1.6 Soil and Yield Variability in a Rolling Landscape

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INTRODUCTION

In a rolling landscape, soil properties vary depending on position in the landscape. Soil depth, organic C, plant-available N and P, and spring moisture contents all increase downslope. Since these factors may affect yield and yield response to applied fertilizer, it is inefficient to manage all elements of the landscape as a single unit.

Most Saskatchewan fields cover at least 80 acres and hence soil properties will vary within a field with undulating topography. Technology is now available to vary rates of fertilizer application from the tractor cab. This technology allows potentially high-yielding lowlands to be fertilized differently from other areas of the field and may be used to increase production on eroded areas to prevent further deterioration.

If variable rate fertilizer technology is to be used to its full potential, landscape features which identify similar soils must be recognized and yield responses to fertilizer applications investigated so that fertilizer use can be optimized.

MATERIALS AND METHODS

The study site was located on SW-13-28-2-W3, near Bladworth, Saskatchewan, and had been intensively surveyed. The soil was classified as a Weyburn loam, on knob and kettle topography, with slopes of 6 to 9%. The field had been fallow in 1989.

An elevation survey was conducted so that the shape of the landscape at each sampling site could be described in terms of down-slope and cross-slope curvature and assigned to a landscape element. Seven landscape elements were identified: level (L), converging footslope (CF), diverging footslope (DF), converging backslope (CB), diverging backslope (DB), converging shoulder (CS), and diverging shoulder (DS). Prior to seeding, soil was sampled every 10 m in an east-west transect across the field. At each sampling position, the soil profile was described and sampled to 120 cm depth. The surface 30 cm was divided into two 15 cm samples, but the rest of the profile was sampled in 30 cm increments. Moisture content, pH, and electrical conductivity were measured for the entire profile, but organic carbon and ^{137}Cesium concentration were only measured to 30 cm, and available plant nutrients (NPKS) were only determined to 60 cm.

Wheat was seeded, using a zero-till drill with hoe openers, in east-west strips, 3 m wide by 800 m long, across the quarter-section. Nitrogen was applied as urea (46-0-0) and phosphorus as ammonium phosphate (11-55-0) in the ten rate combinations shown in Table 1.6.1.

Table 1.6.1 Fertilizer rate combinations used in this study

Fertilizer rates	P_2O_5, kg ha^{-1} 0	12.5	25	50
	----- Number of fertilizer strips -----			
N 0 kg ha^{-1}	4	1	1	1
N 10	-	1	1	-
N 20	-	-	2	-
N 40	-	-	1	-
N 80	-	-	1	1

At harvest 1.9 m^2 samples were taken every 10 m along each fertilizer strip and dry matter yield and grain yield were measured. Grain samples from each landscape element in a strip were then combined and total nitrogen was determined. After harvest, soil samples were taken every 10 m on three strips (N0:P0, N44:P25, and N88:P50), and analyzed for soil moisture and nitrate concentration.

The significance of differences between landscape elements and rates of fertilizer application was tested using analysis of variance and Fisher's protected least significant difference method.

RESULTS AND DISCUSSION

Soil Variability in the Landscape

There were significant differences between soil profile properties found on different landscape elements. Figure 1.6.1 shows the distribution of soils in the landscape. Since only two sampling sites were found on converging shoulders and diverging footslopes, there was insufficient replication and these two elements were excluded from

