

The Agricultural Potential of Northwestern Canada and Alaska and the Impact of Climatic Change

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ABSTRACT. Climate change studies have indicated the potential for increased drought in the southern Canadian prairies, and with this the potential exists for a northward shift in agricultural production areas. In order to assess the potential for agriculture, the arable soils of northwestern Canada (approximately north and west of 55°N latitude and 110°W longitude) and Alaska were summarized. The study area was divided into several sub-regions or major land resource areas (MLRA) within which the soils with potential for agricultural use were identified through existing soil surveys. These surveys indicate an area of greater than 57 M hectares (Ha) of potentially arable land, which could be used for either annual cropping or grazing on perennial forages, according to the Canada Land Inventory class 1-5 criteria. The climatic limitations for each MLRA were assessed separately through the use of Climate Classification Software. These limitations were then applied to the 57 M Ha of potentially arable land identified earlier, with the result that the area was rated as overall class 5 climate, limited primarily by heat, and the size of the area was reduced to 39.2 M Ha. The impact of a 2 × CO₂ changed climate on this area was then assessed by the use of climatic data generated with the Canadian Climate Centre, Global Circulation Model. These data show a much improved climatic capability for agriculture, being substantially warmer and somewhat drier. The overall climate class increased to a rating of 3, and 55.3 M Ha of arable land were shown to be potentially available in the study area.

Key words: climate change, agriculture, soil, resource assessment, northwestern Canada, Alaska

RÉSUMÉ. Des études sur le changement climatique ont révélé que la sécheresse pourrait s'aggraver dans le sud de Prairies canadiennes et entraîner une migration vers le nord des zones de production agricole. Pour vérifier cette hypothèse, on a regroupé les sols arables du nord-ouest du Canada (situés à peu près au nord et à l'ouest du 55° degré de latitude nord et du 110° degré de longitude ouest) et de l'Alaska pour en évaluer les aptitudes agricoles. La région à l'étude a été répartie en plusieurs sous-régions ou zones principales de sols (ZPS) dont on a déterminé, à l'aide des prospections pédologiques existantes, les aptitudes à l'agriculture. Ces prospections révèlent qu'une superficie de plus de 57 millions d'hectares de terre potentiellement cultivable pourrait servir à la culture de plantes annuelles ou à la paissance de plantes fourragères vivaces selon les critères d'évaluation des sols de classe 1 à 5 de l'Inventaire des terres du Canada (ITC). On a évalué séparément les restrictions climatiques de chaque ZPS au moyen du Logiciel de classification climatique. On a ensuite appliqué ces restrictions aux 57 millions d'hectares de terre potentiellement cultivable susmentionnés. Selon cette opération, la superficie en question entre dans la grande classe climatique 5, limitée principalement par la chaleur; il a donc fallu la réduire à 39,2 millions d'hectares. On a ensuite évalué l'effet d'un changement climatique (le double de la concentration de CO₂) sur cette superficie à l'aide des données climatiques produites par le Modèle de circulation atmosphérique à l'échelle mondiale du Centre climatologique canadien. Ces données révèlent une grande amélioration des possibilités du climat pour l'agriculture, qui devient beaucoup plus chaud et un peu plus sec. La superficie entre alors dans la classe climatique 3 et 55,3 millions d'hectares de terre arable deviennent alors potentiellement accessibles dans la région à l'étude.

Mots clés : changement climatique, agriculture, sol, évaluation des ressources, nord-ouest du Canada, Alaska

РЕФЕРАТ. Изучение изменений климата показало потенциальную возможность сильной засухи в южных районах канадских прерий, в связи с чем можно ожидать сдвига сельскохозяйственного производства в северном направлении. Для оценки значения этого сдвига для сельского хозяйства было проведено суммарное обследование пахотных земель Северо-Западной Канады (примерно к северу от 55° с.ш. и к западу от 110° з.д.) и Аляски. Изучаемая площадь была разделена на несколько подрайонов, или "основных участков земельных ресурсов", в пределах которых почвы, потенциально пригодные для сельского хозяйства, были идентифицированы путем использования имеющихся данных почвенных съемок. Эти съемки показывают наличие свыше 57 млн. га потенциально пахотной земли, которые могут быть использованы либо для ежегодного выращивания сельскохозяйственных культур, либо для выпаса скота на многолетних кормах в соответствии с критериями Земельного реестра Канады, классы 1-5. Климатические ограничения были оценены для каждого из основных участков земельных ресурсов отдельно с помощью компьютерной программы классификации климата. Эти ограничения были затем приложены к выявленным ранее 57 млн. га потенциально пахотной земли, в результате чего эта площадь была отнесена в целом к 5-у климатическому классу, ограниченному главным образом теплом, и размер площади был уменьшен до 39,2 млн. га. Воздействие на эту площадь климатических изменений, вызванных 2 X CO₂, было оценено путем использования климатических данных, полученных с помощью модели глобальной циркуляции в Канадском климатическом центре. Эти данные показывают значительно улучшившиеся, существенно более теплые и несколько более сухие климатические условия для сельского хозяйства. Общий климатический класс возрос до 3, и на изученной площади было установлено потенциальное наличие 55,3 млн. га пахотной земли.

Ключевые слова: изменение климата, сельское хозяйство, почва, оценка ресурсов, Северо-Западная Канада, Аляска.

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INTRODUCTION

The land area of northwestern Canada and Alaska that has potential for agricultural uses has been widely debated for over 20 years (Harris *et al.*, 1972; Eley and Findlay, 1977). These debates have dwelt on what the potential areas are and if the primary limiting factor is soil or climate. The arable soils of the Yukon Territory, the western portion of the Northwest Territories, Alaska and the northern portions of Alberta and British Columbia have generally been perceived as having excessively thin topsoil horizons, having low fertility and being located in widely dispersed pockets along primary river valleys such that they were not worthy of development (Beattie *et al.*, 1981). In fact, according to the original soil surveyors there are substantial areas of land which are suitable for agricultural use.

