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Landscape Influences on Soil and Agronomic Dynamics

Annual Research Report

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

1.0 Summary

Understanding the influence of landform elements on soil nutrients, crop growth, and nutrient uptake by crops is essential to develop management strategies for precision agriculture. In 2000, detailed measurements of soil processes, crop growth, and nutrient demands were made at a field site seeded to wheat. Results from this field with rolling topography confirmed previous years' result that soil nutrient supply dynamics were related to landscape position. The higher levels of crop growth in lower slope positions were associated with higher crop production and associated nutrient demands by the crop. Moisture dynamics appear to have a strong influence on the soil and agronomic dynamics of this rolling topography.

This is the fourth year at this field site. Installation of the soil moisture and temperature sensors at one landscape transect (shoulder, backslope and footslope positions) was completed. Measurement of soil nutrient, crop growth and crop nutrient uptake dynamics was also completed. Results indicate that landscape position has a significant impact on water redistribution and soil temperature regimes. The shoulder and backslope is drier with very little subsoil infiltration compared to the footslope position. The shoulder is also warmer with greater temperature fluctuations than the backslope and footslope positions. The differences in the moisture and temperature regimes among the landscape positions influences soil nutrient dynamics, crop growth and crop uptake of nutrients. Evaluation of the *ecosys* model indicates a good prediction of soil moisture and temperature dynamics. Results were presented at the American Society of Agronomy meetings in Minneapolis, November 2000. Future work will evaluate the nutrient dynamics and crop growth functions of *ecosys*. In addition, two other models (EPIC and DSSAT) will be evaluated using the data from this site.

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 impact 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 depression 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 slopes 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 and should be related to field topographic features.

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, greater depth to carbonates, 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 processes that impacts crop production and soil management. 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-region in east central Alberta, near Viking, Alberta. It has a rolling topography with moderate slopes (10-13%). The field is dominated by black chernomzemic soils. The field is under a conventional cultivation system with a wheat, barley and canola crop rotation, and managed using precision agriculture technology (global positioning system, variable rate technology, yield mapping, etc.).

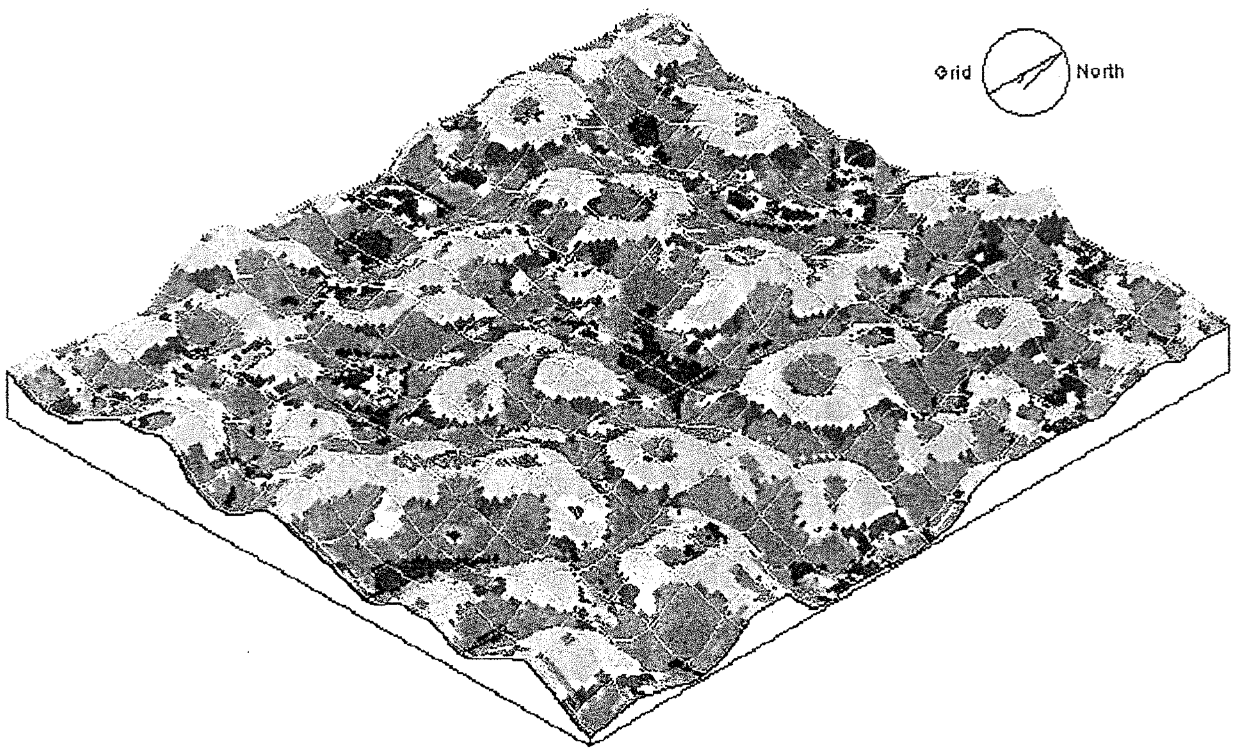

Figure 1. Topographic map of the Viking site

Soil Sampling: In the spring of 1997, the field was soil sampled using a landscape transects system for four transects with three landscape positions (shoulder, backslope and footslope). A complete profile description was conducted for each landscape position and the dominant soil horizons were sampled. 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

Samples were air dried and analyzed by Norwest Laboratories, Edmonton. In 1998, one of the original transects (1a) was replaced with a new transect (1) with three landscape positions. A complete profile description was conducted and the dominant horizons sampled. In 1998, 1999 and 2000, each landscape position for the four transects were soil sampled in the spring and fall at 15 cm increments to a depth of 90 cm. Samples were air dried and analyzed and by the Agri-Food Laboratories Branch, Alberta Agriculture, Food and Rural development and or the Department of Renewable Resources, University of Alberta. Analyses included nutrients (NH_4-N, NO_3-N, PO_4-P, K and SO_4-S), pH, electrical conductivity, total nitrogen, total carbon, bulk density, texture, gravimetric moisture, soluble cations and anions from saturated paste and cation exchange capacity.

Meteorological Data: An automated meteorological station was established at the field site. Air temperature, relative humidity, surface soil temperature, precipitation, solar radiation, wind speed and wind direction on a hourly basis was collected for 1997 - 2000 growing season. Supplemental data from nearby meteorological stations was collected from the University of Alberta and Environment Canada to complete the full year dataset.