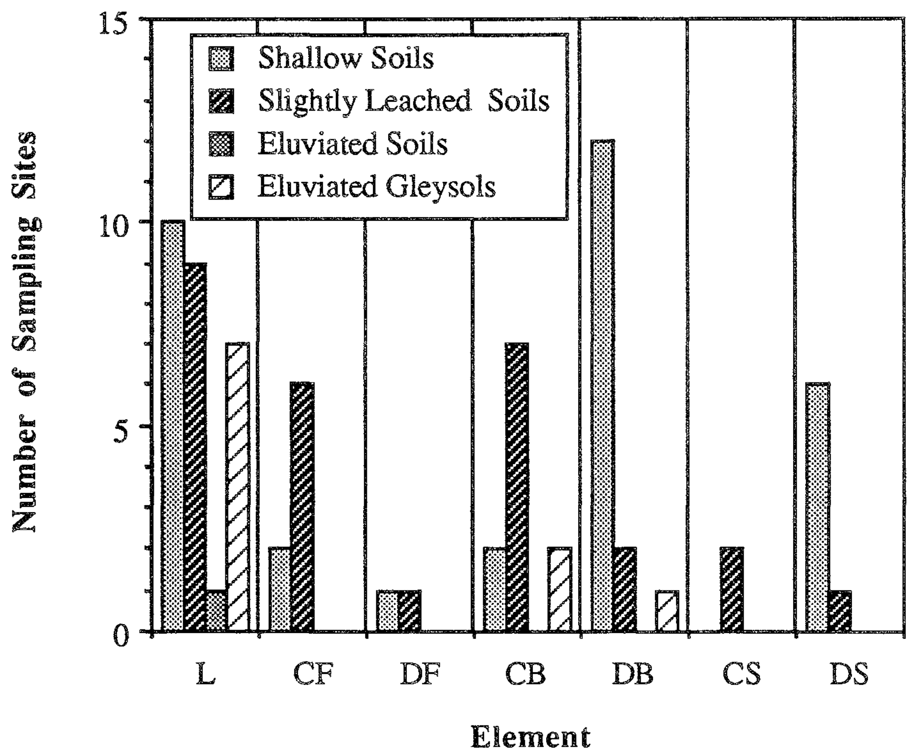

Figure 1.6.1 Distribution of soil types on the landscape elements

further analysis. Shallow soils predominated on the diverging shoulders and backslopes while on converging backslope and footslope elements deeper, slightly leached soils were found. Eluviated soils were generally confined to level elements.

Soil properties measured on the landscape elements in the spring are shown in Table 1.6.2. Significant differences in A horizon depth, depth to calcium carbonate, organic carbon, pH, and ^{137}Cesium concentrations were found between landscape elements but electrical conductivity was not significantly affected by landscape position. Generally, nutrient, organic carbon and cesium concentrations were lower on diverging shoulders and backslopes than on converging backslope, footslope or level elements. A horizon depth and phosphorus, organic carbon, and ^{137}Cesium concentrations were greatest on the level elements but nitrate concentrations and depth to calcium carbonate were greatest on the converging backslopes. The diverging elements had the highest pH values and the lowest values were found on the converging backslope.

Table 1.6.2 Soil properties measured on the landscape elements in the spring

Landscape Element	Depth of A cm	Depth to Carbonates cm	pH	EC µS cm^{-1}	Org. C %	Cesium kBq m^{-2}
			-- (0-120 cm) --		-- (0-15 cm) --	
DS	5.0 a	15.0 a	8.2 ab	634	1.23 a	1.02 ab
DB	10.8 a	30.0 a	8.3 a	809	1.18 a	0.98 a
CB	15.6 ab	66.7 b	7.7 b	735	1.79 b	1.58 b
CF	13.2 ab	47.2 ab	7.9 b	861	1.67 a	1.62 b
L	21.1 b	63.5 ab	7.8 b	736	1.83 b	1.91 b

The distributions of the major plant nutrients (NPKS) are given in more detail in Table 1.6.3 and soil water data is given in Table 1.6.4. Available nutrient levels were generally lower in the spring on diverging shoulder and backslope elements than in the rest

Table 1.6.3 Distribution of the major plant nutrients between landscape elements in spring

Landscape element	N Mean	N sd	P Mean	P sd	K Mean	K sd	S Mean	S sd
	$\mu g\ g^{-1}$							
0-15 cm								
DS	8.9	1.9	6.3	2.3	221	49	5.3	1.3
DB	9.8	3.4	6.5	2.8	210	89	5.9	2.5
CB	12.1	5.4	11.1	4.6	255	78	7.6	0.9
CF	14.0	3.7	9.0	4.0	230	73	7.0	1.9
L	12.2	5.7	13.0	7.0	344	107	6.7	2.8
15-30 cm								
DS	8.3	3.4	3.1	0.8	124	32	4.1	2.0
DB	10.0	6.2	3.6	1.5	146	87	6.0	2.5
CB	12.8	6.4	5.1	3.4	109	37	4.8	2.1
CF	14.2	5.2	4.5	2.5	138	48	6.1	2.9
L	10.3	5.3	5.5	4.0	174	52	6.7	2.6
30-60 cm								
DS	6.9	2.7	3.7	2.9	169	48	4.4	1.2
DB	6.9	3.4	3.5	1.4	166	62	6.6	2.6
CB	12.9	10.4	3.8	1.1	119	29	6.8	4.0
CF	11.9	6.0	2.9	0.5	115	25	6.9	3.8
L	8.2	4.3	4.5	4.3	175	75	6.3	3.8