The existing soil resources for agricultural purposes have been inventoried on a region or basin basis by a number of different authors (Northern Research Group, 1978; Rostad and Kozak, 1977). These inventories have been done over a period of approximately 45 years, largely under the auspices of exploratory soil surveys, and have used criteria such as the Canada Land Inventory System (CLI) (Canada Land Inventory, 1969) and variations of the older Land Classification System or Storie Index (Storie, 1933). Since the surveys have been done independently, divergent assessments have resulted from different criteria being used and improved knowledge of the region being incorporated over time. Early assessments of selected areas in Alaska identified approximately 0.8 M hectares (Ha) of arable land. By 1974, more comprehensive studies dramatically increased this figure to 6.2 M Ha (Rieger, 1974), then 7.5 M Ha (Alaska Rural Development Council, 1983) and finally the currently accepted value of 8.2 M Ha of "fair" or better agricultural land, as defined in the Exploratory Soil Survey of Alaska (Rieger *et al.*, 1979). Due to the widespread publication and dated nature of the detailed soil surveys conducted within the study area, there have been few efforts to summarize them into a single document (Harris *et al.*, 1972; Miller, 1984).

In light of recent developments in the area of climatic change, there is increasing agreement that a warmer climate is inevitable and there will be increasing pressures on northern development (Magill and Geddes, 1988).

The objective of this study is to tabulate the total soil resource, defined in the original soil surveys, over the study area extending north and west from approximately 55°N latitude and 110°W longitude (Fig. 1). Subsequently, the capability of the existing climate of the study area to support agriculture is assessed and the effect of a $2 \times \text{CO}_2$ atmosphere on the temperature and precipitation regimes is determined. The study then assesses the impact of the projected $2 \times \text{CO}_2$ temperature and precipitation regimes on the climatic suitability for agriculture and the extent of the previously defined potentially arable lands in the study area.

MATERIALS AND METHODS

The spatial extent of potentially arable lands in northwestern North America was assessed by defining the overall area of study and subsequently breaking that down into manageable

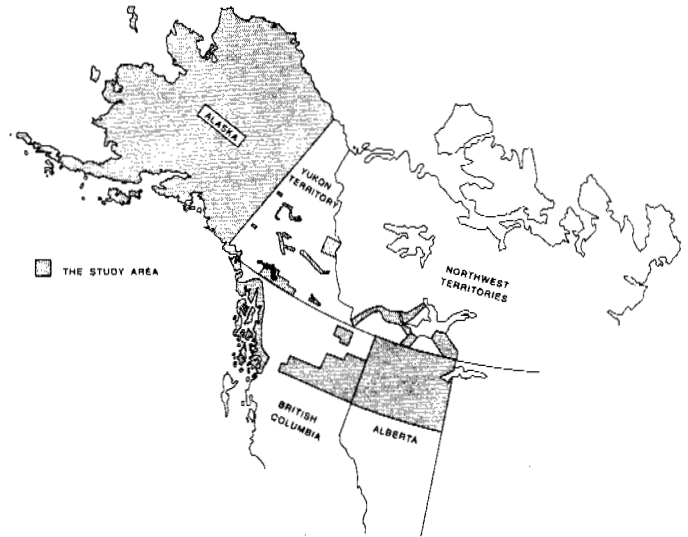


FIG. 1. The study area.

zones referred to as major land resource areas (MLRAs). Representative meteorological sites were also selected for each MLRA. The literature was then examined for existing soil surveys or related documentation that could provide an assessment of the extent and suitability of the potentially arable lands for each MLRA. The primary system used in these soil survey reports is a soil class or soil capability class for agriculture. This approach defines criteria for such parameters as fertility, infiltration, stoniness, slope and soil texture and then integrates the results for each soil series or soil type into a numeric class. Depending on the classification scheme used, there can be from 3 to 7 classes representing excellent to non-arable soils.

Due to the differences over time and between the two countries involved, it was necessary to develop a system to cross correlate the various rating systems used and reduce each to one common classification system. The Canada Land Inventory System was chosen for this purpose because it was the predominant system used in the literature and with its seven classes it became easier to fit other systems into it. The correlation matrix shown in Table 1 is based on the published subjective definitions used for the different surveys involved.

One obvious limitation of this approach was the problem of determining the matching classes when a 3- or 4-class system was incorporated into a 7-class system. For purposes of this study, wherever there was a choice of 2 classes the soil series in question was placed in the lower quality class. For this paper, arable land is defined as soil capability classes 1-4, which are suitable for annual cropping, and class 5, which is suitable for perennial forages or grazing and has some potential for improvement. The following qualitative class definitions are used by the CLI and are used within this study for the definition of both soil and climate capability.

Arable: Class 1, excellent agricultural potential for all common crops. Class 2, good potential for common annual crops. Class 3, fair potential for common annual crops. Class 4, suitable for grazing, perennial crops or hardy annual

TABLE 1. Soil ratings correlation matrix

Soil rating system	Arable					Non-arable	
Canada Land Inventory	1	2	3	4	5	6	7
Land capability classes (mid-1950s)	1	2	3	4	5	6	
Land classes (mid-1940s)	Arable		Temporarily non-arable			Non-arable (forest)	
Productivity soil ratings (early 1960s)	Good to very good		Fairly good to good	Fair to fairly good	Poor to fair	Pasture or woodland	
Alberta exploratory soil surveys (late 1950s)	Arable			Doubtful		Pasture and woodland	
Exploratory soil survey of Alaska	Good		Fair		Poor	Unsuitable	

crops. Class 5, suitable for grazing with potential for improvement.

Non-arable: Class 6, suitable for native grazing with no potential for improvement. Class 7, no agricultural potential of any type.

The study area was subdivided into MLRAs based on both political and physiographic boundaries to aid in the delineation of the agricultural potential of each area. The political delineation was required largely on the basis of the federal, provincial, territorial or state agency that did the original soil survey work, while the physiographic delineation was based on the actual surveys or recognized areas (Department of Mines and Technical Surveys, 1957). Once the correlations were established, data were tabulated according to their MLRA and applicable CLI suitability class.

