INTRODUCTION

The identification of soil landscapes suitable for the production of food began with the dawn of arable agriculture (Simonson 1968). Ahrens et al. (2002, p. 1) states “. . . pedology and soil science in general have their rudimentary beginnings in attempts to group or classify soils on the basis of productivity. Early agrarian civilizations must have had some way to communicate differences and similarities among soils.” At the beginning of the 19th century, the German agronomist A. D. Thaer proposed a scale to describe the intrinsic fertility of soil based on texture, lime and humus content (Feller et al. 2003). Canada was no exception with references in the notes of early explorers such as Champlain in the early 1600s (Fischer 2008) and Palliser (Spry 1963) who, in addition to characterizing the landscapes of the Canadian Prairies in the 1850s, provided an assessment of the potential for agricultural crop production. These early types of assessments were very subjective and qualitative (good-fair-poor) based on general observations of features such as topography, stoniness, wetness and tree cover.

As agriculture became more mechanized and intensified in the 20th Century, there was a concomitant increase in scientific research into the agronomic requirements of arable crops. The evaluation of production potential became much more specific and quantitative with assessments such as the Storie Index Rating (Storie 1933). This mathematical treatment of individual parameters such as texture, organic matter and pH was well accepted by the technical community of soil specialists and ratings based on his procedure were incorporated into numerous soil reports produced as part of the National Cooperative Soil Survey Program in the United States (see, for example, Goodman 1955 and Arroues and Anderson 1986). In Alberta Canada, soil survey reports of the late 1930s to the late 1950s included an interpretive land class map derived primarily from the physical characteristics of the study area. When compiling the map, soil physical data (texture, surface colour, pH, type of soil profile (classification), mode of deposition, and degree of stoniness) landscape data (type of topography and relief) and climate data (rainfall and rainfall variability) were all taken into consideration (Wyatt et al. 1939). Each of these factors was assigned a numeric value for each soil area, and the multiplying together of these values gave the final index rating of the soil area. Using available pasture carrying capacity and wheat yield data, a seven class productivity grouping of these rated areas was created. Some of the later soil survey reports produced until the end of the 1960s incorporated a stocking rate and/or wheat yield range for each group as an estimate of productivity (see, for example, Bowser et al. 1951 and Odynsky et al. 1952).

By the middle of the century agriculture was becoming a mature industry. With greater intensification and further expansion into the less suitable fringe lands, there was recognition that some of the agricultural practices associated with the push for higher productivity were negatively affecting environmental sustainability (Standing Committee on Agriculture, Fisheries and Forestry 1984). In Canada, this discussion had started with the wind erosion concerns in the 1920s and 30s. Also there was a growing competition with other land uses such as forestry, wildlife habitat, and recreation all associated with a growing population. It was into this setting that the broader concept of land capability, which included an aspect of sustainability, was introduced both in the United States (Klingebiel and Montgomery 1961) and Canada (ARDA 1965).

The Canada Land Inventory (CLI) was introduced in Canada in the mid-1960s (ARDA 1965). The system used a general comparative capability approach based on severity of limitations for broadly defined land uses, specifically, agriculture, forestry, wildlife, and recreation. In the words of the authors of the first CLI report (ARDA 1965, p. 3), the new system “is designed primarily for planning rather than for management. It is of a reconnaissance type, it provides information essential for land development planning at the municipal, provincial and federal levels of government. It does not provide the detailed information required for management of individual parcels of land, nor for land planning in small watersheds, local government units, etc.” The capability ratings were to be presented on maps at a scale of 1:250k. At the time of its development in the mid-to-late 1960s, the then relatively new profession of land use planning was becoming important and quickly embraced this new rating system as capability was an intuitive and easily understandable concept. Municipal planners and realtors particularly liked the approach. The classification system incorporated seven classes with Class 1 being the best with no limitation for the intended use, Class 4 being marginal for the use and Class 7 being completely unsuitable. Under the umbrella of a cooperative federal-provincial program, approximately 2.5 million hectares covering all regions of Canada with multiple land use issues associated with agriculture were mapped from 1965 to 1980 using the CLI (Canada Land Inventory 1998).

The CLI system worked very well for its intended regional development objectives; however, these regional assessments, while based on specific soil and land information still required a significant amount of interpretation and extrapolation and amalgamation. In addition, the capability classes are nominal, categorical data that may be well-suited to land use planning functions but not useful for more detailed productivity assessments within each category (Mueller et al. 2010). Many land evaluators and managers required a much more detailed assessment at scales of 1:50k or larger (with units as small as several hectares), but in many areas there simply was not a more detailed database available. The CLI, however, was not intended for use at detailed or site specific scales because of the limitations associated with the broad nature of the fieldwork, cartographic restrictions and complexity of mapped units (AENR 1983). Attempts to extend the CLI approach to address the more detailed requirements provided variable results. Over the years, agencies in a number of provinces (e.g., Ontario, Alberta and British Columbia) either modified the original CLI system or developed entirely new systems of land capability classification for a variety of purposes (AIWG 1995). In other instances, soils specialists with different agencies within a province simply used two parallel systems following the CLI and Storie-type approaches (ASAC 1983). As well, as long as one person or one closely correlated group was providing the interpretations there was at least consistency within a region; however, as more people and agencies became involved, consistent evaluations became a problem (ASAC 1987).

