting and tillage system that retains at least 30 per cent crop residue cover on the soil surface (Magleby et. al., 1985). Some of the benefits of keeping crop residue on the soil surface at all times include less sealing of the soil surface, increased water infiltration and greatly reduced soil loss by protecting the surface from the effects of wind and water.

The use of conservation tillage is not widespread in western Canada, but there is a growing number of farmers who are practicing this method. A great deal of basic research is required to gain a better understanding of how soils deteriorate, and how they may be restored. The Senate Committee feels that the key to successful conservation efforts lies in the transfer of information and accompanying technology to the farmer.

1.2 STUDY AREA LOCATION

The South Interlake Management Association's (SILMA) target area includes the three agricultural representative districts of Teulon, Selkirk, and Stonewall, in the South Interlake region of Manitoba (Figure 1). These districts take up 520,000 hectares (1.3 million acres), of land, about one quarter of which is subject to wind erosion - the main cause of this erosion being excessive tillage.

1.3 PROBLEM STATEMENT

The governments of Canada and Manitoba signed a Subsidiary Agreement on Agri-Food Development in 1984. The sub-agreement consists of approximately 130 projects that have been designed by producers or in response to needs expressed by producers and others in the agri-business sector. Under the Canada-Manitoba Agri-Food program, there are several soil and water conservation projects being initiated. One of these projects is taking place in the South Interlake region of Manitoba by the South Interlake Land Management Association (SILMA). The Association has as its mandate to develop and implement a systematic district land management program to investigate and promote the conservation, maintenance and/or enhancement of the agricultural land in the South Interlake. The Association wishes to deal with land degradation problems through a coordinated local district approach between producers, extension workers, and researchers. The major overall objective of SILMA's project is:

> "The maximization of the productivity of the land base by promoting the utilization of the land to its optimum agricultural capability, and the management of its constraints (SILMA 1985 Constitution)".

The Soil and Water Management Section of PFRA, initiated field work in the fall of 1986 to obtain ground reference data on existing post-harvest, surface residue conditions as a reflection of tillage practices being used. Limited time and funding, as well as a large project area, have necessitated that an alternative method for acquiring this information, on existing post-harvest ground cover types be explored.

The central problem being addressed by SILMA is land degradation. This study addresses the related problem that arises from a lack of up-to-date and timely information on the location, extent, and condition of the agricultural land base in the South Interlake region. The solution is to have current and reliable land resource data to assist SILMA in the proper management of the agricultural land base.

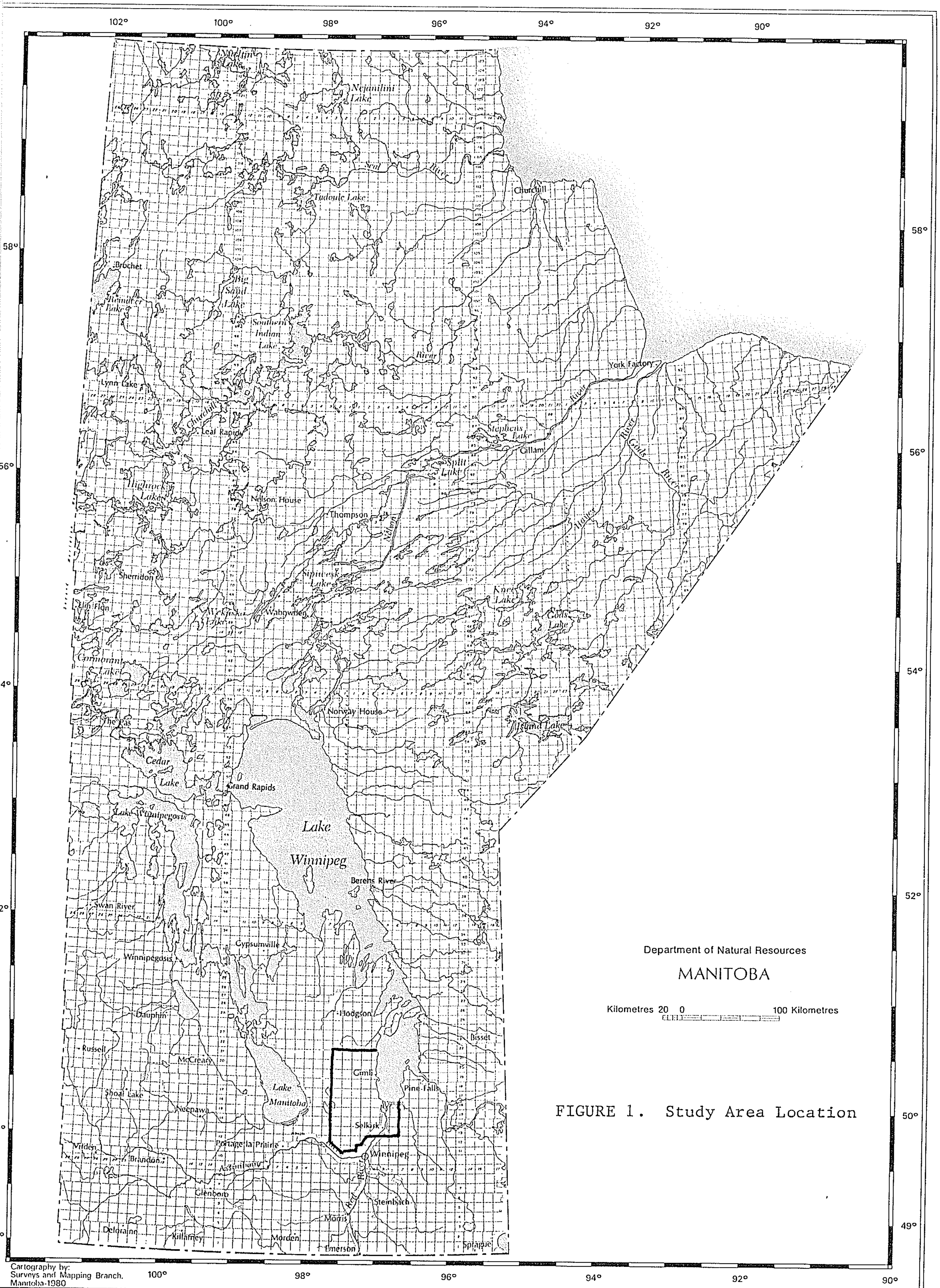

FIGURE 1. Study Area Location

Remote sensing provides a means of obtaining specific environmental data. The procedure using remotely sensed data offers several advantages over the conventional approach. The image acquisition takes only a short time, and hence the data are comparable and consistent. The images can be used alone or in combination with others to obtain information for a variety of applications such as land use, land use change, and forestry. Most important, remote sensing techniques can meet the accuracy and timeliness requirements at a low cost for even sub-provincial areas. Because of a satellite's sensor's ability to generate spatial data on land, water and environmental conditions, LANDSAT has been used extensively in resource management. SILMA has shown an interest in the possible application of remote sensing techniques in identifying and mapping ground cover conditions in the South Interlake region of Manitoba.

Specific ground cover monitoring would also allow both producers, and resource managers to assess whether or not tillage practices and cropping systems are changing and at what rate, if any, the changes occur. Information provided by remote sensing is accessible and surveys a large area making it a viable tool in the resource decision-making process.

1.4 OBJECTIVES

The aim of this project was to assess the value of remote sensing techniques in the inventorying, assessment, and analysis phases of the resource management process.

Specifically:

1) To investigate the value of remote sensing techniques in providing reliable and detailed distribution patterns and area values for post-harvest, ground cover conditions.

2) To develop a data overlay procedure involving the use of Landsat derived, crop residue cover maps in conjunction with ancillary resource data, specifically soil textural criteria used in assigning Manitoba soil types to Wind Erodibility Groups (WEG), in order to identify site-specific problem areas.

3) To describe the type of residue management required to reduce soil loss to a tolerable level.

4) To describe the implications of remote sensing as a tool to aid the South Interlake Land Management Association in identifying areas at risk to soil wind erosion.

1.5 METHODS

The methods used in this study to achieve the objectives can be divided into four major phases: data acquisition, data analysis, synthesis and evaluation, and recommendations. In the data acquisition stage an October 20, 1986 LANDSAT computer compatible tape (CCT) was obtained. Field reference data was available as training data for classifying the LANDSAT image. Available published and regional mapped information was collected including soil textural criteria used in assigning Manitoba soil types into Wind Erodibility Groups (W.E.G.) and the development of erosion risk maps.

Data analysis provided an indication of ground cover conditions in the South Interlake. The soil erodibility criteria was converted to digital form and overlaid onto the Landsat thematic map.

In the synthesis and evaluation stage, by analysis and intuitive deduction, the overlay procedure indicated areas of conflict, lands with potential soil erosion, and site-specific problem areas needing improved management for optimal productivity.

The literature provided information regarding the type, effects, and influences of specific residue management techniques, specifically tillage systems, which are recommended to reduce potential soil loss to a tolerable level of 11 tonnes per hectare per year. A discussion followed which addressed the management implications that flowed from the study. Recommendations pertaining to project planning and the feasibility of further remote sensing projects in the South Interlake were outlined.

1.6 JUSTIFICATION

With the results of this study SILMA can move toward achieving their goal: to develop and implement a district land management program to investigate and promote the conservation, maintenance and/or enhancement of the agricultural land in the South Interlake. Timely production of data on post-harvest ground cover conditions that are spatially accurate and can be processed into information relevant to management decision-making (Estes, 1982), would be a major benefit of this project.

This study will also have implications of interest to other local agricultural organizations, government agencies and conservation districts. The methodology developed and information generated should be useful in developing and implementing land-use management guidelines and policies.

1.7 LIMITATIONS

While this study will be restricted to the South Interlake region of Manitoba, the methodology could be used to develop land management guidelines in other areas of the province. Recommendations suggested in this study reflect the unique, local characteristics of the study area. No attempt was made to incorporate socio-economic information, but current awareness of, and attitudes towards, proper soil management practices by farmers are important in the development of any management plan.

1.8 SUMMARY

This chapter outlined the need for a timely, accurate, and cost effective method for acquiring information on existing agricultural land-use practices, specifically post-harvest ground cover conditions in the South Interlake area of Manitoba.

The following two chapters provide background material necessary to understand the methodology developed, as well as the results and discussion sections contained in Chapters IV and V. Relevant trends and research involving the application of remote sensing to resource management are reviewed in Appendix B.

CHAPTER II

CONCEPTS OF CROP RESIDUE MANAGEMENT

The purpose of the next two chapters is to outline some of the technical concepts and principles of crop residue management and remote sensing technology. Realizing that knowledge of both agricultural land management characteristics and remote sensor data is essential, this information is presented to provide a basis for understanding the role played by remote sensing in the mapping and management of our land resource.

The process of wind erosion[1] involves several factors: wind velocity, direction, and turbulence; surface roughness; soil texture; ground cover; field size and orientation; and moisture balance (MDA(a), 1987; Shaykewich, 1987). Wind erosion results in change in the surface texture, physical condition and the fertility of the cultivated layer (Shaykewich, 1987; Slevinsky, 1983). The sorting action of the wind removes the finer soil particles aggregates and organic material first, followed by larger aggregates containing silt and clay particles. However, the wind must reach some "critical velocity" before any erosion will take place (Shaykewich, 1987).

The need for improved soil erosion control has resulted in extensive research to develop better soil management systems based on reduced tillage and manipulation of crop residue. This has led to conservation tillage systems that minimize soil erosion and maximize crop residue retention. In Manitoba, highly erodible sandy textured soils, stripped of vegetation, can potentially lose

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[1]Relevant information concerning soil degradation and mechanisms of wind erosion are provided in Appendix C.

from 120 to 170 tonnes of top soil per hectare per year or a loss of 0.9 to 1.2 cm. annually. In addition the wind would also remove organic matter and nitrogen. Whereas, clay textured soils, also bare of vegetation, can potentially lose from 30 to 53.8 tonnes of top soil per hectare per year or 0.2 to 0.33 cm. annually (MDA, 1987b; Slevinsky, 1983).

2.1 Crop Residue

Retaining crop residues on the soil surface is an effective measure for the prevention of wind erosion. Crop residue prevents erosion by reducing wind velocity at the surface of the soil (Shaykewich, 1987). Residue cover reduces the intensity of erosion by trapping soil particles. **The amount of residue required to protect the soil depends upon the erodibility of the soil.** Generally, the greater the quantity of residue on the surface the better protection provided. **The type of residue, both in terms of crop variety and orientation, is also important in controlling erosion.** Standing straw is considerably more effective than an equal amount of flattened residue.

Different crops produce different types and amounts of straw, thus different quantities of residue are needed to control erosion. Table 1 shows crop residue requirements for wind erosion control. Finer residue covers more ground, and hence is more effective in reducing wind erosion. Cereal straw is more effective than a coarse material such as corn stalks. It follows that it is also important to know how much residue is produced for a given yield. Table 2 shows the ratio of straw to grain and the estimated crop residue factor. The key information in this table is the residue factors which can be used to calculate the straw production from any yield. Residue from flax, mustard, rape, and sunflowers provides less protection from erosion than does residue from cereal crops (Slevinsky, 1983).

Table 1. Standing Crop Residue Requirements (kg/ha) for Erosion Control i.e. To reduce erosion to 11 tonnes/ha/yr

Surface Texture	Cereals	Flax	% Ground Cover
fine sand, peat	>1900	>3200	>65
loamy sand /clay loam	1600	2700	50 - 65
clay loam to clay	1100	2000	20 - 50

Source: modified from Manitoba Agriculture, 1986; Slevinsky, 1983.

Table 2. Estimated Crop Residue Factors

Crop	Straw to Grain Ratio straw/grain (tons)	kgs. straw/bu.
Wheat	1.67	112
Barley	1.00	54
Flax	1.25	78
Canola	2.20	123

Source: Manitoba Agriculture, 1986.

The quantity of residue required to protect the soil from wind also varies with soil texture and type. About 1700 kg./ha. of standing residue provides enough protection for medium textured soils (loamy sands, sandy loams, clay loams), while larger quantities are required to adequately protect sandy soils. Specifically, in dry areas and during periods of drought in moist areas, total residue production seldom exceeds that required to protect the soil (Slevinsky, 1983). Consequently, residue requirements are greater for more erodible soils, to achieve an adequate level of protection.

Residue requirements can also be expressed in per cent ground cover rather than kilograms per hectare (see Table 3 and Figure 2). The greater the amount of crop residue, the higher the percentage of ground cover, and hence the greater protection.

Table 3. Relation Between Estimated Ground Cover and Weight of Residue

% Ground Cover	Corn Stalks (kg/ha)	Cereal Straw (kg/ha)
20	700	400
30	1000	500
40	1500	800
50	2000	1000
60	2500	1300
70	3400	1700
80	4300	2200
90	5800	3000
95	7800	4000

Source: Manitoba Agriculture, 1986.