In addition to the inventory of the potentially arable soils of the study area, an attempt was undertaken to identify the climate for each MLRA. Representative meteorological sites for each MLRA were selected. These sites, along with their locations, are listed in Table 2. Mean monthly air temperature and precipitation data for each of the representative sites under the current climate conditions ($1 \times \text{CO}_2$) were extracted from Canadian and United States summaries (Atmospheric Environment Service, 1982a; National Oceanic and Atmospheric Administration, 1988) of long-term climatic data. These data were typically 30-year normals, although some newer sites were less (Table 3). The data were then used as direct input into version 2.0 of the Climate Classification System (CCS) computer program originally developed for use in Alberta (Alberta Agrometeorology Advisory Committee, 1987). This has recently been updated and coded for use on a personal computer (Mills, 1992).

The CCS utilizes mean monthly air temperature and precipitation data to calculate a numeric rating of the climate's suitability for agriculture based on an energy term, a moisture term and several modifying factors. The energy term is based upon the growing degree day (5°C base) concept and is modified to consider day length and the diurnal temperature range to generate the final energy term, the effective growing degree days (EGDD). The moisture term is based on the concept of precipitation (P) minus the potential evapotranspiration (PE). The resulting P-PE value is modified by a crop water demand curve based on annual cereal grains. Separate modifying factors considered are spring and fall moisture excesses affecting seeding and harvest operations, hail and the susceptibility of the site to atypically early fall frosts. The numeric values generated for the energy and moisture terms are used to determine if heat or moisture is

the greatest limiting factor. The modifying factors are then applied, and the resulting numeric value is converted into one of seven corresponding capability classes. The CCS utilizes the same class definitions that are found in the CLI soil capability system.

The impact of climatic change on each sites' climate capability rating was assessed through the use of two condensed data sets of monthly Global Circulation Model (GCM) data from the second generation GCM developed by the Canadian Climate Centre (Canadian Climate Centre, 1991). This version of the GCM incorporates several enhancements over its predecessor. In addition to the increased resolution provided by a 3.75° latitude \times 3.75° longitude grid, ocean mixing, sea ice thermodynamics and cloud parameterization are included in the model. Improved algorithms for solar and terrestrial radiative heating and land surface processes are also incorporated (McFarlane *et al.*, 1992). This model was chosen in preference to other GCMs such as the National Centre for Atmospheric Research, the United Kingdom Meteorological Office or the Goddard Institute of Space Studies models both due to data availability and because in comparison tests this model has produced fewer extreme results than some of the others (Intergovernmental Panel on Climate Change, 1990).

As indicated earlier, this model produced two complete condensed databases of monthly values on a 3.75° grid for a wide range of surface and upper air parameters. The first database represents the $1 \times \text{CO}_2$ data, while the second represents the future projected $2 \times \text{CO}_2$ atmosphere. The GCM undertakes a complete three-dimensional treatment of the atmosphere; however, for this work only the initial and final conditions have been used and the behaviour of the atmosphere during the transition from the $1 \times \text{CO}_2$ to the $2 \times \text{CO}_2$ status has not been considered. Since the GCM output consisted of grid cell data, it was necessary to adapt these values to the site-specific meteorological sites chosen earlier. This was done by comparing the two databases and establishing changes for each grid cell over the study area. In order to maintain localized topographic influences such as slope, aspect and elevation, these changes were then applied to the mean monthly temperature and precipitation data for each of the representative sites that existed within that cell. Temperature values were adjusted through the addition of the temperature differences, while precipitation was adjusted on the basis of a percentage change. In no case were there more than two sites within one cell. A new database of surface climatological data for each of the representative sites is shown in Table 4.

TABLE 2. Representative meteorological sites for major land resource areas

Major land resource area	Site	Latitude	Longitude	Elevation (m)
Southern Alaska				
Southeastern Alaska	Sitka	57°04'	135°21'	5
South central Alaska mountains	Yakutat	59°31'	139°40'	9
Cook Inlet - Susitna lowland	Anchorage	61°10'	150°01'	35
Alaska Peninsula and Southwestern islands	Kodiak	57°45'	152°30'	4
Interior Alaska				
Copper River plateau	Eureka Lodge	61°57'	147°10'	1015
Alaska Range	McKinley Park	63°45'	148°58'	631
Interior Alaska lowlands	Fairbanks	64°49'	147°52'	133
Kuskokwim highlands	Dillingham	59°11'	158°27'	24
Interior Alaska highlands	Hughes	66°04'	154°14'	168
Arctic and western Alaska				
Norton Sound highlands	Unalakleet	63°53'	160°48'	5
Western Alaska coastal plains and deltas	Bethel	60°47'	161°48'	3
Bering Sea islands	Mekoryuk	60°23'	166°12'	14
Brooks Range	Anaktuvuk Pass	68°10'	151°46'	640
Arctic foothills	Umiat	69°22'	152°08'	81
Arctic coastal plain	Barrow	71°18'	156°47'	9
Alberta				
Upper Peace	Beaverlodge	55°12'	119°23'	745
Lower Peace	Fort Vermilion	58°23'	116°04'	279
British Columbia				
North central interior	Smithers A	54°49'	127°11'	523
Northern B.C. - Ft. Nelson, Liard	Fort Nelson A	58°50'	122°35'	382
Prince George	Prince George A	53°53'	122°41'	676
Peace	Fort St. John A	56°15'	120°50'	674
Yukon				
Klondike Plateau	Dawson	64°04'	139°26'	324
Lewes plateau	Fort Selkirk	62°49'	137°22'	454
Liard plain	Watson Lake	60°07'	128°49'	690
Pelly plateau	Ross River	61°58'	132°26'	705
Teslin plateau	Whitehorse	60°43'	135°04'	703
Takhini-Dezadeash	Carcross	60°11'	134°42'	660
Wellesley plain	Snag A	62°22'	140°24'	587
Northwest Territories				
Slave River lowlands	Fort Smith A	60°01'	111°57'	203
Liard valley and upper Mackenzie	Fort Simpson A	61°45'	121°14'	169
Mackenzie River	Wrigley A	63°12'	123°26'	150
Hay River	Hay River A	60°50'	115°47'	166

A = airport.