The overall result was that by the mid-1980s there were many agricultural rating systems being used across Canada. These included the systems used in British Columbia (Kenk and Coltic 1983), Alberta (ASAC 1987), the Ottawa area (Marshall et al. 1979), Ontario (Brokx and Presant, 1986), Quebec (Mailloux et al. 1984), and the Atlantic Region (Atlantic Advisory Committee on Soil Survey, 1988). With different parameters and thresholds, the same crops could have different absolute ratings under the different systems. The original CLI was also not consistent across Canada as the ratings were based on regionally important crops that differed from one region to another. For example, an area rated as CLI Class 1 for agriculture in Saskatchewan would be based on wheat and other small grains while an area rated as CLI Class 1 for agriculture in Ontario would have to grow corn.

The use of multiple capability classification systems as well as the inconsistent manner in which the CLI was being applied nationally resulted in much confusion and conflict. Concern about this was expressed at the meeting of the Expert Committee on Soil Survey (ECSS) in 1986, and in response the Land Resource Research Centre of Agriculture and Agri-Food Canada struck an Agronomic Interpretations Working Group (AIWG) in 1987 to pursue the development of a national rating system for Canada (AIWG 1995). It was asked to address several specific concerns related to the CLI - Soil Capability for Agriculture, namely:

* the proliferation of modifications to the CLI by several agencies that had resulted in a variety of non-comparable approaches to the classification of land capability for agriculture across Canada;
* the inadequate consideration of the influence of climate on land suitability for crop production;
* the omission of organic soils in the CLI, and;
* the lack of specificity in definitions and applications which lead to inconsistent ratings by those applying the system.

The result of the work of the AIWG was the technical bulletin entitled “Land Suitability Rating System for Agricultural Crops: 1. Spring-seeded small grains”, published in 1995 (AIWG 1995). The purpose of this paper is to present the rationale associated with the development of the national Land Suitability Rating System (LSRS), describe the structure and methodology of its use, and present recent modifications, additional modules and examples of application of LSRS.

SYSTEM DEVELOPMENT

Capability versus Suitability

Before describing the approach and methods used in the development of LSRS the difference between land capability (as used in CLI) and land suitability (as used in LSRS) warrant some discussion. Capability is an assessment which focuses on the nature and degree of limitations imposed by the physical characteristics of a land unit for a specific use. In the New Zealand Land Use Capability (LUC) Classification (Lynn et al. 2009), capability refers to “suitability for productive use or uses after considering the physical limitations of the land” (p. 8). Similarly, the land capability classification for agriculture in the UK developed by the Macauley Land Research Institute describes “the agricultural potential of land based on the degree of limitation imposed by its biophysical properties” (Wright et al. 2006, p. 4). Land capability classification involves systematically arranging units of the landscape in a way that reflects inherent properties that determine the ability of the land to produce sustainably into the future (Hockensmith 1953, Lynn et al. 2009). In Canada, the Canada Land Inventory (CLI) series of capability maps have been an important reference for assessing present and potential land use activities and planning across Canada from the inception of the system to present time. In terms of capability ratings there are issues related to specificity. The agricultural capability classification rates soils according to their potentialities and limitations for sustained production of common cultivated crops. The underlying assumption is that the better the capability rating (i.e. Class 1 vs Class 4) a wider variety of agricultural crops may be grown; however, the number of crops successfully grown varies from one region of Canada to another. For example, corn may be grown in the CLI Class 1 or 2 areas in southern Ontario, but within the Prairie region areas of equivalent capability cannot sustain equivalent corn crops. As a result of regional application of the system, classes are no longer truly comparable nationally.

Suitability is an estimate of the fitness of a given type of soil landscape for a specific use or for producing a specific agricultural crop. As plants have specific requirements related to the functional status of soil, classifications based on production limitations and crop productivity must have a certain stratification or orientation on crops or groups of crops (Mueller et al. 2010). In the 19th century, federal German states used soil suitability classification systems employing classes ranging from “prime Wheat soil” to “Rye soil” or “Oats soil”, to describe the suitability of specific areas (Feller et al. 2003). More recently, the Muencheberg Soil Quality Rating is a soil suitability classification developed as a tool to assess the capacity of land across all scales to produce small grains (Mueller et al. 2007). Similarly soil suitability rating systems have been developed for a variety of specific purposes such as direct drilling or reduced tillage (Cannell et al. 1978), irrigation (Alberta Agriculture, Food and Rural Development 2000), the spreading of animal manure (Eilers and Buckley 2002), and carcass burial (Carcass Burial Site Selection Technical Committee 2004).