Crop Management: Crop management by the producer is outlined in Table 1. The crop rotation for the field is wheat, barley and canola. The field is conventionally tilled and fertilized in the fall and spring. In 1997, the field was seeded to Teal hard red spring wheat; in 1998, the field was seeded to Dolly barley; in 1999, the field was seeded to LG 3295, a glyphosate tolerant canola; and in 2000, the field was seeded to Teal hard red spring wheat. The crop was fertilized according to soil test recommendations. The producer would also conduct strip trials for variable rate fertilizer application. The transect/landscape positions used to sample soil status and crop performance were outside these strips and received a constant rate of fertilizer. 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

Table 1. Field management history for the Viking site, 1997 - 2000

	1997	1998	1999	2000
Crop	Wheat	Barley	Canola	Wheat
Variety	Teal	Dolly	LG 3295	Teal
Spring Tillage Date	25-Apr-97	21-Apr-98	28-Apr-99	24-Apr-00
Spring Tillage Equipment	Heavy Harrow	Heavy Harrow	Heavy Harrow	Heavy Harrow
Spring Tillage Depth	1/2 in to 3/4 in	1/2 in to 3/4 in	1/2 in to 3/4 in	1/2 to 3/4 in
Spring Fertilizer Date	6-May-97	1-May-98	4-May-99	4-May-00
Spring Fertilizer Formulation (N-P-K-S)	10-10-0-5	Variable Rate	Variable Rate	10-20-20-5
Spring Fertilizer Source / Blend	Drys	Drys	Drys	Drys
Spring Fertilizer Rate		0 to 250 lbs	0 to 165 lbs	
Spring Fertilizer Placement	With Seed	With Seed	With Seed	With Seed
Spring Fertilizer Depth	1 3/4 in	2 in	2 in	1 1/2 in
Spring Fertilizer Spacing	9 in	9 in	9 in	9 in
Spring Fertilizer Equipment	AirDrill	AirDrill	Airdrill	Airdrill
Seeding Date	6-May-97	1-May-98	4-May-99	4-May-00
Seeding Rate	112 lbs/ac	96 lbs/ac	5 lbs/ac	110 lbs/ac
Seeding Depth	1 3/4 in	2 in	1/2 in	1 1/2 in
Seeding Row Spacing	9 in	9 in	Broadcast	9 in
Herbicide Dates	4-Jun-97	12-Jun-97	24 May/10 Jun 98	5-Jun-00
Herbicides	Puma, Ally, MCPA Ester	Attain, Super Puma	Round-Up	Sundance, Buctril M
Harvest Date	15-Sep-97	30-Aug-98	13-Sep-99	18-Sep-00
Average Yield	55 bu/ac	34 bu/ac	39 bu/ac	50 bu/ac
Straw Removed (Yes or No)	No	No	No	No
Fall Tillage Date	15-Oct-96	25-Sep-97	14-Sep-98	16-Sep-99
Fall Tillage Equipment	Cultivator	Cultivator	Cultivator	Cultivator
Fall Tillage Depth	4 in	5 in	4 in	4 in
Fall Fertilizer Date	19-Oct-96	15-Oct-97	12-Oct-98	17-Oct-99
Fall Fertilizer Formulation (N-P-K-S)	70-24-0-7	70-15-0-10	55-12-0-8	55-12-0-8
Fall Fertilizer Source / Blend	Liquid	Liquid	Liquid	Liquid
Fall Fertilizer Placement	Band	Band	Band	Band
Fall Fertilizer Depth	3 1/2 in	3 1/2 in	3 1/2 in	3 1/2 in
Fall Fertilizer Spacing	10 in	9 in	12 in	12 in

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: In 1998, 1999 and 2000, 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. In 2000, four root exclusion tubes were placed at each landscape position, and PRS probes were used to measure nutrient dynamics of the soil without the influence of the crop roots. SAS GLM procedure was used to conduct an ANOVA for a nested design for landforms.

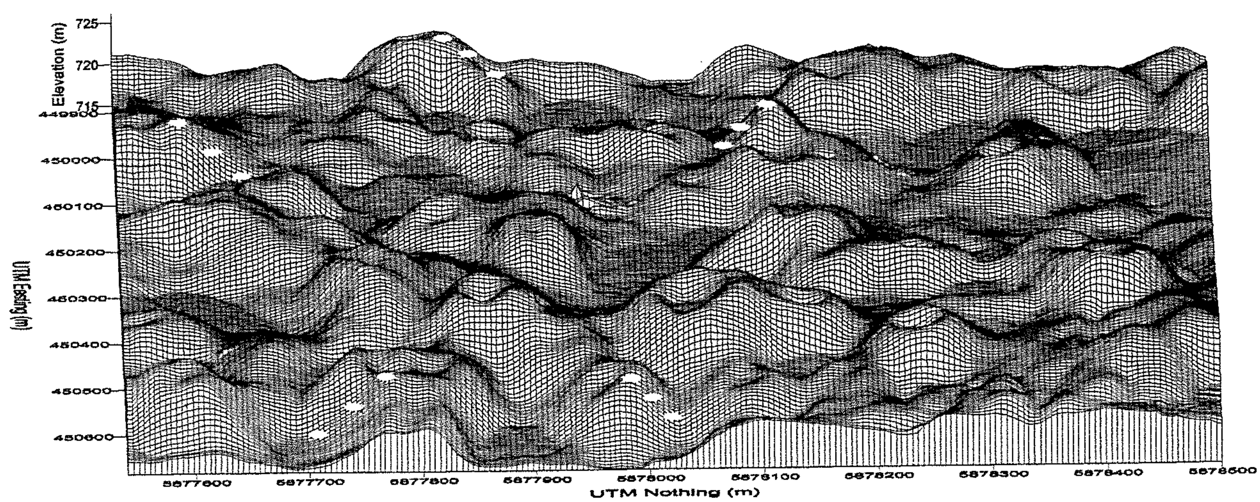

Figure 2. Topographic map of Viking site with transect point locations

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 2).

