The Scott Alternative Cropping Systems Study: Background and Treatment Structure

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Abstract

Over the past 20 years grain crop production on the Canadian prairies has experienced the adoption of minimum tillage practises and extended cropping rotations that incorporate an ever increasing diversity of crops. This change has been driven in part by long term rotation studies revealing soil erosion and degradation with mechanical tillage and numerous short term studies that document the benefits of diverse cropping systems. Change has been accelerated in recent years as producers faced with the challenge of depressed grain prices adopt technological change, respond to consumer demands, and reduce inputs in an attempt to remain profitable. These changes in farm management practises while having short term economic objectives also have long term implications for the environment, production sustainability, and food safety. While long term studies in the past have generally compared components of production systems such as rotations or soil amendments, a long term multidisciplinary cropping system study initiated at Scott in 1994 is based on a comparison of different cropping systems. To evaluate the sustainability of arable crop production on the Canadian Prairies the study incorporates three levels of inputs (Organic, Reduced, High) and three levels of cropping diversity (low, diverse annual grains, diverse annual forage) in a six year rotation cycle. This paper is the first in a series of papers discussing results from the first 6 year cycle. This document provides an introduction to the issue of sustainable agricultural crop production with a focus on the objectives, experimental design of the study, and management practices within each of the systems.

Introduction

Wheat-fallow rotations prior to 1980 were the primary crop production systems on the Canadian prairies providing a means of normalizing returns by minimizing the impact of year to year variations in precipitation patterns and supplying an ever present demand for quality wheat. Since 1980 however a number of issues have generated significant change. Long term rotation studies as reported by researchers such as Cambell et al. (1993) and Biederbeck et al. (1994) were instrumental in associating soil organic matter loss with mechanical tillage. With the adoption of minimum and zero tillage practises came research showing that cereal rotations could be extended and yields enhanced when pulse crops were incorporated into the rotations (Stevenson et al. 1996). Although agronomic research provided the initial impetus to change crop production practices, economic realities have accelerated the adoption of different crop production systems as producers respond to low commodity prices, rising costs of production, and changing consumer demands. Environmental concerns regarding fertilizer and pesticide use and movement of residues to non target areas, cadmium uptake, green house gases, and soil carbon sequestration have in recent years been added to the long list of concerns shaping the way we view crop production. To address some of these concerns while at the same time maintaining producer profitability much research effort has gone into investigating various components that when combined define a production system. While such research is valuable in identifying useful components of a production system it falls short of providing insights into component interactions and their long term implications within a production system. Current long term rotation and tillage studies provide a wealth of information on soil degradation, soil quality, nutrient dynamics, crop production and quality and to a lesser extent economics. However they are unable to contribute to our understanding of the long term impact of a production system as defined by its individual components and their interactions on economic, soil quality and environmental issues. Issues surrounding the impact of agriculture on water quality, biological diversity, food safety, impact of manuring and altered levels of inputs requires long term studies that are best addressed through a systems approach. By comparing input use and cropping diversity on a system level a broad range of crop production practises can be investigated. With sustainability as the one goal which encompasses all elements of a production system the primary focus of a new long term study was to provide guidelines for the development of sustainable arable crop production systems on the Canadian Prairies based on the five pillars of Sustainable Land Management using three levels of production inputs and three levels of cropping diversity. The five pillars of sustainable land management as defined by A.J. Smyth and J. Dumanski, 1993;

"Sustainable land management combines technologies, policies and activities aimed at integrating socio-economic principles with environmental concerns so as to simultaneously:
-maintain or enhance production/services (Productivity)
-reduce the level of production risk (Security)
-protect the potential of natural resources and prevent degradation of soil and water quality (Protection)
-be economically viable (Viability)
-and socially acceptable (Acceptability)."