Preliminary Orientation

Development of LSRS was based on an “expert system” approach that made use of existing sources of data and the collective knowledge and experience of professionals from the fields of land and plant science and those familiar with the evaluation of land suitability for crop production throughout Canada. The AIWG, composed of members from each province plus Yukon Territory, examined a number of systems that were actively being used at the time to rate land for the production of agricultural crops, keeping in mind the need for national consistency and the other concerns raised by the ECSS. Several climatic stratifications were also reviewed (Chapman and Brown 1966; FAO 1976; Williams 1983).

Recommendations from the initial assessment were:

1. The basic concept of the seven (7) class CLI system (ARDA 1965) should be retained. It was sound and easy to understand, and it was the basis of land legislation in several provinces.
2. Since climate, soil and landscape factors could independently control the suitability of a tract of land for crop production, each one should be rated separately.
3. Organic soils must be included and should (at least in the initial development stages) be rated for the same crops as mineral soils.
4. As a limited number of factors were common to all systems reviewed and included most of the parameters of an optimum approach to soil productivity assessment (Huddleston 1984) these should be individually defined and explicitly rated using an expert system approach (McCracken and Cate 1986) based on present knowledge and available data.
5. The individual parameter ratings should follow scientifically proven relationships and managed in a mathematical setting leading to a composite index (climate, soil and landscape) in an approach similar to that of Storie (Storie 1933).
6. The system should be developed using the small seeded cereals (wheat, oats and barley) with an emphasis on barley which is the one crop that is grown in every agricultural region of Canada.
7. The system must use data that was presently available across Canada.

The first recommendation provided the overall approach that should be taken while the next four addressed the major weaknesses that had been identified in the CLI approach. The final two recommendations addressed the issue of national consistency and provided further direction for system development.

It may be noted that no mention is made of scale. The reason is that the system is meant to be scaleless - the ability to be used at any scale appropriate to the objectives of the project and available data.

Assumptions

Arising from the preliminary discussion there were a number of assumptions or guidelines that were required to provide boundary conditions for the system:

1. Standard recommended husbandry should be assumed.
2. External economic factors such as distance to market, availability of transportation and size of farm would not be criteria. These are important for Municipal assessment and taxation but would not be part of this natural resource evaluation.
3. One-time costs such as clearing of trees or drainage would not be criteria but continuing annual costs such stone removal and erosion control should be considered in the sustainability considerations.
4. Exceptional skills or resources of the farm manager or specific cultural practices would not be considered.
5. Permafrost would not be a factor. This was based on the observation that once the vegetative cover is removed permafrost recedes to depths greater than 1 m in any region of Canada where commercial crop production is considered feasible.

Structure of the Land Suitability Rating System

Class and Subclass

The basic structure of the LSRS follows that of CLI, namely the use of two hierarchical categories – classes and subclasses. Classes are broad in scope and are based on the degree of limitation of land for production of the specified crop or crops. Seven classes are recognized: Classes 1-3 are considered arable – suitable for sustained production of the specified crop; Class 4 is considered marginal, and; Classes 5-7 are considered unsuitable or not capable of supporting sustained production under presently recommended practices. Subclasses identify the attributes that have the greatest limiting influence on the final class rating. They reflect the kind of climate, soil and landscape limitations that are present. The subclass information is critical for determining conservation and management practices and for land use planning. Subclass designations used in LSRS are: climate – temperature/aridity (H) and moisture (A); mineral soil – water supplying ability (M), structure and consistence (D), organic matter content (F), depth of topsoil (E), reaction (V), salinity (N), sodicity (Y), organic (peaty) surface (O), and drainage (W); organic soil – soil temperature (Z), water supplying ability (M), degree of decomposition (B), reaction and nutrient status (V), salinity (N), and drainage (W), and; landscape – basic landform rating/slope (T), stoniness (P), wood content (J), landscape pattern (K), and flooding (I).

It is important to note that areas assigned to the same suitability class are similar only with respect to the degree, and not the kind, of limitation for the production of the specified crop. Areas of similar class can include different climate, soil and landscape characteristics that may differ markedly and require different management practices.

Factors and Parameters

LSRS is an interpretive assessment based on the limitations controlling crop specific production. Three major rating factors are identified: climate, soil and landscape. The rating factor that is most limiting ultimately determines the suitability class rating. The components and measureable parameters identified to characterize and evaluate the major rating factors were selected from those used in earlier approaches to rating land for the production of agricultural crops, and acknowledged to be critical in crop production (Huddleston 1984). The following criteria were used in selecting the specific parameters used to characterize the major rating factors used in the LSRS model (Table 1):

* parameter is known to affect the ability to produce crops;
* parameter is known to affect the ability to respond to management stress (e.g., could withstand drought);
* parameter must be measurable or able to be estimated from known relationships (i.e, pedotransfer functions), and;
* parameter data must be commonly available.