Table 2. 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

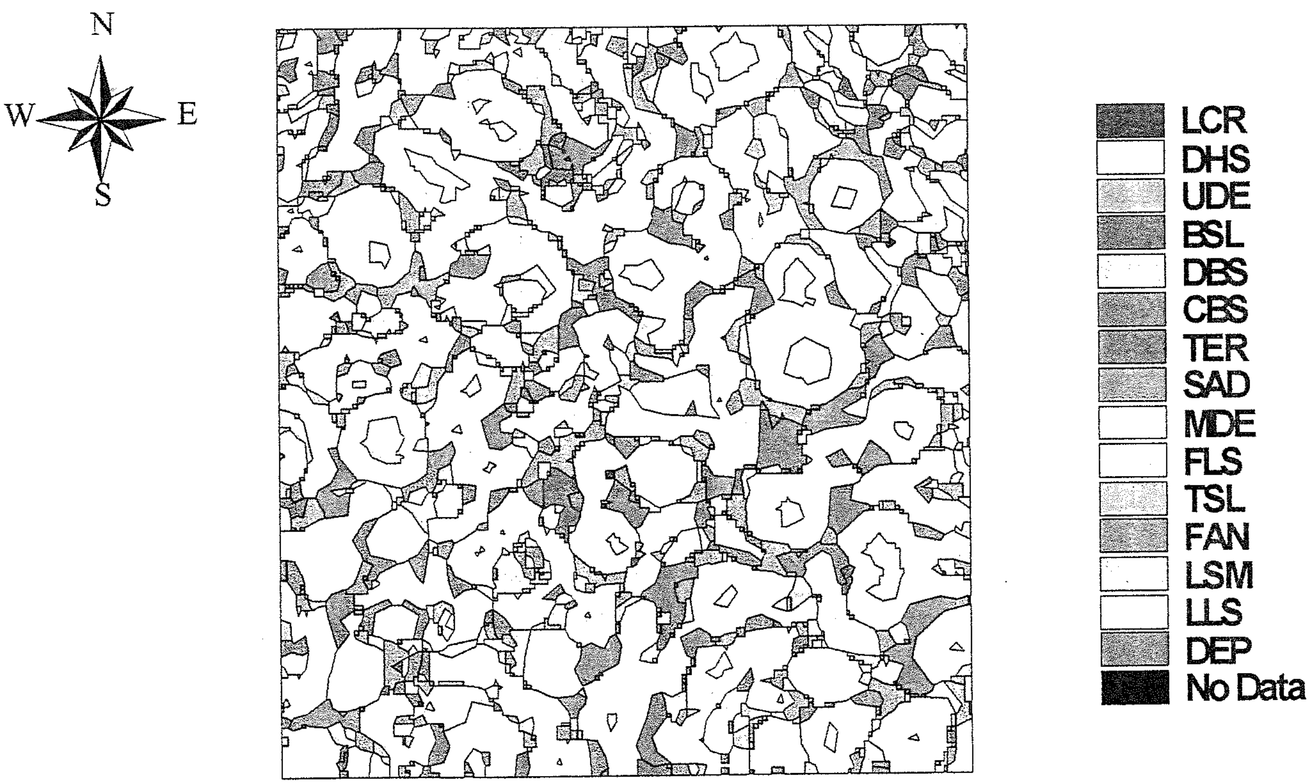

Figure 3. Landscape classification map of Viking

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. Crop yields by landforms varied depending on the climatic conditions. In 1997, the growing season precipitation totaled 327 mm. In that year, the higher yields occurred in the upper slope positions. In comparison, 1998, was a dry year (118 mm), and the higher yields occurred in the lower slope positions. In 1999, the total growing season precipitation was 286 mm and canola yield was relatively uniform across the field. In 2000, wheat yields ranged from 10 to 120 bu/ac. The total growing season precipitation was 337 mm. The landscape influence was visibly evident such that the higher yields occurred in the lower slope positions and lowest yields were on the upper slope positions.

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 included: bulk density, soil moisture, water holding capacity, nutrient levels (NH_4-H, 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. Tables 3a - 3e provide the pedological summary of each transect. Table 4 provides a summary of spring 2000 soil samples. The elevated nutrient levels in the surface soil samples reflect the fall 1999 fertilizer application.

5.3 Soil Moisture and Temperature Dynamics

Automated dataloggers, TDR probes and thermisters were positioned on three landscape positions for one transect to monitor soil moisture and soil temperature dynamics in the spring of 2000. Thermisters and TDR probes were placed at 5 soil depths at each transect point. Data were recorded every 15 minutes and the data will be downloaded periodically. Figure 4 illustrates the precipitation events for the site and Figure 5 provides the average hourly air temperature.

Table 3a. Soil chemical and physical charactersitics of transect 1a at Viking, 1997

Landscape Position	Horizon	Depth cm	Horizon Width	Bulk Denity Mg m-3	Sand %	Silt %	Clay %	Texture	pH water	EC dS m-1	Total N %	Total C %	CaCo3 %	Organic C %	CEC meq/100g
Shoulder	Ap	0 - 14	14	1.12	40	31	29	CL	7.4	1.0	0.22	0.00	2.17	2.17	19.3
	Bm	14 - 23	9	1.56	52	23	25	SCL	7.8	0.6	0.10	0.25	1.11	1.08	12.6
	Cca	23 - 59	36	1.46	35	31	34	CL	8.4	0.5	0.07	10.70	2.05	0.77	14.4
	IIC	59 - 115	56												
	IIIC	115 - 120+													
Backslope	Ap	0 - 14	14	1.09	41	34	25	L	5.8	0.4	0.32	0.00	3.60	3.60	21.3
	Bm1	14 - 28	14	1.46	38	29	33	CL	6.5	0.4	0.09	0.00	0.96	0.96	16.7
	Bm2	28 - 85	57		40	27	33	CL	6.2	0.2	0.60	0.00	0.65	0.65	17.1
	Ck	85 - 95+													
Footslope	Ap	0 - 14	14	1.09	46	31	23	L	6.1	0.6	0.27	0.00	3.04	3.04	18.7
	Ah	14 - 18	4												
	Bm	18 - 28	10	1.58	48	25	27	SCL	7.5	0.4	0.09	0.00	0.82	0.82	16.9
	Bmk	28 - 51	23		52	21	27	SCL	8.7	0.6	0.08	0.70	0.84	0.76	15.4
	Ck	51 - 80	29												
	Cca	80 - 90+													

Table 3b. Soil chemical and physical charactersitics of transect 2 at Viking, 1997

Landscape Position	Horizon	Depth cm	Width	Bulk Denity Mg m-3	Sand %	Silt %	Clay %	Texture	pH water	EC	Total N %	Total C %	CaCo3 %	Organic C %	CEC meq/100g
Shoulder	Ap	0 - 10	10	1.08	44	27	29	CL	7.7	0.7	0.18	0.00	1.78	1.78	17.9
	Cca1	10 - 25	15	1.54	39	30	31	CL	8.1	0.6	0.10	3.75	1.43	0.98	15.7
	Cca2	25 - 85+	60		40	28	32	CL	8.6	0.5	0.06	5.40	1.36	0.71	15.1
Backslope	Ap	0 - 14	14	1.20	48	27	25	SCL	6.4	0.5	0.20	0.00	2.20	2.20	15.7
	Bnt	14 - 35	21	1.52	40	24	36	CL	7.2	0.5	0.10	0.00	0.96	0.96	20.7
	Bmk	35 - 50	15		42	25	33	CL	8.7	0.9	0.06	0.00	0.66	0.66	18.3
	Ck	50 - 95+	45												
Footslope	Ap1	0 - 13	13	1.20	49	28	23	L	5.4	0.5	0.25	0.00	2.78	2.78	16.4
	Ap2	13 - 28	15		47	31	22	L	5.2	0.2	0.22	0.00	2.31	2.31	16.1
	Ah	28 - 40	12	1.09	49	34	17	L	4.9	0.3	0.38	0.00	4.34	4.34	21.1
	AB	40 - 53	13		44	37	19	L	5.6	0.2	0.10	0.00	1.07	1.07	10.5
	Cg	53 - 80	27												
	Cg2	80+													

Table 3c. Soil chemical and physical charactersitics of transect 3 at Viking, 1997

Landscape Position	Horizon	Depth cm	Horizon Width	Bulk Denity Mg m-3	Sand %	Silt %	Clay %	Texture	pH water	EC dS m-1	Total N %	Total C %	CaCo3 %	Organic C %	CEC meq/100g
Shoulder	Ap	0 - 10	10	1.26	44	27	29	L	5.9	0.6	0.22	0.00	2.44	2.44	18.0
	Bm	10 - 43	33	1.52	40	29	31	CL	6.3	0.3	0.10	0.00	0.88	0.88	16.4
	Ck	43 - 90	47		37	30	33	CL	8.1	0.5	0.07	4.10	1.32	0.83	14.1
	Cca	90 - 110+													
Backslope	Ap	0 - 13	13	0.94	48	31	21	L	5.6	0.3	0.45	0.00	5.22	5.22	23.9
	Ah	13 - 23	10		47	30	23	L	5.4	0.2	0.30	0.00	3.50	3.50	19.1
	Bm1	23 - 37	14	1.55	56	29	15	SL	5.3	0.1	0.11	0.00	1.18	1.18	8.7
	Bm2	37 - 97	60		41	32	27	CL	5.7	0.2	0.10	0.00	1.00	1.00	14.9
	Ck	97 - 105+													
Footslope															
	Ap	0 - 16	16	1.03	42	37	21	L	6.2	0.5	0.48	0.00	5.60	5.60	28.1
	Ah	16 - 23	7		38	37	25	L	7.0	0.6	0.47	0.00	5.05	5.05	29.9
	Bmk1	23 - 30	7	1.41	38	28	34	CL	7.9	0.6	0.15	5.90	1.59	0.88	20.1
	Bmk2	30 - 49	19		33	29	38	CL	8.2	0.7	0.10	11.00	1.67	0.35	19.7
	Cca	49 - 75+	26												