Since the GCM data supplied were on a monthly time base, they did not provide daily information for the date of the start of the growing season or the date of the first fall frost used in the CCS. Data for the date of the first fall frost were generated through the use of TABLECURVE® curve fitting software. This was done by fitting a model relating the long-term data for the date of the first fall frost ($\leq 0^\circ\text{C}$) to the daily mean minimum temperature for a number of sites in the area (Atmospheric Environment Service, 1982b). The intercept of the regression surface between mean minimum temperature and the date of the first fall frost was found to be 5.16°C . The $2 \times \text{CO}_2$ mean minimum monthly temperature data for each of the sites used in this study were then input into the TABLECURVE® software and evaluated for the date at which the resulting curve crossed the previously established 5.16°C threshold representative of the date of the first fall frost. The start of the growing season was calculated by an algorithm within the CCS as the first of five consecutive

days after 15 March with daily mean temperatures of 5.0°C or greater. Error analysis of the CCS program has shown that due to the very low energy levels being considered at either of these times of year, an error of up to a week in these dates produces errors of only about 1% in the calculated energy term for the site, the EGDD. The climate capability class ratings subsequently derived from the CCS were applied to each MLRA, and those with a rating of 6 or 7 were dropped on the basis that the climate for that MLRA would not support agriculture. Summation of the remaining areas provided the measure of potentially arable land under that climate or atmosphere scenario.

RESULTS

Potentially Arable Soils

The summary of the potentially arable lands currently recognized in the study area is shown in Table 5. As can

TABLE 3. 1 × CO₂ Mean monthly climate data

Site	Precipitation (mm)							Maximum temperature (°C)							Minimum temperature (°C)							Frost
	Apr	May	Jun	Jul	Aug	Sep	Oct	Apr	May	Jun	Jul	Aug	Sep	Oct	Apr	May	Jun	Jul	Aug	Sep	Oct	
Sitka	129.2	119.3	90.9	112.5	169.6	264.1	346.4	8.7	11.8	14.1	16.2	16.7	14.6	10.3	2.0	4.9	8.0	10.4	10.9	8.7	5.3	Nov 02
Yakutat	218.9	231.6	141.2	209.8	255.5	400.8	511.0	6.2	9.8	13.1	15.3	15.4	12.9	8.4	-1.8	2.1	6.2	8.6	7.9	5.1	1.3	Sep 16
Anchorage	16.7	14.5	27.4	50.0	53.6	62.2	43.9	5.9	12.3	16.6	18.4	17.3	12.9	4.9	-2.1	3.5	8.3	10.6	9.6	5.1	-2.0	Sep 25
Kodiak	122.9	196.3	85.6	99.3	132.3	193.0	253.7	6.3	9.1	13.4	15.2	16.1	13.3	8.4	0.4	3.3	6.3	8.9	9.2	6.6	1.8	Sep 30 E
Eureka Lodge	11.4	28.4	77.0	69.9	53.6	33.0	21.6	0.1	8.2	14.7	16.4	14.9	9.2	-0.9	-11.2	-2.8	3.3	5.3	4.4	0.1	-9.3	Aug 16 E
McKinley Park	9.7	20.8	62.5	77.7	60.5	36.3	23.4	3.4	11.7	17.6	19.1	16.7	10.6	0.5	-9.4	-1.7	3.9	5.7	4.2	-1.0	-9.9	Aug 17
Fairbanks	17.3	14.5	29.5	54.4	55.9	62.7	41.9	4.9	15.1	21.2	22.1	19.2	12.4	0.3	-6.9	2.9	9.2	10.7	8.1	1.9	-8.1	Sep 06