Table 1.6.4 Soil water data

Landscape element	Volumetric Water Content 0-15cm	15-30cm	30-60cm	60-90cm	90-120cm	Profile moisture
	$cm^3\ cm^{-3}$					cm
DS	0.245	0.245	0.234	0.227	0.217	27.7
DB	0.237	0.254	0.241	0.231	0.225	28.3
CB	0.249	0.257	0.245	0.243	0.232	29.2
CF	0.239	0.264	0.226	0.211	0.221	27.3
L	0.264	0.292	0.266	0.228	0.232	30.1

of the landscape. Not all differences were significant: only K availability showed significant differences between landscape elements at all depths, N was only significant at the 30- to 60-cm depth, P at the 0- to 15-cm depth, and S at the 15- to 30-cm depth. There were no significant differences in spring moisture between landscape elements (Table 1.6.4). Profile moisture did however appear to be greater on the converging backslope and level elements than elsewhere in the landscape. The level areas probably receive spring run-off to supplement their moisture supply. Snow commonly accumulates on converging backslopes and hence infiltration of snow-melt is usually high relative to other elements.

Yield Variability between Landscape Elements

Tables 1.6.5 and 1.6.6 summarize total and grain yields for all fertilizer treatments and landscape elements. Significant differences in total and grain yields occurred between landscape elements. The highest yields were found on converging backslope, converging footslope, and level elements. Diverging backslopes and diverging shoulders had the lowest yields overall. Harvest indices were significantly higher on diverging shoulder and diverging backslope elements than on converging footslope and level elements.

At intermediate rates of fertilization there were no significant differences in grain yield between landscape elements (Table 1.6.5). On the control strips and high fertilizer rate strips yields varied significantly between landscape elements. The diverging shoulder and converging backslope elements on the control strips had significantly lower total yields than the level element. This difference is due to fertility differences between landscape elements (Table 1.6.2). Spring nitrate levels on the diverging shoulder were significantly lower than on the converging backslope and overall fertility was best on the level element.

The significant differences in yield between landscape elements observed at high fertilizer rates probably result from differences in water availability during the growing season discussed later. At intermediate fertilizer rates fertility differences between elements were annulled and crop growth was insufficient to cause plant water stress and highlight differences in moisture content between the landscape elements. In 1990 growing season precipitation at Bladworth was above normal (147 mm between May 15 and August 15) but in a drier year water stress might have resulted in significant yield differences between landscape elements at lower fertilizer rates.

Table 1.6.5 Differences in total and grain yield between the landscape elements at the rates of fertilizer application. (Letters following the yields refer to differences between landscape elements at the 95% probability level).

	N:0 P:O	N:2 P:12.5	N:12 P:12.5	N:4 P:25	N:14 P:25	N:8 P:50	N:24 P:25	N:44 P:25	N:84 P:25	N:88 P:50	
						Total yield					
DS	4187 a	4684 ab	4888	5193	5674	4989 a	5070 a	4968	5182	5128 a	4791 a
DB	4439 a	4594 a	4765	5107	5230	5011 a	4829 a	5134	5048	5257 a	4839 a
CB	4877 b	5364 ab	5524	5829	5706	5684 ab	5807 ab	5882	5754	5460 a	5449 b
CF	5209 bc	5535 ab	5561	5358	5230	5305 a	5535 a	5647	6155	5941 ab	5508 b
L	5455 c	5604 b	5791	5765	5941	6396 b	5941 c	5620	6214	6503 a	5823 c
Mean	4920	5187	5364	5465	5578	5594	5508	5503	5743	5743	
						Grain yield					
DS	1930 a	1695	2342	2396	2824	2433	2396 ab	2321	2631 ab	2251 ab	2213 ab
DB	2107 ab	2043	2112	2299	2278	2439	2123 a	2316	2203 a	2209 ab	2181 a
CB	2214 ab	2369	2310	2465	2417	2594	2604 b	2551	2449 ab	2107 a	2390 c
CF	2278 b	2219	2428	2406	2460	2251	2428 ab	2262	2604 ab	2513 ab	2358 bc
L	2289 b	2508	2364	2465	2658	2647	2545 b	2481	2743 b	2524 b	2470 c
Mean	2176	2246	2283	2374	2481	2465	2433	2417	2465	2326	

Table 1.6.6 Differences in total and grain yield between the fertilizer treatments on the five landscape elements. (Letters following the yields refer to differences between fertilizer treatments at the 95% probability level).