Materials and Methods

Site Characterization

Due to the nature of soil and climatic variability on the Canadian prairies the study was established in 1994 at Scott, Saskatchewan (52^0 22';108^0 50', elevation=713 metres) near the geographic centre of the Canadian Prairies in the Dark Brown soil zone between the semi-arid and sub-humid prairies. A topographical survey of the area revealed a general 0.6 degree slope across the 18.5 ha site decreasing in elevation from east to west by approximately 3.5 meters with good surface drainage. Site characterization work was conducted in 1994 to identifying soil and biological properties and their variability to create a baseline from which change over time could be measured and to account for inherent biases in data sets caused by spatial variability. Work by Allan Moulin (Brandt et al.,1994) indicated bulk density to 15 cm and particle size distribution were relatively uniform at the site while aggregate size distribution, hydraulic conductivity, geometric mean diameter and erodible fraction were highly variable. Electrical conductivity, bulk density, silt and clay fractions, erodible aggregate fraction (<0.84 mm), and soil moisture were correlated with sand content which was observed to be high in the north west corner of the experiment.

Geometric mean diameter of the aggregates was correlated with silt content. Soil characterization work by Fernando Selles (Brandt et al.,1994) revealed soil bulk density was normally distributed to the 15 cm depth reflecting the impact of transient freeze-thaw and wetting-drying cycles, and soil management practices. Spatial structure of soil bulk density below 15 cm to the 120 cm reflected the combined effects of geological and pedological processes. In the effort to determine N -supplying power of the soil, greater total N in areas of near level relief were observed suggesting organic matter may have been modified by erosion-deposition processes and exacerbated by cultivation. Biological baselines were identified by uniformly cropping the site and conducting weed plant and seed bank, mycorrhizal and anthropod surveys in 1994. Uniform barley cropping revealed low grain yield cv's of 9.2% with no significant differences observed between planned treatments affirming that the most appropriate experimental design had been used. Although site characterization work revealed considerably more variability across the site then expected it underlined the importance of baseline identification for understanding agronomic results, measuring change over time, and relating chemical and physical properties of the site to biological distributions.

Experimental Design

The experiment is a 4 replicate split plot experiment with main plot treatments consisting of 3 levels of inputs and sub-plots comprised of three levels of cropping diversity each on a six year rotation cycle. Input levels are described as Organic (ORG), Reduced (RED), and High (HIGH) and cropping diversity levels as Low, Diverse Annual Grains (DAG), and Diverse Annual Perennial (DAP). Main plots were 1.8 ha in size with 0.3 ha sub plots (see figure 1). Up to one third of each sub plot has been used for destructive sampling and to accommodate sub-sub treatments for more detailed study. The remaining area was used to maintain integrity of the main and sub treatments and to allow for future sub division. Input and cropping diversity levels have the following general definitions (Brandt et al., 1996).

Input Level

1. Organic (ORG): Pest control and nutrient management practices based on "non-chemical" means. Long term cultural pest control with organic green manures legumes used extensively with this treatment along with other acceptable organically certified products. This treatment is an attempt to mimic what an organic grower would do within the constraints of the three diversification options.

2. Reduced (RED): This system uses integrated long-term management of pests and nutrients, with chemicals used to supplement other management practices. The objective is to reduce inputs (pesticides, fertilizers and fossil fuels) such that any yield reduction is more than offset by reduced input costs. Any appropriate technology that can be substituted for or used to reduce such inputs can be used. Typically new technologies would be incorporated into this treatment at an early stage and later into the Organic or High input system as appropriate.

3. High(HIGH): Pesticides and fertilizers used “as required” based on conventional recommendations associated with pest thresholds and soil tests. Long term management of pests and nutrients is of minimal concern as chemicals are used to respond to problems or deficiencies as they arise. (This treatment does not preclude use of cultural practices considered to be normal agronomic practice such as certified seed or pre-seeding tillage for weed control). Only those technologies typically in use can be employed with this treatment.

Cropping Diversity

1. Low (LOW): A wheat based rotation of fallow-wheat-wheat-fallow-canola-wheat reflect cropping systems chosen by risk averse producers. (With legume green manures used as fallow substitutes in the Organic system and where appropriate in the Reduced input system, but not the High input system).