Dillingham	29.5	40.1	44.2	70.9	99.8	87.1	65.8	3.4	10.4	15.7	17.7	16.7	12.9	5.4	-5.1	0.8	5.2	7.7	7.7	4.1	-2.7	Sep 12 E
Hughes	9.9	11.7	24.4	49.8	63.0	33.5	27.2	1.8	12.2	20.4	21.3	17.7	10.7	-0.9	-12.1	0.3	8.1	9.9	6.8	0.8	-8.9	Aug 29 E
Unalakleet	12.2	16.3	29.7	59.9	90.9	57.4	25.7	-1.3	7.6	12.7	16.2	15.0	10.5	0.8	-10.4	-0.9	5.3	8.8	7.7	2.5	-6.0	Sep 06 E
Bethel	18.0	20.3	34.0	53.6	87.9	56.4	32.8	-0.2	9.3	14.9	16.7	15.2	11.1	2.0	-9.3	-0.1	5.7	8.5	7.9	3.4	-4.6	Sep 17
Mekoryuk	0.3	0.0	0.0	0.8	27.2	19.3	9.9	-1.8	2.9	11.9	13.0E	12.1	11.3	3.6	-10.5	-7.1	4.6	7.2E	3.2	-0.1	-2.3	Sep 12 E
Anaktuvuk Pass	14.7	13.0	37.3	45.0	39.1	25.9	19.6	-10.1	4.2	13.9	16.0	11.7	3.6	-9.5	-20.4	-6.4	2.3	4.8	1.8	-4.2	-16.7	Jul 26 E
Umiat	5.3	3.3	20.3	17.0	26.9	13.2	15.0	-13.7	-1.3	12.5	18.1	14.2	4.9	-7.8	-25.8	-9.8	2.2	5.5	3.2	-3.1	-15.8	Aug 09 E
Barrow	5.3	4.1	9.4	21.8	24.9	15.0	14.0	-14.8	-4.7	3.0	7.0	5.8	1.0	-7.3	-22.7	-10.1	-1.5	0.7	0.8	-2.6	-12.5	Aug 08
Beaverlodge	19.3	39.0	68.4	64.0	63.8	42.0	28.6	7.9	15.6	19.2	21.6	20.5	15.3	9.5	-2.7	3.1	6.9	8.8	7.8	3.7	-0.7	Sep 07
Fort Vermilion	16.4	32.0	50.7	66.3	52.7	34.7	25.6	7.6	16.8	21.1	22.9	21.1	14.5	6.7	-4.5	3.4	7.7	10.1	8.3	2.9	-3.0	Sep 03
Smithers A	17.6	30.0	40.0	45.9	43.7	50.3	63.8	9.9	15.4	18.9	21.3	20.6	15.7	9.0	-1.7	2.5	6.0	8.1	7.6	4.0	0.5	Sep 06
Fort Nelson A	16.7	41.7	69.1	84.3	61.2	41.6	24.3	7.9	16.2	20.7	22.8	21.0	14.5	6.2	-4.7	3.0	8.0	10.4	8.6	2.8	-4.1	Sep 09
Prince George A	27.4	47.3	66.9	59.7	68.2	58.7	59.2	10.3	16.1	19.5	22.0	20.8	15.9	9.6	-1.7	2.5	6.2	8.1	7.2	3.5	-0.1	Aug 31
Fort St. John A	21.5	38.9	68.0	77.1	60.3	39.2	27.7	8.2	15.7	19.2	21.3	20.1	14.8	8.7	-2.4	3.7	7.7	9.9	8.7	4.2	-0.3	Sep 13
Dawson	9.7	21.1	38.8	47.2	44.0	28.2	28.7	5.4	14.4	20.8	22.4	19.4	11.9	-0.5	-8.7	0.7	6.6	8.9	6.5	1.0	-7.5	Aug 28
Fort Selkirk	11.1	19.2	34.1	49.5	33.5	24.7	21.4	6.9	14.5	20.6	22.2	19.9	13.3	2.5	-7.7	-0.1	5.0	7.5	4.9	-0.4	-7.9	Aug 17
Watson Lake	15.1	29.4	51.6	58.2	42.0	43.7	35.0	6.0	13.3	18.9	21.0	19.3	12.9	4.4	-7.1	0.5	6.4	8.8	7.0	2.3	-4.6	Sep 04
Ross River	12.3	14.5	31.9	41.5	32.4	22.9	15.8	6.0	13.4	19.8	21.8	19.1	13.1	3.1	-8.8	-2.1	2.8	5.3	2.3	-2.6	-9.6	Jul 27
Whitehorse A	9.5	12.9	30.7	33.9	37.9	30.3	21.5	5.6	12.7	18.4	20.3	18.4	12.4	4.4	-5.1	0.6	5.5	7.9	6.5	2.6	-3.1	Aug 30
Carcross	6.5	11.8	15.0	19.2	21.2	21.8	20.4	5.6	11.5	16.7	18.9	17.9	12.3	5.1	-5.9	-0.5	4.6	6.4	4.9	1.4	-3.2	Aug 17
Snag A	17.9	28.9	58.3	61.1	39.0	29.0	21.0	5.5	13.5	19.3	20.9	18.8	11.9	-0.6	-9.9	-0.7	4.8	7.0	4.2	-1.7	-11.6	Aug 10
Fort Smith A	16.2	27.8	41.2	56.9	42.5	41.1	26.5	4.2	14.4	20.3	22.5	20.7	12.6	4.5	-8.6	1.2	6.8	9.5	7.6	2.3	-3.9	Aug 20
Fort Simpson A	14.6	31.1	38.7	59.3	44.8	31.3	24.0	3.9	14.5	21.1	23.2	21.0	12.9	2.4	-8.8	1.4	7.7	10.0	7.8	1.7	-6.2	Aug 21
Wrigley A	17.5	27.2	43.5	54.3	46.0	30.2	32.7	2.7	13.7	20.7	22.8	20.1	11.6	0.0	-9.9	0.8	7.4	9.8	7.5	1.5	-7.1	Aug 17
Hay River A	15.8	20.1	26.8	48.1	37.7	42.3	30.5	1.5	10.8	17.2	20.7	19.4	12.4	4.8	-9.9	0.4	6.5	10.8	9.3	3.7	-2.9	Sep 11

