AB-19

Landscape Influences on Soil and Agronomic Dynamics

Research Report

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Potash and Phosphate Institute of Canada

By: Len Kryzanowski P.Ag.
Crop Nutrition Agronomist
Alberta Agriculture, Food and Rural Development
Edmonton, Alberta
Len.Kryzanowski@agric.gov.ab.ca

1.0 Summary

Understanding the influence of landform elements on soil nutrients, crop growth, and nutrient uptake by crops will help develop management strategies for precision agriculture. In 1999, detailed measurements of soil processes, crop growth, and nutrient demands were made at a field site seeded to canola. Results from this field with rolling topography indicate soil nutrient supply dynamics were related to landscape feature. The higher levels of crop growth in lower slope positions were associated with higher nutrient demands. Moisture dynamics appear to have a strong influence on the soil and agronomic dynamics of this rolling topography.

For 1999, data regarding soil variability, soil nutrient dynamics, meteorological conditions and crop growth and development were collected at the field site near Viking, Alberta. Delays in acquiring automated equipment (dataloggers, TDRs and thermisters) prevented measurement of soil moisture and soil temperature. A detailed calibration of the TDRs was completed in preparation to install equipment in the spring of 2000. A new meteorological station will be established to replace the old station damaged by vandalism. Work has begun on preparing data for use in evaluating three simulation models to simulate landscape dynamics.

2.0 Introduction

Precision management of agricultural land has the potential to improve crop production and environmental protection by harmonizing inputs with crop requirements at the sub-field level. Fertilizer use efficiency across a field can be quite variable and in the case of nitrogen, reduced to levels of 50% or less. Fertilizer is a significant input for Western Canadian agriculture, and targeting its application could improve use efficiency, may reduce costs of production and decrease the environmental loading of nutrients.

Precision agriculture techniques allow users to identify crop productivity variation by soil landscape, determine the factors contributing to variability, delineate areas with similar productivity potential, and develop a management system that harmonizes inputs with productivity. These techniques allow the separation of crop yield constraints into those caused by soil fertility and those caused by other soil and climate characteristics such as water, salinity or temperature. Such separation allows fertilizer to be used to overcome only those constraints caused by nutrient deficiency. This provides an opportunity for producers to take advantage of the spatial variability of crop growth to enhance productivity, improve fertilizer efficiency and reduce environmental problems caused by excess fertilizer.

Field topography influences microclimate and the hydrological conditions within a landscape by the redistribution of water and temperature dynamics. Water will move from upper slope positions to lower slope and depressions areas either by runoff or by subsoil movement. Excessive runoff will result in the physical redistribution of surface soils (erosion). Subsoil water movement will result in the translocation of soluble nutrients or accumulation of salts. The end result of this redistribution is drier upper slope positions and wetter lower slope and depressions. Soil moisture and temperature follow seasonal trends and are episodically controlled by precipitation events and periods of drought. Soil moisture and temperature dynamics influence soil biological, chemical and physical processes. As a result, differences in moisture, nutrients and salts will have a significant impact on crop growth.

The spatial variability of crop growth and yield are associated with soils and landscapes. Often, the lowest crop yields are measured on the upper slope positions and the highest yields on the lower slope positions (Miller et al., 1988; Halvorson and Doll, 1991). Upper slope positions are prone to erosion, shallow surface horizons, higher carbonate levels, lower organic matter levels and lower available water. The lower slope positions have deposits of eroded surface material, deeper surface horizons, depth to carbonates are greater, higher organic matter levels and higher available water. However, consistent spatial relationships in productivity across landscape with higher productivity in lower areas of the landscape do not always exist. Yield may be constrained by abiotic factors, pests and management practices, which may or may not have an associated spatial pattern.

3.0 Objectives

There is a spatial relationship among soil parameters, landscape positions, and soil quality processes. Soil water distribution and temperature are influenced by landscape position and will affect soil biological, chemical thermodynamic and physical transfers processes.

The purpose of this project is to investigate the impact of landscape variability on soil properties, dynamic soil processes and crop growth. This information will be used to evaluate soil quality simulation models for making agronomic decisions plus long-term options for best management practices based on landscape units and field management. This research will systematically:

1. Determine the influence of landscape position on soil moisture and soil temperature dynamics among three landscape (upper, mid, and lower) positions,
2. Determine the influence of landscape position on soil nutrient dynamics using ion exchange membranes.
3. Determine the influence of landscape position on crop growth and development among three landscape (upper, mid, and lower) positions,
4. Simulation of landscape dynamics. This portion of the study will evaluate three simulation models (CERES, EPIC and *ecosys*) the spatial dynamics of soil moisture and temperature, investigate the relationship of soil moisture and temperature regimes on soil nutrient dynamics, investigate the spatial simulation of soil nutrient dynamics as influenced by episodic and seasonal climatic moisture and temperature conditions, and the landscape simulation of crop growth and development.
5. Derive short and long term soil quality management strategies based on cultivation practices, residue management, crop rotation, fertilizer use and longterm climatic data for variable landscapes.

4.0 Approach

Site Description: The site is a quarter section field representative of the black soil region or the aspen parkland eco-district of east central Alberta, near Viking, Alberta. It has a rolling topography with moderate slopes. The field is dominated by black chernomzemic soils. The field is under a conventional cultivation system with various annual crops and managed using precision agriculture technology (global positioning system, variable rate technology, yield mapping, etc.).

