RELATIONS BETWEEN SPATIAL VARIABILITY OF SOIL PROPERTIES AND GRAIN YIELD RESPONSE TO NITROGEN FERTILIZER IN A VARIABLE MANITOBA SOIL-LANDSCAPE

BY

GRANT RUSSELL MANNING

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

Department of Soil Science
University of Manitoba
Winnipeg, Manitoba

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Relations Between Spatial Variability of Soil Properties and Grain Yield Response to Nitrogen Fertilizer in a Variable Manitoba Soil-Landscape

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Grant Russell Manning

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University

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ABSTRACT

Manning, Grant Russell. M.Sc., The University of Manitoba, June, 1999. Relations Between Spatial Variability of Soil Properties and Grain Yield Response to Nitrogen Fertilizer in a Variable Manitoba Soil-Landscape. Major Professor; Lesley G. Fuller.

Wheat (*Triticum aestivum L.*) grain yield response to N fertilizer and grain protein concentration were investigated in an undulating Newdale glacial till soil-landscape. The objective of the study was to characterize spatial variability in: 1. Static topographic and pedogenic soil attributes, 2. Dynamic soil attributes, and 3. Crop response attributes, in order to assess the viability of variable-rate N fertilization.

The study site was delineated into Upper (U), Mid (M) and Lower (L) elevation Landform Element Complexes (LECs). Topographic attributes derived included relative elevation, slope gradient, plan and profile curvature, and global and local catchment. Convergent landscape character increased in the order U < M < L. Measured static soil attributes included A horizon depth, solum depth, depth to calcium carbonate, Ap horizon pH, and A horizon organic carbon content. Static soil attribute values were largest in the L and lowest in the U. LECs were useful in capturing gross variability in static soil attributes in the landscape.

Measured dynamic soil attributes included soil moisture and plant-available nutrients (NO_3-N, NH_4-N, extractable P, exchangeable K and SO_4-S). There was a general ranking of L > M > U for soil moisture and spring nitrate-N, P, K and S. While relative rankings were temporally persistent, the magnitude of the landscape-induced differences in soil moisture and residual N were smaller than those due to differences in precipitation between years and differences among N treatments, respectively.

Crop response attributes included above-ground biomass production at anthesis (*ABM*), grain yield (*GY*) and grain protein concentration (*GPC*). In 1997, median *GY* and *ABM* values increased with both N fertilizer and with convergent character in the landscape (U < M < L). 1997 was moisture-deficient with growing season precipitation 37% below average. *GPC* increased with N fertilizer, but decreased with convergent landscape character. A wider range of *GY* and *ABM* was apparent in 1998 due to the increased disparity between the N-depleted check and the well-supplied 135 kg/ha treatment, and due to growing season precipitation 62% above average. Ranking of median *GY* and *ABM* values among LECs was opposite to that of 1997. This was ascribed to excessive moisture, which increased with convergent landscape character. In 1998, *GPC* increased with N applied, but did not vary among LECs. *GY* was modeled as a function of estimated plant-available N supply (EPANS). Modeled 1997 *GY* maxima were 2077, 2261 and 2485 kg/ha in the U, M and L, where the L responded most strongly to the first increment of EPANS. In 1998, the relative order of predicted *GY* maxima among LECs was reversed, but responses to the first increments of EPANS were practically uniform. *GY* values of 2501, 2355 and 2227 kg/ha were modeled in the U, M and L. Modeled *GY*-N relationships from 1997, which indicated production was enhanced by allocating more N fertilizer to the more convergent L, were most characteristic of an ‘average’ year. However, successful variable-rate fertilization by LEC will require more calibration to establish risk-based *GY*-N relationships, and to determine if an economic advantage over conventional fertilization practices exists.

ACKNOWLEDGEMENTS

I would like to acknowledge the Land Resource Unit and the Matching Investment Initiative Program of Agriculture and Agri-Food Canada, Westco Fertilizers, Norwest Labs and NSERC for their financial support.

I would also like to extend my gratitude to my advisor Les Fuller and committee members Bob Eilers, Don Flaten and Rene Van Acker. Thank you for your assistance and encouragement.

Others who were selfless with their time and expertise: Bob MacMillan, Dan Pennock & crew at the U of S, the staff of the Land Resource Unit, Gary Crow.

Thank you Ron and Murray Bell for the use of your land, time and for your attention to detail during the busiest weeks of the year.

Thanks to fellow graduate students, technical staff, and summer staff for assistance in the field and in the lab.

To my family, thank you for the support you have given me over the years.

FOREWORD

This thesis has been prepared in the manuscript format in accordance with the Department of Soil Science guidelines. The referencing style used throughout the thesis follows that of the Canadian Journal of Soil Science. Three manuscripts will be submitted for publication to the Canadian Journal of Soil Science. These papers are entitled 1. Spatial variability of static soil properties in a variable Manitoba soil-landscape; 2. Spatial variability of dynamic soil properties in a variable Manitoba soil-landscape; and 3. Investigating wheat yield response to N-fertilizer in a variable Manitoba soil-landscape.

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1. INTRODUCTION

Variable-rate N application has potential to improve on-farm efficiency by closely matching N fertilizer supply to the amount required by the crop. It has long been known that landscape positions within traditional management units (whole fields) can differ significantly with respect to N fertilizer requirements. Fertilizing these landscape positions uniquely and accurately would improve profitability and sustainability by reducing over- and under-application of N fertilizer. N deficiency results primarily in lost production, while excessive N results in increased expenses, potential for nitrate leaching and gaseous losses of N, and potential yield reduction. Relatively recent advancements in our ability to quantify variation in grain yield and to apply N amendments specific to such landscape positions has encouraged further investigation into optimizing N applications for within-field management units.

The optimum amount of fertilizer N in a given landscape position depends largely on crop yield potential, yield response to N fertilizer (efficiency of N use), and the amount of N supplied by the soil over the course of the growing season (Fiez, 1994b), all of which must be established before site-specific recommendations are feasible. Variation in these properties within fields is both systematic and random. Only differences arising from predictable, systematic influences are manageable, and it is these which must be investigated for their influence on crop N requirements within homogenous, sub-field management units.

In undulating to hummocky Western Canadian landscapes, systematic variation in factors determining the amount of N required has been consistently linked to the soil-landscape. Crop yield potential (Moulin et al., 1994), and incidentally, grain protein concentration (McKercher, 1964), have been shown to vary within the soil-landscape. Systematic differences in response to N fertilizer have been demonstrated within the soil-landscape (Kachanoski et al., 1985; Elliot and de Jong, 1992a; Beckie et al., 1997). N losses such as denitrification affect apparent yield responses to N (Fiez et al., 1995), and have been shown to vary systematically within the soil-landscape (Pennock et al., 1992). Landscape-scale differences in residual soil mineral N (Spratt and McIver, 1972) and mineralization (Jowkin and Schoneau, 1998) have been demonstrated. In undulating to hummocky landscapes, sub-field management units should therefore be based on topography, due to the underlying soil-landscape relationships which are reflective of historical productive potential and inherent fertility.

Systematic landscape control of required N results largely from topographic control over microclimatic variables such as moisture distribution and soil and air temperature. Historical integration of these and other pedogenic influences results in characteristic soil -landscape associations. Variation in such pedogenic character both coincides with and regulates the more immediate determinants of required N at any given point in the soil-landscape. However, while the influence of the soil-landscape has been demonstrated to be a large and systematic source of variation in required N, the net influence is not predictable (temporally stable) due to typically large annual variation in growing season weather. In semi-arid, typically moisture-limited Western Canadian dryland crop production, it is generally not feasible to manage N fertility past the time of seeding, and producers often apply N fertilizer well in advance of the growing season. As a result, there is a need for quantitative, long-term definition of N fertilizer requirements within landforms typified by unique microclimatic regimes.

This study was initiated as a step toward long-term site characterization which will allow the development of risk-based recommendations of required fertilizer N within morphologically unique landform element complexes (LECs). The Landform Description Program created by MacMillan and Pettapiece (1997) was used to delineate distinct, homogenous and manageable LECs. The objectives of this study were to (i) establish differences and interrelationships in topographic attributes, static and dynamic soil attributes, and crop response attributes among LECs, and in light of this information, (ii) to model grain yield response and yield potential as a function of estimated plant-available N supply within landforms, in order to assess the potential utility of site-specific N recommendations over two growing seasons.

2. LITERATURE REVIEW

2.1 Soil Properties in the Soil-Landscape Continuum

"The spatial pattern of soil properties results from systematic variations in soil processes and superposition of random variations on this systematic pattern" (Pennock and de Jong, 1990b). Systematic soil properties in the landscape result from predictable, ongoing geomorphic and pedogenic processes reflective of a dynamic continuum. Milne (1936) noted the occurrence of soil types in the context of the topography in which they occurred and the processes (geomorphic, pedological, hydrological) responsible, currently known as the 'catena concept'. Pedogenic and hyrdrologic processes act in concert across the entire landscape and are not restricted to a given point. If enough observations of a soil property of interest are made, the amount of variability apportioned to randomness can be reduced. Alternatively, variability may be explained systematically if the effects of formative processes can be successfully modeled (Hall and Olson, 1991).

By the evolution model of pedogenesis (Johnson and Watson-Stegner, 1987), soils evolve into increasingly polygenetic entities over time via progressive and regressive pedogenesis. Progressive pedogenesis includes the components of horizonation, developmental upbuilding and soil deepening, and regressive pedogenesis includes haploidization (loss of definition between soil horizons), retardant upbuilding and soil removal. While the soil is continually in transition towards some equilibrium, soil properties at any point in a catena may be explained in terms of the 'current' result of components (processes) comprising the two counteracting pathways, at any point in the evolutionary continuum.

2.1.1 Static Soil Properties and the Soil-Landscape

Productivity often influenced by, or coincides with, the spatial distribution of soil profile attributes. It is known that these relatively stable attributes are a systematic function of topographic and hydrologic influences--hence the soil-landscape paradigm. Therefore, in establishing a context in which to evaluate agricultural productivity, systematic spatial variation in the soil-landscape must be understood. While these attributes are highly dynamic in a geologic time scale, they may be considered to be static for the purposes of agricultural research, which is relatively short-term.

2.1.1.1 Landscape Morphology

The 'lay of the land' is the result of geomorphologic processes. The characteristic configuration of the vast majority of Western Canadian farmland is due to glacial-depositional processes, including glacial till, glaciolacustrine and glaciofluvial formations, resulting in characteristic topography which ranges from level to hummocky. These clastic/skeletal geomorphic attributes formed the context in which pedogenic processes occur, and physio-chemical characteristics throughout the soil-landscape reflect contributions from both geomorphic and pedogenic influences (Pennock and Acton, 1989).

The areal percentage of discrete landscape segments is reflective of differences in geomorphic origins of Western Canadian landscapes. For example, glacial till landscapes tend to have a lower percentage of level landform elements than do glaciofluvial or glaciolacustrine landscapes (Pennock and de Jong., 1987). Spratt and McIver (1972) found 45, 7 and 10% of an Oxbow landscape was composed of midslopes, crests and depressions, respectively. Areal percentage of landscape segments has implications for the feasibility of variable-rate N management, where they are to be employed as management units.

2.1.1.2 Solum Development

Within a region of similar parent material, climate and vegetation, solum development is largely dependent on landscape morphology. Surface and subsurface water redistribution on slopes is the principal reason for occurrence of characteristic soil-slope associations in the landscape (Pennock et al., 1987). Convergent character generally encourages greater profile development (horizonation and soil deepening). In divergent landform elements, reductions in hydraulic conductivity to unsaturated flow occurs with depth (in surface soils) as genetic profiles develop, encouraging regressive pedogenesis. Internal flow becomes more anisotropic and the rate of profile development is further diminished, such that lateral flow becomes increasingly important (Hugget, 1975). Essentially, convergent and divergent character determines the balance between runoff (water unavailable for solum development) and infiltration (water available for development).

The influence of convergent and divergent character must be considered in three dimensions. Two-dimensional generalizations are useful only in rectilinear landform elements; both down-slope and cross-slope curvature must be considered to properly evaluate profile development in the context of surface and subsurface flow (Zaslavsky, 1969; Hugget, 1975). Plan curvature can greatly influence the lateral distribution of geomorphic, hydrological and pedological processes and the resultant soil properties (Pennock et al., 1987).

Due to characteristic soil-landscape relationships, researchers have used mathematical models for soil property prediction. Aandahl (1948) found that with an adequate description of three-dimensional configuration, plant-microclimates and soil properties become predictable, and that changes in soil type often occur at the point of inflection between convexity and concavity. Using three-dimensional mathematical descriptions of topography including slope, rate of change of slope and radius of curvature, Troeh (1964) achieved good correlation with soil drainage characteristics. However, high spatial variability often precludes accurate prediction of soil properties by such methods (Florinsky[1], unpublished data).

Others have quantified soil properties in the landscape by segmentation into recognizable landform elements in order to make comparisons among them. Pennock et al. (1987) developed a three-dimensional classification of seven hillslope elements in hummocky terrain, using gradient, plan curvature and profile curvature. These original elements were dubbed divergent and convergent shoulders (DSH, CSH), backslopes (DBS, CBS), footslopes (DFS, CFS), and level (L) elements. MacMillan et al. (1997) developed a similar method of defining landform elements, using gradient and relative relief as division criteria. Both authors made provisions to amalgamate smaller, disjointed *elements* (i.e., picture elements/pixels) into spatially homogeneous landscape-scale

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[1] Land Resource Unit, Agriculture and Agri-Food Canada.

landform element *complexes*. Using more strictly quantitative criteria, Florinsky et al. (unpublished data) partitioned an undulating glacial till landscape into areas of relative accumulation, transit and dissipation of flow of water.

'A' horizon depth and depth to carbonated or calcareous parent material are key indicators of progressive soil development in Chernozemic soils developed on glacial-depositional parent material. 'A' horizons result from the addition of organic matter to mineral soil and subsequent mixing of the two. The thickness of the A horizon, reflective of the rate of C addition, is a function of moisture regime (Pennock and de Jong, 1990b). Carbonate depth is controlled by the penetration of moisture, by the balance between weathering and leaching, and by carbon dioxide concentration, which is influenced by rooting depth. Pennock et al. (1987) found intuitive trends among landform elements for solum and A horizon depth, whereas variability explained by individual topographical variables were weak, even with stepwise multiple regression. Ranges of 12.6 to 32.7 cm (A horizon thickness) and 22.8 to 96.6 cm (depth to carbonates) were observed among elements of convergent and divergent character, respectively. As well, there were more eluvial horizons in convergent areas with higher catchment values, than in divergent areas with lower catchment values. Global catchment area increased in the order shoulders < backslopes < level < footslopes. Statistically, it was possible to group landform elements on the basis of A horizon thickness and carbonate depth (DSH, CSH, and DBS; CBS, DFS, L; CFS) as a result of the topographic effects of surface morphology on pedogenic processes. Others have observed that upper slope soils are often eroded and carbonated (Simmons et al., 1989) with relatively thinner A horizons (Fiez et al., 1994a), whereas footslope soils have thicker A horizons and deeper carbonates. Miller et al. (1988) observed carbonate depths of 80 to 150 cm in footslopes.

Regional differences in moisture regime are also important to the extent of profile development. Pennock and de Jong (1990b) demonstrated systematic differences in profile development among soil zones, along with systematic, consistent differences within catenas. Within catenas in the Brown, Dark Brown and Black Chernozems, they found distinct groupings of landform elements emerged for depth to carbonates (DSH-CSH-DBS < CSH-DBS-CBS < CBS-DFS-L < CFS), and A horizon thickness (all others < CFS). Among Chernozems, they found Black soils had consistently greater A thicknesses, while depth to carbonates was greatest for the Black > Brown > Dark Brown. While all other differences were reasonably attributed to variable local and regional moisture regimes, the deeper depth to carbonates within the more arid Brown Chernozem was ascribed early postglacial dominance of a spruce forest assemblage (for approximately 2500 years). Forested soils tend to be more strongly leached. Regardless, differences within catenas proved to be an order of magnitude greater than those induced climatically on a regional basis. Ranges in A horizon thickness and depth to carbonates were greatest on sites with higher slope classes (2.1 to 4.3 degrees), as spatial differences in convergent and divergent character are accentuated with higher gradients.

Depth to carbonates is generally greatest at locations where net downward infiltration is large and sustained, e.g., footslope and toeslope landform elements. However, local hydrologic conditions have resulted in instances of higher carbonate concentration in more convergent landscape positions because the depth to carbonates is also a function of water table dynamics. For example, Malo and Worcester (1975) observed a ring of shallow carbonates at a footslope location adjacent to a depression. Moulin et al. (1994) described the occurrence of 'rego rings' with relative elevation of approximately 1 meter, adjacent to recharge depressions where upward water flux resulted in carbonated surface soils.

Predictable pedogenic effects of convergent and divergent landscape morphology results in the occurrence of characteristic taxonomic soil types on given slope locations. King et al. (1983) noted the occurrence of thin Calcareous or Regosolic Chernozems, with thin or non-existent B horizons in convex upper slopes. Midslope units were typically Orthic, and concave lower slope and depressional soils were generally Eluviated or Gleyed, with argillic B horizons. Rennie and Clayton (1960) noted a sequence of Calcareous Black, Orthic Black, Orthic Dark Grey, and Eluviated Gleysol moving from the uppermost point in a toposequence to the lowest, most poorly drained. Such sequences indicate a progressive increase in solum development moving from the more arid, divergent crest to the more moist, convergent footslopes and depressions in semi-arid grassland toposequences. From the convex to the concave, there is a concomitant increase in organic matter accumulation and transformations, carbonate weathering and leaching, and pervection and weathering of clay minerals. Gleying in depressions is due to reducing conditions caused by a water table that is high and relatively static, or by a water table which drops from spring to fall but has a capillary zone extending into the solum. The result is Rego Humic Gleysols and Rego Gleysols. While still part of a larger continuum, soils result which are taxonomically and functionally distinct at the landscape scale due to varying intensities of accumulation and net downward flux of water.

Sedimentologic and geomorphic processes may also be critical to solum morphology (Pennock and Vreeken,1986; Pennock and Acton, 1989). As a result, landscape morphology alone is not always a sufficient predictor for solum characteristics. Using multiple regression, Walker (1968) found relative elevation and slope were often most proportional to A horizon thickness and depth to mottles, and that as concavity increased, A horizon thickness increased, and mottles were closer to the surface. However, there were irregularities that could only be attributed to paleosolic land surface and drainage characteristics and soil faunal activity. Sand lenses within an otherwise loamy parent material have been observed to result in a deeper solum depth regardless of topographic position (Pennock et al., 1987). Sedimentologic processes, such as post-glacial sedimentation, may result in anomalies. Pennock and Vreeken (1986) described four distinct facies from four geomorphic episodes, smoothing the landscape. One such episode resulted in an eolian layer overlaying a till landscape which had a higher carbonate concentration than the underlying colluvial sediment. This was reflective of the timing of parent material deposition.

Erosion is a geomorphic process which affects soil-landscape morphology over time and confuses observations of pedogenic development. Paleosolic surfaces may be quite different from present-day morphology (Pennock and Acton, 1989). Erosion results in soil removal on divergent landform elements and can result in retardant upbuilding in convergent landform elements, as solum depth is often diminished in susceptible upslope areas and increased in downslope depositional locations—i.e., erosion tends to level the landscape. Net losses, as well as redistribution, also affect solum depth predictions by morphology, and the surface morphology itself is of course altered. Erosion may be due to natural processes or human activity. Moulin et al. (1994) noted accentuated differences in solum depth by landscape position of cultivated transects when compared to native transects. Elliott and De Jong (1992) observed fewer differences in soil properties among landform elements in more recently broken Black Chernozem toposequences, due to the lack of long-term crop production, summerfallow and soil erosion. Verity and Anderson (1990) observed a typical redistribution of carbon-rich surface soil, with eroded upper slopes and maximal deposition in the footslope. Pennock and de Jong (1990a) were able to group derived landform elements into distinct groups: DSH-CSH-DBS-CBS, experiencing soil losses of up to 24 t/ha/year; DFS-L, with losses of up to 6.4 t/ha/year; and CFS with a net gain of 15 t/ha/yr. Erosion was better explained with three-dimensional elements than by any single descriptor of slope morphology.

2.1.1.3 Soil organic carbon

Soil organic carbon (SOC) is an indicator of the historical production of biomass in a given location, mineralization, and erosion. The amount of SOC affects the chemical and physical properties of a soil, and hence fertility and moisture retention. Increases in SOC correspond with topsoil depth and available water holding capacity (Gollany et al., 1992) and with total nitrogen (Gregorich and Anderson, 1985).

Various researchers have demonstrated that distribution of SOC with respect to landscape position is not random; Pennock and Vreeken (1986) found that SOC accumulation was a function of more recent pedogenic episodes and corresponded well with present-day land surface morphology. The amount of SOC produced *in situ* within a variable landscape is largely determined by soil water and its influence on historical biomass production. The concentration (Pennock and Vreeken, 1986) and absolute amount (on an area basis) (Gregorich and Anderson, 1985) of SOC generally increases with distance downslope (i.e., with convergent landscape character) within a toposequence, corresponding with moisture redistribution. Complexity, stability and therefore quality of SOC tends to increase with available moisture (Anderson, 1979), and one would therefore expect more stable and complex SOC in more convergent portions of a toposequence. SOC distribution is also a function of microrelief. Chang (1995) found 65% of the variation in total organic matter concentration could be explained as a function of relative relief over a transect where the range of relief did not exceed 62 cm. The author attributed this result to better soil moisture conditions at lower elevations and/or deposition of organic matter from upslope.

Mineralization rates influence assessments of *in situ* SOC accumulation by accentuating or attenuating differences in net production of carbon. Mahinakbarzideh et al. (1991) noted differences in drainage class was a source of variability in SOC. On deep, well-drained soils with good aeration, SOC decomposition may be accelerated, and on deep, poorly drained soils where reducing conditions prevail, SOC accumulation may be enhanced. Gregorich and Anderson (1985) observed that the absolute amount of SOC lost at lower slope areas by mineralization was more than double the amount of SOC lost by erosion in upper slope positions in cultivated transects, despite the larger amounts of SOC present in the lower slopes. In general, net SOC accumulation increases with moisture availability within a given temperature range, and decreases with temperature under similar available moisture conditions (Anderson, 1987).

SOC gradients within toposequences are further accentuated by the process of erosion. Surface soil samples have lower concentrations (Miller et al., 1988; Pierson and Mulla, 1990; Pan and Hopkins, 1991) and overall amounts of SOC (Gregorich and Anderson, 1985; Verity and Anderson, 1990) at divergent upper slope positions where larger historical rates of topsoil loss have occurred, and have higher SOC in depositional, convergent lower slope positions. Differences in amounts of SOC among landscape positions are largely attributable to the redistribution of topsoil by tillage, wind and water erosion, as evidenced by ^{137}Cs gradients (Verity and Anderson, 1990). Relative to cultivated transects, soil redistribution is negligible within native and very recently broken toposequences (Elliott and de Jong, 1992a; Moulin et al., 1994).

2.1.1.4 Soil pH

Alkaline pH values predominate in the glacial depositional surface soils of the Prairie Ecozone of Western Canada. In an Oxbow catena in Southern Saskatchewan, Spratt and McIver (1972) found pH to be generally alkaline, varying from 7.8 in the upper slopes and decreasing to 7.4 in the depressions. The alkaline pH is due to the presence of sizeable amounts of lime (calcium and magnesium carbonates). Infiltration of water into the soil leaches the bases, thereby reducing the pH in more strongly leached surface horizons. Soil pH is also affected by erosion. For example, Gollany et al. (1992) noted pH was higher where $CaCO_3$ concentration was higher in eroded Ap horizons. Thus, depth to carbonates corresponds inversely with trends with soil pH.

2.1.2 Dynamic Soil Properties and the Soil-Landscape

'Dynamic' soil attributes were arbitrarily distinguished from those which are 'static' due to the fact that dynamic attributes vary appreciably between and within growing seasons. In addition, temporal variation in these 'dynamic' attributes is important to crop production.

2.1.2.1 Soil Moisture Content

Soil moisture generally increases with convergent landscape character (Pennock, 1987). The apparent landscape influence on moisture redistribution is regulated by the intensity of precipitation relative to infiltration and soil water holding capacity, the form of precipitation, precipitation distribution, and evapotranspiration.

Both surface and subsurface, saturated and unsaturated flow are important to soil moisture redistribution. In Israel, Sinai et al. (1981) found 90% of the variability in soil moisture levels at a 40 cm depth could be accounted for by soil surface curvature. In Nebraska, Hanna et al. (1982) found aspect and slope position significantly influenced moisture content of soils with uniform water holding capacity. Footslope and backslope positions had an additional 5 cm of available water over the summits and shoulders due to surface runoff and unsaturated flow. Various other researchers have demonstrated increasing moisture deficiency with increasing divergent landscape character in a toposequence (Malo and Worcester, 1975; Pierson and Mulla, 1990; Verity and Anderson, 1990; Pan and Hopkins, 1991).

The landscape influence is limited with low intensity rainfall with near complete infiltration into the soil profile. Miller et al. (1988) observed that landscape redistribution was negligible under limited, low intensity rainfall on soils of high clay content. The clay likely limited redistribution by unsaturated flow under dry conditions. Hanna et al. (1982) noted that differences among landscape positions were most evident under moist conditions. Rainfall may received unevenly across the landscape, and snow is subject to drifting, which can regulate the apparent landscape effect (De Jong and Rennie, 1969). Soil recharge from snow melt is affected by frost, which can influence hydraulic conductivity of the surface soil in the early spring.

Soil moisture may fluctuate widely depending on evapotranspirative demands and management practices in agro-ecosystems (Campbell et al., 1977a). Across the landscape, Hanna et al. (1982) observed maximum available soil available water at the time of seeding, when evapotranspirative demand is low. Within landscape positions, average moisture content over the course of a season may be lower in toeslope positions due to heavier crop and weed growth (Spratt and McIver, 1972). Soils with cool microclimates tend to maintain higher levels of available water due to lower evapotranspirative demand. Soils of north-facing backslopes have lower incident irradiation, remain cooler, and as a result, lose less water to simple evaporation (Hanna et al., 1982). Aspect is not important in all landscapes, however. Helvey et al. (1972) did not detect a significant difference in moisture among aspects due to quick infiltration and uniform shading of all slope aspects, where trees were present.

Available water holding capacity is not always uniform throughout the landscape. Textural influences will vary depending upon parent material and geomorphic influences, but in general, deeper surface horizons with greater SOC have greater water holding capacity. Gollany et al. (1992) demonstrated this effect of soil depth and SOC on water holding capacity, but also noted SOC influenced soil structure and porosity, further accentuating landscape differences. Strong correlations between soil water and SOC (Pierson and Mulla, 1990), and soil water and solum depth relationships (Power et al., 1981) have been demonstrated.

2.1.2.2 Soil Nitrogen

Plant-available N includes existing inorganic nitrate and ammonium in the soil and nitrogen mineralized from organic N over the growing season. Mineral forms are given the most consideration for agricultural purposes. Crop access to nitrate and ammonium is affected by factors such as loss processes, rooting patterns, nutrient mobility interactions with soil water and weed competition. Explanation of systematic differences in plant-available N as a function of landscape requires integration of soil properties, N-cycling, previous management and cropping effects (Fiez et al., 1994a).

Residual soil nitrate is the most important inorganic form of N to consider when creating fertilizer recommendations in Western Canada (Campbell, 1988a). Studies have revealed consistent trends of nitrate concentration in the landscape. Spratt and McIver (1972) discovered a progression from 18 to 57 ppm nitrate moving from crest to depression in an Oxbow catena. Subsequent to a fallow year, this was likely due to higher levels of organic matter, and therefore greater mineralization and higher overall N concentrations in more convergent areas. The authors found total percent N varied from 0.3 on eroded knolls to 0.5 in depressions. Pan and Hopkins (1991) found progressively greater levels of total inorganic N in the Palouse of Washington moving from ridgetop to toeslope. Malo and Worcester (1975) attributed like findings to higher organic matter content and increased clay content, coinciding with higher moisture and sedimentation. Fiez et al. (1994a) found consistently high residual nitrate concentrations on eroded shoulders, among years and locations, and hence a negative correlation with A horizon depth (r-sq=-0.70). Farrel et al. (1996) found higher residual nitrate levels below the rooting zone on divergent landscape positions. Franzen et al. (1998) observed a persistent spatial pattern of nitrate distribution in a three-year study on a loam-clay loam glacial till soil in North Dakota. The authors found that topography-based sampling, using 'hilltops, slopes and low-lying landscapes', was superior to a 67 m grid in capturing spatial variability in nitrate distribution.

Alternatively, studies have failed to detect consistent trends in nitrate concentration in the landscape. Jones (1989) found high variability in nitrate concentration in the surface 15 cm among landscape positions, and no significant differences among landscape positions, in loess-derived Midwestern soils. Cahn et al. (1994) found that the spatial dependence of nitrate concentration was less than 5 m, which for the purposes of management by landscape, exhibits no spatial structure. The authors attributed this small spatial dependence to greater mobility of nitrate-N relative to other soil nutrients. Mulla (1993) found nitrate values were spatially random. Wibawa et al. (1993) found little correspondence between nitrate concentration, which had high variability over short distances, and soil map units in the landscape. The presence of detectable, systematic landscape influences on inorganic N distribution is largely influenced by past agricultural management. Under modern agricultural conditions with much less fallow and considerably higher fertilizer N inputs, landscape variations in nitrate concentration are often masked. Pennock[2] (personal communication) has not found consistent, practically significant differences in nitrate concentration among landform element complexes.

Both soil residual nitrate levels and growing season mineralized N are important for accurate assessment of inherent fertility of a given landscape position (Fiez et al., 1994a). In Western Canada, fertilizer recommendations generally utilize levels of nitrate-N in the top 60 cm of soil at seeding, and it is assumed that mineralization is not important or is closely correlated to residual nitrate levels (Campbell et al., 1988a). Despite the numerous limitations of such partial 'snapshots' of inherent fertility, ease of measuring residual soil nitrate, coupled with a lack of predictability for the dynamic and spatially complex nature of N cycling in the soil, have resulted in current practices.

Accurate assessments of inherent soil fertility should then consider distribution of potentially mineralizable N in the soil-landscape. Total organic matter and total mineralizable N are strongly related, and as a result, there is a strong landscape influence on inherent N fertility. The total amount of mineralizable N generally increases with convergent character in the landscape, corresponding with more moist, productive locations with greater amounts of SOC. Rennie and Clayton (1960) examined inherent differences in productivity, as affected by fertility, among pedogenically unique soil

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[2] Department of Soil Science, University of Saskatchewan

member profiles. Observed differences in inherent fertility were proportional to the relative distribution of soil organic matter and typical moisture regimes. Fiez et al. (1994b) found N mineralization was proportional to organic matter, which increased with convergent character in the landscape. Campbell et al. (1988a) noted that estimates of mineralization in Saskatchewan could be made in the surface 15 cm of the soil, where most mineralizable substrate is partitioned.

Temperature and moisture are the predominant controllers of mineralization rate (an aerobic process) of organic N substrates in a given location. Hence, rate of mineralization is influenced by temporal and macroscale landscape variability in these controllers. N mineralization is optimized from –0.01 to –0.03 Mpa, and approaches 0 at –4.0 Mpa. Normalized to available moisture between –0.03 and –4.0 Mpa, net mineralization is directly and linearly related to soil moisture (Myers et al., 1982) and must therefore be affected by landscape influences on soil moisture. Rates of mineralization at optimum soil moisture (-0.01 Mpa, 27%w/w) in the surface 15 cm of a Yorkton soil were in the order of 24 ppm over a 2 week period. While the Q_{10} (the multiplicative factor by which reaction rate increases for each 10°C temperature increase) for the mineralization process is often assumed to be 2, Campbell (1988a) noted that Q_{10} will differ among soils and is not constant over all temperatures. As the landscape exerts influence over temperature by differences in aspect (insolation), slope position (wind exposure), plant residue distribution, soil color and soil water content, the landscape therefore affects mineralization rates.

In a Saskatchewan study, mineralization rates in the mid and lower slopes were consistently higher than the rates observed in the shoulders for cultivated landscapes in the Ardill, Weyburn, Oxbow and Waitville associations (Roberts, 1985, as cited in Solohub, 1994). At Hepburn, SK, also on the Oxbow soil association (Yates, unpublished data) potentially mineralizable N increased from the shoulder to the footslope, and then dropped off slightly for the depression, which had lower quality organic matter in a thin Ah horizon over Gleysolic subsoil. Fiez et al. (1994b) found that while mineralization rates were highly variable, average values were highest on the footslope (98 kg/ha) and lowest on the shoulder (4 kg/ha). Using ion-exchange membranes, Schoneau and Greer (1996) observed higher mineralization rates in lower slopes relative to upper slopes over a 2-week period.

Temporal variability in net mineralization in the landscape could be expected to be large, given the influence of environmental conditions. For example, Fiez et al. (1995) found differences in mineralization of 27 to 86 kg/ha between two years on the same landscape positions at the same site. Campbell et al. (1988a) obtained reasonable predictions of mineralization, but due to inadequately simulated wetting and drying cycles, consistently underestimated mineralization. Amount of residue returned to the soil from the previous year varies with landscape position (Elliott and De Jong, 1992a), but also from year to year. Differences in substrate availability markedly influences mineralization (Campbell et al., 1988a; Fiez, 1994a). Goovaerts and Chiang (1993) observed that oxidizable C (r^2=0.64) and gravimetric soil moisture (r^2=0.46) accounted for much of the variability in nitrogen mineralization, and while these properties were stable, they were based only on two observation times, before and after winter. Geostatistical analyses indicated that microscale spatial variability (<1 m) was the major component of the variability in potentially mineralizable N.

Losses of N influence the amount that is crop available and hence inherent fertility. All loss processes are regulated by landscape controls. For example, denitrification (an anaerobic process) is most strongly affected by oxygen, nitrate and carbon supply (N and C are required substrates). Pennock et al. (1992) found most losses occur in footslope locations rather than shoulders, following depression-centered patterns. Greater carbon supplies and anaerobic conditions are more likely to occur in landform elements of greater convergent character. Loss processes are also very dynamic, and temporal instability invalidates generalizations. Corre et al. (1996) demonstrated higher denitrification rates in lighter textured, divergent landform elements in early spring due to temperature effects. Farrel et al. (1996) stated that nitrate leaching, like denitrification, is controlled by landscape-scale interactions between topography and hillslope hydrology. The authors found that nitrate concentrations below the rooting zone, to a sampled depth of 3 m, increased with divergent character in the landscape. It was suggested that higher rates of denitrification in the convergent elements, as demonstrated by Pennock et al. (1992) at the same location, may have reduced nitrate concentrations below the rooting depth. However, this did not preclude the possibility of leaching below the 3 m sample depth.

2.2 Moisture and N Supply: Effects on Crop Production and Quality

Soil moisture and mineral nitrogen supply are the two most important determinants to wheat yield and quality in Western Canada. Understanding their individual effects and interactive effects on wheat yield and quality is a necessary prerequisite to understanding response behaviour with spatial variation in these controls in the soil-landscape.

2.2.1 Water and Yield

Transpiration and photosynthesis are closely linked; moisture-stressed plants have reduced access to carbon dioxide, and hence lower photosynthetic rates. There is a minimum moisture threshold to be met for grain production to occur, and further precipitation usually results in linear yield increases under moisture limiting conditions. Staple and Lehane (1954) summarized soil moisture, precipitation and wheat yield on seven farms in the Brown soil zone in southwest SK. They demonstrated that 125 to 150 mm of moisture available from the soil or from precipitation was required for wheat to initiate wheat production, and that each additional mm resulted in another 10 to 12 kg wheat per hectare. Due to better management, threshold moisture values have since decreased to 50 mm (Campbell et al., 1988b). Henry et al. (1986) summarized a number of Western Canadian studies for a number of cultivars, in which the minimum threshold values ranged from 36 to 152 mm, with an increase of 9.3 to 14.9 kg/ha per mm of additional water. Yield increase values of 11 to12 kg/ha/mm have been described for the Black soil zone (Henry, 1990). In general, satisfactory wheat yields are obtainable with 200 to 254 mm of precipitation (Selles et al., 1992).

Water is the most frequent and unpredictable limitation for wheat yield in Western Canada (Grant and Flaten, 1998). The Great Plains is a zone of regional moisture deficit, and available water supplies are often exhausted to near the permanent wilting point (Pan and Hopkins, 1991). As a result, yield goals may be constructed under the assumption that all soil moisture and growing season precipitation are utilized for yield formation. Such predictions have been shown to correspond well to historical crop insurance data (Henry, 1990). Prairie-wide crop yield has been successfully modeled as a function of growing season precipitation and temperature. Raddatz et al. (1994) were able to explain 69% of the variability in crop yield across Western Canada based on daily meteorological data. Actual yields were underestimated somewhat, as the model did not incorporate negative effects of high-moisture growing seasons. Korentajer and Berline (1988) noted that such an approach is valid only where moisture is consistently the main limiting factor. Gehl et al. (1991) found that in a Manitoba Newdale glacial till, soil moisture to 120 cm at seeding explained 91% of the variation in final grain yields. In a summary of water use by soil zone, Stepphuhn and Zentner (1986) demonstrated correlations of stubble-cropped wheat yield and growing season available water were highest in the Brown soils of Western Canada (r^2=0.41). Coefficients were lower in the Dark Brown zone (r^2=0.35) and least in the Black soil zone (r^2=0.25). This was reflective of the relative extent of moisture limitations to yield in these soil zones.

Water use efficiency (WUE) is estimated by dividing yield by evapotranspirative water use by a crop (Stepphuhn and Zentner, 1986). WUE is affected by fertility levels, tillage regimes and soil types. As WUE ignores redistribution of water, differences among soil types and textures may be due to varying levels of retention and transmission of soil water. WUE gradually improved in the 25 years up to 1986 (and presumably thereafter) across the Canadian prairies, but variability among season and locations is high, regardless of the measure used to assess water use. A generally accepted expression of WUE is as follows (Stepphuhn and Zentner, 1986):

WUE = (yield)/((growing season precipitation) + (spring soil water) – (harvest soil water))

2.2.2 N , Water and Yield

Grain yield will increase with N fertilizer applied if N is limiting, following Mitscherlich's law of diminishing returns as rates increase (Campbell, 1977b). High production areas in the Canadian prairies often have residual nitrate-N levels of less than 30kg/ha, and supplemental N is generally required (Fowler et al., 1990). Henry et al. (1986) demonstrated that under a consistent moisture regime, grain yield response to N fertilizer was highest under conditions of low residual soil mineral N. The author found that the first increment of fertilizer N under irrigated conditions resulted in an increase of 26 kg red spring wheat/ha, on a Dark Brown soil with a low soil contribution to mineral N supply. Olson et al. (1976) found wheat was unlikely to respond to fertilizer when residual N concentrations exceeded 90-135 kg/ha.

Moisture-N fertility interactions are often more important to yield than the main effects of these variables alone (Campbell et al., 1977a; Henry et al., 1986; Selles et al., 1992). As a result, effects of N on yield are often discussed in the context of accompanying environmental conditions. There can be considerable annual variation for crop response to N fertilizer on the same soil as a result of meteorological variability, the amount of vegetative growth relative to grain yield, and how these factors interact with water and nutrient absorption (Campbell, 1977b, Gehl et al., 1990). N fertilizer recommendations created from pooled data from long-term fertilizer trials may not be applicable in areas where moisture stress is highly variable. Korentajer and Berliner (1988) improved a (yield x N) regression model, constructed from two years of data, from r^2 =0.27 to 0.94 by including a moisture stress index. The main effect of the stress index accounted for 69% of the variability alone. Selles et al. (1992) modeled wheat yields from nine years of data in southwestern Saskatchewan and found that the effects of soil and fertilizer N and P on yield were only significant in their interaction with the effect of water supply on yield. Water supply alone explained 15% of the variability in yield.

Fertility-induced improvements in WUE are commonly observed in dryland wheat production (Stepphuhn and Zentner, 1986). N fertilizer and soil moisture are synergistic in their effect on crop yield. Campbell et al. (1977b) found that yield increased from a base yield of 1600 kg/ha by 71, 47 and 300% when water, 164kg/ha N, and water and 164 kg/ha N were added, respectively. Each enhanced the efficient utilization of the other for production of grain. Recovery of N fertilizer was more efficient under optimal moisture conditions; up to 84% was recovered under irrigation as opposed to a maximum of 65% in the dryland plots (Campbell and Paul, 1978). The authors explained that optimal moisture resulted in a larger N sink, and also enhanced mobility of nitrate-N. In turn, addition of N-fertilizer reduced the net moisture requirement for production of a unit of yield (i.e., improved WUE) up to 61.5 kg/ha, despite a corresponding increase in total water use under irrigated conditions. Under dry conditions, all water was depleted at all N rates, but the higher N treatments depleted it faster. The authors also noted that WUE was higher under irrigated conditions at like N levels, in contrast to the findings of Talha (1975). In a Sceptre heavy clay soil, Warder et al. (1963) also found that wheat with inadequate fertility did not exploit available moisture reserves as efficiently as well-fertilized treatments.

2.2.3 N, Water and Grain Protein Concentration (GPC)

Wheat GPC is an important quality consideration to end users, and as a result, the Canadian Wheat Board financially rewards farmers for attaining high GPC. For Canadian Western Red Spring wheat, protein premiums are currently increased for every 0.5% increase in GPC from a base price at 12% to a maximum of 15%, and will soon be based on 0.1% increments. These premiums can have a significant impact on producer profit, and it is unrealistic to ignore the potential impact of variable-rate N fertilization on GPC.

GPC in wheat, typically ranging from 8-20%, is a ratio of the mass of grain protein to the total mass of grain in question. Fundamentally, GPC is a ratio of N:C accumulation by the crop. As a result, GPC is a function of all factors influencing the crop's ability to assimilate and translocate N to the grain and those which influence the crop's ability to produce total yield. Water availability (inversely related to GPC) and temperature (positively related to GPC) are the major factors resulting in observed variation in GPC, and regulate the effect that N fertilizer will have on GPC (Campbell et al., 1977a,b; Fowler, 1998). From 40 to 80% of the variation in GPC observed across years can be explained by climatic variables, primarily due to influences on the net C accumulation of the crop (Selles and Zentner, 1998). Carbohydrate accumulation in the grain is more sensitive to adverse growing conditions than grain protein accumulation (Grant and Flaten, 1998). While protein content of a crop depends on N supply adequacy, 'adequacy' is relative to crop demand. Crop demand is a function of yield potential, which is in turn a function of water availability (Grant et al., 1991).

Under constant climatic conditions, an increase in plant available N will usually increase GPC, and it will often continue to increase after yield has become limited (Terman, 1979; Grant and Flaten, 1998). The N status of the crop determines the magnitude of GPC response to added N (Selles and Zentner, 1998). Under favorable growth conditions and low levels of N (low N status), Fowler and Brydon (1989) observed a minimum GPC of 9.54% in winter wheat. N fertilizer stimulated grain yield and grain protein yield proportionally, and resulted in a 'lag phase', where GPC remained essentially constant with additions of N fertilizer. The extent of the 'lag phase' is a function of N and environmental limitations to crop growth. Under less favorable growing conditions, smaller N additions are required to exceed the lag phase, as the crop produces less grain in relation to the amount of N available. Gauer et al. (1992) observed that under 'high' moisture conditions, addition of 120 kg/ha was required to achieve a significantly higher GPC for spring wheat, while under 'moderate' moisture conditions, only 80 kg/ha was required. Often no lag phase is observed under dry, moisture-limited conditions (Fowler, 1998). When enough N is available to exceed the lag phase, additional N increments produce increases in yield which become increasingly marginal and relatively large GPC increases (Fowler, 1998). A maximum phase, where GPC ceases to rise, is reached when genetic or environmental limitations curtail further responses to N.

GPC is generally proportional to the temperature under which the crop was grown. This effect is difficult to remove from the effect of water availability since temperature and moisture are often highly correlated (Selles and Zentner, 1998). However, Partridge and Shaykewhich (1972) demonstrated that under controlled conditions, wheat grown under high temperatures had higher GPC than wheat grown under low temperatures. Increased

GPC due to higher temperatures is mainly attributable to the drop in net photosynthate accumulation (Selles and Zentner, 1998). Sustained periods of high temperatures after anthesis reduce grain yield by shortening the duration of the grain filling, resulting in a decreased number of kernels and kernel mass, but not the amount of N accumulated.

As a result of characteristic yield-GPC relationships, GPC has proven to be a useful post-harvest indicator for the sufficiency of N fertilization for yield. Goos et al. (1982) identified a critical level of 11.5% GPC at which the transition from N deficiency to sufficiency was realized for dryland winter wheat in Colorado. At GPC levels of less than 11.1%, wheat yields were depressed by inadequate N fertility. At GPC levels above 12.0%, N was no longer the most limiting factor to yield. Glenn et al. (1984) stated that GPC was a better indicator of N-sufficiency than straw or chaff protein concentration. Flaten and Racz (1997) identified a critical GPC of 13.5% for red spring wheat in Manitoba. At GPCs below this level, economic yield is sacrificed due to inadequate N fertility.

2.2.4 The Concept of N Use Efficiency

As N is used more effectively to produce yield or grain protein, lower costs and pollution risks are realized. NUE is most commonly expressed as yield per unit of N supply. However, NUE can be subdivided into components of total soil supply of N, plant available N, uptake of plant-available N, and utilization of N taken up for yield formation. Doing so permits identification of specific management or genetic inefficiencies which might be alleviated (Huggins and Pan, 1993).

Differences in NUE among systems or locations are expressed when yield response patterns vary with respect to N supply. Total N supply includes fertilizer, residual mineral N, mineralizable N, fixed N, and depositional N. Conversion to yield depends on the plant's uptake and utilization of plant available N, which is total N supply minus losses or otherwise sequestered N sources. A balance method of approximating plant available N is performed by summing above-ground plant N and residual soil N at harvest, whereas total N supply may be approximated by summing N fertilizer applied and control plot above-ground plant N and harvest residual mineral N (Huggins and Pan, 1993). This balance method is subject to a number of assumptions, but has been utilized by researchers for NUE calculations (Fiez et al., 1994b; Sowers et al., 1994).

Other researchers have simply focused on fertilizer use efficiency (FUE) within landscape positions (Beckie et al., 1997). Such an approach focuses on immediate economic benefits, but does not account for residual soil N and other soil sources such as mineralization. In comparing systems, higher FUE translates into greater profit due to better yield responses at a given N rate, or reductions in fertilization requirements which do not reduce yield proportionately. While N rates are primarily the concern in a variable-rate N study, timing and application methods are important to FUE comparisons among systems (Sowers et al., 1994).

There are efficiency considerations for protein yield and GPC as well. Fowler et al. (1990) found that since maximum grain yield is reached at the end of the increase phase for GPC, high GPC may only be obtained at the expense of NUE for grain yield and protein yield. Absolute increases in grain protein yield were much the same as grain yield, such that the first increments of N fertilizer stimulated the greatest increases in grain protein yield. The authors found NUE as high as 80% at low levels of soil available N, but it dropped off rapidly, approaching zero for maximum grain yield, and reaching zero at maximum protein yield.

2.3 The Soil-Landscape: Implications for Productivity

Slope geometry (angle, length, aspect, curvature) influences runoff, drainage, soil temperature, soil erosion and therefore soil formation. The resulting differences in soil formation often result in or coincide with systematic variation in crop yields, and as a result, different landscape positions may require different levels of inputs to optimize production and efficiency (Brubaker, 1994). Systematic variation in soil properties can be predicted based on landscape morphology (Moore et al., 1993), and such attempts may provide a useful decision aid to optimize efficiency. However, some understanding of the effect of soil properties on productivity is required to validate any such approach.

2.3.1 Landscape Morphology and Productivity

Slope and aspect are important in areas with variable topography (Fiez et al., 1994a). Aspect determines the total irradiation a given area receives, thus directly influencing the productive potential of a given area. It also influences soil water content over the soil-landscape. North facing slopes tend to have greater soil water content at all positions (Hanna, 1982), due to lower soil and air temperatures than on south-facing slopes (Fiez et al., 1994a). Lower slope positions tend to be more sheltered, and those which face south also tend to have greater soil and air temperatures. Spratt and McIver (1972) found south facing slopes had greater check yields, but north-facing slopes responded better to N and P fertilizer, despite higher residual nutrient levels in the north slope.

Changes in slope position and gradient often result in large differences in soil type, along with available moisture, soil temperature and other important conditions for wheat growth (Ciha, 1984). The development of temporally stable, long-term solum characteristics as a result of topography is a good indicator of the long-term productive potential of a given point in the soil-landscape. Moore et al. (1993) described A horizon thickness as a fossil record of root activity. Aandahl (1948) recognized that topography influences soil formation by affecting plant growth through temperature, runoff, evaporation and transpiration such that plants within a relatively small area have different microclimates. In turn, these microclimates contribute to pedological properties at a given location. This creates the context in which moisture and mineral N affect yield, such that comparisons with respect to productivity are often made among landscape positions.

Convergent positions with negative surface curvature, such as footslopes and lower linear landscape positions, will often produce higher yields, where there is higher organic carbon, thicker topsoil, and where water is received from upslope (Stone et al.,1985; Simmons et al., 1989; Jones et al., 1989; Moulin et al., 1994). However, these relationships may be complex and inconsistent. Jones et al. (1989) found that corn, sorghum and soybean yields were not consistently higher yielding on any one landscape position, even with the same crop on a like parent material, such that different positions were ranked differently in terms of productivity from year to year. Nonetheless, systematic effects existed that could be related to surface morphology and resultant static soil properties. In general, lower linear and upper linear slopes with larger surface gradients had thinner Chernozemic profiles and lower yields. Pennock et al. (1987) identified the footslope as the slope segment where eroded soil from upslope is deposited, such that the soil is deeper and more productive. Verity and Anderson (1990) noted an increase in SOC and grain yield in the footslope. Yield was double that of the crest, and slightly higher than the adjacent lower level landscape position. Pan and Hopkins (1991) found crest and midslope yields were 54 and 95% of toeslope yields, respectively, due to impeded rooting and inability to access water and nutrients in the crest.

Lower yields on convergent positions have been reported as well, reinforcing the potential importance of subsurface hydrology. Malo and Worcester (1975) and Moulin et al. (1994) reported the occurrence of more strongly carbonated 'rego rings' where in fact yield was depressed due to presence of calcium carbonates in the footslope immediately adjacent to the depression. These carbonated soils resulted from the upward flux of moisture in soils bordering leached depressions. The former authors observed the highest sunflower and barley yields on the backslope, and that yields were also depressed on the eroded shoulder position.

High concentrations of soluble salts may also reduce yields in low-lying areas due to regional and/or local hydrologic conditions. Calcium, magnesium and sodium sulfates predominate in Western Canada, and affect production primarily through osmotic imbalances between the soil and the plant roots such that growing crops become drought stressed. Salts dissolved in the groundwater originate from soil parent material and underlying geologic formations. Saline soils result when high water tables with potentially damaging salt concentrations occur under soils in which evaporation exceeds infiltration of moisture. Accordingly, saline soils predominate in or adjacent to depressional discharge landscape positions. Excessively high water tables result from artesian discharge of glacial till or bedrock aquifers, from evaporitic rings around depressions (which may also occur in recharge depressions), and from saline seeps (Henry et al., 1987). Cropping practices on the prairies (especially crop-fallow systems) have increased water storage in and below the root zone, thereby exacerbating discharge salinity. Accumulated moisture moves down through the profile until a less permeable stratum is encountered, moves laterally, and evaporates at depressions or breaks in slopes, depositing salts in the root zone. The concentration of salts occurs due to the small areas in which saline seeps or high water tables occur relative to recharge areas, the additional salts dissolved in groundwater en route to the affected area, and by surface evaporation of this saline water in or near depressions (Christie et al., 1985).

Excessive moisture in depressions may also result in pest problems, depressing yields. Miller et al. (1988) reported a reduction in yield in the depositional toeslope, possibly due to weeds, disease and textural limitations, resulting in an inverse relationship between surface soil thickness and crop yield. Spratt and McIver (1972) noted higher *Avena fatua* densities in depressional locations, Wibawa et al. (1993) found infestations of *Polygonum persicaria*, which depressed crop yields in a year with above-average precipitation.