A = airport.
E = estimated.

TABLE 4. 2 × CO₂ Estimated mean monthly climate data

Site	Precipitation (mm)							Maximum temperature (°C)							Minimum temperature (°C)							Frost
	Apr	May	Jun	Jul	Aug	Sep	Oct	Apr	May	Jun	Jul	Aug	Sep	Oct	Apr	May	Jun	Jul	Aug	Sep	Oct	
Sitka	140.1	138.2	107.9	91.2	232.2	219.4	392.4	11.9	20.2	22.2	19.7	19.3	17.1	13.7	9.1	13.1	15.5	14.4	14.2	11.3	7.7	Nov 14 E
Yakutat	245.3	220.7	145.8	194.5	305.2	372.5	566.8	9.6	13.4	16.9	19.0	18.9	16.1	11.5	1.7	5.7	10.0	12.3	11.4	8.3	4.5	Oct 14 E
Anchorage	19.6	14.5	32.2	54.0	48.9	78.4	60.3	6.9	18.5	21.2	22.2	20.8	16.1	8.4	4.6	8.8	12.9	15.0	13.4	8.3	0.1	Sep 30 E
Kodiak	140.8	198.5	84.7	135.2	119.6	207.8	332.8	10.2	13.0	17.4	19.1	19.9	17.1	12.1	4.4	7.2	10.3	12.9	13.1	10.4	5.4	Oct 18 E
Eureka Lodge	12.1	28.7	78.3	89.9	59.4	41.1	32.2	2.2	13.2	25.2	21.0	18.5	12.5	2.7	-7.5	4.5	12.7	10.6	8.6	3.2	-6.7	Sep 07 E
McKinley Park	12.5	24.4	91.0	101.1	65.8	38.8	30.6	4.8	15.4	22.8	23.2	20.1	13.5	3.1	-5.7	2.9	9.3	10.2	8.1	0.9	-5.1	Aug 31 E
Fairbanks	17.1	16.7	40.6	74.9	67.1	60.0	53.7	6.2	18.0	27.4	26.6	22.6	15.3	2.7	-4.5	7.0	15.0	15.6	12.1	3.8	-4.0	Sep 13 E
Dillingham	30.5	31.8	40.8	89.0	117.9	137.9	95.3	8.5	15.5	21.1	22.8	21.7	17.5	9.7	1.4	6.6	10.5	12.9	12.7	8.8	1.6	Oct 01 E
Hughes	12.1	25.7	36.7	53.3	80.1	51.9	31.7	3.9	18.3	24.5	24.5	21.1	13.2	2.3	-5.0	7.1	12.5	13.5	10.9	3.0	-4.4	Sep 07 E
Unalakleet	16.0	33.2	37.0	71.5	82.3	62.1	28.4	4.5	16.5	17.3	19.7	18.3	13.8	4.8	-0.4	8.8	9.6	13.0	10.9	5.4	-3.6	Sep 15 E
Bethel	18.0	20.3	34.0	53.6	87.9	56.4	32.8	-0.2	9.3	14.9	16.7	15.2	11.1	2.0	-9.3	-0.1	5.7	8.5	7.9	3.4	-4.6	Sep 09 E
Mekoryuk	0.4	0.0	0.0	1.2	25.7	20.8	12.5	1.3	4.7	14.5	15.6	14.7	14.3	6.8	-2.0	-1.8	7.3	9.8	5.9	2.8	0.8	Aug 26 E
Anaktuvuk Pass	10.3	15.0	71.0	59.1	45.1	32.2	19.7	-7.6	6.0	22.4	20.9	14.5	6.0	-5.2	-18.2	-3.1	11.0	10.1	5.5	-2.3	-9.4	Aug 30 E
Umiat	5.0	4.8	40.9	21.6	42.8	22.1	15.7	-8.8	2.0	21.5	22.0	17.6	8.3	-2.8	-20.7	-4.5	10.7	10.2	7.8	-0.2	-7.6	Sep 06 E
Barrow	7.3	5.1	15.0	27.7	35.5	19.5	16.0	-9.4	-1.0	12.2	11.2	9.3	4.7	-2.8	-16.5	-4.6	7.1	5.8	5.4	0.2	-4.0	Aug 29 E
Beaverlodge	21.0	61.1	46.7	56.4	77.0	59.7	28.9	9.3	22.9	23.0	24.6	23.1	17.9	13.4	3.0	8.2	10.9	12.4	10.8	6.5	1.4	Sep 28 E
Fort Vermilion	21.8	30.6	41.6	71.8	38.1	42.2	34.9	8.5	20.8	24.7	25.5	24.1	17.2	9.7	-2.8	6.3	11.5	13.7	12.2	6.2	-0.8	Sep 24 E
Smithers A	19.3	26.1	31.4	42.3	64.0	44.4	69.5	15.6	20.5	22.9	24.7	22.8	18.0	12.3	1.5	6.6	10.1	11.6	10.8	6.5	3.4	Oct 05 E
Fort Nelson A	20.7	53.4	56.6	87.1	94.8	38.9	30.8	8.8	22.0	25.1	26.2	23.8	17.2	9.3	0.4	6.9	12.6	14.3	12.0	5.2	-2.2	Sep 19 E
Prince George A	26.3	50.1	50.8	56.3	78.8	68.0	62.8	14.0	23.0	23.4	25.4	23.2	18.4	13.2	3.4	7.2	10.2	11.7	10.2	6.1	2.5	Sep 30 E
Fort St. John A	30.2	44.1	54.5	83.2	62.4	44.4	36.8	9.1	20.7	23.3	24.3	23.1	17.5	11.8	0.5	6.9	11.8	13.7	12.4	7.0	1.7	Oct 01 E
Dawson	10.1	30.1	54.1	54.5	62.0	24.4	36.6	7.0	15.4	26.5	28.5	22.6	14.5	2.0	-6.4	4.4	12.8	15.2	10.2	3.0	-4.5	Sep 09 E
Fort Selkirk	13.7	17.9	36.0	51.6	40.1	29.3	26.4	8.1	16.7	30.0	26.3	23.2	16.3	5.9	-5.1	6.1	12.6	12.5	8.8	2.7	-6.1	Sep 06 E
Watson Lake	14.6	30.2	62.8	69.6	44.5	48.7	42.6	6.6	17.6	23.5	24.5	22.4	15.6	6.9	-3.2	3.5	11.7	13.0	10.4	5.1	-3.2	Sep 16 E
Ross River	13.0	12.7	38.6	46.9	34.8	31.8	19.7	6.9	17.5	25.6	25.5	22.0	15.8	5.7	-5.6	1.7	8.9	9.8	5.7	0.3	-8.2	Aug 24 E
Whitehorse	12.7	11.3	42.6	40																		

be seen, the decision to place soil series in the lower class when there was a choice of 2 classes has resulted in excessive quantities of class 5 and class 7 soils at the detriment of classes 4 and 6. When compiled in this way the soil resources represent a very substantial land area easily equal to other large agricultural regions of Canada. Currently, there are over 15 M Ha of potentially arable land in the Canadian portion of the study area and over 41 M Ha in Alaska, for a total of over 57 M Ha of identified land with agricultural potential for use in either annual cropping or perennial forage systems. Of particular note are the areas of southern and interior Alaska and northern Alberta. By comparison, the 1981 Canadian Census of Agriculture (Statistics Canada, 1982) showed the total area of farms in Canada to be 65.8 M Ha. Of this, 46.1 M Ha were classed as improved land and 38.6 M Ha of that were in the four western provinces.