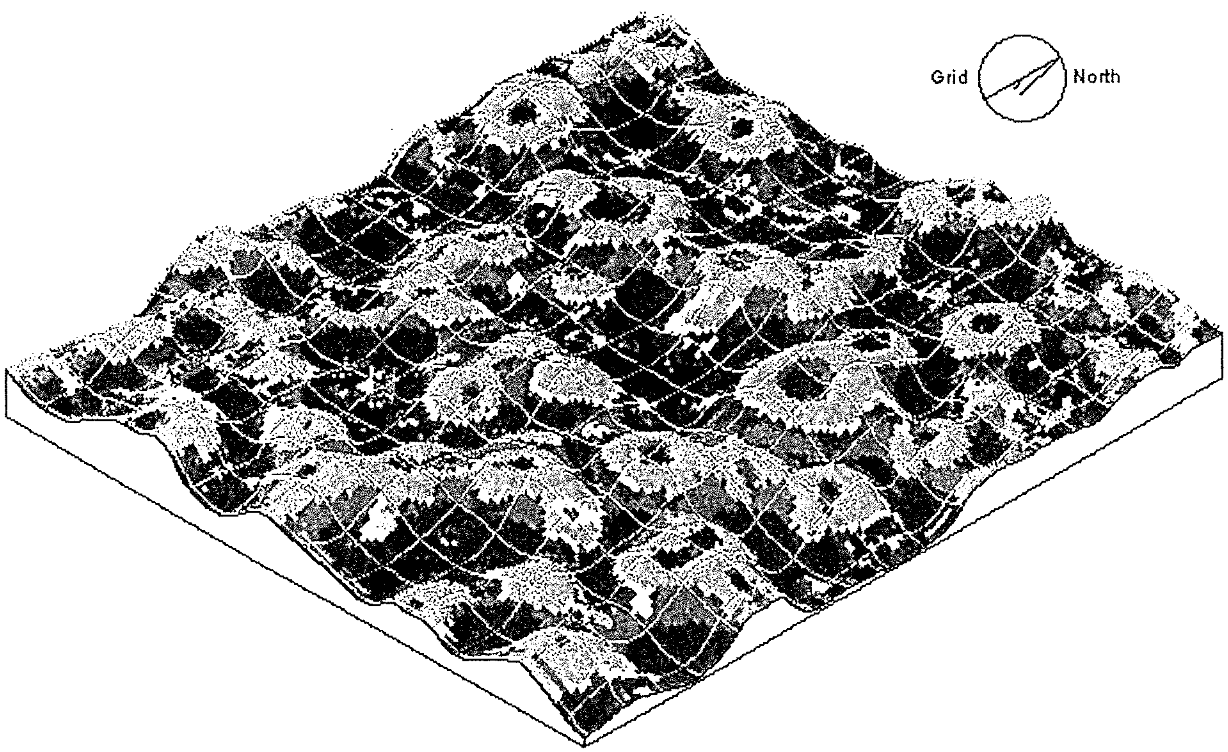

Figure 1. Topographic map of the Viking site

Soil Sampling: In the spring of 1997, the field was soil sampled using a landscape transect system where four transects with three landscape positions (shoulder, backslope and footslope) each were sampled based on dominant soil horizons. After harvest, these same landscape positions were fall soil sampled. In 1998, prior to seeding, the field was soil sampled using a 100 X 100 m grid system Composite soil samples were collected at each grid point for three depths (0-15, 15-30, and 30-60 cm). In addition, the four transects were soil sampled again in the spring and fall. In 1999, the four transects were sampled spring and fall. Samples were air dried and analyzed by Norwest Laboratories, Edmonton and by the Soil and Crop Diagnostic Centre, Alberta Agriculture, Food and Rural development. Analyses included nutrients (NO_3-N, PO_4-P, K and SO_4-S), pH, electrical conductivity, organic matter bulk density and moisture.

Meteorological Data: An automated meteorological station was established at the field site to collect air temperature, relative humidity, soil temperature, precipitation, solar radiation, wind speed and wind direction on a hourly basis.

Crop Management: In 1997, the field was seeded to Teal hard red spring wheat and fertilized according to soil test recommendations. In 1998, the field was seeded to barley and fertilized according to soil test recommendations. In 1999, the field was seeded to Quest, a glyphosate tolerant canola. The crop was fertilized according to soil test recommendations. Glyphosate (360 g/L) was applied at 1.25 L/ha on May 28 and June 15 to control weeds. Crop grain yield data was collected for the field using a combine yield monitor.

Crop Performance: Crop performance data was collected at the four transect/landscape locations, at four growth stages. Replicated crop samples (¼ m^2) were collected to measure biomass production, Leaf Area Index, crop density, growth stage, tiller development, and number of heads. Biomass material was also analyzed for nutrient (N, P, K and S) content.

Soil Nutrient Dynamics: 1n 1998 and 1999, Plant Root Simulator (PRS) ion exchange membrane probes were used to evaluate soil nutrient dynamics during the growing season at selected transects. Probes were repeatedly installed and removed at 2-week intervals. NH_4+ and K+ cations were measured from the cation probes and NO_3-, PO_4-, and SO_4- anions were measured from anion probes. SAS GLM procedure was used to conduct an ANOVA for a nested design for landforms.

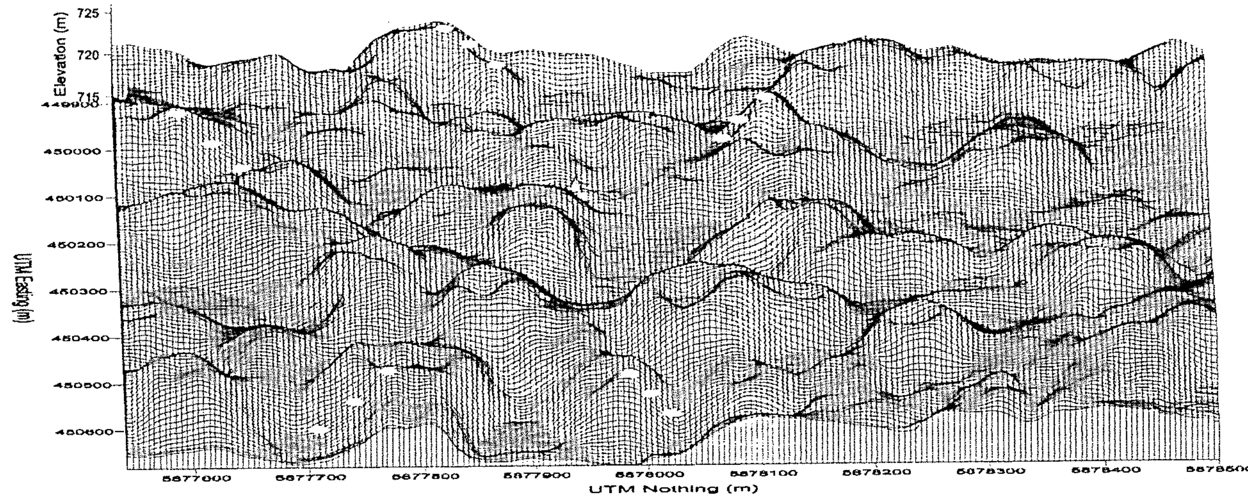

Figure 2. Topographic map of Viking site with transect point locations

Digital Elevation Model: GPS equipment on the farmer's combine was used to collect positional and elevation data. This data was used to derive a digital elevation model and identify landform elements (MacMillan and Pettapiece, 1997; MacMillan et al., 1999). The landscape model segments the field into 15 possible landform elements (Table 1).

Table 1. Landscape Classification Scheme

Landscape Class	Landscape Code	Landscape Description
1	LCR	Level Crest
2	DSH	Divergent Shoulder
3	UDE	Upslope Depression
4	BSL	Backslope
5	DBS	Divergent Backslope
6	CBS	Convergent Backslope
7	TER	Terrace
8	SAD	Saddle
9	MDE	Midslope Depression
10	FSL	Footslope
11	TSL	Toeslope
12	FAN	Fan
13	LSM	Lower Slope Mound
14	LLS	Level Lower Slope
15	DEP	Depression