2.2 Tillage Practices

Tillage has a direct influence on the amount of crop residue that is left on the surface to control erosion in the spring. Tillage practices in Manitoba

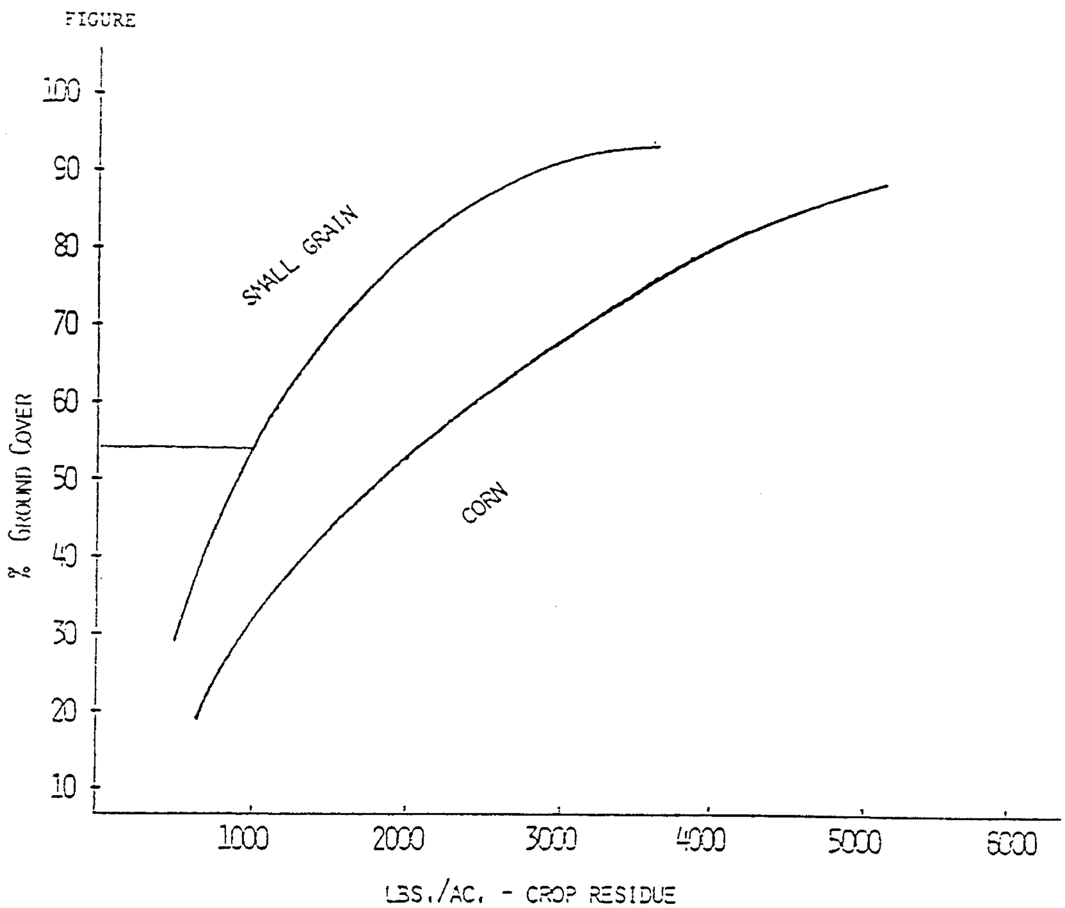

FIGURE 2. RELATIONSHIP BETWEEN PER CENT GROUND COVER AND AMOUNT OF CROP RESIDUE FOR CORN AND SMALL GRAIN

vary with location, soil type, climate, crops, and attitude. There are five generally accepted reasons or objectives of tillage:

1) to prepare the seedbed.
2) to control weeds
3) to improve internal drainage of the soil
4) to incorporate crop residue for plant disease and insect control.
5) to incorporate fertilizers and herbicides

(MDA, 1987b; Slevinsky, 1988).

2.3 Tillage Systems

Conventional: a tillage system where the soil surface is totally mixed or inverted by plowing, disking, etc., to prepare the soil for seeding and to control weeds. Usually conventional tillage involves more operations than is required. Excessive tillage is expensive and leaves the soil susceptible to erosion and destroys its natural, physical properties.

Minimum Tillage: in general, a portion of the previous crop's residue remains on the soil surface by using the least number of operations necessary for crop production in the following year. Chemical weed control is often necessary.

Zero Tillage: a system where a crop is seeded directly into undisturbed stubble from the previous crop, with less than 25% soil disturbance. Chemical weed control is essential.

Conservation Tillage: a general term used to describe any soil management practice that leaves the soil more resistant to erosion and includes minimum, reduced, or zero till systems. A protective layer of crop residue remains on the soil surface all year round. A combination of herbicides or chemicals and tillage is used to control weeds.

Conservation tillage systems are being recognized as essential to the long-term maintenance of soil resources susceptible to erosion. Tillage buries crop residue and reduces its effectiveness as a protective cover. Therefore, for maximum erosion control, tillage operations should be kept to a minimum. The type of implement and the number of tillage operations has a direct influence on meeting residue management objectives. Table 4 shows the amount of residue buried by various tillage implements. As the number of tillage operations increases the residue cover decreases.

Table 4. Effect of Several Types of Tillage Implements on Residue Cover

Implement	Amount of Straw Buried With Each Pass
Wide Blade Cultivator	10%
Heavy Duty Cultivator	20%
One-way Discs	40% - 50%
Heavy Tandem or Offset Disc	40% - 60%
Moldboard Plow	90% - 100%

Source: Manitoba Agriculture, 1986

2.4 WIND ERODIBILITY GROUPS

The degree of soil wind erosion in Manitoba varies with location, climate, soil type, soil texture, crop type, and farming practices. For this reason, Manitoba soils have been assigned into Wind Erodibility Groups (WEG), based on erodibility, and surface roughness criteria (Slevinsky, 1983). Table 5 shows the susceptibility of common soils to wind erosion in Manitoba. For the purposes of this study, WEG were combined as follows: WEG1; WEG2 and WEG3 were combined and renamed WEG2; and WEG4 and WEG4L were combined and renamed WEG3. Soils in wind erodibility group one (WEG1) have a sandy surface texture, soils in WEG2 range from loamy sands through to clay loams; and soils in WEG3 consist of non-calcareous and calcareous clays. The remaining wind erodibility groups WEG5 and WEG6, were not found in the study area. The amount of residue required to protect the soil depends upon the erodibility of the soil. **The susceptibility of the soil to erosion decreases as soil texture changes from WEG1 to WEG3.**

Table 5. Wind Erodibility Groups

W.E.G.	Texture
1	very fine; fine and medium sands; dune sands.
2	loamy sands; loamy fine sands; very fine sandy loams; fine sandy loams; sandy loams.
3	clay, silty clays; clay loams and silty clay loams.

2.5 WIND EROSION EQUATION

As with water erosion, wind erosion can be estimated by considering relevant factors. A wind erosion equation which expresses the many factors involved in soil loss from erosive wind effects, has been suggested by Chepil and Woodruff (1963) and used by the United States Department of Agriculture (USDA, 1977) and Woodruff and Siddoway (1965):

E=f(I,K,C,L,V)

where E = predicted annual soil loss

I = soil erodibility factor

K = soil surface roughness factor

C = climatic factor

L = equivalent unsheltered distance factor

V = equivalent quantity of vegetative cover

(See appendix D for factor descriptions).

This equation is used to predict the potential amount of wind erosion or soil loss for a given field under local climatic and average moisture conditions, in other words, to determine if a particular field is adequately protected. Charts and figures have been developed to permit graphical solutions of the equation (Woodruff and Siddoway, 1965). Once the potential amount of soil loss (E) for a given WEG has been estimated residue requirements to control wind erosion and to reduce potential soil loss to a tolerable soil loss level[2] can be determined.

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[2]Tolerable soil loss refers to the maximum allowable soil loss that can occur and still maintain long-term productivity. Based on the analysis of soil reports from North Dakota, Manitoba soils were assigned a tolerable level of soil loss at 5 tons per acre per year (11 tonnes per hectare per year), which is approximately equal to the removal of a 1/32 of an inch of topsoil from an acre of land. The concept of tolerable soil loss depends upon the rate of soil formation and the effect of soil loss on crop production (Shaykewich, 1987; Slevinsky, 1983).

discusses principles of remote sensing as a basis for understanding the role played by remote sensing in resources management.

CHAPTER III

PRINCIPLES OF MULTISPECTRAL REMOTE SENSING

3.1 Remote Sensing: What is it?

Remote sensing is the science and art of acquiring information about material objects by detection and from measurements made at a distance without coming into physical contact with the objects (Curran, 1985; Estess, 1985; Lintz and Simonett, 1976; Sabins, 1978). The field of remote sensing, as an outgrowth of aerial photographic interpretation, has been expanding and evolving since the 1960s. Remotely sensed data of the earth expanded with the launching of Landsat I on July 23, 1972. It was originally called Earth Resources Technology Satellite (ERTS), but its name changed to Landsat I when a second similar Landsat II was launched in February, 1975. Five Landsat satellites have been launched in total carrying sensors that record images of the earth.

Today remote sensing usually refers to "the use of electromagnetic radiation sensors to record images of the environment which can be interpreted to yield useful information" (Curran, 1985, p.1).

3.2 Multispectral Approach

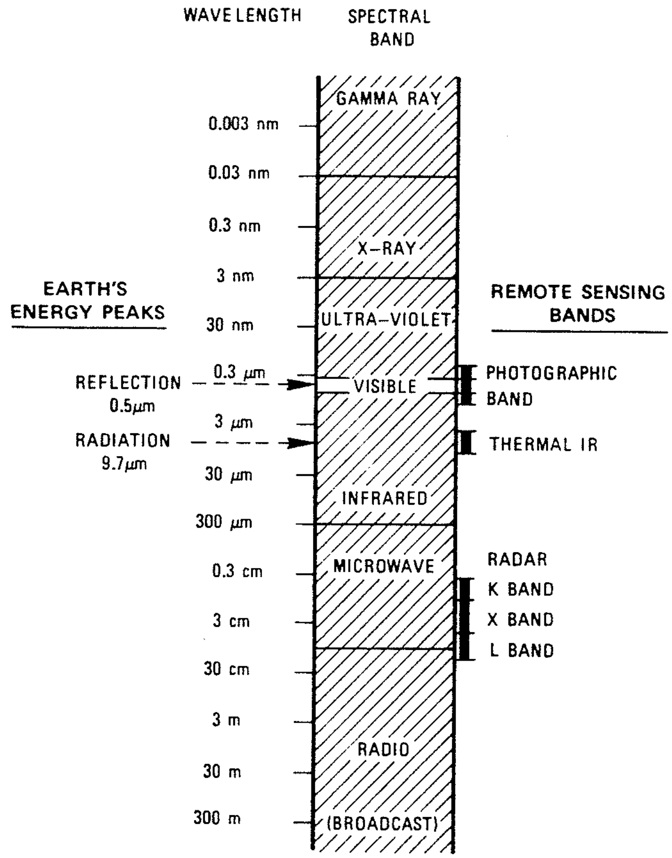
Multispectral sensing, a type of remote sensing, may be defined as "the sensing of an object using more than one part of the electromagnetic spectrum (EMS) at the same time, from the same place, and from the same altitude. . . . The purpose of multispectral remote sensing is to obtain information from different spectral bands simultaneously" (Rehder, 1985, p.259).

3.2.1 Electromagnetic Spectrum

The objective of remote sensing is to detect and record energy in a selected portion of the electromagnetic spectrum (EMS). Electromagnetic energy occurs as a continuum of frequencies and wavelengths from long, very low frequency radio waves to very short, high frequency gamma ray and x-rays (Figure 3). Remote sensing detectors sense levels of emitted and/or reflected radiation in various portions of the EM spectrum. The wavelengths of particular interest and value to environmental remote sensing include reflected radiation in the visible, near infrared and middle infrared bands, emitted radiation in the middle and thermal infrared wavebands, and reflected radiation in the microwave band (Curran, 1985). Vegetation, soil, and water reflect, absorb and transmit incident radiation of varying wavelengths throughout the EM spectrum. The signature or spectral reflectance characteristics of targets are governed by the amount of energy transmitted to the sensor, within a wavelength range in which that sensor images. Sensors vary in their ability to detect differences in reflectance characteristics. For example, the Thematic Mapper (TM) sensor on Landsat V can detect 256 levels of brightness while the multispectral scanner can detect 64 levels brightness (Curran, 1985), (see section 3.3.2).

3.2.2 Spectral Reflectance Curves

There are particular spectral regions which are more useful for certain applications than others. Therefore, before an image can be interpreted knowledge is needed of the interaction of electromagnetic energy with various components of a remotely sensed scene: vegetation, grass, soil, and water.

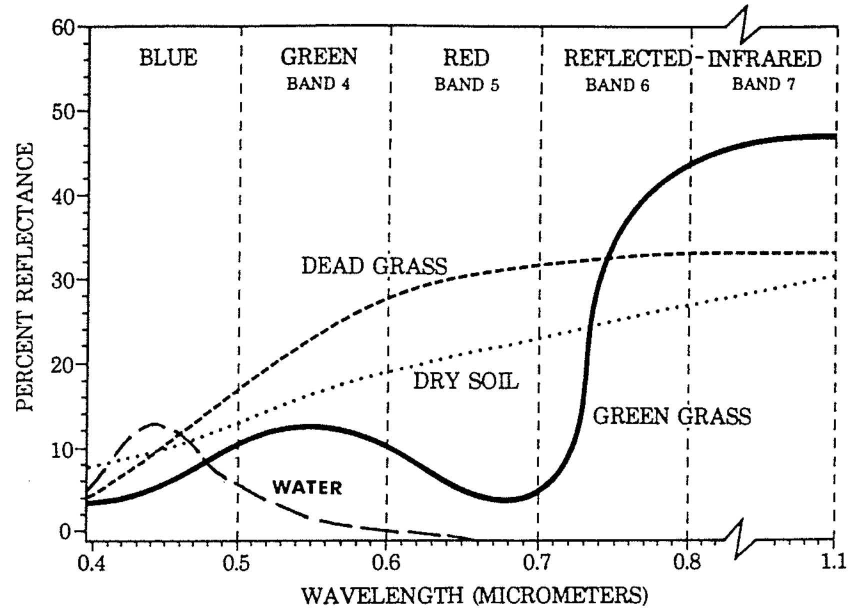


Source: Sabins, 1978.

FIGURE 3. **Electromagnetic Spectrum (EMS)**

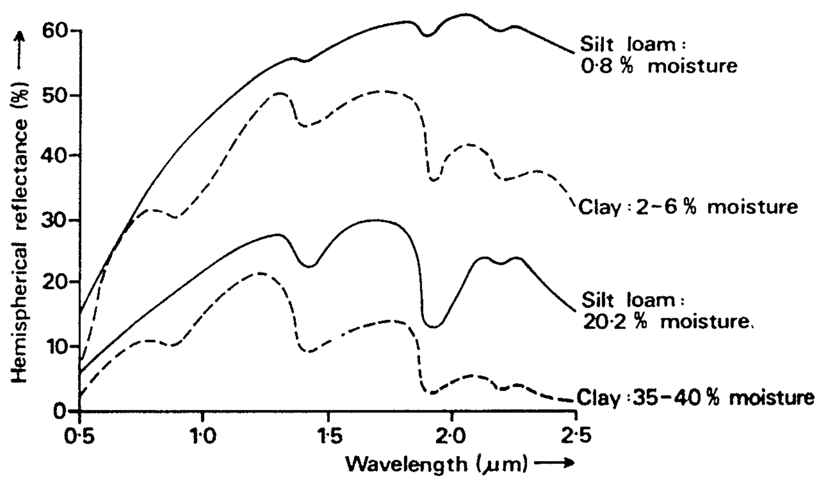
Spectral reflectance curves represent the relative response (reflectance) of earth surface features as a function of wavelength (Landgrebe, 1976; Sabins, 1978). Figure 4 shows typical spectral reflectance curves for the wavelength interval from visible (0.4 micrometers) to reflected infrared (1.1 micrometers) regions for healthy green vegetation, dead or senescent vegetation, dry soil, and water. Such curves are used to recognize the spectral regions in which various surface features can be differentiated. For example, healthy green vegetation generally reflects 40 to 50% of the incident near-infrared energy (0.7 to 1.1 micrometers), with the chlorophyll in the plants absorbing approximately 80 to 90% of the incident energy in the visible (0.4 to 0.7 micrometers) part of the spectrum (Jensen, 1986). Dead or senescent vegetation reflects a greater amount of energy than healthy vegetation in the visible spectrum (0.4 to 0.7 micrometers). Conversely, dead grass reflects less than green vegetation in the reflective infrared (0.75 to 1.1 micrometers) region. In the visible red portion of the spectrum (0.6 to 0.7 micrometers) healthy green vegetation and dry soil reflect differently. Soils and vegetation have greatest contrast between 0.6 and 0.7 micrometers, it is this region in which differentiation between vegetative cover and bare soil can best be accomplished. Dry soil generally has lower reflectance than dead vegetation in the visible region, similarly in the near-infrared, dry soil generally has lower reflectance than green or senescent vegetation (Jensen, 1986).

