SOIL AND YIELD VARIABILITY IN A ROLLING LANDSCAPE

J. A. Elliott, L.E. Cowell, and E. de Jong
Department of Soil Science, University of Saskatchewan
Saskatoon, Sask.

Crop yield varies in the landscape as a result of differences in soil type and water content. This study utilized a landscape classification system to characterize soil and yield variability within a quarter-section field. Wheat was grown on fertilizer strips, 800 m long and 3 m wide, on a Weyburn soil, in rolling topography, near Bladworth, Saskatchewan. Soil and yield samples were taken every 10 m along the transect and the soil type and landscape position were noted. Variation in yield among the landscape elements could be related to differences in soil fertility and water use.

INTRODUCTION

In a rolling landscape, soil properties vary depending on position in the landscape (Pennock et al. 1987). Soil depth, organic C, plant-available N and P, and spring moisture contents have all been shown to increase downslope (Ayres et al. 1987, de Jong et al 1988, Pennock and de Jong 1987, Spratt and McIver 1972). 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. The objectives of this study were to identify landscape characteristics affecting soil distribution and to characterize yield variability in the landscape. The potential for variable rate fertilization was evaluated by examining responses to fertilizer application throughout the landscape.

MATERIALS AND METHODS

The study site was located on SW 13-28-2-W3 , near Bladworth, Saskatchewan, and had been intensively surveyed by King (1976). 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 (Pennock et al. 1987). 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.

Table 1. Fertilizer rate combinations used in this study.

Fertilizer	P_2O_5, kg ha^{-1}			
Rates	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 fertilizer rates was tested using Fisher's protected least significant difference method (Snedecor and Cochran 1980).

RESULTS AND DISCUSSION

There were significant differences between soil profile properties found on different landscape elements. Figure 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 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 2. Significant differences in A horizon depth, depth to calcium carbonate, organic carbon, ^{137}Cesium, nitrate and phosphorus concentrations were found between landscape elements but spring moisture and electrical conductivity were 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.

Table 2. Soil properties measured on the landscape elements in the spring.

Landscape Element	Avail. N kg ha^{-1}	Avail. P kg ha^{-1}	Water cm	EC µS cm^{-1}	Org. C %	Cesium kBq m^{-2}
	--- (0-60 cm) ---		-- (0-120 cm) --		-- (0-15 cm) --	
DS	61.9 a	33.7 a	27.7	634	1.23 a	1.02 ab
DB	67.1 a	34.0 a	28.3	809	1.18 a	0.98 a
CB	101.1 b	47.7 ab	29.2	735	1.79 b	1.58 b
CF	104.0 a	38.8 a	27.3	861	1.67 a	1.62 b
L	77.6 ab	55.0 b	30.1	736	1.83 b	1.91 b

Table 3 summarises 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.

Table 3. Total and grain yields and harvest indices for the landscape elements averaged over all fertilizer treatments.

Landscape Element	Total Yield kg ha^{-1}	Grain Yield kg ha^{-1}	Harvest Index
DS	4996 a	2322 a	0.46 a
DB	4941 a	2213 a	0.44 a
CB	5589 b	2408 b	0.43 ab
CF	5548 bc	2385 ab	0.43 b
L	5923 c	2522 b	0.42 b

Yields for three of the landscape elements (upper, mid, and lower slope) and three fertilizer rates are shown in Table 4. At low rates of fertilization there were no significant differences in grain yield between landscape elements. On the control strips total yields varied significantly between landscape elements and at high fertilizer rates there were significant differences in both grain and total yield.

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 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 4. Total and grain yields for the diverging shoulder, converging backslope, and level elements at three rates of fertilizer application. (Significant vertical differences are indicated by the letters following the numbers, bracketed letters refer to horizontal differences).

Landscape Element	Fertilizer Rate, kg ha^{-1} N:0 P:0			N:44 P:25		N:88 P:50		
Total Yield, kg ha^{-1}								
DS	4187	a	(a)	4968	(b)	5128	a	(b)
CB	4877	b	(a)	5882	(b)	5460	a	(ab)
L	5455	c	(a)	5620	(a)	6503	b	(b)
Grain Yield, kg ha^{-1}								
DS	1930		(a)	2321	(b)	2251	a	(b)
CB	2214		(a)	2551	(b)	2106	a	(ab)
L	2289			2480		2522	b	

There were also significant fertilizer responses within a number of the landscape elements (Table 4). On diverging shoulders and converging backslopes, there were significant differences in both total and grain yield between fertilizer treatments. On level elements there were significant differences in total yield only. In most cases even the lowest fertilizer rate increased yield above that on the control strip. The highest fertilizer rate (N88:P50) appeared to depress total yield on the converging backslope element but increased total yield on level elements.

Water use efficiencies for the fertilizer strips sampled in the fall are shown in Figure 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 element had higher water use efficiency than the other landscape elements at all rates of fertilizer application because this element received water which ran-off from higher in the landscape in addition to precipitation, and therefore had more water available to the wheat crop.

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.

REFERENCES

Ayres, K.W., D.F. Acton and J.G. Ellis. 1985. The Soils of the Swift Current Map Area 72J Saskatchewan. Sask. Inst. of Pedology, University of Saskatchewan, Saskatoon, Sask.

de Jong, E., L.E. Cowell, P.L. Flaten, N.J. Livingston and C. van Kessel. 1988. Innovative Acres 1987 Report. Publ. M86, Sask. Inst. of Pedology, University of Saskatchewan, Saskatoon, Sask.