Table 3d. Soil chemical and physical charactersitics of transect 4 at Viking, 1997

Landscape Position	Horizon	Depth cm	Horizon Width	Bulk Denity Mg m-3	Sand %	Silt %	Clay %	Texture	pH water	EC dS m-1	Total N %	Total C %	CaCo3 %	Organic C %	CEC meq/100g
Shoulder	Ap	0 - 10	10	1.21	59	22	19	SCL	7.4	0.4	0.18	5.55	1.88	1.21	15.0
	Bmk	10 - 24	14	1.47	52	28	20	L	7.9	0.5	0.09	9.80	1.23	0.05	9.8
	Ck	24+		1.43	57	22	21	SCL	8.2	0.4	0.07	13.25	1.61	0.02	8.1
Backslope	Ap	0 - 12	12	1.20	55	27	18	SL	5.9	0.4	0.28	5.10	3.10	2.49	16.1
	AB	12 - 32	20		68	18	14	SL	7.3	0.4	0.16	5.60	1.70	1.03	7.3
	Bm	32 - 84	52	1.54	64	13	23	SCL	6.6	0.2	0.05	5.40			11.6
	Cca	84 - 99+													
Footslope	Ap	0 - 13	13	1.21	56	27	17	SL	5.4	0.5	0.35	3.25	4.00	3.61	19.6
	Ah	13 - 28	15		46	36	18	L	5.2	0.3	0.38	4.05	4.26	3.77	21.9
	Bm1	28 - 49	21	1.50	42	32	26	L	5.3	0.2	0.09	5.20	0.86	0.24	11.4
	Bm2	49 - 58	9												
	Ck	58 - 80	22												
	IICk	80 - 110+													

Table 3e. Soil chemical and physical charactersitics of transect 1 at Viking, 1998

Landscape Position	Horizon	Depth cm	Horizon Width	Bulk Denity Mg m-3	Sand %	Silt %	Clay %	Texture	pH water	EC dS m-1	Total N %	Total C %	CaCo3 %	Organic C %	CEC meq/100g
Shoulder	Ap	0 - 12	12	1.22	45	30	25	L	6.4	0.5	0.24				22.0
	Bm	12 - 46	34	1.63	44	26	30	CL	6.8	0.6	0.08				20.4
	Ck	46+		1.72	41	27	32	CL	8.5	0.8	0.04				19.3
Backslope	Ap	0 - 12	12	1.07	45	31	24	CL	5.9	0.4	0.27				24.7
	AB	12 - 25	-12		45	31	24	L	6.0	0.2	0.19				23.1
	Bm1	25 - 32	7	1.48	41	29	30	CL	6.4	0.2	0.06				20.6
	Bm2	32 - 65	33												
	Ck	65+			44	30	26	L	8.1	0.4	0.03				15.1
Footslope															
	Ap1	0 - 11	11	1.07	41	37	22	L	5.7	0.5	0.39				28.1
	Ap2	11 - 25	14		40	38	22	L	5.3	0.4	0.45				32.7
	Ah	25 - 48	23	1.06	36	44	20	L	5.2	0.3	0.55				36.7
	Ahe	48 - 55	7												
	Bgj	55 - 95	40		40	38	22	L	5.0	0.4	0.41				29.3
	C	95+													

Table 4. Summary of soil fertility and chemical analyses of four transects at Viking, Spring 2000

Landscape Position	Depth cm	NH_4 (mg kg^{-1}) Mean	Std Dev	NO_3 (mg kg^{-1}) Mean	Std Dev	PO_4 (mg kg^{-1}) Mean	Std Dev	K (mg kg^{-1}) Mean	Std Dev	SO_4 (mg kg^{-1}) Mean	Std Dev	pH water Mean	Std Dev	EC (dS m^{-1}) Mean	Std Dev
Shoulder	0 -15	32.5	55.6	13.3	3.3	17.5	9.3	205.3	29.8	13.7	7.6	7.1	1.0	0.6	0.2
	15 - 30	5.5	1.3	2.3	1.3	3.5	4.5	125.3	41.0	4.7	0.9	7.9	0.5	0.5	0.1
	30 - 45	4.3	0.5	1.8	1.0	0.8	1.0	159.5	53.4	6.2	4.9	8.5	0.2	0.6	0.2
	45 - 60	4.3	0.5	1.8	1.0	0.8	0.5	211.8	38.7	26.7	32.2	8.7	0.3	0.8	0.3
	60 - 75	4.5	1.9	2.0	1.4	1.0	1.2	254.0	37.3	49.9	51.7	8.8	0.2	1.0	0.4
	75 - 90														
Backslope	0 -15	20.3	28.5	13.5	5.5	23.0	8.9	205.8	88.7	13.1	5.3	6.1	0.7	0.4	0.1
	15 - 30	5.3	1.5	5.0	1.8	7.8	4.2	70.8	12.3	4.5	0.9	6.2	1.0	0.3	0.1
	30 - 45	4.3	1.3	2.3	2.5	3.3	1.7	82.8	24.3	6.2	4.6	6.8	1.2	0.3	0.1
	45 - 60	4.0	0.8	1.8	1.5	2.5	1.3	93.8	34.9	28.7	43.0	7.6	1.0	0.6	0.3
	60 - 75	4.3	1.0	1.8	1.0	3.0	1.8	95.8	16.8	328.4	647.7	7.8	0.8	1.9	2.6
	75 - 90	4.7	1.2	6.3	7.1	7.0	3.6	107.0	16.4	486.7	770.1	7.4	0.3	2.5	2.8
Footslope	0 -15	31.8	27.8	26.8	4.0	35.0	10.7	357.0	110.1	10.2	2.3	5.7	0.6	0.4	0.1
	15 - 30	10.8	6.7	15.3	3.8	14.0	6.4	106.8	38.4	8.4	2.7	5.8	1.3	0.4	0.1
	30 - 45	5.5	2.1	9.3	4.6	5.5	3.7	97.5	43.7	12.3	11.0	6.2	1.4	0.4	0.3
	45 - 60	4.5	1.3	8.0	7.4	5.0	5.1	101.5	23.2	44.8	48.3	6.4	1.6	0.6	0.5
	60 - 75	3.8	1.0	3.3	2.2	5.8	6.5	95.8	21.4	549.7	675.1	6.3	1.2	2.4	2.7
	75 - 90	5.0	1.4	4.0	2.4	4.3	3.1	118.3	28.4	661.0	760.3	6.5	1.1	2.7	3.0