2. Diversified Annual Grains (DAG): A rotation of a diversity of cereal, oilseed and pulse crops with the possibility of some crops used as annual forages for off-farm export or as green manures. The rotation could vary between input levels depending upon their requirements, but must include a spring cereal, an oilseed, a pulse and where feasible, a winter cereal. Actual choices from year to year for each input level would be based on conditions and requirements for each system. Fallow would only be an option if no other alternative existed. As a general guideline, a canola - winter cereal - pea - barley - flax - wheat rotation would be used. Recommendations by organic growers facilitated the incorporation of two green manure fallow phases into the ORG-DAG system to produce the following rotation GM fallow-wheat-pea-barley-GM fallow-canola. Where appropriate crops could be harvested as forage, but planned primary usage would be as grain. The winter cereal would be fall rye or winter wheat as appropriate.

3. Diversified Annual and Perennial (DAP): A mixed rotation of grain and forage crops following a oilseed-cereal-cereal-forage-forage-forage sequence with partial fallow after the first cut on third year forage stands. The same basic rotation used at all input levels but actual crop choices based on requirements for each. One cereal could be a feed grain and the first forage crop could be oats under-seeded to perennial forage cut for hay. This treatment would assume that a livestock operation was associated with the farm unit. The forage used should be alfalfa in the Organic system to meet some of the crop N requirements.

The livestock operation would be based on grazing from a land base unsuited to cultivation. Forages plus straw from the cereal rotation phases would be used as winter livestock feed along with grain from one of the cereals. Straw removed from the cereal phases would be offset by manure applications, based on amounts that could be generated from the forage and cereal inputs.

Impact of Input Level and Cropping Diversity on Management Decisions between 1995 and 2000

General cropping diversity models were altered along with management practices to accommodate the constraints imposed by each level of input and to improve the sustainability of each system. Within the Low diversity rotation fallow phases were managed differently for each of the three levels of inputs. In the Organic system fallow was green manured with the nitrogen fixing legume Indian Head lentils. In the Reduced system the first fallow phase was green manured using Indian Head lentils with leave strips left after incorporation followed by chemical fallow in the 4^{th} phase. In the High input system fallow phases were mechanically tilled. In 1996, fall rye and flax were removed from the DAG diversity under the Organic input system to incorporate two nitrogen fixing green manure fallow phases (Indian Head lentils and Sweet Clover) providing a source of nitrogen and to enhanced weed control. The DAP diversity remained the same across all three levels of inputs. Table 1 summarizes general cropping diversity models and documents changes based on input level.

Crop varieties were altered slightly as older varieties were replaced by higher yielding varieties. Makwa was replaced by AC Barrie in 1999. The canola variety Reward (*B. rapa*) was grown in the Organic input system and *B. napus* in the Reduced and High input system (Cyclone from 1995-1997 and Hudson from 1998-2000). Field pea variety was updated from Radley grown between 1995 and 1998 to Espace in 1999 and 2000. Feed barley grown in the DAP diversity was Brier for all years except 1999 when AC Harper was grown. Other crop varieties included Harrington, Norlin flax, and Prima fall rye grown in the DAG diversity and Signal brome and Nordica alfalfa grown in the DAP diversity. Nitrogen fixing green manure fallow crops included Indian Head lentils and Sweet Clover.

The most significant management difference between input levels was the ban on chemicals and processed fertilizers and the sole reliance on tillage within the Organic input system. Seeding of annual crops in the Organic input system was generally delayed until the last week in May to enhance weed control and ensure quick germination and emergence of the seeded crop. In the Reduced and High input systems annual crops were typically seeded near the middle of May. In the Reduced input system products were applied on a plot by plot basis to more closely match application amounts with need in an attempt to reduce inputs. In the High input system product applications were based on requirements averaged over 4 replicates. A typical set of field operations and inputs for canola grown under High, Reduced, and Organic input levels is shown in table 2. An accurate and thorough recording of management activities within a systems based experimental design provides the opportunity to make comparisons between cropping systems on an operations level as well as a product input level. Figures 2 illustrates the distribution of annual tillage and herbicide operations between 1995 and 2000 for each system revealing a complete reliance on tillage in the Organic input system and greater emphasis on chemicals in the Reduced input system then in the High. Figure 3 illustrates in-crop weed control operation differences, between systems. Table 3 summarizes annual nitrogen inputs between 1995 and 2000 with less nitrogen fertilizer required in the Reduced input system then in the High for the DAG and DAP cropping diversities but not for the LOW diversity. Less required N for the LOW-High system can be attributed to greater N mineralization occurring in the 2 mechanically tilled fallow phases then in the green manure and chemical fallow phases of the Reduced input system.