King, G.J. 1976. The evaluation of soil series in Saskatchewan landscapes. MSc. Thesis, University of Saskatchewan, Saskatoon, Sask.

Pennock, D.J. and E. de Jong. 1987. The influence of slope curvature on soil erosion and deposition in hummocky terrain. Soil Sci. 144: 209-217

Pennock, D.J., B.J. Zebarth and E. de Jong. 1987. Landform classification and soil distribution in hummocky terrain, Saskatchewan, Canada. Geoderma 40: 297-315.

Snedecor, G.W. and W.G. Cochran. 1980. Statistical Methods. Seventh edition. Iowa State University Press, Ames, Iowa.

Spratt, E.D. and R.N. McIver. 1972. Effects of topographic position, soil test values, and fertilizer use on yields of wheat in a complex of Black Chernozemic and Gleysolic soils. Can. J. Soil Sci. 52: 53-58.

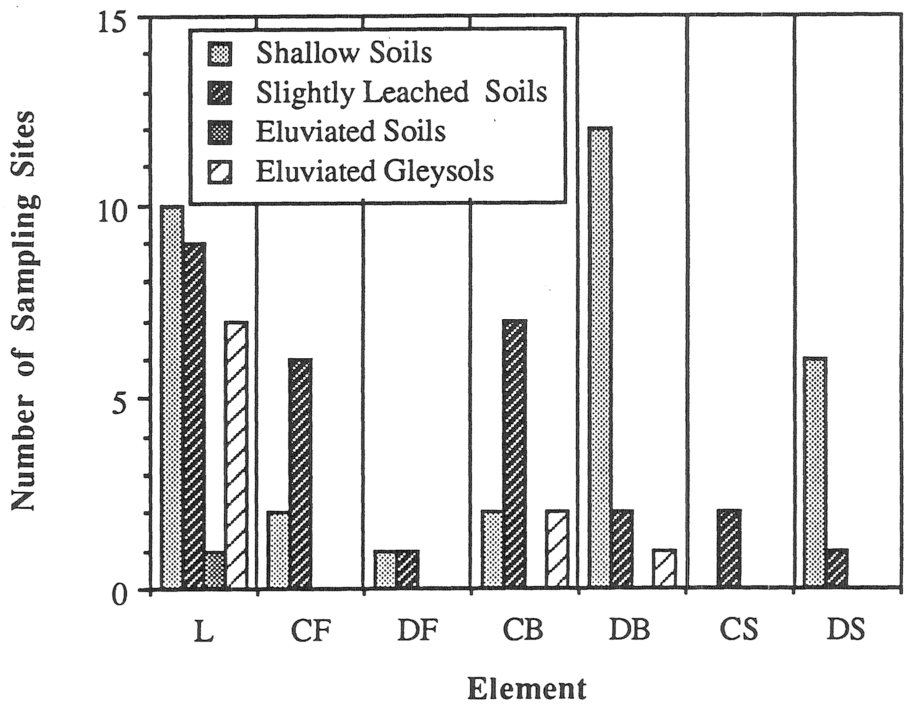

Figure 1. Distribution of soil types on the landscape elements.

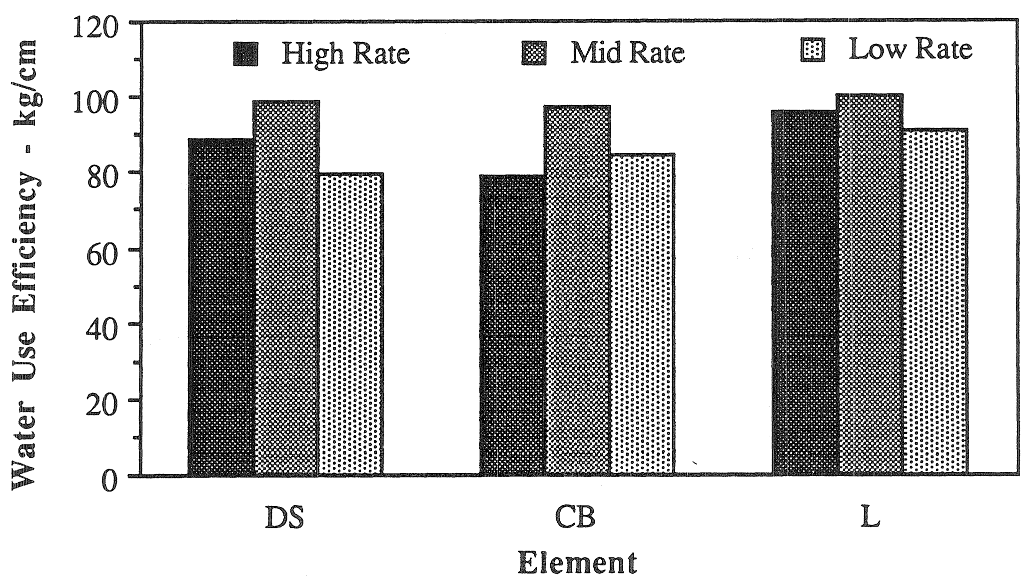

Figure 2. Water use efficiency on the landscape elements sampled in the fall.