Spectral reflectance properties of soil are influenced by several factors including texture, structure, and soil moisture (Bowers et. al., 1965; Curran, 1985). A clay soil with a high moisture content, will tend to form aggregates and result in low reflectance values. In contrast, a sandy soil with a smooth surface and low moisture content, generally results in high reflectance values



Source: Jensen, 1986; Rehder, 1985.

FIGURE 4. **Typical Spectral Reflectance Characteristics**



Source: Curran, 1985.

FIGURE 5. **Spectral Reflectance Curves for Wet and Dry Soils**

(Bowers et.al., 1965). Moisture reduces the surface reflectance of soil, particularly in the near and mid-infrared wavelengths (Currans, 1985; Sabins, 1978). The effect of moisture is more noticeable in clay soils due to the presence of bound water (Figure 5).

In the green region (0.5 to 0.6 micrometers) water is differentiated from soil and green vegetation. Beyond its peak at 0.45 micrometers the spectral curve for water drops off sharply due to its low reflectance in this region. Surface water absorbs rather than reflects infrared radiation, and thus appears black to navy blue on colour infrared imagery from Landsat false-colour imagery (Holz, 1985). However, spectral reflectance characteristics can only provide useful information if all four curves are situated in a different position eg. not on top of one another.

In terms of applications, green vegetation can be identified and mapped as contrasted to dead or senescent vegetation and bare soil surfaces. Obviously, the physiological development of crops will influence the spectral response so that by autumn with the breakdown of plant pigments (chlorophyll), any stubble left in the fields would result in a lower spectral curve in the red (0.6 to 0.7 micrometers) and near-infrared (0.7 to 1.1 micrometers) regions of the spectrum.

The spectral reflectance of varying amounts (percentages) of crop residue or stubble is not well documented in the literature. The results of a 1981 study (Spiridonov, et.al., 1981), on spectral reflectance characteristics for various types of cultivated vegetation in Eastern Europe found that spectral reflectance values depended upon the following: 1) the phenological state of vegetation, from healthy to ripe to post-harvest stubble; 2) the per cent coverage, as the ratio between vegetation areas and soil (or other vegetative types); and 3) the location and thickness of cover. In this study, the spectral curves displayed a smooth and gradual increase in reflectance with increasing wavelength, as one moved towards the infrared region, and is due to low chlorophyll absorption in the visible wavelengths.

A study be Earing and Ginsberg (1988) developed a model for selection and prediction of appropriate channels to be used at seven stages of growth in the Midwest, USA, including stubble. Unfortunately, no distinction was made between quantity of stubble or its orientation.

These are examples where multitemporal, multispectral remote sensing of cover types is unlikely to be successfull without adequate knowledge of the crop residue, e.g. its spectral reflectance characteristics, and confirms the necessity for detailed and reliable field reference data.

3.2.3 Pattern Recognition

The scattergram in Figure 6 shows the spectral response data of various surface features (vegetation, soil, water) in two regions of the EMS, plotted with respect to one another. The reflectance values as a function of wavelength for vegetation, soil, and water are differenct and lie in different portions of two dimensional space, called feature space, giving each feature a unique spectral signature. Note that a larger number of bands could be plotted. For example, the response of a third band could be used, and the data plotted in three dimentional space, and so on, except that a 4D plot is not possible on paper. When several spectral response values are plotted, all of the same ground cover type but from different locations on the ground, they tend to plot as localized cluster of points (Figure 7), rather than as a single point. The

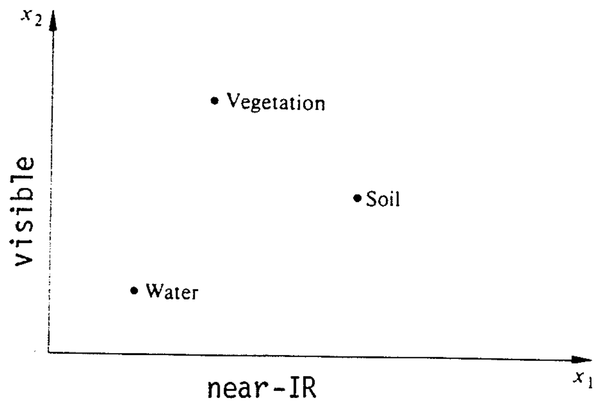


FIGURE 6. **Scattergram: Data in 2D Space**

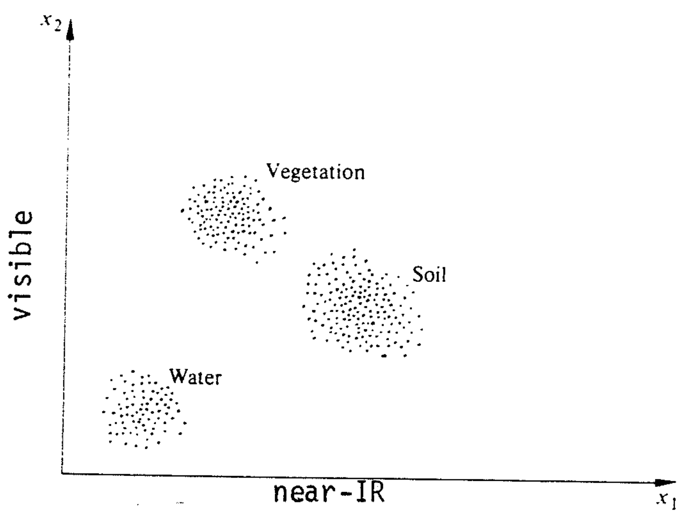


FIGURE 7. **Clusters of Data Points**

clusters corresponding to specific ground covers are said to be discriminable or spectrally separable.

Scattergrams are used in digital image analysis to classify a geographic region by its remotely sensed spectral response (Merchant, 1982; Robinove, 1981), specifically to extrapolate training data over the whole data set and to determine the degree of separability of one cover type from another. However, variations in response within a class or cover type are to be expected.

3.3 LANDSAT

The Landsat 5 satellite orbits the earth in a circular, sun synchronous, near polar orbit at an altitude of approximately 705 km. (Curran, 1985; Taranik, 1985). Orbiting the earth once every 99 minutes, Landsat 5 completes 14.5 orbits of the earth per day providing complete coverage of the earth every 16 days (Ryerson, et. al., 1983). There are two sensors aboard Landsat 5 that currently collect data relevant to agriculture - Multispectral Scanner (MSS) and the Thematic Mapper (TM). This information is collected and stored on magnetic tapes, in digital format, which can be later processed to produce photographs and computer compatible tapes (CCT) covering an area of 34,225 square kilometers (13,214 square miles). These sensors divide the image into tiny picture elements called pixels, and measure the brightness of each pixel in several portions of the electromagnetic spectrum. Table 6 compares the spectral bands and other capabilities of operation for MSS and TM sensors.

Table 6. Comparison of Landsat TM and MSS Measurement Capabilities

	MSS (micrometers)	TM
Band width 1	0.5 - 0.6	0.45 - 0.52
2	0.6 - 0.7	0.53 - 0.61
3	0.7 - 0.8	0.62 - 0.69
4	0.8 - 1.1	0.78 - 0.91
5		1.57 - 1.78
6		10.42 - 11.66
7		2.08 - 2.35
Spatial resolution (IFOV) metres	79	30 m. in bands 1,5 & 7; 120 m. in band 6
Pixel size (metres)	56 x 79	30 x 30
Field of view (FOV) in degrees	11	17
Grey levels	64	256
Number of detectors	6	16
Mirror recording mode	forwards	forwards and backwards
CCT/scene (1600 bpi)	1	7

Source: Curran, 1985.

3.3.1 Multispectral Scanner

The multispectral scanning system (MSS) senses the earth in four spectral bands: band 1 (green), band 2 (red), band 3 (near-infrared), and band 4 (near-infrared) shown in Table 7. The numbering of the MSS wavebands was changed for Landsat 4 and 5 from bands 4, 5, 6, 7, to bands 1, 2, 3, 4. Each band senses a specific part of the EMS. Band 1 senses the green part of the spectrum, where water has a relatively high degree of reflectance; band 2, in the visible red, allows for distinction between living vegetation and bare soil or rock; band 3, a near-infrared band, senses high reflectance of vegetation and soil in contrast to water which absorbs radiation; band 4, another infrared band, distinguishes between land and water boundaries, wetlands, and areas of high soil moisture (Rehder, 1985). Today, Landsat MSS data are used for mapping land cover and for monitoring change.

Table 7. Landsat MSS Wavebands

Landsat 1,2 & 3	Landsat 4 & 5	Band Width	Waveband Name
4	1	0.5 - 0.6	green
5	2	0.6 - 0.7	red
6	3	0.7 - 0.8	near-IR
7	4	0.8 - 1.0	near-IR

Source: Curran, 1985.

3.3.2 Thematic Mapper

The most recent Landsat satellite, Landsat 5, was launched by NASA in March, 1984, with a new sensor on board called the Thematic Mapper (TM). The wavelength selection of this instrument is specifically adapted to vegetation studies and agricultural monitoring. The TM has a spatial or ground resolution of 30 metres, records 256 radiance (brightness) levels and allows recording of data in seven spectral bands. In general the best combination for agricultural uses involves one of three bands in the visible spectrum in combination with the near-infrared band and one of the two shortwave IR bands (CCRS, 1987). This study used bands 2, 3 and 4 for the primary colours of blue, green, and red, respectively. This combination gives the same colour rendition as colour infrared film and the familiar Landsat MSS combination of bands 4, 5 and 7. The Thematic Mapper employs narrow bands that provide improved data information extraction (Richason, 1983). Table 8 shows TM spectral bands and their specific applications. The improved spatial and spectral quality and resolution of TM data have potential to provide a new and detailed level of information.

Table 8. Thematic Mapper Wavebands and Applications

Band	Band Width	Applications
1 (blue/green)	0.45-0.52	good water penetration; coastal water mapping; soil, vegetation differentiation.
2 (green)	0.52-0.60	strong vegetation reflectance for vigour assessment.
3 (red)	0.63-0.69	chlorophyll absorption.
4 (near-IR)	0.76-0.90	sensitive to plant stress; high land/water contrasts.
5 (near/mid-IR)	1.55-1/75	sensitive to moisture content of vegetation and soil
6 (thermal IR)	10.4-12.5	soil moisture discrimination; sensitive to vegetation stress.
7 (middle IR)	2.08-2.35	geological discrimination & hydrothermal mapping.

Source: modified from Curran, 1985; Holz, 1985; Richason, 1983.

3.4 TEMPORAL AND SPATIAL CHARACTERISTICS

A basic underlying premise is that the cover types of interest are indeed spectrally separable. Effective utilization of remote sensor data requires a thorough knowledge and understanding of the temporal and spatial characteristics inherent in the cover types present and of the related changes in spectral response. Variations in spectral response due to temporal effects involve situations where the spectral characteristics of target cover types, in a given location, change over time. When, at a given point in time, the spectral response values for a single type of cover, differ in different geographic location, this is referred to as a spatial effect. Spatially, such variations might be due to differences in soil types, soil moisture, uneven germination, etc.

Temporal characteristics pertain to the development of crops through time. It is important to ascertain when the area has reached a stubble stage after the crop has been harvested for image acquisition purposes. Many crops exhibit physiological development stages: a bare soil prior to seeding, a crop emergence stage, a green vegetative canopy stage, a senescent vegetative phase, a post-harvest stubble stage, and a final bare soil stage if the harvested field is plowed (Hay, 1982; Rundquist & Samson, 1983). The timing of each stage depends upon crop type, geographic location and cultural or farming practices. Through an understanding of the physiological development of crops, flight schedules can be arranged to coincide with the optimum interpretive utillity of the resultant imagery e.g. optimum crop development stage.

3.5 Remote Sensing as a Tool for Resources Management

Accurate and timely information is essential to more effective use, management and growth of Canada's natural resource sector (forestry, agriculture, energy, minerals). Remote sensing contributes to the inventory, monitoring, and analysis phases of the resource management process (Godby and Thie, 1981). Its ability to generate spatial data of our land and water resources will contribute to improved management of these resources and benefit the economy as a whole.

Remote sensing is a tool and not a remedy for soil erosion problems. The major contribution of Landsat 5 TM data to resources management is that of providing the user a quick and economical assessment of the spatial distribution of various ground cover types, an important aid in resource planning activities. Another advantage of Landsat TM data is its ability to reduce fieldwork during these times of increasing costs.

The need to better organize and analyze information to provide improved resource management decisions has driven the development of geographically based information systems (GIS), in recent years (Mooneyhan, 1982). The integration of remote sensing data with computer-based GIS systems, will facilitate the use of combined data sets, to inventory earth resources and monitoring changes in the landscape, resulting from changing farming practices. The combination of land cover derived from Landsat data and other geobased information has proven to be a useful and effective tool for the resource manager.

3.6 SUMMARY

In summary, the preceeding two chapters provided background information for understanding applied concepts and terminology of the procedure developed to assess post-harvest, ground cover conditions. Chapter II reviewed concepts of crop residue management for improved soil erosion control. Tillage was described as having a direct influence on the amount of crop residue that is left on the soil surface to control erosion. The amount of residue required to protect the soil depends upon the erodibility of the soil as influenced by soil texture. The Wind Erosion Equation is used to predict potential soil loss in order to estimate the amount of residue required to control erosion to a tolerable level. Chapter III examined some basic principles of remote sensing: definition; objective; electromagnetic spectrum; spectral reflectance curves; pattern recognition; and spatial, temporal, and spatial considerations.

The purpose of the next chapter is to describe the procedure which utilized remote sensing techniques to assess the location, extent, and condition of post-harvest, ground cover in the South Interlake.

CHAPTER IV

METHODOLOGY

The methodology used involved a series of stages: data acquisition, data analysis, synthesis and evaluation, and recommendations. A pre-acquisition phase in which the user determines the time at which the imagery must be acquired, as well as to make arrangements for collecting ground reference data to coincide with the satellite imagery was not part of the planning and design of this study. Accurate and reliable field data is critical for verification and as a basis for spectral signature generation (training areas). Subsequent quality control, accuracy assessment, and classification difficulties were later realized as a result of incomplete project planning prior to data acquisition. These problems are discussed later in the chapter 5 (results and discussion) and chapter 6 (recommendations).

4.1 DATA ACQUISITION

A LANDSAT 5 computer compatible tape (CTT), for October 20, 1986 was obtained. Field reference data[3] on existing post-harvest, ground cover conditions had previously been collected and used as training sites, in other words, in developing the spectral signature of the cover types of interest. A wind erosion risk map delineating wind erodibility groups had previously been prepared for Agri-Manitoba (Slevinsky, 1987). Erosion risk was based upon local climatic and soil conditions, average moisture, and no vegetative cover. Degree of risk (annual soil loss in tonnes per hectare) was determined through the application of the Wind Erosion Equation, E = f(I,K,C,L,V), as discussed in

[3]See Appendix E for ground cover survey sheets.

chapter 2 and appendix D. The equation serves two purposes: to determine the soil erosion hazard at the WEG level, as well as in particular fields; and to determine alternate management practices required to reduce potential loss to a tolerable level.

4.2 DATA ANALYSIS

4.2.1 Training Areas

Landsat TM data was analyzed using a DIPIX ARIES III digital image analysis system in co-operation with the Manitoba Remote Sensing Centre. This involved "training" the computer to recognize a particular combination of numbers representing the reflectance in each of several wavelength bands from the cover types of interest. These training statistics must be truly representative of the spectral characteristics of the various cover types, since different cover types have different amounts of reflectance in the various wavelength bands. The field reference data played a critical role during this stage as it provided the basis for interpreting the satellite data. It is essential to choose variations of each cover type in order to account for spectral variation due to date of harvesting, soil types, and moisture conditions.

Figure 8 shows a histogram which proved useful as a graphic representation of the information content and distribution of the ground reference data. The relative frequency with which different values (%) of cover occurred, assisted in defining categories or classes of cover type that the computer could be trained to recognize. Each class had to be both spectrally separable and have information of value. Three crop residue cover classes, as well as three additional land cover types were selected for classification.