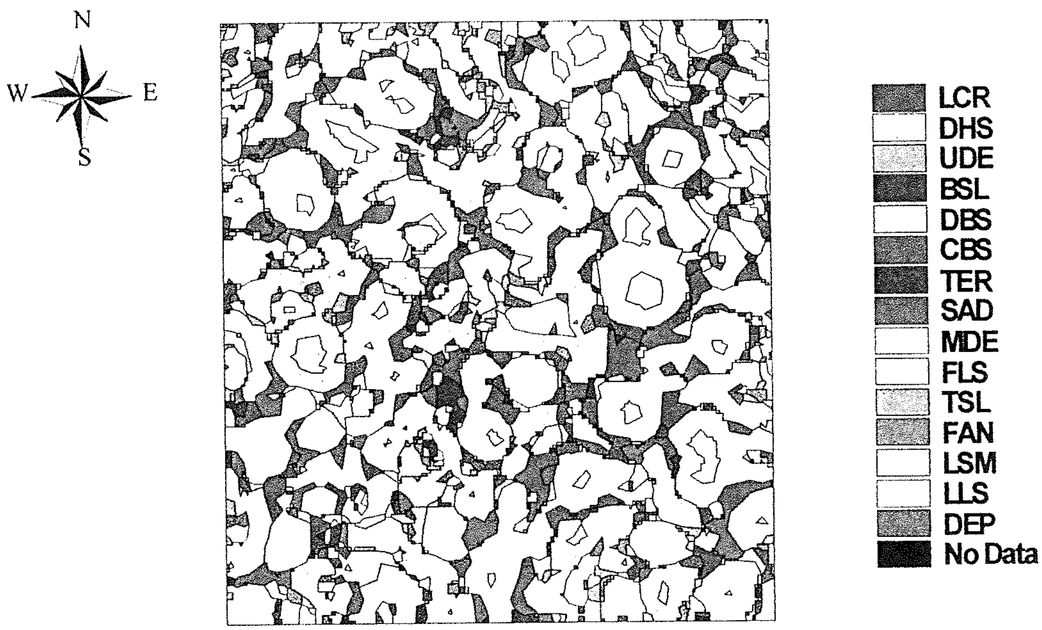

Figure 3. Landscape classification map of the Viking site

5.0 Results and Discussion

5.1 Crop Yield

Crop yield as measured by the combine yield monitor was quite variable across the field. In 1997, wheat yields ranged from 15 to 100 bu/ac, in 1998, barley yields ranged from 15 to 100 bu/ac and in 1999, canola yields ranged from 15 to 60 bu/ac. Yield data was summarized by landform element using ArcView. Crop yields by landforms varied depending on the climatic conditions. In 1997, a wetter year, the higher yields occurred in the upper slope positions. In comparison, 1998, was a dry year, and the higher yields occurred in the lower slope positions. In 1999, precipitation levels were similar to 1997 but canola yield was relatively uniform across the field.