	N:0 P:O	N:2 P:12.5	N:12 P:12.5	N:4 P:25	N:14 P:25	N:8 P:50	N:24 P:25	N:44 P:25	N:84 P:25	N:88 P:50
					Total yield					
DS	4187 a	4684 ab	4888 b	5193 b	5674 c	4989 a	5070 b	4968 b	5182 b	5128 b
DB	4439 a	4594 a	4765 ab	5107 b	5230 b	5011 a	4829 ab	5134 b	5048 ab	5257 b
CB	4877 b	5364 ab	5524 ab	5829 b	5706 b	5684 ab	5807 b	5882 b	5754 b	5460 ab
CF	5209 bc	5535	5561	5358	5230	5305 a	5535	5647	6155	5941
L	5455 c	5604 b	5791 abc	5765 abc	5941 abc	6396 b	5941 ab	5620 ab	6214 b	6503 c
Mean	4920 a	5187 ab	5364 abc	5465 b	5578 b	5594 c	5508 b	5503 b	5743 c	5743 c
					Grain yield					
DS	1930 a	1695 ab	2342 abc	2396 b	2824 c	2433 abc	2396 c	2321 abc	2631 c	2251 abc
DB	2107	2043	2112	2299	2278	2439	2123	2316	2203	2209
CB	2214 ab	2369 ab	2310 ab	2465 ab	2417 ab	2594 b	2604 b	2551 b	2449 ab	2107 a
CF	2278	2219	2428	2406	2460	2251	2428	2262	2604	2513
L	2289	2508	2364	2465	2658	2647	2545	2481	2743	2524
Mean	2176 a	2246 ab	2283 abc	2374 b	2481 c	2465 c	2433 c	2417 b	2465 c	2326 abc

Fertilizer Response on the Landscape Elements

There were also significant fertilizer responses within a number of the landscape elements (Table 1.6.6). On diverging shoulders and converging backslopes, there were significant differences in both total and grain yield between fertilizer treatments. On level and diverging backslope elements there were significant differences in total yield and on converging footslopes there was no significant fertilizer response. On all landscape elements, yields were lowest on the control strips. On the diverging shoulders, fertilizer applications as low as N12:P12.5 were sufficient to significantly increase total production above that on the control. On other elements more fertilizer was required to cause significant yield increases. Only the level element appeared to be able to make use of the highest rate of fertilizer application (N88:P50) but even then only total yield was significantly increased.

Nitrogen Use

Table 1.6.7 is a budget of the nitrogen used to grow the wheat crop on the landscape elements at high, intermediate, and low levels of fertilizer. The N found in plant tissue increased significantly as the rate of N fertilizer application increased. The were also differences between the landscape elements with the diverging shoulders and backslopes having less N in plant tissue than the converging backslopes and footslopes, and level elements. On the control strips, up to 60% of the N found in the plant must have become available from the soil N pool during the growing season. At the mid fertilizer rate, both the converging backslope and footslope elements could have supplied plant needs without mineralization, and at the high fertilizer rate only the diverging backslope required N in excess of spring nitrate and applied fertilizer.

Table 1.6.7 Nitrogen budget for the landscape elements at the High (N88:P50), Mid (N44:P25), and Low (N0:P0) rates of fertilizer application

Fertilizer rate	Landscape element	Grain N %	Straw N* %	N plant kg ha^{-1}	N used kg ha^{-1}	Difference kg ha^{-1}
High	DS	2.87	0.60	81.9	93.0	11.1
	DB	2.95	0.60	83.4	78.6	-4.8
	CB	3.02	0.60	83.8	102.2	18.4
	CF	3.00	0.60	96.0	120.5	24.5
	L	2.89	0.60	96.9	106.2	9.3
Mid	DS	2.76	0.50	77.3	65.4	-11.9
	DB	2.76	0.50	78.0	53.1	-24.9
	CB	2.76	0.50	87.1	99.4	12.3
	CF	2.80	0.50	80.3	92.4	12.1
	L	2.83	0.50	85.9	65.1	-20.8
Check	DS	2.74	0.45	64.4	24.6	-39.8
	DB	2.59	0.45	65.6	27.6	-38.0
	CB	2.79	0.45	77.8	53.0	-24.8
	CF	2.70	0.45	79.2	50.8	-28.4
	L	2.75	0.45	80.0	41.8	-38.2

* Eric Bremer (personal communication)

Water Use Efficiency

Water use efficiencies for the fertilizer strips sampled in the fall are shown in Figure 1.6.2. The water use efficiency is the weight of grain produced per cm of soil water used and precipitation during the growing season. The efficiencies were generally greater at the mid fertilizer rate (N44:P25) than on either the check strip (N0:P0) or the high fertilizer rate (N88:P50). At the high fertilizer rate, too much water was used in the production of straw and the grain yield was limited by water stress. The level and converging footslope elements had higher water use efficiency than the other landscape elements at all rates of fertilizer application because these elements received water which ran-off from higher in the landscape in addition to precipitation, and therefore had more water available to the wheat crop.