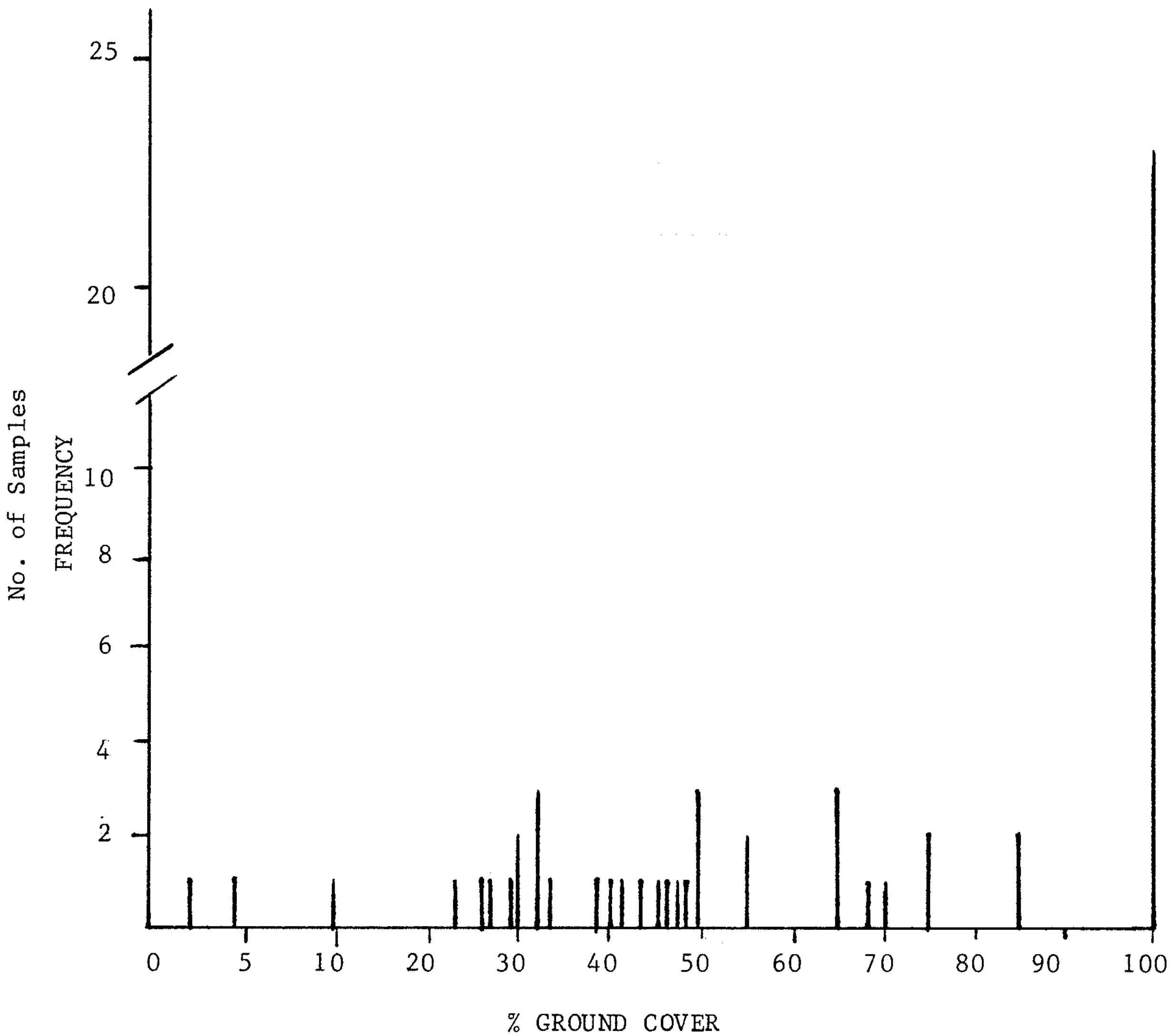


FIGURE 8. **Frequency Histogram**
Distribution of Ground Reference Data

4.2.2 Classification

After the training statistics were defined the data was classified using a supervised maximum-likelihood classification algorithm. This algorithm has generally been found to produce classification results that usually have a relatively high degree of accuracy (Hoffer(b), 1980). This algorithm calculates the mean vector[4], the variance, and correlation for each land cover class in the training data, assuming data is normally distributed (Curran, 1985). In this classification the spectral response values associated with each pixel are sorted by the computer into the classes defined during the development of the training statistics and to which it most probably belongs (Hoffer(b), 1980; Kalensky et.al., 1981). In Figure 9, pixel X would be allocated to the class "soil".

Post classification filtering of the image was performed to eliminate small scattered pixel groups resulting from spectral anomalies. This technique removes the speckled effect which would normally occur in an unfiltered thematic map production (Pokrant, H. and Gaboury, 1983).

Figures 10, 11, and 12 show scattergrams of the recorded digital reflectance values for the three crop residue cover classes. The relative reflectance values for each cover type are plotted in two-dimensional feature space at two wavelengths: band 3 (red) versus band 4 (colour infrared). These scattergrams were used to determine the spectral relationship between the three target cover classes, and thus to determine the degree of separability of one cover type from another. It should be mentioned that an overlay of the scattergrams indicates a straight line relationship between the relative reflectance values for each cover type. This would imply that it should be

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[4]The mean digital number of a class, representing the spectral reflectance, in the training data is calculated for all bands.