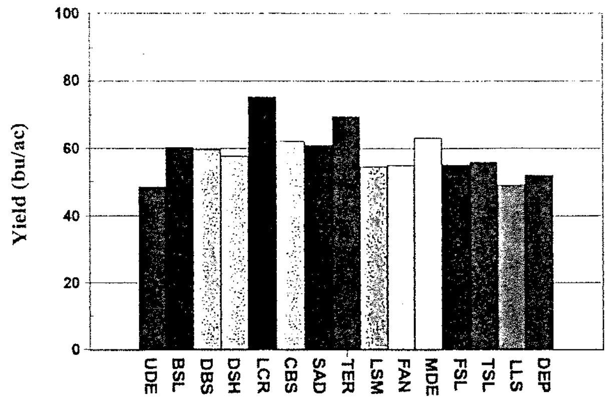

Figure 4. Mean wheat grain yield by landform at Viking, 1997

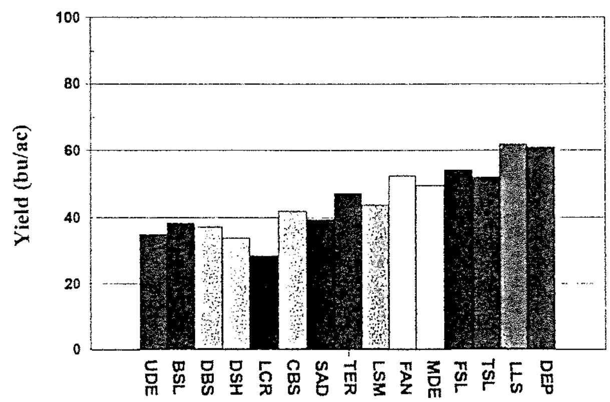

Figure 5. Mean barley grain yield by landform at Viking, 1998

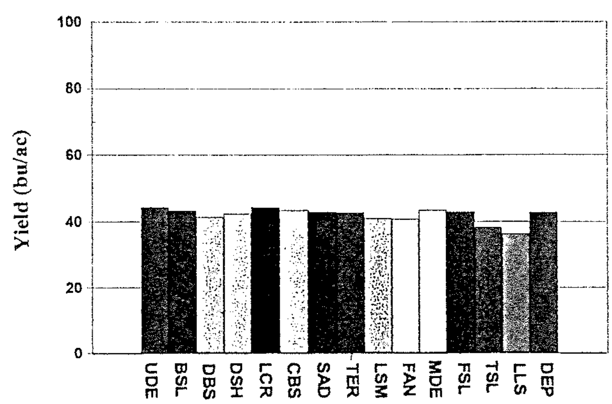

Figure 6. Mean canola seed yield by landform at Viking, 1999

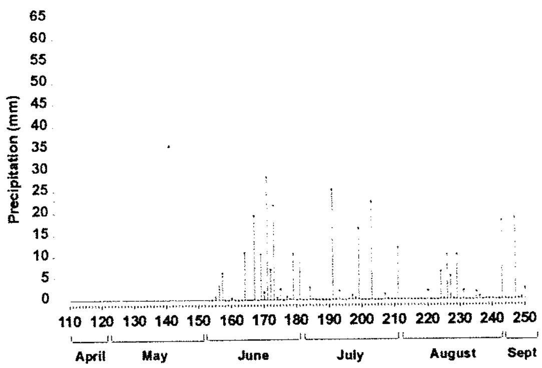

Figure 7. Daily precipitation, Viking 1997

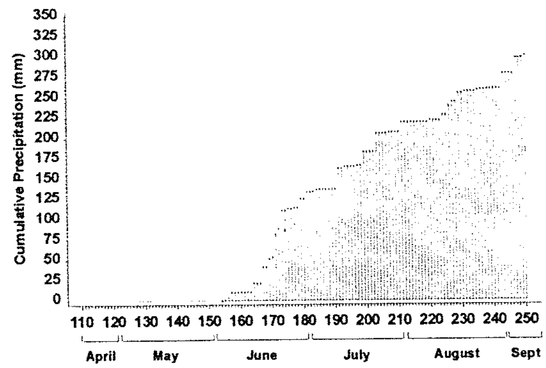

Figure 8. Cumulative precipitation, Viking 1997

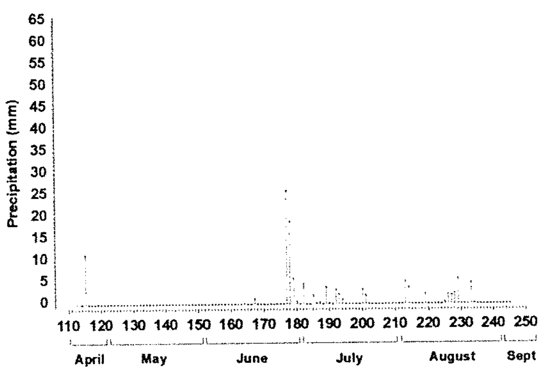

Figure 9. Daily precipitation, Viking 1998

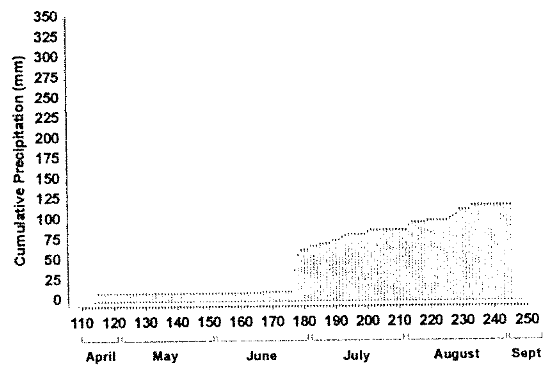

Figure 10. Cumulative precipitation, Viking 1998

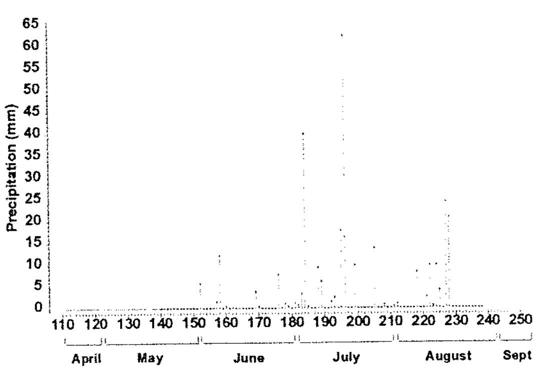

Figure 11. Daily precipitation, Viking 1999

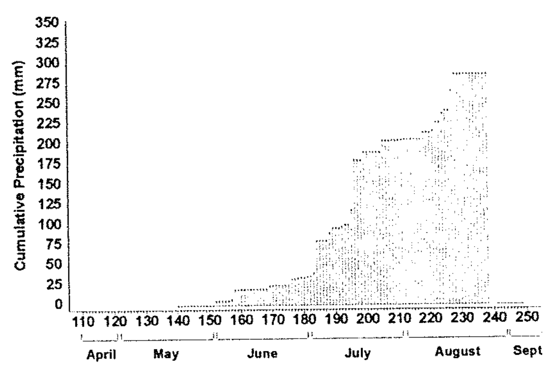

Figure 12. Cumulative precipitation, Viking 1999

5.2 Soil Analysis

To assess landscape variability, an existing set of four transects with three point (upper, midslope and lower slope) landscape positions were utilized. Each transect point had a detailed soil profile description, and major soil horizons sampled for laboratory analyses. Analyses will include: bulk density, soil moisture, water holding capacity, nutrient levels (NO_3-N, P, K, and SO_4-S), pH, electrical conductivity, total organic carbon, total nitrogen, exchangeable cations, cation exchange capacity and mechanical analysis. Summary of results are to be completed.

5.3 Soil Moisture and Temperature Dynamics

The late arrival of the automated dataloggers, TDR probes and thermisters meant the equipment could not be placed into the field until spring 2000. Detailed calibration of the TDR probes was conducted. For each TDR, a separate calibration equation was calculated. Soil salinity is not a factor for the selected transect. For spring 2000, one transect will be used to monitor soil temperature and moisture content in situ with thermisters and TDR probes linked to data loggers. Thermisters and TDR probes will be placed at 5 soil depths at each transect point. Data will be recorded quarter hourly and the data will be downloaded periodically.

5.4 Nutrient Dynamics

In situ measurement of plant nutrients using ion exchange membranes (Schoenau et al., 1993; Qian et al., 1993) along with soil moisture movement can be used to model dynamic soil processes based on landscape properties. At the same transect for which soil temperature and moisture is monitored, in situ dynamics of N, P, K and S will be monitored bi-weekly at each landscape position using ion exchange resin Plant Root Simulators (PRS) probes. Cation and anion PRS probes will be nested (5 of each probe type) within a one square meter area replicated three times at each landscape position.

The ion exchange membrane technique measures the nutrient supply power of a soil. An extended (2-week) burial of the ion exchange membrane probes provides information on the dynamics of nutrient supply. Results indicate a fairly consistent dynamic pattern for nutrient levels. In general, nutrient levels initially increase until mid summer and then decease by late summer (table 2). Differences between landscape positions reflect the net processes controlled by moisture and temperature (i.e. mineralization, immobilization, translocation, precipitation and dissolution reactions, and crop uptake). Results reflect the complex interaction of moisture, soil temperature, crop demand, stage of crop growth and landscape position. As temperature and moisture condition increase, nutrient availability increases. As the crop develops, crop demands for nutrients increase and soil nutrient availability declines. Once the crop demands for nutrients cease near maturity, soil nutrient availability increases due to such processes as mineralization.

Table 2. Influence of landscape position on soil nutrient dynamics

Landscape Position	May 28 June 10	June 10 June 23	June 23 July 07	July 07 July 21	July 21 August 03	August 03 August 18	August 18 August 26
Ammonium – Nitrogen ug/cm^2 / day							
Shoulder	0.22 a	0.49 a	0.46 a	0.33 a	0.09 a	0.06 a	0.68 a
Backslope	0.15 b	0.42 a	0.39 a	0.33 a	0.07 a	0.06 a	0.53 ab
Footslope	0.17 b	0.28 b	0.26 b	0.39 a	0.08 a	0.06 a	0.45 b
Nitrate – Nitrogen ug/cm^2 / day							
Shoulder	3.44 a	17.51 a	16.26 a	3.84 a	0.43 a	0.44 b	1.74 b
Backslope	3.54 a	18.31 a	17.00 a	4.96 a	0.46 a	0.93 a	2.44 ab
Footslope	1.81 b	7.71 b	7.16 b	2.80 a	0.47 a	0.30 b	3.03 a
Phosphate ug/cm^2 / day							
Shoulder	0.27 a	0.36 c	0.33 c	0.59 b	0.19 a	0.29 b	0.20 a
Backslope	0.25 a	0.56 b	0.52 b	1.09 a	0.16 a	0.40 a	0.23 a
Footslope	0.25 a	0.73 a	0.68 a	0.60 a	0.33 a	0.15 c	0.28 a
Potassium ug/cm^2 / day							
Shoulder	9.65 b	20.28 b	18.83 b	18.51 b	10.03 b	33.13 a	12.10 b
Backslope	11.17 b	31.80 a	29.53 a	24.94 b	11.88 b	30.93 a	16.72 b
Footslope	20.88 a	35.18 a	32.66 a	36.23 a	19.29 a	20.21 b	32.36 a
Sulphate-Sulphur ug/cm^2 / day							
Shoulder	0.52 a	2.12 ab	1.97 ab	1.28 a	0.42 a	4.27 a	0.73 b
Backslope	0.51 a	2.89 a	2.68 a	1.73 a	0.27 a	4.32 a	0.65 b
Footslope	0.44 a	1.15 b	1.07 b	1.76 a	0.51 a	4.49 a	1.39 a

Means followed by the same letter within a column are not significantly different at the $p<0.10$ level using the Student-Newman-Keul test.

5.5 Crop Growth and Development

A completely randomized experimental design will be used to assess the landscape variability of crop growth. Each transect point will be crop sampled with three replications at 3 or 4 times during the growing season. The crop samples will be measured for number of plants, growth stage and total dry matter biomass. At least two transects will have the crop samples separated by plant organ (leaves, stems, heads, and grain). Crop samples will be analyzed for nutrient (N, P, K and S) content and digestible energy. In addition, field measurements of Leaf Area Index (LAI) will be made at each transect point to assess crop canopy development using a Li-Cor 2000 plant canopy analyzer.