Landscapes influenced by erosional-depositional processes may not behave synonymously with unaffected sites (Miller et al., 1988)—general trends in productivity with soil properties may be confounded by soil loss (Pennock and de Jong, 1990a). Such statements indicate the need to consider magnitude of soil erosional effects when evaluating landscape-productivity relationships, despite the fact that erosional effects can be masked or alleviated by productive aids such as fertilizer N (Jones et al., 1989; Verity and Anderson, 1990; Stone et al., 1985) and overshadowed by landscape effects (Stone et al., 1985). Elliott and De Jong (1992a) noted that differences in soil characteristics are less accentuated in more recently broken sites where erosion was less severe, and as a result, yield differences among landform element complexes were undetectable. Generally, soils made thin by erosion, be it wind erosion on exposed knolls or water erosion on upper slopes have lower productivity (Verity and Anderson, 1990). The authors estimated that overall losses from strongly eroded landscape positions with a typical areal distribution of 25-30% in hummocky landscapes may reduce average yields by 10%.

Different parent materials, i.e., stratigraphic differences among regions, would be expected to influence 'typically' observed productivity-landscape relationships, such that there is a need to consider local information. For example, Jones et al. (1989) thought observed results to be general for loess-derived Midwestern soils, but did not expect them to be consistent with eastern landscapes where the rooting zone may be restricted by shallow soils. Physical restrictions due to soil erosion and high clay content have been blamed for low root proliferation, low N and P accumulation and low biomass and yield (Pan and Hopkins, 1991). Loess-derived soils of the Palouse in Washington and glacial soils of Western Canada may behave quite differently. Ciha (1984) found interfluves yielded better than the toeslopes in the loess-derived Palouse soil, as it consisted of a deeper surface layer and had better water holding capacity. Also, soil type varied among landscape position due to textural differences.

There are few safe generalizations about the relative productivity of topographic units with associated pedogenic character. Relative yield can be highly inconsistent among years (Pennock[2], personal communication; Beckie, 1997), largely due to the impact of varied amounts and timing of precipitation. Nonetheless, 'typical' relative order of yield potential observed among such basic topographic units in Western Canada has been reported to be Depression > Midslope > Crest (Kachanoski et al., 1985; Elliott and de Jong, 1992a) due to fertility and moisture gradients. More moist and fertile convergent lower slopes can generally be expected to yield higher than shoulders and crests in semi-arid, moisture-limited environments.

Power et al. (1981, 1982) investigated solum thickness and relative distribution of topsoil and subsoil effects on crop yield and quality. Soil thickness affected productivity due to its influence on rooting depth and quantities of available nutrients and water. On like amounts of topsoil, greater rooting depth and more available water occurred with greater subsoil depth, resulting in increased biomass, yield and dilution of the available N pool. On like amounts of subsoil, GPC was positively related to topsoil thickness due to the increased N supplying power. Total water use was often higher with addition of topsoil. In general, increased plant growth and yield occurred on greater solum depths. In a topsoil addition experiment with eroded soils, Verity and Anderson (1990) found an

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[2] Department of Soil Science, University of Saskatchewan.

addition of 50 mm of topsoil increased yields by 45 to 58%, mainly due to enhanced fertility. Pan and Hopkins (1991) noted that wheat yields have been correlated with the depth of the Bt horizon. While such results are qualitatively intuitive, it is not possible to develop a simple quantitative relationship between topsoil depth and crop production (Gollany et al., 1992). The authors found that yield differences were greater in wet years, and that topsoil depth was more important as growing season water use increased.

2.3.2 Mechanistic Yield Determinants and Productivity

It has been demonstrated that soil profile type, solum depth and carbon accumulation mirror the historical redistribution of water in the landscape, and often correspond with yield differences. However, water and nutrients are the limiting, mechanistic factors important to plant growth (Elliott and de Jong, 1992a). Hence, systematic productive relationships with soil depth and/or landscape position is merely a reflection of the net effect of pedogenic and hydrologic formative processes and redistribution of materials in the landscape on water and nutrient status (Verity and Anderson, 1990; De Jong and Rennie, 1969; Kachanoski et al., 1985). Fiez et al. (1994a) noted that surface morphological descriptors such as slope and aspect are insufficient to explain yield variability, and that the focus should be on variation in yield determinants.

In an adequately managed system with sufficient fertility, the ability of a dryland soil to produce is largely determined by the soil's ability to store and supply water to the crop. Differential concentration of water flow in the landscape is most strongly reflected by productivity in such moisture-limited areas. In an Oxbow catena in Saskatchewan, Spratt and McIver (1972) determined yield was primarily limited by moisture, such that yields were progressively higher downslope regardless of fertility treatment. Fertility treatments could not compensate for the pedological, hydrological and microclimatological limitations of yield potential in more divergent, arid landscape positions. In an Israel study location with annual precipitation of 200 mm, Sinai (1981) found a 1400 kg/ha difference in grain yield between convex and concave positions. Based on soil moisture content, a 10kg/ha yield increase was observed for each additional mm of water. As well as having a higher yield, grain size was 32% larger in the concave position. Hanna et al. (1982) also stressed the importance of soil water to crop growth in dryland farming systems. With an additional 5 cm of water available in footslopes and backslopes, the authors predicted corn yield differences among convergent and divergent areas of up to 1000 kg/ha in a typical growing season.

Spratt and McIver (1972) recognized the difficulty in evaluating the fertility status of undulating fields and defining relationships between crop responses and fertilizer. Like Rennie and Clayton (1960), they found fertility gradients resulted in differential responses among landscape positions. While grain yields were 50% more in depressional areas over the crown, the crown and upper slope had a 25% response to mono-ammonium phosphate as opposed to a 10% response in lower slope and depressional areas. This difference in response was at least in part due to gradients in the residual levels of P; which progressed from 8 to 21 ppm from crest to depression. However, yield response to N fertilizer was consistent among landscape positions, despite a nitrate gradient of 18 to 57 ppm within the catena. The responses were temporally persistent within landscape positions, and over four years of data, were consistent enough to pool the data.

Response to N fertilizer in the landscape is largely complicated by interactions with soil moisture. Kachanoski et al (1985) hypothesized that landscape positions with low organic matter, low inherent fertility, and low levels of soil residual mineral N should respond more strongly to N fertilizer. In actuality, the maximum response to the first increment of N was greatest on the lower slope on almost every occasion over five years of data. Significantly higher water availability in the lower slope offset the higher residual fertility and resulted in greater responses to N fertilizer, due to the fact that water was limiting in the Brown, Dark Brown and Black great groups evaluated. The authors calculated that the maximum response to fertilizer N would remain constant if each 10-15 kg increase in residual N was accompanied by 1 cm of available water. On average, the lower slope yielded 3.9 kg grain/ha per kg N more than the upper slope, and the net result was that more fertilizer would have been recommended for the lower slope. De Jong and Rennie (1969) noted that WUE increased with fertilization, and increased moving downslope from knoll to depression. Elliott and de Jong (1992a) found that while yields were generally lower on the divergent shoulders, relative magnitude of N responses among landscape positions was inconsistent among site locations. Fiez et al. (1994a) found that on more convergent footslopes and N-backslopes, a rate of at least 140 kg/ha N was required to achieve maximum yield . Other landscape positions did not require as much N to achieve maximum yield. Yields were significantly and positively related to soil water balance and precipitation, and more soil water was used at higher N rates on most landscape positions.

2.3.3 Grain Protein

The factors controlling GPC vary throughout the soil-landscape. Characteristic redistribution of soil moisture may have a large impact on within-field variability in GPC. McKercher (1964) demonstrated that GPC varied more among slope positions within a field than overall mean percentages varied among widely separated fields. Also, he noted wheat on Solonetzic or Gleysolic soils had lower GPC than other profile types. Fiez et al. (1994a, 1995) found that soft white winter wheat GPC tended to be greatest on eroded shoulders and lowest in more convergent and moist N-backslope positions, varying by up to 51%. GPC was inversely related to A horizon depth (r^2=-0.57), indicating moisture was a contributing factor. Also, GPC was strongly related to pre-plant residual nitrate levels (r^2=0.82), significant amounts of which occurred below 91 cm. Residual levels varied widely among landscape positions, such that no consistent GPC-N fertilizer relationships emerged among landscapes or years.

2.3.4 Variable-Rate N Application

As a result of observed variability in grain yield and response to N, several investigators have stated that no single N rate can be optimal for an entire field (Mulla, 1993; Fiez et al., 1994a,b, 1995; Carr et al., 1991; Beckie et al., 1997). Researchers have sought to define areas that behave alike with respect to productivity for the purpose of management. Utility of spatially fixed management units is determined by their ability to explain variability in fundamental yield determinants, moisture and fertility, and to reflect resultant differences in crop production. To benefit from managing inherent productive differences that exist within fields, the increased economic returns must be sufficient to offset the additional cost of intensified management requirements. The potential economic benefits depend on the extent of N misallocation, i.e., the variability in response to N fertilizer, among such management units. Potential yield increases obtained from variable rate fertilization (VRF) depends on the areal percentage of the field identified as deficient with respect to a particular input applied at a uniform rate, and the magnitude of that deficiency. Likewise, input savings are dependent on the areal percentage of a field which is over-fertilized and the magnitude of the excess (Sawer, 1994; Fiez et al., 1994a,b). Also, Fiez et al. (1994b) noted that where the N rate identified at maximum economic yield (MEY) is exceeded, additional yield may offset some loss, since N requirements for the productive optima are generally higher.

Western Canada's hummocky landscapes are quite variable, and are thus potentially well-suited to VRF (Beckie et al., 1997). Topography is the predominant criterion that is being investigated for delineation of VRF management units in Western Canada. Pennock and de Jong (1987) developed landform elements based on surface curvature and gradient which can be smoothed to form landform element complexes (LECs). The individual elements were used extensively to evaluate pedogenic and geomorphic controls in Western Canadian landscapes (Pennock et al., 1987b, 1989, 1990a,b,c), but the LECs have also been subsequently utilized to evaluate productivity differences in the soil-landscape (Elliott and de Jong, 1992a, Solohub, 1994, Jowkin and Schoneau, 1998). Elliott and de Jong (1992a) noted that among study sites, the areal percentage of LEC type differed noticeably, which has implications for management. McCann et al. (1996) successfully used image analysis of black and white photos to stratify areas of differing amounts of organic and inorganic carbon and soil moisture, presumed to have like productive characteristics, into knolls, midslopes, lower slopes and depressions. Under a uniform fertilization rate and typical rotation over three landscape positions and three years, Beckie et al. (1997) did not detect a consistent landscape-yield relationship. However, the authors in fact realized a positive economic return by varying N rates based on expected yield potential over the three years, largely by reducing rates on the upper slope.

Fiez et al. (1994a, 1995) stated that any variable rate N program must account for spatial differences in crop yield potential and the ability of the crop to respond to fertilizer N to reach that yield potential, which is in part determined by the amount of plant-available N supplied by the soil. While yield potential was easier to quantify and predict, the authors stated that response to N, expressed as Unit N Requirement (UNR) for unit yield production, was more difficult to determine. UNR is essentially the inverse of NUE, such that a higher value means less efficiency and more fertilization is required to reach a given yield potential. When broken down into components of N uptake efficiency and N utilization efficiency (Huggins and Pan, 1993), the authors found uptake efficiency accounted for most of the variation in the UNR, which was proportional to the apparent amount of N lost. While this indicated the need to accurately quantify plant-available N, more importantly, it indicated the need to account for UNR deviations on a landscape scale. UNR at the predicted MEY varied among landscape positions by 43-70% over the course of the two year study. Using a difference method, calculated losses of greater than 50% of applied N were attributed to leaching, denitrification or lateral movement losses, mainly from the north backslope position. The authors determined that site-specific UNR values were needed to account for differences in soil supply of N and losses among landscape positions. When experimentally determined UNRs were employed in each of the landscape positions to calculate crop requirement, average economic return with site-specific UNRs over 4 site years was $10.02/ha above that of conventional methods.

Researchers have delineated fields on the basis of SOC for the purpose of VRF. This is because moisture and fertility, the two most limiting factors to crop yield, tend to be related to SOC (Beckie et al., 1997, Mulla, 1993). Beckie found that by gaining FUE with lower N rates (59 kg/ha) on the low SOC areas, by assigning medium N (92kg/ha) to the medium SOM area, and medium N to the high SOC area where mineralization was expected to contribute more strongly, net profitability was increased over the conventional rates. Mulla (1993) delineated management units by splitting a frequency distribution of SOC at plus and minus one standard deviation from the mean to create high, medium and low SOC classes. Using yield potential estimates and residual nitrate levels, rates of 37, 45 and 28 kg/ha were applied to each class, respectively. No significant yield reduction was observed, despite the fact area producers typically applied uniform rates of 73-95 kg/ha, and hence greater efficiency was observed. Data was obtained from 1 year and 3 years for Mulla and Beckie et al., respectively.

It has long been an important hypothesis in soil classification that yield differences may be associated with the pedogenic differences used to delineate soil series. Hence, studies have examined the link between productivity and soil types as they occur in the landscape. Rennie and Clayton (1960) studied soils from Black, Solonetzic Dark Brown and Solonetzic Brown great groups. In the Oxbow association, the overall rank of yield potential was always Orthic Black>>Orthic Dark Grey>Calcareous Black>Low Humic Eluviated Gleysol. This was consistent with expectations for moisture-limited production (the Gleysol suffered from excess moisture and management problems). This demonstrated the short-range variability in yield potential for hummocky landscapes. The authors stated that as a result of such large differences, any recommendation derived from small plot studies should only be applied to like soil series within an association.

While Carr et al. (1991) found large differences in production among soil-survey derived series in Montana, soil series do not necessarily reflect characteristic crop yields; variation may be as high within soils as among them (Sawer, 1994). Karlen et al. (1990) found that some yield variation was explained by depth to Bt/argillic horizons. However, variation in crop yield was large within delineated soil series. In total, 19 soil series were identified in the 8 ha used in the study (scale not specified) and 'boundaries' were clarified with additional cores, such that the delineations in the Coastal Plain field were meaningful with respect to soil series. The productive inconsistency indicated the need to account more directly for causal factors in the management units and examine their temporal stability. Soil map units are variable and may often contain inclusions of dissimilar soils (Steinwald et al., 1996). 'Purity' of a map unit depends on scale and mechanics of construction. As complexity of the landscape increases, taxonomic classification becomes more difficult, affecting the utility of soil map units for agricultural management decisions. Moore et al. (1993) suggested a scale of 1:6000 was needed for management purposes. Within the Newdale soil association in southern Manitoba, a scale of 1:5000 is sufficient to delineate individual soil series for the purposes of VRF, whereas an increase in scale to 1:3000 or 1:2000 would be more practical for research purposes (Eilers[3], personal communication).

Soil residual nitrate nitrogen is an important determinant of FUE, and has been evaluated as a criterion for defining management units for VRF. As nitrate concentrations can be unpredictable and highly variable over short distances, one approach to defining management units is to systematically sample fields in a grid pattern. Where yield potential is assumed to be constant across a field, N fertilizer requirements are therefore dependent on residual nitrate concentrations. Beckie et al. (1997) did not observe an increase in FUE or economic returns for VRF when management units were based solely on soil residual nitrate-N levels and a constant yield potential. The approach was not successful because of systematic variation in yield potential due to topographic variation within the field. Wibawa et al. (1993) collected soil fertility and crop yield data in a grid pattern, in order to evaluate the efficiency and profitability of different combinations of samping density and predicted yield goals within individual soil series. Production was maximized by systematically sampling on a 15.2 m grid, and using this information in conjuction with uniform or series-specific yield goals to create fertility reccommendations. The higher production was gained by adressing point-specific nutrient deficiencies, but costs were prohibitive, due to sampling and analysis costs. Economic returns were greatest with 1) a field composite soil sample, a uniform yield goal, and a uniform application rate or 2) series-specific composite sampling, uniform or series-specific yield goals, and the resultant series-specific fertilizer rates. This indicated

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[3] Land Resource Unit, Agriculture and Agri-Food Canada

that from an economic standpoint, fertility reccomendations within sub-field management units should be oriented towards detection of underlying, systematic soil-landscape variability in residual fertility.

2.3.5 Variable-Rate Fertilization and Environmental Protection

The objective of a variable-rate N fertilization program is usually to maximize utility of N inputs, where utility is most often defined as profitability. Profitability is then dependent on response to N fertilizer at a given location. Several authors infer that enhanced profitability and sustainability are synonymous, due to a reduction in soil residual N excesses (Carr et al., 1991; Fiez et al., 1994). For example, enhanced efficiency would result in lower leaching, denitrification and other losses.

However, it is over-simplistic to assume more profitable variable rate application will always be more sustainable. Kachanoski et al. (1985) found that N fertilizer response was most often higher and most profitable in convergent portions of the landscape despite the additional potential for mineralization. In areas of regional recharge, downward groundwater fluxes tend to be strongest at these same convergent portions of the landscape, as reflected by soil genetic characteristics, such that there may be greater potential for deep nitrate leaching. Also, given the greater potential for anaerobiosis and the greater carbon supply, these same areas are more prone to denitrification (Pennock et al., 1992; Farrel et al., 1996).

VRF application of lower than average N rates may have negative impacts. Elliott and De Jong (1992a) noted that fertilizer on upper slopes might enhance crop growth and reduce potential for erosion. However, the authors also noted that the practice may be redundant if these areas are water-limited. Mahli et al. (1996) found that annual additions of fertilizer N to bromegrass resulted in a substantial increase in storage of C in the soil. Reduction of N inputs due to a characteristic lack of response may avoid redundant soil N levels, but it may be at the cost of C sequestration under conditions where soil residual N or applied fertilizer N actually elicit a biomass response.

2.4 Summary

Hydrologic and geomorphic processes are a function of soil surface morphology, and interact to form characteristic, generally predictable, soil-landscape relationships. Hydrologic influences accentuate pedogenic processes in the glacial-depositional landscapes in the Prairie Ecozone of Western Canada. As a result, studies have elucidated relationships with three-dimensional surface morphology and soil morphological characteristics such as solum depth and A horizon depth, and chemical properties such as SOC and soil pH. All such relationships arise mainly from the characteristic redistribution of water in the landscape, such that convergent elements tend to receive moisture from surface and subsurface flow. As a result of such differential distribution, there are implications for productivity. Inherent fertility and available soil water are strongly related to organic carbon distribution. Productive implications of this characteristic distribution are largely dependent on growing season conditions from year to year. In moisture limited climates, yield potential is largely a function of available moisture. The amount of available moisture determines the relative utility of plant-available N, and the amount of residual soil N and mineralization determine the utility of fertilizer N in achieving MEY. Since yield potential and N response have been observed to vary widely among landscape positions, several researchers have studied the possibility of matching N inputs more closely to crop demand in the landscape to achieve MEY in the hope of improving profitability. Thus far, these attempts have met with mixed success and there are no consistently observed relationships in yield potential, N response and landscape morphology. Growing season weather has been and will continue to be the factor that determines the success of any such attempt. Long-term probabilities must be established to evaluate the utility of fixed management units for capturing variability in productive potential and N response.

3. SPATIAL VARIABILITY OF STATIC SOIL PROPERTIES IN A VARIABLE MANITOBA SOIL-LANDSCAPE

3.1 Abstract

The relationship between static soil properties (soil organic carbon (*SOC*), soil pH (*Ap pH*), A horizon depth (*A d*), solum depth (*Solum d*) and depth to carbonates (*CO3 d*)) and landscape morphology was studied in ten intensively sampled transects in a gently undulating glacial till landscape near Miniota, Manitoba. Using a landform description model by MacMillan and Pettapiece (1997), the study site was delineated into Upper (U), Mid (M), Lower-Mid (LM) and Lower (L) elevation Landform Element Complexes (LECs). The program used a digital elevation model created from relative elevation data collected on a 10 m grid. Over all LECs, correlations between individual topographic descriptors (as described by Pennock et al., 1987) and soil properties, and correlations within soil properties, were generally weak. Within individual LECs, correlations tended to improve. General trends were observed in median values of topographical descriptors and soil properties among LECs. Differences in soil properties were often statistically significant among LECs, where the L was most clearly distinct. There was a general trend of L > M > U for *CO3 d*, *A d* and *Solum d* and *SOC*. Relative ranking of *Ap pH* was the opposite. The LECs were useful in capturing gross variability in the soil properties in the landscape. Some of the remaining variability was ascribed to the occurrence of differing hydrologic and pedogenic regimes, as determined by examination of genetic profiles within the LECs.

3.2 Introduction

Characteristic, predictable soil-slope associations occur in the hummocky landscapes of the Prairie Ecozone of Western Canada as a result of the influence of topography on pedogenesis, mostly through control of the hydrologic regime throughout the landscape. Redistribution of water by areas of convergent and divergent flow strongly influences pedogenic development in the landscape (Pennock et al., 1987). Aandahl (1948) found that with an adequate description of three-dimensional configuration, plant-microclimates and soil properties become predictable, and that changes in soil type often occur at the point of inflection between convexity and concavity. The use of topography to segment or describe the landscape for prediction of the occurrence of soil properties is attractive for its convenience. The distribution of physical and chemical soil properties are of interest because of their direct and indirect influences on productivity, which has implications for site-specific management.

Various researchers have investigated means of quantitatively describing topography and segmenting landscapes to better understand hydrologic controls of pedogenesis. Hugget (1975) noted that two-dimensional descriptions of topography are meaningful only in rectilinear landscapes. Using three-dimensional mathematical descriptions of topography including slope, rate of change of slope and radius of curvature, Troeh (1964) achieved good correlation with soil drainage characteristics. Pennock et al. (1987) developed a three-dimensional classification of seven hillslope elements, using gradient, plan curvature and profile curvature. These original elements were dubbed divergent and convergent shoulders (DSH, CSH), backslopes (DBS, CBS), footslopes (DFS, CFS), and level (L) elements.

Soil A horizons result from addition of organic matter to mineral soil and subsequent mixing of the two. *A d* is reflective of the rate of carbon addition and is a function of moisture regime. *CO3 d* at a given point is predominantly controlled by the penetration of moisture in the soil (Pennock and de Jong, 1990b). Comparisons among landform elements by Pennock et al. (1987) resulted in intuitive trends for *A d* and *CO3 d*, whereas variability explained by individual topographic descriptors were weak. Pennock and de Jong (1990b) found that both soil properties, along with global catchment and the presence of eluvial horizons, increased with convergent character in the landscape. Shallow, more carbonated soils in divergent upper slope positions, and greater solum depths in convergent, often depositional, lower slope positions are commonly observed (Miller et al., 1988; Simmons et al., 1989; Fiez et al., 1994a).

Distribution of *SOC* within a variable landscape is largely determined by the redistribution of water. Pennock and Vreeken (1986) found that *SOC* accumulation was a function of more recent pedogenic episodes and corresponded well with present-day topography. *SOC* is an indicator of the historical production of biomass in a given location and affects the chemical and physical properties of a soil, and hence fertility and moisture retention. Accordingly, Gollany et al. (1992) noted that *SOC* decreased as topsoil depth decreased, as did available water holding capacity. Distribution of *SOC* (as well as *A d*) may be largely influenced by tillage, wind and water erosion, with greater amounts occurring in areas of more convergent character (Moulin et al., 1994; Verity and Anderson, 1990; Mulla, 1993). Distribution is also a function of microrelief. Chang

(1995) found 65% of the variation in total *SOC* could be explained as a function of relative relief over a transect where the range of relief did not exceed 62 cm.

In relatively young glacial-depositional surface soils of the Prairie Ecozone, alkaline pH values tend to predominate due to the presence of basic, unweathered carbonated parent material. In an Oxbow toposequence in southern Saskatchewan, Spratt and McIver (1972) found soil pH to be generally alkaline, varying from 7.8 in the upper slopes and decreasing to 7.4 in the depressions. Infiltration of water into the soil removes bases from the soil profile, thus reducing the pH in more strongly leached surface horizons. Thus, *CO3 d* corresponds with trends in soil pH. Miller et al. (1988) observed more alkaline soil pH occurred with greater carbonate concentrations in eroded Ap horizons.

King et al. (1983) noted the characteristic occurrence of thin Calcareous or Regosolic Chernozems, with thin or non-existent B horizons in convex upper slopes. Midslope units were typically Orthic, and concave lower slope and depressional soils were generally Eluviated or Gleyed, with argillic B horizons. Rennie and Clayton (1960) noted a sequence of Calcareous Black, Orthic Black, Orthic Dark Grey, and Eluviated Gleysol moving from the uppermost point in a toposequence to the lowest, most poorly drained. Such sequences indicate a progressive increase in solum development moving from the more arid, divergent crest to the more moist, convergent footslopes and depressions in semi-arid grassland toposequences. From the convex to the concave, there is a concomitant increase in organic matter accumulation and transformations, carbonate weathering and leaching, and pervection and weathering of clay minerals. Gleying results due to reducing conditions in depressional landscape positions caused by water table dynamics. The result is soils which are taxonomically and functionally distinct at the landscape scale, due to varying intensities of accumulation and net downward flux of water.

Based in part on landform segmentation procedures by Pennock et al. (1987), a landform description program was created by MacMillan and Pettapiece (1997). The model uses topographic derivatives from digital elevation data for the description of terrain orientation, shape and scale. The program then delineates discrete LECs of similar convergent or divergent character, with consideration given to the landscape context in which they occur. The program may also be used to predict the occurrence of most probable soil type.

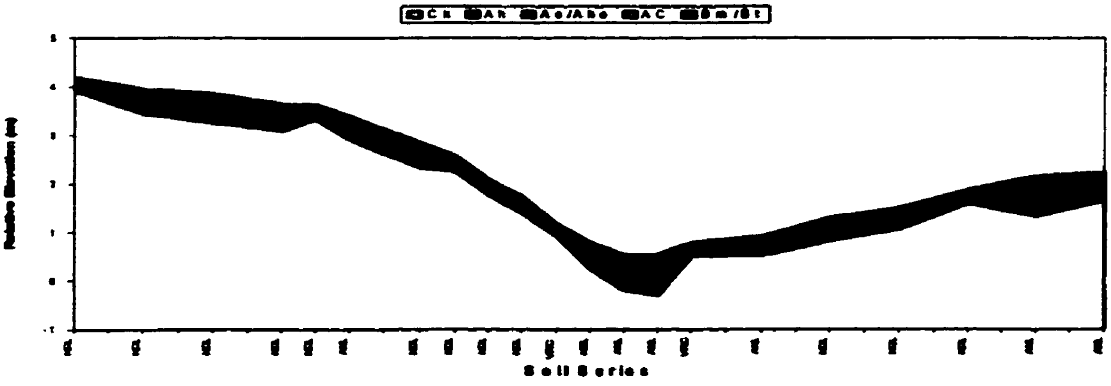
The purpose our study was to characterize the distribution of 'static' soil properties in a simple glacial till landscape, to provide a context in which to evaluate productivity. 'Static' soil properties are those which were not expected to vary appreciably over the course of the two year study. This was done by examining the relative magnitude of the selected properties among LECs derived by MacMillan and Pettapiece (1997), and also by examining bivariate relationships with topographic descriptors as described by Pennock et al. (1987). These LECs have not been previously evaluated for their utility in capturing variability in static soil properties in Manitoba soil-landscapes.

3.3 Materials and Methods

3.3.1 Site Characteristics

The study was located near Miniota, Manitoba on a gently undulating glacial till landscape. The site is representative of a broad region of glacial till landscapes in the Black soil zone. The site has been farmed for over 50 years. Prior to 1976, the site was in a wheat-fallow rotation. In 1976, continuous cropping was initiated; in 1978, tillage was reduced to a minimum-till system; and in 1988, a zero-till system was established along with a more consistent cereal-broadleaf crop rotation.

A 1:5000 soil survey was conducted on the entire quarter section by the staff of Land Resource Unit of Agriculture and Agri-Food Canada (Fitzmaurice et al., 1999), resulting in the differentiation of significant soil series in the Newdale association. Typical subgroups were identified and related to defined soil series (Appendix 1). The majority of soils in the site were Black Chernozems. Hydrologically, the area is considered to be a regional recharge site. Soils in the M and U portions of the landscape were predominantly well-drained Orthic profiles, described by the Newdale soil series. There were also minor occurrences of Regosolic and Calcareous soils, and on more convex surfaces, slightly eroded Orthic soils. Imperfectly drained soils in the lower to toe slope positions were of a typically higher moisture regime. Characterized by more strongly leached and eluviated horizons, these profiles were classified Gleyed Eluviated Black Chernozems (Angusville soil series). Minor areas of imperfectly drained Gleyed Carbonated Rego Black Chernozems, identified by the Varcoe soil series, occurred near the toe slopes in close association with Angusville soils. The distribution of soil series within the study site transects is represented schematically in Figure 3.1.



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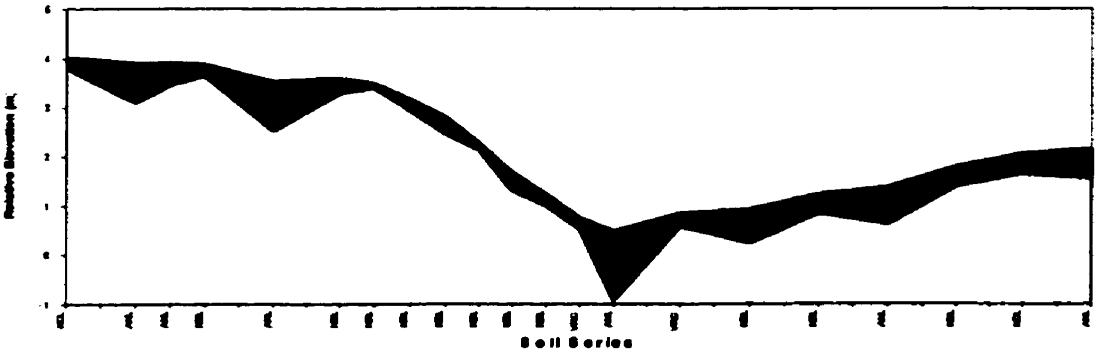

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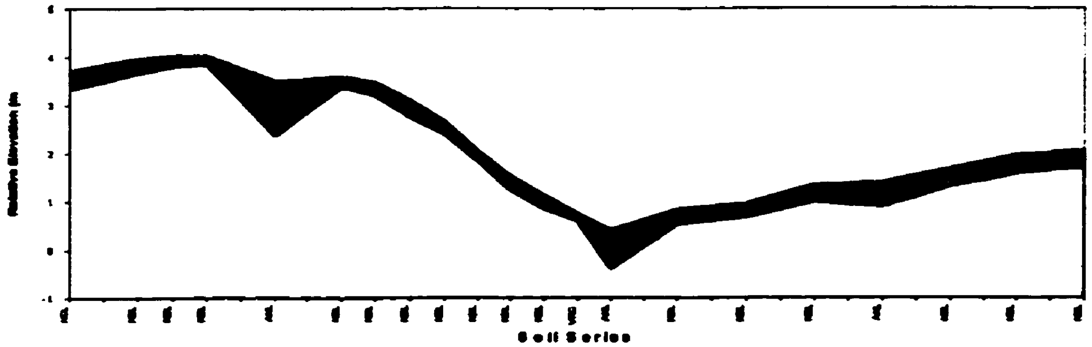

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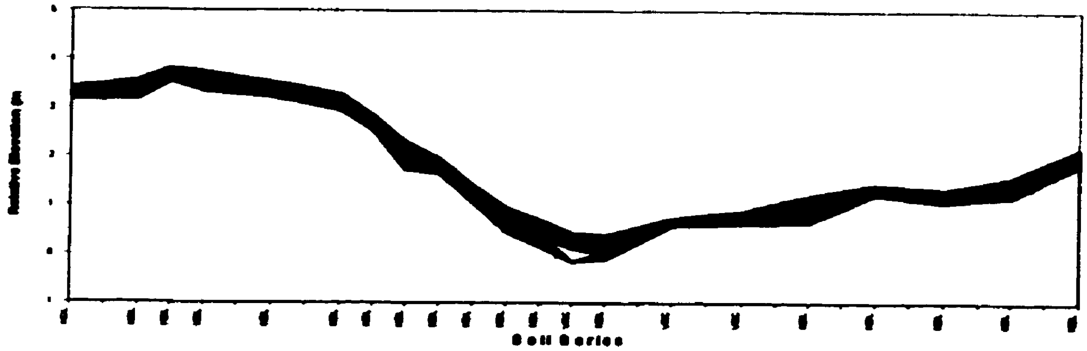

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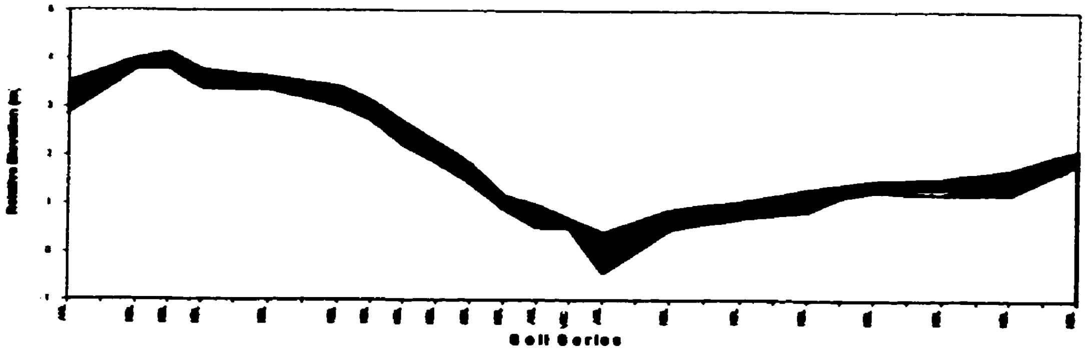
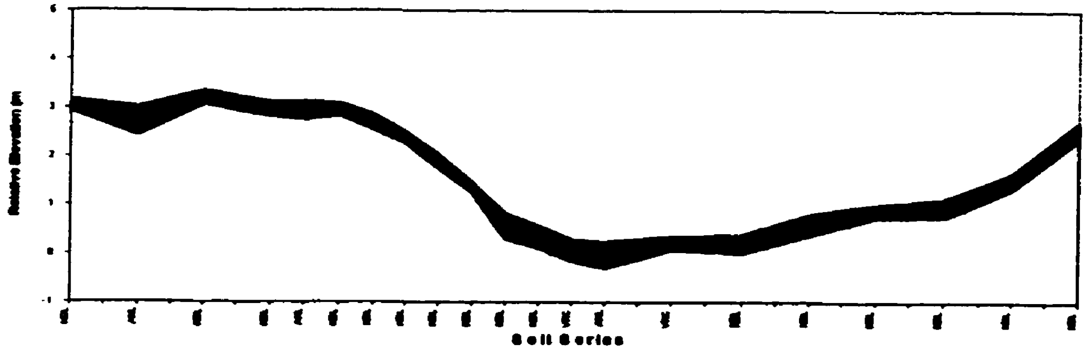
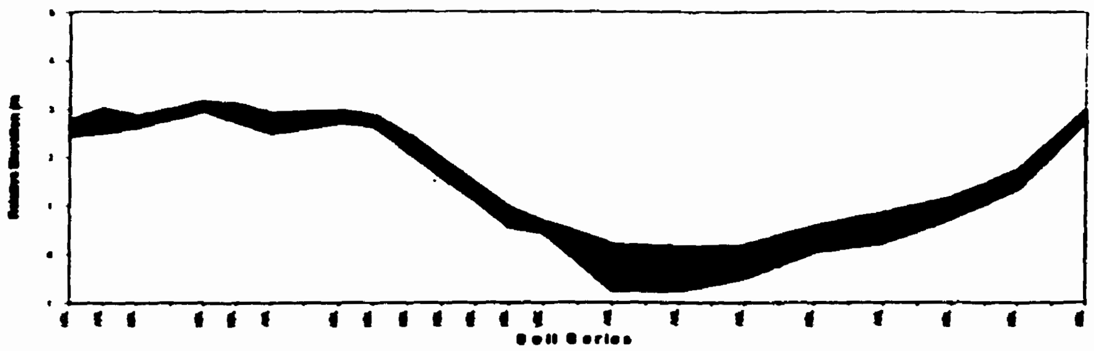


(e) Transect 5

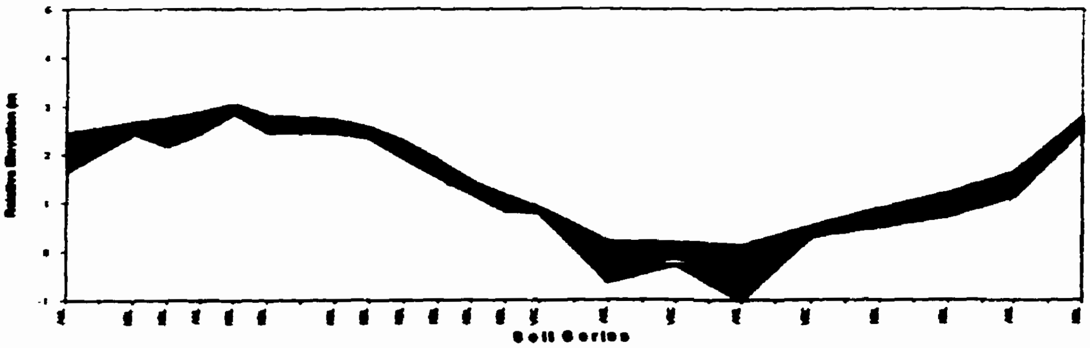
(f) Transect 6



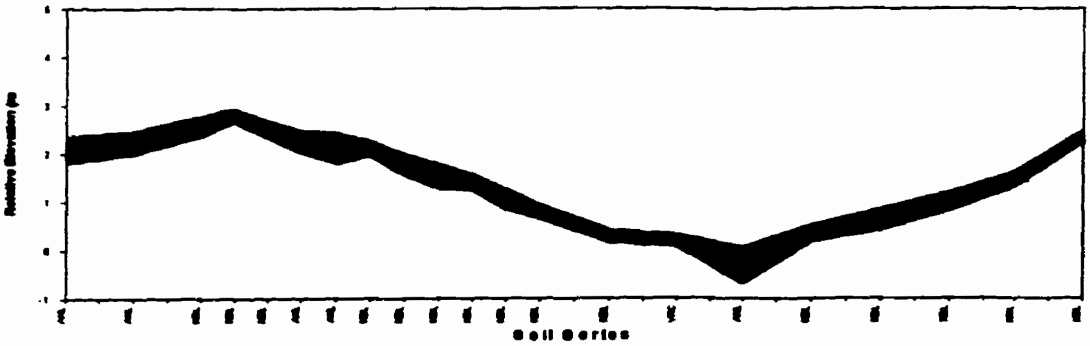
(g) Transect 7



(h) Transect 8



(i) Transect 9



(j) Transect 10

*[NDL=Newdale (Orthic Black Chernozem, with minor inclusions of Rego Black Chernozems (Rufford), Calcareous Black Chernozem (Cordova), and slightly eroded Orthic Black Chernozems), VRC=Varcoe (Gleyed Rego Black Chernozem), and ANL=Angusville (Gleyed Eluviated Black Chernozem)]

Figure 3.1 Distribution of soil series within study site transects

Mean annual temperature at the site is 2.5°C (Environment Canada, 1991), with a mean annual frost-free period of 120 days (Environment Canada, 1982). Mean annual precipitation is 460 mm with 298 mm occurring from May 1 to September 1 (Environment Canada, 1991). This information is based on data from a nearby climatic center at Virden, Manitoba.

3.3.2 Experimental Design

The site consisted of ten adjacent 11m x 450 m transects over a variable landscape with 21 sampling points in each of these transects, for a total of 210 sampling points in a site area of 5.6 ha (Figure 3.2). There was a maximum of 30 m separation between sampling points within a transect. Of the 21 points in each transect, there were 16 uniformly spaced sampling points on a regular 30 m basis, located by GPS and demarcated by pinflags. The additional 5 points were interspersed at 15 m intervals between the original 16 points at areas of more pronounced inflection in the landscape curvature, where one might expect greater changes in genetic profile characteristics. The site encompassed classic crest, midslope and depression toposequence components, extending from one crest to another via an open depression bisecting the site at right angles.

3.3.3 Sampling Activities

In June of 1997, a formal topographic characterization was performed on the site and surrounding area. A rod and level were utilized within the site boundaries to collect elevation data at each 10m grid point intersection and at each of the 210 sampling points. Elevation data was collected for a minimum of 20 m beyond the site boundaries. This

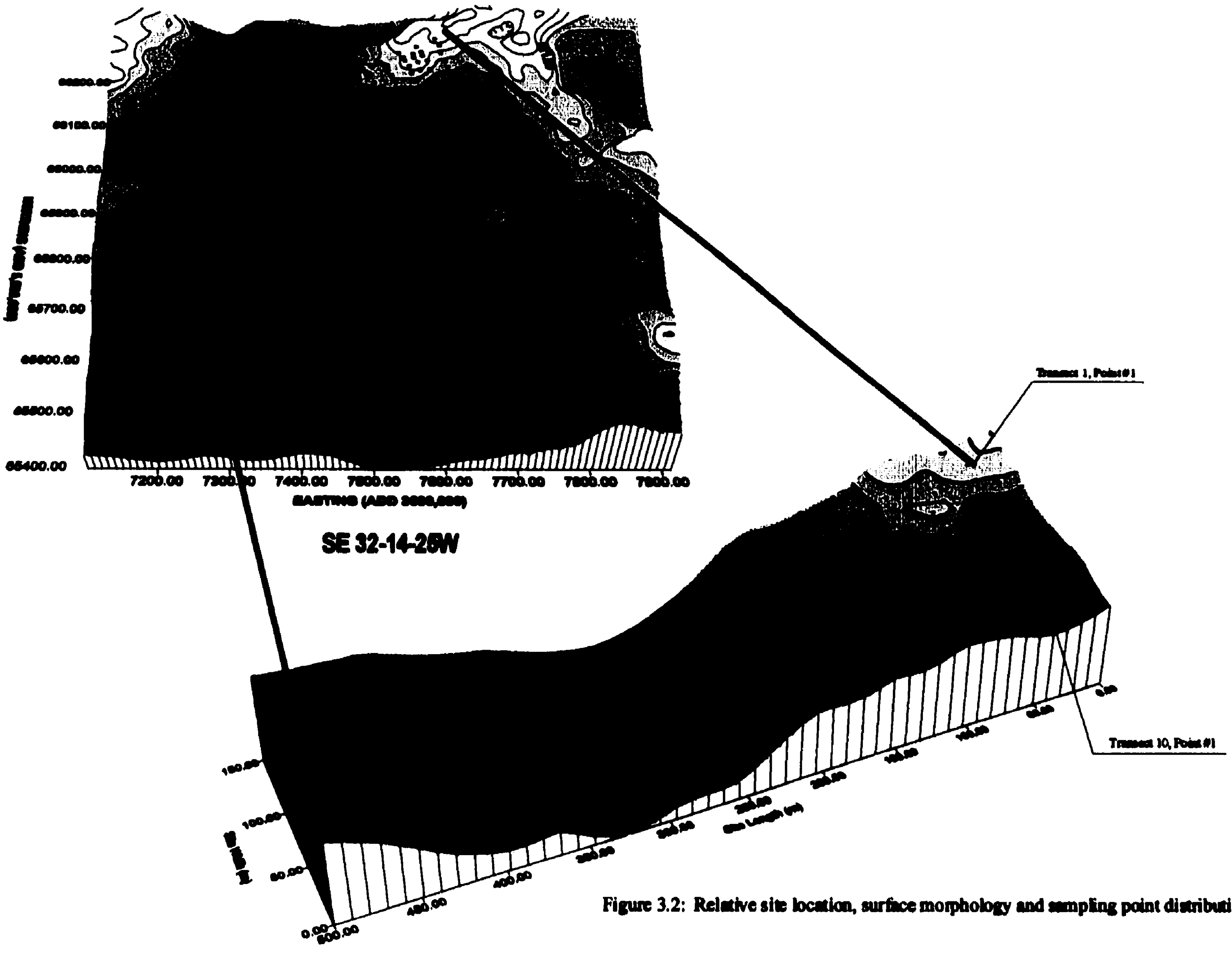


Figure 3.2: Relative site location, surface morphology and sampling point distribution.

information was then used to create a digital elevation model. The remainder of the field was surveyed by a kinematic GPS survey using Trimble 4600 LS, also on a 10 m grid.

In September of 1997, a truck-mounted hydraulic coring device was utilized to obtain intact 3.7 cm diameter soil cores in polyethylene sleeves at each of the 210 points. The cores were taken to the minimum depth of the underlying parent material at each point, with the rare exception of solum depths in excess of 120 cm. The intact cores were transported from the field and stored; all profile descriptions were performed in the laboratory.

3.3.4 Sample Analyses

The individual soil cores were characterized by criteria outlined by the Canada Soil Survey Committee (1998) for the occurrence of each genetic horizon and the depth to carbonated parent material. This information was used to calculate *A d*, *Solum d* and *CO3 d*. All individual genetic soil horizons were air-dried and weighed. The A horizons were ground (<2 mm) for subsequent analyses.

SOC was determined by dry combustion of 0.12 g of oven-dried soil with a Leco model CHN 600 C and N determinator (Nelson and Sommers, 1982). While inorganic carbon content was not measured, removal was accomplished prior to *SOC* measurement by amending all A horizon samples with 6N HCl (Tiessen et al., 1983). Samples were then rinsed clean of residual chlorine with deionized water and suction filtration, oven dried at 110 degrees Celsius, and stored in a desiccator.

All A horizon pH values were obtained by a 1:2 soil to $CaCl_2$ suspension. 10 g of air-dried mineral soil (<2 mm) was weighed into a 50 mL centrifuge tube with 20 mL of 0.01M $CaCl_2$. The solution was shaken intermittently for 30 minutes. After standing for one hour, pH was measured with a glass electrode and recorded when the reading equilibrated (Hendershot and Lalande, 1993).

Saturated pastes were performed for a small number of points in the lower slope, expected to be the most vulnerable to the accumulation of soluble salts, to ensure that salinity was not a limitation. 200 to 400 g of soil were mixed with deionized water until saturation was achieved, allowed to sit for 8 hours, and then extracted by vacuum filtration. Electrical conductivity was assessed with a calibrated conductivity meter corrected to 25°C (Janzen, 1993).

3.3.5 Statistical Methods

Elevation data was used in two landform segmentation programs. The Landform Description Program from Landmapper Environmental Solutions (MacMillan and Pettapiece, 1997) delineated four discrete LECs described here as Upper (U), Mid (M), Lower-Mid (LM) and Lower (L) elevation LECs, using site elevation data. These LECs were superimposed on the existing design, and sampling points were assigned accordingly. The LM comprised less than 5% of the sampling points and was considered to be too small to be of manageable significance; these points were amalgamated with the L and M. There were a total of 35, 126 and 49 sampling points in the remaining U, M and L LECs, which accounted for 19, 54 and 27% of the surveyed area, respectively

(Figure 3.3). Topographic descriptors, including relative elevation (E), plan (*Kh*) and profile (*Kv*) curvature, gradient (*G*), and global (*Cg*) and local (*Cl*) catchment, were calculated for each of the sampling points using the algorithms presented by Pennock et al. (1987). *E* is the elevation of a given point relative to the lowest point in the site. *G* is the maximum rate of change of elevation at each grid point, in degrees. *Kh* is the rate of change of aspect along a contour line in degrees/meter, where aspect is the azimuthal bearing of the gradient. *Kv* is the rate of change of gradient in degrees/meter. *Cg* measures the total catchment contributing runoff to a specific location, allowing for 'spill-over' of water from depressions. *Cl* is the total catchment contributing runoff to a given point without 'spill-over'. *Cg* and *Cl* were expressed as the number of 100 m^2 cells contributing runoff to a given point.

An attempt was made to create landform elements with the criteria of Pennock et al. (1987), but most elements were classified as "level", precluding meaningful comparisons. The classification criteria were developed for hummocky topography, which has greater *K* and *G* values than those typically observed in undulating topography. The classification uses gradient as a criterion secondary to curvature, such that linear elements with gradients of less than 3° are classified as level. Our site was dominated by linear midslopes with *G* values less than 3°. The MacMillan and Pettapiece (1997) program was more effective in this gently sloping landscape because it used numerous measures of relative landscape context, rather than relying solely on gradient and curvature.

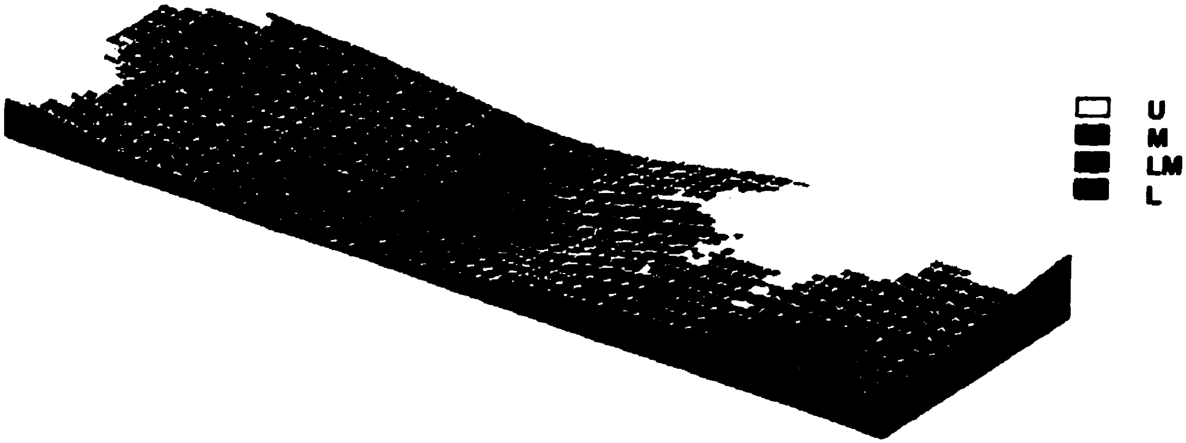


Figure 3.3 Site LEC delineations by MacMillan and Pettapiece (1997).

Surfer™ gridding and contouring software (Golden Software, Boulder, CO) was used for qualitative exploration of elevation data, topographic descriptors and soil morphological variables. Side-by-side boxplots were used to compare differences in centrality among LECs.

Parametric statistical procedures are not applicable unless requirements such as normality are met for variables of interest. Requirements of non-parametric statistics are not as stringent. The tests enlisted here are distribution-free and are based on ranks of observations, as some of the properties observed were not normally distributed. Correlations between variables were done using Spearman correlations, and tests for statistically significant differences among LEC populations was performed using the Kruskal-Wallis test with a multiple-comparison procedure.

Spearman correlations and Kruskal-Wallis tests were obtained with SPSS v. 8.0 software. Multiple-comparison procedures were performed using a technique described by Daniel

(1990). 'Statistical significance' for multiple comparisons was set at $\alpha=0.20$. There is greater error variability at the landscape scale, such that a lower significance level of $\alpha=0.20$ has been justified by various researchers (van Kessel et al., 1993; Pennock et al., 1994; Jowkin and Schoenau, 1998). Significance for correlations was defined as $p<0.05$. All abbreviations utilized within correlation tables and in all subsequent discussion are defined in Appendix VI. A glossary of relevant terms is presented in Appendix VII.

3.4 Results and Discussion

3.4.1 Topographic Descriptors: Differences Among LECs

Over the entire site, there was a maximum of 4.2 m relief and slope *G* did not exceed 3° (Table 3.1). Based on topographic descriptors as calculated by Pennock et al. (1987), it was evident that landscape characteristics differed among the LECs delineated by the Landform Description Program (MacMillan and Pettapiece, 1997). Convergent character increased in the order U < M < L.

Table 3.1 Descriptive statistics for topographic descriptors and static soil attributes, across and within LECs.