<u>Data Collection and Evaluation</u>

Data collection and analyses has been a collaborative effort by scientists from a broad range of disciplines. Similar to other long term soil and crop management studies data collection includes information on soil quality, crop productivity and economics. An extended data set however is also being generated on weed, insect and disease dynamics, including predator-prey dynamics in addition to pest-crop dynamics; movement of nutrients and pesticides from the production system; nutrient dynamics; quality of food produced both from a marketing and a nutritional viewpoint; net balance of green house gases; and development of mathematical models to quantify rates of change over time.

Evaluation involves a wide range of physical, biological, economic and social factors that exert a significant influence on the sustainability of each production system. To identify environmental change indicators of attributes associated with environmental change are in the process of being identified, and critical levels or thresholds of indicators are in the process of being determined as a means of evaluating sustainability. It is hoped this work in combination with indices developed by other researchers around the world will culminate in the development of sustainable indices for the Canadian Prairies.

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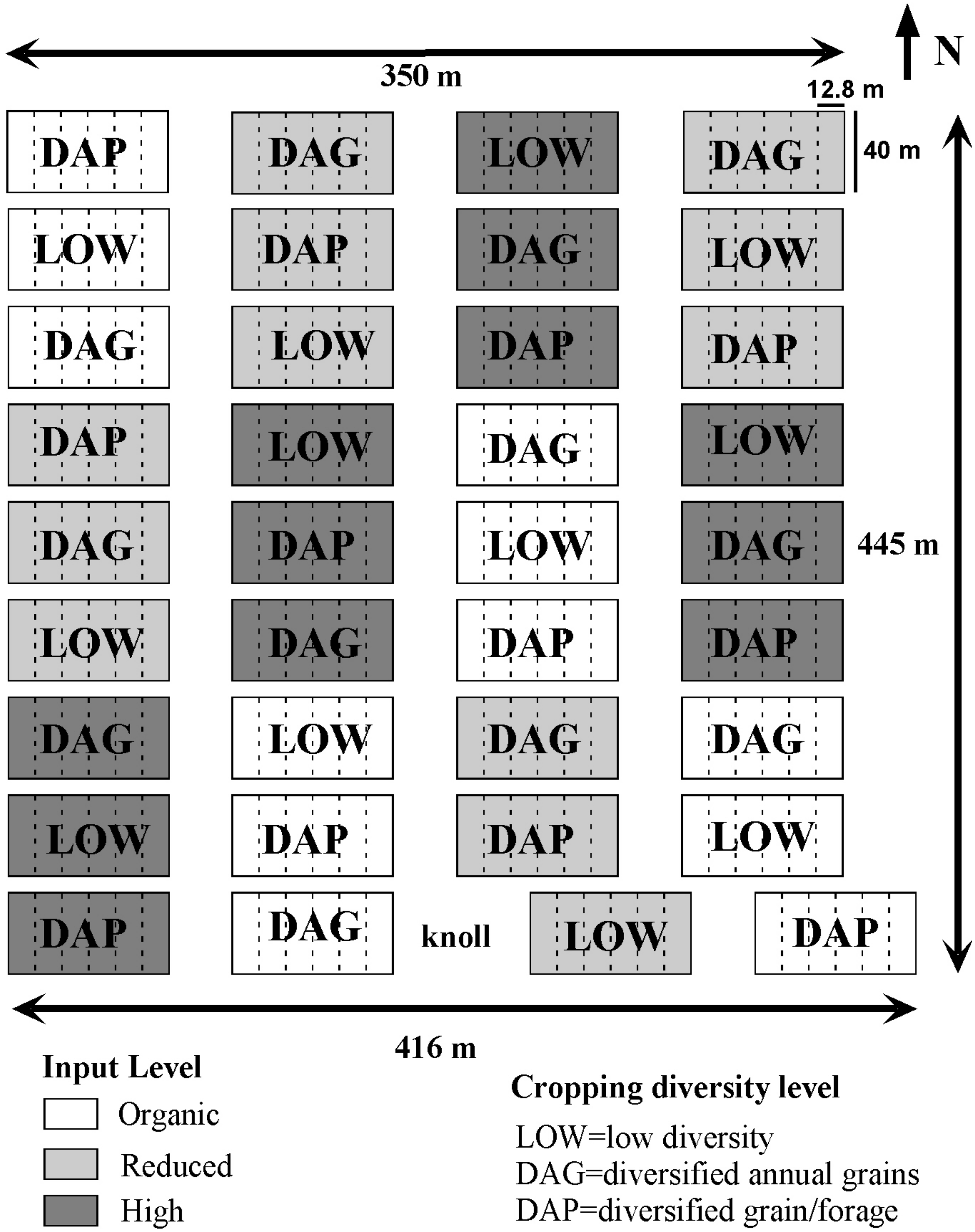