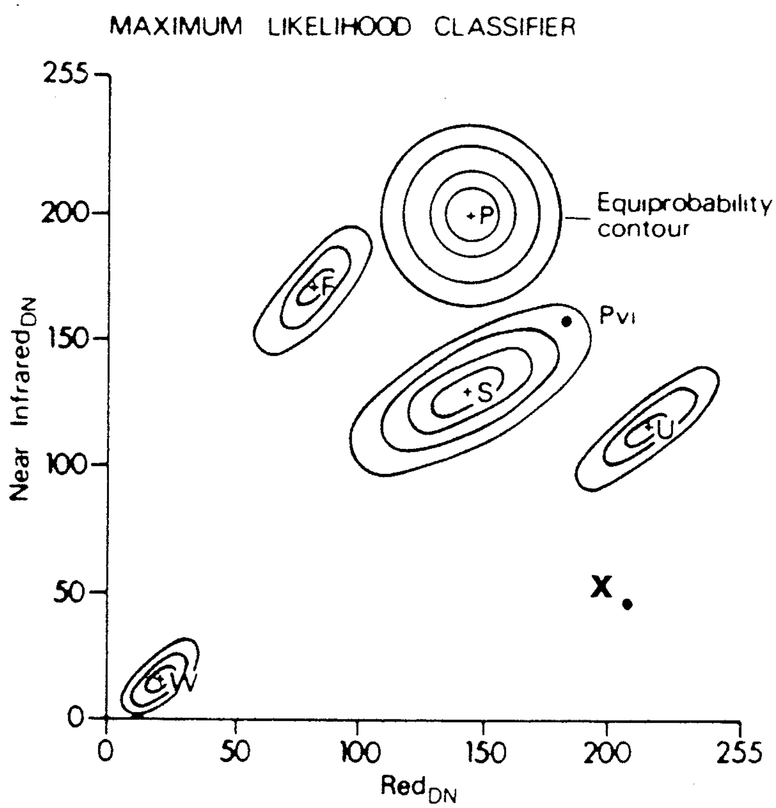

FIGURE 9. **SPECTRAL RESPONSE VALUES OF PIXELS IN NEAR-IR AND VISIBLE WAVEBANDS**

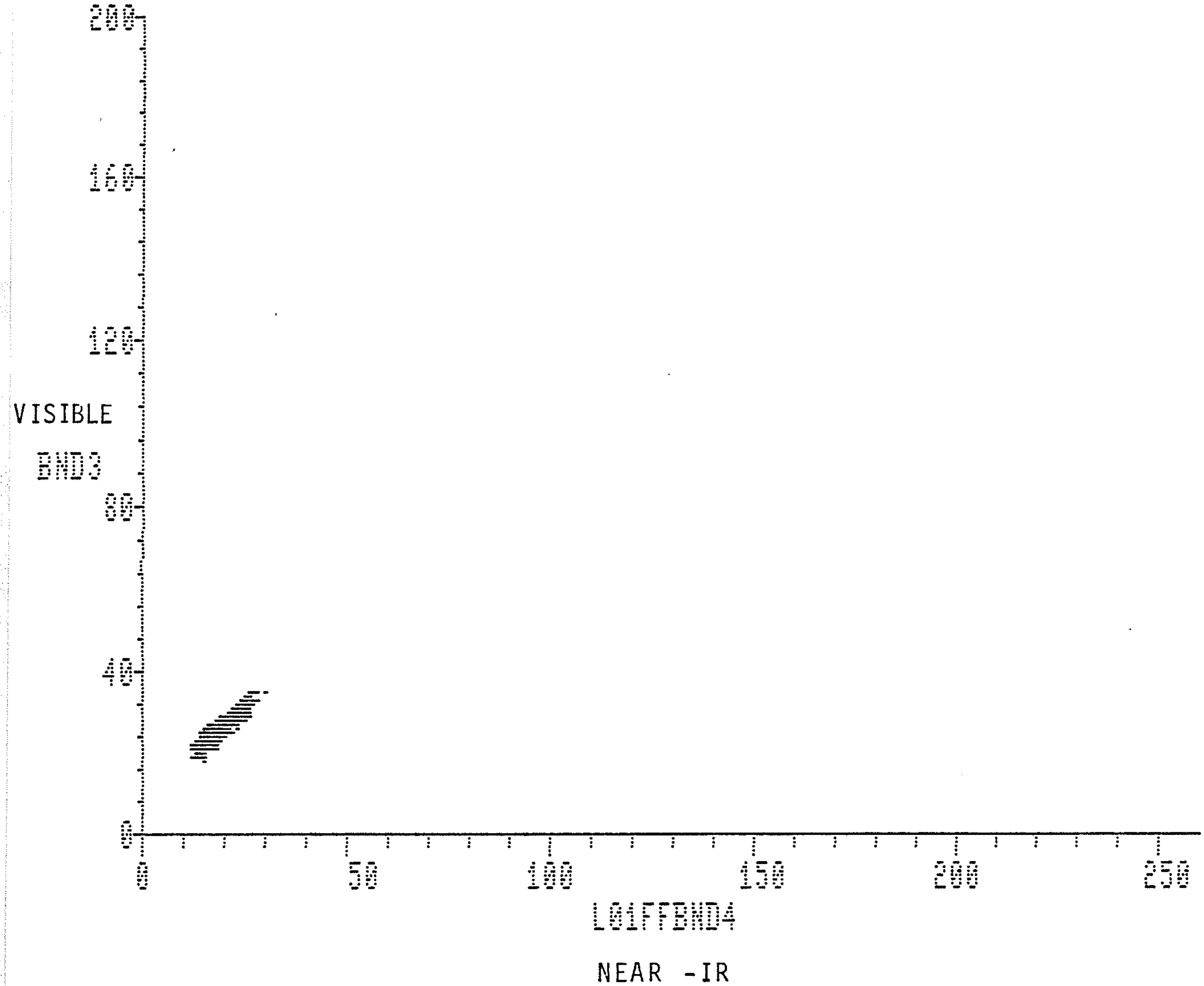

FIGURE 10. **Reflectance Values for 0% - 33% Ground Cover Class**

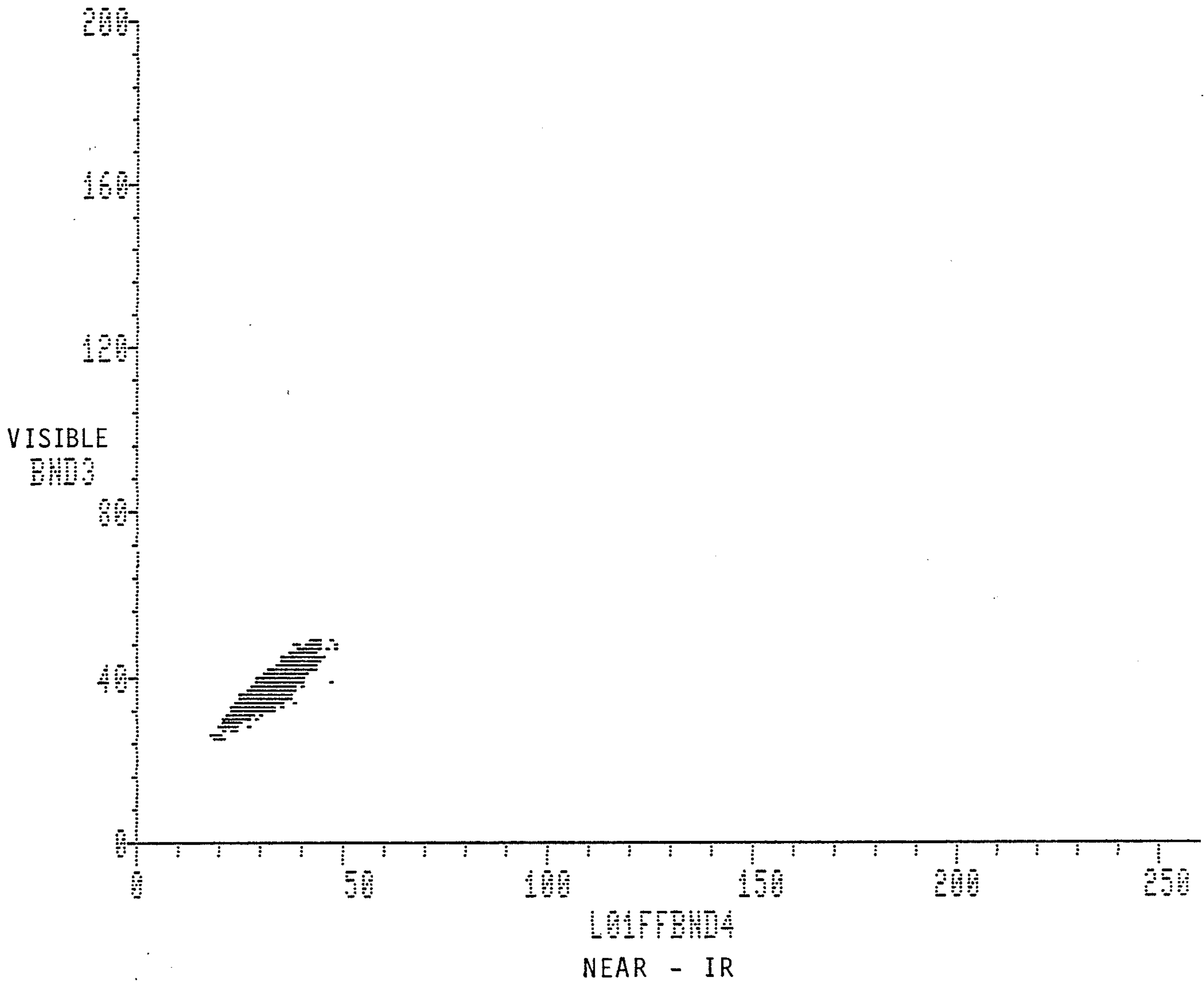

FIGURE 11. **Reflectance Values for 34% - 66% Ground Cover Class**

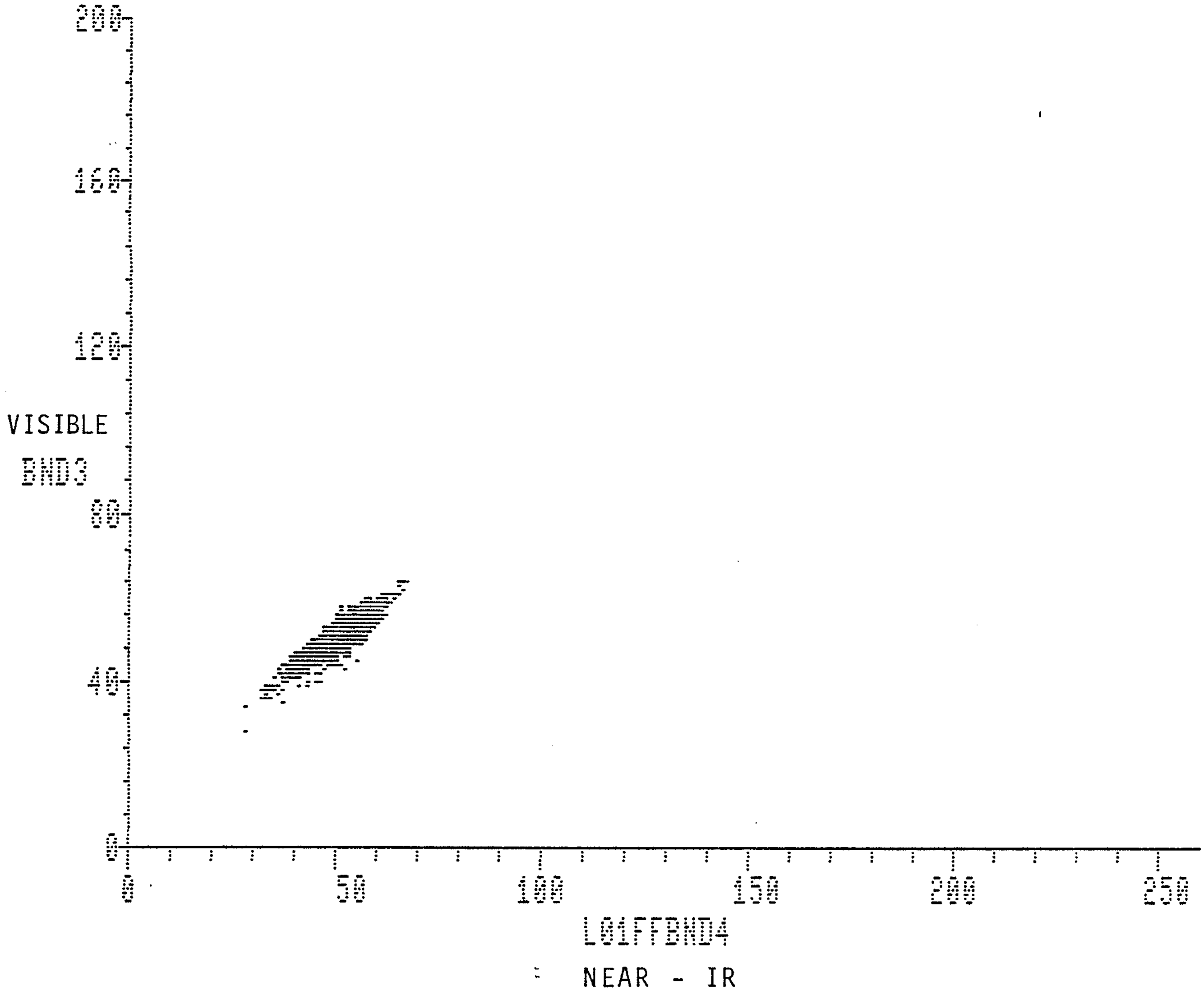

FIGURE 12. **Reflectance Values for 67% - 100% Ground Cover Class**

possible to assess ground cover from reflectance values in only one waveband. However, this relationship could very well change so that each cover type would lie in different portions of two dimensional space, if different waveband or a larger number of bands were plotted, (see section 3.2.3). In addition, the continuous distribution of reflectance values implies that a relationship exists between per cent cover and reflectance in one of the wavebands which, in turn could be used in planning future application projects. However, certain temporal and spatial effects result in variations in the spectral characteristics of target cover types over time and in different geographic locations. Such variations might be due to changes in soil moisture, crop type, weather conditions, and cultural and farming practices, (see section 3.4).

The ARIES computer software permits automated computation of class areas. The percentage of the entire area covered by each of the cover types of interest were easily calculated. Results were printed in tabular format on a line printer, (Table 9). Six coloured thematic map sheets, at a scale of 1:50,000, were generated to show the spatial distribution of the various cover types of interest, (Appendix F). The map output is referred to as a thematic map, since each colour represents a different "theme" or cover type. Six multispectral map sheets were generated from data taken from four bands (red, green, blue, and near IR) of the multispectral scanner.

Table 9. **Classification Summary of Area Estimates**

Class	Map Colour	Cover Type %	Area Value %	No. of Pixels	No. of Hectare
1	lt. blue	0-33 %	10.85	252268	1135963
2	med. blue	34-66 %	26.95	626899	282292
3	dk. blue	67-100 %	4.34	100979	45471
4	yellow	grassland	40.74	947560	426686
5	red	forage	1.72	39974	18000
6	green	woodland	15.39	358000	161207

Source: MRSC, 1988.

4.3 SYNTHESIS AND EVALUATION STAGE

4.3.1 Ancillary Data and Overlay Procedure

The approach taken to incorporate ancillary data (soil textural criteria used in assigning soils to WEGs) into the remote sensing classification process was to actually digitize the ancillary data onto an image format. This approach was an attempt to improve the dimensionality of the information to be extracted from the map. By overlaying ground cover data onto erosion risk data, as defined by the wind erodibility groups (WEGs), localized and site-specific problem areas can be identified.

4.3.2 Residue Management Practices

Chapter II outlined concepts and principles of crop residue management. Related research is extensive and complimentary to this study by providing information and implied solutions in tabular and graphical form. Mathematical relationships have been established describing the influence of the individual factors of the Wind Erosion Equation (Woodruff and Siddoway, 1965). Graphs and charts are available for determining values for the various factors in the equation (see Appendix D). Consequently, soil loss E=f(I,K,C,L,V) based on no vegetative cover, can be determined for each wind erodibility group having different erodibility (I) and surface roughness (K) values. Once determined, the amount of erosion occurring under varying amounts of crop residue can be calculated (Slevinsky, 1983).

4.4 SUMMARY

Chapter IV described the remote sensing procedure utilized to generate spatial distribution patterns and area values of post-harvest, ground cover conditions, and to integrate this information with ancillary data in order to identify site-specific problem areas. The following chapter V outlines the results achieved, as well as discussing the scope and limits of the methodology.

CHAPTER V

RESULTS AND DISCUSSION

Since the digital reflectance values of each of the three crop residue cover types did plot as unique clusters of points, it was decided that these cover types were discriminable e.g. spectrally separable, see Figures 10, 11, 12. A preliminary interpretation of the distribution of field reference data yielded three subintervals or classes. The points dividing the classes were chosen so that no measurement fell on the point of division, thus minimizing any ambiguities regarding the disposition of a particular measurement, Table 10. Once an acceptable classification of the image was obtained three residue cover classes in addition to forage, grassland and woodland classes, were identified. Tabular output of the classification results show area values for each of three classes of residue cover types. The percentage of the entire area covered by each of the cover types of interest was easily calculated and is shown in Table 9, Chapter IV.

Table 10. **Ground Cover Distribution**

Class	Class Limits	Frequency	Relative Frequency
1	0 - 33 %	23	33.33%
2	34 - 66 %	17	24.63%
3	67 - 100 %	29	42.03%

Source: MRSC, 1988.

Out of 2,325,680 pixels (1,047,253.9 hectares) 980,146 pixels (441357.9 ha) or 42.14% were classified as crop residue cover types. The range of discrimination between the three residue cover classes was from a bare soil class with 0% to 33% residue cover, a transition class with 34% to 66% residue cover, and finally, a stubble class with more than 66% residue cover.

The six classes (forage, grassland, woodlands, and three residue cover types) were represented on a thematic map (Appendix E), by three shades of blue (light, medium, dark), red, yellow, and green for classes one through six, respectively. A seventh class is coloured black and represents the digitized boundaries of three wind erodibility groups (WEGs).

5.0.1 Transitional 33%-66% Residue Cover

Of the three residue cover types identified the most dominant is class 2 which appears on the map as medium blue. This class covers 282,292.6 hectares or 63.96% of the target residue cover types, (see Table 11). This class is called transitional for basically two reasons: 1) the satellite image was taken in mid-stream of conventional tillage operations, or 2) the producer has reduced soil manipulation so that a portion of the previous crop's residue is retained.

Table 11. Area Estimates as a Percentage of Total Residue Cover Types

Class or Theme	Hectares	% of Total Residue cover Type	Description
1	113596.3	25.74	0%-33% bare soil
2	282292.6	63.96	34%-66% transition
3	45470.8	10.30	67%-100% stubble

Source: MRSC, 1988.

Evaluation and interpretation of this transition class was problematic. Although desirable, further differentiation of cover types within this class was limited due to an insufficient amount and distribution of field reference data for training areas.

5.0.2 Conventional 0%-33% Residue Cover

The second major residue cover type is class 1 which appears on the map as dark blue. This class covers 113,596.3 hectares or 25.74% of the target residue cover types. This class represents predominantly bare soil conditions where conventional tillage systems are the norm.

5.0.3 Conservational 67%-100% Residue Cover

The least dominant residue cover type is class 3 which appears on the map as light blue. This class covers only 45,470.8 ha. or 10.3% of the target residue cover types. This class represents stubble conditions where conservation tillage systems are being implemented. Class three forms a very small fraction of the South Interlake cropland area.

It was therefore demonstrated that it is possible to classify agricultural land into varying per cent crop residue cover. The spectral confusion of pixels that occurs between classes, and especially within class 2, effectively reduces the accuracy of evaluation and interpretation. However, this problem can be minimized by improving the quantity, quality, and distribution of field reference data for developing training areas for classification.

5.1 INTEGRATION OF ANCILLARY DATA WITH LANDSAT

The overlay procedure developed to integrate Landsat data with ancillary data in the form of WEGs, improved the quantity and quality of the information derived from the final thematic map. The WEG boundaries became another feature or theme, making a total of seven themes. The result is essentially a data base to be used by producers, resource managers, and decision-makers to identify site-specific problem areas. For example, a given field classified as having 0%-33% residue cover, but located in WEG1, on sandy textured soils would indicate an area of conflict, where the field was left without adequate residue cover. Even a field with 33%-66% residue cover, occurring on soils in WEG2, might also indicate inadequate cover if the amount of cover is less than 50%. (see Table 12).

Table 12. Relation Between Wind Erodibility Group and Residue Requirements

WEG	T* (t/ha/yr)	E** (t/ha/yr)	Residue (kg/ha)	Satellite Classes	% Ground Cover
1	11	74	1232-1568	> 66%	> 65%
2	11	49	1008-1232	34%-66%	50%-65%
3	11	20	672-1120	0%-33%	20%-50%

* T: tolerable soil loss level.
**E: predicted erosion values based on no vegetation.

Note: Minimum of 50% ground cover recommended. Anything less is not acceptable.

Source: MRSC, 1988; MDA, 1987; Slevinsky, 1983.

For WEG2, the predicted erosion value (E) for no vegetation is 49 tonnes/ha./yr., whereas the E-value based on 1347 kg./ha. of flat wheat residue is 6.5 tonnes/ha./yr., and 28 tonnes/ha./yr. for the same amount of flax or rapeseed residue (Slevinsky, 1983).

For WEG3, the predicted erosion value (E) for no vegetation is 20 tonnes/ha./yr., whereas the E-value based on 1347 kg./ha. of flat wheat residue is 1.12 tonnes/ha./yr., and 7.4 tonnes/ha./yr. for the same amount of flax or rapeseed residue (Slevinsky, 1983).

Therefore, both the type and amount of residue that remains on the soil surface has a direct influence on the amount of wind erosion that can occur for any soil type.

5.2 RESIDUE MANAGEMENT PRACTICES

One of SILMA's soil management objectives, addressed by this study, was to identify and implement crop residue management practices that protect the soil from damaging wind erosion and therefore, maintain or increase the long-term productivity of the agricultural resource base in the South Interlake.

Based upon the results of a study (Slevinsky, 1983), using the Wind Erosion Equation to predict annual soil loss for each WEG, residue requirements for various crops, on a variety of soil types (WEG) to protect the soil from erosion prior to seeding in the spring, were determined, (Table 13). The residue values are the amount required, during April and May when wind erosion is most critical, to protect the soil from wind erosion. The table illustrates the importance of quantity, and type of residue in reducing erosion. For example, it takes lesser quantities of small grain residue to protect the soil as compared to corn residue.

Table 13. Crop Residue Requirements for Wind Erosion Control (kg/ha)

WEG	Small Grains (flat)	Corn, Sunflower (standing)
1	1904 - 2240	2800 - 3360
2	1008 - 1568	1568 - 2352
3	672 - 1120	896 - 1792

WEG	Rape, Flax (standing)	Corn (flat)
1	3248 - 3920	4592 - 5600
2	1792 - 2688	2464 - 3920
3	1232 - 2016	1680 - 2576

Source: Slevinsky, 1983.

The farm management practice that has a direct influence as to whether or not these residue requirements are met is the type and number of tillage operations conducted in the fall, post-harvest, and in the spring, pre-seeding. Table 4 (see Chapter II), shows the amount of residue buried with each pass for various tillage implements. From a farm management perspective the amount of residue produced for a given yield is important in determining the amount of residue required to control erosion. Crop residue factors shown in Table 2 (see Chapter II), are used to calculate the amount of straw produced for any given yield of wheat, barley, flax, or canola. For example, if the yield of wheat was 2700 kg./ha. (40 bu/ac) the amount of straw produced would be 2700 kg/ha x 1.67 = 4500 kg/ha, or 40 bu/ac x 100 = 4000 lbs./ac. (Slevinsky, 1983). In his study, Slevinsky (1983) provides examples to show that excessive operations with tillage equipment that reduce the per cent of ground cover, will leave the soil vulnerable to erosion in the spring.

5.3 REMOTE SENSING STUDY IMPLICATIONS

The following discussion addresses objective four, by considering the implications that flow from this study which provided insight into the operational aspects of a remote sensing project when applied to a resource management problem.

Remote sensing is a tool, rarely used alone, to solve problems. Information generated from the integration of remote sensing imagery and reference data aids in 1) problem analysis and its solution; 2) signature verification; and 3) verification of remote sensing classification and interpretation (Longeay et. al., 1983). Various considerations must be taken into account if remotely sensed imagery is to be used again to assess ground cover conditions in the South Interlake in order to evaluate the impact of SILMA's district land management program.

This project serves to augment existing information and articles written on the subject of planning a remote sensing applications project. Lindenlaub and Davis (1978) and Ryerson (1986) have subdivided the remote sensing planning process into a set of five steps:

1. Defining resource manager (user) data requirements.
2. Establishing feasibility.
3. Project planning.
4. Implementing project.
5. Assessing the results.

The authors developed a series of questions for establishing the data requirements of the resource manager or user, which includes the following: information required, data format, quality and quantity of information required, and temporal considerations.

In terms of information required, it was specified by SILMA that the earth surface features of interest are crop residues with a goal to obtain acreage estimates for the South Interlake study area, agricultural representative districts, and Wind Erodibility Groups. SILMA required results in both map and tabular form: a working map to assess the spatial distribution of crop residues, and tabular output of area estimates of crop residue cover types.

The quality and quantity of the information required were constrained by available resources - money, manpower, and time. The stages, as set out in the methodology, were carried out simultaneously with other degree course requirements. A single continuous block of time was not devoted to all stages, consequently time spent at each stage was not always documented. There is one exception in that the time spent at the Manitoba Remote Sensing Centre was documented. However, the image analysis stage was also a learning-by-doing process, atypical of an experienced remote sensing technologist. At the projects beginning, the minimum limit on accuracy and coverage were not discussed or specified.

The central reason for considering crop phenology and related spectral characteristics of crop residue and surrounding features is to maximize contrast between the feature of interest, crop residue cover types, and the background (Ryerson, 1986). Temporally, data collected over the same area but at different times, even during harvesting, can display differences in the amount of cover. Often discrepancies occurred between field measurements and what was recorded by the satellite. This can be attributed to the two week gap between the collection of reference data and satellite pass, during which time a field may have been cultivated again. Environmental variables, such as atmospheric conditions, wind, angle of reflection in relation to angle of solar incidence, and have been cultivated again. Environmental variables, such as atmospheric conditions, wind, angle of reflection in relation to angle of solar incidence, and soil moisture conditions are also possible causes of spectral variations (Hoffer, 1978a). Spectral variability, due to temporal effects, must not be overlooked or disregarded. However, much of the variation normally encountered can often be minimized or overcome with proper consideration of the conditions under which remote sensor data is collected.