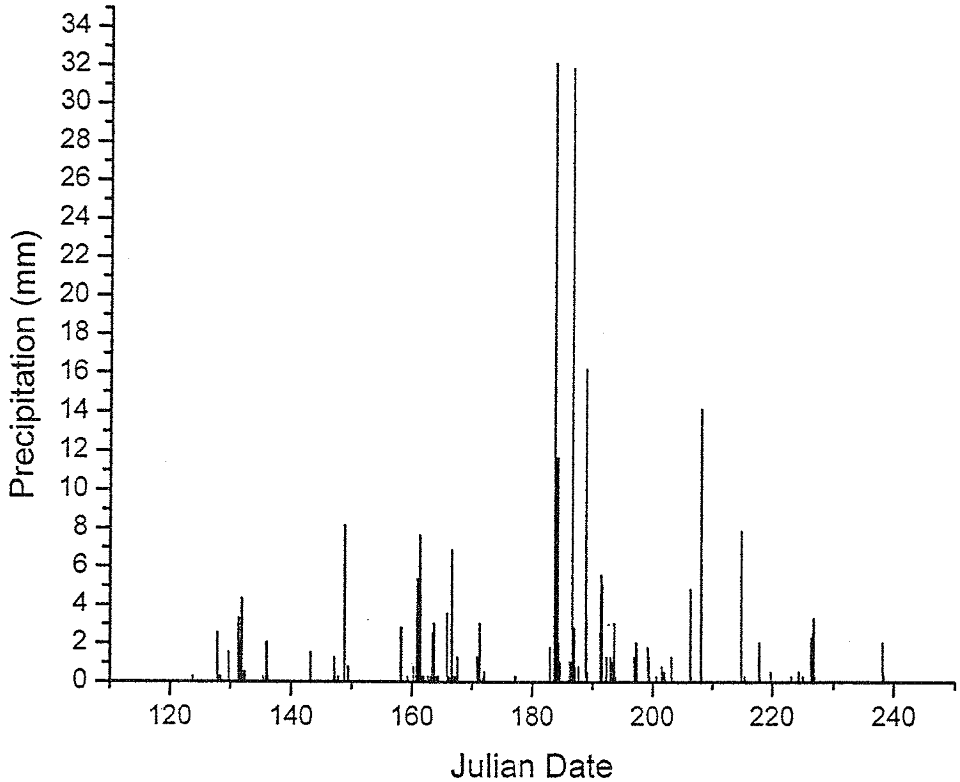

Figure 4. Growing season precipitation, Viking 2000

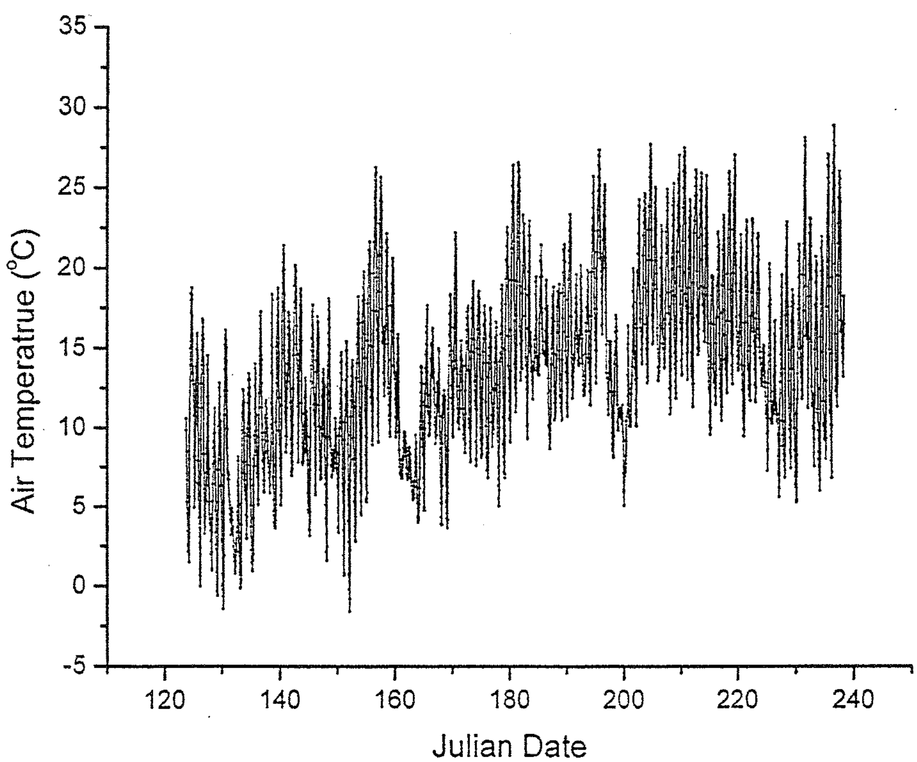

Figure 5. Hourly average air temperature, Viking, 2000

Results indicate that landscape position has a significant impact on water redistribution and soil temperature regimes (Figure 6 and 7). The shoulder and backslope is drier with very little subsoil infiltration compared to the footslope position. The shoulder is also warmer with greater temperature fluctuations than the backslope and footslope positions.

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. For most nutrients, the levels initially increase until mid summer and then decease by late summer (Table 5).

The dynamics of nitrogen species ammonium and nitrate differ, while nitrate and sulfate have similar trends. There was no significant difference among the landscape positions for the NH_4-N levels. As expected, there was no accumulated build up of ammonium in the soil. Ammonium is rapidly oxidized to nitrate (nitrification). For NO_3-N, the footslope position consistently had the lowest nitrate level until mid/late July. From late July to late August, the NO_3-N level for the footslope was greater than the shoulder. This would correspond to the greater crop growth in the footslope compared to the shoulder. The greater crop growth means greater nitrogen uptake by the crop. By mid/late July, the crop demand for nitrogen declines and nitrogen mineralization will exceed crop uptake. For sulfate, during the early to mid season, the shoulder position is higher than the backslope and footslope. After mid July, the footslope has the highest sulfate level.