Crop growth measurements of landscape transects during the 1999 growing season did reveal variations due to landscape position (Table 3.). This yield difference among landscape positions also reflected a difference in the uptake of nitrogen, phosphorus, potassium and sulphur by the crop. The higher productivity of the footslope position results in higher nutrient demands.

Table 3. Influence of landscape position on canola yield and nutrient uptake for landscape transects at Viking, 1999.

Landscape Position	Flowering June 23	Pod Formation July 21	Pod Filling August 18	Harvest August 26
		Dry Matter Yield g/m^2		
Shoulder	127.3 c	474.3 b	628.4 b	665.3 b
Backslope	178.1 b	493.5 b	675.3 b	825.4 a
Footslope	222.3 a	630.9 a	909.0 a	878.7 a
		Nitrogen Uptake g/m^2		
Shoulder	5.9 c	12.6 b	9.6 b	11.1 b
Backslope	7.9 b	12.8 b	9.9 b	14.1 ab
Footslope	10.0 a	17.6 a	14.2 a	16.2 a
		Phosphorus Uptake g/m^2		
Shoulder	0.5 c	1.6 b	2.0 b	2.1 b
Backslope	0.8 b	1.7 b	2.2 b	2.5 b
Footslope	1.0 a	2.3 a	3.6 a	3.2 a
		Potassium Uptake g/m^2		
Shoulder	3.9 c	9.9 ab	11.5 b	13.5 b
Backslope	4.8 b	8.2 b	11.1 b	13.7 b
Footslope	7.4 a	11.3 a	17.9 a	18.0 a
		Sulphur Uptake g/m^2		
Shoulder	1.1 b	3.3 a	3.5 b	4.0 b
Backslope	1.3 b	3.0 a	3.7 b	4.5 b
Footslope	1.6 a	3.4 a	5.9 a	5.7 a

Means followed by the same letter within a column are not significantly different at the p<0.10 level using the Student-Newman-Keul test.

In a spatially variable field, landscape topography influences soil processes, crop growth, and crop nutrient demands through the redistribution of water. A detailed understanding of these processes will lead to the development of management strategies for precision agriculture.

6.0 Acknowledgements

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7.0 References

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8.0 Action Plan 2000-2001

Objective 1: Relationship of landscape position and soil moisture and temperature dynamics

- Climatic data will be collected using automated meteorological data loggers on a hourly basis.
- Soil moisture, water movement, and soil temperature data will be collected using TDR probes and dataloggers on a quarter hour basis.

Objective 2: Relationship of landscape position and soil nutrient dynamics

- Transect soil sampling. Soil samples will be collected for laboratory analyses of nutrient levels, organic matter, soil moisture, and soil chemistry.
- Soil nutrient levels well be measured using PRS anion and cation probes on a biweekly basis.

Objective 3: Relationship of landscape position and crop growth and development

- Crop biomass production will be measured four times during the growing season at specific crop growth stages (apex, anthesis, soft dough and maturity) at 3 replicated points within the landscape element.
- Statistical analysis of landscape variability and crop growth.

Objective 4: Spatial simulation of landscape dynamics for soil quality processes

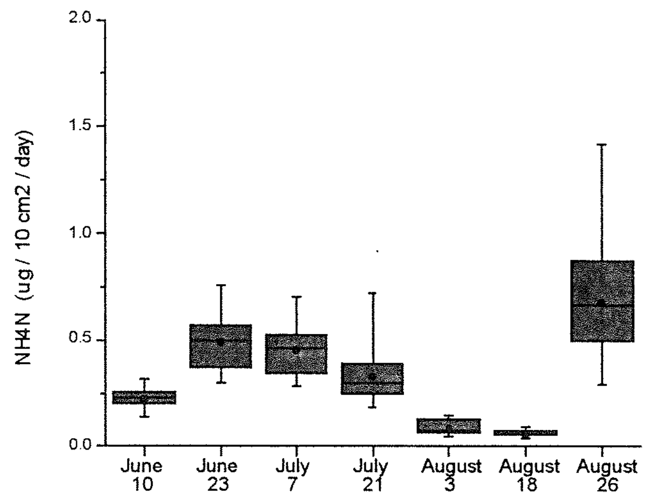
- Simulation model predictions of the hydrological and nutrient processes and crop growth and development will be compared with actual field measurement of water movement and nutrient levels data collected at the field site. The accuracy of the model will be evaluated at each landscape unit. Causes of inaccuracy will be investigated and, if appropriate, the model will be corrected.

Objective 5: Soil quality management strategies for variable landscapes

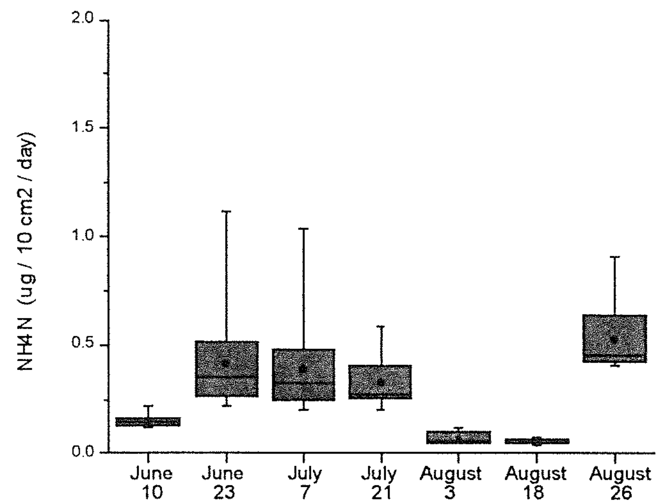
- Long-term (30 year) daily climatic data will be used to run multi-year simulations using the CERES, EPIC and *ecosys* models to evaluate the climatic impact on soil quality management strategies for variable landscapes.
- Management strategies will be based on cultivation practices, residue management, crop rotation, fertilizer use and long-term climatic data for variable landscapes.

Soil ammonium dynamics for three landscape positions,
measured using PRS (ion exchange) probes for Viking, 1999