(a) Overall (n=210)

Attribute	Median	Mean	Std. Dev.	Minimum	Maximum
E (m)	1.9	2.0	1.1	0.1	4.2
G (°)	1.0	1.1	0.6	0.0	2.7
Kv (°/m)	0.0	0.0	0.1	-0.2	0.2
Kh (°/m)	0.3	-0.2	8.5	-102.3	24.2
Cg (m^2*x100)*	1.0	13.2	36.5	0.0	309.0
Cl (m^2*x100)*	1.0	10.8	30.3	0.0	253.0
A d (cm)	19.0	20.8	9.2	7.0	60.0
Solum d (cm)	34.0	37.1	18.1	9.0	140.0
CO3 d (cm)	32.0	35.5	21.4	0.0	140.0
Ap pH	6.3	6.3	0.4	5.2	7.3
SOC (%)	2.2	2.3	0.6	1.0	4.1
SOC (Mg/ha)	47.3	53.9	30.3	6.0	180.6
PDI	.88	.96	.67	.00	3.00

(b) Upper Elevation LEC (n=35)

Attribute	Median	Mean	Std. Dev.	Minimum	Maximum
E (m)	3.6	3.5	0.4	2.5	4.2
G (°)	0.7	0.9	0.5	0.1	2.2
Kv (°/m)	0.1	0.0	0.1	-0.1	0.2
Kh (°/m)	2.4	0.8	7.6	-30.9	14.1
Cg (m^2*x100)*	0.0	1.8	4.9	0.0	24.0
Cl (m^2*x100)*	0.0	1.2	2.9	0.0	13.0
A d (cm)	16.0	17.8	7.5	7.0	45.0
Solum d (cm)	29.0	34.1	19.8	9.0	99.0
CO3 d (cm)	26.0	32.4	25.1	0.0	112.0
Ap pH	6.2	6.2	0.4	5.6	7.0
SOC (%)	1.9	2.0	0.5	1.0	3.4
SOC (Mg/ha)	35.1	40.1	20.3	6.0	79.9
PDI	.85	.95	.78	.00	3.00

(c) Mid Elevation LEC (n=126)

Attribute	Median	Mean	Std. Dev.	Minimum	Maximum
E (m)	1.9	2.0	0.8	0.7	3.8
G (°)	1.2	1.3	0.6	0.1	2.7
Kv (°/m)	0.0	0.0	0.0	-0.1	0.1
Kh (°/m)	0.4	0.5	3.7	-9.7	24.2
Cg (m^2*x100)*	1.0	5.8	14.1	0.0	97.0
Cl (m^2*x100)*	1.0	4.7	12.1	0.0	97.0
A d (cm)	18.0	19.0	6.6	8.0	37.0
Solum d (cm)	33.5	33.8	12.0	13.0	80.0
CO3 d (cm)	32.0	32.4	14.2	0.0	80.0
Ap pH	6.3	6.3	0.4	5.2	7.2
SOC (%)	2.2	2.3	0.5	1.2	3.9
SOC (Mg/ha)	45.2	47.9	20.9	12.4	108.9
PDI	.88	.94	.59	.00	2.30

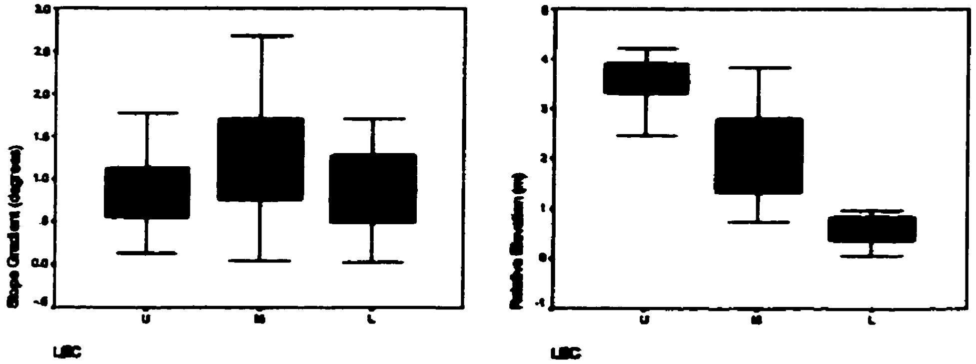
(d) Lower Elevation LEC (n=49)

Attribute	Median	Mean	Std. Dev.	Minimum	Maximum
E (m)	0.6	0.8	0.8	0.1	3.0
G (°)	0.9	0.8	0.4	0.0	1.6
Kv (°/m)	0.0	0.0	0.1	-0.2	0.1
Kh (°/m)	-1.3	-2.9	15.0	-102.3	15.3
Cg (m^2*x100)*	4.0	40.3	65.4	0.0	309.0
Cl (m^2*x100)*	4.0	33.2	54.2	0.0	253.0
A d (cm)	28.0	27.6	12.2	9.0	60.0
Solum d (cm)	45.0	47.6	24.9	9.0	140.0
CO3 d (cm)	45.0	45.6	29.8	0.0	140.0
Ap pH	6.5	6.5	0.3	5.9	7.3
SOC (%)	2.6	2.7	0.6	1.6	4.1
SOC (Mg/ha)	68.1	79.3	41.1	16.8	180.6
PDI	.89	1.02	.78	.00	2.70

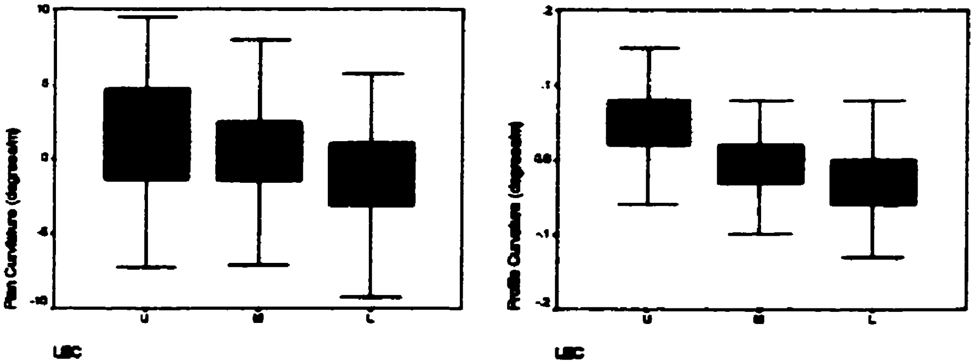
Relative elevation (E) indicates how LECs relate spatially and in general, is inversely proportional to convergent character. Within the site, the progression was U > M > L (Table 3.2, Figure 3.4). G is inversely related to convergent character. Overall, G values were low, but were greatest in the M. The U and L were comprised of more level topography. Negative values for Kv (downslope) and Kh (cross slope) indicate convergence. While there was little difference apparent in Kv values, median Kh values followed a progression from the U to the L. The U was divergent (+2.4), the M was slightly divergent, but more linear in character (+0.4), and the L was most convergent (-1.1). Cg and Cl are calculated by the upland area which contributes overland flow to a given location and are proportional to convergence. Presented are median values of the number of 100 m^2-cells which contributed flow to the sampling points in each LEC. The rank of convergent character with respect to both Cg and Cl indices was L > M > U , similar to observations by Pennock et al. (1987) in numerous glacial-depositional Saskatchewan sites.

Table 3.2 Median values of selected topographic descriptors, across and within LECs.

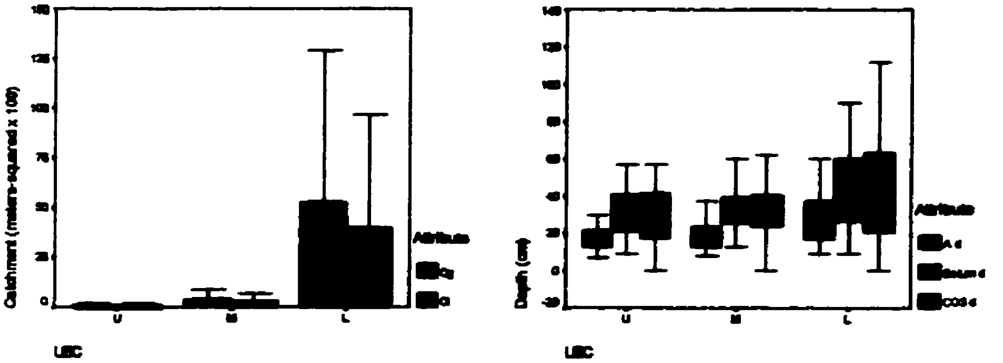
	LEC			
Attribute	Overall	U	M	L
E (m)	1.9	3.6	2.0	0.6
G (°)	1.0	0.7	1.2	0.9
Kv (°/m)	0.0	0.1	0.0	0.0
Kh (°/m)	0.3	2.4	0.4	-1.1
Cg (m^2x100)	1.0	0.0	1.0	4.0
Cl (m^2x100)	1.0	0.0	1.0	4.0



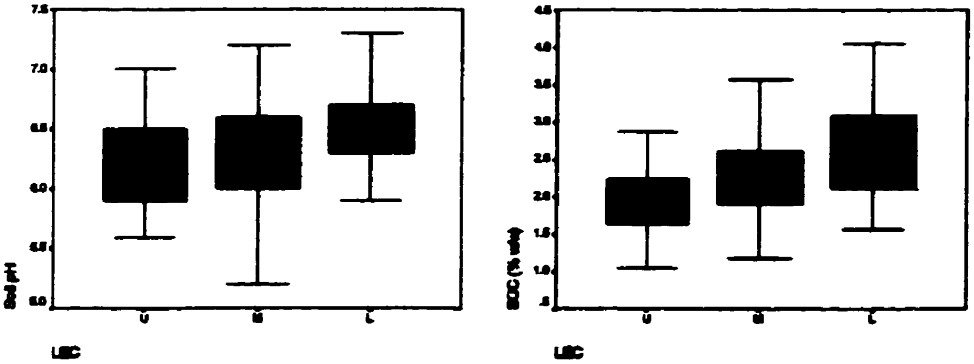
(a) G^a (b) *E*



(c) *Kh* (d) *Kv*



(e) *Cg, Cl* (f) *A d, Solum d, CO3 d*



(g) *Ap pH* (h) *SOC(%)*

Figure 3.4 Relative distribution of static soil attributes and topographic descriptors.
[a][Boxes represent the median and the upper and lower quartiles. Whiskers extend to the largest and smallest observed values that are less than 1.5 times the interquartile range from either end of the box.]

3.4.2 Soil Attributes: Differences Among LECs

3.4.2.1 Ap, Solum and Carbonate-Free Soil Thickness

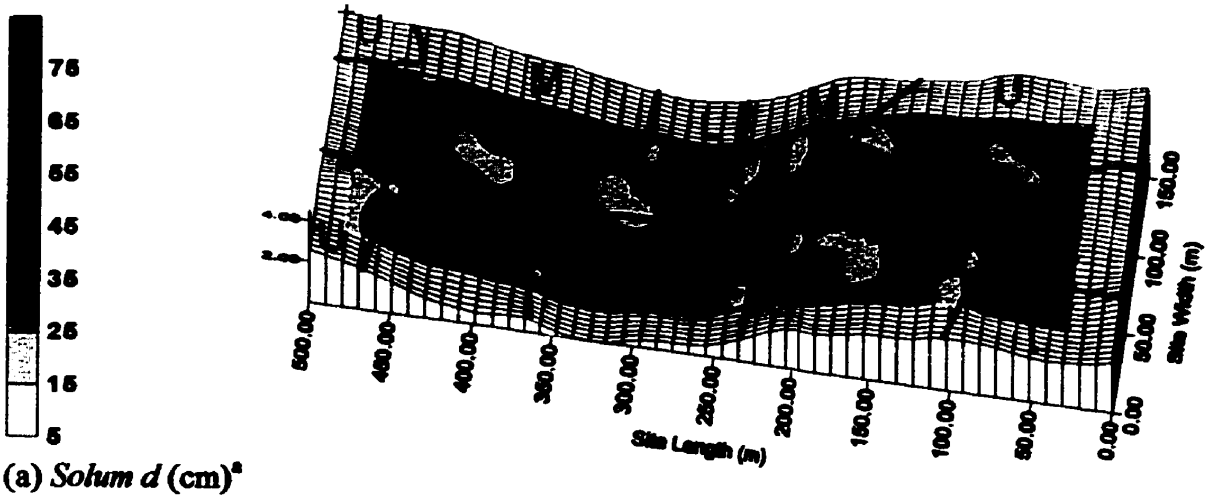
'A' horizon thickness (*A d*), solum depth (*Solum d*) and depth of carbonate-free soil (*CO3 d*) increased moving from the U to the L, coinciding with the extent of convergent character in the landscape (Figures 3.4, 3.5). Over all LECs, total *A d Solum d* and *CO3 d* ranged from 7 to 60 cm, 9 to 140 cm, and 0 to 140 cm, respectively (Table 3.1). Only the L emerged as statistically distinct (Table 3.3). Median *A d*, *Solum d*, and *CO3 d* were 16, 29 and 26 cm in the U ; 18, 34 and 32 cm in the M; and 26, 45 and 44 cm in the L, where most strongly eluviated profiles occurred. Pennock and de Jong (1990b) reported similar average values for *A d*, *Solum d*, and *CO3 d* in the Black soil zone, when the LECs delineated here were considered loosely analogous to groups of landform elements defined by Pennock and de Jong (shoulders, backslopes and footslopes; level elements were excluded due to lack of landscape context).

Table 3.3 Median values of selected static soil attributes, across and within LECs.

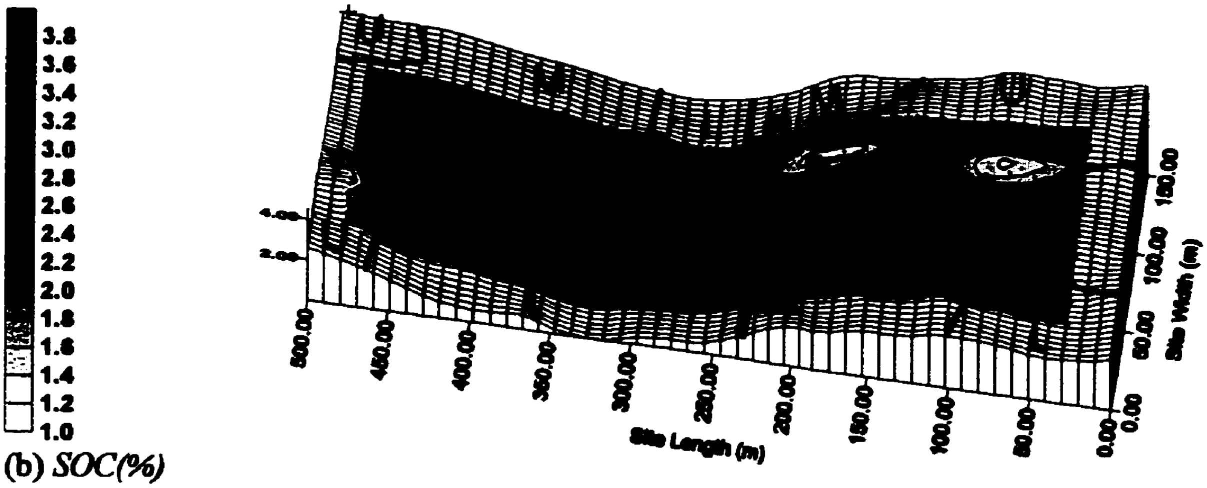
	LEC			
Attribute	Overall	U	M	L
Ap pH	6.3[1]	6.2a[2]	6.3a	6.6b
SOC(%)	2.2	1.9a	2.2b	2.6c
SOC(Mg/ha)	47.3	35.1a	45.2b	64.4c
A d (cm)	19.0	16.0a	18.0a	26.0b
CO3 d (cm)	32.0	26.0a	32.0a	44.0b
Solum d(cm)	34.0	29.0a	34.0a	45.0b
PDI	0.88	0.85	0.88	0.89

[1] Soil pH was determined with a 1:2 soil to $CaCl_2$ suspension

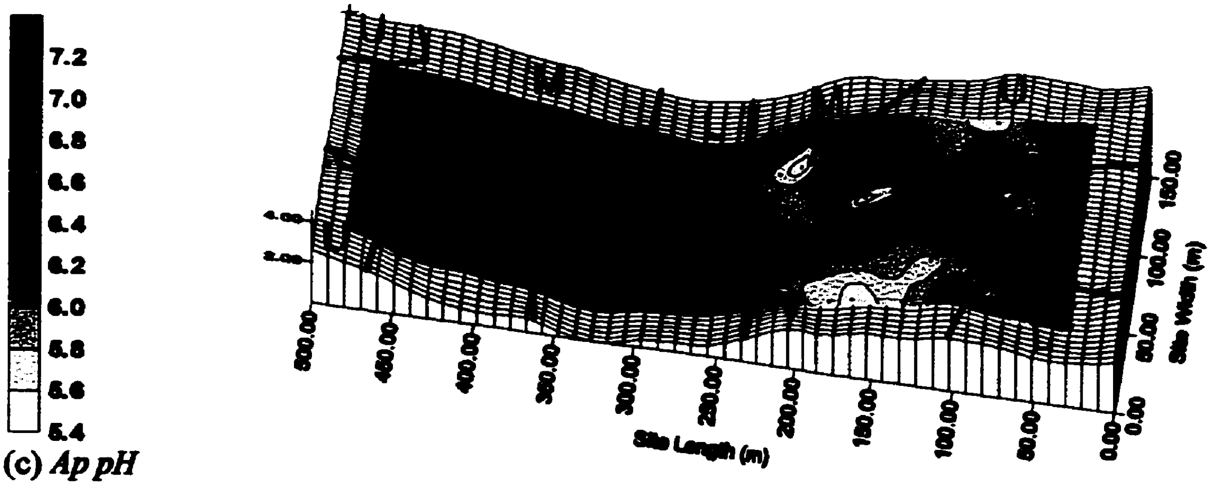
[2] Median values followed by the same letter were not significantly different among LECs at $\alpha=0.20$ (Kruskal-Wallis multiple comparison procedure).



(a) *Solum d* (cm)ª



(b) *SOC(%)*



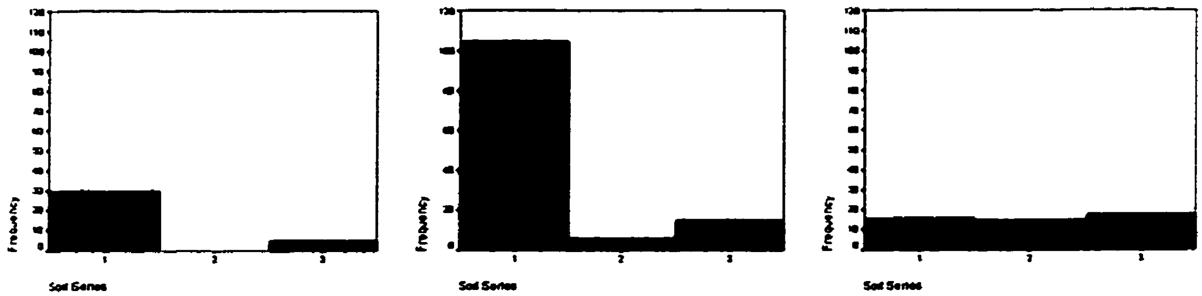
(c) *Ap pH*

ª[U=Upper Elevation LEC , M=Mid Elevation LEC, L=Lower Elevation LEC]

Figure 3.5 Spatial distribution of selected static soil attributes.

Solum d and *CO3 d* are a function of net downward leaching and permeability of the parent material, and as a result are often related to the extent of convergence in the landscape. Pennock et al. (1987) observed similar trends with convergent character in the landscape, where the 'CFS' element was most distinct in terms of *A d* and *CO3 d*, and had the greatest number of gleyed and eluviated horizons. In regions of annual moisture deficits, more strongly convergent portions of the landscape with more strongly developed soil profiles often have greater moisture content, which has important implications for potential productivity. While strongly leached profiles are most likely to occur in convergent portions of the landscape, convergence of flow at a given point does not necessitate downward flux of water. The water table must be sufficiently low, or must drop sufficiently over the course of the season, for downward water flux to occur.

While the L emerged as most distinct with respect to *A d*, *Solum d* and *CO3 d*, two factors affected these differences. The first was the inclusion of the more shallow, often carbonated Varcoe (Gleyed Carbonated Rego Black Chernozem) soils in the L, which occurred in close association with the deeper Angusville (Eluviated and Gleyed Eluviated Black Chernozem) profiles. The second was the delineation of an 'upland' L, in the lower right corner of the site, spatially disjoint from the 'lowland' L. Inclusion of the Varcoe soils and the 'upland' L attenuated the higher *A d*, *Solum d* and *CO3 d* values observed in the 'lowland' L. While the U and M were dominated by the Newdale series, the L was comprised of nearly equal amounts of all three series (Figure 3.6). Varcoe soils comprised 10% of the soil profiles in the site, 70% of which occurred in the L. These soils had median thicknesses of 20, 23 and 19 cm for *A d*, *Solum d* and *CO3 d*,



(a) Upper Elevation LEC[a] (b) Mid Elevation LEC (c) Lower Elevation LEC
[a][1=Newdale, 2=Varcoe, 3=Angusville]

Figure 3.6 Soil series frequency by LEC (*n*=210 sampling points, across all LECs).

respectively (Table 3.4). The respective median values for the closely associated Angusville soils were 32, 59 and 61 cm over all LECs. The Angusville series comprised 18% of the sample points, half of which occurred in the L. Median values for the well-drained Newdale soils, half of which occurred in the M, were 16, 30, and 29 cm over all LECs. The progression from well to imperfectly drained, from Newdale to Varcoe and Angusville, is reflected in the increased *A d* (Newdale < Varcoe < Angusville). The weak leaching regime resulted in the absence of B horizon development and shallow carbonates in the Varcoe soils, a strong leaching regime resulted in the occurrence of greater *Solum d* and *CO3 d* in the Angusville soils, and intermediate to these two extremes were the Newdale soils.

Table 3.4 Median values of selected static soil attributes, across and within soil series.

	Soil Series			
Attribute	Overall	Newdale	Varcoe	Angusville
Ap pH	6.3	6.3	6.7	6.2
SOC(%)	2.2	2.1	2.3	3.0
SOC(Mg/ha)	47.3	41	49	83
Ad (cm)	19.0	16	20	33
CO_3 d (cm)	32.0	29	19	61
Solum d(cm)	34.0	30	23	59
PDI	0.88	0.84	0.00	1.64

Across the entire 65 ha field in which the site was located, other poorly drained associates were present (Fitzmaurice et al., 1999), but only the Newdale, Varcoe and Angusville series are cropped annually. As in the site, the Newdale soils dominate the entire field at 62%, while Angusville soils occupy 10%, and the Varcoe 13%. The relative proportion of soils in the field is much the same as that of the site, despite the fact the Varcoe soils occupy a slightly larger areal percentage in the remainder of the field. Therefore, the well-drained Newdale soils occupy 73% of the cultivated area, and the imperfectly drained Varcoe and Angusville series occupy the remaining 27%.

A relative index of overall soil profile development, (Profile Development Index/*PDI*) described by Fuller[3] (personal communication) was used to assess differences in pedogenic character among LECs. It was apparent that the feature which most differentiated the three main soil series which occurred in the site was the extent of B horizon development. Accordingly, the *PDI* is based on B horizon development and allows normalized comparisons between soils. The thickness of specific genetic B horizons within a given profile, relative to the solum depth, determines the strength of the index. Each genetic B horizon is given a specific weighting factor which is multiplied by its thickness, and this product is divided by the total solum depth for that profile. In a profile with more than one B horizon, values are calculated for each individual B horizon and summed to give the profile *PDI.* Weights of 0, 1, 2, 3 and 4 are assigned for no B horizon, Bmk, Bm, Btj and Bt designations, respectively.

> Example 1: Angusville series, Ah=20cm; Ahe=10cm; Btjgj=25 cm
> *PDI* = (25 cm x 3)/(20 + 10 + 25 cm) = 1.36

Median *PDI* values of 0.00, 0.84 and 1.64 were calculated for the Varcoe, Newdale and Angusville soils respectively, reflecting the extent of B development in each of these series (Table 3.4). Median *PDI* values of 0.88, 0.85, 0.88 and 0.89 were observed across all LECs, and in the U, M and L, respectively (Table 3.1). While not statistically significant, the increase in the index moving from the U to the L reflected the overall increase in the proportion of illuvial genetic horizons, despite the occurrence of the Varcoe series in and near the L, and the inclusion of Angusville soils in U and M. When the Varcoe series was excluded from the L, the mean L *PDI* increased to 1.51 (not shown).

Correlations with individual topographic descriptors support the premise that pedogenic development was proportional to the extent of convergent character at the sampling points. Over all LECs, *A d*, *Solum d*, and *CO3 d* were inversely related to *E, G, Kh,* and *Kv* and positively related to *Cg* and *Cl* (Table 3.5). The correlations were all very significant, with the exception of *CO3 d* versus *E*, which was also significant if Varcoe soils were excluded from the L, and eluvial soils were excluded from the U (not shown). While significant, *E* and *G* correlation coefficients were weak (r^2 = –0.19 to –0.35). Curvature and catchment correlation coefficients were moderate (r^2= -0.41 to -0.57). Pearson correlation coefficients were calculated (not shown) to compare directly with results obtained by Pennock et al. (1987). Coefficients obtained for our glacial till site tended to be slightly better, whereas Pennock et al. (1987) utilized various glacial till, glacio-lacustrine and glacio-fluvial sites. In addition, Pennock et al. (1987) obtained different correlations for *Cg* and *Cl*, which in our study, were essentially alike.

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[3] Axys Environmental Consulting Limited

Table 3.5 Spearman correlations, topograhic descriptors and static soil attributes ($P<0.05$).

(a) Overall	*E*	*G*	*Kv*	*Kh*	*Cg*	*Cl*	*A d*	*Solum d*	*CO3 d*	*Ap pH*	*SOC(%)*	*SOC(Mg/ha)*
E	1.00											
G	NS	1.00										
Kv	0.38	NS	1.00									
Kh	0.25	0.14	0.39	1.00								
Cg	-0.40	NS	-0.52	-0.75	1.00							
Cl	-0.39	NS	-0.55	-0.74	0.98	1.00						
A d	-0.35	-0.26	-0.41	-0.44	0.42	0.44	1.00					
Solum d	-0.19	-0.30	-0.46	-0.57	0.51	0.52	0.70	1.00				
CO3 d	NS	-0.30	-0.44	-0.56	0.53	0.53	0.60	0.89	1.00			
Ap pH	-0.36	NS	NS	0.14	NS	NS	0.14	-0.16	-0.24	1.00		
SOC (%)	-0.39	-0.46	-0.36	-0.42	0.39	0.39	0.55	0.54	0.49	NS	1.00	
SOC (Mg/ha)	-0.44	-0.33	-0.44	-0.45	0.43	0.45	0.92	0.66	0.59	0.22	0.72	1.00

(b) Upper	*E*	*G*	*Kv*	*Kh*	*Cg*	*Cl*	*A d*	*Solum d*	*CO3 d*	*Ap pH*	*SOC(%)*	*SOC(Mg/ha)*
E	1.00											
G	-0.51	1.00										
Kv	NS	0.44	1.00									
Kh	NS	NS	0.43	1.00								
Cg	NS	NS	-0.60	-0.61	1.00							
Cl	NS	NS	-0.61	-0.61	1.00	1.00						
A d	NS	NS	NS	-0.55	NS	NS	1.00					
Solum d	NS	-0.47	-0.52	-0.71	0.43	0.43	0.60	1.00				
CO3 d	NS	-0.55	-0.55	-0.64	0.44	0.44	0.53	0.88	1.00			
Ap pH	NS	0.42	0.44	0.55	-0.56	-0.55	NS	-0.60	-0.59	1.00		
SOC (%)	NS	-0.42	-0.62	-0.59	0.44	0.43	0.48	0.67	0.71	-0.51	1.00	
SOC (Mg/ha)	NS	NS	-0.39	-0.60	NS	0.33	0.85	0.63	0.70	NS	0.73	1.00

(c) Mid	*E*	*G*	*Kv*	*Kh*	*Cg*	*Cl*	*A d*	*Solum d*	*CO3 d*	*Ap pH*	*SOC(%)*	*SOC(Mg/ha)*
E	1.00											
G	NS	1.00										
Kv	NS	NS	1.00									
Kh	0.18	NS	0.23	1.00								
Cg	-0.19	NS	-0.27	-0.73	1.00							
Cl	-0.17	NS	-0.30	-0.72	0.99	1.00						
A d	-0.26	-0.21	-0.21	-0.32	0.28	0.29	1.00					
Solum d	NS	-0.23	-0.28	-0.44	0.32	0.33	0.70	1.00				
CO3 d	NS	-0.25	-0.27	-0.43	0.38	0.38	0.60	0.86	1.00			
Ap pH	-0.21	-0.22	NS	NS	NS	NS	0.20	NS	NS	1.00		
SOC (%)	-0.33	-0.55	NS	-0.24	NS	NS	0.44	0.41	0.39	0.31	1.00	
SOC (Mg/ha)	-0.36	-0.32	-0.21	-0.30	0.25	0.27	0.90	0.61	0.54	0.35	0.63	1.00

(d) Lower	*E*	*G*	*Kv*	*Kh*	*Cg*	*Cl*	*A d*	*Solum d*	*CO3 d*	*Ap pH*	*SOC(%)*	*SOC(Mg/ha)*
E	1.00											
G	0.47	1.00										
Kv	0.36	NS	1.00									
Kh	NS	0.28	0.41	1.00								
Cg	-0.43	-0.33	-0.57	-0.77	1.00							
Cl	-0.43	NS	-0.60	-0.76	0.98	1.00						
A d	-0.49	-0.39	-0.63	-0.53	0.55	0.56	1.00					
Solum d	-0.35	-0.41	-0.57	-0.63	0.70	0.69	0.75	1.00				
CO3 d	-0.29	-0.38	-0.54	-0.63	0.70	0.69	0.70	0.96	1.00			
Ap pH	-0.38	NS	NS	0.28	NS	NS	NS	-0.40	-0.48	1.00		
SOC (%)	-0.39	-0.48	-0.47	-0.54	0.46	0.45	0.65	0.60	0.55	-0.36	1.00	
SOC (Mg/ha)	-0.56	-0.41	-0.57	-0.55	0.53	0.55	0.93	0.72	0.65	NS	0.79	1.00

Correlations were improved when considered individually within LECs, possibly indicating that topographic descriptors did not vary uniformly with soil attributes over the entire landscape. When correlations were considered within the U only, *A d* was significantly correlated only with *Kh* (r^2= -0.55). ***Solum** d* and *CO3 d* were significantly related to all topographic descriptors but *E*, with moderate to strong coefficients (r^2= 0.43 to –0.71). *E* ceased to be of importance as all of the U occurred at like elevations. In the M, most correlations were significant, but coefficients were generally weaker than those found in the U (r^2= –0.21 to 0.43). As it was for the U, *E* explained little variation. In the L, *E* was again significantly correlated with solum attributes, even when the data from the 'upland' L was omitted (not shown). Coefficients were all significant and were strongest for the curvature and catchment indices (r^2= –0.53 to 0.70).

3.4.2.2 Surface Soil pH

Surface soil pH (*Ap pH*) (measured in $CaCl_2$) ranged from 5.2 to 7.3 over all LECs (Table 3.1), a range that was not limiting to production. Among management units, observed *Ap pH* was ranked L > M > U (Figure 3.4, 3.5), where only the L was statistically distinct. Median values of 6.2, 6.3 and 6.6 were observed for U, M and L, respectively (Table 3.3). *Ap pH* is generally expected to be more alkaline in the thin surface soils in upper slope positions (Miller et al., 1988). As the L was most strongly leached in this regional recharge landscape, based on solum characteristics, *Ap pH* was expected to be lower in the L and greater on the U, such that expected ranking of pH values was opposite to that observed overall.

The unexpected pH trend was partially a function of pedogenic factors in the site overlooked by grouping of sample points into LECs. The Varcoe soils had the highest median *Ap pH* of 6.7 (Table 3.4), as these soils were characterized by the lowest net downward flux of moisture of the three soil series occurring in the site. While the inclusion of the Varcoe soils in the L accentuated the differences in pH among LECs, the L was still of a higher median *Ap pH* with removal of those points (not shown). *Ap pH* of points from the 'upland' L were significantly less than the points in the 'lowland' L, and when removed from comparisons, the significance of the differences between the 'lower' L and the U and M was improved (not shown). There may have been a concentration gradient of $CaCO_3$ in the Ap horizon across LEC delineations, providing more basic cations and resulting in a higher *Ap pH* in the L. Knuteson et al. (1989) observed the deposition of soil and precipitated carbonates on the soil surface of microdepressions, carried by runoff from precipitation events. If sediment deposition resulted in the higher L pH (e.g., due to tillage erosion), one would expect elevated carbonate concentrations only at the A horizon surface. *Ap pH* values coincided with the hydrologic progression from well to imperfectly drained, moving from the U to the L. It may be that since cultivation, the site has been experiencing a hydrologic reversal, such that eluvial soils now receive bases from below via capillary action from a shallower, less dynamic water table. If a hydrologic reversal resulted in the higher L pH, one would expect carbonate accumulation throughout a previously lime-free solum in the L, with an elevated calcite:dolomite ratio.

Corresponding with observed differences among LECs, *Ap pH* was significantly and negatively correlated with *E* over the entire site (r^2=-0.35). When divided into LECs, more trends emerged. In the U, *Ap pH* was unrelated to *E*, but was positively and significantly related to *G*, *Kv* and *Kh* values, and negatively related to *Cg* and *Cl* (r^2= 0.42 to 0.55). In the M, *Ap pH* was significantly and inversely related to *E* and *G*, albeit weakly (r^2=-0.21 and -0.22). There was no significant correlation to *Cg* or *Cl.* By definition, midslopes have little curvature, and *G* values were greatest in the M. In the L, *Ap pH* was significantly and inversely related to *E* (r^2=-0.38), but only when points from the 'upland' L were included. *Ap pH* was positively and weakly correlated with *Kh* in the L, and when 'upland' L points were not considered, weakly and negatively related to *Cg* and *Cl* as well (not shown). Overall correlations for the site, and those calculated within the M, indicated that *Ap pH* increased with the extent of convergent character in the site. However, within the L and most notably within the U, correlations indicated the opposite. *Ap pH* tended to be inversely related to individual topographic indices of convergent character within these LECs, such that more strongly leached and weathered locations in the landscape had lower *Ap pH* values. Over all LECs, there was only a weakly positive correlation between *A d* and *Ap pH*, but *Solum d* and *CO3 d* were weakly negatively related to *Ap pH* (r^2= -0.16 and -0.24). In the U, *Solum d* and *CO3 d* were significantly inversely related to pH, with stronger coefficients than those obtained for the entire site (r^2=-0.59). In the L, *Solum d* and *CO3 d* were significantly and inversely related to *Ap pH* (r^2=-0.40, -0.48 respectively). This implies that convergence of flow resulted in a stronger net downward flux of water which removed relatively more basic cations from the soil surface in the U and L. No significant correlations were observed within the 'upland' L (not shown).

3.4.2.3 Soil Organic Carbon

SOC was expressed as a concentration (% w/w) in the Ap horizon, and on an area basis (Mg/ha) for all of the A horizon. The latter statistic integrated total *A d* and *SOC(%)* in each A horizon, allowing an expression of the absolute amount of *SOC* partitioned in the A horizon on an area basis. Differences in bulk density can occur among landscape positions (Gregorich and Anderson, 1985), which can influence the use of *SOC(%)* to calculate *SOC* on an area basis (Ellert and Bettany, 1995). Therefore, in our study, mass per unit area was calculated without individual bulk density values. *SOC* concentration expressed on an oven-dried basis was multiplied by the mass of each respective horizon and divided by the average circular area of the soil cores.

SOC accumulation is governed by concentration of water in the landscape and landscape effects on temperature. These fundamental factors determine the variation in preferential accumulation of plant material, differences in mineralization rates, and erosional and depositional processes (Gregorich and Anderson, 1985). All else being equal, processes resulting in differences in *SOC* and *A d* are alike and reflective of long term productivity differences in the landscape (Solohub, 1994). *SOC(%)* ranged from 1.04 to 4.05 overall, and amounts of *SOC(Mg/ha)* varied from 6 to 181 within the site (Table 3.1, Figure 3.5). Both measures increased with convergent character in the landscape; relative rank of LECs was L > M > U for both descriptions. Median values were 1.94, 2.17 and 2.60 (%), and 35, 45, and 64, (Mg/ha) for the U, M and L, respectively (Table 3.3). All differences were statistically significant. Increases in *SOC* (both concentration and mass per unit area) with increased convergent character have been recorded by other researchers (Gregorich and Anderson, 1985; Pierson and Mulla, 1990; Verity and Anderson, 1990;

Pan and Hopkins, 1991). As *SOC* is strongly related to mineralizable N and available water holding capacity (Goovaerts and Chiang, 1993), the observed differences among LECs may well have implications for productivity. One would expect the L to be the most productive for a crop limited by lack of moisture or plant-available N.

While the L emerged as statistically distinct for both measures of *SOC*, differences were attenuated by pedogenic variability within the LECs and by the different character of the 'lowland' and 'upland' L. Newdale and Varcoe series had lower *SOC* (% w/w and Mg/kg) than Angusville soils, and their inclusion in the L reduced median levels somewhat (Table 3.4). Inclusion of data from the 'upland' L also slightly depressed the median *SOC* values, but the two spatially disjoint L areas were not statistically different with respect to *SOC* (not shown).

Correlations with topographic descriptors also indicated a tendency for *SOC* to increase with convergent character, across all LECs and within individual LECs (Table 3.5). Across LECs, both measures of *SOC* in the landscape were significantly and negatively related to *E* and *G*, and positively related to *Cg* and *Cl* (r^2= –0.36 to -0.46). In the U, *E* was not significantly correlated with *SOC(%)*, but strength of association was improved for other topographic indices (r^2= –0.42 to –0.62). In the M, *SOC(%)* was significantly and inversely related to *G* and *E* (r^2= -0.55 and -0.33, respectively), and there was a weak but significant inverse relationship with plan curvature. In the L, *SOC(%)* was significantly inversely related to gradient, elevation and curvature, and significantly positively related to catchment indices (r^2=-0.39 to -0.54).

Variations in *SOC* accumulation, *Solum d* and *A d* tend to coincide (Gregorich and Anderson, 1985). Across LECs, *A d* was significantly and positively correlated with *Solum d* and *CO3 d*, as one might expect (r^2=0.60, 0.70), and all were positively correlated with *SOC(%)* (r^2= 0.49 to 0.55) (Table 3.5). Within each LEC, *A d*, *Solum d* and *CO3 d* were again strongly inter-related, and significantly and positively correlated with *SOC(%)*. Within the L, correlations were not strongly affected by omission of Varcoe soils or 'upland' L sample points. In general, the relationships indicated that *SOC(%)* was proportional to the extent of pedogenic development (and hence water availability).

3.4.2.4 Salinity

There was no indication of serious salinity in this regional recharge landscape. Selected samples were analyzed for electrical conductivity by saturated paste, but there was no comparison of conductivity among LECs. Electrical conductivity was a maximum of 4.67 dS/m at a depth of 90 to 120 cm. As a result, no agronomic limitations for *Triticum aestivum* production were expected at any point in the landscape due to soluble salts.

3.4.2.5 Pedogenic Variability

Discontinuities and inclusions of less common soil series (e.g., Varcoe soils) in LECs dominated by more typical soils influenced the ability of the delineated LECs to account for variability in pedogenic character in the soil-landscape. An additional example was the occurrence of Angusville soils in U and M LECs, which were primarily mapped as the Newdale series. The observation is not surprising or unique; Wilding and Drees (1983, as cited in Pennock, 1987) noted that within a soil map unit, other soil series may account for up to 50-60% of the area occupied within.

There are two factors responsible for reductions in the amount of pedogenic variability explained by the LECs. The first is a matter of scale. Microrelief, which can result in significant variability in soil properties, may be missed entirely by a 10 m grid, such that variability will be unaccounted for with any number of individual landform elements. For example, Chang (1995) found 65% of the variation in total organic matter could be explained as a function of relative relief over a transect where the range of relief did not exceed 62 cm. A 3% slope over 10 m is equivalent to 30 cm of relief. With the delineation of spatially homogenous 'smoothed' LECs rather than individual landform elements, the problem is further compounded. Small upland depressions or convergent areas are not distinguishable from upland divergent areas, when working with homogeneous LECs as described by MacMillan and Pettapiece (1997). While more fragmented, the individual landform elements/facets used in the creation of LECs may account for more pedogenic variability.

Scale is not the only issue, since topography alone is not sufficient to mechanistically model the occurrence of any given pedogenic property. Hydrologic processes are mainly responsible for pedogenic development, but they may be masked by other formative controllers. Pennock et al. (1987) noted that sedimentologic influences were extremely important, as a sandy 'lense' may increase solum depth regardless of topographic position. Even the stratigraphy of 'simple' glacial till soils may have pockets of textural discontinuities (Eilers[4], personal communication). Within the study site, parent material texture ranged from a clay-loam texture to sandy-loam, with the occurrence of gravel beneath some points in the 'lower' L. Occurrence of eluvial horizons in the M often occurred at or near sample points where soil texture was notably coarser.

Hydrologic influences themselves are not predictable by surface morphology alone. The occurrence of the Varcoe series was a result of groundwater interactions and a lower net downward flux, adjacent to the Angusville soils. Other researchers have observed the occurrence of carbonated soils, adjacent to depressions, due to net upward fluxes of carbonate-containing soil water (Malo and Worcester, 1975; Knuteson et al., 1989; Moulin et al., 1994). While their occurrence may be qualitatively predictable, their extent is dependent on the extent of flow convergence and hydraulic conductivity of the underlying material in a given landscape.

While it is important to recognize the limitations of characteristically smoothed LECs for prediction of differences in pedogenic character, practical considerations dictate the amount of information that will be collected (assuming that an increase in scale will decrease variability). The intended application, and the accuracy required, must also be taken into consideration. The prediction of pedogenic properties reflective of biophysical processes in the landscape is not an end unto itself, but a means of more accurate resource characterization for more efficient and sustainable management. For example, the practical use of any such LEC for site-specific fertilizer application requires that they are in fact spatially coherent, and that they are large enough to be managed uniquely. It

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[4] Land Resource Unit, Agriculture and Agri-Food Canada

would be possible to uniquely manage individual soil series, but management of delineations of this complexity is precluded by current adopted technology. The importance of prediction of highly local variation in pedogenic properties may be negligible compared to other agronomic uncertainties related to production.

3.5 Summary and Conclusions

Differences in convergent and divergent character were apparent among LECs described using the model by MacMillan and Pettapiece (1997). Accordingly, these LECs were useful in accounting for variability in various pedogenic properties. *SOC*, *A d*, *CO3 d* and *Solum d* increased in magnitude in the progression U < M < L. The trend of *Ap pH* among LECs was the opposite. This may have been attributable to downslope movement and precipitation of dissolved carbonates, or deposition of carbonated, suspended soil on the L surface. If erosion were responsible, elevated carbonate concentrations would be expected on the A horizon surface only. It may also be possible that since cultivation the site has been experiencing a hydrologic reversal, such that eluvial soils now receive bases from below via capillary action, from a more shallow, less dynamic water table. If hydrology were responsible, elevated carbonate concentrations would be expected throughout previously carbonate-free soil profiles in the L. Within the LECs, *SOC*, *A d*, *CO3 d* and *Solum d* were significantly proportional to indices of convergence, the individual topographic descriptors described by Pennock et al. (1987). Within the U and the L, *Ap pH* was inversely proportional to indices of convergence. While variation in pedogenic character was observed within the described LECs, division of the site in this manner provided a practical means of capturing gross variability in temporally stable soil attributes. Practical considerations include scale, the influence of pedogenic controls other than hydrology, and 'manageability'. As a result, the LECs warrant further investigation as a means of capturing systematic variability in more temporal yield determinants and productivity.

4. SPATIAL VARIABILITY OF DYNAMIC SOIL PROPERTIES IN A VARIABLE MANITOBA SOIL-LANDSCAPE

4.1 Abstract

The relationship between 'dynamic' soil properties (volumetric soil moisture content (*V*), nitrate-N (NO_3), ammonium-N (NH_4), extractable phosphorous (*P*), exchangeable potassium (*K*), and sulphate-sulphur (*S*)) and topography was studied in ten intensively sampled transects in an undulating glacial till landscape near Miniota, Manitoba. The soils encountered belong to the Newdale Association, consisting of a variety of soil series (Appendix 1). Using a landform description model by MacMillan and Pettapiece (1997), the study site was delineated into Upper (U), Mid (M), Lower-Mid and Lower (L) elevation Landform Element Complexes (LECs) using a digital elevation model of the site. Significant correlations with topographic descriptors as described by Pennock et al. (1987) and with static properties were generally fair to good but did not occur consistently. The LECs were useful in capturing gross variability at a manageable landscape scale. Among LECs, there was a general trend of L > M > U for *V*, NO_3, *P*, *K* and *S*, as these attributes generally increased with convergent character. Differences among LECs were often statistically significant, and relative distributions exhibited temporal persistence. Landscape-productivity influences due to soil attributes such as *P*, *K* and *S* were not expected because *P* was seed-placed at rates sufficient for high yields of wheat, and *K* and *S* were not at limiting concentrations for wheat production.

4.2 Introduction

Moisture is the single most limiting factor for crop production in the semi-arid climate of Western Canada (Grant and Flaten, 1998). Nitrogen is the most limiting nutrient for cereal grain production on the majority of soils of the world (Olson et al., 1976). Differential distribution of moisture and residual N in the soil-landscape is therefore extremely important to potential productivity and yield response to N fertilizer. It should be possible to develop N recommendations for the most commonly encountered moisture regime in the landscape, if there is sufficient temporal stability in moisture supply and soil N supply.

In a pedogenic context, moisture and N fertility are relatively dynamic, in the sense that they are not stable spatially or temporally (within and among growing seasons). However, their distribution is influenced by systematic variation in more static, predictable soil-landscape attributes. Soil moisture content is generally greater on portions of the landscape with more strongly convergent character (Malo and Worcester, 1975; Pennock et al., 1987; Pierson and Mulla, 1990; Verity and Anderson, 1990; Pan and Hopkins, 1991). Both surface and subsurface and saturated and unsaturated flow are important to redistribution. In Israel, Sinai et al. (1981) found 90% of the variability in soil moisture levels to 40 cm could be accounted for with soil surface curvature. In a Nebraska study, Hanna et al. (1982) found both aspect and slope position significantly influenced soil moisture in the landscape. The authors noted that footslopes and backslopes had an additional 5 cm of available water over the summits and shoulders due to surface runoff and unsaturated subsurface flow. Additionally, *SOC* increases the water holding capacity of the soil, and accumulates in greater amounts in convergent areas of the landscape.

Management and additional agrometeorological conditions regulate the landscape influence on soil moisture, as it may fluctuate widely depending on management and evapotranspirative demands in agro-ecosystems. For example, water use often increases with additional plant-available N (Campbell et al., 1977a), and evapotranspirative demand may vary in the landscape. Spratt and McIver (1972) noted average moisture content over the course of a season may be lower in toeslope positions due to heavier crop and weed growth. Moisture redistribution in the landscape may be negligible under dry conditions (Hanna et al., 1982; Miller et al., 1988; Halvorson and Doll, 1990). Differences in snow accumulation (drifting) and irregular rainfall distribution may also regulate landscape effects (de Jong and Rennie, 1969).

Soil fertility includes the plant-available sources of inorganic, residual nutrients in the profile, and organic nutrients, which are potentially mineralizable in the growing season. Explanation of systematic differences in plant-available N as a function of landscape requires integration of soil properties, N-cycling, previous management and cropping effects (Fiez et al., 1994a). Distribution of residual NO_3, the most agronomically important form of mineral N, may be spatially random (Mulla, 1993), greater in convergent areas (Malo and Worcester, 1975), or greater in divergent areas of the landscape (Farrell et al., 1996). This is because inherent potential of the soil to mineralize N is often 'masked' by fertilization effects. Regardless, total N concentration and mineralization generally increase with soil organic matter and convergent character (Aandahl, 1948; Rennie and Clayton, 1960; Fiez et al., 1994a). Organic matter is important to the storage, exchange and mineralization of many plant nutrients. The rate of mineralization is proportional to soil temperature and moisture content (Campbell et al., 1988a), which are strongly influenced by the soil-landscape.

In our previous manuscript, we established that the LECs created by MacMillan and Pettapiece (1997) were useful in capturing topographic and resultant pedogenic variability in the soil-landscape. Under the premise of strong topographic influence on soil moisture and nutrient distribution, we hypothesized that discrete LECs will differ with respect to these more dynamic soil attributes as well. 'Dynamic' soil attributes were arbitrarily distinguished from the 'static' attributes discussed in the previous manuscript by their appreciable variation between and within growing seasons. The objective of our study was to characterize the distribution of dynamic soil properties in a simple glacial till landscape, to improve the context in which to evaluate productivity. We examined the relative magnitude of the selected properties among LECs, and the bivariate relationships with topographic descriptors as described by Pennock et al. (1987) and previously evaluated static soil properties. These management-scale LECs have not been previously evaluated for their utility in capturing variability in dynamic soil properties which directly affect crop yield in Manitoba landscapes.

4.3 Materials and Methods

4.3.1 Site Characteristics

Site pedogenic characteristics were described in our previous manuscript. Established in spring 1997, the study site was an undulating glacial till landscape near Miniota, MB. The site was representative of a broad region of glacial till landscapes in the Black soil zone.

The site consisted of ten adjacent 11m x 450m transects over a variable landscape with 21 sampling points in each of these transects, for a total site area of 5.6 ha. Within transects, there was a maximum of 30 m separation between sampling points. There was a total of 4.2 m relief within the plot area, and slopes did not exceed 3°. The site encompassed classic crest, midslope and depressional elements, extending from one crest to another via an open depression bisecting the site at right angles.

Formal topographic characterization was performed on the site and surrounding area by collecting relative elevation data to develop a digital elevation model (DEM) of the site. The site DEM was used in the Landform Description Program created by MacMillan and Pettapiece (1997) to delineate four discrete LECs. Due to low areal percentage, points in the LM was amalgamated with those of the L and M. These LECs were superimposed on the existing design, and sampling points were assigned accordingly.

4.3.2 N Fertilizer Application and Site Management

Experimental design was best described as a duplicated field-scale strip trial. For 1997 and 1998, there were 5 different N fertilizer treatments in the 10 transects, replicated twice. There were 0, 45, 90 and 135 kg/ha uniform rate transects, along with two transects in which the N rate was variable. In all cases, nitrogen fertilizer was surface broadcast as ammonium nitrate (34-0-0) after seeding. In 1997, the air drill itself was used to distribute N on June 17, and in 1998, N was broadcast using a Valmar spreader on May 25. All N-fertilizer rates were pre-determined and were not adjusted to reflect residual soil test levels. In 1997 and 1998, treatments were identical and were superimposed on the same locations. Treatments were designed to impose a range of available N concentrations across a representative cross-section of the regional soil landscape, such that the same range was received by each of the localized LECs within. Sample points from one of the 135 kg/ha transects (#5) was omitted from subsequent comparisons due to an application error.

Within the variable rate transects there were six 22 kg/ha N treatments, omitted from further comparison due to lack of representation among LECs. The variable rate transects were fertilized on qualitative predictions of yield response to N fertilizer within topographically unique areas of the soil-landscape. In general, areas of greater convergent character received higher N prescriptions with the exception of locations where a) predicted productive potential was low due to potential for excessive wetness or b) yield response was expected to be low due to potentially high N mineralization. The relative number of sampling points contained within each of the treatments and LECs is presented in Table 4.1. For the purpose of this study, the variable rate transects provided additional data at various rates of applied N for comparison of N-related attributes among LECs.

Table 4.1 Sample point allocation (*n*) by LEC and N fertilizer treatment.

LEC	N Fertilizer Rate (kg/ha) (Transects Assigned)			
	0 (3,8)	45 (4,6,2[a],10[a])	90 (1,9,2[a],10[a])	135 (5[b],7)
Upper El. LEC	9	12	7	4
Mid El. LEC	25	36	34	29
Lower El. LEC	8	14	17	9

[a] Variable rate transects.

[b] Points in transect 5 excluded from subsequent comparisons due to N application error.

Canadian Western Red Spring wheat was air-drilled into the mature zero-till seedbed in 1997 (May 10, cv. Roblin) and 1998 (May 4, cv. Teal) on a 25 cm row spacing at a seeding rate of 128 kg/ha and a depth of 2.5 cm. The 10 m air drill was equipped with low disturbance 1.9 cm openers. Seed-placed phosphorus was applied with the seed at a uniform rate across the site at a rate of 70 kg/ha of mono-ammonium phosphate (12-51-0-0), adding 8.4 kg/ha to the applied N listed for all treatments.

Field-scale pesticide applications were at manufacturers' recommended rates. Glyphosate, 2,4-D and triallate were applied in fall 1996. In 1997, thifensulfuron, tribenuron methyl, MCPA and clopyralid were applied post-emergence, and glyphosate was applied pre-harvest. In 1998 dichlorprop, 2,4-D ester and imazamethabenz were applied post-emergence. Propiconazole fungicide was used to reduce foliar diseases.