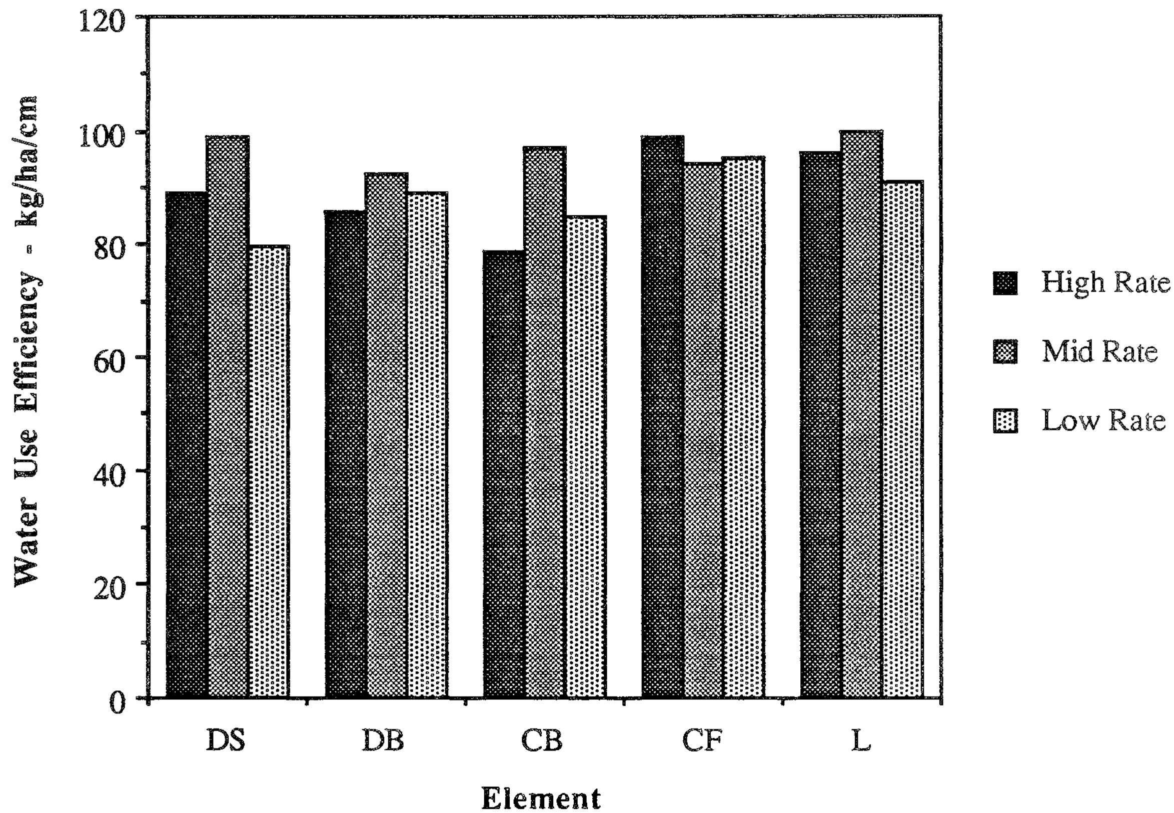

Figure 1.6.2 Water use efficiencies for the landscape elements at three rates of fertilizer application

CONCLUSIONS

Soil characteristics varied with position in the landscape. Shallow soils were predominantly associated with diverging shoulder and backslope elements, whilst eluviated soils and eluviated gleysols were largely confined to level elements. Yields varied significantly between landscape elements, with converging elements yielding more than diverging elements and greater yields on lower slopes than upper slopes.

Yields on most landscape elements were increased by the addition of small amounts of fertilizer but on the level element there was no significant increase in grain yield on the fertilized treatments although total yield was increased by fertilizer addition.