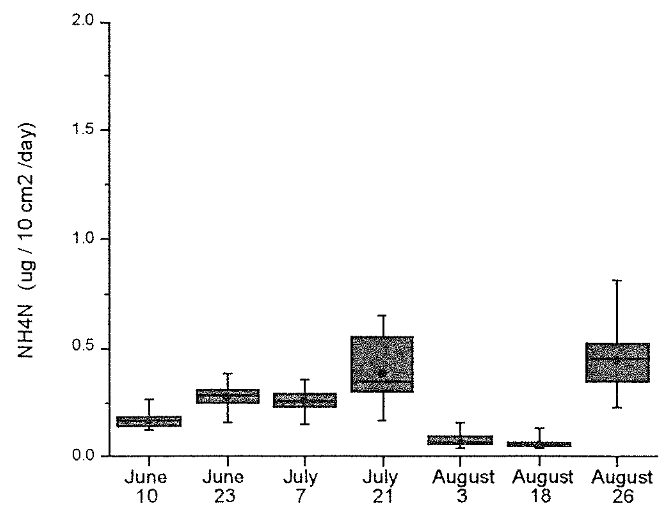
Shoulder



Backslope

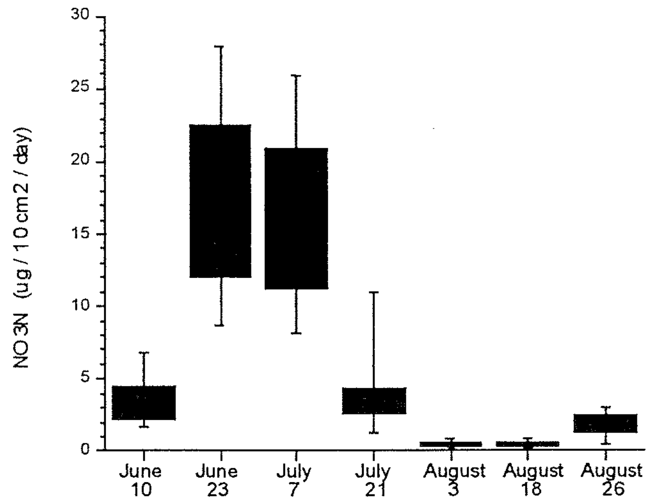


Footslope

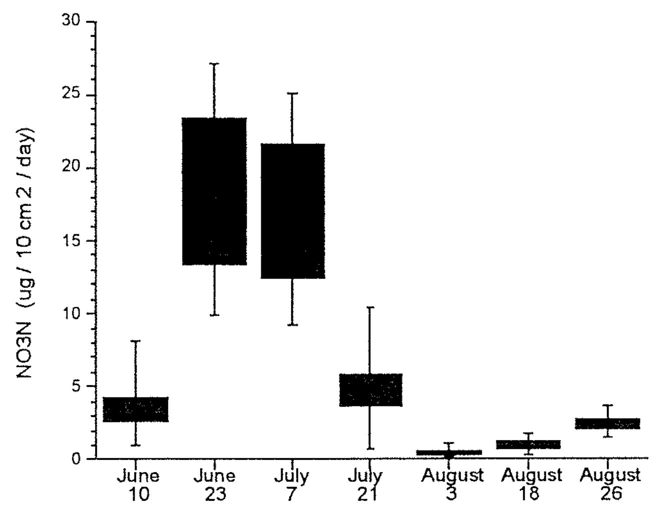


Soil nitrate dynamics for three landscape positions,
measured using PRS (ion exchange) probes for Viking, 1999

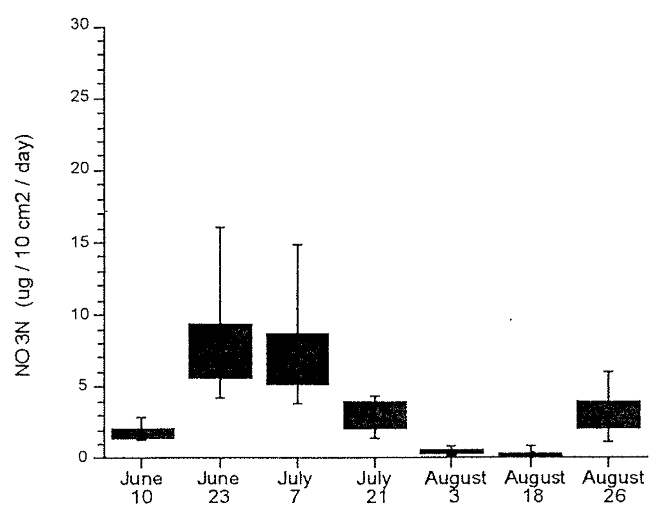
Shoulder



Backslope

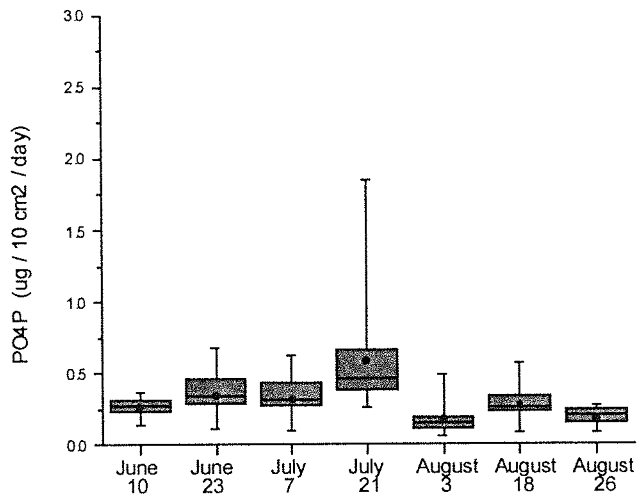


Footslope

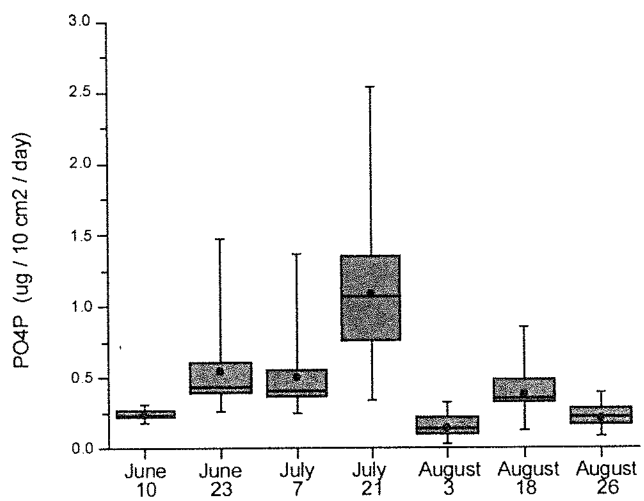


Soil phosphate dynamics for three landscape positions,
measured using PRS (ion exchange) probes for Viking, 1999