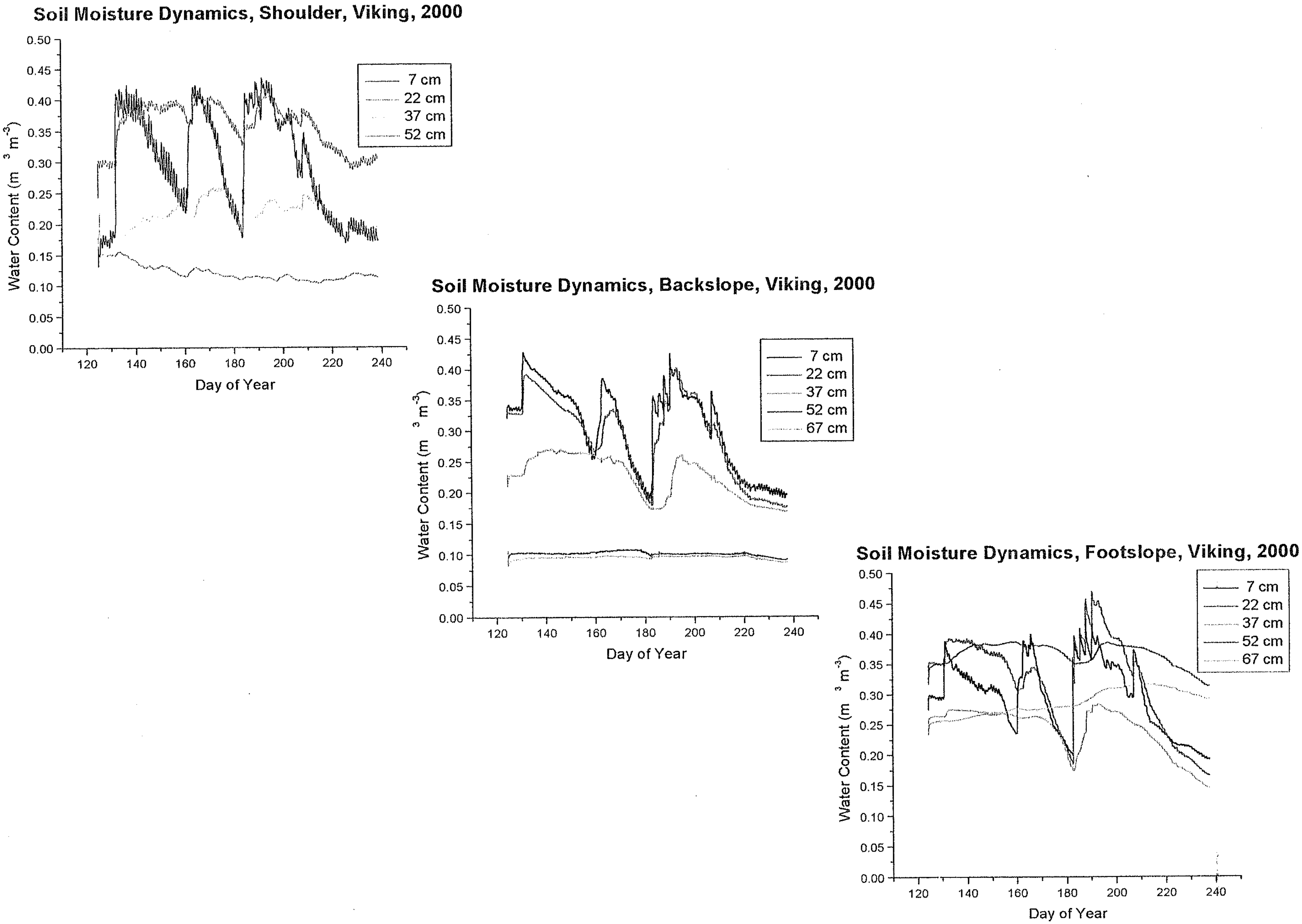

Figure 6. Soil moisture dynamics for 3 landscape positions at Viking, 2000

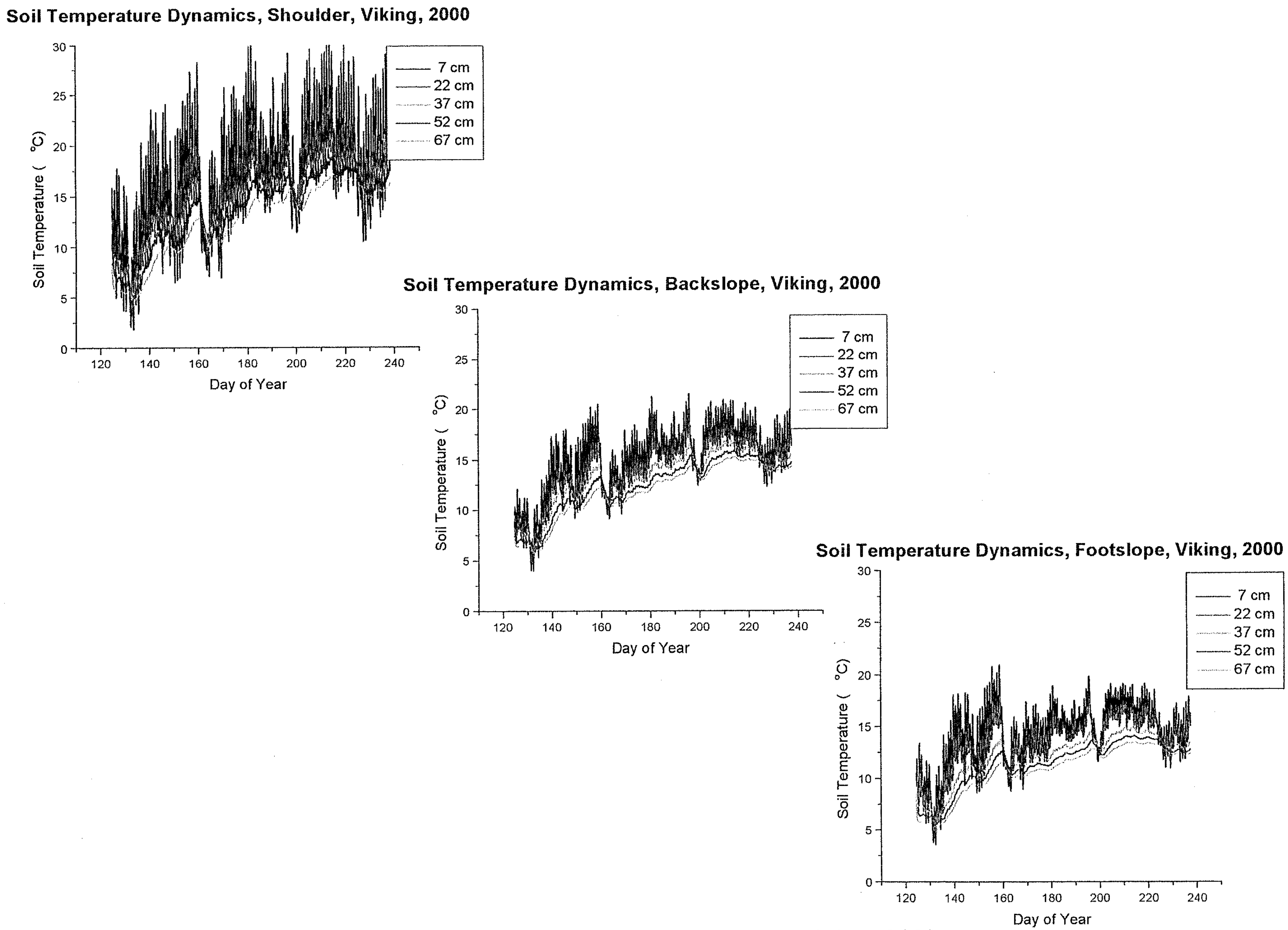

Figure 7. Soil temperature dynamics for 3 landscape positions at Viking, 2000

Table 5. Soil nutrient dynamics within the crop at three landscape positions using plant root simulator probes at Viking, 2000.