Timing and amounts of precipitation were monitored locally (Appendix V).

4.3.3 Sample Collection

Dynamic soil attributes were measured at each of the 210 sample points over the 1997 and 1998 growing seasons. There were three primary intervals for data collection: early in the season prior to seeding (*ES*), mid-season near anthesis (*MS*), and harvest or post-harvest (*H*). All soil samples were collected in 30 cm increments to 120 cm. *ES* soil sampling for NO_3, NH_4, *P*, *K* and *S* was performed using mechanized soil augers. Each of these four depths was subsampled for *V* determination. *MS* soil sampling for *V* was performed using hand-held soil probes. *H* sampling for NO_3 and NH_4, subsampled for *V*, was performed on September 2, 1998, within a week of harvest. Again, all points were sampled to 120 cm in 30 cm increments using a soil auger.

4.3.4 Soil Nutrient and Soil Moisture Determination

Soil samples were refrigerated for transport and frozen for storage. Spring 1997 and 1998 macronutrients were analyzed by Norwest Labs (Winnipeg, Manitoba). Air-dried soils were ground to pass through a 2mm sieve. NO_3 and NO_2-nitrogen were extracted using a 0.001 M $CaCl_2$ solution and analyzed by automated colorimetry. Detection limit for the process is 0.1 ppm (MSS 4.35 APHA). NH_4 was extracted by a 1 M KCl solution and analyzed by phenate automated colorimetry, with a detection limit of 0.005 ppm (ASOA No. 9). Extractable *P* and exchangeable *K* were extracted using acetic fluoride (Modified Kelowna method). P was analyzed by automated molybdate colorimetry, with a detection limit of 1 ppm (ASSW 26:178; APHA 4500-P:E; Comm. Soil Sci. Plant Anal. 26: 5-6, 1995). K was analyzed by flame photometry, with a detection limit of 10 ppm (ASSW 26:178; APHA 3500-K:D; Comm. Soil Sci. Pl. Anal. 26: 5-6, 1995). *S* was extracted with 0.001 M $CaCl_2$ solution and analyzed for sulphate by methyl thymol blue automated colorimetry, with a detection limit of 1 ppm (APHA 4500-SO_4:F). Estimated plant-available N supply (*EPANS*) was calculated as the sum of spring residual nitrate-N to a depth of 90 cm plus applied fertilizer N in each treatment.

Fall 1998 NO_3 and NH_4 levels were extracted using a 10:1 2N KCl to soil extraction ratio using 50 mL of KCl and 5 g of air-dried soil. The samples were shaken for 30 minutes, filtered through Whatman #42 filter paper and subsequently analyzed colorimetrically with a Technicon Autoanalyzer II System (Labtronics Inc., Tarrytown, NY, USA). Extraction and analysis followed the methodology outlined by Maynard and Kalra (1993).

V was determined by heating 20 to 30 g of moist soil at 105° C for 24 hours (Topp, 1993). Bulk density measurements used in conversion of nutrient and moisture concentration to area basis were obtained on an oven dry basis, using the 3.7 cm soil cores obtained in September 1997 by the method of Blake (1965). Composite bulk density values for each 30 cm increment were calculated using bulk densities for each genetic profile member, averaged across the entire site.

Values obtained for *H V* in 1997 should be interpreted with caution. Gravimetric soil moisture from 0 to 60 cm was measured after the samples had been frozen for several months. It is possible that the samples were subject to sublimation while in storage. Samples were not obtained for 60 to 120 cm, but rather values from spring of 1998 for 60 to 120 cm were used. This was done in order to express *H* moisture as an estimate to 120 cm. It was reasoned that recharge from precipitation in the fall of 1997 and over winter would have been limited (in September and October 1997, a total of 4.1 cm of rainfall was received). Also, familiar patterns of relative moisture distribution were observed for the 0-30 and 30-60 cm increments (not shown). Among LECs, ranking was consistent with other times at which soil moisture was assessed, and the L was statistically distinct for both the 0-30 and 30-60 cm increments. However, it is possible that moisture from 60-120 cm was influenced by upward vapor phase movement from groundwater over the winter of 1997-1998.

4.3.5 Grain and Straw Total N Determination

To estimate net mineralization, knowledge of crop N removal was required. Grain and straw yields were obtained from hand-harvested 1 and 2 m^2 quadrats in 1997 and 1998, respectively. Grain and straw total N was determined on 70 to 100 mg of ground plant material (< 2mm) with a Leco FP 428 and CHN-600 (Leco Corporation, St. Joseph, MI) by combustion nitrogen analysis, on an oven-dry basis (Williams et al., 1998).

4.3.6 Statistical Methods

Surfer gridding and contouring software (Golden Software, Boulder, CO) and side-by-side boxplots were used for qualitative exploration of data. Spearman correlations were calculated between all attributes. Tests for significant differences among LEC populations were performed using the Kruskal-Wallis test, with a multiple-comparison technique described by Daniel (1990). Spearman correlations and Kruskal-Wallis tests were obtained with SPSS v. 8.0 software. Statistical significance for multiple comparisons was set at $\alpha=0.20$. There is greater error variability at the landscape scale, such that a lower significance level has been justified by various researchers (van Kessel et al., 1993; Pennock et al., 1994; Jowkin and Schoenau, 1998). Significance for correlations was defined at $p<0.05$.

4.4 Results and Discussion

4.4.1 Dynamic Soil Attributes: Differences Among LECs

4.4.1.1 Soil Moisture

Overall, volumetric soil moisture to 120 cm (*V 120*) varied widely between seasons and LECs, ranging from 10.1 to 48.5 cm (Table 4.2). Nonetheless, relative distribution was consistent among LECs, with a trend of L > M > U (Figure 4.1, 4.2) in both years. In all instances, only the L emerged as statistically distinct (Table 4.3). Accordingly, differences between the U and M were generally negligible. The characteristic increase in *V 120* with increasing convergent character in the landscape was consistent with the findings of Jowkin and Schoenau (1998). The landscape difference was likely accentuated by variable distribution of *SOC*, which was previously observed to be significantly greater in the L.

Table 4.2 Descriptive statistics for dynamic soil attributes, across and within LECs.

(a) Overall

N Rate (kg/ha)	Attribute	Median	Mean	Std. Dev.	Minimum	Maximum
All	*ESV120 97 (cm)*	27.9	28.2	3.9	13.5	42.2
All	*MSV120 97 (cm)*	26.1	26.1	3.4	13.3	35.5
All	*HV120 97 (cm)*	21.8	22.0	3.0	10.1	31.0
All	*ESV120 98 (cm)*	24.9	25.2	3.8	12.9	37.1
All	*MSV120 98 (cm)*	35.5	35.9	3.6	24.9	48.5
All	*HV120 98 (cm)*	28.9	28.8	3.5	15.0	41.2
0	*HV120 98 (cm)*	31.3	30.7	3.8	15.0	35.6
45	*HV120 98 (cm)*	29.1	29.5	3.6	16.7	41.2
90	*HV120 98 (cm)*	28.2	28.1	2.5	22.8	34.1
135	*HV120 98 (cm)*	27.1	27.3	2.8	22.0	32.6
All	NO_3 *90 97 (kg/ha)*	48	50	15	18	146
All	NH_4 *w 97 (kg/ha)*	8	9	4	0	34
All	*P w 97 (kg/ha)*	46	54	31	8	164
All	*K w 97 (kg/ha)*	783	884	421	343	4594
All	*S 120 97 (kg/ha)*	78	322	891	22	9012
All	NO_3 *90 98 (kg/ha)*	43	49	29	12	295
0	NO_3 *90 98 (kg/ha)*	35	40	42	12	295
45	NO_3 *90 98 (kg/ha)*	35	37	12	12	67
90	NO_3 *90 98 (kg/ha)*	54	54	18	17	112
135	NO_3 *90 98 (kg/ha)*	86	87	24	57	152
All	NH_4 *w 98 (kg/ha)*	10	10	4	3	26
0	NH_4 *w 98 (kg/ha)*	7	8	4	3	16
45	NH_4 *w 98 (kg/ha)*	10	11	4	6	26
90	NH_4 *w 98 (kg/ha)*	12	13	4	7	26
135	NH_4 *w 98 (kg/ha)*	8	8	2	5	11
All	*H* NO_3*90 98(kg/ha)*	32	38	30	15	382
0	*H* NO_3*90 98(kg/ha)*	29	31	12	16	69
45	*H* NO_3*90 98(kg/ha)*	31	32	10	15	57
90	*H* NO_3*90 98(kg/ha)*	33	42	47	19	382
135	*H* NO_3*90 98(kg/ha)*	56	58	22	32	108
All	*H* NH_4 *w 98(kg/ha)*	24	25	10	9	73
0	*H* NH_4 *w 98(kg/ha)*	23	25	9	13	51
45	*H* NH_4 *w 98(kg/ha)*	24	26	9	12	53
90	*H* NH_4 *w 98(kg/ha)*	23	26	11	13	73
135	*H* NH_4 *w 98(kg/ha)*	24	25	10	9	52
All	*P w 98 (kg/ha)*	51	59	34	11	186
All	*K w 98 (kg/ha)*	761	849	357	256	3330
All	*S 120 98 (kg/ha)*	93	416	1206	19	10534

(b) Upper Elevation LEC

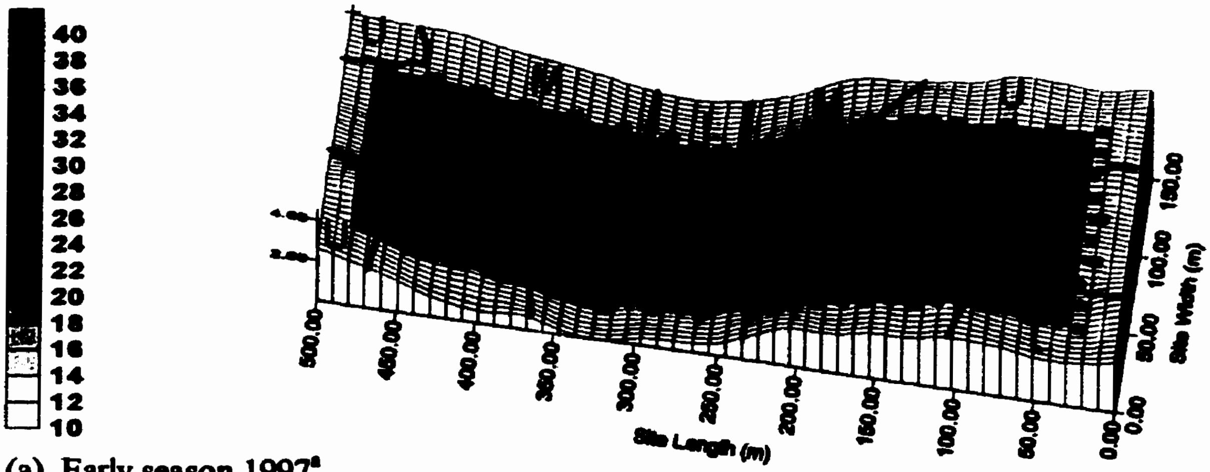
N Rate (kg/ha)	Attribute	Median	Mean	Std. Dev.	Minimum	Maximum
All	*ESV120 97 (cm)*	27.2	26.6	3.8	13.5	34.2
All	*MSV120 97 (cm)*	25.0	24.7	3.2	13.3	31.1
All	*HV120 97 (cm)*	21.3	20.6	3.6	10.1	26.5
All	*ESV120 98 (cm)*	24.0	23.3	4.0	12.9	30.5
All	*MSV120 98 (cm)*	34.9	35.1	3.0	30.0	44.1
All	*HV120 98 (cm)*	28.2	27.7	4.5	15.0	35.0
0	*HV120 98 (cm)*	32.0	30.1	6.2	15.0	35.0
45	*HV120 98 (cm)*	28.3	26.8	4.1	16.7	31.2
90	*HV120 98 (cm)*	26.9	26.6	1.7	23.4	28.2
135	*HV120 98 (cm)*	24.7	24.7	2.0	23.3	26.1
All	*NO_3 90 97 (kg/ha)*	44	47	15	27	85
All	*NH_4 w 97 (kg/ha)*	7	9	4	5	28
All	*P w 97 (kg/ha)*	39	48	28	15	128
All	*K w 97 (kg/ha)*	699	723	172	453	1229
All	*S 120 97 (kg/ha)*	49	62	51	31	333
All	*NO_3 90 98 (kg/ha)*	33	45	50	12	295
0	*NO_3 90 98 (kg/ha)*	24	56	90	12	295
45	*NO_3 90 98 (kg/ha)*	29	33	11	22	54
90	*NO_3 90 98 (kg/ha)*	43	44	16	17	67
135	*NO_3 90 98 (kg/ha)*	70	70	4	67	73
All	*NH_4 w 98 (kg/ha)*	10	10	3	6	17
0	*NH_4 w 98 (kg/ha)*	10	11	3	7	16
45	*NH_4 w 98 (kg/ha)*	11	10	3	6	17
90	*NH_4 w 98 (kg/ha)*	9	9	1	7	10
135	*NH_4 w 98 (kg/ha)*	9	9	2	7	10
All	*H $NO_3$90 98(kg/ha)*	32	36	17	15	108
0	*H $NO_3$90 98(kg/ha)*	40	41	13	22	58
45	*H $NO_3$90 98(kg/ha)*	27	27	7	15	41
90	*H $NO_3$90 98(kg/ha)*	33	34	8	21	46
135	*H $NO_3$90 98(kg/ha)*	73	73	49	39	108
All	*H NH_4 w 98(kg/ha)*	28	29	12	14	53
0	*H NH_4 w 98(kg/ha)*	33	31	14	15	51
45	*H NH_4 w 98(kg/ha)*	26	27	11	14	53
90	*H NH_4 w 98(kg/ha)*	28	27	8	16	39
135	*H NH_4 w 98(kg/ha)*	34	34	25	17	52
All	*P w 98 (kg/ha)*	45	48	21	18	99
All	*K w 98 (kg/ha)*	707	711	150	256	1071
All	*S 120 98 (kg/ha)*	60	64	34	19	199

(c) Mid Elevation LEC

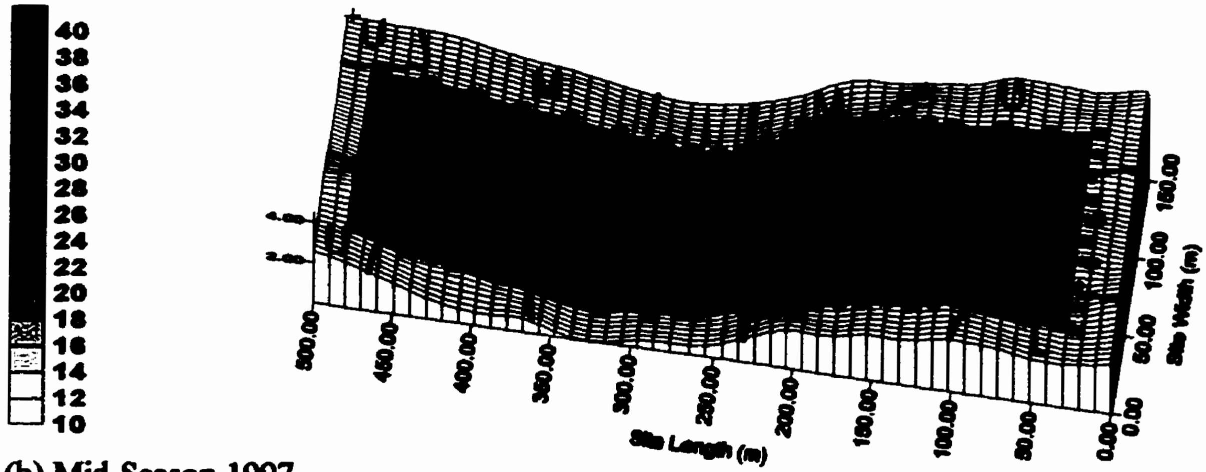
N Rate (kg/ha)	Attribute	Median	Mean	Std. Dev.	Minimum	Maximum
All	*ESV120 97 (cm)*	27.7	27.5	3.1	18.0	38.5
All	*MSV120 97 (cm)*	25.6	25.5	2.9	13.6	33.1
All	*HV120 97 (cm)*	21.4	21.5	2.4	13.6	31.0
All	*ESV120 98 (cm)*	24.6	24.4	2.8	16.9	35.5
All	*MSV120 98 (cm)*	35.4	35.5	3.0	24.9	45.8
All	*HV120 98 (cm)*	28.6	28.5	3.1	20.4	35.6
0	*HV120 98 (cm)*	30.9	31.0	2.7	23.7	35.6
45	*HV120 98 (cm)*	29.1	29.2	2.7	21.5	34.8
90	*HV120 98 (cm)*	27.7	27.5	2.3	22.8	32.5
135	*HV120 98 (cm)*	27.4	27.7	2.5	24.0	32.6
All	*NO_3 90 97 (kg/ha)*	47	49	14	18	146
All	*NH_4 w 97 (kg/ha)*	8	8	3	1	18
All	*P w 97 (kg/ha)*	45	52	29	8	154
All	*K w 97 (kg/ha)*	778	920	498	443	4594
All	*S 120 97 (kg/ha)*	79	255	869	22	9012
All	*NO_3 90 98 (kg/ha)*	41	48	22	12	110
0	*NO_3 90 98 (kg/ha)*	35	34	9	19	48
45	*NO_3 90 98 (kg/ha)*	35	37	11	12	59
90	*NO_3 90 98 (kg/ha)*	57	56	18	26	100
135	*NO_3 90 98 (kg/ha)*	91	85	19	57	110
All	*NH_4 w 98 (kg/ha)*	10	11	4	3	26
0	*NH_4 w 98 (kg/ha)*	7	8	3	3	15
45	*NH_4 w 98 (kg/ha)*	10	11	4	6	26
90	*NH_4 w 98 (kg/ha)*	13	13	4	7	26
135	*NH_4 w 98 (kg/ha)*	8	7	2	5	11
All	*H $NO_3$90 98(kg/ha)*	33	40	37	15	382
0	*H $NO_3$90 98(kg/ha)*	27	29	11	16	69
45	*H $NO_3$90 98(kg/ha)*	32	32	9	15	54
90	*H $NO_3$90 98(kg/ha)*	40	49	60	22	382
135	*H $NO_3$90 98(kg/ha)*	65	61	20	32	100
All	*H NH_4 w 98(kg/ha)*	26	26	9	13	73
0	*H NH_4 w 98(kg/ha)*	26	24	7	13	43
45	*H NH_4 w 98(kg/ha)*	24	25	7	13	48
90	*H NH_4 w 98(kg/ha)*	27	29	12	15	73
135	*H NH_4 w 98(kg/ha)*	28	28	6	20	38
All	*P w 98 (kg/ha)*	47	55	31	11	184
All	*K w 98 (kg/ha)*	722	856	409	398	3330
All	*S 120 98 (kg/ha)*	98	349	1152	25	10534

(d) Lower Elevation LEC

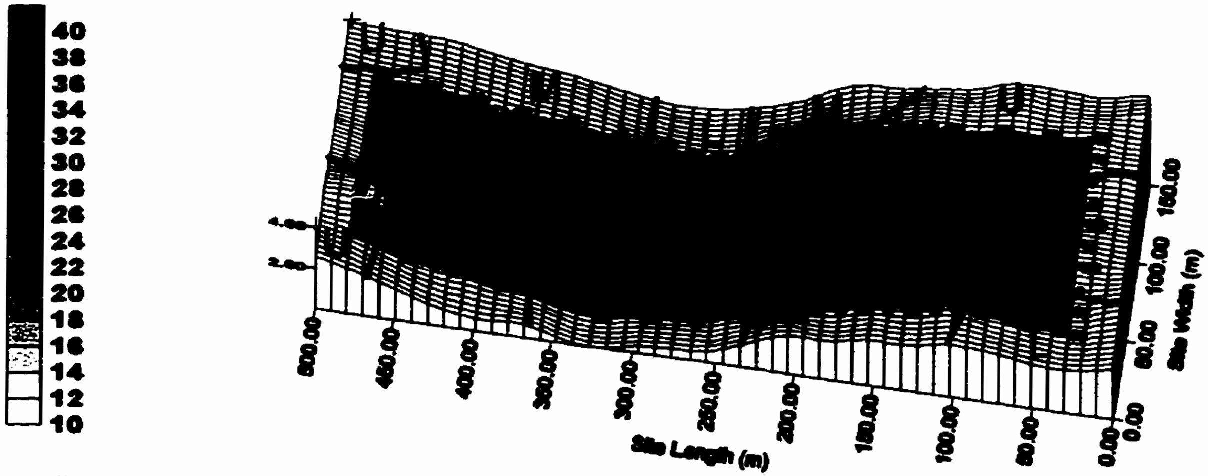
N Rate (kg/ha)	Attribute	Median	Mean	Std. Dev.	Minimum	Maximum
All	*ESV120 97 (cm)*	31.8	31.1	4.5	20.6	42.2
All	*MSV120 97 (cm)*	28.5	28.6	3.5	19.5	35.5
All	*HV120 97 (cm)*	24.7	24.2	3.0	16.7	30.5
All	*ESV120 98 (cm)*	28.6	28.7	3.9	19.2	37.1
All	*MSV120 98 (cm)*	37.2	37.6	4.8	25.4	48.5
All	*HV120 98 (cm)*	30.7	30.4	3.4	22.0	41.2
0	*HV120 98 (cm)*	31.3	30.5	4.0	23.7	34.9
45	*HV120 98 (cm)*	32.8	32.7	3.2	27.5	41.2
90	*HV120 98 (cm)*	30.4	29.9	2.4	25.9	34.1
135	*HV120 98 (cm)*	27.9	27.4	3.4	22.0	31.0
All	*NO_3 90 97 (kg/ha)*	52	56	17	32	129
All	*NH_4 w 97 (kg/ha)*	8	9	6	0	34
All	*P w 97 (kg/ha)*	51	64	37	16	164
All	*K w 97 (kg/ha)*	895	906	286	343	1977
All	*S 120 97 (kg/ha)*	158	678	1139	46	4710
All	*NO_3 90 98 (kg/ha)*	49	54	26	17	152
0	*NO_3 90 98 (kg/ha)*	40	40	14	17	68
45	*NO_3 90 98 (kg/ha)*	43	43	14	22	67
90	*NO_3 90 98 (kg/ha)*	52	56	19	29	112
135	*NO_3 90 98 (kg/ha)*	89	96	34	60	152
All	*NH_4 w 98 (kg/ha)*	9	10	5	3	24
0	*NH_4 w 98 (kg/ha)*	4	5	4	3	14
45	*NH_4 w 98 (kg/ha)*	9	11	4	6	19
90	*NH_4 w 98 (kg/ha)*	13	13	4	8	24
135	*NH_4 w 98 (kg/ha)*	10	10	1	8	11
All	*H $NO_3$90 98(kg/ha)*	31	34	12	18	68
0	*H $NO_3$90 98(kg/ha)*	26	28	9	18	47
45	*H $NO_3$90 98(kg/ha)*	35	35	12	22	57
90	*H $NO_3$90 98(kg/ha)*	29	31	10	19	60
135	*H $NO_3$90 98(kg/ha)*	43	47	13	34	68
All	*H NH_4 w 98(kg/ha)*	20	21	8	9	51
0	*H NH_4 w 98(kg/ha)*	17	19	6	13	30
45	*H NH_4 w 98(kg/ha)*	22	25	11	12	51
90	*H NH_4 w 98(kg/ha)*	20	19	4	13	25
135	*H NH_4 w 98(kg/ha)*	17	17	7	9	28
All	*P w 98 (kg/ha)*	68	79	40	30	186
All	*K w 98 (kg/ha)*	828	926	289	557	2071
All	*S 120 98 (kg/ha)*	163	841	1608	35	7905



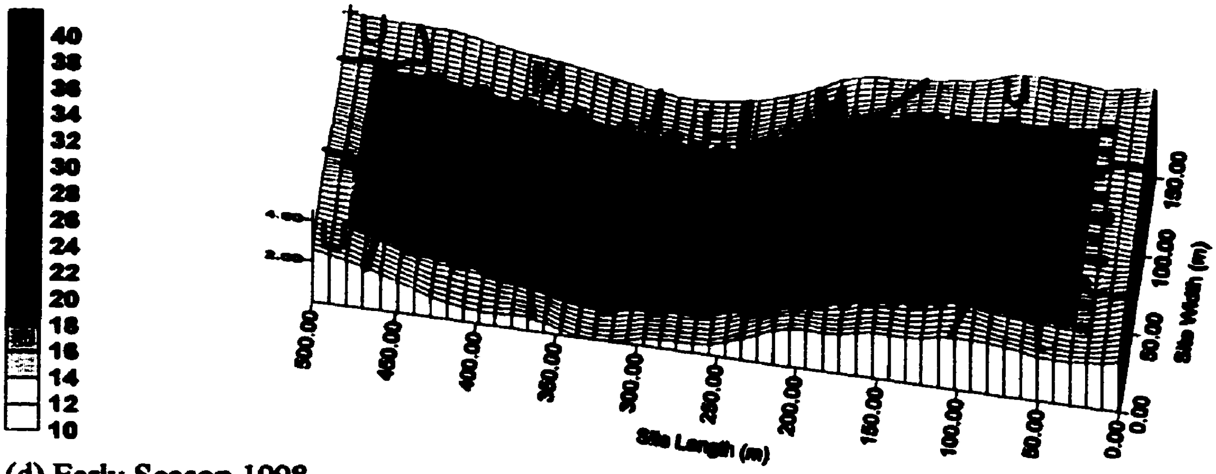
(a) Early season 1997[a]



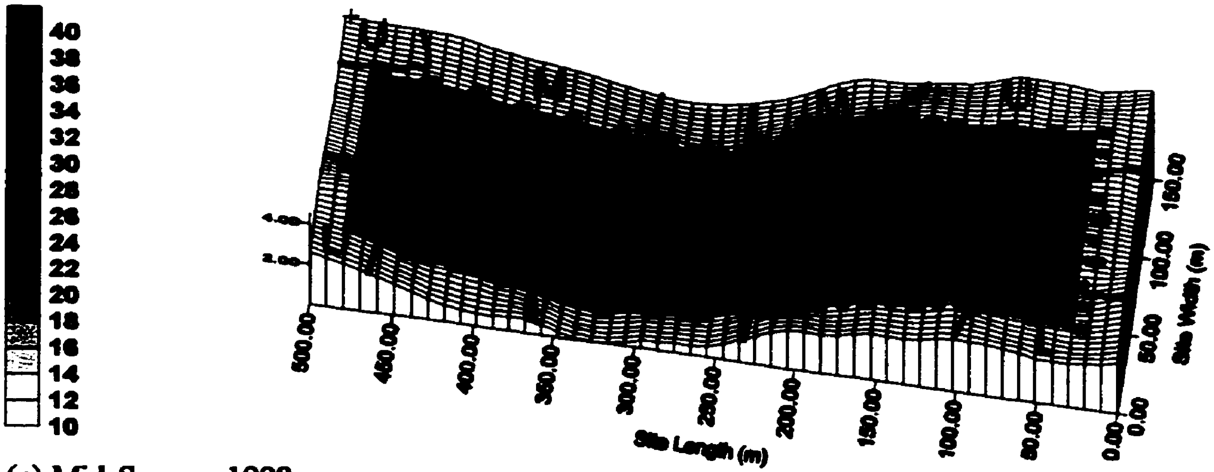
(b) Mid-Season 1997



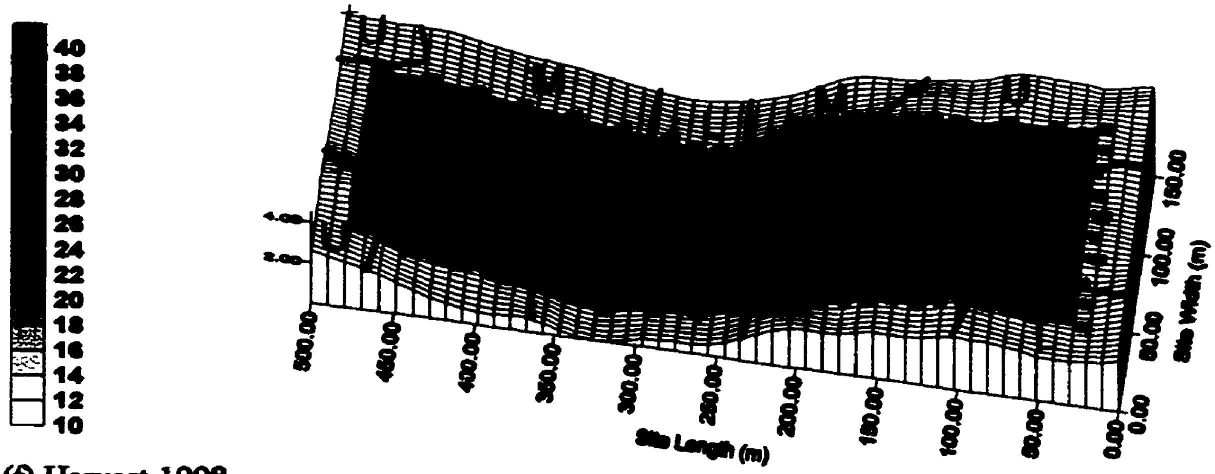
(c) Harvest 1997



(d) Early Season 1998



(e) Mid-Season 1998



(f) Harvest 1998

Figure 4.1 Spatial distribution of volumetric soil moisture to 120 cm at six sampling times, 1997 and 1998 (cm). [a][N fertilizer treatment rates indicated beside each sampling point in kg/ha]

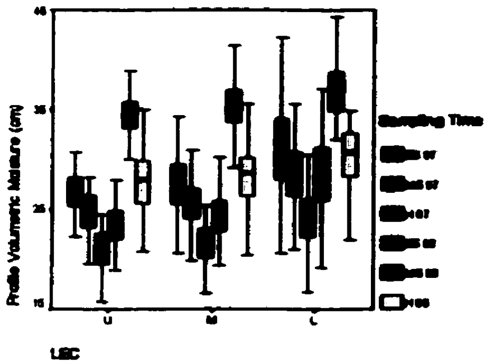


Figure 4.2 Relative distribution of volumetric moisture to 120 cm within time of sampling.

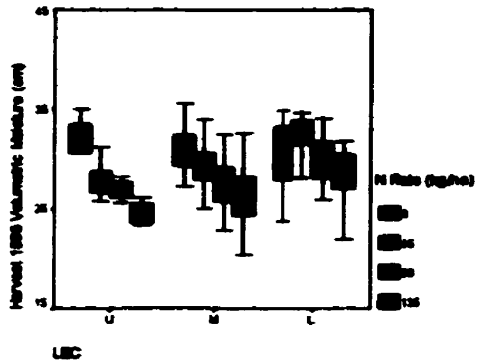
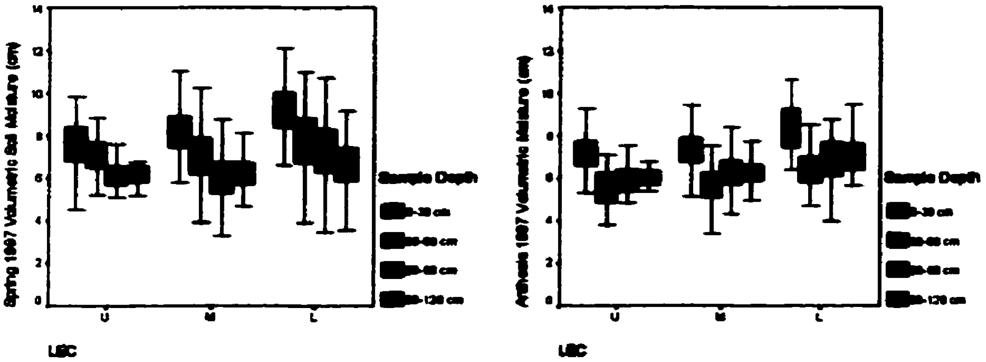
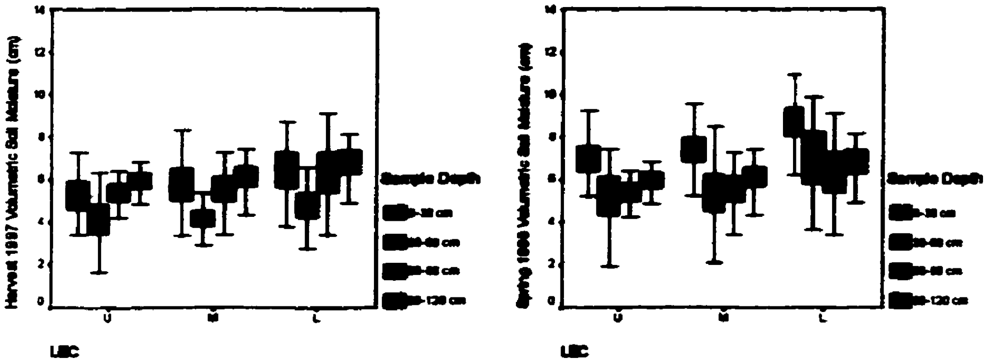


Figure 4.3 Relative distribution of volumetric moisture to 120 cm within N treatments, Harvest 1998.



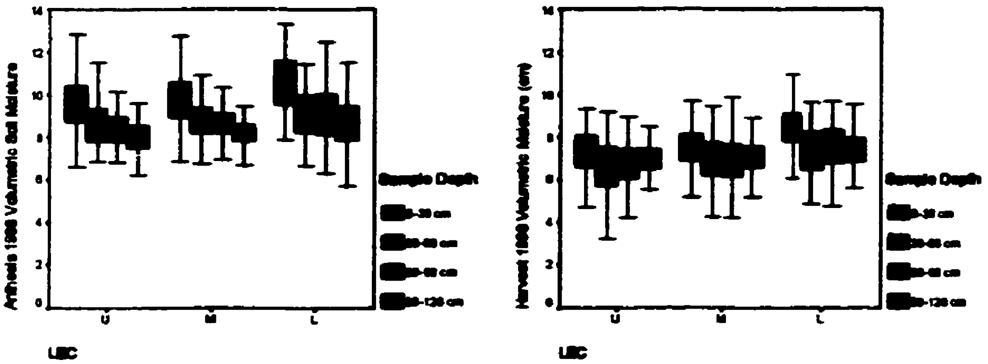
(a) *ES 97*

(b) *MS 97*



(c) *H 97*

(d) *ES 98*



(e) *MS 98*

(f) *H 98*

Figure 4.4 Relative distribution of volumetric soil moisture within 30 cm depth increments, 1997 and 1998.

Table 4.3 Median values of volumetric soil moisture to a depth of 120 cm, across and within LECs.

Time of Sampling	LEC Overall	 U	 M	 L
	cm			
ES 97	27.9	27.2a[1]	27.7a	31.8b
MS 97	26.1	25.0a	25.6a	28.5b
H 97	21.8	21.3a	21.4a	24.7b
ES 98	24.9	24.0a	24.6a	28.6b
MS 98	35.5	34.9a	35.4a	37.2b
H 98	28.9	28.2a	28.6a	30.7b

[1] Median values followed by the same letter were not significantly different among LECs at α=0.20 (Kruskal-Wallis multiple comparison procedure).

Moisture conditions were more different between growing seasons than among LECs. Historical growing season precipitation at the site was estimated to be 21.0 cm (Ash, 1991). 1997 was a dry year, in which 13.2 cm of precipitation was received from May to August 15. As a result, soil moisture was depleted over the course of the growing season, such that *ES V120* was highest (27.9 cm), *MS V120* was intermediate (26.1 cm), and *H V120* was lowest (21.8 cm), over all LECs. Over the winter and in the early spring of 1998, precipitation was low, but in the period from May to July, 23.7 cm of rainfall was received. As a result, *MS V120* was the highest (35.5 cm), and *ES V120* the least (24.9 cm). *H V120* (28.9 cm) was relatively high as well, as 13.2 cm of precipitation fell in the month of August, prior to *H* sampling.

Median *V120* values in the U expressed as a percentage of those measured in the L were 86, 88 and 86%, at *ES*, *MS* and *H* of 1997, respectively; and 84, 94 and 92% in 1998. There was little difference among sampling times in 1997, but in 1998, the greatest relative difference was observed under the dry conditions at *ES*. The corresponding absolute differences between median volumetric soil moisture contents among the U and

L were 4.6, 3.5 and 3.4 cm in 1997, and 4.6, 2.3 and 2.5 cm in 1998 for spring, at *ES*, *MS* and *H*, respectively. In both seasons, the greatest difference occurred at *ES*. While this was the sampling time with the most moisture in 1997, it was of the least in 1998. Also, the differences among LECs were smallest at the 'wettest' sampling time at *MS* of 1998, when soil profiles in all LECs approached field capacity. This is contrary to the observations of Halvorson and Doll (1990) and Miller (1988), who found that the landscape control of moisture distribution was least apparent under dry conditions.

The apparent landscape influence on moisture redistribution is regulated by the intensity of precipitation relative to infiltration and soil water holding capacity, the form of precipitation, precipitation distribution, and evapotranspiration. The landscape influence would be limited with low intensity rainfall with near complete infiltration into the soil profile, as observed by Halvorson and Doll (1991). Precipitation received as snow is subject to drifting, and soil recharge from snow melt is affected by frost. The larger differences among LECs at *ES* may have been due to accumulation of snow in convergent areas. As well, the presence of frost likely limited hydraulic conductivity of the surface soil in the early spring, retarding recharge from snow melt in divergent areas and thereby accentuating the landscape influence on moisture redistribution. In both years, absolute differences among LECs decreased from *ES* to *H*. Later in the growing season, apparent lateral movement of water due to landscape morphology was likely attenuated by the growing crop.

Addition of N fertilizer may increase the amount of moisture used by a growing crop (Campbell et al., 1977a). *V120* did not vary with estimated plant-available N supply

(*EPANS*) with the exception of *H* 1998, at which time *V120* was significantly and inversely correlated to *EPANS* (r^2=-0.38), across LECs (Table 4.4). Under moisture-deficient conditions such as those experienced in 1997, it is likely that all available soil moisture was utilized, regardless of N treatment. In 1998, there was ample soil moisture due to June precipitation (15.3cm), and therefore differences among N treatments were negligible at *MS* (not shown). However, additional fertilizer and soil residual N greatly stimulated biomass and leaf area production, delayed senescence, and likely resulted in additional transpiration which resulted in the observed differences at *H* 1998 (Table 4.5; Figure 4.3). With the exception of the check, median 1998 *H V120* increased from U to L for all N treatments, and within each LEC, *H V120* decreased with each additional N increment. The differences between median *H V120* values between the check and 135 kg/ha treatment were 7.3, 3.5, and 3.4 cm, for the U, M and L, respectively. It is possible that the increase in convergent character in the L attenuated moisture differences among N treatments by lateral moisture redistribution, such that the greatest moisture differences among N treatments were observed in the more divergent U. The magnitudes of the *H V120* 1998 differences due to treatments were greater than those due to landscape effects over all N rates. As a result, large differences in soil fertility among LECs may confound assessments of the landscape effect on moisture redistribution due to the influence of fertility on crop water use.

Table 4.4 Spearman correlations, dynamic soil attributes ($P<0.05$).

(a) Overall 1997	ESVw 97	ESVx 97	ESVy 97	ESVz 97	ESV120 97	MSVw 97	MSVx 97	MSVy 97	MSVz 97	MSV120 97	HVw 97	HVx 97	HVy 97	HVz 97	HV120 97	NO3w 97	NO3x 97	NO3y 97	NO3z 97
ESVw 97	1.00																		
ESVx 97	0.32	1.00																	
ESVy 97	0.22	0.56	1.00																
ESVz 97	0.15	0.37	0.57	1.00															
ESV120 97	0.61	0.78	0.80	0.63	1.00														
MSVw 97	0.52	0.27	0.33	0.19	0.45	1.00													
MSVx 97	0.37	0.42	0.39	0.21	0.47	0.50	1.00												
MSVy 97	0.13	0.31	0.41	0.38	0.38	0.32	0.49	1.00											
MSVz 97	0.14	0.23	0.42	0.49	0.39	0.21	0.27	0.56	1.00										
MSV120 97	0.37	0.42	0.53	0.41	0.57	0.67	0.76	0.80	0.63	1.00									
HVw 97	0.26	NS	0.28	NS	0.27	0.36	0.24	0.21	0.16	0.30	1.00								
HVx 97	0.34	0.30	0.25	NS	0.35	0.39	0.47	0.24	NS	0.38	0.37	1.00							
HVy 97	NS	0.39	0.42	0.40	0.45	0.28	0.30	0.36	0.28	0.38	0.27	0.30	1.00						
HVz 97	0.22	0.35	0.37	0.36	0.42	0.37	0.36	0.41	0.28	0.46	0.16	0.27	0.70	1.00					
HV120 97	0.31	0.41	0.44	0.30	0.50	0.46	0.46	0.40	0.26	0.50	0.69	0.64	0.74	0.67	1.00				
NO3w 97	0.17	NS	NS	NS	NS	0.15	NS	NS	NS	NS	NS	NS	NS	NS	NS	1.00			
NO3x 97	NS	0.17	0.16	NS	0.19	NS	-0.14	NS	NS	NS	NS	NS	NS	NS	NS	0.44	1.00		
NO3y 97	NS	NS	0.18	NS	0.17	NS	NS	NS	0.21	NS	NS	-0.16	NS	NS	NS	0.22	0.47	1.00	
NO3z 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.23	NS	0.30	1.00
NO390 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.90	0.70	0.35	0.24
EPANS 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.21	NS	NS	NS	NS	0.28	0.22	NS	NS
NH4w 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NH4x 97	NS	NS	NS	NS	NS	NS	NS	NS	-0.14	NS	NS	0.19	NS	NS	NS	NS	-0.20	-0.20	NS
NH4y 97	-0.15	NS	NS	NS	NS	-0.15	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NH4z 97	-0.20	0.23	NS	NS	NS	-0.13	NS	NS	NS	NS	NS	NS	0.15	NS	NS	-0.18	NS	NS	NS
Pw 97	0.28	NS	NS	NS	0.17	0.27	0.14	NS	0.14	0.18	NS	NS	NS	NS	NS	0.37	0.21	0.16	NS
Px 97	0.33	NS	NS	NS	NS	0.26	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.24	0.17	0.27	NS
Py 97	0.16	NS	NS	-0.17	NS	NS	NS	-0.17	NS	NS	NS	NS	NS	NS	NS	0.18	NS	0.25	NS
Pz 97	NS	-0.16	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.19	NS	NS	0.16
Kw 97	0.34	NS	NS	NS	0.17	0.19	NS	NS	NS	0.14	NS	0.15	NS	NS	NS	0.46	0.25	NS	NS
Kx 97	0.32	0.16	NS	NS	0.16	0.16	NS	NS	NS	NS	0.13	0.21	NS	NS	NS	0.21	NS	NS	NS
Ky 97	NS	0.18	0.14	NS	0.15	NS	NS	NS	NS	NS	NS	0.14	NS	NS	NS	NS	NS	NS	NS
Kz 97	-0.14	0.21	0.14	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sw 97	0.27	NS	0.14	NS	0.20	0.25	NS	NS	NS	0.15	0.16	NS	NS	NS	NS	0.34	0.13	NS	0.13
Sx 97	0.37	0.27	0.31	NS	0.36	0.30	0.13	NS	0.20	0.27	0.17	0.18	NS	0.13	0.17	0.24	0.31	0.18	NS
Sy 97	0.26	0.18	0.18	0.18	0.26	0.26	0.15	NS	NS	0.20	NS	0.16	0.15	0.17	0.19	0.20	NS	NS	0.18
Sz 97	0.26	NS	NS	0.15	0.18	0.23	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.18	NS	NS	NS
S120 97	0.30	NS	0.14	0.14	0.22	0.28	NS	NS	NS	0.17	0.15	NS	NS	NS	NS	0.27	NS	NS	NS
E	-0.40	-0.18	-0.27	-0.24	-0.36	-0.35	-0.22	-0.24	-0.40	-0.37	-0.31	-0.15	-0.33	-0.29	-0.36	-0.37	NS	NS	NS
G	-0.32	NS	NS	NS	-0.16	-0.36	-0.20	NS	NS	-0.24	-0.23	-0.19	0.03	-0.04	-0.18	NS	NS	NS	NS
Kv	-0.26	NS	NS	NS	NS	-0.20	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Kh	-0.25	NS	NS	NS	NS	-0.16	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.13	NS	NS	NS
Cg	0.29	NS	NS	NS	NS	0.25	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.15	NS	NS	NS
Cl	0.29	NS	NS	NS	NS	0.23	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.14	NS	NS	NS
Ap d	0.32	NS	NS	NS	NS	0.19	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.21	0.14	0.30	0.16
Solum d	0.21	-0.27	NS	-0.19	NS	0.15	NS	-0.17	NS	NS	NS	NS	NS	NS	NS	0.15	NS	0.19	NS
CO3 d	0.18	-0.25	NS	-0.20	NS	NS	NS	-0.14	NS	NS	NS	NS	-0.14	NS	NS	NS	NS	0.19	NS
SOC (%)	0.47	NS	NS	NS	0.19	0.41	0.13	NS	NS	0.17	0.24	NS	NS	NS	0.14	0.27	NS	NS	NS
SOC (Mg/ha)	0.45	NS	NS	NS	0.16	0.31	NS	NS	NS	NS	0.17	NS	NS	NS	NS	0.28	0.16	0.27	0.17
Ap pH	0.23	0.24	0.21	0.18	0.28	0.24	NS	0.16	0.22	0.23	0.18	NS	NS	NS	0.17	NS	NS	NS	0.14

(a) Overall 1997	*NO390 97*	*EPANS 97*	*NH4w 97*	*NH4x 97*	*NH4y 97*	*NH4z 97*	*Pw 97*	*Px 97*	*Py 97*	*Pz 97*	*Kw 97*	*Kx 97*	*Ky 97*	*Kz 97*	*Sw 97*	*Sx 97*	*Sy 97*	*Sz 97*	*S120 97*
ESVw 97																			
ESVx 97																			
ESVy 97																			
ESVz 97																			
ESV120 97																			
MSVw 97																			
MSVx 97																			
MSVy 97																			
MSVz 97																			
MSV120 97																			
HVw 97																			
HVx 97																			
HVy 97																			
HVz 97																			
HV120 97																			
NO3w 97																			
NO3x 97																			
NO3y 97																			
NO3z 97																			
NO390 97	1.00																		
EPANS 97	0.48	1.00																	
NH4w 97	NS	NS	1.00																
NH4x 97	NS	NS	0.75	1.00															
NH4y 97	NS	NS	0.50	0.57	1.00														
NH4z 97	NS	NS	0.44	0.51	0.81	1.00													
Pw 97	0.33	NS	NS	NS	-0.17	-0.27	1.00												
Px 97	0.25	NS	NS	NS	-0.18	-0.31	0.48	1.00											
Py 97	0.19	NS	-0.19	-0.19	-0.19	-0.30	0.26	0.64	1.00										
Pz 97	NS	NS	-0.19	-0.20	-0.22	-0.26	NS	0.44	0.72	1.00									
Kw 97	0.41	0.19	NS	NS	NS	-0.14	0.46	0.22	NS	NS	1.00								
Kx 97	0.15	NS	0.24	0.42	0.16	NS	0.31	0.17	0.22	0.15	0.51	1.00							
Ky 97	NS	NS	0.16	0.28	0.56	0.48	NS	NS	NS	NS	0.19	0.43	1.00						
Kz 97	NS	NS	0.14	0.22	0.48	0.57	-0.19	-0.20	-0.16	-0.15	0.08	0.20	0.80	1.00					
Sw 97	0.22	NS	NS	NS	-0.13	-0.15	0.14	0.20	NS	NS	0.41	0.27	NS	NS	1.00				
Sx 97	0.24	NS	NS	NS	NS	-0.18	0.23	0.20	NS	NS	0.42	0.21	NS	NS	0.59	1.00			
Sy 97	NS	NS	NS	NS	NS	NS	NS	0.14	NS	NS	0.26	NS	NS	NS	0.44	0.52	1.00		
Sz 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.26	NS	NS	NS	0.45	0.45	0.85	1.00	
S120 97	NS	NS	NS	NS	-0.13	-0.14	NS	0.19	NS	NS	0.35	0.14	NS	NS	0.66	0.62	0.89	0.93	1.00
E	-0.31	-0.18	NS	NS	0.24	0.25	-0.18	-0.23	NS	NS	-0.23	NS	0.24	0.28	-0.37	-0.40	-0.38	-0.35	-0.43
G	NS	NS	0.18	NS	NS	0.17	-0.26	-0.34	-0.21	-0.16	-0.44	-0.40	-0.23	NS	-0.16	-0.26	-0.20	NS	-0.14
Kv	NS	NS	-0.15	NS	0.14	0.23	-0.23	-0.24	-0.24	NS	NS	-0.14	0.24	0.35	-0.21	NS	NS	NS	NS
Kh	NS	NS	NS	NS	0.18	0.29	-0.39	-0.35	-0.24	NS	-0.16	-0.24	0.14	0.30	-0.17	-0.19	NS	NS	NS
Cg	NS	NS	NS	NS	-0.20	-0.28	0.36	0.32	0.14	NS	NS	0.19	-0.26	-0.40	0.18	0.14	NS	NS	NS
Cl	NS	NS	NS	NS	-0.19	-0.27	0.35	0.32	0.15	NS	NS	0.19	-0.27	-0.41	0.16	NS	NS	NS	NS
Ap d	NS	NS	NS	NS	-0.23	-0.37	0.31	0.35	0.27	0.18	0.20	0.25	-0.18	-0.36	0.27	0.29	0.17	0.12	0.20
Solum d	NS	NS	NS	NS	-0.17	-0.36	0.45	0.43	0.36	0.22	0.15	0.29	-0.20	-0.41	0.16	0.16	NS	NS	NS
CO3 d	NS	NS	NS	NS	-0.15	-0.35	0.49	0.40	0.38	0.24	0.16	0.31	-0.19	-0.39	0.14	0.15	NS	NS	NS
SOC (%)	0.17	0.18	NS	NS	-0.13	-0.28	0.31	0.24	0.19	NS	0.44	0.44	-0.04	-0.21	0.36	0.39	0.30	0.27	0.35
SOC (Mg/ha)	0.19	0.15	NS	NS	-0.20	-0.32	0.35	0.35	0.25	NS	0.33	0.30	-0.16	-0.33	0.32	0.38	0.24	0.21	0.29
Ap pH	NS	NS	NS	NS	NS	NS	-0.14	NS	-0.17	-0.14	0.22	NS	NS	NS	0.23	0.31	0.26	0.23	0.28