Figure1. Alternative crops study site plan.

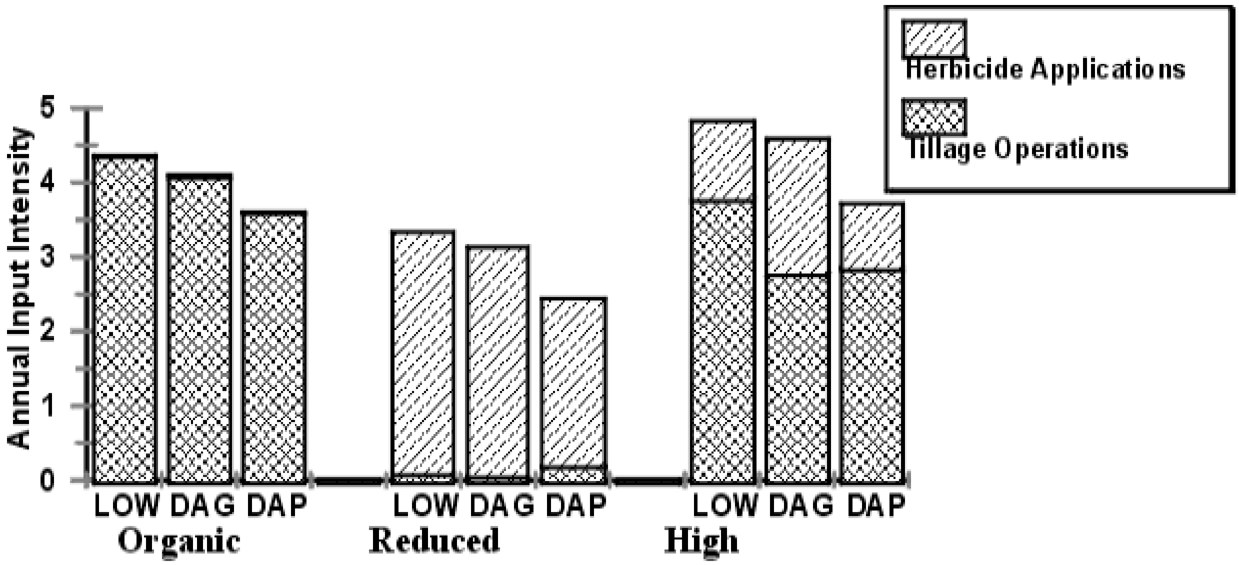

Figure 2. Average annual operations (tillage + herbicide) between 1995 and 2000.