While Table 5 identifies very large areas of potentially arable land, it should be pointed out that this may still be an underestimation of the total area available. This table reflects only those areas that have been soil surveyed and for which the soil survey specifically assessed the land capability for agriculture (Fig. 1). There are large areas that have either not been surveyed to date or, particularly in British Columbia, where several surveys were even more exploratory in nature, the surveys simply listed the soil series present with no assessment of their suitability for agriculture or other uses. These areas have not been included in this summary. Also, in many surveys and assessment systems the soil survey personnel intrinsically incorporated a perceived climate or climatic restrictions into the soil capability for agriculture. It would appear that these perceptions were often based on more southern agricultural practices, and this has resulted

TABLE 5. Proportionment of potentially arable soils for major land resource areas

Major land resource area	Potential arable soil area (ha)						Total (1-5)	MLRA total
	Class 1-2	Class 3	Class 4	Class 5	Class 6	Class 7		
Southern Alaska								
*Southeastern Alaska	2023	4451		1 906 946		5 671 870	1 913 420	7 585 290
*South central Alaska mountains	11 331	102 793		1 276 423		10 767 852	1 390 547	12 158 399
Cook Inlet - Susitna lowland	507 898	260 626		1 331 463		867 676	2 099 987	2 967 663
*Alaska Peninsula and southwestern islands	—	12 141		2 339 166		6 816 362	2 351 307	9 167 669
Interior Alaska								
*Copper River plateau	7689	142 049		664 112		2 828 043	813 850	3 641 893
*Alaska Range	16 997	3237		535 822		7 117 863	556 056	7 673 919
Interior Alaska lowlands	3 514 819	367 872		6 052 288		2 432 247	9 934 979	12 367 226
*Kuskokwim highlands	1 054 243	464 190		7 123 529		10 308 518	8 641 962	18 950 480
Interior Alaska highlands	1 582 781	167 950		10 039 392		9 835 019	11 790 123	21 625 142
Arctic and western Alaska								
*Norton Sound highlands	59 086	25 497		963 186		11 469 602	1 047 769	12 517 371
**Western Alaska coastal plains and deltas	809	—		869 700		6 589 730	870 509	7 460 239
**Bering Sea islands	—	—		10 117		1 053 838	10 117	1 063 955
**Brooks Range	—	—		10 117		11 790 529	10 117	11 800 646
**Arctic foothills	—	—		6879		12 736 313	6879	12 743 192
**Arctic coastal plain	—	—		—		4 987 118	—	4 987 118
Alberta								
Upper Peace	1 951 609	1 331 717	1 541 184	2 525 013	—	11 379 366	7 349 523	18 728 889
Lower Peace	1 346 191	194 077	789 423	759 120	253 289	16 729 003	3 088 811	20 071 103
British Columbia								
North central interior	14 771	92 959	171 228	118 779	496 931	147 796	397 737	1 042 464
Northern B.C. - Ft. Nelson, Liard	—	6552	51 722	33 333	—	216 737	91 607	308 344
Prince George	—	20 828	53 214	178 421	—	350 525	252 463	602 988
Peace	91 975	150 332	487 209	451 852	43 119	146 585	1 181 368	1 371 072
Yukon								
Klondike Plateau (Dawson)	—	—	24 380	16 912	17 238	13 613	41 292	72 143
Lewes Plateau (Carmacks)	—	—	27 730	143 721	17 127	67 691	171 451	256 269
Liard plain (Watson Lake)	—	—	10 447	209 267	267	97 737	219 714	317 718
*Pelly plateau (Ross River)	—	—	644	31 912	67 235	12 768	32 556	112 559
Teslin plateau (Whitehorse)	—	—	—	73 240	17 472	79 278	73 240	169 990
*Takhini - Dezadeash	—	—	—	126 215	14 887	26 178	126 215	167 280
*Wellesley Basin (Snag)	—	—	—	35 821	2018	17 766	35 821	55 605
Northwest Territories								
Slave River lowlands	160 787	478 517	—	47 066	—	144 073	686 370	830 443
Liard Valley and upper Mackenzie	—	292 799	148 072	449 019	87 554	278 067	889 890	1 255 511
Mackenzie River	—	231 286	318 256	262 367	—	942 789	811 909	1 754 698
Hay River	—	19 337	4786	109 615	—	123 635	133 738	257 373
Totals								
Not restricted	10 323 009	4 369 210	3 628 295	38 700 813	1 017 137	136 046 187	57 021 327	194 084 651
Current climate restricted	9 170 831	3 614 852	3 627 651	22 800 868	932 997	43 851 837	39 214 202	83 999 036
2 × CO ₂ climate restricted	10 314 511	4 227 161	3 628 295	37 146 767	1 017 137	108 796 929	55 316 734	165 130 800

*MLRAs removed by current climate restrictions.

**MLRAs removed by 2 × CO₂ climate restrictions.

in downgrading of many areas that have adequate soils from their real capability. The areas shown in Table 5 are the total gross areas from the respective surveys. These areas have not been adjusted for losses due to rights-of-way, lakes, drainage patterns or activities such as habitat protection or land claims. In spite of these factors and the class placement problem, these areas should be considered as reasonable estimates.

Current Climate Resources

The climate capability ratings, effective growing degree days and effective moisture stress for each site are shown as the 1 × CO₂ environment in Table 6. From this it is clear that a wide range of climatic capability exists within the study area. The results shown in Table 6 indicate that a number

of MLRAs were identified as being limited by the current climate and hence were deemed non-arable. This reduced the currently potential area from more than 57 M Ha to just over 39 M Ha through climate considerations (Table 5). The study area is classified as having an overall average class 5 (primarily heat limited) climate. This ranges from a class 2 to a class 7 due to the wide range of conditions present in each of the sub-regions. The currently available 39 M Ha of arable land area can be broken down to 23.8 M Ha in Alaska and 15.3 M Ha in Canada. Despite extensive agricultural industry in other parts of both countries, development within the study area has been slow. This can be attributed to the effects of small or distant markets and poorly developed infrastructures.