(b) Overall 1998	ESVw 98	ESVx 98	ESVy 98	ESVz 98	ESV120 98	MSVw98	MSVx98	MSVy 98	MSVz 98	MSV120 98	HVw 98	HVx 98	HVy 98	HVz 98	HV120 98	NO3w 98	NO3x 98	NO3y 98
ESVw 98	1.00																	
ESVx 98	0.41	1.00																
ESVy 98	0.22	0.53	1.00															
ESVz 98	0.30	0.47	0.70	1.00														
ESV120 98	0.63	0.85	0.73	0.72	1.00													
MSVw 98	0.27	NS	NS	NS	0.15	1.00												
MSVx 98	NS	NS	NS	0.13	NS	0.32	1.00											
MSVy 98	0.16	0.19	0.25	0.22	0.24	0.24	0.38	1.00										
MSVz 98	0.18	NS	NS	0.13	0.17	0.20	0.22	0.51	1.00									
MSV120 98	0.26	0.14	0.14	0.19	0.23	0.65	0.65	0.72	0.63	1.00								
HVw 98	0.56	0.31	0.22	0.25	0.42	0.29	NS	0.15	NS	0.26	1.00							
HVx 98	0.17	0.32	0.36	0.26	0.34	NS	NS	0.16	NS	NS	0.35	1.00						
HVy 98	0.22	0.26	0.39	0.34	0.37	NS	NS	0.22	NS	NS	0.32	0.64	1.00					
HVz 98	0.13	0.15	0.32	0.32	0.27	NS	NS	NS	NS	NS	0.23	0.51	0.65	1.00				
HV120 98	0.34	0.32	0.40	0.35	0.43	NS	NS	0.22	NS	0.17	0.59	0.82	0.86	0.74	1.00			
NO3w 98	0.34	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.15	-0.19	-0.20	-0.16	-0.13	1.00		
NO3x 98	0.31	0.25	NS	NS	0.23	NS	NS	NS	NS	NS	0.14	-0.18	-0.16	-0.18	NS	0.69	1.00	
NO3y 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.14	NS	NS	0.37	0.47	1.00
NO3z 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.20	NS	NS	-0.16	0.33	0.36	0.61
NO390 98	0.34	0.19	NS	NS	0.17	NS	NS	NS	NS	NS	0.16	-0.18	-0.23	-0.21	-0.16	0.93	0.85	0.53
EPANS 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.36	-0.42	-0.40	-0.38	0.71	0.67	0.43
NH4w 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.14	NS	NS
NH4x 98	NS	NS	NS	0.13	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NH4y 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.25	-0.20	NS
NH4z 98	NS	NS	0.14	0.15	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.27	-0.19	NS
Pw 98	0.37	0.17	NS	NS	0.21	0.15	NS	NS	0.16	NS	0.22	NS	NS	NS	NS	0.51	0.37	NS
Px 98	0.24	NS	NS	NS	0.14	0.17	NS	NS	NS	NS	0.25	NS	0.15	NS	0.19	NS	0.17	NS
Py 98	0.19	NS	NS	NS	NS	0.18	NS	-0.14	NS	NS	0.24	NS	NS	0.14	0.18	NS	0.16	NS
Pz 98	0.15	NS	NS	NS	NS	0.17	NS	NS	NS	NS	0.23	NS	NS	NS	0.16	NS	0.16	NS
Kw 98	0.42	0.17	NS	NS	0.18	0.25	NS	0.17	NS	0.25	0.27	NS	NS	NS	NS	0.45	0.32	NS
Kx 98	0.25	0.16	NS	NS	0.20	0.20	NS	NS	NS	0.18	0.28	NS	NS	NS	0.16	NS	NS	NS
Ky 98	NS	NS	0.17	NS	NS	NS	NS	NS	NS	NS	NS	0.15	NS	NS	0.18	-0.17	-0.14	NS
Kz 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.14	NS	NS	NS	-0.20	-0.17	NS
Sw 98	0.37	NS	NS	0.13	0.18	0.16	0.14	NS	NS	0.16	0.32	NS	NS	NS	0.17	0.31	0.17	NS
Sx 98	0.36	NS	0.25	0.22	0.38	0.18	NS	NS	0.14	0.20	0.31	0.16	0.18	NS	0.23	0.16	0.25	NS
Sy 98	0.16	NS	0.24	0.18	0.20	NS	NS	0.17	0.16	0.21	0.20	0.26	0.16	0.14	0.21	NS	-0.19	NS
Sz 98	0.16	NS	0.20	0.15	0.16	NS	0.14	0.19	NS	0.20	0.16	0.26	0.14	0.13	0.20	NS	-0.17	NS
S120 98	0.25	0.14	0.19	0.18	0.22	0.14	NS	0.16	0.14	0.22	0.25	0.24	0.14	NS	0.21	NS	NS	NS
HNO3w 98	0.13	NS	NS	NS	NS	NS	NS	NS	NS	0.13	0.32	NS	NS	NS	NS	0.29	0.33	0.26
HNO3x 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.14	NS	NS	NS	NS	0.27	0.34	0.30
HNO3y 98	NS	NS	-0.19	-0.15	-0.17	NS	NS	-0.18	NS	NS	NS	-0.26	-0.25	-0.22	-0.24	0.39	0.35	0.33
HNO3z 98	NS	NS	-0.22	-0.19	-0.17	NS	NS	NS	NS	NS	NS	-0.23	-0.27	-0.19	-0.22	0.43	0.36	0.31
HNO390 98	NS	NS	NS	NS	0.02	NS	NS	NS	NS	NS	0.27	NS	NS	NS	NS	0.32	0.37	0.30
HNH4w 98	NS	-0.19	NS	NS	-0.15	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HNH4x 98	-0.14	-0.19	NS	NS	-0.19	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HNH4y 98	NS	-0.18	NS	NS	-0.15	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HNH4z 98	-0.16	-0.20	NS	NS	-0.17	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.18	NS	NS
E	-0.42	-0.37	-0.33	-0.29	-0.44	-0.23	-0.15	-0.27	-0.36	-0.34	-0.35	-0.21	-0.29	-0.20	-0.34	-0.26	-0.24	NS
G	-0.25	NS	NS	NS	NS	-0.35	NS	NS	-0.16	-0.29	-0.33	NS	NS	NS	NS	NS	NS	NS
Kv	-0.29	-0.14	NS	NS	-0.19	NS	NS	NS	NS	NS	-0.19	NS	NS	NS	NS	-0.25	-0.20	NS
Kh	-0.19	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.17	0.18	NS	NS	NS	-0.21	-0.16	NS
Cg	0.25	NS	NS	NS	NS	0.16	NS	NS	0.15	0.17	0.17	NS	NS	NS	NS	0.22	0.24	NS
Cl	0.26	NS	NS	NS	NS	0.15	NS	NS	0.16	0.15	0.17	NS	NS	NS	NS	0.24	0.24	NS
Ap d	0.32	NS	NS	NS	NS	0.17	NS	NS	NS	NS	0.35	NS	NS	NS	NS	0.35	0.24	0.23
Solum d	0.26	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.21	-0.29	NS	NS	NS	0.36	0.20	0.18
CO3 d	0.23	NS	-0.14	NS	NS	NS	NS	NS	NS	NS	0.16	-0.34	NS	NS	NS	0.34	0.22	NS
SOC (%)	0.49	NS	NS	NS	0.20	0.31	NS	NS	0.14	0.25	0.42	NS	NS	NS	0.15	0.48	0.29	0.14
SOC (Mg/ha)	0.44	NS	NS	NS	0.15	0.29	NS	NS	NS	0.24	0.40	NS	NS	NS	NS	0.37	0.24	0.26
Ap pH	0.18	0.15	NS	NS	0.14	0.27	0.22	0.26	0.21	0.31	0.18	0.25	0.22	0.14	0.27	NS	0.14	NS

(b) Overall 1998	NO3z 98	NO390 98	EPANS 98	NH4w 98	NH4x 98	NH4y 98	NH4z 98	Pw 98	Px 98	Py 98	Pz 98	Kw 98	Kx 98	Ky 98	Kz 98	Sw 98	Sx 98	Sy 98
ESVw 98																		
ESVx 98																		
ESVy 98																		
ESVz 98																		
ESV120 98																		
MSVw 98																		
MSVx 98																		
MSVy 98																		
MSVz 98																		
MSV120 98																		
HVw 98																		
HVx 98																		
HVy 98																		
HVz 98																		
HV120 98																		
NO3w 98																		
NO3x 98																		
NO3y 98																		
NO3z 98	1.00																	
NO390 98	0.40	1.00																
EPANS 98	0.36	0.83	1.00															
NH4w 98	NS	NS	NS	1.00														
NH4x 98	NS	NS	NS	NS	1.00													
NH4y 98	NS	-0.19	NS	NS	NS	1.00												
NH4z 98	NS	-0.20	NS	0.60	0.68	0.85	1.00											
Pw 98	NS	0.44	0.15	-0.17	NS	-0.26	-0.28	1.00										
Px 98	0.14	NS	NS	NS	NS	NS	NS	0.22	1.00									
Py 98	0.19	NS	NS	NS	0.16	NS	NS	0.28	0.71	1.00								
Pz 98	0.27	NS	NS	NS	0.16	0.15	NS	0.18	0.64	0.78	1.00							
Kw 98	NS	0.41	0.22	NS	NS	NS	NS	NS	NS	NS	NS	1.00						
Kx 98	NS	NS	NS	0.19	0.42	0.26	0.17	0.22	0.25	0.37	0.42	0.42	1.00					
Ky 98	NS	-0.19	NS	0.24	0.43	0.61	0.50	-0.04	0.31	0.32	0.40	0.15	0.61	1.00				
Kz 98	NS	-0.19	NS	0.25	0.38	0.54	0.59	-0.15	0.20	0.19	0.32	NS	0.46	0.84	1.00			
Sw 98	0.17	0.26	0.14	NS	NS	NS	NS	0.18	0.20	0.25	0.19	0.37	NS	NS	NS	1.00		
Sx 98	0.18	0.19	NS	NS	NS	NS	NS	0.23	0.21	0.24	0.22	0.38	NS	NS	NS	0.58	1.00	
Sy 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.16	NS	NS	NS	0.47	0.59	1.00
Sz 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.15	NS	NS	NS	0.44	0.48	0.90
S120 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.25	NS	NS	NS	0.63	0.68	0.94
HNO3w 98	0.29	0.33	0.43	NS	NS	NS	NS	NS	0.20	0.22	0.23	NS	NS	NS	NS	NS	NS	NS
HNO3x 98	0.24	0.34	0.46	NS	NS	NS	NS	NS	0.19	0.17	0.21	NS	NS	NS	NS	NS	NS	NS
HNO3y 98	0.35	0.46	0.59	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HNO3z 98	0.38	0.45	0.57	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HNO390 98	0.32	0.38	0.50	NS	NS	NS	NS	NS	0.22	0.21	0.24	NS	NS	NS	NS	0.13	NS	NS
HNH4w 98	NS	NS	NS	0.14	NS	0.14	0.14	NS	NS	0.16	0.23	NS	NS	0.16	0.18	NS	NS	NS
HNH4x 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.22	0.28	NS	NS	0.16	0.17	NS	-0.14	NS
HNH4y 98	NS	NS	NS	NS	0.18	0.26	0.27	NS	NS	NS	0.23	NS	0.16	0.32	0.36	NS	-0.17	NS
HNH4z 98	NS	NS	NS	NS	0.14	0.29	0.33	-0.24	NS	NS	0.16	NS	NS	0.32	0.38	-0.15	-0.19	NS
E	NS	-0.26	-0.14	NS	NS	0.15	0.16	-0.24	NS	NS	NS	-0.24	NS	0.25	0.33	-0.32	-0.45	-0.37
G	NS	NS	NS	NS	-0.18	NS	NS	-0.32	-0.21	-0.24	-0.22	-0.48	-0.35	-0.21	-0.14	-0.17	-0.24	NS
Kv	-0.13	-0.19	NS	NS	0.17	0.30	0.32	-0.28	NS	NS	NS	NS	NS	0.25	0.35	NS	-0.14	NS
Kh	NS	-0.19	NS	0.13	NS	0.31	0.34	-0.37	-0.15	-0.19	NS	-0.25	NS	0.25	0.29	-0.13	NS	NS
Cg	NS	0.25	NS	-0.15	-0.23	-0.40	-0.41	0.34	NS	NS	NS	0.20	NS	-0.38	-0.44	0.18	0.18	NS
Cl	NS	0.27	NS	-0.17	-0.26	-0.42	-0.43	0.35	NS	NS	NS	0.21	NS	-0.40	-0.45	0.17	0.17	NS
Ap d	0.20	0.25	NS	NS	NS	-0.28	-0.34	0.48	0.26	0.33	0.24	0.34	NS	-0.16	-0.28	0.25	0.26	NS
Solum d	0.18	0.25	NS	NS	NS	-0.31	-0.38	0.49	0.16	0.31	0.23	0.32	0.17	-0.20	-0.30	0.14	NS	NS
CO3 d	0.15	0.28	NS	NS	NS	-0.30	-0.38	0.50	0.16	0.29	0.22	0.30	0.21	-0.20	-0.30	NS	NS	NS
SOC (%)	0.22	0.39	0.23	NS	NS	-0.25	-0.31	0.54	0.19	0.25	0.19	0.56	0.22	NS	-0.15	0.32	0.31	0.18
SOC (Mg/ha)	0.24	0.34	0.18	NS	NS	-0.28	-0.33	0.54	0.27	0.31	0.21	0.48	0.23	NS	-0.24	0.28	0.31	0.15
Ap pH	NS	0.16	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.17	NS	NS	NS	0.16	0.30	0.20

(b) Overall 1998	*Sz 98*	*S120 98*	*HNO3w 98*	*HNO3x 98*	*HNO3y 98*	*HNO3z 98*	*HNO390 98*	*HNH4w 98*	*HNH4x 98*	*HNH4y 98*	*HNH4z 98*
ESVw 98											
ESVx 98											
ESVy 98											
ESVz 98											
ESV120 98											
MSVw 98											
MSVx 98											
MSVy 98											
MSVz 98											
MSV120 98											
HVw 98											
HVx 98											
HVy 98											
HVz 98											
HV120 98											
NO3w 98											
NO3x 98											
NO3y 98											
NO3z 98											
NO390 98											
EPANS 98											
NH4w 98											
NH4x 98											
NH4y 98											
NH4z 98											
Pw 98											
Px 98											
Py 98											
Pz 98											
Kw 98											
Kx 98											
Ky 98											
Kz 98											
Sw 98											
Sx 98											
Sy 98											
Sz 98	1.00										
S120 98	**0.92**	1.00									
HNO3w 98	NS	NS	1.00								
HNO3x 98	NS	NS	**0.59**	1.00							
HNO3y 98	NS	NS	**0.46**	**0.64**	1.00						
HNO3z 98	NS	NS	**0.40**	**0.56**	**0.78**	1.00					
HNO390 98	NS	NS	**0.96**	**0.72**	**0.61**	**0.52**	1.00				
HNH4w 98	NS	NS	**0.25**	**0.27**	**0.26**	**0.17**	**0.29**	1.00			
HNH4x 98	NS	NS	**0.24**	**0.32**	**0.28**	**0.19**	**0.29**	**0.64**	1.00		
HNH4y 98	NS	NS	NS	**0.22**	**0.21**	NS	**0.16**	**0.53**	**0.61**	1.00	
HNH4z 98	NS	**-0.15**	NS	**0.18**	**0.13**	NS	NS	**0.41**	**0.49**	**0.76**	1.00
E	**-0.35**	**-0.42**	**-0.17**	NS	NS	NS	NS	**0.18**	**0.24**	**0.33**	**0.40**
G	NS	NS	NS	NS	NS	NS	NS	NS	**-0.14**	NS	NS
Kv	NS	NS	NS	NS	NS	NS	NS	NS	**0.17**	**0.29**	**0.39**
Kh	NS	NS	**-0.16**	NS	NS	NS	**-0.14**	NS	NS	NS	**0.26**
Cg	NS	NS	**0.19**	NS	NS	NS	**0.16**	NS	NS	**-0.16**	**-0.35**
Cl	NS	NS	**0.19**	NS	NS	NS	**0.15**	NS	NS	**-0.18**	**-0.36**
Ap d	NS	NS	**0.26**	**0.17**	**0.13**	**0.16**	**0.21**	NS	NS	**-0.15**	**-0.30**
Solum d	NS	NS	**0.14**	NS	NS	NS	NS	NS	NS	NS	**-0.25**
CO3 d	**-0.15**	NS	**0.16**	NS	NS	NS	NS	NS	NS	NS	**-0.24**
SOC (%)	**0.15**	**0.25**	**0.29**	NS	**0.15**	**0.21**	**0.25**	NS	NS	NS	**-0.22**
SOC (Mg/ha)	NS	**0.20**	**0.30**	**0.19**	**0.18**	**0.19**	**0.25**	NS	NS	NS	**-0.30**
Ap pH	**0.22**	**0.23**	**0.21**	**0.21**	NS	NS	**0.21**	**-0.17**	NS	NS	NS

(c) 0 kg/ha 1998	NO3w 98	NO3x 98	NO3y 98	NO3z 98	NO390 98	NH4w 98	NH4x 98	NH4y 98	NH4z 98	HNO3w 98	HNO3x 98	HNO3y 98	HNO3z 98	HNO390 98	HNH4w 98	HNH4x 98	HNH4y 98	HNH4z 98
NO3w 98	1.00																	
NO3x 98	0.45	1.00																
NO3y 98	0.35	NS	1.00															
NO3z 98	NS	0.38	0.42	1.00														
NO390 98	0.96	0.61	0.35	0.34	1.00													
NH4w 98	-0.48	NS	NS	NS	-0.52	1.00												
NH4x 98	-0.33	NS	NS	NS	-0.36	0.80	1.00											
NH4y 98	-0.50	NS	NS	NS	-0.46	0.71	0.78	1.00										
NH4z 98	-0.44	NS	NS	NS	-0.42	0.73	0.78	0.93	1.00									
HNO3w 98	NS	0.36	NS	NS	NS	NS	0.39	0.44	0.45	1.00								
HNO3x 98	NS	NS	NS	NS	NS	0.32	NS	0.43	0.39	0.48	1.00							
HNO3y 98	NS	NS	NS	NS	NS	NS	NS	0.42	0.38	NS	0.62	1.00						
HNO3z 98	NS	0.34	NS	NS	NS	NS	NS	0.40	0.31	0.46	0.56	0.52	1.00					
HNO390 98	NS	0.34	NS	NS	NS	NS	0.41	0.52	0.54	0.97	0.55	0.44	0.52	1.00				
HNH4w 98	NS	NS	NS	NS	NS	0.54	0.48	0.41	0.50	NS	NS	NS	NS	NS	1.00			
HNH4x 98	NS	NS	0.37	NS	NS	0.43	0.50	0.49	0.55	NS	0.37	NS	NS	NS	0.81	1.00		
HNH4y 98	NS	NS	NS	NS	NS	0.45	0.54	0.55	0.63	NS	0.45	0.35	NS	0.31	0.66	0.79	1.00	
HNH4z 98	NS	NS	NS	NS	NS	0.46	0.57	0.67	0.66	NS	0.60	0.42	0.36	0.37	0.55	0.77	0.82	1.00
ESVw 98	0.45	0.51	NS	NS	0.50	-0.30	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ESVx 98	NS	0.36	NS	NS	0.31	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ESVy 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ESVz 98	NS	NS	NS	NS	NS	NS	0.33	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ESV120 98	NS	0.35	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSVw 98	NS	NS	NS	0.36	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSVx 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSVy 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSVz 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSV120 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HVw 98	NS	0.43	NS	NS	0.33	NS	NS	NS	NS	0.47	NS	NS	NS	0.44	NS	NS	NS	NS
HVx 98	NS	NS	NS	NS	NS	NS	0.31	NS	0.31	0.37	0.33	NS	NS	0.40	NS	0.38	0.31	0.33
HVy 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.36	NS
HVz 98	NS	0.34	NS	NS	NS	NS	NS	NS	0.30	NS	NS	NS	NS	NS	NS	NS	0.30	NS
HV120 98	NS	0.39	NS	NS	NS	NS	0.32	0.30	0.32	0.52	NS	NS	NS	0.50	NS	NS	NS	NS
Pw 98	0.59	NS	NS	NS	0.56	NS	NS	-0.36	-0.31	NS	NS	NS	NS	NS	NS	NS	NS	NS
Px 98	NS	0.50	NS	NS	NS	0.34	0.40	0.39	0.32	0.44	NS	NS	NS	0.42	0.31	0.32	NS	0.32
Py 98	NS	0.34	NS	NS	NS	0.52	0.54	0.53	0.48	0.47	NS	NS	NS	0.45	0.39	0.36	NS	0.32
Pz 98	NS	0.33	NS	NS	NS	0.49	0.56	0.63	0.57	0.59	0.43	NS	0.37	0.60	0.46	0.49	0.42	0.50
Kw 98	0.42	0.34	NS	NS	0.43	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Kx 98	NS	NS	NS	NS	NS	NS	0.32	0.31	0.31	0.36	NS	NS	NS	0.33	NS	NS	NS	NS
Ky 98	-0.35	NS	NS	NS	-0.33	0.47	0.55	0.72	0.64	0.52	NS	0.34	NS	0.54	NS	0.33	0.40	0.47
Kz 98	NS	NS	NS	NS	NS	0.60	0.64	0.74	0.74	0.49	0.44	0.35	NS	0.53	0.35	0.39	0.47	0.54
Sw 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sx 98	NS	0.43	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sy 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sz 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S120 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
E	NS	NS	NS	NS	NS	NS	NS	0.34	0.31	NS	0.55	0.58	0.40	NS	NS	NS	NS	0.32
G	-0.30	-0.32	NS	NS	NS	NS	NS	NS	NS	-0.32	NS	NS	NS	NS	NS	NS	NS	NS
Kv	-0.42	NS	NS	NS	-0.40	0.39	0.40	0.48	0.46	NS	0.31	NS	NS	NS	NS	NS	NS	0.44
Kh	-0.39	NS	NS	0.32	-0.33	0.32	NS	0.35	0.35	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cg	0.43	NS	NS	NS	0.43	-0.40	-0.43	-0.46	-0.43	NS	NS	NS	NS	NS	NS	NS	NS	-0.44
Cl	0.50	NS	NS	NS	0.49	-0.46	-0.48	-0.51	-0.49	NS	NS	NS	NS	NS	NS	-0.34	NS	-0.43
Ap d	0.57	0.49	NS	NS	0.59	-0.30	NS	-0.38	-0.42	NS	NS	NS	NS	NS	NS	NS	NS	NS
Solum d	0.58	NS	NS	NS	0.54	NS	-0.34	-0.54	-0.50	NS	NS	NS	NS	NS	NS	NS	NS	NS
CO3 d	0.57	0.31	NS	NS	0.57	NS	-0.37	-0.50	-0.48	NS	NS	NS	NS	NS	NS	NS	NS	-0.32
SOC (%)	0.60	NS	NS	NS	0.59	-0.42	NS	-0.34	-0.30	NS	NS	-0.43	NS	NS	NS	NS	NS	NS
SOC (Mg/ha)	0.61	0.43	NS	NS	0.62	-0.38	NS	-0.40	-0.41	NS	NS	NS	NS	NS	NS	NS	NS	NS
Ap pH	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

(d) 45 kg/ha 1998	NO3w 98	NO3x 98	NO3y 98	NO3z 98	NO390 98	NH4w 98	NH4x 98	NH4y 98	NH4z 98	HNO3w 98	HNO3x 98	HNO3y 98	HNO3z 98	HNO390 98	HNH4w 98	HNH4x 98	HNH4y 98	HNH4z 98
NO3w 98	1.00																	
NO3x 98	0.61	1.00																
NO3y 98	NS	0.34	1.00															
NO3z 98	NS	NS	0.51	1.00														
NO390 98	0.86	0.84	0.30	NS	1.00													
NH4w 98	-0.30	NS	NS	NS	NS	1.00												
NH4x 98	-0.37	-0.31	NS	NS	-0.29	0.73	1.00											
NH4y 98	-0.41	-0.41	NS	NS	-0.39	0.73	0.80	1.00										
NH4z 98	-0.39	-0.41	NS	NS	-0.40	0.63	0.75	0.83	1.00									
HNO3w 98	NS	NS	NS	NS	NS	-0.30	-0.26	-0.32	-0.31	1.00								
HNO3x 98	NS	NS	NS	NS	NS	-0.38	-0.27	-0.42	-0.33	0.44	1.00							
HNO3y 98	NS	NS	0.32	0.27	NS	NS	NS	NS	NS	NS	NS	1.00						
HNO3z 98	0.26	0.28	NS	NS	0.27	-0.34	-0.26	-0.29	-0.28	0.09	0.34	0.48	1.00					
HNO390 98	NS	NS	NS	NS	NS	-0.30	-0.25	-0.32	-0.28	0.99	0.53	NS	NS	1.00				
HNH4w 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	1.00			
HNH4x 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.33	NS	NS	NS	0.42	1.00		
HNH4y 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.29	0.39	1.00	
HNH4z 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.38	0.68	1.00
ESVw 98	0.46	0.31	NS	NS	0.43	NS	NS	NS	-0.32	NS	NS	NS	NS	NS	NS	NS	NS	NS
ESVx 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ESVy 98	NS	NS	0.33	NS	NS	0.33	0.29	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ESVz 98	NS	NS	0.28	NS	NS	0.39	0.26	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ESV120 98	NS	0.32	NS	NS	0.26	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSVw 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.28	NS	NS	NS
MSVx 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.32	NS	NS	NS	NS	NS
MSVy 98	0.28	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSVz 98	0.43	0.25	NS	NS	0.40	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.31
MSV120 98	NS	NS	NS	NS	0.27	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.27	NS	NS	NS
HVw 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.45	NS	NS	NS	0.44	0.26	NS	NS	NS
HVx 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.26	NS	NS	NS	0.33	NS	NS	NS	NS
HVy 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.28	NS	NS	0.25	NS	NS	NS	NS
HVz 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HV120 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.40	0.29	NS	NS	0.44	NS	NS	NS	NS
Pw 98	0.69	0.49	NS	NS	0.60	-0.32	-0.31	-0.35	-0.32	NS	0.35	NS	0.29	NS	NS	NS	NS	NS
Px 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Py 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Pz 98	NS	NS	NS	0.25	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.25	NS	NS
Kw 98	0.50	NS	NS	NS	0.39	NS	NS	NS	NS	NS	0.29	NS	NS	NS	NS	NS	NS	NS
Kx 98	NS	NS	NS	NS	NS	NS	0.37	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Ky 98	-0.37	-0.46	NS	NS	-0.45	0.37	0.54	0.69	0.62	NS	-0.32	NS	-0.27	NS	NS	NS	NS	0.26
Kz 98	-0.37	-0.43	NS	NS	-0.46	0.26	0.38	0.54	0.63	NS	NS	NS	NS	NS	NS	NS	NS	0.35
Sw 98	0.36	NS	NS	NS	0.38	NS	NS	NS	-0.29	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sx 98	0.25	0.37	0.25	NS	0.39	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sy 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sz 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.25	NS	NS	NS	NS	NS	NS	NS
S120 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.27	NS	NS	NS	NS	NS	NS	NS
E	-0.31	-0.36	NS	NS	-0.36	NS	NS	NS	NS	-0.28	-0.35	NS	NS	-0.31	NS	NS	NS	0.34
G	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.29	-0.27	NS
Kv	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.36
Kh	-0.26	-0.25	NS	NS	-0.25	NS	NS	0.32	0.42	-0.27	-0.26	NS	NS	NS	NS	NS	NS	NS
Cg	0.36	0.37	NS	NS	0.37	-0.28	-0.45	-0.54	-0.62	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cl	0.37	0.37	NS	NS	0.38	-0.28	-0.45	-0.53	-0.62	NS	NS	NS	NS	NS	NS	NS	NS	-0.29
Ap d	0.27	NS	NS	NS	NS	NS	NS	-0.28	-0.40	NS	NS	NS	NS	NS	NS	NS	NS	-0.28
Solum d	NS	NS	NS	NS	NS	NS	-0.28	-0.30	-0.45	NS	NS	NS	NS	NS	NS	NS	NS	NS
CO3 d	NS	NS	NS	NS	NS	NS	NS	NS	-0.39	NS	NS	NS	NS	NS	NS	NS	NS	-0.29
SOC (%)	0.39	NS	NS	NS	0.27	NS	-0.27	NS	-0.25	0.31	NS	NS	NS	0.30	0.26	NS	NS	NS
SOC (Mg/ha	0.33	NS	NS	NS	0.34	NS	-0.25	-0.32	-0.43	0.33	0.26	NS	NS	0.30	NS	NS	NS	NS
Ap pH	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.32	NS	NS	0.28	NS	NS	NS	NS

(e) 98 kg/ha 1998	NO3w 98	NO3x 98	NO3y 98	NO3z 98	NO390 98	NH4w 98	NH4x 98	NH4y 98	NH4z 98	HNO3w 98	HNO3x 98	HNO3y 98	HNO3z 98	HNO390 98	HNH4w 98	HNH4x 98	HNH4y 98	HNH4z 98
NO3w 98	1.00																	
NO3x 98	0.60	1.00																
NO3y 98	0.37	0.42	1.00															
NO3z 98	0.38	0.37	0.69	1.00														
NO390 98	0.90	0.81	0.54	0.43	1.00													
NH4w 98	NS	NS	NS	NS	NS	1.00												
NH4x 98	NS	NS	NS	NS	NS	0.55	1.00											
NH4y 98	-0.28	NS	NS	-0.39	NS	0.27	0.32	1.00										
NH4z 98	-0.41	-0.31	NS	NS	-0.34	0.28	0.35	0.62	1.00									
HNO3w 98	0.30	0.34	0.34	0.31	0.35	NS	NS	-0.27	-0.31	1.00								
HNO3x 98	NS	0.34	0.39	0.33	NS	-0.25	-0.36	NS	NS	0.54	1.00							
HNO3y 98	NS	NS	0.43	0.42	NS	NS	NS	NS	NS	0.47	0.63	1.00						
HNO3z 98	NS	NS	0.45	0.56	0.29	NS	NS	-0.27	NS	0.32	0.47	0.73	1.00					
HNO390 98	NS	0.37	0.42	0.37	0.33	NS	NS	NS	-0.26	0.93	0.74	0.64	0.45	1.00				
HNH4w 98	NS	NS	NS	NS	NS	NS	-0.32	NS	NS	0.31	0.29	0.33	NS	0.33	1.00			
HNH4x 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.32	0.32	0.40	0.27	0.36	0.52	1.00		
HNH4y 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.33	0.34	NS	NS	0.61	0.57	1.00	
HNH4z 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.34	NS	NS	NS	0.45	0.30	0.74	1.00
ESVw 98	NS	0.37	NS	NS	0.31	NS	NS	NS	-0.34	NS	NS	NS	NS	NS	NS	NS	NS	-0.10
ESVx 98	NS	0.32	NS	NS	0.12	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.34	NS
ESVy 98	NS	NS	NS	-0.31	0.02	NS	NS	NS	NS	NS	NS	-0.31	-0.32	NS	-0.28	-0.35	-0.31	NS
ESVz 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.32	NS	NS
ESV120 98	NS	0.26	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.26	-0.29	-0.29	NS
MSVw 98	0.10	NS	NS	NS	NS	NS	NS	NS	-0.32	NS	NS	0.42	0.33	NS	0.27	0.33	NS	NS
MSVx 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSVy 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.28	NS	NS	NS	NS	-0.30	NS	NS
MSVz 98	NS	NS	NS	NS	NS	NS	NS	NS	0.25	NS	-0.27	NS	NS	NS	NS	-0.32	NS	NS
MSV120 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HVw 98	NS	0.36	NS	NS	0.26	NS	NS	NS	-0.31	0.36	NS	NS	NS	0.30	NS	NS	NS	NS
HVx 98	NS	NS	NS	-0.32	NS	NS	NS	0.25	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HVy 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HVz 98	NS	NS	0.31	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HV120 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Pw 98	0.53	0.44	NS	NS	0.53	NS	NS	NS	-0.33	NS	NS	NS	NS	NS	NS	NS	NS	-0.32
Px 98	NS	0.33	0.29	0.43	NS	-0.37	NS	-0.31	-0.31	0.34	0.49	0.37	0.39	0.42	NS	NS	NS	NS
Py 98	0.43	0.38	NS	0.31	0.40	-0.26	NS	-0.27	-0.47	0.38	0.33	0.27	NS	0.38	NS	NS	NS	NS
Pz 98	0.40	0.47	0.26	0.42	0.43	-0.28	NS	-0.34	-0.40	0.32	0.38	0.39	0.29	0.38	NS	NS	NS	NS
Kw 98	0.49	0.29	NS	NS	0.45	NS	NS	NS	-0.34	NS	NS	NS	NS	NS	NS	NS	NS	NS
Kx 98	0.32	0.42	NS	NS	0.37	NS	0.38	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Ky 98	NS	0.28	NS	NS	0.26	NS	NS	0.33	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Kz 98	NS	NS	NS	NS	NS	NS	NS	0.31	0.42	NS	NS	NS	NS	NS	NS	NS	0.29	0.31
Sw 98	0.27	NS	NS	NS	NS	NS	NS	NS	-0.26	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sx 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sy 98	NS	-0.36	-0.38	-0.27	-0.31	NS	NS	NS	NS	NS	-0.26	NS	NS	NS	NS	NS	NS	NS
Sz 98	NS	-0.39	-0.42	NS	-0.33	NS	NS	NS	NS	NS	-0.38	-0.26	NS	NS	NS	NS	NS	NS
S120 98	NS	-0.29	-0.28	NS	NS	NS	NS	NS	NS	NS	-0.29	NS	NS	NS	NS	NS	NS	NS
E	NS	NS	NS	NS	NS	-0.32	NS	NS	NS	NS	NS	NS	NS	NS	0.31	NS	0.35	0.27
G	NS	NS	-0.29	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.38	NS	NS
Kv	-0.50	-0.40	-0.29	-0.32	-0.51	NS	NS	0.29	0.32	-0.28	NS	NS	NS	NS	NS	NS	NS	NS
Kh	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.38	-0.28	NS	NS	-0.40	NS	NS	NS	NS
Cg	NS	0.36	NS	NS	NS	NS	NS	NS	-0.26	0.35	NS	NS	NS	0.33	NS	NS	NS	-0.28
Cl	NS	0.38	NS	0.30	0.27	NS	NS	-0.27	-0.29	0.30	NS	NS	NS	0.28	NS	NS	NS	-0.32
Ap d	0.40	0.31	0.45	0.53	0.37	NS	NS	-0.34	-0.34	0.32	NS	0.35	0.28	0.27	NS	NS	NS	-0.29
Solum d	0.52	0.39	0.44	0.45	0.47	NS	NS	-0.43	-0.53	0.45	0.26	0.34	0.32	0.37	NS	0.32	NS	NS
CO3 d	0.52	0.48	0.44	0.46	0.50	NS	NS	-0.43	-0.54	0.44	0.29	0.37	0.36	0.40	NS	0.31	NS	NS
SOC (%)	0.50	0.30	0.28	0.32	0.40	NS	NS	-0.38	-0.53	0.31	NS	0.36	0.32	NS	NS	0.33	NS	NS
SOC (Mg/ha	0.42	0.33	0.43	0.50	0.37	NS	NS	-0.44	-0.42	0.34	NS	0.41	0.31	0.31	NS	0.27	NS	-0.26
Ap pH	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

(f) 135kg/ha 1998	NO3w 98	NO3x 98	NO3y 98	NO3z 98	NO390 98	NH4w 98	NH4x 98	NH4y 98	NH4z 98	HNO3w 98	HNO3x 98	HNO3y 98	HNO3z 98	HNO390 98	HNH4w 98	HNH4x 98	HNH4y 98	HNH4z 98
NO3w 98	1.00																	
NO3x 98	NS	1.00																
NO3y 98	NS	NS	1.00															
NO3z 98	0.59	NS	NS	1.00														
NO390 98	0.83	0.52	0.59	0.58	1.00													
NH4w 98	NS	NS	NS	NS	NS	1.00												
NH4x 98	NS	NS	NS	NS	NS	0.56	1.00											
NH4y 98	NS	-0.61	NS	-0.43	NS	NS	0.45	1.00										
NH4z 98	NS	NS	NS	NS	-0.52	NS	NS	0.78	1.00									
HNO3w 98	NS	NS	NS	0.44	NS	NS	NS	NS	NS	1.00								
HNO3x 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.59	1.00							
HNO3y 98	0.47	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.67	1.00						
HNO3z 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.78	1.00					
HNO390 98	NS	NS	NS	0.44	NS	NS	NS	NS	NS	0.87	0.81	0.66	0.52	1.00				
HNH4w 98	NS	NS	NS	NS	NS	-0.58	NS	NS	NS	NS	NS	NS	NS	NS	1.00			
HNH4x 98	NS	NS	NS	NS	NS	-0.53	NS	NS	NS	NS	NS	NS	NS	NS	0.82	1.00		
HNH4y 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.63	0.76	1.00	
HNH4z 98	-0.48	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.52	0.73	0.85	1.00
ESVw 98	NS	NS	0.56	NS	NS	NS	0.47	NS	NS	NS	NS	NS	NS	NS	-0.50	-0.44	-0.43	-0.56
ESVx 98	NS	NS	0.59	NS	NS	NS	NS	NS	NS	NS	NS	-0.46	-0.43	-0.49	NS	NS	NS	NS
ESVy 98	NS	NS	0.43	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ESVz 98	NS	NS	NS	NS	NS	NS	0.51	NS	NS	NS	NS	-0.43	NS	-0.44	NS	NS	NS	NS
ESV120 98	NS	NS	0.65	NS	NS	0.55	NS	NS	NS	NS	NS	-0.51	-0.43	NS	NS	NS	NS	NS
MSVw 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.66	-0.55	-0.61	-0.61
MSVx 98	NS	NS	NS	NS	-0.46	NS	0.45	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSVy 98	-0.63	NS	NS	NS	-0.47	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.53	NS	NS	NS
MSVz 98	-0.52	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.46	NS	NS	NS	-0.44	-0.54	NS	NS
MSV120 98	NS	NS	NS	NS	NS	0.47	NS	NS	NS	NS	NS	NS	NS	NS	-0.55	-0.57	-0.60	NS
HVw 98	NS	NS	0.54	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.49
HVx 98	NS	-0.53	NS	NS	NS	NS	NS	0.46	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HVy 98	NS	-0.46	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HVz 98	NS	-0.61	NS	NS	NS	-0.43	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HV120 98	NS	-0.63	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Pw 98	NS	NS	NS	NS	NS	NS	NS	-0.61	-0.64	NS	NS	NS	NS	NS	NS	NS	NS	NS
Px 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.48	-0.62	NS	-0.52
Py 98	0.48	NS	NS	0.71	0.45	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Pz 98	NS	NS	NS	0.53	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Kw 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Kx 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.46	NS	NS	-0.43	NS	NS	NS	NS
Ky 98	NS	-0.49	NS	NS	NS	-0.54	NS	0.61	NS	-0.47	NS	NS	NS	NS	NS	NS	NS	NS
Kz 98	NS	-0.43	NS	-0.48	NS	NS	NS	0.43	NS	-0.51	-0.46	NS	NS	-0.46	NS	NS	NS	NS
Sw 98	0.51	NS	NS	0.66	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sx 98	NS	NS	NS	0.50	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.43
Sy 98	NS	NS	NS	0.46	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.49	-0.44	NS	-0.43
Sz 98	0.46	NS	NS	0.49	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S120 98	0.47	NS	NS	0.49	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
E	NS	NS	-0.49	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.55	0.79	0.80	0.86
G	NS	NS	NS	NS	NS	NS	NS	NS	0.47	NS	NS	NS	NS	NS	NS	NS	NS	NS
Kv	-0.46	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.51	0.65	0.74
Kh	NS	NS	NS	NS	NS	NS	NS	0.69	0.82	NS	NS	NS	NS	NS	NS	NS	NS	0.47
Cg	NS	NS	0.51	NS	NS	NS	NS	-0.50	-0.63	NS	NS	NS	NS	NS	NS	NS	-0.46	-0.60
Cl	NS	NS	0.51	NS	NS	NS	NS	-0.50	-0.63	NS	NS	NS	NS	NS	NS	NS	-0.46	-0.60
Ap d	NS	NS	0.44	NS	NS	NS	NS	NS	-0.48	NS	NS	NS	NS	NS	NS	-0.47	-0.62	-0.69
Solum d	0.45	NS	0.63	NS	0.59	NS	NS	-0.46	-0.49	NS	NS	NS	NS	NS	NS	NS	NS	NS
CO3 d	NS	NS	NS	NS	NS	NS	NS	-0.57	-0.69	NS	NS	NS	NS	NS	NS	NS	NS	NS
SOC (%)	0.52	NS	0.52	NS	0.44	NS	NS	NS	-0.53	NS	NS	NS	NS	NS	NS	-0.51	-0.44	-0.76
SOC (Mg/ha)	NS	NS	NS	NS	NS	NS	NS	NS	-0.54	NS	NS	NS	NS	NS	-0.46	-0.60	-0.66	-0.78
Ap pH	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.70	-0.68	-0.44	NS

(g) Overall 1997, 1998	ESVw 98	ESVx 98	ESVy 98	ESVz 98	ESV120 98	MSVw98	MSVx98	MSVy 98	MSVz 98	MSV120 98	HVw 98	HVx 98	HVy 98	HVz 98	HV120 98	Pw 98	Px 98	Py 98	Pz 98	Kw 98	Kx 98	Ky 98	Kz 98	Sw 98	Sx 98	Sy 98	Sz 98
ESVw 97	0.47	0.24	NS	0.22	0.33	0.35	NS	0.25	0.19	0.34	0.51	0.17	0.33	0.27	0.41	0.32	0.30	0.23	0.17	0.38	0.24	NS	NS	0.29	0.26	0.22	0.25
ESVx 97	0.25	0.35	0.39	0.35	0.41	NS	NS	0.25	NS	0.18	0.21	0.46	0.41	0.29	0.46	NS	0.15	NS	NS	NS	NS	0.16	0.14	NS	0.15	NS	NS
ESVy 97	0.23	0.38	0.42	0.38	0.44	NS	NS	0.22	NS	0.16	0.24	0.39	0.49	0.37	0.49	NS	NS	NS	NS	0.15	NS	0.13	NS	NS	0.18	NS	NS
ESVz 97	NS	0.21	0.40	0.36	0.31	NS	NS	0.20	NS	NS	NS	0.30	0.49	0.45	0.43	NS	NS	NS	NS	NS	NS	0.15	NS	NS	0.16	NS	NS
ESV120 97	0.35	0.39	0.45	0.42	0.50	0.19	NS	0.32	NS	0.27	0.36	0.45	0.59	0.45	0.62	0.16	0.26	0.18	NS	0.21	0.15	0.17	NS	0.15	0.23	0.15	0.14
MSVw 97	0.52	0.45	0.28	0.37	0.51	0.32	NS	0.19	NS	0.27	0.51	0.29	0.35	0.28	0.45	0.21	0.25	0.20	0.16	0.34	0.22	NS	NS	0.27	0.23	0.22	0.22
MSVx 97	0.33	0.36	0.30	0.36	0.41	0.13	0.17	0.20	NS	0.20	0.32	0.36	0.32	0.26	0.40	NS	0.15	NS	NS	NS	0.16	0.15	NS	NS	NS	NS	NS
MSVy 97	NS	0.31	0.36	0.41	0.36	NS	NS	0.20	0.16	0.14	NS	0.27	0.37	0.33	0.35	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.14	NS	NS
MSVz 97	NS	0.22	0.28	0.28	0.27	NS	NS	0.13	NS	NS	NS	NS	0.34	0.30	0.29	NS	NS	NS	NS	0.14	NS	NS	NS	NS	0.20	NS	NS
MSV120 9	0.33	0.44	0.38	0.46	0.50	0.20	0.16	0.24	0.14	0.25	0.32	0.35	0.46	0.40	0.50	NS	NS	NS	NS	0.21	0.16	0.14	NS	0.15	0.18	0.15	NS
HVw 97	0.34	0.24	0.27	0.16	0.33	0.19	NS	0.18	0.20	0.28	0.36	NS	0.15	NS	0.22	NS	NS	NS	NS	0.21	NS	NS	NS	0.15	0.18	0.20	NS
HVx 97	0.31	0.33	0.30	0.27	0.39	0.17	0.15	0.15	NS	0.21	0.42	0.29	0.18	0.14	0.32	NS	NS	NS	NS	0.16	0.29	0.24	NS	0.14	0.18	0.17	NS
HVy 97	0.22	0.53	-	-	-	NS	NS	0.25	NS	0.14	0.22	0.36	0.39	0.32	0.40	NS	NS	NS	NS	NS	NS	0.17	NS	NS	0.25	0.24	0.20
HVz 97	0.30	0.48	-	-	-	NS	0.13	0.22	0.13	0.19	0.25	0.26	0.34	0.32	0.35	NS	NS	NS	NS	NS	NS	NS	NS	0.13	0.22	0.18	0.15
HV120 97	0.40	0.52	-	-	-	0.17	0.18	0.31	0.21	0.32	0.42	0.30	0.34	0.24	0.41	NS	NS	NS	NS	0.14	0.21	0.20	NS	NS	0.27	0.23	0.15
Pw 97	0.21	NS	NS	NS	NS	0.20	NS	NS	NS	0.19	0.16	-0.15	NS	NS	NS	0.28	0.27	0.26	0.18	0.27	0.27	NS	NS	NS	NS	NS	NS
Px 97	0.26	NS	NS	NS	NS	0.14	NS	NS	NS	0.19	0.24	-0.17	NS	NS	NS	0.23	0.31	0.27	0.21	0.21	0.20	NS	NS	NS	0.21	NS	NS
Py 97	0.15	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.16	-0.17	-0.16	NS	NS	0.20	NS	0.17	NS	0.15	0.16	NS	NS	NS	NS	NS	NS
Pz 97	0.14	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.18	-0.15	NS	0.13	NS	NS	NS	NS	0.16	NS	NS	NS	NS	NS	NS
Kw 97	0.25	NS	NS	NS	NS	0.25	0.26	0.20	0.16	0.34	NS	NS	NS	NS	NS	0.22	NS	NS	NS	0.63	0.23	NS	NS	0.30	0.26	0.18	0.22
Kx 97	0.22	NS	NS	NS	NS	0.17	NS	NS	NS	0.17	0.20	NS	NS	NS	NS	0.38	NS	0.15	NS	0.57	0.49	0.20	0.15	NS	NS	NS	NS
Ky 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.14	0.16	NS	NS	NS	NS	NS	NS	NS	0.37	0.57	0.52	-0.20	NS	NS	NS
Kz 97	-0.15	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.15	0.21	0.16	NS	NS	-0.21	NS	-0.17	NS	NS	0.22	0.58	0.62	-0.19	NS	NS	NS
Sw 97	0.30	NS	NS	NS	0.14	0.15	NS	0.16	NS	0.22	0.22	NS	0.18	NS	0.17	0.27	NS	NS	NS	0.38	NS	NS	NS	0.45	0.40	0.39	0.39
Sx 97	0.34	0.24	NS	0.14	0.26	0.28	NS	0.18	NS	0.25	0.30	NS	0.19	NS	0.20	0.27	NS	NS	NS	0.43	NS	NS	NS	0.43	0.40	0.33	0.36
Sy 97	0.30	0.20	0.15	0.17	0.26	0.18	NS	0.23	0.21	0.29	0.30	0.22	0.15	NS	0.22	0.17	NS	NS	NS	0.29	NS	NS	NS	0.42	0.51	0.66	0.66
Sz 97	0.25	NS	NS	NS	0.14	NS	NS	0.18	0.14	0.21	0.23	0.18	NS	NS	0.17	NS	NS	NS	NS	0.28	NS	NS	NS	0.44	0.51	0.73	0.78

Table 4.5 Volumetric soil moisture to 120 cm across and within LECs and within N treatments, Harvest 1998.

	LEC			
N Rate (kg/ha)	Overall	U	M	L
	cm			
0	31.3	32.0a[1]	30.9a	31.3a
45	29.1	28.3a	29.1a	32.8b
90	28.2	26.9a	27.7a	30.4b
135	27.1	24.7a	27.4a	27.9a

[1] Median values followed by the same letter were not significantly different among LECs at α=0.20 (Kruskal-Wallis multiple comparison procedure).

V distribution varied with depth (Figure 4.4). In both seasons, moisture content fluctuated most in the 0-30 cm (*w*) increment. At *ES* 1997, moisture was greatest from 0-30 cm, and decreased in deeper increments. Over the course of the season, moisture appeared most depleted in the 30-60 cm (*x*) increment. This trend persisted until midseason 1998, at which time moisture conditions likely resulted in recharge of the entire profile. At both *MS* and *H* of 1998, gradual reductions in *V* from the *w* to the 90-120 (*z*) increment were apparent. From *MS* to *H* 1998, levels decreased within all depth increments, indicating the use of deep profile water (across N rates and within landforms).

In general, *V120* was not well-related to topographic attributes and static soil attributes in 1997 and 1998. Topographic attributes included relative elevation (*E*), slope gradient (*G*), plan curvature (*Kh*), profile curvature (*Kv*), global catchment (*Cg*) and local catchment (*Cl*). Static soil attributes included A horizon thickness (*A d*), solum depth (*Solum d*), depth to carbonates (*CO3 d*), Ap horizon pH (*Ap pH*) and soil organic carbon (*SOC(%)* and *SOC(Mg/ha)*). Topographic and static soil attributes were defined in the previous manuscript. Over all LECs, moisture was inversely and significantly related to *E* at all sampling times (r^2=-0.34 to –0.44), and *G* (r^2=-0.16 to –0.29) at most sampling times (Table 4.4). *ES V120* was inversely correlated to *Kh* in 1998 (r^2=-0.19), and *MS V120* was positively correlated to *Cg* and *Cl* in 1998 (r^2=0.17 to 0.15). No other significant correlations occurred. While infrequent, all significant correlations indicated that *V120* increased with convergent landscape character. Over all LECs, there were low but significant and positive correlations with *SOC(%)* (r^2=0.14 to 0.25) and *Ap pH* (r^2=0.14 to 0.31), reflecting the coinciding tendency of *V120* to increase with convergent character in the landscape. *ES V120* 1997, *ES V120* 1998 and *MS V120* 1998 were significantly correlated with *SOC(Mg/ha)* (r^2=0.15, 0.16 and 0.24 respectively).

Topographic descriptors and static soil attributes were better related to *V* in the *w* depth increment than in deeper depth increments of 30-60 cm (*V x*), 60-90 cm (*V y*) and 90-120 cm (*V z*). There were more significant correlations for *V w* and the coefficients were generally improved. *V w* was proportional to convergent character (negatively related to *E, G, Kh, Kv*; positively related to *Cg, Cl*) and progressive solum development (positively related to *A d, Solum d, CO3 d, SOC*) in this depth increment (r^2=0.15 to 0.49). *SOC(%)* and *A d* were the static soil attributes best related to *V w* (r^2=0.17 to 0.49). The frequency of significant correlations in this increment was noticeably less at *H* 1997 and *MS* 1998. It is likely that uniform depletion of soil moisture by *H* 1997 resulted in a reduced number of significant correlations. Alternatively, high soil moisture likely masked the influence of soil-landscape attributes at *MS* 1998. *V* in some deeper depth increments (*x, y* and *z*) were significantly and inversely related to convergent landscape character and solum development at various sampling times. Significant correlations at depth occurred infrequently compared to the *w* increment.

The general weakness and inconsistency of correlations within depth increments and through the entire profile may have been a reflection of a) the influence of transpiration or b) subsurface hydrologic controls which related differently to soil-landscape attributes. The latter is the most likely explanation for the increased number of significant correlations in the *A* increment alone, as it would have been most directly influenced by topographic attributes and solum characteristics. The weak and inconsistent correlations in lower depths, however they resulted, resulted in poor correlations for *V 120*.

Crop water use at depth is important to yield in Western Canada; therefore yield predictions requires more than a systematic explanation of soil moisture distribution at the surface. If moisture measured at *MS* 1998 is excluded, at which time landscape differences were likely attenuated by high June precipitation, *V 120* was significantly and positively correlated among sampling times (r^2=0.41 to 0.62) (Table 4.4). This suggested a persistent pattern of moisture distribution in the landscape, despite the lack of consistency in correlations with individual soil-landscape attributes. In addition, there were visually apparent landscape-influenced patterns which persisted among sampling times (Figure 4.1). Accordingly, delineation of the landscape into smoothed LECs captured meaningful variation in soil moisture.

4.4.1.2 Soil Residual Nitrate

Differences in soil residual NO_3 among LECs in the 1997 and 1998 growing seasons were considered to a depth of 90 cm (NO_3 *90*). Soil test labs generally consider NO_3 to a depth of 60 cm (Selles et al., 1992), and some researchers have considered residual NO_3 to 122 cm (Soper and Huang, 1963). However, Racz[5] (unpublished data) observed optimum correlation between plant uptake and NO_3 to a depth of 90 cm in Manitoba soils (r^2=0.86). For the purposes of production, differences in plant-available N supply among LECs are of greatest interest. The highest concentrations of NO_3 were found in the 0-30 cm depth increment (*w*) in both growing seasons and in all LECs (Figure 4.5), but some measurable concentrations did occur at depth in both seasons.

In spring of 1997, NO_3 *90* values were relatively low. Overall, there was a median amount of 48 kg/ha, ranging from extremes of 18 to 146 kg/ha (Table 4.2). Median amounts in each individual LEC were 44, 47 and 52 kg/ha in the U , M and L respectively (Table 4.6). While the L was statistically distinct from the other LECs, such differences were negligible for agronomic purposes. In the spring of 1998, there were residual effects due to the 1997 fertilizer treatments; amounts of NO_3 *90* increased with N rate applied. Median amounts of 35, 36, 54 and 86 kg/ha were observed for the 0, 45, 90 and 135 kg/ha N treatments respectively, across LECs. A landscape effect persisted, as amounts of NO_3 *90* in the U were consistently lower than those observed in the L and M (Figure 4.5). For example, within the check treatment, amounts of 24, 35 and 40 kg/ha were observed in the U , M and L, respectively. Within the 135 kg/ha treatment, median amounts 70, 91 and 89 kg/ha were observed in these LECs. Higher NO_3 *90* concentrations may have been a result of greater mineralization as convergent character increased, within both growing seasons.