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| **Table 1. Components and parameters chosen to characterize the major rating factorsz** | | |
| Factor | Component | Measureable parameter |
| Climate | Heat (energy) supply | Growing degree days, growing season |
|  | Moisture supply | Precipitation, evapotranspiration, growing season |
|  |  |  |
| Mineral Soils | Moisture supply | Texture, climate, rooting depth, watertable |
|  | Nutrient supply | Organic matter content, soil reaction |
|  | Physical conditions | Soil structure, soil density |
|  | Chemical conditions | Soil salinity, soil reaction |
|  | Drainage | Depth to water table, climate |
|  |  |  |
| Organic Soils | Moisture supply | Fibre content, climate, water table |
|  | Nutrient supply | Fibre type, soil reaction |
|  | Physical conditions | Soil structure, soil density |
|  | Chemical conditions | Soil reaction, soil salinity |
|  | Drainage | Depth to water table, climate |
|  |  |  |
| Landscape | Erodability potential | Slope steepness, slope length, climate |
|  | Management factors | Stoniness, drainage, pattern**y** |
|  | Flooding potential | Wetness, duration of flooding, landform position |
| **z**See AIWG (1995) for definitions.  **y**Identified but not incorporated for initial development. | | |

Relationships and Linkages of Factors, Components and Parameters to the Suitability Assessment

In keeping with the recommendations of the AIWG, LSRS assesses the climate, soil and landscape factors independently with a precisely defined index procedure that links the results to the 7 class system. This methodology required the development of clear relationships and guidelines for the assessment of the factors.

The Relationship Between Climate, Soil and Landscape Factors

In LSRS, the major rating factors are related to three of the major elements that describe crop production suitability:

* Climate - controls the type and range of crops that can be grown (flexibility of production);
* Soil - controls how well the crops grow (productivity), and;
* Landscape - controls the annual cost to manage environmental constraints (sustainability).

Although it is recognized that there are many instances of overlap and synergy between the major factors, there are advantages with respect to simplicity, clarity and the ability to highlight specific limitations by assessing each factor separately. Having built the major climatic-soil interactions into the soil factor, any other remaining discrepancies are considered small. This decision is reasonable given the constraint of available data and the need for national coverage. This approach provides the greatest flexibility to assess various environmental, crop and climatic scenarios.

Each of the major factors is assessed a rating index between 0 (most limiting) and 100 (least limiting). Initially, each factor is assigned an index rating of 100. Limitations are assessed using the specific parameters identified for each factor (Table 1) and point values are deducted from the initial index ratings. The final index rating assigned is that of the most limiting of the three factors.

Linkage of Numerical Assessment to the Descriptive Class Structure

As productivity is an important consideration in suitability assessments, studies of the relationships of Canada Land Inventory (CLI) classes to the yields of cereals in Alberta (Peters 1977; Peters and Pettapiece 1981) and apples in Ontario (van Vliet et al. 1979) provided the initial guidance in developing an assessment of limitations based linkage between the prescriptive numerical index ratings (0-100) and the descriptive suitability class ratings (1-7). These studies reported a reasonably good correlation for the better classes with Class 1 (none to slight limitation) generally yielding 80% to 100% of the crop maximum. Class 3 areas (moderate limitation but still considered “Good”) generally had yields about 50% of maximum or better. It was also noted that with increasing limitations - particularly landscape limitations, the yield relationships disappeared. That is, landscape features may be difficult or costly to manage but are not directly related to yield. Additional expert opinion suggested that index rating of less than approximately 1/3 of maximum (33 out of 100 points) should be considered a very severe limitation to the long-term sustainability of production.

Using the above noted considerations as a guide, a relationship framework was formulated that provides the conceptual and mathematical linkage between the factor index ratings and LSRS classes and also assisted in the development of the individual parameter indices (Fig. 1).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Suitability  class | Index  rating | Limitation level for specified crop | General  assessment | Comments |
| 1 | 100–80 | None to slight | Excellent | Primeland |
| 2 | 79–60 | Slight | Good |
| 3 | 59-45 | Moderate | Fair |
| 4 | 44-30 | Severe | Poor | Marginal land |
| 5 | 29-20 | Very severe | Very poor | Unsustainable or unsuitable land |
| 6 | 19-10 | Extreme | Unsuitable |
| 7 | 9-0 | Unsuitable |  |

Fig. 1. Framework for LSRS outlining the relationship between LSRS class, index rating and degree of limitation.

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