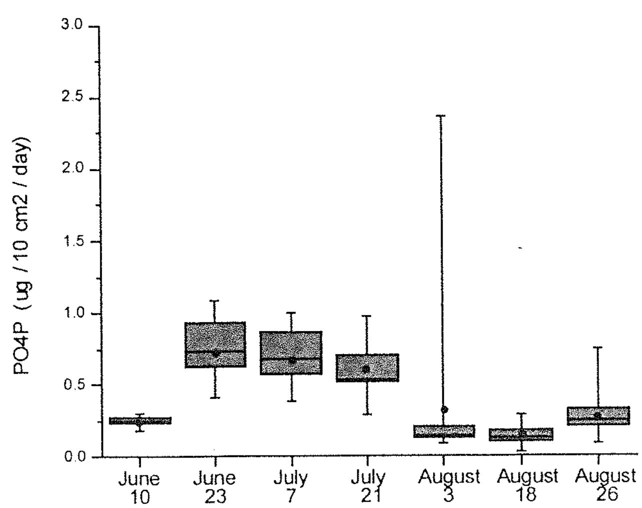
Shoulder



Backslope

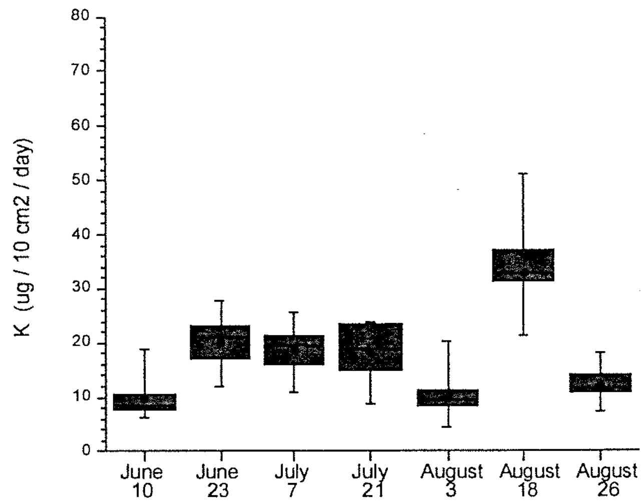


Footslope

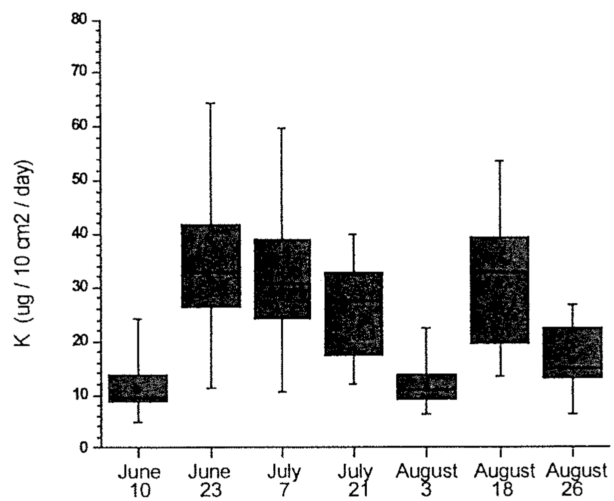


Soil potassium dynamics for three landscape positions,
measured using PRS (ion exchange) probes for Viking, 1999

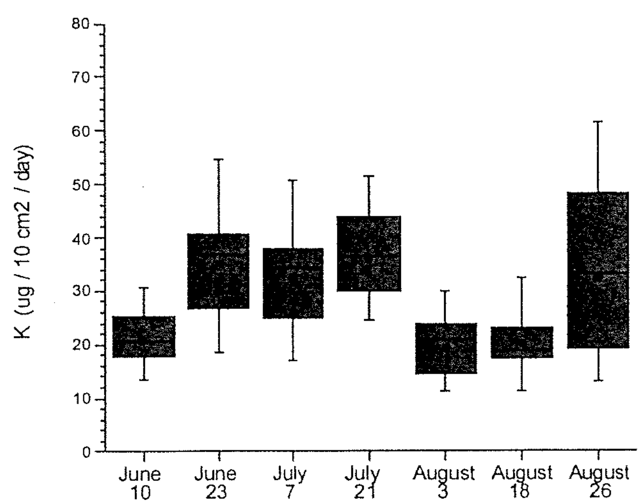
Shoulder



Backslope

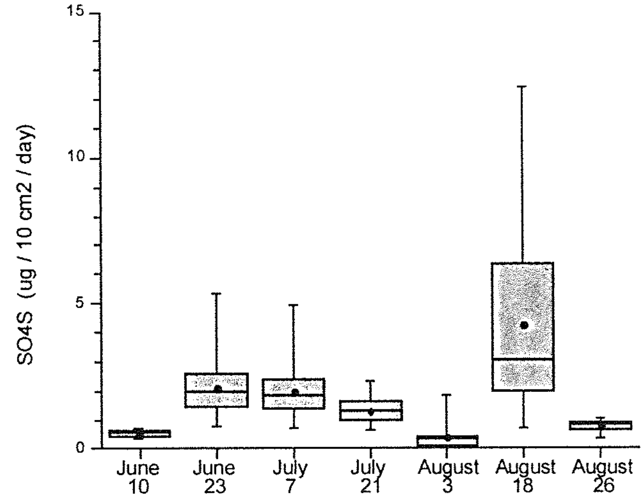


Footslope

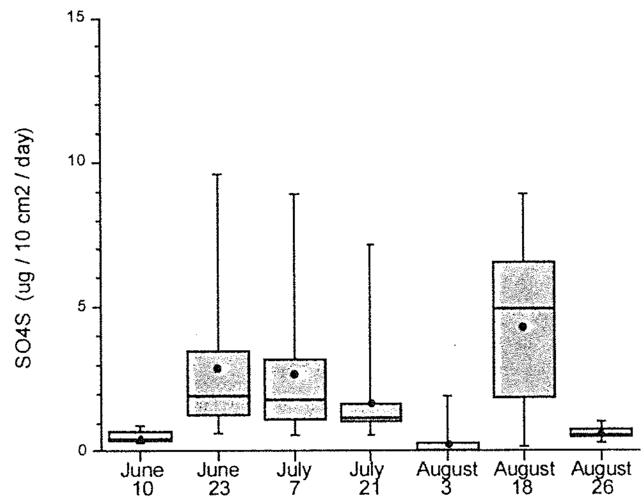


Soil sulphate dynamics for three landscape positions, measured using PRS (ion exchange) probes for Viking, 1999