This study has established the feasibility of using remote sensing techniques to meet the objective of identifying and mapping ground cover conditions in the South Interlake. The narrow spectral bands of the Thematic Mapper (TM) provided improved data for information extraction. Its spatial resolution allowed identification of crop residue conditions on individual fields. Therefore, step two of the planning process, establishing feasibility, was fulfilled through the results of this study.

The third step, project planning, was augmented by this study. What has evolved is areas in need of refinement, which are recommended in Chapter VI. Decisions must be made with respect to the frequency of satellite data collection, reference data and ground observation requirements, preacquisition and preprocessing requirements, and accuracy and coverage specifications. In this study, project planning resulted in decisions to use Landsat TM data with existing field observations (PFRA, 1986), and erosion risk maps (Slevinsky, 1983), to serve as reference data. Preprocessing and data analysis procedures were also detailed with the assistance of the MRSC.

The fourth step, project implementation, was the phase of the study in which the work was actually done and is described in Chapter IV.

By establishing project feasibility[5], a qualitative assessment (step five) of the remote sensing applications project was also established. Quantitative accuracy assessment measures were not applied. A simple accuracy measure is recommended in Chapter VI.

The five steps as summarized, provide a simple framework for a remote sensing applications project. Defining the user data requirements are central to a well thought out remote sensing project.

5.4 TEMPORAL CONSIDERATIONS

Temporal information, such as crop calendars, can be used in determining the optimum time (biological window) to survey post-harvest, crop residue conditions. The length of the biological window depends on local weather conditions, seeding dates, and harvesting practices. Harvesting in the South Interlake area usually occurs between late August and November, and hence the optimal biological window for crop residue would be projected to coincide with these dates, plus or minus one week. It should be noted that the optimal biological window for this project was not predetermined, instead the project depended upon finding an appropriate image that coincided with the post-harvest stage of the 1986 crop calendar, already underway. Since harvesting can vary from one year to the next, depending on the weather conditions of that particular year, there is a distinct need for interaction between user and remote sensing analyst in the process of projecting the optimal biological window.

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[5]By concluding that the information derived from the remote sensing data did, indeed, satisfy the requirements of the client.

5.4 OTHER CONSTRAINTS

If not properly considered a number of critical factors could reduce the reliability of the crop residue assessment project. The key factors related to the characteristics of remote sensor systems are 1) optimum biological window, as discussed above, and 2) the minimum field size, (its distribution and number), required for training the computer to recognize the associated spectral response patterns.

There will always be a need for field reference data in remote sensing that are truly representative. The greater the amount of information observed at ground level, the better the understanding and accuracy of the related remotely sensed imagery. Most field observations needed in the study, are those which would normally be used if remote sensing data were unavailable or not feasible. Certain general considerations of the amount and distribution of field observations, as well as knowledge gained from past experience will help in planning future remote sensing field data collection. The spatial distribution of field measurements and observations should be biased so that all cover types are well represented for training the computer to recognize the spectral response patterns.

Cloud cover during the passage of a satellite will render the procedure invalid for data under localized cloud or cloud shadows, or even the entire image. In the case of localized cloud, cover types can be imputed or estimated, assuming that cover types under the clouds are similar to adjacent areas in the same region. However, such signature extensions may increase the probability of errors in classification.

Boundary pixels present another constraint to classification of remote sensor data. Retraining on these pixels may increase the measured accuracy substantially (Ryerson, et. al., 1983). This problem can also be minimized by ensuring that reference data and training areas are representative of the entire area under study. These training areas should be strategically selected in representative areas of each different cover type to account for as many spectral signature differences as possible.

The spectral response of a given feature can change with variations in crop residue type, amount, and orientation; soil type, texture and moisture; field size and orientation; weather conditions; and cultural factors, such as tillage practices. Consequently, the resource specialist must be well acquainted with these variations, in order to identify crop residue cover types, even though the spectral response pattern of that cover type may not be well known due to a lack of field reference data. In other words, there is a distinct need for a man-machine interaction in the process of analyzing remote sensor data (Hoffer, 1980b).

5.6 SUMMARY

Chapter V described the results achieved from the Landsat TM classification. This was followed by a discussion of the overlay procedure developed to integrate remote sensor data with soil textural criteria. The implications that flow from the study, as they relate to the planning and implementation of future remote sensing projects, were discussed. The remainder of the chapter examined several critical factors or constraints that must be considered. The following chapter summarizes and draws conclusions regarding the outcome of the research project, based on the objectives. Recommendations are then outlined based on the results obtained.

CHAPTER VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 SUMMARY

The main objective of this study was to assess the value of remote sensing technology in managing our land-base resources. This was achieved by classifying agricultural land into crop residue cover types to provide information regarding the effectiveness of alternate land management practices to control wind erosion. In this study, Landsat 5 Thematic Mapper imagery and ground verification data were used in conjunction with soil texture criteria to yield surface residue cover types, per cent area values, and erosion risk.

6.2 CONCLUSIONS

1. Six colour thematic map sheets of the digital classification were produced at a scale of 1:50,000. The thematic map shows the spatial distribution of three classes of residue cover within the study area in addition to forage, grassland, and woodland classes. The maps allow for temporal and spatial variations to be assessed quickly and inexpensively. Tabular output of the classification results show area values for each of three classes of residue cover. The percentage of the entire area covered by each of the cover types of interest was easily calculated. **This study has established the feasibility of using remote sensing techniques to aid in the solution of a resource problem.** The results of the study support the value of using satellite TM imagery and digital image analysis to assess post-harvest ground cover conditions in the South Interlake. It was decided that the cover types of interest were spectrally separable, that suitable computer-aided data-handling and analysis facilities were

available at a reasonable cost, and that the information generated (maps and area values) will aid SILMA to make better management decisions. The procedure developed is of most value to producers and resource managers. The procedure will aid in obtaining information concerning location, extent, and condition of our land-base resources. Efforts to improve the statistical accuracy in classification and the reliability in hectarage estimation can be accomplished by improvements in the pre-acquisition stage, specifically field reference data collection. Input by knowledgeable interpreters is a key and essential ingredient for the effective analysis of remote sensor data. This approach is not an attempt to replace the effectiveness and benefits achieved by manual interpretation and field observations. Its value is in its capability of providing a quick, overall indication of the location, extent, and condition of the resource base of interest.

2. The overlay procedure, using Landsat classified data in conjunction with soil textural criteria, as used in assigning Manitoba soil types to Wind Erodibility Groups (WEG), offers promise for many other ancillary data sources, such as topographical data (elevation, slope, aspect), surficial geology, as well as land, political, watershed and soil type boundaries. Essentially, the result is a data base of potential or possible correlations between existing cover types and soil wind erosion risk.

3. Remote sensing contributes to achieving the third objective, by providing information regarding ground cover conditions and allowing subsequent comparison between ground cover to WEGs. In terms of susceptible soil types, the majority of soils in the area fall into WEG2 and WEG3, with isolated

pockets of WEG1, the more highly erodible sands and peats. The map shows that soil wind erosion problems in the South Interlake tend to be site-specific problems and do not necessarily indicate an overall wind erosion problem. A visual or qualitative evaluation of the thematic map indicates that approximately twenty five per cent of the land in the study area was left with inadequate residue cover in the fall of 1986. Remote sensing contributed to the identification of potential problem areas. The procedure developed will clearly facilitate planning and decision making for SILMA, as well as other resource managers. By identifying problem areas, managers can tailor land management practices and programs to the local situation.

4. Various implications flow from the study, as discussed in the previous chapter, are summarized:

-remote sensing is a tool for solving environmental and natural resource related problems.

-critical factors to be considered for future remote sensing application projects, before work continues, include: user data requirements, data format, ground reference data collection, temporal and spatial effects, preprocessing and analysis procedures, and accuracy and coverage specifications.

5. The procedure using remote sensor data offers several benefits:

-image acquisition takes only a short time, and hence data are comparable and consistent.

-when used in combination with other images, information can be obtained concerning land-use changes.

-remote sensing techniques can meet the accuracy and timeliness at a reasonable cost.

-provide for the possibility of decreasing the quantity of field reference data required to obtain adequate and statistically valid samples.

6.2 RECOMMENDATIONS

A number of recommendations are suggested as a result of this study.

1. To ensure accurate analysis of remote sensing data it is recommended:

i) Based on the results of the classification of this study, 2 to 3 per cent of each cover class of interest (crop residues) must be verified by accurate ground level measurements and observations (Pokrant, personal communication, 1988).

ii) Field data collection methods should be standardized in order to ensure consistency and reliability of crop residue measurements. This would require the development of a simple manual on the collection of measurements and observations about crop residue type, orientation, height, condition, and any other salient features. There would be costs incurred in the development and printing of such a manual.

iii) A simple accuracy assessment in the form of confusion matrices to express the correlation between computer classified themes and the manually assigned pure theme files for the established training areas.

This would allow for an estimation of the potential use of this remote sensing application project.

2. It is recommended that user requirements or information needs be identified via a series of questions (Lindenlaub and Davis, 1978; Ryerson, 1986):

i) What are the earth surface features or cover types of interest?

ii) Exactly what does the user (resource managers and producers) want to know about these earth surface features?

iii) What size area is involved?

iv) In what format are the results needed: maps, tables, or both?

v) How accurate must the results be?

vi) Is complete coverage of the area required, or will a sample of the entire area be sufficient to yield the necessary information?

vii) Are there any special temporal considerations: time of day or season of the year?

3. It is recommended to integrate socio-economic and attitude information regarding tillage practices collected from in person surveys. The results of the crop residue cover classification could be used as a data base that identifies site-specific problem areas, and hence aid in survey sampling design.

4. It is recommended that the cropland lying east of the Red River be classified for residue cover, since this area falls within the boundaries of the agricultural planning district of interest. However, due to a lack of field

reference data in this area, the accuracy in classification and the reliability in area estimation will be affected.

5. The procedure developed, using remote sensing techniques to assess post-harvest, ground cover conditions, will facilitate the evaluation of SILMA's Agri-Food project. It is recommended that a similar remote sensing application project be conducted in order to evaluate the effectiveness of the Association's district land management program.

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Appendix A

Definition of Terms

Algorithm: a computer-oriented step by step procedure for solving a problem.

Ancillary Data: secondary data pertaining to the area or classes of interest, such as topographic, demographic, climate, etc.; may be digitized and used in the analysis process in conjunction with primary remote sensing data.

Angle of Reflectaion: the angle that electromagnetic radiation, reflected from a surface, makes with the a surface.

Brightness Value: Remote sensing systems record the amount of reflected or emitted energy exiting from the earth's surface. Data is stored as digital values or numbers on computer compatible tapes.

Class: the surface characteristic type that is of interest to investigators (forest, water, vegetation).

Classification: a process of assigning individual pixels of multispectral images to dicrete categories.

Clustering: statistical analysis of a set of pixels to detect their inherent tendancy to form clusters in multidimensional space.

Covariance: a measure of how two variables change in relation to each other.

Digitization: a process of converting material from a continuous into a discrete format.

Feature: in pattern recognition, a measurement of a pattern or mathematical transformation of such measurements; in remote sensing often the reflectance measurement in one channel of the sensor; the number of features associated with a pattern defines its dimensionality.

Filtering: the removal of certain spectral or spatial frequencies to enhance features in the remaining image.

Geographic Information Systems (GIS): a data base management sytem used to store, retrieve, manipulate, analyze, and display spatial information.

Infrared: that portion of the EMS lying between the red end of the visible spectrum and microwave radiation. For remote sensing, the infrared wavelengths are often subdivided into near infrared (0.7-1.3 micrometers), middle infrared (1.3-3.0 micrometers) and thermal infrared (3.0-14.0 micrometers).

Landsat: unmanned, polar orbiting, earth resources satellite.

Multispectral Scanner (MSS): a scanning detector system that records reflected or emitted energy from the earth's surface in discrete wavelength intervals from 0.3 micrometers to 14.0 micrometers.

Nadir: that point on the ground, vertically beneath the perspective centre of the camera lens.

Pattern: the regularity and characteristic placement of tones or textures.

Pattern Recognition: an automated process through which unidentified patterns can be classified into a limited number of discrete classes through comparison with other class-defining patterns or characteristics.

Pixel: a "picture element" having both spatial and spectral properties.

Preprocessing: the processing of data received from the sensor to a form acceptable by the data bank and subsequent processing functions (geometric and radiometric calibration).

Reference Data: data about the physical state of the earth used in support of the remote sensing data analysis (maps, aerial photographs, topographic information, weather data, etc.

Resolution (resolving power): a measure of the ability of an optical system to distinguish between signals that are spatially or spectrally similar.

Spectral Band: a well-defined, continuous range of wavelengths in the electromagnetic spectrum.

Spectral Response: the response of a material as a function of wavelength to incident EM energy, particularly in terms of the measurable energy reflected from and emitted by the material.

Spectral Signature: the spectral characteristic of an object on the earth's surface.

Supervised Classification: a computer-implemented process through which each measurement vector is assigned to a class according to a specified decision rule, where the possible classes have been defined on the basis of representative training samples of known identity.

Training: a process of informing an image processor which sites to analyze for spectral properties as a prerequisite to supervised class.

(Source: Curran 1985; Jensen, 1983; Swain, 1978).

Appendix B

REMOTE SENSING LITERATURE REVIEW

Effective mapping of land use and capability has traditionally depended on manual interpretation of aerial photographs at considerable cost in time and dollars. The existing Canada Land Inventory (CLI) program has produced 20,000 1:50,000 scale and 12,000 1:250,000 scale maps at a cost of over 37 million dollars, mainly from photo interpretation sources (Coombs and Thie, 1977). Monitoring of land use change requires development of a data system capable of collecting and interpreting large amounts of land data quickly and at low cost. Since the initiation of the LANDSAT program, considerable attention has been devoted to experimental mapping of land use/cover types and to developing remote sensing compatible land use classification, such as by Anderson (1976) in the United States, and Ryerson and Gierman (1975) in Canada. However, few practical demonstrations of specific land use/cover type mapping and change detection with LANDSAT have been reported in the literature.

References to remote sensing have previously concentrated on research areas, but more recently efforts are being directed towards operational programs. The literature on agriculture applications of remote sensing is concentrated more on capability for identifying crop and land cover types. There is an increasing demand for regular information on crop status, area estimates and their sequence and change in time (Gillot, 1980). Remote sensing provides a means of obtaining specific environmental data. Because of satellite sensor ability to generate spatial data on land, water and environmental conditions, LANDSAT has been used extensively in resource management.

Remote sensing contributes to the inventory, monitoring, and analysis phases of the resource management process (Godby et. al., 1981).

In Manitoba there have been a number of major remote sensing projects conducted mainly by the Manitoba Remote Sensing Centre and the Forestry Branch. For example: LANDSAT data projects for barrenland caribou habitat mapping (Dixon, 1981); Land use/land cover changes affecting the Dauphin Lake Fishery (Pokrant and Gaboury, 1983); a 1983 Manitoba Crop Area Estimate Project (Horn et. al., 1984); a 1984 Manitoba Crop Area Estimate Project (Pokrant et. al., 1984); Land Use Monitoring in southwestern Manitoba (Rubec and Thie, 1978), and recently, a world crop monitoring project by the MRSC for the Canadian Wheat Board.

Pokrant and Gaboury (1983) undertook a land use/land cover type mapping project of the Valley River watershed to quantify and to assess implications of land use changes on the fishery resource. The study showed that between 1948 and 1980, cultivated land increased dramatically from 37 per cent to 60 per cent. This was primarily at the expense of woodland and to a lesser extent, pasture and wetland. They concluded that classification of LANDSAT MSS images can provide useful, up-to-date and location-specific data on present land use/cover types for agriculture and fisheries resource managers, that digital analysis of LANDSAT is fast, accurate and very cost effective, and that hard copy classification results from LANDSAT can be provided to the resource managers in the form of colour coded, thematic maps in a variety of scales.