Nutrient / Landsacpe Position	May 16 May 30	May 30 June 13	June 13 June 27	June 27 July 13	July 13 July 25	July 25 Aug 8	Aug 8 Aug 22	Observations
Ammonium - Nitrogen ug cm^{-2}								
Shoulder	13.2 a	4.2 a	2.9 a	2.7 a	1.5 a	1.4 a	2.0 a	15
Backslope	3.3 a	2.6 ab	3.8 a	2.7 a	3.3 a	2.6 a	1.6 a	15
Footslope	1.4 a	1.5 b	2.1 a	2.0 a	1.3 a	1.6 a	2.1 a	15
Nitrate - Nitrogen ug cm^{-2}								
Shoulder	106.8 a	170.4 a	85.5 a	154.7 a	20.5 a	35.2 b	20.1 a	15
Backslope	77.4 a	128.8 b	38.4 b	135.2 a	30.8 a	55.9 ab	16.0 a	15
Footslope	96.1 a	90.0 c	43.1 b	62.6 b	27.2 a	71.2 a	25.2 a	15
Phosphate ug cm^{-2}								
Shoulder	2.9 a	3.3 b	4.4 b	5.6 c	3.4 a	4.6 b	1.2 b	15
Backslope	2.2 b	7.6 a	7.1 a	18.0 a	4.2 a	8.0 a	1.1 b	15
Footslope	2.4 b	7.3 a	6.3 a	12.6 b	4.2 a	3.8 b	1.9 a	15
Potassium ug cm^{-2}								
Shoulder	137.9 b	192.0 c	167.2 c	211.0 b	142.8 b	172.3 c	128.3 b	15
Backslope	178.0 b	289.1 b	221.9 b	353.0 a	169.8 b	254.3 b	92.6 b	15
Footslope	425.0 a	396.7 a	345.9 a	381.5 a	244.0 a	321.0 a	209.8 a	15
Sulfate - Sulfur ug cm^{-2}								
Shoulder	47.0 a	73.7 a	31.6 a	37.5 a	6.2 a	8.6 b	5.1 b	15
Backslope	36.0 a	53.0 b	16.8 b	24.6 b	8.9 a	11.8 ab	4.7 b	15
Footslope	48.4 a	46.3 b	23.9 ab	20.8 b	10.5 a	14.7 a	7.5 a	15

Means followed by different letters are significantly different ($p<0.05$) among slope positions according SNK means test.

Phosphorus and potassium dynamics appear to be similar. For phosphate levels, landscape rankings were variable for the backslope and footslope. The shoulder position tended to be consistently the lowest or only equal to the backslope and footslope positions. Being drier, the shoulder position illustrates an environment that reduces the phosphate solubility and crop availability. The potassium levels measured indicated a consistent relationship among the landscape positions. The footslope position was always the highest and the shoulder position was almost consistent at being the lowest. The potassium availability appears to be influenced by soil moisture conditions and, maybe the higher historic crop residue that was produced at the footslope position.

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. As the crop demands for nutrients decline, near maturity, soil nutrient availability increases due to such processes as mineralization.

In 2000, root exclusion tubes were added to the site to get a measure of the potential nutrient availability without competition crop plant roots. The number of observations restricted the significance testing of the measurements (Table 6). The majority of the root excluded measurements were higher than the in crop measurements. The dynamics of phosphorus and potassium are similar for both the in crop and root excluded soils, and landscape influences are consistent. Ammonium levels are low for both in crop and root excluded soils and no influence by landscape position. There was almost an inverse influence of landscape position on the nitrate and sulfate dynamics for the root excluded soil and the in crop soil. Without the crop roots, the higher nitrate and sulfate levels reflect accumulation from N and S mineralization. However since nitrates and sulfates are mobile in the soil, the late season decline maybe due to some leaching. Unfortunately, the ion exchange probes were used for only the surface soil and subsoil measurements are not available.

Table 6. Soil nutrient dynamics for root exclusion tubes at three landscape positions using plant root simulator probes at Viking, 2000.

Nutrient / Landsacpe Position	May 16 May 30	May 30 June 13	June 13 June 27	June 27 July 13	July 13 July 25	July 25 Aug 8	Aug 8 Aug 22	Observations
Ammonium - Nitrogen ug cm^{-2}								
Shoulder	4.7 a	0.5 b	2.4 a	5.1 a	3.6 a	1.2 a	1.3 a	4
Backslope	1.1 a	0.8 a	2.3 a	2.5 a	1.3 a	1.3 a	1.5 a	4
Footslope	1.0 a	0.8 a	2.0 a	3.5 a	5.3 a	5.5 a	1.6 a	4
Nitrate - Nitrogen ug cm^{-2}								
Shoulder	95.3 a	111.1 a	124.0 a	111.4 ab	80.5 a	148.7 a	30.8 a	4
Backslope	127.2 a	148.3 a	89.8 a	191.9 a	94.2 a	142.7 a	56.0 a	4
Footslope	110.2 a	204.0 a	139.4 a	69.2 b	29.2 a	54.0 a	50.6 a	4
Phosphate ug cm^{-2}								
Shoulder	6.1 a	1.8 a	2.6 a	6.2 b	3.2 a	1.2 a	1.1 a	4
Backslope	5.2 a	2.4 a	4.1 a	15.4 a	3.4 a	1.7 a	0.7 a	4
Footslope	7.8 a	2.6 a	2.4 a	9.3 ab	7.4 a	7.4 a	2.0 a	4
Potassium ug cm^{-2}								
Shoulder	170.0 b	237.4 c	199.0 b	200.4 b	203.5 a	190.9 a	122.8 b	4
Backslope	253.6 ab	351.5 b	289.5 ab	411.3 a	249.3 a	238.8 a	154.2 b	4
Footslope	354.4 a	425.1 a	370.0 a	349.5 a	287.8 a	341.0 a	242.9 a	4
Sulfate - Sulfur ug cm^{-2}								
Shoulder	38.3 a	72.8 a	62.3 a	76.6 ab	25.8 a	30.6 a	4.2 a	4
Backslope	30.29 a	63.9 a	28.7 a	33.3 b	13.3 a	16.6 a	7.0 a	4
Footslope	31.2 a	62.9 a	39.8 a	92.5 a	15.2 a	12.2 a	8.2 a	4

Means followed by different letters are significantly different ($p<0.05$) among slope positions according SNK means test.

5.5 Crop Growth and Development

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

Leaf Area Index (LAI) provides a measure of the crop canopy development. The influence of landscape position is consistent across all transects (Table 7). The footslope was always the highest and the shoulder was always the lowest. The LAI will provide an additional measure to test the performance of a crop simulation model.

Crop biomass measurements of landscape transects during the 2000 growing season did reveal variations due to landscape position (Table 8.). 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. Results are consistent for all four years. Table 9 provides the same information, but on a kg/ha basis. The annual influence of climate especially, precipitation are evident. 1998 had the lowest growing season precipitation that severely reduced the shoulder and backslope yields. The nutrient requirements were consistent with respect to landscape position. The highest crop nutrient levels were for the footslope position and decreases as one moves up the landscape. There is a definite difference due to crop type. Cereals have higher crop nitrogen uptake than canola. However, canola has higher phosphorus, potassium and sulfur uptake than cereals.

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. Rolling landscapes present an interesting problem for precision agriculture. The highest yield potential is usually the footslope position. The footslope has higher levels of soil moisture, lower soil temperatures and greater mineralization potential due to higher soil organic matter levels.