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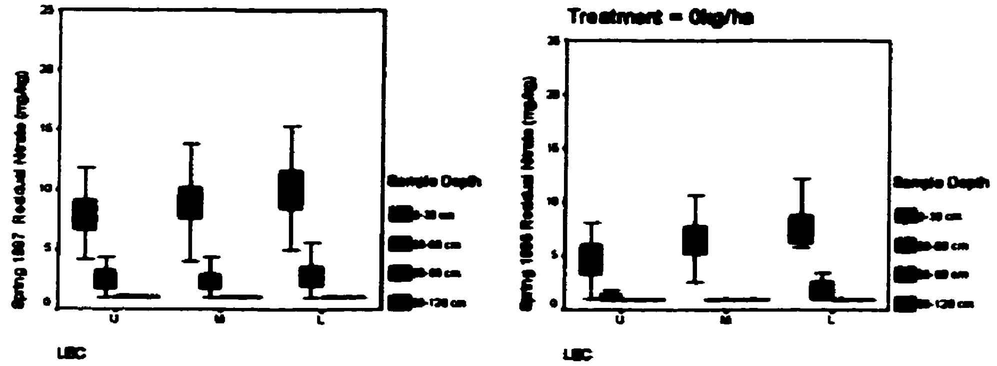
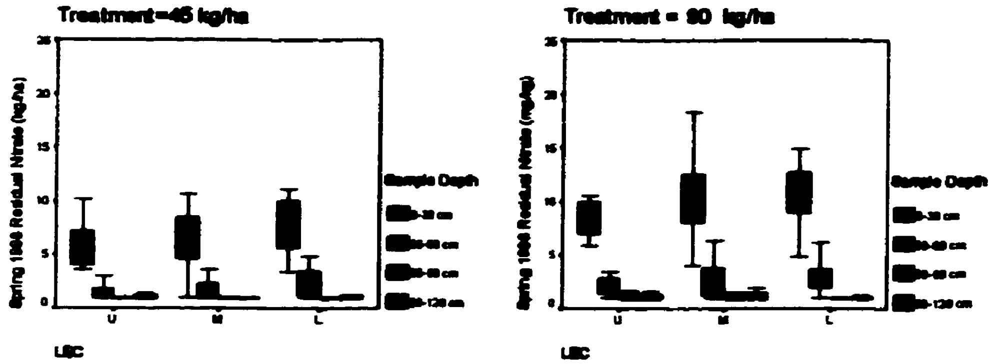
[5] Department of Soil Science, University of Manitoba



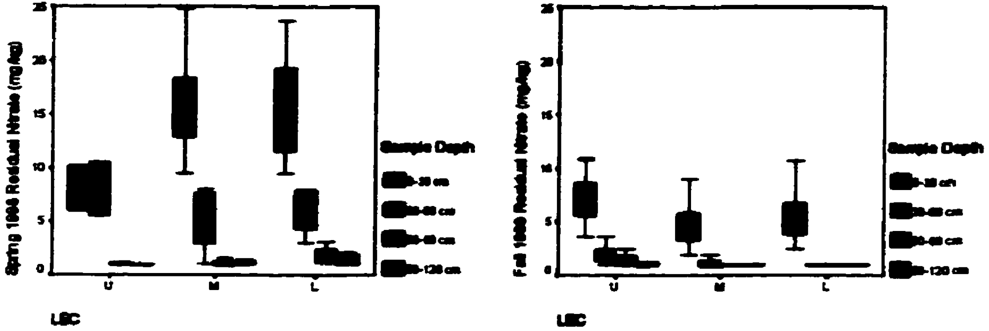
(a) Overall 1997

(b) 0 kg/ha 1998



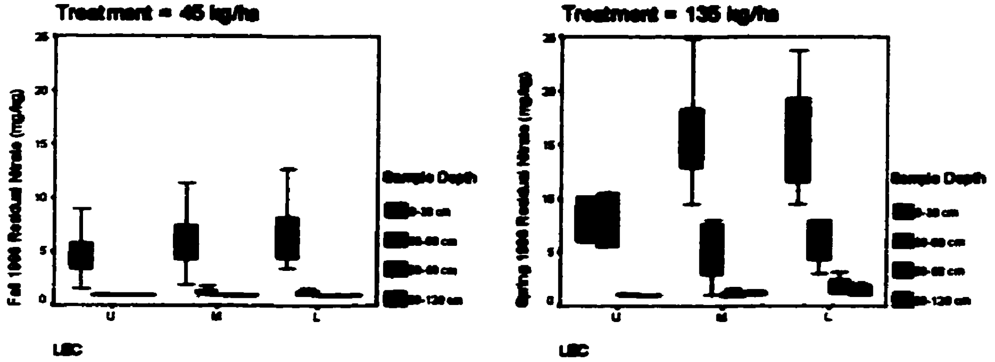
(c) 45 kg/ha 1998

(d) 90 kg/ha 1998



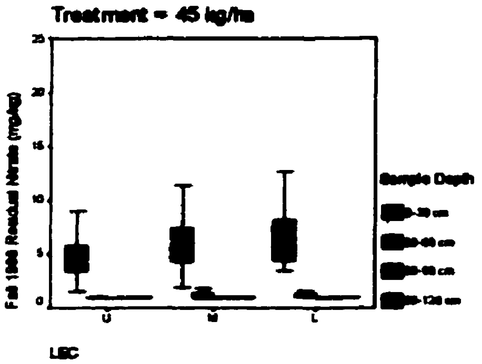
(e) 135 kg/ha 1998

(f) 0 kg/ha Harvest 1998



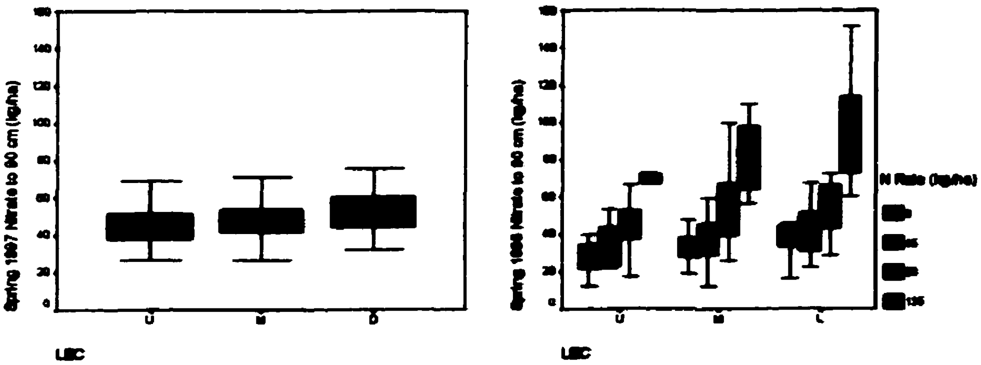
(g) 45 kg/ha Harvest 1998

(h) 90 kg/ha Harvest 1998

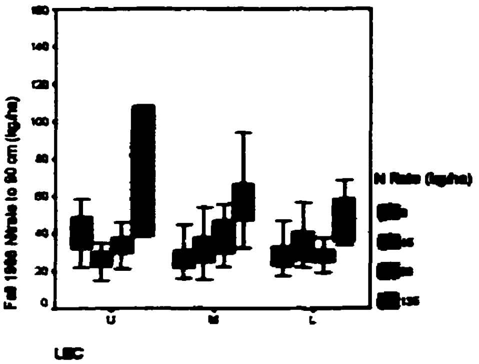


(i) 135 kg/ha Harvest 1998

Figure 4.5 Relative distribution of nitrate within 30 cm depth increments.



(a) Early Season 1997 (b) Early Season 1998



(c) Harvest 1998

Figure 4.6 Relative distribution of nitrate to 90 cm.

Others have recorded lower mineralization rates in divergent landscape positions (Fiez et al., 1994b; Schoenau and Greer, 1996), likely due to differences in organic matter concentration or quality, along with temperature and moisture conditions. Within the site, it is known that *SOC (%)* and *V* were higher in the L. Regardless, differences among LECs were mostly statistically insignificant, and were not visually apparent in contour maps (Figure 4.7).

Table 4.6 Median values of soil residual nitrate to 90 cm, N removal and N balance[*] across and within LECs

Attribute	N Rate (kg/ha)	LEC			
		Overall	U	M	L
		cm			
NO_3 *90 ES 97*	All	48	44a	47a	52b
NU 97	0	53	53a	51a	53a
	45	74	73a	74a	74a
	90	89	85a	87a	93a
	135	100	87a	101a	99a
NO_3 *90 ES 98*	0	35	24a	35a	40a
	45	36	29a	35ab	43b
	90	54	43a	57a	52a
	135	86	70a	91a	89a
NU 98	0	53	51a	53a	55a
	45	82	86b	82b	77a
	90	118	112ab	121a	97b
	135	143	143a	143a	141a
NO_3 *90 H 98*	0	29	40b	27a	26a
	45	31	27a	32ab	35b
	90	33	33ab	40b	30a
	135	56	73a	65a	43a
N Balance 98[2]	0	37	52b	36ab	29a
	45	26	36a	24a	18a
	90	2	29ab	9b	-28a
	135	-27	37b	-25ab	-54a

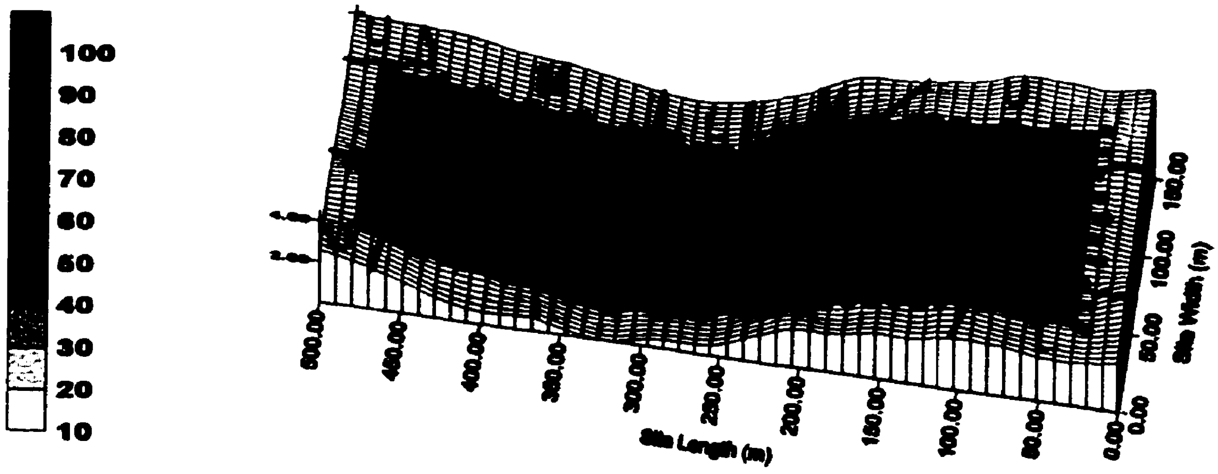
[1] Median values followed by the same letter are not significantly different between management units at α=0.20 (Kruskal-Wallis multiple comparison procedure).

[2] Simple N balance = (Crop Removal + Fall Residual N) – (Spring Residual N + N Fertilizer Applied)

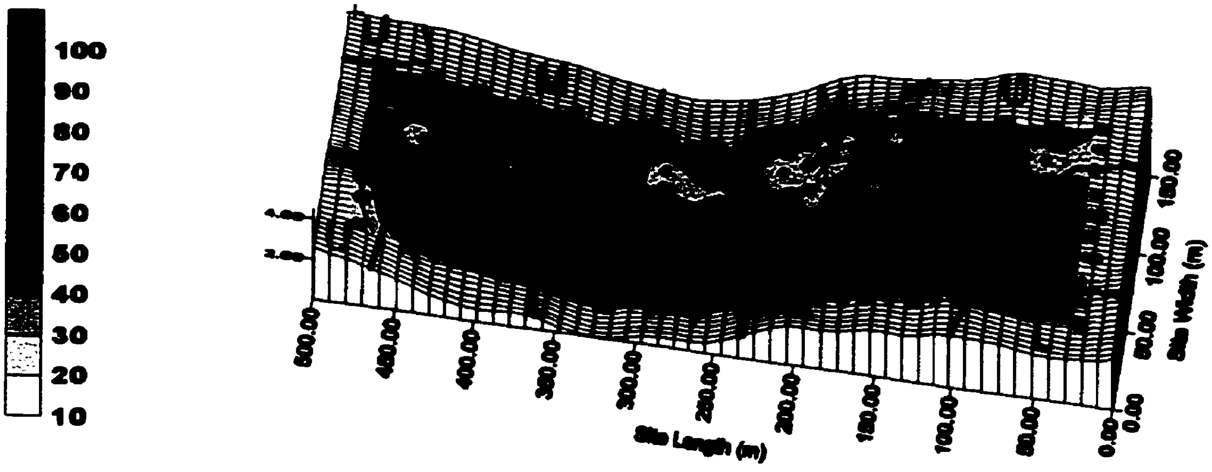
[*] N balance available for 1998 only.

In the fall of 1998, the treatment effect persisted as expected, as treatments were applied identically in 1998. Over all LECs, median *NO_3 90* values were 29, 31, 33, 56 kg/ha for the 0, 45, 90 and 135 kg/ha N treatments. However, the landscape effect at *H* was decidedly different from the *ES* observations. While most treatments did not appear to differ consistently among LECs and few differences were significant, the L had the lowest median *NO_3 90* for all but the 45 kg/ha treatment. This tendency was most notable for the 135kg/ha treatment, with median *NO_3 90* values of 73, 65 and 43 kg/ha in the U , M and L, respectively. Lower residual amounts in the L, while not significantly different, may have been indicative of higher losses. Pennock et al. (1992) observed greater rates of denitrification in depression-centered landform elements. With greater amounts of *SOC* and ample moisture throughout the growing season and subsequent to maturity, it is possible that denitrification reduced *NO_3* levels in the L. Greatly elevated *NO_3* concentrations were not observed below the 60 cm, so leaching losses were not suspected.

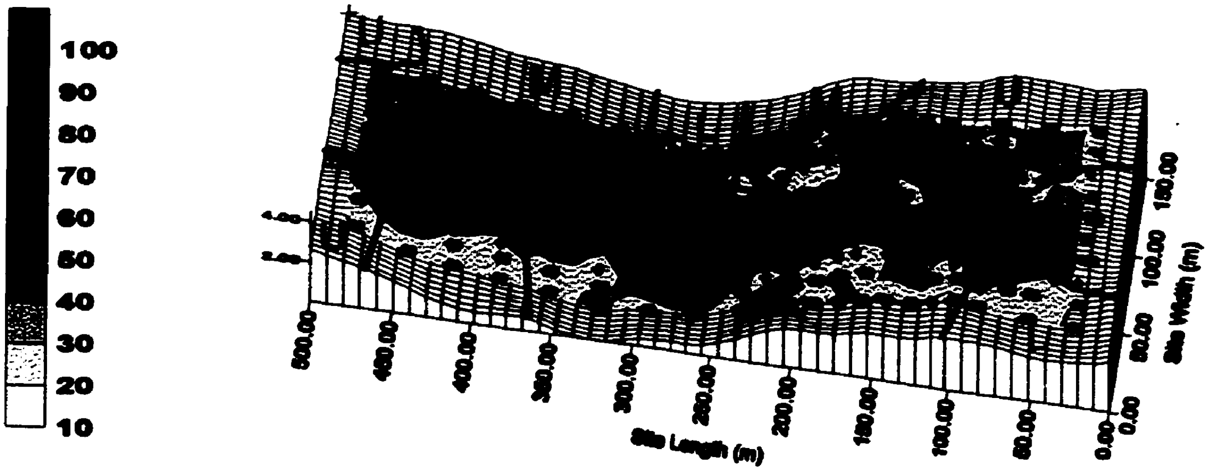
An estimate of apparent in-season mineralization (a mineralization/loss balance) using spring and fall soil residual *NO_3* levels and crop nitrogen uptake (*NU*), as employed Campbell et al. (1988), was utilized to compare differences among LECs in 1998 (Table 4.6). This simple nitrogen balance indicated that within all N rates, mineralization was less, or potential losses were greater, moving from the U to the L. Within LECs, apparent net mineralization also decreased as N fertilizer rate increased. There was a maximum of 54 kg *NO_3*/ha that was unaccounted for in the L within the 135 kg/ha treatment. Losses and potential consumption of N by competing weeds, probably increased with convergent landscape character.



(a) Early Season 1997



(b) Early Season 1998



(c) Harvest 1998

Figure 4.7 Spatial distribution of soil residual nitrate to 90 cm (kg/ha).

In the 1997 growing season, it was not possible to accurately estimate growing season mineralization without fall *NO_3* data. However, using crop removal data from the check strips, LECs were compared under the assumption that most of the mineralized N was taken up by the crop. Median *NU* values were essentially alike, at 53, 51 and 53 kg/ha in the U , M and L, respectively. This suggested that mineralization did not vary a great deal with landscape position within the 1997 growing season. In 1998, crop *NU* in the check strip was nearly identical to that of 1997, and did not differ among LECs. Median crop removal values were 51, 53 and 55 kg/ha in the U , M and L, respectively.

Differences in *NO_3 90* due to N treatments were much greater and more agronomically significant than those arising from landscape-scale differences. Hence, it is important to consider the impact of past fertility management practices when assessing differences in residual nitrate among LECs.

Correlations were inconsistently significant between spring *NO_3 90* and soil-landscape attributes, but most suggested that higher nitrate levels coincided with convergent landscape character and progressive soil development. In 1997, *NO_3 90* was significantly and inversely related to *E* (r^2=-0.31) and positively related to *SOC(%)* and *SOC (Mg/ha)* (r^2=0.17 and 0.19) (Table 4.4). Significant correlations were most common in the 0-30 cm (*w*) increment. Over all LECs in 1997, *NO_3 w* was significantly inversely related to *E* and *Kh* (r^2=-0.37 and –0.13) and positively correlated with *Cg* and *Cl* (r^2=0.14 and 0.15). *NO_3 w* was significantly correlated with *A d*, *Solum d*, *SOC(%)* and *SOC(Mg/ha)* (r^2=0.21, 0.15, 0.27 and 0.28, correspondingly).

In 1998, it was necessary to evaluate correlations within individual N treatments. Again, spring residual nitrate (*NO_3 w, x,y,z* and *NO_3 90*) was generally proportional to the extent of convergent landscape character and progressive solum development. *NO_3* was inversely related to *E* (r^2=-0.31 to -0.49), *G* (r^2=-0.29 to -0.32), *Kh* (r^2=-0.25 to -0.39), and *Kv* (r^2=-0.32 to -0.51), and positively related to *Cg* and *Cl* (r^2=0.27 to 0.60). *NO_3* was positively related to *A d* (r^2=0.27 to 0.59), ***Solum d*** and *CO3 d* (r^2=0.31 to 0.63), and SOC (%, Mg/ha) (r^2=0.27 to 0.61). In both 1997 and 1998, the direction of these associations may have reflected better mineralization conditions as convergent character and soil profile development increased. Correlations between fall 1998 residual nitrate concentrations and topographic and static soil attributes were not consistent in direction and occurred less frequently. While fall *NO_3* was inversely related to convergent landscape character and soil profile development in the check and 135 kg/ha treatments, the 45 and 90 kg/ha treatments indicated the opposite. This may have been a function of high rates of midseason N loss followed by net N mineralization. Median residual levels in the L were only marginally different than the U within the 45 and 90 kg/ha N treatments.

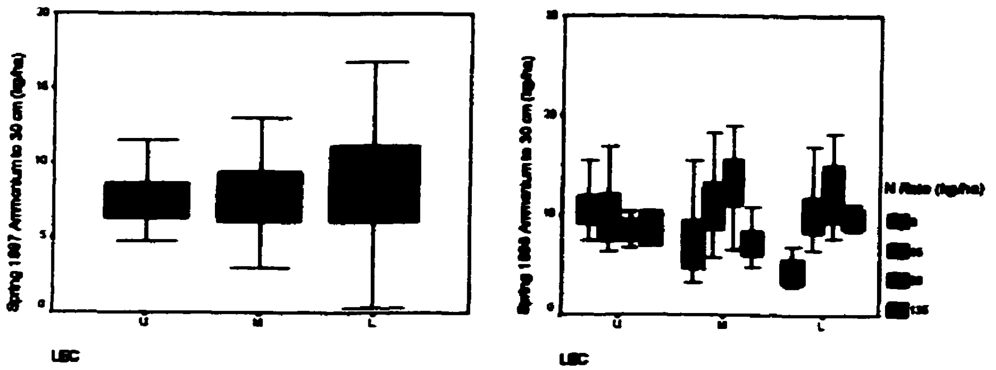
4.4.1.3 Soil Residual Exchangeable Ammonium

Exchangeable ammonium (*NH_4*) concentrations were low. Median spring residual amounts (0-30 cm) did not exceed 12 kg/ha in both years. In 1997, there were no significant differences among LECs (Table 4.7). In spring of 1998, while some differences among LECs were statistically significant, variation among treatments and LECs was not consistent (Figure 4.8). In the check treatment, amounts were progressively lower moving from the U to the L for all sampling depths; the opposite was observed for the 90 and 135 kg/ha treatments, in the 0-30 cm (*w*) increment. In fall of 1998, the L was consistently lower in residual ammonium within treatments. At both sampling times, NH_4 *w* did not vary consistently with N treatment within LECs. The low and inconsistent concentrations of NH_4 *w* in our study indicated low potential utility in using this factor as an indicator of variation in plant-available N across LECs. Similarly, Campbell and Paul (1978) encountered low NH_4 concentrations (4-6mg/kg) which did not appear to be influenced by N or moisture conditions, and as a result chose to exclude NH_4 from mineralization estimates.

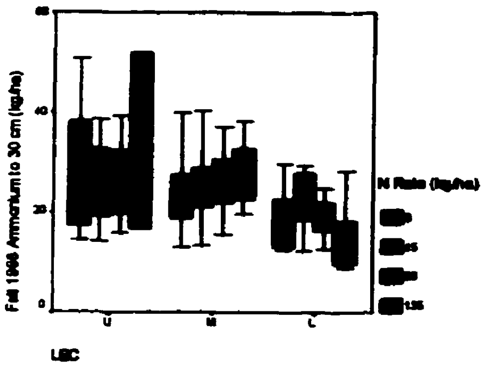
Table 4.7 Median values of residual exchangeable soil ammonium from 0-30 cm across and within LECs.

Attribute	N Rate (kg/ha)	LEC			
		Overall	U	M	L
		kg/ha			
NH_4 *w 97*	All	8	7a	8a	8a
NH_4 *w 98*	0	7	10c	7b	4a
	45	10	11a	10a	9a
	90	12	9a	13b	13b
	135	8	9ab	8a	10b
H NH_4 *w 98*	0	23	33b	26ab	17a
	45	24	26a	24a	22a
	90	23	28b	27b	20a
	135	24	34ab	28b	17a

[1] Median values followed by the same letter are not significantly different between management units at $\alpha=0.20$ (Kruskal-Wallis multiple comparison procedure).



(a) Early Season 1997 (b) Early Season 1998



(c) Harvest 1998

Figure 4.8 **Relative distribution of residual exchangeable soil ammonium to 30 cm, 1997 and 1998.**

4.4.1.4 Soil Residual Extractable P, Exchangeable K, and S

Extractable phosphorus (*P*) concentrations increased with convergent character in the landscape (Figures 4.9, 4.12, 4.15) in both 1997 and 1998 (Table 4.8). In 1997, median amounts of 39, 45 and 51 kg/ha were observed in the 0-30 cm increment in the U, M and L. In 1998, 45, 47, and 68 kg/ha were observed in these respective LECs. *P* is relatively insoluble and immobile; therefore, concentrations were expected to be similar among growing seasons. In both years, only the L emerged as statistically distinct. The vast majority of *P* was concentrated in the surface 30 cm, which averaged 51 kg/ha over all LECs in both years. Across LECs and years, *P w* was generally significantly proportional to convergent landscape character, *A d*, *Solum d* and *SOC*. Mulla (1993) found that available *P* tended to increase with convergent character in a Washington study, and accordingly, with *SOC(%)* and profile moisture. In our study, monoammonium phosphate was applied with the seed at the recommended rate of 54 kg/ha (27 kg P_2O_5/ha); therefore, *P* was not expected to be limiting for crop production within any LEC.

Table 4.8 Median values of extractable phosphorous (elemental), exchangeable potassium (elemental) and sulphate-sulphur across and within LECs.

Nutrient	LEC			
	Overall	U	M	L
	kg/ha			
P w 97	46	39a	45ab	51b
K w 97	783	699a	778b	895b
S 120 97	78	49a	79b	158c
P w 98	51	45a	47a	68b
K w 98	761	707a	722a	828b
S 120 98	93	60a	98b	163c

[1] Median values followed by the same letter are not significantly different between management units at α=0.20 (Kruskal-Wallis multiple comparison procedure).

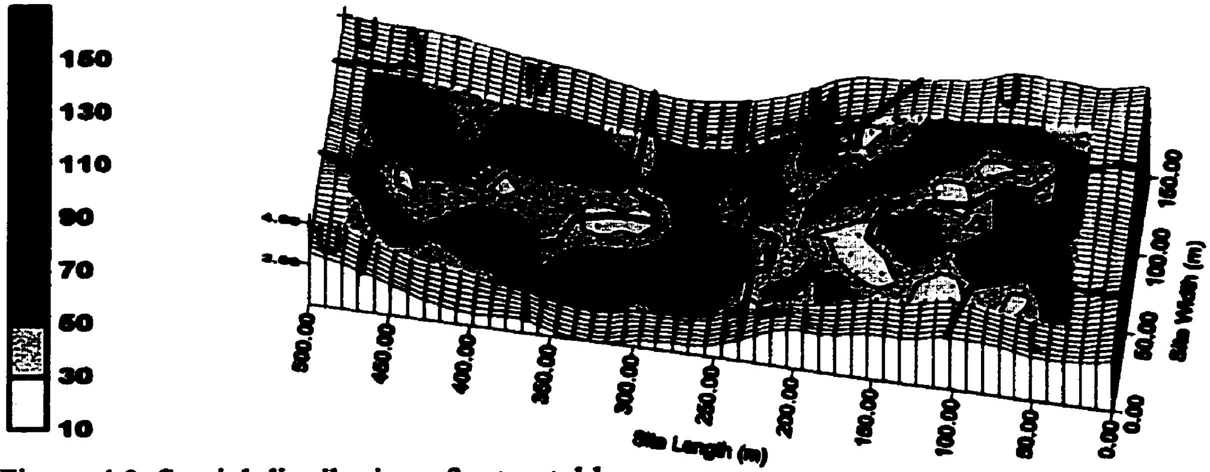


Figure 4.9 Spatial distribution of extractable phosphorous to 30 cm (kg P/ha), 1997

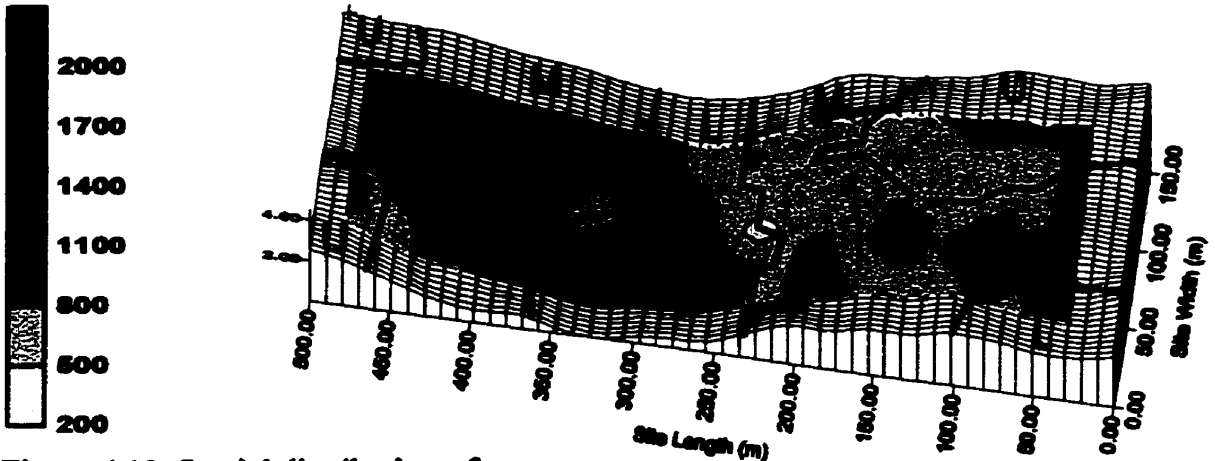


Figure 4.10 Spatial distribution of exchangeable potassium to 30 cm (kg K/ha), 1997

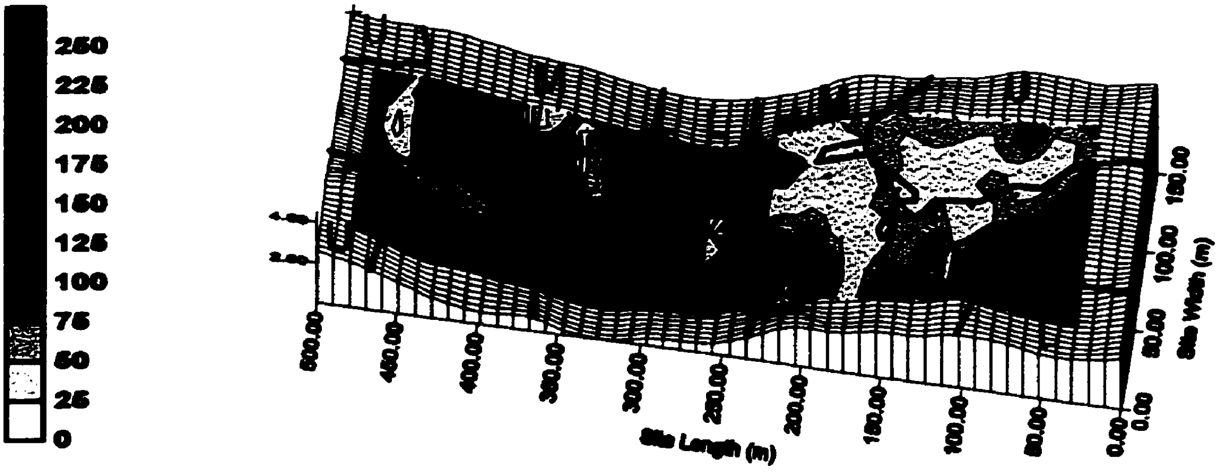


Figure 4.11 Spatial distribution of sulphate-sulphur to 120 cm (kg S/ha), 1997

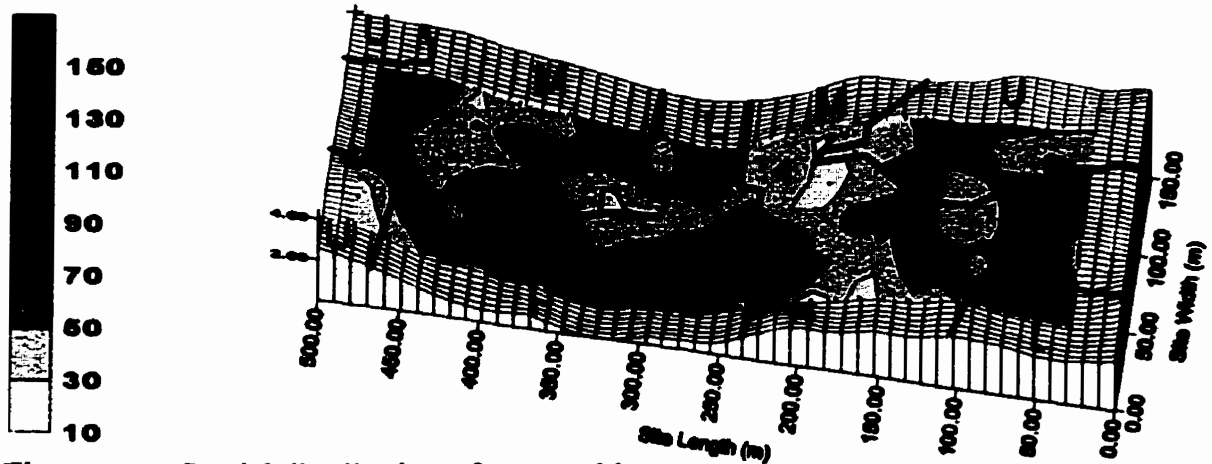


Figure 4.12 Spatial distribution of extractable phosphorous to 30 cm (kg P/ha), 1998

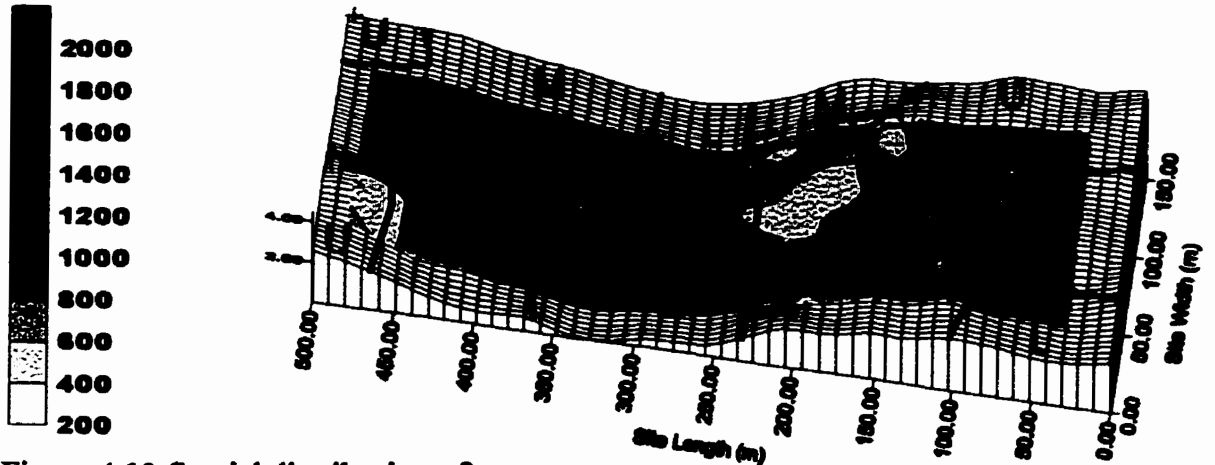


Figure 4.13 Spatial distribution of exchangeable potassium to 30 cm (kg K/ha), 1998

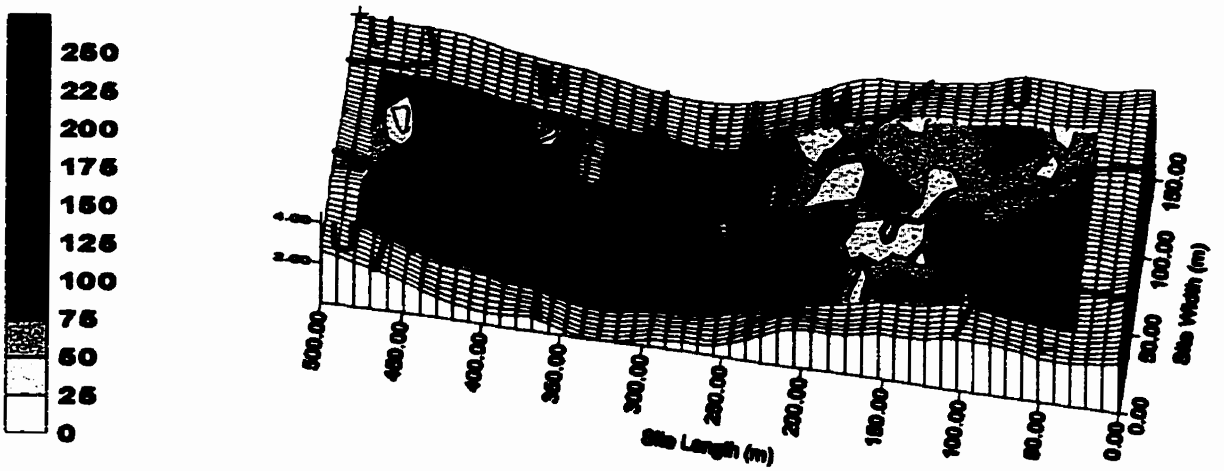


Figure 4.14 Spatial distribution of sulphate-sulphur to 120 cm (kg S/ha), 1998

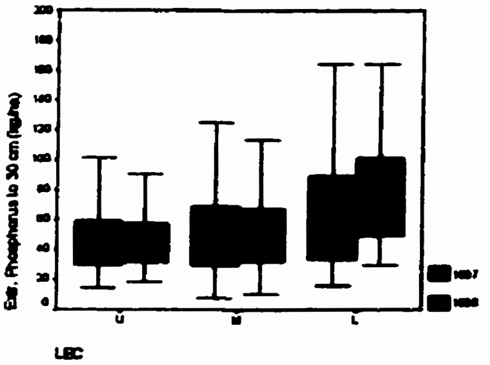


Figure 4.15 **Relative distribution of extractable phosphorus to 30 cm, 1997 and 1998.**

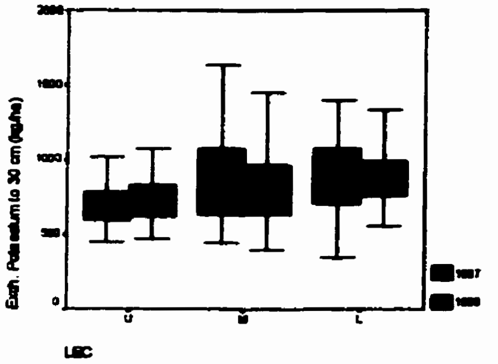


Figure 4.16 **Relative distribution of exchangeable potassium to 30 cm, 1997 and 1998.**

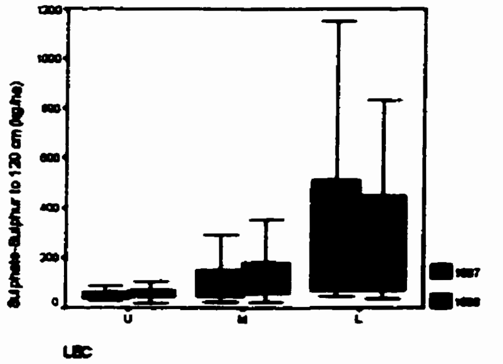


Figure 4.17 **Relative distribution of sulphate-sulphur to 120 cm, 1997 and 1998.**

Spatial distribution of exchangeable postassium (*K*) was similar to that of *P*, and increased with convergent character in the landscape (Figures 4.9, 4.12, 4.15) (Table 4.8). This was consistent with the findings of Walker et al. (1996). In 1997, 699, 778 and 895 kg/ha *K* were observed in the U, M and L, and in 1998, 707, 722, and 828 kg/ha were observed in those respective LECs, in the 0-30 cm (*w*) depth increment. The L was distinct from the U in both years, and from the M in 1998. *K*, like *P*, is a relatively stable nutrient, and sampling variability was likely a major contributor to spatial variation between growing seasons. It was not possible to sample identical locations in 1998, and there was likely significant variation in *K* and *P* concentrations even over distances of 15 to 30 cm. Median amounts from 0-30 cm were 783 and 761 kg/ha overall for 1997 and 1998. These concentrations should not have been limiting for wheat production.

Sulphate-sulphur (*S*) also increased with convergent character in the landscape (Figures 4.10, 4.13, 4.16). To a depth of 120 cm, there was 49, 79 and 158 kg/ha *S 120* for 1997 and 60, 98, and 163 kg/ha for 1998 in the U, M and L, respectively, all of which were statistically distinct from each other (Table 4.8). These concentrations were somewhat consistent between years, despite the fact that *S* is highly mobile. Extremely high concentrations of *S* in excess of 4000 kg/ha occurred in the 90-120 cm (*z*) increment of several sampling points, and were spatially persistent for the two growing seasons. Over all LECs, 78 and 93 kg/ha *S 120* were observed in 1997 and 1998 respectively. These concentrations of *S* are not regarded as deficient for wheat production in Western Canada.

4.5 Summary and Conclusions

For the purpose of variable N management, knowledge of spatial variability of soil residual mineral N, potential mineralization and crop yield potential in the landscape is required. The landscape influenced the distribution of soil moisture and spring residual NO_3, P, K and S. Differences were not always significant, but all tended to increase with convergent character in the landscape, resulting in trends of L > M > U . Differences among LECs with respect to V tended to be greatest at *ES*, and decreased as the growing season progressed. Correlations between soil-landscape attributes and individual measures of V and NO_3 were generally weak to moderate and were not consistently significant.

The LECs described by MacMillan and Pettapiece (1997) captured some systematic variability in moisture and nutrients at a gross landscape scale. However, the practical significance of the differences among LECs, though statistically significant, was overshadowed by other factors, including temporal variation and N fertilization practises. Differences in *V120* of up to 4.6 cm between the U and the L were observed, and the relative distribution remained consistent. However, these differences were minor in comparison to the 13.7 cm difference in precipitation between the two growing seasons, totaled over the critical months of May to July. Given that growing season precipitation and early season soil moisture are often considered to be additive in yield-water models in the moisture-limited Canadian prairies, variation of this magnitude is quite important when predicting yield potential. However, 1997 and 1998 were very different from one another and from the long-term average, with respect to growing season precipitation. If near-average conditions were to occur in most growing seasons, a more consistent amount of soil moisture would be expected across the landscape from year to year.

NO_3 90 ranged from 44 to 52 kg/ha among LECs in 1997, on a previously uniformly managed field. Such a difference is not important agronomically. In the spring of 1998, median residual levels ranged from 35 to 86 kg/ha due to the influence of the N treatments, largely outweighing the landscape influence. This difference in N-supply resulted in considerable differences in moisture use to 120 cm as observed in fall of 1998.

It is important to account for variation in yield limitations within the soil-landscape, but they must be put in the context of management-induced variability and weather variability. The soil-landscape must be the systematic root of the largest source of variability in production-limiting factors if it is to be used as a predictive tool for crop productive potential and response to N fertilizer.

5. INVESTIGATING WHEAT YIELD RESPONSE TO N-FERTILIZER IN A VARIABLE MANITOBA SOIL-LANDSCAPE

5.1 Abstract

The objective of the study was to evaluate landform element complexes (LECs) as discrete management units for variable N fertilizer application. Crop response attributes including grain yield (*GY*), grain protein concentration (*GPC*) and total above-ground biomass at anthesis (*ABM*) were studied in ten intensively sampled transects in an undulating glacial till soil near Miniota, Manitoba. The 5.6 ha site was delineated into Upper (U), Mid (M), Lower-Mid (LM) and Lower (L) elevation LECs using a landform description program (MacMillan and Pettapiece, 1997). The program utilized a digital elevation model of the site, based on relative elevation data collected on a 10 m grid. In 1997, median *GY*, *ABM* and straw yield (*SY*) increased with both N fertilizer and with convergent character in the landscape, because the 1997 crop was moisture-deficient with growing season precipitation 37% below average. *GPC* increased with N fertilizer, but decreased with convergent character in the landscape. In 1998, *GY*, *ABM* and *SY* responses to N fertilizer were greater, due in part to declining N fertility in the check and 45 kg/ha N treatments. A wider range of *GY* was apparent in 1998 due to the increased disparity between the N-depleted check and the well-supplied 135 kg/ha N treatment. Differences among N treatments were also strongly expressed due to growing season precipitation which was 62% above average. Trends among LECs were opposite to those in 1997, as median *GY*, *SY* and *ABM* decreased with convergent landscape character.

This was attributed to excess moisture in the L. In both years, significant correlations were obtained with topographic attributes as described by Pennock et al. (1987), and with previously defined static and dynamic soil properties, but correlations did not occur consistently. Directions of the correlations were generally in agreement with relative ranking of crop response attributes in the LECs. Grain yield was modeled as a function of estimated plant-available N supply (*EPANS*), which included spring residual nitrate-N to a depth of 90 cm plus applied fertilizer N in each treatment. Modeled 1997 grain yield maxima were 2077, 2261 and 2485 kg/ha in the U, M and L, where the L responded most strongly to *EPANS*. *EPANS* at the yield maxima were 89, 130 and 130 kg N/ha, correspondingly. In 1998, the relative order of modeled maxima among LECs was reversed. *GY* of 2501, 2355 and 2227 kg/ha were predicted in the U, M and L. Initial response to *EPANS* was similar among LECs, but the response in the U was slightly greater than the M and L. *EPANS* at the yield maxima were 146, 142 and 154 kg N/ha, correspondingly. We concluded that modeled *GY-EPANS* relationships from 1997 were more characteristic of a typical year, as the amount of precipitation received in 1997 was closer to the long-term average than that received in 1998. However, successful variable-rate fertilization by LEC will require long-term empirical study to establish risk-based *GY*-N relationships, and to determine if an economic advantage over conventional fertilization practices exists.

5.2 Introduction

In the glacial-depositional soils of the Northern Great Plains, differences in productive potential and responses to N fertilizer are often observed throughout the soil-landscape continuum. Such differences are due to spatial variability in production-limiting factors, which may be systematic or random in nature. Systematic distributions of production limiting factors coincide with and are influenced by the spatial distribution of soil attributes derived from the long term integration of pedogenic processes. Landscape-scale differences in such soil attributes have been accentuated by long-term crop production (Elliott and de Jong, 1992a). Aandahl (1948) recognized that topography influences soil formation by affecting plant growth through temperature, runoff, evaporation and transpiration such that plants within a relatively small area have different microenvironments. In turn, these microenvironments contribute to pedological properties at a given location, creating the context in which moisture and mineral nitrogen affect yield.

Productive potential and yield response to N fertilizer vary within the soil-landscape. Conventional agricultural practices rely on uniform application of N fertilizer within management units, but such management units often encompass areas which respond quite differently to N fertilizer. As a result, areas of over- and under-application generally occur, resulting in lost profits due to reduced yield where N supply is inadequate, and due to increased costs where N supply is excessive. Such misapplication has environmental ramifications as well, most notably deep leaching of nitrate and gaseous denitrification losses due to N excesses. As a result, there is interest in defining manageable, spatially homogeneous areas which respond similarly to N fertilizer within conventional dryland fields, in which specific and optimal rates of N fertilizer would be applied. Wide-spread feasibility of such intensified management has been enhanced by the mechanization of real-time, georeferenced variable-rate product application.

Successful variable-rate N management requires knowledge of the spatial variability of soil residual mineral N, potential mineralization and crop yield potential in the landscape. The variation must be systematic, recognizable, of sufficient magnitude, and manageable (Everett and Pierce, 1996). In addition, the spatial variability should be temporally stable (i.e., predictable). Discrete landscape positions have been investigated for the purposes of variable rate N application (Beckie et al., 1997; Fiez et al., 1994a,b), under the basic premise that yield variability will reflect characteristic pedogenic patterns of historic productive potential and moisture redistribution. While significant, systematic differences in yield potential and response to N fertilizer may occur among landscape positions within a growing season, differences among landscape positions may be highly inconsistent among growing seasons (Wibawa et al., 1993). For example, convergent landscape positions may produce higher relative yields in a dry growing season, but may produce lower relative yields in a wet year due to excess moisture. Temporal instability in yield potential and inherent N supply can dramatically affect response to added N. Blackmer and White (1996) stated that while it will never be possible to adjust N rates for weather conditions after fertilization, it should be possible to identify the rates most likely to maximize profits for the producer within the range of weather conditions normally encountered. Under 'typical' conditions in the sub-humid to semi-arid Western Canadian prairies, yield potential (Moulin et al., 1994) and response to N fertilizer (Kachanoski et al., 1985) tend to increase with convergent character in the landscape due to moisture gradients. A risk-based approach, based on long-term calibration data, is required to establish 'typical' yield potential and N requirements within fixed LEC management units.

In previous manuscripts, we observed systematic differences in pedogenic attributes and the more dynamic yield determinants of soil moisture and nutrients among LECs derived by MacMillan and Pettapiece (1997). Despite the large temporal variability observed in the dynamic yield determinants, we hypothesized that landscape-scale differences should result in systematic differences in yield potential and response to N fertilizer among these LECs. A key objective of our two year study was to characterize modeled differences in relative yield potential and yield response to N fertilizer among LECs over two growing seasons, and to define the rates of plant-available N supply at the productive optima. As well, controls on dry matter production, grain yield and grain protein were investigated by examining relationships with topographic descriptors and previously evaluated 'static' and 'dynamic' soil properties. These management-scale LECs have not been previously evaluated for their utility in capturing variability in crop production and quality in undulating soil-landscapes.

5.3 Materials and Methods

5.3.1 Site Characteristics

The study site was located on an undulating glacial till landscape with soils of the Newdale association (Appendix 1) near Miniota. The site was representative of a broad region of glacial till landscapes in the Black soil zone. The site consisted of ten adjacent 11m x 450m transects over a variable landscape with 21 sampling points in each of these transects, for a total site area of 5.6 ha. There was a total of 4.2 m relief within the plot area, and slopes did not exceed 3°. Digital elevation data was used to delineate discrete landform element complexes corresponding to U, M and L using the Landform

Description Program created by MacMillan and Pettapiece (1997). These LECs were superimposed on the existing design, and sample points were assigned accordingly.

The site has been cropped for over 50 years. Prior to 1976, the site was in a wheat-fallow rotation. In 1976, continuous cropping was initiated, with a wheat-wheat-canola rotation. In 1978, a minimum-tillage system was introduced, and in 1988, a completely zero-till system was established along with a more consistent cereal-broadleaf rotation. The crop rotation sequence was as follows from 1995 to 1998: field peas (*Pisum sativum*), canola (*Brassica napus*), wheat (*Triticum aestivum*) and wheat. Wheat was grown on the site for two consecutive years for consistency, but the surrounding field was canola in 1998.

5.3.2 Soil Sampling and Treatment Application

Soil sampling and analysis activities were described in detail previously, so only a brief summary is given. Prior to seeding in 1997 and 1998, soil samples were collected and analyzed for spring residual soil nitrate-N, ammonium-N, extractable P, exchangeable K and sulphate-S. Near anthesis and subsequent to harvest, soil moisture was again assessed in 1997 and 1998. At harvest of 1998, soil samples were also analyzed for residual nitrate and ammonium N. All soil samples were collected in 30 cm increments to 120 cm. In the fall of 1997, intact cores were collected and characterized for individual genetic soil horizons, depth to carbonates, A horizon SOC and A horizon pH.

N fertilizer treatments were described in the previous manuscript. In both 1997 and 1998, there were 5 different duplicated N fertilizer treatments in the 10 transects. Rates of 0, 45, 90 and 135 kg/ha were applied on eight of the transects, and the remaining two transects were variable-rate treatments in which a range of N rates were applied. In all cases, nitrogen fertilizer was surface broadcast as ammonium nitrate (34-0-0) after seeding. All N-fertilizer rates were pre-determined and were not adjusted to reflect residual soil test levels. In 1998, treatments were identical and were superimposed on the same locations as for 1997. Treatments were designed to have a range of applied fertilizer N values across a representative cross-section of the regional soil landscape, such that the same range was received by each of the localized LECs within. One 135 kg/ha transect (# 5) was omitted from comparisons due to an application error.

5.3.3 Site Management: Seeding and Pest Control

Canadian Western Red Spring wheat was air-drilled into the mature zero-till seedbed in 1997 (c.v. Roblin, May 10) and 1998 (c.v. Teal, May 4) on a 25 cm row spacing at a seeding rate of 128 kg/ha at a depth of 2.5 cm. The 10m air drill was equipped with low disturbance 1.9 cm openers. Seed-placed phosphorus (11-51-0) was applied with the seed at a uniform rate across the site at a rate of 70 kg/ha of mono-ammonium phosphate, adding 8.4 kg/ha to the listed applied N for all treatments.

Field-scale pest control was practiced for 1997 and 1998. In the fall of 1996, 2,4-D and glyphosate were applied post-harvest. In addition, a surface application of triallate was performed. 1997 in-crop broadleaf weed control was performed with thifensulfuron and tribenuron methyl and MCPA and clopyralid. A pre-harvest application of glyphosate was repeated subsequent to maturity. In 1998 the site received an in-crop application of dichlorprop, 2,4-D ester and imazamethabenz. An application of propiconazole fungicide was performed to reduce foliar diseases. All pesticides were applied at manufacturers' recommended rates.