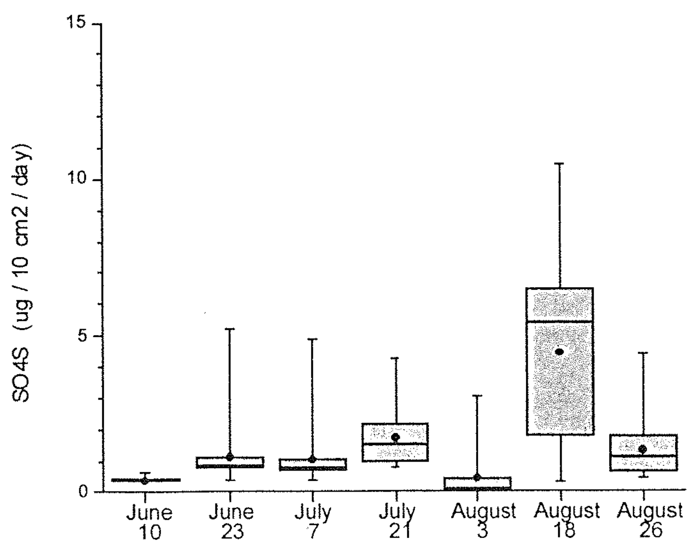
Shoulder

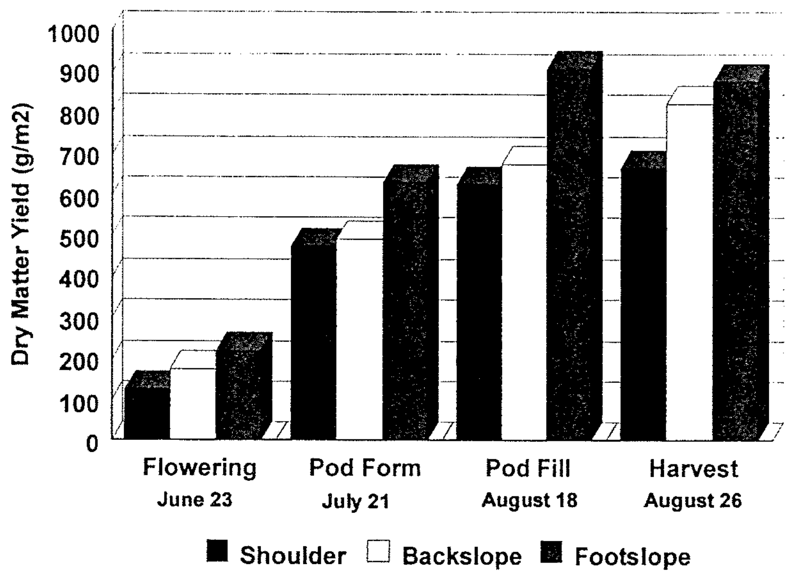


Backslope

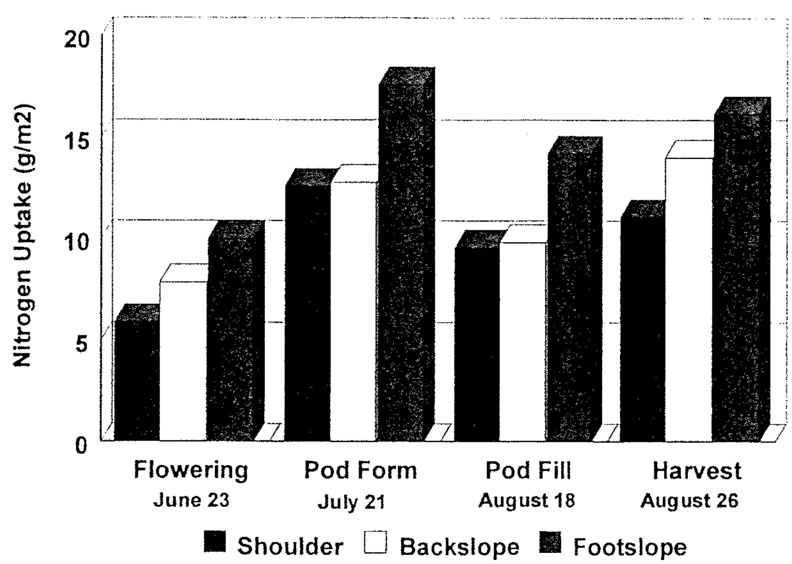


Footslope

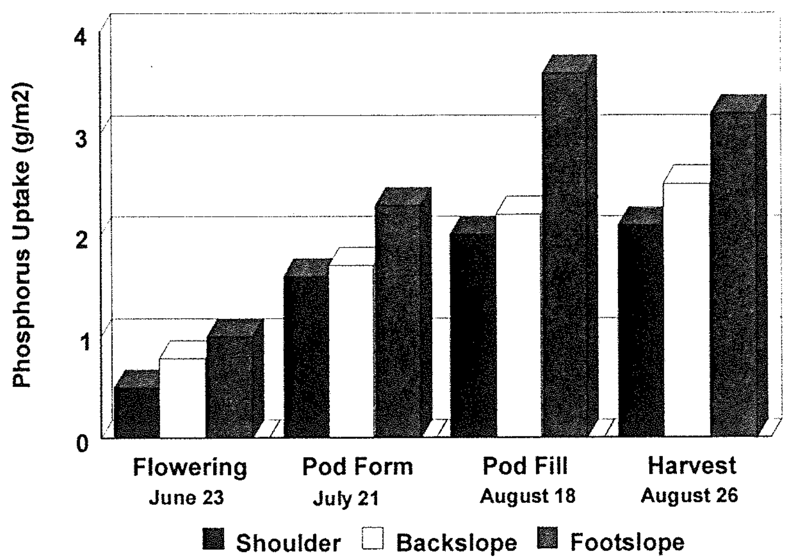




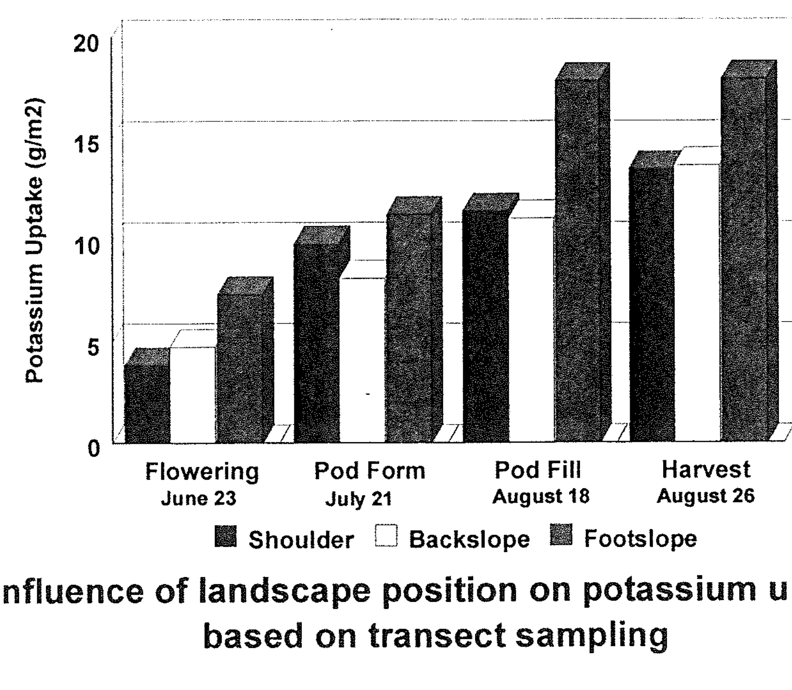
Influence of landscape position on canola dry matter yield based on transect sampling



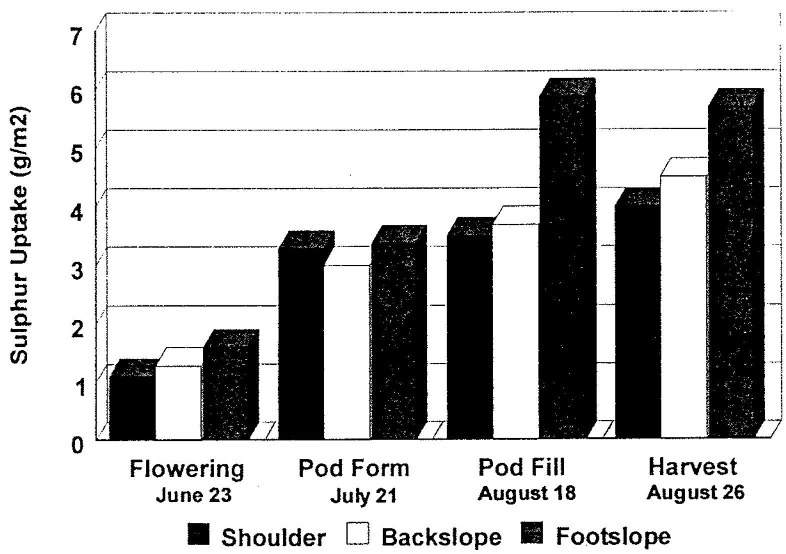
Influence of landscape position on nitrogen uptake based on transect sampling



Influence of landscape position on phosphorus uptake based on transect sampling



Influence of landscape position on potassium uptake based on transect sampling



Influence of landscape position on sulphur uptake based on transect sampling