Rubec and Thie (1978) showed LANDSAT digital data interpretation to be effective for mapping and summarizing certain land use/cover types in a rural Manitoba environment at 1:50,000 scale permitting operational and accurate land use monitoring.

Under the Federal/Provincial Technological Enhancement Program, a Remote Sensing Crop Area Estimate Project was undertaken in 1983 in Manitoba. The project provided evidence that reliable estimates for canola/rapeseed, grains, and fallow could be achieved through remote sensing techniques (Horn et. al., 1984). In 1984, this cooperative project was significantly expanded to encompass all of agro-Manitoba (Pokrant et. al., 1984).

The Canadian Wheat Board and other agencies are using NOAA data to monitor crop conditions over large areas, to make decisions for agricultural marketing and for early warning of food aid requirements, in conjunction with other data sources, such as meteorological information (CCRS, 1988). NOAA satellites carry an imaging system that can image at a resolution of 1.1 km. to provide information on vegetation condition and density.

The Large Area Crop Inventory Experiment (LACIE) was a joint effort by the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmosphere Administration (NOAA), the United States Department of Agriculture (USDA), and several American remote sensing centres to use Landsat data for estimating acreage, yield, and production of wheat (Curran, 1985; Rundquist et. al., 1983; Simonett, 1976). Landsat MSS data were used in conjunction with global weather data. MacDonald and Hall (1980) concluded that the LACIE results have significance for future crop forecasting technology because of their applicability at international and global levels.

The Systeme Probatoire d'Observation de la Terre (SPOT), program was initiated in 1978 and launched in February 1986 by the French Government in cooperation with Belgium and Sweden. SPOT's high resolution visible (HRV) imaging instruments provide for 10 metre resolution panchromatic and 20 metre multispectral imaging as well as the ability for off-nadir viewing to allow for stereoscopic observations and improved re-visit possibilities (Brachet, 1984; Courtois, 1984). The satellite follows a near-polar, sun-synchronous orbit at an altitude of approximately 813 km. crossing the equator daily. The orbital cycle is 26 days, however the repeatability of data acquisition over Manitoba is eleven times during the 26 days (Canada Centre for Remote Sensing, 1987).

Simulated SPOT data has yielded the following results, significant to the agricultural sector:

1. permits detection and identification of field boundaries and road networks; valuable for updating existing agricultural land survey maps and for conducting thematic mapping in new area.

2. permits descrimination of crop canopies of low per cent cover (<20%).

3. permits discrimination of field variability due to irrigation and harvesting and tillage practices.

4. permits improved ability to separate various crops (possible barley and spring wheat separation).

5. improved data base regarding crop distributions, farm practices, and soil drainage.

In summary, remote sensing is a most efficient way for natural resource managers to review land and water resources. Yet, the use of digital remote sensing techniques in resource management is a relatively new development. The value of remote sensing data for natural resource decisions, specifically agricultural land use, has been adequately demonstrated in the literature reviewed. Specific, agricultural problem-oriented information needs include, among others, real time, accurate, timely and quantitative information on crop residue amounts. Hence, this study is an extension of the more traditional application of remote sensing to general land use/cover type mapping. Benefits can be claimed only through the conversion of remote sensing data to information in the resource management decision-making process.

Appendix C

SOIL WIND EROSION CONCEPTS

C.1 SOIL DEGRADATION

The loss of topsoil from erosion by wind is the most wide spread form of soil degradation in Canada (Science Council of Canada, 1985). Wind erosion has the potential to adversely effect approximately 141,000 hectares of land in the South Interlake (SILMA, 1985). From an agricultural point of view, erosion leads to changes in surface texture, physical condition, and fertility of the soil (Slevinsky, 1983). Erosion redistributes soil particles and transports or removes the necessary organic matter and fine mineral fractions (Anderson and Gregorich, 1984; Coote, 1983; PFRA, 1983). Erosion reduces the organic matter content of soil, weakens its structure, lowers available plant nutrients, diminishes its water-holding capacity and lowers productivity (Science Council of Canada, 1985).

Soil degradation is increasingly becoming the focus of scientific research because of its agreed economic and environmental importance. Related literature is extensive, with new material on the subject of soil erosion emerging rapidly. This is a reflection of the growing concern for erosion problems and control, as well as an increasing awareness of the limited land resource base. The development and implementation of soil-water management projects and programs to investigate and promote conservation, maintenance and enhancement of the agricultural land base requires a thorough understanding of erosion, a major land limitation in the South Interlake. Wind erosion in the area is due to susceptible soil types, inadequate trash management, and the lack of permanent shelterbelts, hence there is a need to develop long-term controls (SILMA, 1985).

C.2 MECHANISMS OF WIND EROSION

The mechanics of wind erosion involves three factors: wind, the nature of the surface, and the soil (Shaykewich, 1987). Soil movement occurs when the force of the wind is strong enough to overcome gravity. Once the process begins, soil particles are carried along by suspension, saltation, and surface creep (MDA, 1987b; Shaykewich, 1987).

Saltation: fine and medium sand particles move in a bouncing or jumping action along the surface of the ground. Approximately 50% to 75% of erosion occurs this way. On striking the ground the particles dislodge other particles, and project them into the windstream. This results in a chain reaction which increases with intensity as it moves across the surface, and forms part of the movement in surface creep.

Surface Creep: larger particles, that are too heavy to be lifted by the wind are pushed or rolled along the soil surface by the impact of the smaller particles in saltation. A smaller percentage of the particles are moved by surface creep than are by saltation.

Suspension: very fine sand and clay particles (dust) are brought into wind currents through the saltation process, kept suspended by the turbulence of the wind currents, and consequently, may move great distances. Although, this process accounts for only 3% to 4% of the particles moved the dust contains most of the plant nutrients in the soil.

The process of wind erosion is dependent on soil particle size: smallest particles are carried in suspension, medium size are moved by saltation, and the largest particles by surface creep. However, the wind must reach some "critical velocity" before erosion occurs. As a general rule, erosion occurs only if the wind velocity is greater than 20 km/hr.

C.3 FACTORS AFFECTING WIND EROSION

Soil Texture: refers to the percentage by weight of individual particles of sand, silt, and clay in the soil. Thus, a soils' ability to resist movement is related to the size of individual particles and the ability of these particles to form stable aggregates or clods. Soils with high percentage of sand are least likely to form aggregates, and therefore most susceptible to wind erosion. Silt and clay serve as binding agents in formation of aggregates. Loams, silt loams, and clay loams are therefore the least erodible.

Surface Roughness: increased surface roughness decreases the rate of soil wind erosion. Ridges and depressions formed by tillage operations reduce wind velocity at the soil surface. The effectiveness of surface roughness in reducing erosion is dependent on soil texture and vegetative cover.

Surface Cover: vegetation also provides a protective cover against wind erosion. Vegetation can reduce wind velocity at the soil surface and also trap soil particles, preventing their movement. The effectiveness of vegetative cover, such as residue, depends on type, amount, and orientation of the straw or stubble. Finer cereal residues provide greater surface cover than coarse residue such as cornstalks. Standing stubble offers greater protection than flattened residue.

Soil Moisture: a moist soil is more stable than a dry soil due to cohesion created by the water film surrounding soil particles. Moist soils require very strong winds to overcome this cohesion, and thus are much less susceptible to erosion.

Field Size: field width and length can influence the amount of soil loss. The rate of wind erosion increases with distance across a field. Shelterbelts offer an effective method of reducing the field size, and hence distance over which the wind can gain speed and reach a maximum rate. The distance necessary to contain erosion will be short for highly erodible soils and longer as the erodibility of the soil decreases.

C.4 CULTURAL PRACTICES

A soils' susceptibility to wind erosion is influenced by various types of cultural practices, such as excessive tillage, summerfallow, the use of soil incorporated herbicides, and stubble burning (Slevinsky, 1983). When combined with large fields containing no windbreaks, these farming practices produce conditions of extreme wind erosion hazard (Agriculture Canada, 1985; Lindwall and Dubetz, 1984; PFRA, 1983). However, tradition and habit do not necessarily justify such practices. Land management practices need to be planned in the context of soil protection and conservation.

C.5 SOLUTIONS

Many technical or farm-level solutions to land management problems have been examined in the literature. It is important, however that these practices be tailored to the local situation and that their effectiveness be evaluated in quantitative terms.

Principles of wind erosion control include: (MDA, 1987b)

1. Establish and maintain vegetation or vegetative residues to protect the soil.

2. Roughen the land surface to reduce wind velocity and trap drifting soils.

3. Create or bring to the surface, soil aggregates large enough to resist the wind.

4. Reduce the unsheltered distance along the prevailing wind by establishing wind barriers at designated intervals to reduce the wind velocity.

Crop residue management is a most effective and practical means of controlling wind erosion (Manitoba Agriculture, 1986). Information exists that outlines quantities of crop residue required to effectively control erosion for a variety of soil groups, as well as the susceptibility of common soils to wind erosion in Manitoba (Manitoba Agriculture, 1986). Crop residues prevent erosion by reducing wind velocity at the surface of the soil (Shaykewich, 1987). The quantity of residue cover required to protect the soil depends upon the erodibility of the soil. The more prone a soil is to wind erosion the greater the quantity of crop residue is required to protect it (MDA, 1987b). For example, larger quantities are required to adequately protect sandy soils in WEG1, while lesser amounts are required to adequately protect clay soils in WEG3.

The type of residue is also important in controlling wind erosion. Residue from crops, such as flax and corn provide less protection from erosion than residue from cereal crops (Shaykewich, 1987). The orientation of crop residue also has a bearing on reducing wind erosion. Standing residue is more effective than an equal amount of flat residue.

As discussed above, excessive tillage is one of the major causes of soil erosion. The use of tillage equipment buries crop residue, reducing its effectiveness in erosion control. Conservation tillage (CT) refers to any tillage system that uses the least amount of tillage necessary, such as zero or minimum till. CT essentially reduces the exposure of soil to the erosive effects of wind and water, and consequently increases agricultural productivity. However, CT generally requires a higher level of management skills and more knowledge of chemicals and equipment (PFRA, 1983).

Literature on soil erosion is extensive, yet there is an apparent lack of information on the appropriate application of remedial soil-water management practices that are tailored to the local situation. At present, very little information exists relating tillage practices to soil types (Slevinsky, 1987).

Appendix D

WIND EROSION EQUATION FACTOR VALUES

WIND EROSION EQUATION: E = f(I,K,C,L,V)

E = predicted annual soil loss

SOIL ERODIBILITY FACTOR (I): potential annual soil loss that would occur from an isolated, smooth, unsheltered, wide, and bare field. It is governed, primarily by the size of aggregates, and the percentage of non-erodible fractions greater than 0.84 mm. in diameter as determined by dry seiving. For Manitoba, I-values were adopted from the state of North Dakota for soils having similar surface textures, and used in assigning Manitoba soil types into Wind Erodibility Groups (W.E.G.).

SOIL RIDGE ROUGHNESS FACTOR (K): refers to soil surface roughness, indicated by average height of clods or ridges constituting the surface. A field is described as smooth, semi-ridged, or ridged.

CLIMATIC FACTOR (C): local climatic factor based on average wind velocity and on the precipitation-evaporation index for a particular location based on official weather records. The climatic factor can be computed from the equation:

$C = 34.483\ v^3/(P\text{-}E)^2$

where v = mean annual wind velocity, $(P\text{-}E)^2$ is the annual Thornthwaite precipitation-evaporation index.

UNSHELTERED DISTANCE FACTOR (L): equivalent unsheltered field width across the field along the prevailing wind direction. The prevailing wind direction refers to the direction of maximum wind erosion forces, and thereby the direction in which the greatest amount of soil is moved.

VEGETATIVE COVER FACTOR (V): equivalent quantity of vegetative cover and dependent upon the quantity of cover (kg/ha. or per cent), the kind of cover, and the orientation of the cover. The V-value is expressed as equivalent flat small grain residue (Pettapiece, 1983; Shaykewich, 1987; Slevinsky, 1983; Woodruff and Siddoway, 1965).

Woodruff and Siddoway (1965) describe 5 steps for solving the equation with each step evaluating the effect of an additional variable:

Step 1: select appropriate erodibility, E_1=I, value adopted from North Dakota and shown in Table D1.

Step 2: account for effect of roughness, K, and find E_2=I*K. The K-values applied to Manitoba are the values used in North Dakota for their spring conditions (Table D1).

Step 3: account for the effect of local wind velocity and surface soil moisture, C, and find E_3=I*K*C. An average C-value of 30 for the South Interlake, for April and May, is used since it is during this spring period where the soils in the province are most susceptible to wind erosion (Slevinsky, 1983).

Table D1. **Descriptions Of Wind Erodibility Groups (WEG) For North Dakota**

WEG	Soil Texture	Dry Soil Aggregates >0.84 mm	Erodibility "I" T/ac/yr	Roughness Factor "K"
1	very fine, fine, medium sands; peats	3%	220	1.0
2	loamy sands; loamy fine sands; sandy loams; sandy loams.	10 - 25%	134	1.0
3	clays; silty clays; clay loams; silty clay loam	25%	86	0.75

Source: Slevinsky, 1983.

Step 4: account for the effect of the unsheltered distance i.e. length of field and determine E_4=IxKxCxf(L). For a determined preponderance of wind erosion forces (Winnipeg = 1.69 in May), a prevailing wind direction (180'), and an angle of deviation value (0), a wind erosion direction factor can be obtained. When multiplied by the field width the result is the unsheltered distance factor (1.25), (Slevinsky, 1983).

Step 5: account for the effect of vegetative cover, V, and determine the actual annual erosion for a specific field, E_5=E=IxKxCxf(L)xf(V). A graphical solution is given in Figure D1.

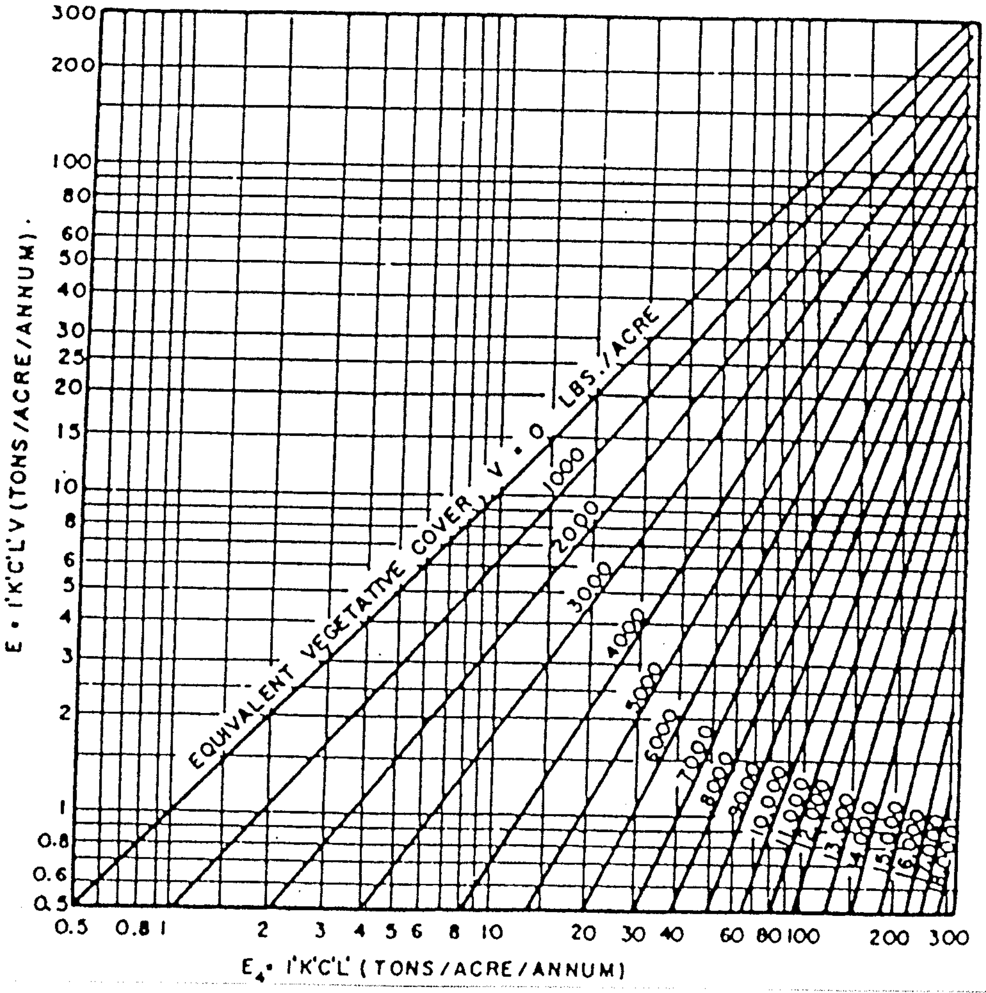

FIGURE D1. **Graphical Solution for Pedicted Annual Soil Loss, E = IKCLV and Vegetative Cover Needed to Control Erosion to a Tolerable Level**

In their article, Woodruff and Siddoway provide examples of the use of the equation to (i) determine potential average annual soil loss, I; (ii) determine vegetative cover needed to control erosion at a tolerable level of 5 tonnes per acre per year; and (iii) determine width of strips needed to control erosion at a tolerable level.