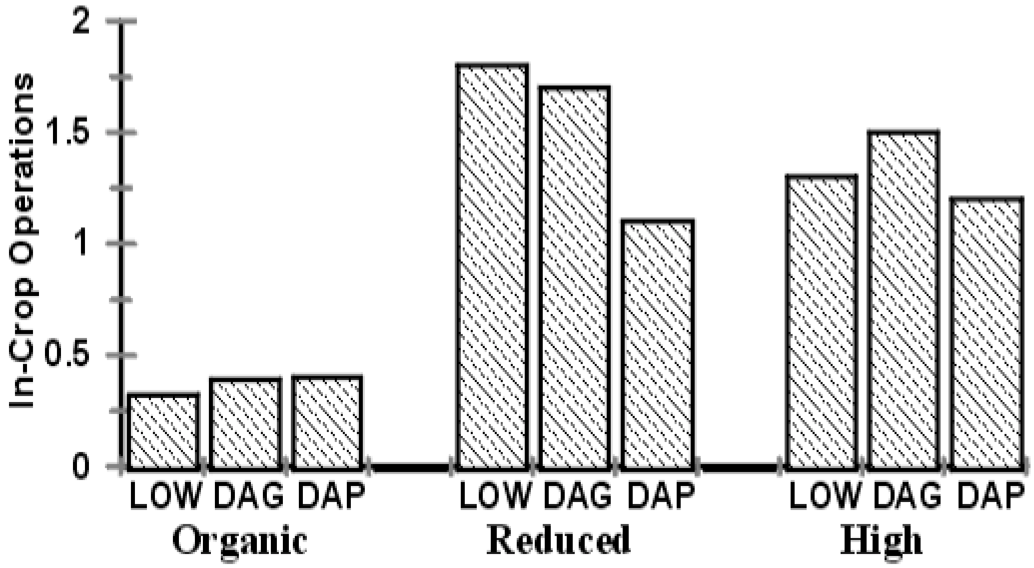

Figure 3. Average annual in-crop operations primarily for weed control between 1995 and 2000.

Table 1. General crop phase models for three levels of cropping diversity with fallow management differences between input levels of the LOW diversity and alterations to the DAG model for the Organic input system.

		Crop Phase					
Div.	Input Level	1	2	3	4	5	6
LOW	**Model:**	**fallow**	**wheat**	**wheat**	**fallow**	**canola**	**wheat**
	Organic	GM lentil	"	"	GM lentil	"	"
	Reduced	GM lentil	"	"	chemical	"	"
	High	tillage	"	"	tillage	"	"
DAG	**Model:**	**canola**	**fall rye**	**field pea**	**malt barley**	**flax**	**wheat**
	Organic	GM lentil	wheat	"	malt barley (swt clvr)*	GM swt clvr	canola
DAP	**Model:**	**canola**	**wheat**	**feed barley**	**Oat (brome/alfalfa)***	**brome/alfalfa**	**brome/alfalfa**

* crop was under seeded to the crop in brackets
swt clvr: sweet clover

Table 2. Illustration of management differences among three levels of inputs for canola grown within the diversified annual grains rotation of the alternative cropping study.

Operation	Organic	Reduced	High
fall applied herbicide		granular +2,4-D	granular + HDC
pre-seed weed control/ seedbed	2 x HDCwth		HDCwth
Seed implement	double disc	hoe drill	hoe drill
date	late May	early May	early May
canola variety	*B. rapa*	*B. napus*	*B. napus*
seed treatment	enhance phosphorus uptake	disease+flea beetle	disease+flea beetle
applied N & P		$N_{(mrb)}$ $P_{(below\ seed)}$	$N_{(deep\ band)}$ $P_{(below\ seed)}$
post-seed/in-crop weed control	harrow	herbicide	herbicide
harvest	direct combine	swath + combine	swath + combine
post harvest weed control	2 x HDCwth	fall 2,4-D ester	HDC

HDC-heavy duty cultivator, wth- with harrows, mrb-mid row band

Table 3. Mean annual level of applied N (kg/ha) for different input and cropping diversity levels during the first six year crop rotation cycle (1995-2000).

	Organic	Reduced	High
Low	0.0	25.5	25.5
Diverse Annual Grains	0.0	33.1	37.9
Diverse Annual Perennial	0.0	25.1	30.5