TABLE 6. Climate capability ratings

Site	1 × CO ₂ environment			2 × CO ₂ environment		
	Energy (EGDD)	Moisture deficit (mm)	Class	Energy (EGDD)	Moisture deficit (mm)	Class
Southern Alaska						
Sitka	1005	305.8	6H	1855	249.0	1M
Yakutat	677	726.0	7H	1282	663.2	3H
Anchorage	970	-157.0	5H	1705	-263.4	2M
Kodiak	762	283.3	7H	1404	256.3	2H
Interior Alaska						
Eureka Lodge	411	-51.4	7H	1237	-132.9	2H
McKinley Park	587	-159.6	6H	1210	-147.7	2H
Fairbanks	1152	-292.4	3H	1835	-318.1	3M
Dillingham	723	-58.5	7H	1598	-126.7	1M
Hughes	946	-276.8	5H	1609	-300.9	3M
Arctic and Western Alaska						
Unalakleet	587	-12.2	7H	1279	-68.1	2H
Bethel	661	-70.3	6H	659	-70.3	6H
Mekoryuk	309	-172.1	7H	550	-240.1	6H
Anaktuvuk Pass	281	-140.1	7H	860	-160.9	6H
Umiat	358	-253.8	7H	968	-296.0	5H
Barrow	0	31.4	7H	278	-30.4	7H
Alberta						
Beaverlodge	1070	-228.4	4H	1791	-327.6	3M
Fort Vermilion	1202	-296.1	2M	1787	-371.0	3M
British Columbia						
Smithers A	1042	-337.8	4H	1733	-413.3	4M
Fort Nelson A	1181	-202.3	3H	1842	-256.1	2M
Prince George A	1053	-264.7	4H	1814	-365.2	3M
Fort St. John A	1134	-174.8	3H	1759	-249.7	2M
Yukon Territory						
Dawson	974	-346.8	4H	1675	-381.3	4M
Fort Selkirk	836	-393.9	5H	1675	-490.0	5M
Watson Lake	911	-256.8	5H	1516	-289.5	3M
Ross River	557	-439.1	6H	1242	-498.8	5M
Whitehorse A	826	-333.9	5H	1608	-399.1	4M
Carcross	594	-377.3	6H	1369	-459.2	5M
Snag A	681	-280.8	6H	1503	-373.0	4M
Northwest Territories						
Fort Smith A	1049	-324.9	4H	1614	-410.8	4M
Fort Simpson A	1119	-330.2	3H	1661	-290.8	3M
Wrigley A	1053	-313.1	4H	1642	-395.7	4M
Hay River A	959	-254.9	5H	1430	-314.5	3M
Averages	802	-170.4	5.2	1437	-227.3	3.5

A = airport.

The Effects of Climatic Change

The GCM showed average increases in the April–October minimum and maximum temperatures for all sites of 4.06°C and 3.58°C respectively. Precipitation for the same period was shown to increase by an average of 16.6% for all sites. The use of long-term climatic data and the output from the GCM as input into the CCS software allowed the determination of climatic capability ratings for both the current climate and that projected to exist given a $2 \times \text{CO}_2$ environment (Table 6).

The $2 \times \text{CO}_2$ climate shows a very significantly warmer and somewhat drier environment, with overall increased moisture deficits and improved climatic capability ratings. As a result of the changed climate the overall energy term has increased approximately 75%, the moisture deficit has increased by approximately 60 mm and the study area's overall average capability rating has risen from class 5.2 (primarily heat limited) to class 3.5 (primarily moisture limited) (Table 6). The area of potentially arable soils increased significantly from just over 39 M Ha with the current climate restrictions to more than 55 M Ha with the $2 \times \text{CO}_2$ climate restrictions and is only slightly lower than the total area without climate restrictions (Table 5). These changes have resulted in an increase in the usable arable soil area of approximately 16 M Ha. The majority of this increase is in Alaska, where the arable land area increases from 23.8 M Ha to 39.7 M Ha, while the Canadian portion increases from 15.3 M Ha to 15.5 M Ha. This area would be capable of supporting a much expanded agricultural industry, particularly in northern Alberta, British Columbia and the southern portions of Alaska, where a greater infrastructure currently exists. There are numerous other related questions that must be answered before this can happen. Principal among these are the questions relating to the adaptation of our existing plant species and varieties to a higher CO_2 and the longer photoperiod environment that will be found with latitudinal adaptation.

Given the very large spatial extent of the study area, the range of $2 \times \text{CO}_2$ climate data was not particularly large. This can be seen as a resolution problem attributable to both differences in scale between the sites within the study area and the GCM grid cell dimensions, as well as the lack of soil survey areas at higher elevations. An obvious improvement could be made through the use of a third-generation GCM with smaller nested cells over the study area. Such third-generation data would not be expected to change the basic results of this study; however it might provide improved resolution among or within the various MLRAs.

CONCLUSIONS

The problem of determining and adopting universally acceptable criteria for use in the assessment of soil capability for agriculture still needs to be addressed. As may be clearly seen from the data presented here, and in light of the potential for a changing climate, the practice of biasing the soil rating with a qualitative climate assessment has historically led to improper interpretations. A preferable system is the assessment of the soil and climate resources separately,

allowing end-users to reach their own conclusions with regard to which is the most limiting. Such an evaluation tool in the form of the Climate Classification System has been shown to be effective. However, additional development is warranted. Such development should include additional verification for areas outside Alberta and the development of a forage production rating given the large areas of class 4 and 5 land in the study area. An improved understanding of the crop species and varietal responses to photoperiod and the general climate/soil interactions of the areas covered by this study would allow improved resolution and confidence in these results.

There are in excess of 57 M Ha of potentially arable soil resources within the study area. This is approximately 29% of the total study area and represents all the currently identified areas without, as far as possible, restrictions due to climate, infrastructure or other factors. When the current climate for these areas is overlaid, this area reduces to approximately 39 M Ha, or approximately 68% of the potentially arable area. This is comparable to an area slightly less than all agricultural land currently in use in Canada east of Saskatchewan. Under the $2 \times \text{CO}_2$ climate, an area of over 55 M Ha would be arable, representing an increase of approximately 16 M Ha due to the changed climate. This represents approximately 97% of the total potential area. This total area is close to what is currently in use on the entire Canadian prairies (Statistics Canada, 1982). While this represents a significant potential addition to North America's agricultural land base, it is anticipated that there would be some corresponding loss of land base due to moisture limitations. These losses would be expected to occur in areas of the southern Canadian prairies or parts of the continental United States, where moisture is currently limiting and fallow cropping is an accepted practice. As a result of increased moisture deficits, agricultural endeavours in a number of these prospective areas will have to consider the use of moisture conservation practices such as zero tillage, fall cereals or the use of fallow land.

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