Slevinsky (1983) applied the equation to determine the effects of field size and unsheltered distance along the prevailing wind erosion direction on wind erosion for varying amounts of flat small grain residue for WEG3 and WEG4 (WEG2 and WEG3 in this study). Residue requirements were established for various crops to protect the soil to the tolerable level for each WEG in the province. Examples are provided to show that excessive operations with tillage equipment that result in high reductions in per cent ground cover will leave the soil vulnerable to erosion in the spring (April and May) when wind erosion is most critical.

Appendix E

GROUND SURVEY SHEETS

Appendix F

THEMATIC MAP SHEETS (6)

The Original Maps are Located in the

Natural Resources Institute Library.

Sent to Alan C. Nov 3/86

SOIL CONSERVATION PROGRAM

CROP RESIDUE SURVEY

Month: Oct 24 | Year: 1986

Sampled by: F Wilson [illegible]

SAMPLE ID# (1-5)	Office Use Only (6-9)	MAP POLYGON # (10-13)	RLIESVKEL (14)	QTR (15-16)	SEC (17-18)	TWP (19-20)	RGE (21-22)	MER (23-24)	% GROUND COVER (25-27)	CROP (28)	Stubble Condition (29)	WEIGHT OF RESIDUE (30-33)	CROP TYPE COMMENTS	Rotation (34)	TILLAGE (35)	Office Use Only (36-37)	TILLAGE EQUIPMENT COMMENTS	Office Use Only (38-39)	GENERAL COMMENTS
5599				NW	35	12	02	E1	100				hayland						
5598				NE	34	12	02	E1	038				cultivated, Small grain						
5597				SW	05	13	02	E1	100				hayland						
5596				NW	32	12	02	E1	100				standing stubble						
5595				NE	31	12	02	E1	065				cultivated S.G.						
5594				SE	06	13	02	E1	047				Cult stubble S.G.						
5593				SW	06	13	01	E1	041				cult small grain						
5592				NW	31	12	01	E1	100				Standing stubble 63 bu wheat						
5591				NE	36	12	01	W1	032				cult. Sm Grain flat						
5590				SE	01	13	01	W1	014				cult. Sm. Grain flat				100% ?		
5580				SW	06	13	01	W1	000				plowed corn				75/99		
5588				NW	31	12	01	W1	100				standing small grain						
5587				NE	36	12	02	W1	0[illegible]2				cult small grains						
5586				SE	01	13	02	W1	100				hayland						
5585				SW	06	13	02	W1	100				native grass						
5584				NW	31	12	02	W1	000				summerfallow, Some regrowth						
5583				NE	36	12	03	W1	100				alfalfa						
5582				SE	01	13	03	W1	100				natural grass						
5581				SW	18	14	02	W1	033				cult. sm. grains flat						
5580				NW	07	14	02	W1	023				cult " " "						
5579				NE	12	14	03	W1	100				bush - poplar						
5578				SE	13	14	03	W1	100				pasture, overgrazed.						
5577				SW	18	14	01	W1	030				cult. small grains						
5576				NW	07	14	01	W1	027				deep cult. Small grain						
5575				NE	12	14	02	W1	100				hayland						
5574				SE	13	14	02	W1	100				Standing Stubb. Straw baled						
5573				SW	18	14	01	E1	100				grass						
5572				NW	07	14	01	E1					commercial						
5571				NE	12	14	01	W1	046				cult. Small grains						
5570				SE	13	14	01	W1	026				cult sm. gr. Straw Removed						
5569				SW	18	14	02	E1	063				cult sm. grains						
5568				NW	07	14	02	E1	050				cult. Small grains						
5567				NE	12	14	01	E1	100				standing flax stubble. straw baled						
5566				SE	13	14	01	E1	068				cult Small grains						
5565				SW	18	14	03	E1	026				cult sm grains. volunteer						
5564				NW	07	14	03	E1	032				Cult Sm grain						
5563				NE	12	14	02	E1	100				hayland						
5562				SE	13	14	02	E1	029				cult small grain						
5561				SW	11	15	02	E1	048				cult small grain						
5560				NW	02	15	02	E1	004				cult hayland						
5559				NE	03	15	02	E1	100				good pasture						
5558				SE	10	15	02	E1	100				poor pasture (sheep)						

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SOIL CONSERVATION PROGRAM

CROP RESIDUE SURVEY

Month	Year
Oct 24/86	1986
Sampled by: F. Nelson (measure...	

OK
1/33 →
1/66 →
1/66 →
1/33 →

SAMPLE ID# (1–5)	Office Use Only (6–9)	MAP POLYGON # (10–13)	RIVER LAKE SWAMP SINKHOLE (14)	LOCATION QTR (15–16)	SEC (17–18)	TWP (19–20)	RGE (21–22)	MER (23–24)	% GROUND COVER (25–27)	CROP (28)	Stubble Condition (29)	WEIGHT OF RESIDUE (30–33)	CROP TYPE COMMENTS	Rotation (34)	TILLAGE (35)	Office Use Only (36–37)	TILLAGE EQUIPMENT COMMENTS	Office Use Only (38–39)	GENERAL COMMENTS
5557				SW	11	16	02	E1	100				hayland						
5556				NW	02	16	02	E1	013				cult. rape						
5555				NE	03	16	02	E1	002				cult. corn (plow, disc?						
5554				SE	10	16	02	E1	000				Summerfallow)						
5553				SW	12	17	02	E1	100				native veg.						
5552				NW	01	17	02	E1	026				cult. sm. grains						
5551				NE	02	17	02	E1	020				cult sm. grains						
5550				SE	11	17	02	E1	043				cult sm. grains						
5549				SW	12	17	03	E1	100				unimp. yard & pasture						
5548				NW	01	17	03	E1	030				cult (dep) sm grains						
5547				NE	02	17	03	E1	000				S/F. some regrowth						
5546				SE	11	17	03	E1	000				S/F some regrowth						

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SOIL CONSERVATION PROGRAM
CROP RESIDUE SURVEY

Month	Year

Sampled by:

SAMPLE ID# (1-5)	Office Use Only (6-9)	MAP POLYGON # (10-13)	RLIESVKEL (14)	LOCATION QTR (15-16)	SEC (17-18)	TWP (19-20)	RGE (21-22)	MER (23-24)	% GROUND COVER (25-27)	CROP (28)	Stubble Condition (29)	WEIGHT OF RESIDUE (30-33)	CROP TYPE COMMENTS	Rotation (34)	TILLAGE (35)	Office Use Only (36-37)	TILLAGE EQUIPMENT COMMENTS	Office Use Only (38-39)	GENERAL COMMENTS
05459		0097	2	NW	06	14	02	1W	040	5	2	0800	forage?	9	4		cultivated (3x) N-S		stony
05460		0097	2	NE	01	14	03	1W	050	2	2	1000	barley stubble	9	4		cultivated (3x) (NW-SE)		uniform coverage
05461		0097	2	SE	12	14	03	1W	100	2	3	4000	barley stubble	9	9				field not worked
05462		0097	2	SW	07	14	02	1W	055	5	2	1150	forage?	9	4		cultivated (2x) N-S		
05463		0098	3	NW	06	14	01	1W	010	5	1	0200	pasture	9	3		plow		pasture worked
05464		0098	3	NE	01	14	02	1W	070	2	2	1500	barley stubble	4	4		cultivated (2x) (W-E)		non uniform
05465		0098	3	SE	12	14	02	1W	075	2	2	1750	wheat stubble	4	4		cultivated (2x) (N-S)		uniform coverage
05466		0098	3	SW	07	14	01	1W	085	2	2	2500	wheat stubble	4	4		cultivated (1x)		regrowth
05467		0097	2	NW	06	14	01	1E	065	2	2	1400	wheat stubble	4	4		cultivated (2x) (W-E)		uniform coverage
05468		0097	2	NE	01	14	01	1W	050	2	2	1000	wheat stubble	4	4		cultivated (3x) (N-S)		uniform coverage
05469		0097	2	SE	12	14	01	1W	100	2	3	4000	wheat stubble	4	9				field not worked

SOIL CONSERVATION PROGRAM
CROP RESIDUE SURVEY

Month	Year

Sampled by:

	SAMPLE ID# (1–5)	Office Use Only (6–9)	MAP POLYGON # (10–13)	RISKEL (14)	LOCATION QTR (15–16)	SEC (17–18)	TWP (19–20)	RGE (21–22)	MER (23–24)	% GROUND COVER (25–27)	CROP (28)	Soil Condition (29)	WEIGHT OF RESIDUE (30–33)	CROP TYPE COMMENTS	Rotation (34)	TILLAGE (35)	Office Use Only (36–37)	TILLAGE EQUIPMENT COMMENTS	Office Use Only (38–39)	GENERAL COMMENTS
10	05470		0097	2	SW	07	14	01	1E	085	2	2	2500	wheat stubble	4	4		cultivated (N-S) (1x)		uniform coverage
11	05471		0098	3	NW	06	14	02	1E	065	2	2	1400	wheat stubble	4	4		cultivated 2x)		uniform coverage
12	05472		0098	3	NE	01	14	01	1E	055	2	2	1150	wheat stubble	4	4		cultivated (N-S) (3x)		only half field worked
3	05473		0098	3	SE	12	14	01	1E	045	3	2	0900	Flax stubble	4	4		cultivated (2-3x) harrowed		flax straw blowing all over field
4.	05474		0098	3	SW	07	14	02	1E	075	2	2	1750	wheat stubble	4	4		cultivated (2x)		non uniform coverage
5	05475		0081	3	NW	06	13	08	1E	030	2	2	0600	wheat stubble	4	4		tandem disc (W-E)		uniform coverage
6	05476		0081	3	NE	01	13	07	1E	065	5	1	1400	forage	9	4		cultivate (2x) (N-S)		uniform coverage
7	05477		0081	3	SE	12	13	07	1E	010	5	1	0200	Pasture/forage	9	3		plow (W-E)		break up of permanent coverage?
8	05478		0081	3	SW	07	13	08	1E	000	1	1	0000	fallow	9	2				stones.
9	05479		0087	5	SW	05	04	07	1E	005	1	1	0100	fallow -cereal stubble	9	2				stones
0	05480		0087	5	SE	05	14	07	1E	020	3	1	0150	Canola stubble with winter wheat	9	3		cultivated? seeder		winter wheat gives good cover

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SOIL CONSERVATION PROGRAM

CROP RESIDUE SURVEY

Month	Year

Sampled by:

SAMPLE ID# (1-5)	Office Use Only (6-9)	MAP POLYGON # (10-13)	RLIESVKEL (14)	LOCATION: QTR (15-16)	SEC (17-18)	TWP (19-20)	RGE (21-22)	MER (23-24)	% GROUND COVER (25-27)	CROP (28)	Soil Conservation (29)	WEIGHT OF RESIDUE (30-33)	CROP TYPE COMMENTS	Rotation (34)	TILLAGE (35)	Office Use Only (36-37)	TILLAGE EQUIPMENT COMMENTS	Office Use Only (38-39)	GENERAL COMMENTS
05481		0087	5	NE	06	14	07	1E	010	2	1	0200	cereal stubble	9	3		Disc (2x)? (NW-SE)		field v. black
05482		0087	5	NW	05	14	07	1E	075	2	2	1750	wheat stubble	9	4		cultivate (1x) (NE-SW)		uniform coverage
05483		0087	5	SW	08	14	07	1E	000	1	1	0000	pasture / forage	9	3		plow ? cultivate? (W-E)		field v. black
05484		0087	5	SE	07	14	07	1E	000	1	1	0000	pasture / forage	9	3		plow ? cultivate ? (W-E)		" " "
05485		0087	5	SW	19	14	07	1E	075	2	2	1750	wheat stubble	9	3		cultivate (2x) (W-E)		winter wheat growing
05486		0087	5	SE	24	14	06	1E	070	2	2	1500	wheat stubble	9	4		cultivate (2x) (W-E)		part of field worked more than 70%
05487		0087	5	SW	18	14	07	1E	045	2	2	0900	wheat stubble	9	4		Disc (2x) (W-E)		non uniform coverage
05488		0087	5	SE	13	14	06	1E	055	2	2	1150	wheat/cereal stubble	9	4		cultivate (3x) (W-E)		regrowth
05489		0087	5	NE	12	14	06	1E	015	2	2	0300	cereal stubble	9	3		Disc (2x) (W-E)		field v. black
05490		0087	5	NW	07	14	07	1E	000	1	1	0000	fallow with winter wheat	9	3				winter wheat gives good coverage
05491		0087	5	SW	07	14	07	1E	020	2	1	0400	cereal stubble	9	4		Disc (2x)? (W-E)		non uniform coverage

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SOIL CONSERVATION PROGRAM

CROP RESIDUE SURVEY

Month	Year

Sampled by:

SAMPLE ID# (1-5)	Office Use Only (6-9)	MAP POLYGON # (10-13)	RLSKL / IEVEL (14)	LOCATION QTR (15-16)	SEC (17-18)	TWP (19-20)	RGE (21-22)	MER (23-24)	% GROUND COVER (25-27)	CROP (28)	SC Soil Conn. (29)	WEIGHT OF RESIDUE (30-33)	CROP TYPE COMMENTS	Rotation (34)	TILLAGE (35)	Office Use Only (36-37)	TILLAGE EQUIPMENT COMMENTS	Office Use Only (38-39)	GENERAL COMMENTS
05492		0087	5	NE	01	14	06	1E	005	2	1	0100	cereal stubble	9	3		plow (w-E)		
05493		0087	5	NW	06	14	07	1E	000	1	1	0000	fallow with winter wheat?	9	3		seeder?		winter wheat comir along very slowly
05494		0087	5	SE	01	14	06	1E	060	2	2	1300	wheat stubble	9	4		cultivate (2-3x) (w-E)		non uniform coverage
05495		0087	5	SW	24	14	06	1E	070	2	1	1500	wheat stubble	9	4		cultivate (2x) harrow		uniform coverage
05496		0087	5	SE	23	14	06	1E	060	3	2	1300	flax stubble	9	4		cultivate (1-2x)		non uniform coverage
05497		0087	5	NW	24	14	06	1E	075	2	1	1750	wheat stubble	9	4		cultivate (1x) harrow (1-2x)		uniform coverage
05498		0087	5	NE	23	14	06	1E	065	3	2	1400	flax stubble	9	4		cultivate (1x) (NE-SW)		edge worked (2x)
05499		0087	5	SE	26	14	06	1E	050	5	2	1000	pasture	9	4		Disced?		pasture just broker
05500		0087	5	NE	26	14	06	1E	100	2	3	4000	wheat stubble	9	9				burned straw swat

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