Table 7. Leaf area index statistics (means and standard errors) for wheat at four growth stages at four transects with three landscape positions at Viking, 2000

Transects	Landsacpe Position	June 13 Apex Mean	June 13 Apex SE	July 13 Anthesis Mean	July 13 Anthesis SE	August 8 Soft Dough Mean	August 8 Soft Dough SE	September 1 Harvest Mean	September 1 Harvest SE	Measurements
Transect 1										
	Shoulder	0.57	0.06	1.19	0.09	1.57	0.09	1.63	0.09	20
	Backslope	0.95	0.08	2.55	0.14	2.22	0.16	2.58	0.14	20
	Footslope	1.33	0.12	4.04	0.11	4.17	0.17	3.31	0.14	20
Transect 2										
	Shoulder	0.68	0.07	1.39	0.09	1.50	0.13	1.91	0.08	20
	Backslope	1.42	0.08	1.98	0.12	1.73	0.14	2.31	0.09	20
	Footslope	1.78	0.17	3.50	0.15	3.93	0.11	3.21	0.13	20
Transect 3										
	Shoulder	0.93	0.10	1.47	0.08	1.19	0.12	1.99	0.11	20
	Backslope	1.38	0.16	2.35	0.13	2.02	0.20	2.58	0.10	20
	Footslope	2.19	0.14	4.84	0.18	3.95	0.25	4.04	0.16	20
Transect 4										
	Shoulder	1.10	0.13	1.94	0.14	1.70	0.10	2.23	0.09	20
	Backslope	1.55	0.17	2.86	0.14	2.35	0.19	2.49	0.13	20
	Footslope	2.09	0.18	4.59	0.11	3.32	0.12	3.68	0.13	20
All Transects										
	Shoulder	0.85 c		1.50 c		1.49 c		1.94 c		80
	Backslope	1.33 b		2.44 b		2.08 b		2.49 b		80
	Footslope	1.85 a		4.24 a		3.84 a		3.56 a		80

Means followed by different letters are significantly different ($p<0.05$) among slope positions according to SNK Means test

Table 8. Crop yield and nutrient (g m^{-2}) uptake at harvest at Viking, 1997 - 2000.

Yield Parameter / Landsacpe Position	1997, Wheat Grain	1997, Wheat Straw	1998, Barley Grain	1998, Barley Straw	1999, Canola Grain	1999, Canola Straw	2000, Wheat Grain	2000, Wheat Straw
Dry Matter Yield (g m^{-2})								
Shoulder	412.7 b	595.7 b	172.4 b	367.8 c	175.1 a	490.0 b	331.1 c	276.3 c
Backslope	466.9 ab	717.8 a	177.0 b	440.8 b	219.2 a	606.0 a	453.2 b	445.1 b
Footslope	491.9 a	808.5 a	380.0 a	626.2 a	237.6 a	633.2 a	521.8 a	618.2 a
Nitrogen Uptake (g m^{-2})								
Shoulder	11.0 a	3.2 a	4.1 b	4.5 b	7.1 a	4.0 b	9.5 c	2.1 c
Backslope	12.1 a	3.5 a	4.5 b	6.1 a	9.2 a	4.9 b	13.9 b	3.4 b
Footslope	12.2 a	4.0 a	9.6 a	6.7 a	9.8 a	6.6 a	16.3 a	5.1 a
Phosphorus Uptake (g m^{-2})								
Shoulder	1.6 b	0.04 c	0.6 b	0.4 b	1.1 a	1.0 b	1.4 c	0.1 c
Backslope	1.8 ab	0.1 b	0.6 b	0.5 a	1.4 a	1.0 b	2.0 b	0.2 b
Footslope	2.0 a	0.2 a	1.2 a	0.5 a	1.6 a	1.5 a	2.3 a	0.4 a
Potassium Uptake (g m^{-2})								
Shoulder	NA	NA	1.2 b	7.1 b	1.5 a	12.0 b	1.2 b	3.0 c
Backslope	NA	NA	1.1 b	7.5 b	1.9 a	11.8 b	1.6 a	5.6 b
Footslope	NA	NA	2.4 a	12.9 a	2.2 a	15.8 a	1.3 a	13.1 a
Sulfur Uptake (g m^{-2})								
Shoulder	NA	NA	0.3 b	0.8 b	0.7 a	3.2 a	0.7 b	0.3 c
Backslope	NA	NA	0.3 b	1.0 b	1.0 a	3.5 a	0.9 a	0.6 b
Footslope	NA	NA	0.7 a	1.4 a	1.1 a	4.2 a	1.0 a	1.0 a

Means followed by different letters are significantly different ($p<0.05$) among slope positions using SNK means test

Table 9. Crop yield and nutrient uptake (kg ha^{-1}) at harvest at Viking, 1997 - 2000.

Yield Parameter	1997, Wheat		1998, Barley		1999, Canola		2000, Wheat		
Landsacpe Position	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	HI
Dry Matter Yield (kg ha^{-1})									
Shoulder	4127 b	5957 b	1724 b	3678 c	1751 a	4900 b	3311 c	2763 c	.54
Backslope	4669 ab	7178 a	1770 b	4408 b	2192 a	6060 a	4532 b	4451 b	.50
Footslope	4919 a	8085 a	3800 a	6262 a	2376 a	6332 a	5218 a	6182 a	.46
Nitrogen Uptake (kg ha^{-1})									
Shoulder	110 a	32 a	41 b	45 b	71 a	40 b	95 c	21 c	.82
Backslope	121 a	35 a	45 b	61 a	92 a	49 b	139 b	34 b	.80
Footslope	122 a	40 a	96 a	67 a	98 a	66 a	163 a	51 a	.76
Phosphorus Uptake (kg m^{-1})									
Shoulder	16 b	0.4 c	6 b	4 b	11 a	10 b	14 c	1 c	.93
Backslope	18 ab	1.0 b	6 b	5 a	14 a	10 b	20 b	2 b	.91
Footslope	20 a	2.0 a	12 a	5 a	16 a	15 a	23 a	4 a	.85
Potassium Uptake (kg ha^{-1})									
Shoulder	NA	NA	12 b	71 b	15 a	120 b	12 b	30 c	.29
Backslope	NA	NA	11 b	75 b	19 a	118 b	16 a	56 b	.22
Footslope	NA	NA	24 a	129 a	22 a	158 a	18 a	131 a	.12
Sulfur Uptake (kg ha^{-1})									
Shoulder	NA	NA	3 b	8 b	7 a	32 a	7 b	3 c	.70
Backslope	NA	NA	3 b	10 b	10 a	35 a	9 a	6 b	.60
Footslope	NA	NA	7 a	14 a	11 a	42 a	10 a	10 a	.50

Means followed by different letters are significantly different ($p<0.05$) among slope positions using SNK means test

However, because of the high yields in the footslope, the footslope is subject to more problems from lodging. The lowest yielding areas are the upper shoulder positions. These positions are subject to harsh environmental conditions as a result of the higher soil temperatures, more evaporation, poor water infiltration into the subsoil and greater water loss due to runoff. The nutrient requirements for the crop in these upper areas are much lower. Compared to the shoulder position, the backslope has much lower soil temperatures, higher organic matter levels, and better subsoil moisture dynamics. The backslope position may present the greatest opportunity to manage fertilizer application to increase crop productivity for a field with a rolling landscape.

6.0 Acknowledgements

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7.0 References

Halvorson, G.A., and E.C. Doll. 1991. Topographic effects on spring wheat yields and water use. Soil Sci. Soc. Am. J. 55:1680-1685

MacMillan, R.A. and W.W. Pettapiece. 1997. Soil landscape models: Automated landscape characterization and generation of soil-landscape models. Technical Bulletin 1997-1E, Research Branch, Agriculture and Agri-Food Canada, Lethbridge, AB. 75pp.

MacMillian, R.A., W.W. Pettapiece, S.C. Nolan and T.W. Goddard. 1999. A generic procedure for automatically segmenting landforms into landform elements using DEMs, Heuristic rules and fuzzy logic. In Press

Miller, M.P., M.J. Singer, and D.R. Nielsen. 1988. Spatial variability of wheat yield and soil properties on complex hills. Soil Sci. Soc. Am. J. 52:1133-1141.

8.0 Action Plan 2001 - 2002

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

- Climatic data collected using automated meteorological data loggers on an 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.