5.3.4 Response Attribute Sampling Activities

ABM was sampled at each point near anthesis in both 1997 and 1998; with a sampled area of 0.51 and 1.00 m^2 in each of the respective years. Phenological development (*Z*) was recorded at each of the sample points using a decimal growth scale ranging from 0 to 100 (Zadoks et al., 1974). *ABM* samples were weighed and expressed on an oven-dry basis. Weed densities were assessed by use of single 0.5 and 0.25 m^2 quadrats at each individual sampling point, on July 22 and July 30 of 1997 and 1998, respectively.

Crop yield was measured at each point from hand-harvested 1 and 2 m^2 samples in 1997 and 1998, respectively. The grain and straw were separated and weighed. *GY* was adjusted to 13.5% moisture and *SY* was expressed on an oven-dry basis. Yield data was also collected with a combine-mounted instantaneous yield monitor (AgLeader Technology, Aimes, Iowa, USA). The center 8 m of each 10.7 m transect was harvested by combine, and total transect yields were massed with a trailer-mounted scale.

Grain and straw total N were determined on 70 to 100 mg of ground plant material (< 2mm) with a LECO FP 428 and a CHN-600 (LECO Corporation, St. Joseph, MI) by combustion nitrogen analysis, on oven-dry samples (Williams et al., 1998). *GPC* was determined by multiplying N percentage by a factor of 5.7, expressed on the basis of 13.5% grain moisture. Straw N percentage (*SN*) was expressed on an oven-dry basis.

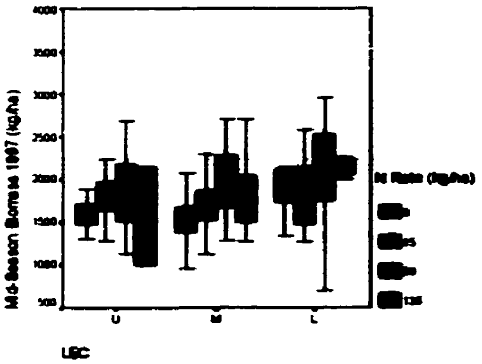
5.3.5 Statistical Methods

Surfer gridding and contouring software (Golden Software, Boulder, CO) and side-by-side boxplots were used for qualitative exploration of data. Correlations between variables were done using Spearman correlations, and tests for statistically significant differences among LEC populations was performed using the Kruskal-Wallis test, with a multiple-comparison technique described by Daniel (1990). Spearman correlations and Kruskal-Wallis tests were obtained with SPSS v. 8.0 software. Statistical significance for multiple comparisons was set at $\alpha=0.20$. There is greater error variability at the landscape scale, such that a lower significance level has been justified by various researchers (van Kessel et al., 1993; Pennock et al., 1994; Jowkin and Schoenau, 1998). Significance for correlations was defined at $p<0.05$. Yield response to estimated plant available N supply (*EPANS*) was defined by a "quadratic-plus-plateau" model (Cerrato and Blackmer, 1990), using the Statistical Analysis System (SAS Institute, 1985).

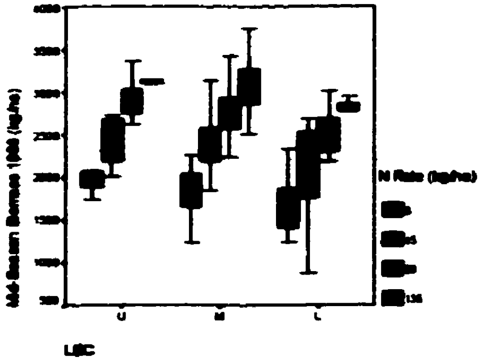
5.4 Results and Discussion

5.4.1 Total Above-Ground Biomass and Zadoks Growth Stage Near Anthesis

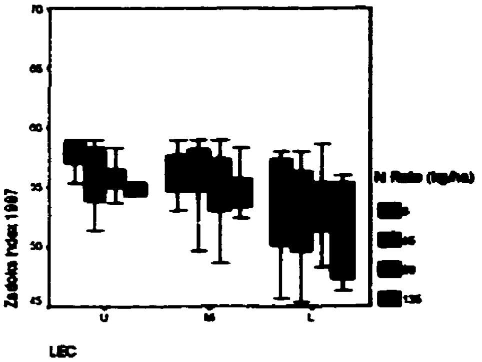
Differences in response variables were observed among growing seasons, LECs and N fertilizer treatments. Median *ABM* values were greater in 1998 than in 1997 for equivalent N rates (Table 5.1). This was indicative of differences in moisture supply between the two growing seasons; up until the time of sampling, the site received 9.2 cm of rainfall in 1997, and in 1998, 21.6 cm. As well, 1998 *ABM* samples were harvested at a slightly more advanced stage of maturity. With the exception of the 45 kg/ha N rate, the M and/or L had higher median *ABM* values than the U in 1997 (Figures 5.1,5.2,5.3). *ABM* increased with convergent character in 1997. However, differences among LECs were smaller in 1998, and the most convergent L had the lowest *ABM* yield within each N treatment due to excess moisture.



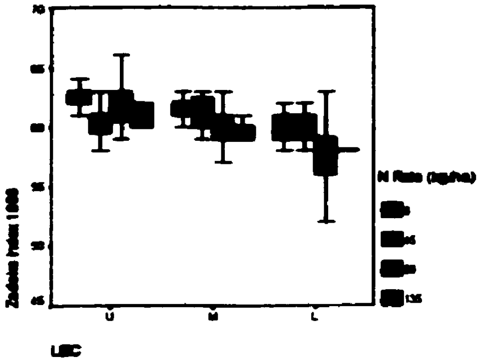
(a) *ABM 97*



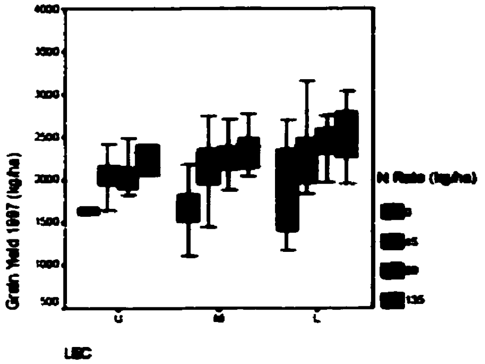
(b) *ABM 98*



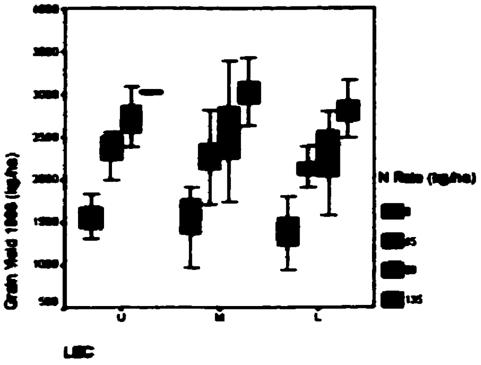
(c) *Z 97*



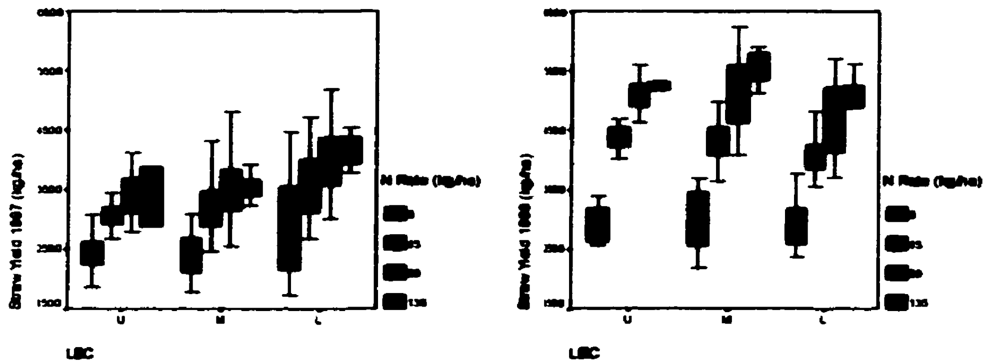
(d) *Z 98*



(e) *GY 97*

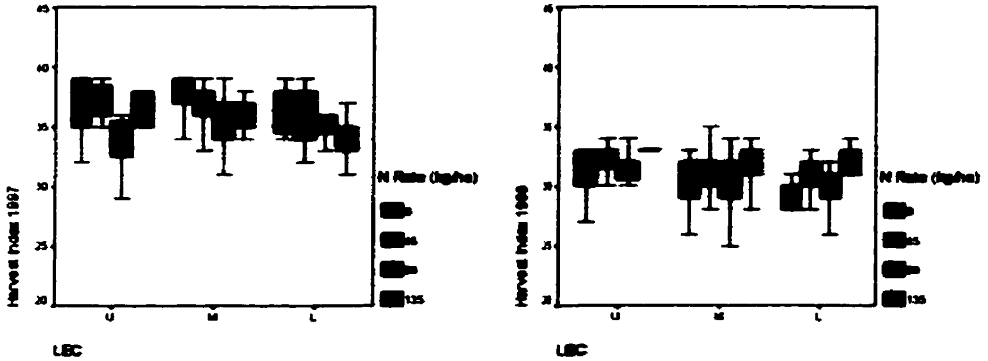


(f) *GY 98*



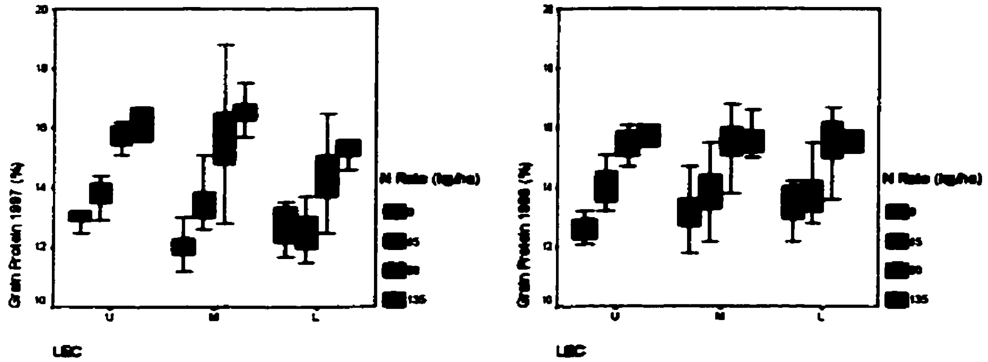
(g) *SY 97*

(h) *SY 98*



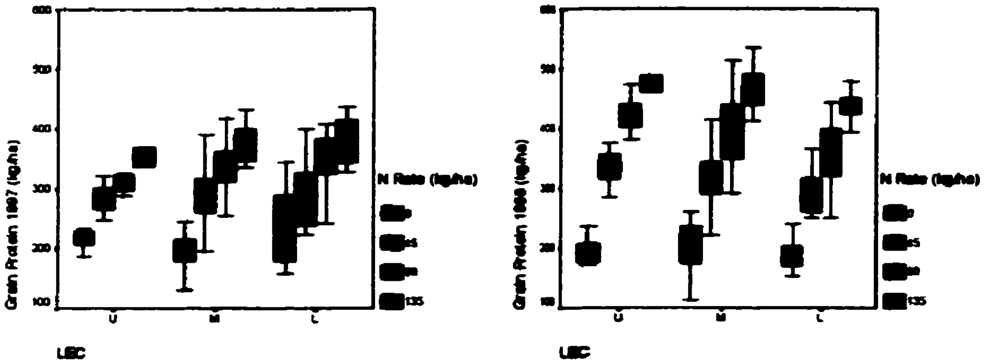
(i) *HI* 97

(j) *HI* 98



(k) *GPC 97*

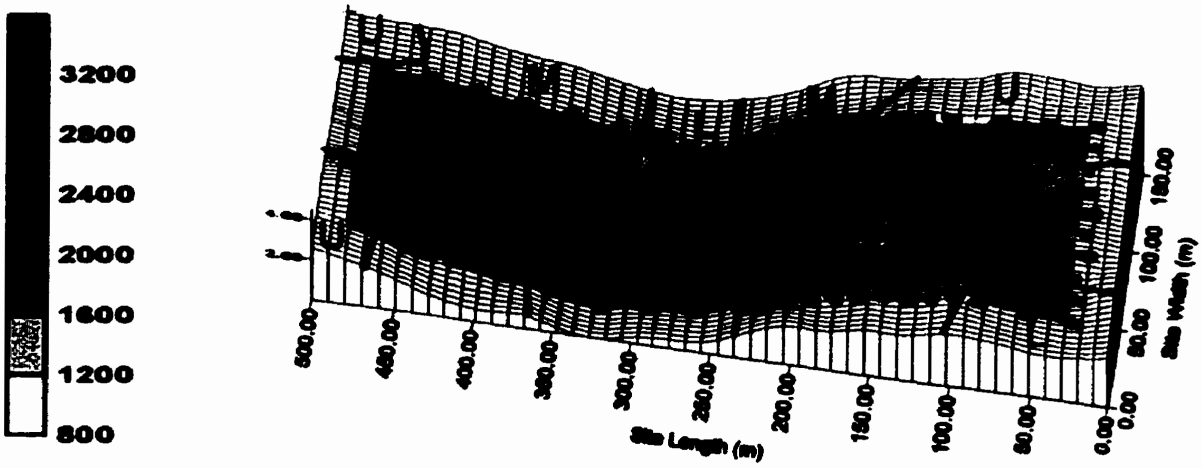
(l) *GPC 98*



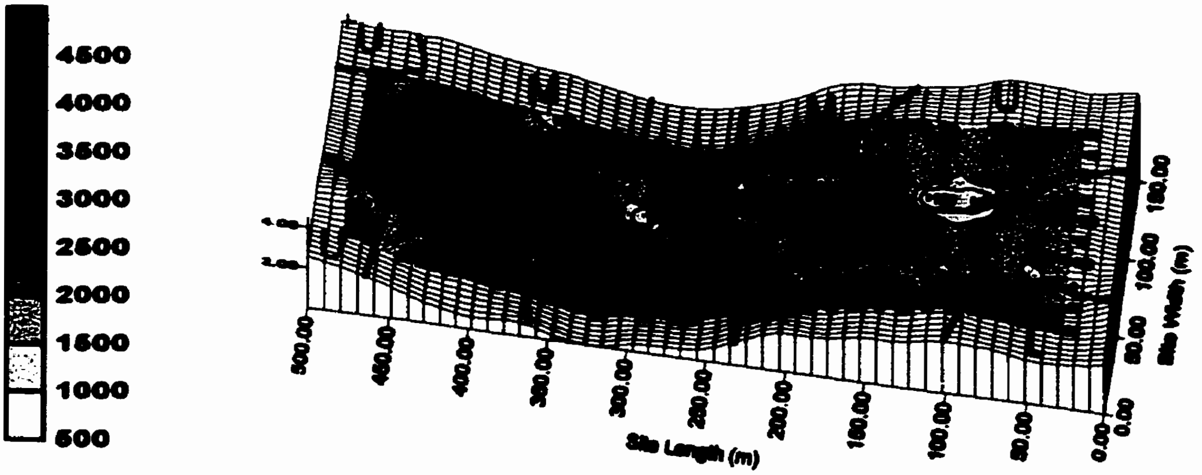
(m) *GPY 97*

(n) *GPY 98*

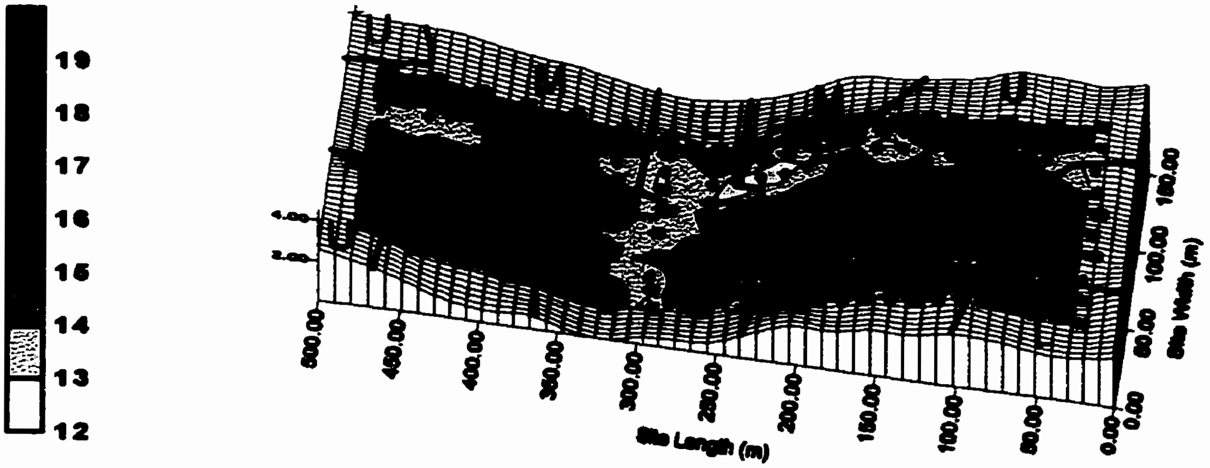
Figure 5.1. Relative distribution of selected response attributes, 1997 and 1998.



(a) Above ground biomass near anthesis (kg/ha).

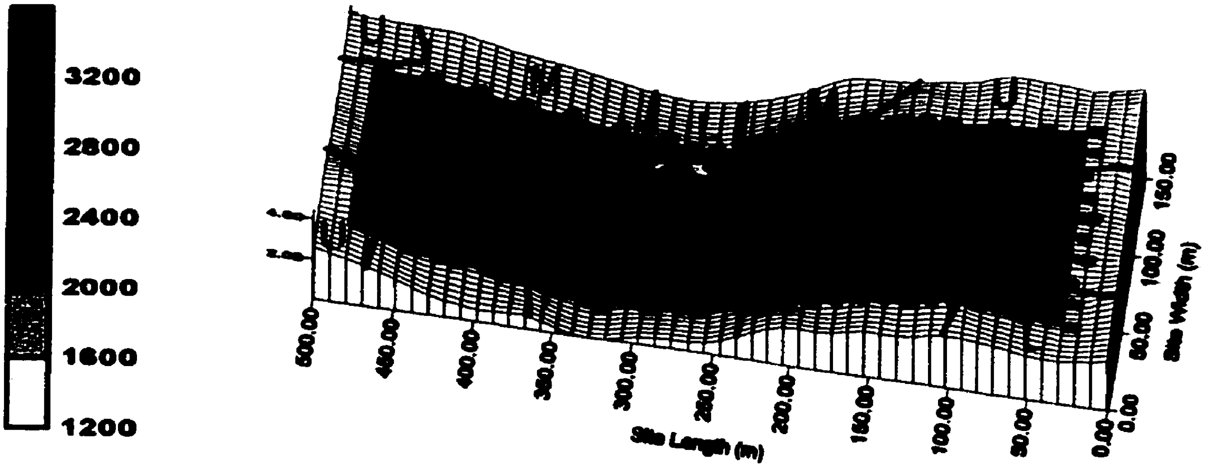


(b) Grain yield (kg/ha).

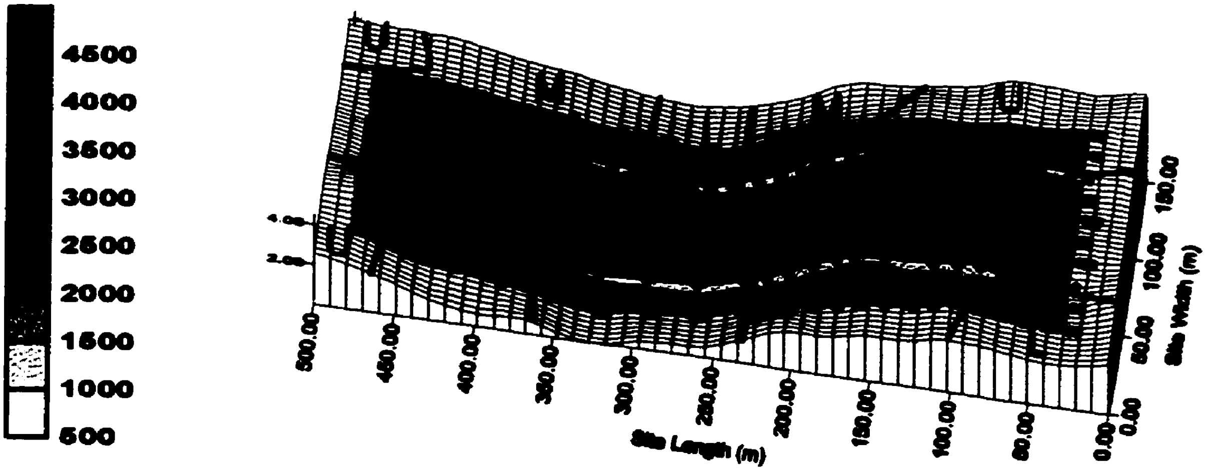


(c) Grain protein concentration (%).

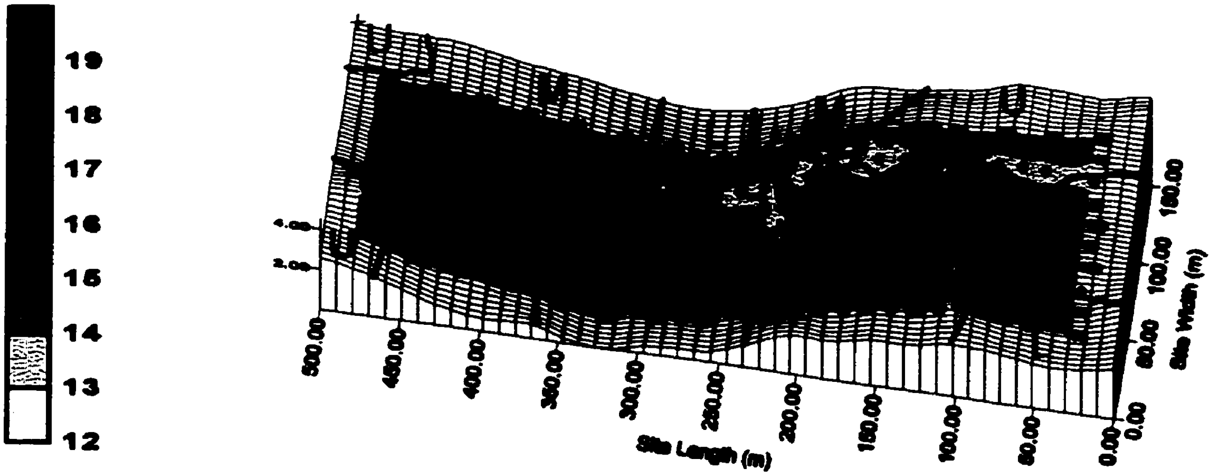
5.2 Spatial distribution of selected response attributes, 1997.



(a) Total above-ground biomass near anthesis (kg/ha).



(b) Grain yield (kg/ha).



(c) Grain protein concentration (%).

5.3 Spatial distribution of selected response attributes, 1998.

Table 5.1. Median values of above-ground biomass (Zadoks decimal growth stage) near anthesis, across and within LECs.

Year	N Rate (kg/ha)	LEC Overall	 U	 M	 L
		kg/ha			
1997	0	1606(57)	1606a(57b)[1]	1492a(57ab)	2005b(55a)
	45	1682(56)	1796a(58b)	1663a(57b)	1615a(53a)
	90	2024(55)	1644a(55a)	2024a(55a)	2024a(54a)
	135	2005(54)	1577a(55a)	1872a(54a)	2195a(52a)
1998	0	1892(62)	1952a(63c)	1904a(62b)	1747a(60a)
	45	2394(61)	2581a(61ab)	2386a(61b)	2214a(59a)
	90	2693(59)	2917b(62c)	2730b(60b)	2424a(59a)
	135	2977(60)	3123ab(61b)	3142b(60b)	2831a(58a)

[1] Median values followed by the same letter are not significantly different between LEC at α=0.20 (Kruskal-Wallis multiple comparison procedure).

1997 *ABM* yield responses to N fertilizer were small within LECs. Trends were not always consistent, but median values indicated that *ABM* response to N fertilizer was least in the more arid U. In 1998, differences among LECs were minor relative to the yield increases gained with fertilization within LECs. Median *EPANS* differed widely among N fertilizer treatments due to depletion of N in the check treatments (43 kg/ha across LECs) and more luxuriant accumulation of N in the 135 kg/ha treatment (229 kg/ha across LECs). Moist 1998 growing conditions also increased productive potential, accentuating biomass yield differences resulting from the broad range in N supply. (Comparisons among discrete treatment levels were valid as *EPANS* levels corresponded with N treatment levels.)

Phenological development (*Z*) was assessed at the time of *ABM* sampling in 1997 and 1998 (Table 5.1, Figure 5.1) (Zadoks et al., 1974). In both 1997 and 1998, maturity decreased with N rate and with convergent landscape character. Differences in maturity due to N treatments were visually evident in the timing of ripening in August of both seasons.

Correlations, while somewhat sporadic, suggested that the differences in *ABM* among LECs were due to moisture limitations in each year (Table 5.2). In 1997, *ABM* production was inversely related to *E, G, Kh* and *Kv* (r^2=-0.28 to –0.64) and positively related to *Cg* and *Cl* (r^2=0.35 to 0.48). While significant positive correlations with *V* did not occur as expected with the dry growing conditions of 1997, correlations with topographic and static soil attributes indicated that *ABM* was likely proportional to the extent of moisture accumulation. In 1998, *ABM* production was proportional to divergent character in the landscape, as evidenced by positive correlations with *E, G, Kh* and *Kv* (r^2=0.26 to 0.42) and inverse correlations with *Cg* (r^2=-0.27), *SOC(%)* (r^2=-0.28) and *Solum d* (r^2=-0.54). Significant inverse correlations (r^2= -0.15 to -0.70) to measures of *V* within N rates were common in 1998, and in conjunction with correlations with topographic and static soil attributes, indicated that *ABM* was likely limited by excess moisture at more convergent, strongly leached locations in the landscape.

In 1997, significant positive correlations between *ABM* and residual NO_3, *P, K* and *S* were observed within N treatments. Within treatments in 1998, *ABM* was essentially unrelated to residual soil nutrient concentrations. However, over all N treatments, *ABM* was strongly correlated with *EPANS* in 1998 (r^2=0.78), and only moderately so in 1997 (r^2=0.39). This reflected the greater range of available N supply combined with more favorable conditions for biomass production overall, early in the 1998 growing season.

Table 5.2. Spearman correlations, crop response attributes ($P<0.05$).

(a) Overall 1997	ABM 97	Z 97	GY 97	SY 97	HBM 97	HI 97	GPC 97	GPY 97	SN 97	NU 97	WU 97	WUE 97
ABM 97	1.00											
Z 97	-0.28	1.00										
GY 97	0.43	-0.37	1.00									
SY 97	0.45	-0.44	0.81	1.00								
HBM 97	0.46	-0.44	0.90	0.97	1.00							
HI 97	-0.21	0.25	NS	-0.57	-0.42	1.00						
GPC 97	0.36	NS	0.31	0.44	0.40	-0.39	1.00					
GPY 97	0.52	-0.35	0.86	0.79	0.86	-0.23	0.68	1.00				
SN 97	0.19	NS	NS	0.20	0.18	-0.18	0.68	0.41	1.00			
NU 97	0.52	-0.34	0.79	0.82	0.85	-0.35	0.74	0.96	0.58	1.00		
WU 97	NS	-0.17	NS	NS	NS	NS	-0.17	NS	NS	NS	1.00	
WUE 97	0.39	-0.18	0.73	0.59	0.65	-0.09	0.36	0.69	NS	0.62	-0.56	1.00
E	-0.25	0.37	-0.36	-0.42	-0.42	0.16	NS	-0.23	NS	-0.22	NS	-0.23
G	-0.20	0.28	NS	-0.19	-0.17	0.16	NS	NS	NS	NS	NS	NS
Kv	-0.24	0.19	-0.19	-0.26	-0.26	0.21	NS	-0.16	NS	-0.18	NS	-0.21
Kh	-0.22	0.32	-0.15	-0.27	-0.25	0.16	NS	NS	NS	-0.15	NS	-0.15
Cg	0.24	-0.31	0.19	0.30	0.28	-0.18	NS	NS	NS	0.14	NS	NS
Cl	0.23	-0.31	0.19	0.30	0.28	-0.19	NS	NS	-0.08	0.15	NS	NS
A d	0.40	-0.40	0.18	0.28	0.25	-0.19	NS	0.19	NS	0.21	NS	0.16
Solum d	0.33	-0.30	0.15	0.24	0.21	-0.21	NS	0.17	NS	0.19	NS	0.22
CO3 d	0.29	-0.30	NS	0.23	0.20	-0.22	0.16	0.16	NS	0.20	NS	NS
SOC (%)	0.34	-0.33	0.25	0.39	0.35	-0.28	NS	0.26	NS	0.30	NS	0.17
SOC (Mg/ha)	0.42	-0.43	0.28	0.40	0.37	-0.25	NS	0.26	NS	0.29	NS	0.18
Ap pH	0.17	-0.19	0.21	0.23	0.23	NS	NS	0.15	NS	NS	0.15	NS
ESVw 97	0.18	-0.34	0.20	0.29	0.28	-0.17	-0.15	NS	NS	NS	0.39	NS
ESVx 97	NS	-0.20	NS	NS	NS	NS	-0.20	NS	NS	NS	0.57	-0.30
ESVy 97	NS	-0.31	0.26	0.22	0.25	NS	-0.18	NS	NS	NS	0.47	NS
ESVz 97	NS	NS	NS	NS	NS	NS	-0.19	NS	NS	NS	0.45	-0.20
ESV120 97	NS	-0.34	0.23	0.23	0.25	NS	-0.26	NS	NS	NS	0.63	-0.25
MSVw 97	NS	-0.31	0.19	0.31	0.29	-0.19	-0.16	NS	-0.17	NS	NS	NS
MSVx 97	NS	-0.26	0.16	0.17	0.18	NS	-0.17	NS	-0.15	NS	0.15	NS
MSVy 97	NS	-0.20	NS	NS	NS	NS	-0.21	NS	-0.20	NS	NS	NS
MSVz 97	NS	-0.22	0.28	0.19	0.23	NS	-0.15	0.15	NS	NS	0.23	NS
MSV120 97	NS	-0.33	0.20	0.20	0.22	NS	-0.24	NS	-0.20	NS	0.22	NS
HVw 97	0.21	-0.26	0.35	0.33	0.36	NS	NS	0.29	NS	0.27	-0.26	0.46
HVx 97	NS	-0.21	NS	NS	NS	NS	NS	NS	NS	NS	-0.17	0.18
HVy 97	NS	NS	NS	NS	NS	NS	-0.22	NS	-0.17	NS	NS	NS
HVz 97	NS	NS	NS	NS	NS	NS	-0.19	NS	NS	NS	NS	NS
HV120 97	NS	-0.21	0.18	0.18	0.20	NS	NS	NS	NS	NS	-0.25	0.31
NO3w 97	0.26	-0.16	0.19	0.26	0.25	-0.20	0.17	0.23	NS	0.23	NS	0.19
NO3x 97	0.24	-0.21	0.22	0.24	0.26	NS	0.15	0.26	NS	0.27	0.18	NS
NO3y 97	0.25	-0.23	0.21	0.20	0.22	NS	NS	0.21	NS	0.20	0.17	NS
NO3z 97	0.26	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
EPANS 97	0.39	-0.26	0.58	0.65	0.64	-0.37	0.75	0.79	0.49	0.82	NS	0.53
NH4w 97	NS	NS	NS	NS	NS	NS	NS	-0.15	NS	-0.15	NS	NS
NH4x 97	NS	NS	NS	NS	-0.14	NS	NS	-0.15	NS	NS	NS	NS
NH4y 97	NS	NS	-0.19	-0.24	-0.24	0.18	NS	-0.17	NS	-0.18	NS	-0.15
NH4z 97	-0.15	NS	NS	-0.22	-0.20	0.25	-0.18	-0.17	NS	-0.19	NS	NS
Pw 97	0.23	-0.21	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Px 97	0.31	-0.30	0.19	0.26	0.25	-0.21	NS	0.19	NS	0.19	NS	NS
Py 97	0.27	-0.23	0.25	0.30	0.29	-0.17	0.18	0.28	NS	0.27	NS	0.20
Pz 97	0.21	-0.23	0.18	0.22	0.22	-0.19	0.18	0.23	NS	0.21	NS	0.24
Kw 97	0.24	-0.27	NS	0.17	0.16	NS	NS	0.16	NS	0.17	NS	NS
Kx 97	0.19	-0.28	NS	NS	NS	NS	NS	NS	0.15	0.14	NS	NS
Ky 97	NS	NS	-0.17	-0.22	-0.21	0.17	NS	NS	NS	NS	NS	-0.16
Kz 97	NS	0.15	NS	-0.26	-0.23	0.28	NS	-0.14	NS	-0.15	NS	-0.17
Sw 97	0.17	-0.30	0.19	0.25	0.26	-0.20	NS	0.15	-0.16	NS	NS	NS
Sx 97	0.18	-0.37	0.17	0.25	0.24	-0.18	NS	NS	NS	0.15	0.24	NS
Sy 97	NS	-0.24	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sz 97	NS	-0.21	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

(b) 0kg/ha 1997	*ABM 97*	*Z 97*	*GY 97*	*SY 97*	*HBM 97*	*HI 97*	*GPC 97*	*GPY 97*	*SN 97*	*NU 97*	*WU 97*	*WUE 97*
ABM 97	1.00											
Z 97	-0.35	1.00										
GY 97	0.34	-0.45	1.00									
SY 97	0.46	-0.52	0.85	1.00								
HBM 97	0.46	-0.53	0.92	0.99	1.00							
HI 97	NS	NS	NS	-0.39	NS	1.00						
GPC 97	NS	0.39	NS	NS	NS	NS	1.00					
GPY 97	0.38	NS	0.90	0.78	0.83	NS	NS	1.00				
SN 97	-0.36	NS	NS	NS	NS	NS	NS	NS	1.00			
NU 97	NS	NS	0.86	0.80	0.85	NS	NS	0.91	NS	1.00		
WU 97	NS	NS	NS	NS	NS	NS	-0.20	NS	NS	NS	1.00	
WUE 97	0.38	-0.31	0.83	0.73	0.78	NS	NS	0.81	NS	0.76	-0.30	1.00
E	NS	0.52	-0.31	NS	NS	NS	NS	NS	NS	NS	NS	NS
G	-0.39	0.58	-0.43	-0.55	-0.56	NS	NS	-0.38	NS	-0.38	NS	-0.38
Kv	NS	0.40	NS	NS	NS	0.32	NS	NS	NS	NS	NS	NS
Kh	NS	0.39	NS	NS	NS	NS	0.45	NS	NS	NS	NS	NS
Cg	0.40	-0.42	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cl	0.35	-0.38	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
A d	0.51	-0.53	0.49	0.51	0.53	NS	NS	0.47	NS	0.51	NS	0.48
Solum d	0.45	-0.39	0.32	0.40	0.40	NS	NS	0.33	NS	0.34	NS	0.31
CO3 d	0.46	-0.47	0.34	0.47	0.46	NS	NS	0.31	NS	0.34	NS	0.31
SOC (%)	0.41	-0.65	0.39	0.45	0.47	NS	-0.35	NS	NS	0.36	NS	0.36
SOC (Mg/ha)	0.49	-0.65	0.51	0.55	0.56	NS	NS	0.41	NS	0.48	NS	0.48
Ap pH	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ESVw 97	NS	-0.66	0.33	0.43	0.41	NS	-0.46	NS	NS	NS	NS	NS
ESVx 97	NS	-0.30	NS	NS	NS	NS	-0.33	NS	NS	NS	0.60	NS
ESVy 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.47	NS
ESVz 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.33	NS
ESV120 97	NS	-0.53	0.36	NS	NS	NS	-0.41	NS	NS	NS	0.54	NS
MSVw 97	NS	-0.57	0.51	0.53	0.54	NS	-0.40	0.30	NS	0.39	NS	0.45
MSVx 97	NS	-0.40	NS	NS	NS	NS	-0.37	NS	NS	NS	NS	NS
MSVy 97	NS	-0.31	NS	NS	NS	NS	-0.33	NS	NS	NS	NS	NS
MSVz 97	0.35	-0.44	0.45	NS	NS	0.35	NS	0.39	NS	NS	NS	0.33
MSV120 97	NS	-0.54	0.41	0.33	0.36	NS	-0.46	NS	NS	NS	NS	NS
HVw 97	NS	-0.41	0.52	0.39	0.44	NS	NS	0.42	NS	0.41	NS	0.65
HVx 97	NS	-0.31	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HVy 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HVz 97	NS	NS	NS	NS	NS	NS	-0.30	NS	NS	NS	NS	NS
HV120 97	NS	-0.38	0.35	NS	NS	NS	NS	NS	NS	NS	NS	NS
NO3w 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NO3x 97	0.45	NS	0.34	0.39	0.38	NS	NS	0.37	NS	0.36	NS	NS
NO3y 97	0.31	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NO3z 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
EPANS 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NH4w 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NH4x 97	NS	NS	NS	NS	NS	NS	NS	-0.33	NS	NS	NS	NS
NH4y 97	-0.33	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.31	NS
NH4z 97	-0.44	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.33	NS
Pw 97	0.42	-0.43	NS	0.34	0.34	NS	NS	NS	NS	NS	NS	0.34
Px 97	0.55	-0.35	NS	0.39	0.38	-0.36	NS	NS	NS	NS	NS	NS
Py 97	NS	-0.40	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Pz 97	NS	-0.31	NS	NS	NS	-0.34	NS	NS	NS	NS	NS	NS
Kw 97	NS	NS	NS	NS	NS	-0.33	-0.35	NS	NS	NS	NS	NS
Kx 97	0.36	-0.45	NS	NS	NS	NS	-0.38	NS	NS	NS	NS	NS
Ky 97	NS	-0.44	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Kz 97	NS	-0.41	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sw 97	0.35	-0.41	NS	0.32	NS	NS	NS	NS	NS	NS	NS	NS
Sx 97	NS	-0.41	NS	0.31	NS	NS	-0.32	NS	NS	NS	NS	NS
Sy 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.32	NS
Sz 97	NS	NS	NS	NS	NS	0.39	NS	NS	NS	NS	NS	NS

(c) 45kg/ha 1997	ABM 97	Z 97	GY 97	SY 97	HBM 97	HI 97	GPC 97	GPY 97	SN 97	NU 97	WU 97	WUE 97
ABM 97	1.00											
Z 97	-0.25	1.00										
GY 97	0.29	NS	1.00									
SY 97	NS	-0.36	0.62	1.00								
HBM 97	NS	-0.31	0.78	0.97	1.00							
HI 97	NS	NS	NS	-0.49	-0.31	1.00						
GPC 97	NS	NS	NS	NS	NS	NS	1.00					
GPY 97	0.42	NS	0.84	0.62	0.73	NS	0.30	1.00				
SN 97	NS	NS	NS	NS	NS	NS	0.48	NS	1.00			
NU 97	0.41	NS	0.71	0.70	0.76	NS	0.37	0.90	0.41	1.00		
WU 97	NS	NS	NS	NS	NS	NS	-0.21	NS	NS	NS	1.00	
WUE 97	NS	NS	0.71	0.38	0.48	NS	NS	0.67	NS	0.48	-0.58	1.00
E	NS	0.32	-0.29	-0.48	-0.47	NS	0.36	NS	NS	NS	-0.36	NS
G	NS	0.27	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Kv	NS	NS	NS	-0.31	-0.31	NS	NS	NS	NS	-0.27	NS	-0.28
Kh	-0.28	0.31	-0.25	-0.44	-0.40	NS	NS	-0.33	NS	-0.35	NS	-0.29
Cg	NS	-0.27	0.31	0.52	0.50	-0.26	NS	0.32	NS	0.35	NS	NS
CI	NS	-0.27	0.31	0.52	0.50	-0.26	NS	0.33	NS	0.36	NS	NS
A d	NS	-0.55	NS	NS	NS	NS	NS	0.29	NS	0.19	NS	0.26
Solum d	NS	-0.40	0.27	NS	NS	NS	NS	0.32	NS	0.28	NS	0.33
CO3 d	NS	-0.32	0.28	NS	NS	NS	NS	0.34	NS	0.34	NS	0.32
SOC (%)	NS	-0.25	0.29	0.36	0.38	NS	NS	0.32	NS	0.35	0.26	NS
SOC (Mg/ha)	0.27	-0.50	0.38	0.39	0.41	NS	NS	0.39	NS	0.36	NS	NS
Ap pH	NS	NS	NS	NS	NS	NS	-0.29	NS	NS	NS	0.38	-0.30
ESVw 97	NS	NS	NS	0.30	0.30	NS	NS	NS	NS	NS	0.39	NS
ESVx 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.59	-0.55
ESVy 97	NS	-0.37	NS	NS	NS	NS	NS	NS	NS	NS	0.51	-0.25
ESVz 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.42	-0.28
ESV120 97	NS	-0.26	NS	NS	NS	NS	-0.28	NS	NS	NS	0.67	-0.42
MSVw 97	NS	-0.25	NS	0.27	NS	-0.27	NS	NS	NS	NS	NS	NS
MSVx 97	NS	NS	NS	NS	NS	NS	NS	-0.26	NS	-0.28	NS	NS
MSVy 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSVz 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSV120 97	NS	-0.27	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HVw 97	NS	-0.30	NS	0.26	0.30	NS	NS	NS	NS	NS	NS	NS
HVx 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HVy 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HVz 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HV120 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NO3w 97	NS	NS	NS	0.42	0.40	NS	NS	0.29	NS	0.35	NS	NS
NO3x 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NO3y 97	NS	-0.25	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NO3z 97	0.28	NS	NS	NS	NS	NS	0.37	0.31	0.25	0.32	NS	NS
EPANS 97	NS	NS	NS	0.32	0.30	NS	NS	0.25	NS	0.32	NS	NS
NH4w 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NH4x 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NH4y 97	NS	NS	NS	-0.34	-0.34	NS	NS	-0.29	NS	-0.30	NS	NS
NH4z 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.27
Pw 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.26	NS	NS
Px 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Py 97	NS	NS	NS	NS	NS	NS	NS	0.25	NS	NS	NS	0.26
Pz 97	NS	NS	NS	NS	NS	NS	0.25	NS	NS	NS	-0.35	0.29
Kw 97	NS	-0.27	0.25	0.32	0.35	NS	NS	NS	NS	NS	NS	NS
Kx 97	NS	-0.41	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Ky 97	NS	-0.26	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Kz 97	NS	-0.27	NS	0.28	0.29	NS	NS	NS	-0.32	NS	NS	NS
Sw 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.29	NS
Sx 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.35	NS
Sy 97	NS	NS	-0.25	-0.43	-0.41	0.30	NS	-0.26	NS	-0.34	NS	NS
Sz 97	NS	NS	NS	-0.40	-0.38	NS	NS	-0.28	NS	-0.33	0.28	NS
S120 97												

(d) 90 kg/ha 1997	ABM 97	Z 97	GY 97	SY 97	HBM 97	HI 97	GPC 97	GPY 97	SN 97	NU 97	WU 97	WUE 97
ABM 97	1.00											
Z 97	NS	1.00										
GY 97	0.34	-0.33	1.00									
SY 97	0.31	-0.36	0.74	1.00								
HBM 97	0.36	-0.39	0.86	0.94	1.00							
HI 97	NS	NS	NS	-0.57	-0.37	1.00						
GPC 97	NS	NS	-0.32	NS	-0.26	-0.28	1.00					
GPY 97	0.56	-0.26	0.74	0.62	0.71	NS	NS	1.00				
SN 97	NS	NS	-0.33	NS	-0.28	NS	0.51	NS	1.00			
NU 97	0.50	-0.28	0.60	0.72	0.73	-0.32	0.27	0.87	NS	1.00		
WU 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	1.00	
WUE 97	NS	NS	0.47	NS	0.31	0.27	NS	0.34	-0.31	NS	-0.78	1.00
E	NS	0.31	-0.53	-0.46	-0.50	NS	0.33	-0.30	0.38	NS	NS	NS
G	NS	NS	NS	-0.26	NS	0.40	NS	NS	NS	NS	NS	NS
Kv	-0.29	NS	NS	NS	NS	NS	NS	-0.33	NS	-0.34	NS	NS
Kh	NS	NS	NS	-0.32	-0.27	NS	NS	NS	NS	-0.26	NS	NS
Cg	NS	-0.29	NS	0.26	NS	NS	NS	0.28	NS	NS	NS	NS
Cl	NS	-0.28	NS	0.27	NS	NS	NS	0.32	NS	0.26	NS	NS
A d	0.48	NS	NS	0.36	0.31	-0.39	0.38	0.39	NS	0.44	NS	NS
Solum d	0.38	NS	NS	0.35	NS	-0.53	0.37	NS	NS	0.33	NS	NS
CO3 d	0.29	NS	NS	0.27	NS	-0.47	0.43	NS	0.29	0.32	NS	NS
SOC (%)	0.29	NS	NS	0.45	0.36	-0.46	0.30	0.39	NS	0.44	NS	NS
SOC (Mg/ha)	0.43	NS	NS	0.42	0.35	-0.43	0.32	0.39	NS	0.44	NS	NS
Ap pH	NS	NS	0.30	NS	NS	NS	NS	NS	NS	NS	NS	NS
ESVw 97	NS	-0.31	0.32	0.51	0.47	-0.38	NS	0.36	NS	0.39	0.39	NS
ESVx 97	NS	-0.26	NS	0.31	0.34	NS	-0.41	NS	-0.30	NS	0.59	-0.34
ESVy 97	NS	-0.26	0.38	0.38	0.42	NS	-0.49	NS	NS	NS	0.40	NS
ESVz 97	NS	NS	NS	NS	NS	NS	-0.41	NS	NS	NS	0.57	-0.38
ESV120 97	NS	-0.34	0.41	0.47	0.48	NS	-0.40	NS	NS	0.27	0.65	-0.34
MSVw 97	NS	NS	0.42	0.50	0.49	NS	NS	0.30	-0.27	0.30	NS	NS
MSVx 97	NS	NS	0.40	0.37	0.42	NS	-0.33	NS	-0.29	NS	NS	NS
MSVy 97	NS	NS	0.36	NS	NS	NS	-0.51	NS	-0.43	NS	NS	NS
MSVz 97	NS	NS	0.32	0.30	0.36	NS	-0.52	NS	NS	NS	NS	NS
MSV120 97	NS	-0.29	0.48	0.42	0.48	NS	-0.50	NS	-0.37	NS	NS	NS
HVw 97	NS	NS	0.29	NS	NS	NS	-0.26	NS	NS	NS	-0.43	0.54
HVx 97	NS	NS	NS	NS	NS	NS	NS	NS	-0.33	NS	NS	0.42
HVy 97	NS	NS	0.33	NS	0.32	NS	-0.52	NS	-0.31	NS	NS	0.30
HVz 97	NS	NS	NS	NS	NS	NS	-0.50	NS	NS	NS	NS	NS
HV120 97	NS	NS	0.35	NS	0.33	NS	-0.50	NS	-0.30	NS	-0.36	0.50
NO3w 97	0.33	NS	0.28	NS	NS	NS	NS	0.28	NS	NS	NS	NS
NO3x 97	NS	NS	0.26	0.26	0.33	NS	NS	NS	NS	0.27	0.26	NS
NO3y 97	0.35	NS	0.31	0.30	0.33	NS	NS	0.30	NS	0.34	NS	NS
NO3z 97	0.37	NS	NS	NS	NS	NS	0.27	0.29	NS	0.29	NS	NS
EPANS 97	0.33	NS	0.36	NS	0.29	NS	NS	0.29	NS	NS	NS	NS
NH4w 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.29	NS
NH4x 97	NS	NS	NS	NS	NS	NS	0.30	NS	NS	NS	NS	NS
NH4y 97	NS	NS	-0.26	NS	-0.26	NS	NS	NS	NS	NS	NS	NS
NH4z 97	NS	NS	NS	NS	-0.29	NS	NS	-0.31	NS	-0.29	NS	NS
Pw 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.32	-0.29
Px 97	0.29	-0.31	NS	NS	0.26	NS	NS	0.34	NS	NS	NS	NS
Py 97	0.36	-0.32	NS	NS	NS	-0.26	NS	0.26	NS	0.28	NS	NS
Pz 97	NS	NS	NS	NS	NS	-0.16	NS	0.16	NS	NS	NS	NS
Kw 97	NS	-0.37	0.42	0.48	0.54	-0.24	NS	0.50	NS	0.45	NS	NS
Kx 97	NS	NS	0.35	0.39	0.43	-0.22	NS	NS	NS	NS	NS	NS
Ky 97	NS	NS	NS	NS	NS	0.05	NS	NS	NS	NS	NS	NS
Kz 97	NS	NS	NS	NS	NS	0.14	NS	NS	NS	NS	NS	NS
Sw 97	0.30	NS	NS	NS	NS	-0.21	NS	NS	NS	NS	NS	NS
Sx 97	0.34	NS	NS	0.27	NS	-0.32	0.40	0.30	NS	0.37	NS	NS
Sy 97	0.26	NS	NS	NS	NS	NS	NS	NS	0.27	NS	NS	NS
Sz 97	NS	NS	NS	NS	NS	NS	NS	NS	0.31	NS	NS	NS
S120 97												

(e) 135kg/ha 1997	*ABM 97*	*Z 97*	*GY 97*	*SY 97*	*HBM 97*	*HI 97*	*GPC 97*	*GPY 97*	*SN 97*	*NU 97*	*WU 97*	*WUE 97*
ABM 97	1.00											
Z 97	NS	1.00										
GY 97	NS	NS	1.00									
SY 97	0.64	-0.43	0.61	1.00								
HBM 97	0.56	-0.43	0.82	0.93	1.00							
HI 97	NS	NS	0.47	NS	NS	1.00						
GPC 97	-0.45	0.47	-0.63	-0.68	-0.79	NS	1.00					
GPY 97	NS	NS	0.92	0.53	0.70	0.47	NS	1.00				
SN 97	NS	NS	NS	NS	NS	NS	0.58	NS	1.00			
NU 97	NS	NS	0.71	0.53	0.61	NS	NS	0.80	NS	1.00		
WU 97	NS	NS	0.60	NS	NS	0.52	NS	0.61	NS	NS	1.00	
WUE 97	NS	NS	NS	0.45	NS	NS	NS	NS	NS	NS	-0.72	1.00
E	-0.64	NS	NS	-0.78	-0.64	0.48	0.61	NS	NS	NS	NS	-0.61
G	NS	0.49	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Kv	-0.52	NS	NS	-0.63	-0.54	0.30	NS	NS	NS	NS	NS	NS
Kh	NS	0.44	NS	-0.47	-0.36	0.43	NS	NS	NS	NS	NS	NS
Cg	0.48	-0.46	NS	0.50	0.44	NS	NS	NS	NS	NS	NS	NS
Cl	0.48	-0.46	NS	0.50	0.44	NS	NS	NS	NS	NS	NS	NS
A d	0.54	NS	NS	NS	NS	NS	-0.44	NS	NS	NS	NS	NS
Solum d	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.46	NS
CO3 d	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SOC (%)	0.50	NS	NS	0.52	NS	-0.53	NS	NS	NS	NS	NS	NS
SOC (Mg/ha)	0.53	NS	NS	0.53	0.44	-0.48	-0.49	NS	NS	NS	NS	NS
Ap pH	0.48	NS	0.47	0.44	0.50	NS	-0.54	NS	NS	NS	NS	NS
ESVw 97	NS	-0.46	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ESVx 97	NS	NS	0.56	NS	NS	NS	NS	0.56	NS	NS	NS	NS
ESVy 97	NS	-0.58	0.61	NS	NS	0.58	NS	0.57	-0.45	NS	0.57	NS
ESVz 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ESV120 97	NS	-0.62	0.67	NS	0.51	NS	-0.47	0.63	NS	NS	0.62	NS
MSVw 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSVx 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSVy 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSVz 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.59	NS
MSV120 97	NS	-0.48	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HVw 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.47	0.81
HVx 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HVy 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.62	0.64
HVz 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HV120 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.61	0.74
NO3w 97	0.64	NS	NS	0.66	0.53	-0.53	-0.55	NS	NS	NS	NS	0.47
NO3x 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NO3y 97	NS	NS	NS	NS	NS	NS	NS	NS	-0.47	NS	NS	NS
NO3z 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.45	-0.45
EPANS 97	0.63	NS	NS	0.70	0.65	NS	-0.65	NS	-0.46	NS	NS	NS
NH4w 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NH4x 97	NS	NS	NS	0.46	NS	NS	-0.46	NS	NS	NS	NS	NS
NH4y 97	NS	NS	0.71	NS	0.53	0.47	-0.53	0.53	NS	NS	0.47	NS
NH4z 97	NS	NS	0.44	NS	NS	0.52	NS	NS	-0.51	NS	NS	NS
Pw 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Px 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Py 97	0.47	NS	NS	NS	0.47	NS	NS	NS	NS	NS	0.54	NS
Pz 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Kw 97	0.46	NS	NS	0.49	0.47	NS	NS	NS	NS	NS	NS	NS
Kx 97	NS	NS	NS	0.48	0.44	-0.34	NS	NS	NS	NS	NS	NS
Ky 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.55	NS
Kz 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.52	NS
Sw 97	NS	NS	NS	NS	NS	NS	-0.45	NS	NS	NS	NS	NS
Sx 97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sy 97	NS	NS	NS	NS	NS	0.44	NS	0.43	NS	NS	NS	NS
Sz 97	NS	NS	0.47	NS	NS	0.49	NS	0.61	NS	0.48	NS	NS
S120 97												

(f) Overall 1998	ABM 98	Z 98	GY 98	SY 98	HBM 98	HI 98	GPC 98	GPY 98	SN 98	NU 98	NBAL 98	WU 98	WUE 98
ABM 98	1.00												
Z 98	-0.16	1.00											
GY 98	0.60	-0.33	1.00										
SY 98	0.59	-0.36	0.92	1.00									
HBM 98	0.60	-0.36	0.96	0.99	1.00								
HI 98	0.19	NS	0.39	NS	0.16	1.00							
GPC 98	0.59	-0.52	0.60	0.66	0.65	NS	1.00						
GPY 98	0.66	-0.41	0.96	0.92	0.94	0.32	0.78	1.00					
SN 98	0.56	-0.32	0.49	0.55	0.54	NS	0.61	0.58	1.00				
NU 98	0.69	-0.42	0.89	0.91	0.92	0.16	0.79	0.94	0.79	1.00			
NBAL 98	-0.60	0.27	-0.26	-0.29	-0.28	NS	-0.47	-0.36	-0.39	-0.40	1.00		
WU 98	0.22	-0.22	0.17	0.22	0.20	NS	0.29	0.23	0.39	0.31	-0.38	1.00	
WUE 98	0.51	-0.22	0.89	0.79	0.84	0.42	0.46	0.83	0.30	0.72	NS	-0.24	1.00
E	NS	0.50	NS	NS	NS	NS	-0.17	NS	NS	NS	NS	-0.14	NS
G	NS	0.27	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Kv	NS	0.34	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.15	NS
Kh	NS	0.36	NS	NS	NS	0.14	-0.18	NS	-0.17	NS	NS	NS	NS
Cg	NS	-0.41	NS	NS	NS	-0.14	0.16	NS	0.16	NS	NS	NS	NS
Cl	NS	-0.42	NS	NS	NS	NS	0.17	NS	0.16	NS	NS	NS	NS
A d	NS	-0.42	NS	NS	NS	NS	0.23	NS	NS	NS	NS	NS	NS
Solum d	NS	-0.35	NS	NS	NS	-0.14	0.20	NS	NS	NS	NS	NS	NS
CO3 d	NS	-0.34	NS	NS	NS	NS	0.19	NS	NS	NS	NS	NS	NS
SOC (%)	NS	-0.52	0.18	0.23	0.22	NS	0.27	0.22	0.19	0.24	NS	NS	NS
SOC (Mg/ha)	NS	-0.50	0.17	0.18	0.18	NS	0.29	0.21	0.14	0.20	NS	NS	0.14
Ap pH	NS	-0.15	NS	NS	NS	0.17	NS	NS	NS	NS	NS	NS	0.15
ESVw 98	-0.15	-0.46	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.33	NS
ESVx 98	-0.15	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.52	-0.32
ESVy 98	-0.16	NS	-0.18	-0.19	-0.19	NS	NS	-0.18	NS	-0.16	NS	0.36	-0.32
ESVz 98	-0.18	NS	-0.16	-0.14	-0.15	NS	-0.15	-0.17	NS	NS	NS	0.37	-0.31
ESV120 98	-0.20	-0.22	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.55	-0.35
MSVw 98	NS	-0.24	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSVx 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.14	NS
MSVy 98	NS	NS	-0.17	-0.14	-0.16	NS	NS	-0.15	NS	-0.13	NS	NS	0.36
MSVz 98	NS	-0.27	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSV120 98	NS	-0.30	NS	NS	NS	NS	0.15	NS	NS	NS	NS	NS	NS
HVw 98	-0.21	-0.39	NS	NS	NS	NS	NS	NS	NS	NS	0.16	NS	NS
HVx 98	-0.38	NS	-0.30	-0.33	-0.32	NS	-0.33	-0.34	-0.38	-0.40	0.31	-0.40	-0.13
HVy 98	-0.44	NS	-0.37	-0.41	-0.40	NS	-0.39	-0.42	-0.39	-0.47	0.31	-0.42	-0.18
HVz 98	-0.39	NS	-0.32	-0.35	-0.35	NS	-0.34	-0.36	-0.34	-0.41	0.33	-0.38	-0.15
HV120 98	-0.46	NS	-0.32	-0.35	-0.34	NS	-0.32	-0.36	-0.39	-0.42	0.35	-0.44	-0.13
NO3w 98	0.43	-0.46	0.42	0.47	0.46	NS	0.49	0.49	0.44	0.53	-0.60	0.29	0.29
NO3x 98	0.43	-0.38	0.44	0.45	0.45	NS	0.43	0.48	0.40	0.51	-0.52	0.35	0.28
NO3y 98	0.31	-0.22	0.31	0.29	0.29	NS	0.27	0.33	0.24	0.34	-0.31	0.22	0.18
NO3z 98	0.30	-0.27	0.32	0.29	0.30	0.17	0.27	0.35	0.24	0.35	-0.16	0.16	0.24
EPANS 98	0.78	-0.44	0.68	0.69	0.69	0.15	0.75	0.77	0.69	0.82	-0.78	0.35	0.51
NH4w 98	0.15	-0.14	NS	0.18	0.16	NS	0.17	0.14	0.17	0.17	NS	NS	NS
NH4x 98	0.14	NS	NS	0.16	0.14	NS	0.21	0.15	NS	0.15	NS	0.15	NS
NH4y 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NH4z 98	0.15	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Pw 98	NS	-0.33	NS	NS	NS	-0.15	0.16	NS	NS	NS	-0.17	0.17	-0.14
Px 98	NS	-0.20	NS	NS	NS	NS	NS	NS	NS	NS	0.16	NS	NS
Py 98	NS	-0.14	NS	NS	NS	NS	NS	NS	NS	NS	0.17	NS	NS
Pz 98	NS	-0.16	NS	NS	NS	NS	NS	NS	NS	NS	0.14	NS	NS
Kw 98	NS	-0.46	NS	0.19	0.17	-0.11	0.26	0.17	NS	0.16	-0.16	NS	NS
Kx 98	NS	-0.16	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Ky 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Kz 98	NS	0.14	NS	NS	NS	0.18	NS	NS	NS	NS	NS	NS	NS
Sw 98	NS	-0.35	NS	0.16	0.15	NS	0.14	NS	NS	0.13	NS	NS	NS
Sx 98	NS	-0.28	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.15	NS
Sy 98	NS	-0.16	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sz 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HNO3w 98	0.27	-0.29	0.36	0.31	0.33	0.16	0.37	0.39	0.28	0.39	NS	NS	0.33
HNO3x 98	0.36	-0.20	0.34	0.30	0.32	0.18	0.34	0.39	0.30	0.39	NS	NS	0.33
HNO3y 98	0.47	-0.23	0.40	0.39	0.40	0.16	0.45	0.47	0.46	0.51	-0.29	NS	0.33
HNO3z 98	0.47	-0.26	0.39	0.43	0.42	0.05	0.50	0.47	0.43	0.51	-0.31	NS	0.34
HNO390 98	0.36	-0.29	0.41	0.36	0.38	0.19	0.39	0.45	0.33	0.45	NS	NS	0.38
HNH4w 98	NS	NS	0.19	0.18	0.19	0.19	NS	0.17	0.16	0.20	NS	NS	0.20
HNH4x 98	NS	NS	NS	NS	NS	0.20	NS	NS	NS	NS	NS	NS	0.17
HNH4y 98	NS	NS	0.16	NS	0.14	0.18	NS	0.14	NS	NS	NS	NS	0.18
HNH4z 98	NS	0.20	0.17	NS	0.14	0.24	NS	NS	NS	NS	NS	-0.16	0.23

(g) 0 kg/ha 1998	*ABM 98*	*Z 98*	*GY 98*	*SY 98*	*HBM 98*	*HI 98*	*GPC 98*	*GPY 98*	*SN 98*	*NU 98*	*NBAL 98*	*WU 98*	*WUE 98*
ABM 98	1.00												
Z 98	NS	1.00											
GY 98	**0.47**	NS	1.00										
SY 98	**0.48**	NS	**0.81**	1.00									
HBM 98	**0.49**	NS	**0.91**	**0.97**	1.00								
HI 98	NS	NS	**0.39**	NS	NS	1.00							
GPC 98	NS	**-0.54**	NS	NS	NS	NS	1.00						
GPY 98	**0.50**	NS	**0.96**	**0.82**	**0.91**	**0.32**	**0.40**	1.00					
SN 98	NS	NS	NS	NS	NS	NS	NS	NS	1.00				
NU 98	**0.50**	**-0.32**	**0.82**	**0.86**	**0.89**	NS	**0.44**	**0.86**	NS	1.00			
NBAL 98	NS	NS	**0.38**	**0.40**	**0.40**	NS	NS	**0.31**	NS	NS	1.00		
WU 98	NS	NS	NS	NS	NS	**-0.33**	NS	NS	**0.42**	NS	**-0.33**	1.00	
WUE 98	**0.48**	NS	**0.85**	**0.64**	**0.74**	**0.48**	NS	**0.81**	**-0.42**	**0.57**	**0.43**	**-0.63**	1.00
E	**0.42**	**0.63**	NS	NS	NS	NS	**-0.32**	NS	NS	NS	**0.31**	**-0.50**	**0.35**
G	NS	**0.35**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Kv	NS	**0.59**	NS	**-0.32**	**-0.30**	NS	**-0.35**	NS	NS	**-0.41**	NS	**-0.37**	NS
Kh	NS	**0.54**	NS	NS	NS	NS	NS	NS	**-0.40**	NS	NS	NS	NS
Cg	NS	**-0.64**	NS	NS	NS	**-0.30**	NS	NS	NS	NS	NS	NS	NS
Cl	NS	**-0.64**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
A d	NS	**-0.52**	**0.31**	**0.36**	**0.37**	NS	**0.46**	**0.41**	NS	**0.47**	NS	NS	NS
Solum d	NS	**-0.64**	NS	**0.32**	**0.30**	NS	NS	**0.31**	NS	**0.42**	NS	NS	NS
CO3 d	NS	**-0.65**	NS	**0.36**	**0.34**	NS	**0.30**	**0.34**	NS	**0.40**	NS	NS	NS
SOC (%)	NS	**-0.63**	NS	NS	NS	NS	**0.60**	**0.33**	NS	**0.36**	NS	NS	NS
SOC (Mg/ha)	NS	**-0.66**	NS	**0.38**	**0.37**	NS	**0.61**	**0.38**	NS	**0.49**	NS	NS	NS
Ap pH	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ESVw 98	NS	**-0.46**	NS	NS	NS	NS	**0.41**	NS	NS	NS	NS	**0.36**	NS
ESVx 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ESVy 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**0.30**	NS
ESVz 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ESV120 98	NS	**-0.32**	NS	NS	NS	NS	NS	NS	NS	NS	NS	**0.45**	NS
MSVw 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSVx 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSVy 98	**-0.32**	**-0.41**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSVz 98	**-0.36**	**-0.41**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSV120 98	NS	**-0.33**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HVw 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HVx 98	NS	NS	NS	NS	NS	**0.49**	NS	NS	**-0.45**	NS	NS	**-0.58**	**0.43**
HVy 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HVz 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**-0.40**	NS
HV120 98	NS	NS	NS	NS	NS	**0.32**	NS	NS	**-0.36**	NS	NS	**-0.45**	**0.30**
NO3w 98	NS	**-0.40**	**0.40**	**0.35**	**0.40**	NS	**0.40**	**0.50**	NS	**0.53**	**-0.41**	NS	NS
NO3x 98	NS	**-0.30**	NS	NS	NS	NS	**0.32**	**0.33**	NS	**0.31**	NS	NS	NS
NO3y 98	NS	NS	NS	NS	NS	NS	NS	**0.30**	NS	NS	NS	NS	**0.33**
NO3z 98	NS	NS	NS	NS	NS	**0.31**	NS	NS	NS	NS	NS	NS	NS
EPANS 98	**0.31**	**-0.38**	**0.47**	**0.42**	**0.47**	NS	**0.42**	**0.57**	NS	**0.58**	**-0.36**	NS	**0.33**
NH4w 98	NS	NS	NS	NS	NS	NS	**-0.45**	**-0.35**	NS	**-0.41**	**0.31**	NS	NS
NH4x 98	NS	NS	NS	NS	NS	**0.32**	NS	NS	NS	**-0.35**	NS	NS	NS
NH4y 98	NS	NS	NS	NS	NS	NS	NS	NS	**-0.31**	**-0.31**	**0.47**	**-0.38**	NS
NH4z 98	NS	NS	NS	NS	NS	NS	NS	NS	**-0.30**	**-0.37**	**0.40**	**-0.46**	NS
Pw 98	NS	**-0.58**	NS	NS	NS	NS	**0.40**	NS	NS	NS	NS	NS	NS
Px 98	**0.31**	NS	NS	NS	NS	NS	NS	NS	NS	NS	**0.33**	NS	NS
Py 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**0.34**	NS	NS
Pz 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**0.49**	**-0.31**	NS
Kw 98	NS	**-0.52**	NS	NS	NS	NS	**0.49**	NS	NS	NS	NS	NS	NS
Kx 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Ky 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**0.41**	NS	NS
Kz 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**0.38**	**-0.35**	NS
Sw 98	NS	**-0.35**	NS	NS	NS	NS	**0.36**	NS	NS	NS	NS	NS	NS
Sx 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sy 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sz 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HNO3w 98	NS	NS	NS	NS	NS	NS	**0.31**	NS	**-0.36**	NS	**0.60**	**-0.32**	NS
HNO3x 98	**0.43**	NS	**0.34**	NS	**0.32**	NS	NS	NS	NS	NS	**0.54**	**-0.56**	**0.54**
HNO3y 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**0.33**	**-0.36**	**0.32**
HNO3z 98	NS	NS	NS	NS	NS	NS	NS	NS	**-0.31**	NS	**0.31**	**-0.36**	**0.33**
HNO390 98	NS	NS	NS	NS	NS	NS	NS	NS	**-0.39**	NS	**0.66**	**-0.42**	NS
HNH4w 98	NS	NS	NS	NS	NS	**0.51**	NS	NS	NS	NS	**0.33**	**-0.48**	**0.39**
HNH4x 98	NS	NS	NS	NS	NS	**0.42**	NS	NS	NS	NS	**0.34**	**-0.41**	**0.45**
HNH4y 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**-0.43**	**0.33**
HNH4z 98	NS	NS	NS	NS	NS	**0.34**	NS	NS	NS	NS	**0.40**	**-0.39**	**0.39**

(h) 45 kg/ha 1998	ABM 98	Z 98	GY 98	SY 98	HBM 98	HI 98	GPC 98	GPY 98	SN 98	NU 98	NBAL 98	WU 98	WUE 98
ABM 98	1.00												
Z 98	NS	1.00											
GY 98	NS	NS	1.00										
SY 98	NS	NS	0.71	1.00									
HBM 98	NS	-0.30	0.85	0.96	1.00								
HI 98	NS	NS	0.56	NS	NS	1.00							
GPC 98	NS	-0.46	0.33	0.41	0.42	NS	1.00						
GPY 98	NS	-0.32	0.89	0.67	0.79	0.50	0.67	1.00					
SN 98	NS	NS	NS	0.27	NS	NS	NS	NS	1.00				
NU 98	NS	-0.34	0.65	0.79	0.80	0.06	0.55	0.70	0.62	1.00			
NBAL 98	NS	-0.25	0.40	0.33	0.37	0.16	0.36	0.45	0.34	0.55	1.00		
WU 98	NS	NS	NS	NS	NS	-0.27	NS	NS	NS	NS	-0.39	1.00	
WUE 98	NS	NS	0.83	0.51	0.66	0.55	0.28	0.76	NS	0.52	0.44	-0.71	1.00
E	NS	0.30	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
G	NS	0.37	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Kv	NS	NS	0.30	NS	NS	0.34	NS	NS	NS	NS	NS	NS	0.29
Kh	0.34	0.32	NS	NS	NS	0.33	-0.26	NS	NS	NS	NS	NS	NS
Cg	NS	-0.36	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cl	NS	-0.36	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
A d	NS	-0.29	NS	NS	NS	NS	0.44	NS	NS	NS	NS	NS	NS
Solum d	NS	NS	NS	NS	NS	NS	0.33	NS	NS	NS	NS	NS	NS
CO3 d	NS	-0.26	NS	NS	NS	NS	0.34	NS	NS	NS	NS	NS	NS
SOC (%)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SOC (Mg/ha)	NS	-0.46	NS	NS	NS	NS	0.43	0.34	NS	NS	NS	NS	NS
Ap pH	NS	NS	NS	-0.26	NS	NS	NS	NS	NS	-0.28	NS	NS	NS
ESVw 98	-0.42	-0.45	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ESVx 98	-0.32	NS	-0.38	NS	NS	-0.34	NS	-0.39	NS	NS	NS	0.49	-0.52
ESVy 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.33	NS
ESVz 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.44	-0.41
ESV120 98	-0.39	-0.26	-0.25	NS	NS	-0.25	NS	-0.27	NS	NS	NS	0.58	-0.49
MSVw 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSVx 98	NS	-0.27	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSVy 98	NS	-0.28	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSVz 98	NS	-0.33	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSV120 98	NS	-0.39	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HVw 98	-0.26	-0.54	NS	NS	NS	NS	NS	NS	NS	NS	0.29	NS	NS
HVx 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HVy 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HVz 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HV120 98	NS	-0.29	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NO3w 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.47	NS	NS
NO3x 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.44	NS	NS
NO3y 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NO3z 98	NS	NS	0.30	NS	NS	0.29	NS	0.33	NS	NS	NS	NS	NS
EPANS 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.54	NS	NS
NH4w 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NH4x 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NH4y 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NH4z 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Pw 98	NS	-0.25	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.29	NS
Px 98	NS	NS	NS	NS	NS	NS	0.31	0.26	NS	NS	NS	NS	NS
Py 98	NS	NS	NS	NS	NS	NS	0.34	NS	NS	NS	0.25	NS	NS
Pz 98	NS	NS	NS	NS	NS	NS	0.33	0.34	NS	NS	NS	NS	NS
Kw 98	NS	-0.48	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Kx 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Ky 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Kz 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sw 98	NS	-0.26	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sx 98	NS	-0.29	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sy 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sz 98	NS	-0.26	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HNO3w 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.50	NS	NS
HNO3x 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HNO3y 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HNO3z 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HNO390 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.48	NS	NS
HNH4w 98	-0.32	NS	0.25	NS	NS	NS	NS	NS	NS	NS	0.34	NS	NS
HNH4x 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HNH4y 98	NS	NS	0.31	NS	0.27	NS	NS	0.32	NS	NS	NS	NS	NS
HNH4z 98	NS	NS	0.29	NS	NS	0.26	NS	0.25	NS	NS	NS	NS	NS

(I) 90 kg/ha 1998	*ABM 98*	*Z 98*	*GY 98*	*SY 98*	*HBM 98*	*HI 98*	*GPC 98*	*GPY 98*	*SN 98*	*NU 98*	*NBAL 98*	*WU 98*	*WUE 98*
ABM 98	1.00												
Z 98	**0.35**	1.00											
GY 98	NS	NS	1.00										
SY 98	NS	NS	**0.82**	1.00									
HBM 98	NS	NS	**0.90**	**0.98**	1.00								
HI 98	NS	NS	**0.57**	NS	NS	1.00							
GPC 98	NS	NS	NS	NS	NS	**-0.28**	1.00						
GPY 98	NS	NS	**0.96**	**0.80**	**0.87**	**0.52**	NS	1.00					
SN 98	NS	NS	NS	NS	NS	NS	NS	NS	1.00				
NU 98	NS	NS	**0.78**	**0.82**	**0.83**	0.21	NS	**0.79**	**0.62**	1.00			
NBAL 98	NS	NS	**0.77**	**0.71**	**0.75**	**0.31**	NS	**0.78**	**0.36**	**0.81**	1.00		
WU 98	NS	NS	NS	**-0.26**	NS	NS	NS	NS	NS	NS	NS	1.00	
WUE 98	NS	NS	**0.90**	**0.78**	**0.83**	**0.45**	NS	**0.87**	NS	**0.69**	**0.63**	**-0.56**	1.00
E	**0.31**	**0.55**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
G	**0.26**	NS	**-0.25**	**-0.31**	**-0.33**	NS	NS	NS	NS	NS	NS	NS	NS
Kv	NS	**0.44**	NS	NS	NS	NS	**-0.34**	NS	NS	NS	NS	NS	NS
Kh	**0.32**	NS	**-0.37**	**-0.26**	**-0.30**	NS	NS	**-0.39**	NS	**-0.29**	**-0.34**	NS	**-0.33**
Cg	**-0.27**	**-0.32**	NS	NS	NS	NS	**0.31**	NS	**0.29**	NS	NS	NS	NS
Cl	NS	**-0.36**	NS	NS	NS	NS	**0.34**	NS	NS	NS	NS	NS	NS
A d	NS	**-0.48**	NS	NS	NS	NS	**0.42**	NS	NS	NS	NS	NS	NS
Solum d	NS	**-0.38**	NS	**0.26**	0.25	-0.09	**0.43**	NS	NS	NS	NS	NS	NS
CO3 d	NS	**-0.39**	NS	NS	0.22	-0.10	**0.43**	NS	NS	NS	NS	NS	NS
SOC (%)	**-0.28**	**-0.51**	NS	**0.29**	**0.28**	-0.17	**0.40**	NS	NS	NS	NS	NS	NS
SOC (Mg/ha)	NS	**-0.49**	NS	NS	NS	NS	**0.49**	NS	NS	NS	NS	NS	NS
Ap pH	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ESVw 98	**-0.33**	**-0.57**	NS	NS	NS	NS	NS	NS	NS	NS	NS	**0.39**	NS
ESVx 98	NS	NS	NS	**-0.27**	NS	NS	NS	NS	NS	NS	NS	**0.62**	**-0.33**
ESVy 98	NS	NS	**-0.27**	**-0.29**	**-0.30**	NS	NS	**-0.27**	NS	NS	NS	**0.59**	**-0.44**
ESVz 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**0.50**	**-0.25**
ESV120 98	NS	NS	NS	**-0.30**	**-0.29**	NS	NS	NS	NS	NS	NS	**0.67**	**-0.43**
MSVw 98	**-0.34**	**-0.40**	NS	NS	NS	NS	**0.46**	NS	NS	NS	NS	NS	NS
MSVx 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSVy 98	NS	NS	**-0.43**	**-0.28**	**-0.35**	**-0.38**	NS	**-0.43**	NS	**-0.38**	NS	NS	**-0.43**
MSVz 98	NS	NS	**-0.31**	NS	**-0.27**	**-0.26**	NS	**-0.33**	NS	**-0.30**	NS	NS	**-0.33**
MSV120 98	**-0.38**	**-0.30**	**-0.28**	NS	**-0.26**	NS	**0.30**	NS	NS	NS	NS	NS	**-0.26**
HVw 98	**-0.44**	**-0.39**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HVx 98	NS	NS	NS	NS	NS	NS	NS	NS	**-0.28**	NS	NS	NS	NS
HVy 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HVz 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HV120 98	**-0.34**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NO3w 98	NS	**-0.40**	NS	NS	NS	NS	**0.40**	NS	NS	NS	**-0.27**	NS	NS
NO3x 98	NS	**-0.39**	NS	NS	NS	NS	**0.27**	NS	NS	NS	NS	NS	NS
NO3y 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NO3z 98	NS	**-0.31**	**0.33**	**0.22**	**0.27**	**0.26**	NS	**0.35**	NS	**0.37**	NS	NS	**0.27**
EPANS 98	NS	**-0.44**	NS	NS	NS	NS	**0.35**	NS	NS	NS	**-0.31**	NS	NS
NH4w 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NH4x 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**-0.30**	NS	NS
NH4y 98	NS	NS	NS	NS	NS	NS	**-0.33**	NS	NS	NS	NS	NS	NS
NH4z 98	NS	**0.28**	NS	NS	NS	NS	**-0.33**	NS	**-0.27**	**-0.33**	NS	NS	NS
Pw 98	NS	**-0.41**	**-0.28**	NS	NS	NS	**0.44**	NS	NS	NS	**-0.26**	NS	**-0.28**
Px 98	NS	**-0.39**	NS	NS	NS	NS	**0.26**	NS	NS	NS	NS	NS	NS
Py 98	NS	**-0.33**	**0.28**	**0.29**	**0.31**	NS	**0.44**	**0.38**	NS	**0.38**	**0.26**	NS	NS
Pz 98	NS	**-0.45**	NS	NS	NS	NS	**0.35**	NS	NS	**0.27**	NS	NS	NS
Kw 98	NS	**-0.51**	NS	NS	NS	NS	**0.28**	NS	NS	NS	NS	NS	NS
Kx 98	NS	**-0.29**	NS	NS	NS	NS	NS	NS	NS	NS	NS	**0.26**	NS
Ky 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Kz 98	NS	**0.26**	NS	NS	NS	NS	**-0.28**	NS	NS	NS	NS	NS	NS
Sw 98	NS	**-0.40**	NS	**0.26**	**0.27**	NS	NS	NS	NS	NS	NS	NS	NS
Sx 98	NS	**-0.34**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sy 98	**-0.32**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sz 98	**-0.30**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HNO3w 98	NS	NS	**0.35**	**0.37**	**0.38**	NS	**0.27**	**0.42**	**0.30**	**0.46**	**0.48**	NS	**0.26**
HNO3x 98	NS	NS	**0.52**	**0.40**	**0.45**	**0.37**	NS	**0.53**	NS	**0.43**	**0.46**	NS	**0.41**
HNO3y 98	NS	NS	**0.38**	**0.42**	**0.42**	NS	NS	**0.42**	NS	**0.44**	**0.41**	NS	**0.31**
HNO3z 98	NS	NS	**0.26**	**0.33**	**0.32**	NS	NS	**0.30**	NS	**0.30**	NS	NS	**0.27**
HNO390 98	NS	NS	**0.45**	**0.43**	**0.45**	NS	NS	**0.49**	**0.26**	**0.50**	**0.53**	NS	**0.34**
HNH4w 98	NS	NS	**0.34**	**0.42**	**0.43**	NS	NS	**0.31**	**0.28**	**0.41**	**0.40**	NS	NS
HNH4x 98	NS	NS	**0.32**	**0.38**	**0.39**	NS	NS	**0.37**	NS	**0.28**	**0.34**	NS	**0.28**
HNH4y 98	NS	**0.27**	**0.32**	**0.31**	**0.34**	NS	NS	**0.31**	NS	**0.28**	**0.31**	NS	**0.29**
HNH4z 98	NS	**0.26**	**0.31**	NS	**0.28**	NS	NS	**0.26**	NS	NS	NS	NS	**0.31**

(J) 135kg/ha 1998	ABM 98	Z 98	GY 98	SY 98	HBM 98	HI 98	GPC 98	GPY 98	SN 98	NU 98	NBAL 98	WU 98	WUE 98
ABM 98	1.00												
Z 98	0.57	1.00											
GY 98	NS	NS	1.00										
SY 98	NS	NS	0.51	1.00									
HBM 98	NS	NS	0.76	0.93	1.00								
HI 98	NS	NS	0.44	NS	NS	1.00							
GPC 98	NS	NS	NS	NS	NS	NS	1.00						
GPY 98	NS	NS	0.91	0.56	0.77	NS	NS	1.00					
SN 98	NS	NS	NS	NS	NS	NS	NS	NS	1.00				
NU 98	NS	NS	0.48	NS	NS	NS	0.43	0.62	0.73	1.00			
NBAL 98	0.44	NS	NS	NS	NS	NS	NS	NS	NS	NS	1.00		
WU 98	-0.43	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.47	1.00	
WUE 98	NS	NS	0.54	NS	0.51	0.24	NS	0.46	NS	NS	0.51	-0.93	1.00
E	NS	0.78	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
G	NS	0.39	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Kv	NS	0.63	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Kh	NS	0.54	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cg	NS	-0.75	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cl	NS	-0.75	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
A d	NS	-0.63	NS	NS	NS	NS	0.45	NS	NS	NS	NS	NS	NS
Solum d	-0.54	-0.52	NS	NS	NS	NS	NS	NS	NS	NS	-0.45	0.46	-0.48
CO3 d	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SOC (%)	NS	-0.61	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SOC (Mg/ha)	NS	-0.58	NS	NS	NS	NS	0.43	NS	NS	NS	NS	NS	NS
Ap pH	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ESVw 98	-0.70	-0.62	NS	NS	NS	NS	NS	NS	NS	NS	-0.45	0.50	-0.50
ESVx 98	-0.55	-0.47	NS	-0.43	-0.43	NS	NS	NS	NS	NS	-0.54	0.77	-0.74
ESVy 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.64	-0.58
ESVz 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.48	-0.47
ESV120 98	-0.58	-0.53	NS	NS	-0.43	NS	NS	NS	NS	NS	-0.47	0.83	-0.81
MSVw 98	NS	-0.74	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSVx 98	NS	NS	NS	NS	NS	NS	NS	NS	0.44	NS	NS	NS	NS
MSVy 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSVz 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MSV120 98	NS	-0.50	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HVw 98	-0.53	-0.48	-0.45	-0.48	-0.53	NS	NS	NS	NS	NS	NS	NS	-0.43
HVx 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HVy 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HVz 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HV120 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NO3w 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.49	NS	NS
NO3x 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NO3y 98	-0.55	-0.50	NS	NS	NS	NS	NS	NS	NS	NS	-0.63	0.70	-0.69
NO3z 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
EPANS 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	-0.66	NS	NS
NH4w 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.66	-0.59
NH4x 98	-0.47	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
NH4y 98	NS	NS	NS	NS	NS	0.45	-0.45	NS	NS	NS	NS	NS	NS
NH4z 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Pw 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Px 98	NS	-0.44	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Py 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Pz 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Kw 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Kx 98	NS	-0.46	NS	NS	NS	NS	NS	NS	0.51	NS	NS	NS	NS
Ky 98	NS	NS	NS	NS	NS	NS	-0.54	NS	NS	NS	NS	NS	NS
Kz 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.43	NS	NS	NS
Sw 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sx 98	NS	-0.51	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.45	NS
Sy 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sz 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HNO3w 98	NS	NS	NS	NS	NS	NS	0.55	NS	NS	NS	0.47	NS	NS
HNO3x 98	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HNO3y 98	NS	NS	0.49	NS	NS	NS	NS	0.48	NS	NS	NS	-0.63	0.69
HNO3z 98	NS	NS	0.50	NS	0.51	NS	NS	0.59	NS	NS	NS	-0.46	0.50
HNO390 98	NS	NS	NS	NS	NS	NS	0.45	NS	NS	NS	0.52	-0.51	0.49
HNH4w 98	NS	0.56	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HNH4x 98	NS	0.69	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HNH4y 98	NS	0.71	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
HNH4z 98	NS	0.80	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

5.4.2 Grain Yield, Straw Yield and Harvest Index

Across LECs, median 1997 *GY* values ranged from 1640 kg/ha in the check treatment to 2405 kg/ha in the 135 kg/ha N treatment in 1997, and correspondingly, 1518 to 2954 kg/ha in 1998 (Table 5.3). Across and within LECs, *GY* increased with N addition to at least 135 kg/ha in both 1997 and 1998, almost without exception. More dramatic responses were observed in 1998 due to the aforementioned differences in N supply and growing season conditions.

Table 5.3 Median values of grain yield, straw yield and harvest index, across and within LECs.

			LEC			
Year	Attribute	N Rate (kg/ha)	Overall	U	M	L
1997	Grain (kg/ha)	0	1640	1645a[1]	1598a	1834a
	Straw (kg/ha)		2437	2451a	2366a	2641a
	HI		0.38	0.37a	0.38a	0.37a
	Grain (kg/ha)	45	2142	2103a	2156a	2214a
	Straw (kg/ha)		3192	3092a	3230a	3738b
	HI		0.37	0.38b	0.37ab	0.36a
	Grain (kg/ha)	90	2267	2038a	2188a	2478b
	Straw (kg/ha)		3563	3429a	3482a	4009b
	HI		0.36	0.34a	0.36a	0.36a
	Grain (kg/ha)	135	2405	2237a	2406a	2345a
	Straw (kg/ha)		3648	3387a	3544a	3985b
	HI		0.35	0.37ab	0.36b	0.34a
1998	Grain (kg/ha)	0	1518	1581a	1532a	1453a
	Straw (kg/ha)		3099	3040a	3187a	3078a
	HI		0.31	0.32b	0.31b	0.29a
	Grain (kg/ha)	45	2241	2419b	2259b	2122a
	Straw (kg/ha)		4327	4391b	4358b	3945a
	HI		0.32	0.32a	0.31a	0.32a
	Grain (kg/ha)	90	2534	2784b	2619b	2378a
	Straw (kg/ha)		5106	5225ab	5118b	4342a
	HI		0.30	0.32a	0.30a	0.30a
	Grain (kg/ha)	135	2954	3023a	2954a	2861a
	Straw (kg/ha)		5348	5235ab	5520b	5151a
	HI		0.32	0.33a	0.32a	0.33a

[1] Median values followed by the same letter are not significantly different between LECs at $\alpha=0.20$ (Kruskal-Wallis multiple comparison procedure).

Within N treatments in 1997, *GY* generally increased with convergent landscape character. In 1998, *GY* was least in the L and highest in the U. While most differences between LECs were not significant, the L most frequently emerged as statistically unique. Greater *GY* in the more convergent L in 1997 was most likely due to acquisition of redistributed soil moisture in a moisture-deficient growing season. In contrast, lower *GY* values in the L in 1998 were most likely due to excess moisture. Wetter conditions in the L also coincided with higher weed densities (*Avena fatua* and *Galeopsis tetrahit*). In contour maps of grain yield, the landscape effect was relatively more apparent in 1997 than in 1998, and the N effect was more apparent in 1998 than in 1997 (Figures 5.2, 5.3). The effect of moisture redistribution on yield was more apparent under the moisture deficient conditions of 1997. In 1998, N fertility was relatively more influential for yield than moisture redistribution, due to the abundance of moisture.

Others have observed depressed *GY* and high weed pressure in convergent landscape positions, in years of excess moisture (Wibawa et al., 1993). One might exclude these data points under the premise that weeds might otherwise be eliminated and are not to be considered an integral component of soil-landscape influences on yield. However, it is difficult to assume that elevated weed densities are the only influence. Yields may have been depressed due to periodic anaerobic root zone conditions, pathogen pressures, physical, chemical or microbiological losses of plant-available N, or any number of nutrient interactions and deficiencies, all of which are integral to the soil-landscape microenvironment and are difficult to account for. In an empirical study, it is imperative that any such influences be considered integral to the soil-landscape unless they may typically be eliminated by economically feasible management practices. Points with relatively high weed densities were therefore included in the above comparisons and in subsequent yield models. Regardless, if selected sampling points with significant weed pressure had been excluded in 1997 and 1998, absolute increases in median grain yield values would have been less than 5% (data not shown), and relative yield rankings among N treatments and LECs would not have changed.

The influence of *EPANS* was relatively greater than that of the landscape on *GY* in both 1997 and 1998. Within each N treatment, the median yields in the lowest yielding LEC were of 82 to 95% of the median yields observed in the highest yielding LEC in 1997, and 85 to 95% in 1998. Within LECs in 1997, the median check yields were 74, 66 and 74% of the highest median *GY* values occurring with N addition, in the U, M and L, respectively. In 1998, corresponding values of 52, 52 and 51% were observed, when the median check yield was expressed as a percentage of the median *GY* at 135 kg/ha. In both 1997 and 1998, the absolute differences between U and L median *GY* values were greatest within the 90 kg/ha treatment.

SY followed trends that were similar to *GY* with respect to response to N fertilizer and differences among LECs (Table 5.3). *SY* response to applied N was more dramatic in 1998 than in 1997. Over all LECs, median 1997 *SY* values ranged from 2437 kg/ha in the check strip to 3648 kg/ha in the 135 kg/ha treatment, and correspondingly, 3099 and 5348 kg/ha in 1998. *SY* generally increased with convergent landscape character in 1997, and increased with divergent character in 1998.

The median harvest index (*HI*) within all LECs and N treatments was higher in 1997, indicating that a higher ratio of straw to grain was produced in the wetter year of 1998 (Table 5.3). There was a general but inconsistent tendency for the *HI* to decrease in moving from the U to the L within each N rate in both seasons. Among N rates, *HI* steadily decreased with increasing N rate in the M and L in 1997. While not consistently affected by N rate in 1998, *HI* was always highest in the 135 kg/ha treatment. In general, *HI* values varied only slightly and did not provide much additional insight into production differences among LECs.

Correlations indicated that within N rates, 1997 *GY* and *SY* were directly proportional to the extent of convergent character in the landscape and accordingly, proportional to measures of *V* (r^2=0.26 to 0.67) (Table 5.2). In 1998, correlations with indices of convergence and soil profile development were inconsistent and occurred less frequently. However, all significant correlations between *GY* and *SY* and measures of *V* were negative (r^2=-0.25 to -0.54) within N fertilizer treatments. Over all N treatments, both *GY* and *SY* were moderately to strongly proportional to *EPANS* in 1997 (r^2=0.58 and 0.65) and 1998 (r^2=0.68 and 0.69). This provided additional evidence that yields were likely limited by moisture deficiency in 1997, moisture excess in 1998, and that yields were influenced considerably by the range of N fertilizer treatments in both seasons.

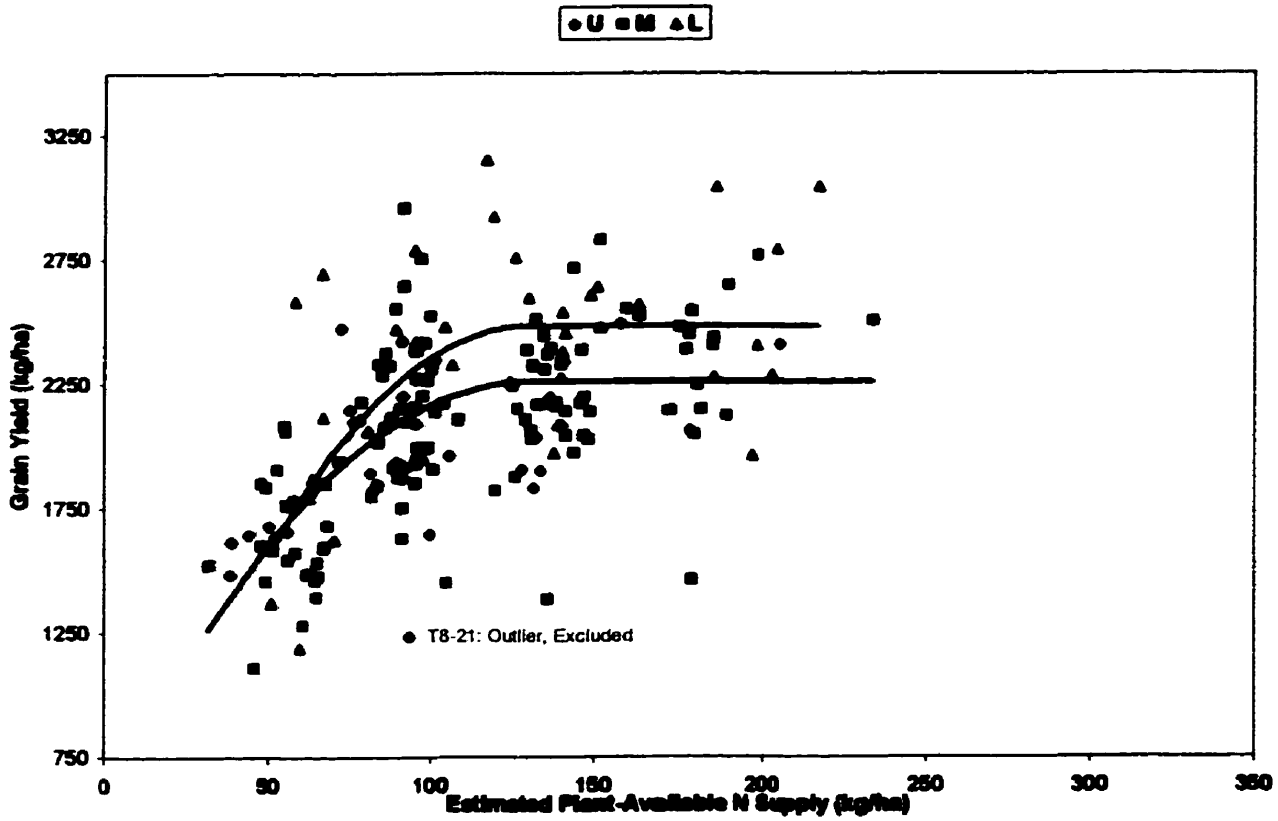
5.4.4 Grain Yield Modeled as a Function of *EPANS*

GY was modeled as a function of *EPANS* in each LEC for both growing seasons. Cerrato and Blackmer (1990) found that a 'quadratic-plus-plateau' regression model worked well for grain yield prediction over a range of N treatments. This model was applied to the data to define the N supply rate at the productive maxima. The model was defined by equations [1] and [2] where *Y* was grain yield (kg/ha), *X* was *EPANS* (kg/ha), *a* was the intercept, *b* was the linear coefficient, and *c* the quadratic coefficient. The critical rate of N supply (*C*), occurring at the intersection of the quadratic response and plateau lines, and plateau yield (*P*) values were (*P*) obtained by fitting the model to the data. Soil nitrate to 90 cm (NO_3 *90*) and fertilizer N sources were considered to be equally available, and no predictions of mineralization were incorporated into the model.

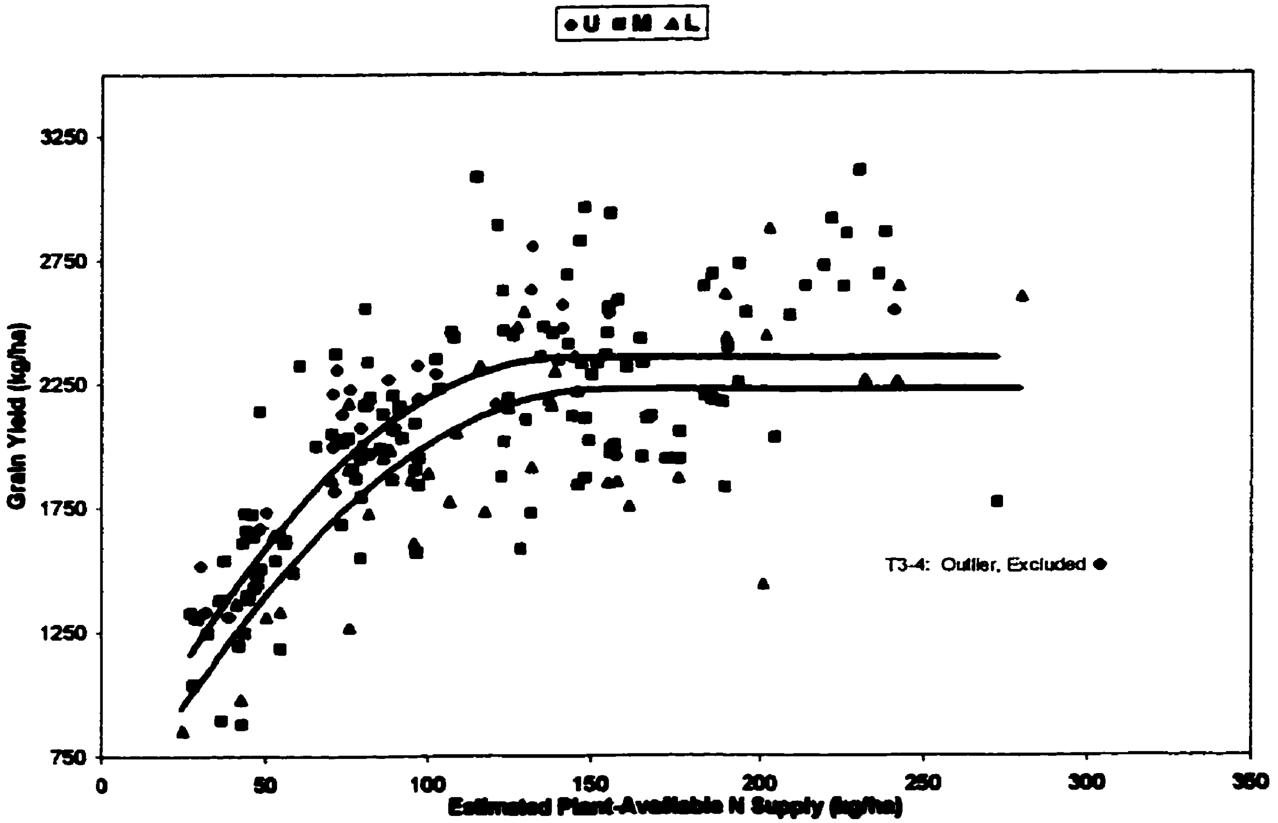
[1] $Y = a + bX + cX^2 \text{ if } X < C$
[2] $Y = P \text{ if } X \geq C$

Unlike rank-based statistics, such parametric procedures are more easily influenced by outliers. Outliers were detected using a procedure by Snedecor and Cochran (1989), in which a point was rejected if its residual exceeded a calculated 'maximum normal residual' at $\alpha=0.05$. One outlier was excluded from the U in each year, as indicated in Figure 5.4.

The most obvious difference between the two growing seasons was the reversal of the relative ranking of yield potential by LEC (Figure 5.4). The relative rank of yield potential among LECs was also apparent in comparisons of median *GY* values among N treatments (Table 5.3). In addition, a wider range of grain yields was apparent in 1998 due to the increased disparity between the N-depleted check and the well-supplied 135 kg/ha treatment. In 1997, the modeled maximum (plateau) yields in the U, M and L were



(a) 1997



(b) 1998

Figure 5.4 Quadratic-plus-plateau modeled yield response to *EPANS* by LEC

2077, 2261, and 2485 kg/ha, respectively (Table 5.4). The corresponding *EPANS* values at the modeled maxima were 89, 130 and 130 kg/ha. In 1998, modeled maximum yields of 2501, 2355 and 2227 kg/ha were observed in the U, M and L. The corresponding *EPANS* values at the modeled maxima were 146, 142 and 154 kg/ha. A procedure outlined in Mead et al. (1993) was used to determine if the individual LEC models resulted in a significant reduction in the residual sum of squares from that of a single model, within each growing season. At α=0.05, it was determined that only a separate L model was statistically valid in both 1997 and 1998.

Table 5.4 Quadratic-plus-plateau model coefficients within individual LECs.

		Model Coefficient					
Year	LEC	a	b	c	P (kg/ha)	C (kg/ha)	r^2
1997	U	269	40.6	-0.23	2077	89	0.42
	M	515	26.8	-0.10	2261	130	0.38
	L	22	38.0	-0.15	2485	130	0.36
1998	U	564	26.5	-0.09	2501	146	0.77
	M	522	25.8	-0.09	2355	142	0.57
	L	392	23.9	-0.08	2227	154	0.59

Coefficients of determination were strongest in 1998. The higher amount of *GY* variation explained by *EPANS* in 1998 suggests that N was more limiting to *GY* in all LECs in 1998, relative to other yield determinants (e.g., water), than in 1997. Also in 1998, the coefficient of determination in the U was considerably higher (r^2=0.77) than for the other LECs, indicating that *GY* dependence on *EPANS* may have been reduced in the M and L due to excessive moisture.

The slope of a yield response equation may be determined by its first derivative. Since *c* is a negative fractional number, the maximum response to plant-available N occurs when the supply of N=0; the *b* coefficient at N=0 represents the change in yield from the first increment of plant-available N. In an N deficient soil, the value of *b* will be positive and represents the maximum N use efficiency under the conditions at a particular site (Kachanoski et al., 1985). In modeling yield as a function of fertilizer N, the authors were not required to extrapolate when specifying that N=0. To perform a similar comparison on this data, N was set to 40 kg/ha to reduce the number of predictions made outside the range of observations. Modeled responses of 22.2, 18.8 and 26 kg grain/kg N were calculated in the U, M and L for 1997, and corresponding responses of 19.3, 18.6 and 17.5 kg grain/kg N for 1998. The values are comparable to the maximum efficiency of 25 kg grain for the first increment of fertilizer N suggested by Henry et al. (1986). Overall 'average' responses were calculated by determining the yield increase per unit of N between *EPANS* = 40 kg/ha and *C*. Ranking among LECs was the same as instantaneous responses; in 1997, average responses of 11.2, 9.3 and 13.1 kg grain/kg N were observed in the U, M and L, and correspondingly, 9.6, 9.3 and 8.8 kg grain/kg N in 1998.

Grain yield responses to N fertilizer are greatly influenced by soil moisture. Kachanoski et al. (1985) found that maximum fertilizer use efficiency (*b*) was consistently higher on lower slopes despite the characteristically greater fertility in the lower slope positions, due to increased amounts of soil moisture. Hence, under the moisture-deficient conditions of 1997, the greater response to additional N in the more moist, convergent L was expected. In 1998, it is likely that moisture supply was adequate to excessive across the landscape, net availability of N to the growing crop was reasonably constant, and therefore similar yield responses to N were observed among LECs.

Inaccurate assessment of soil N supply due to net gains by mineralization, or net losses to denitrification, leaching or immobilization, will affect calculation of N response in the landscape. Fiez et al. (1995) observed that overall nitrogen use efficiency was significantly reduced with unaccounted for losses of N.

Yield model selection is an additional source of variability. Cerrato and Blackmer (1990) demonstrated that model selection could result in different responses and dramatically different economic optima, calculated from the same data set. In order to successfully treat individual LECs as separate management units for the application of N fertilizer, differences in yield response curves among LECs must outweigh all sources of inaccuracy in prediction of yield response within LECs.

5.4.3 Grain Protein Concentration, Grain Protein Yield, and Total N Uptake

GPC can have a significant impact on the economic returns for spring wheat production, and the relationship between GPC and landscape is important to investigate and understand.

In 1997, *GPC*, grain protein yield (*GPY*) and total grain plus straw N (*NU*) increased with N rate within each LEC, with the exception of the L, in which there was a small reduction in median *GPC* with the addition of 45 kg N/ha (Table 5.5). In that year, *GPC* was generally lowest in the L within each N treatment. The general landscape effect in which *GPC* decreased with convergent character was likely due to proportionally more grain yield produced in the L relative to the available N supply, resulting in the dilution of N in a greater pool of grain biomass. Within the L, the slight reduction in median *GPC* at 45 kg/ha was likely due to greater assimilation of grain yield relative to *GPY* with the addition of the first increments of N fertilizer (Grant et al., 1985; Campbell et al., 1997). *GPY* was generally similar among LECs within N rates, but was significantly higher in the L than in other LECs at the 90 kg/ha rate. *NU* was not significantly different among LECs. However, *GPY* and *NU* were influenced greatly by the range of N treatments. While N treatments had the largest role in determining *GPC*, the net result was regulated somewhat by the landscape, most likely due to the influence of moisture redistribution on grain yield. In contour maps of *GPC*, both the treatment and landscape effects were detectable (Figure 5.2).

In 1998, *GPC*, *GPY* and *NU* again increased with N applied within each LEC. *GPC* varied little among LECs within N treatments, and no significant differences were observed. *GPY* and *NU* varied only slightly among LECs, but differences which were significant in the 45 and 90 kg/ha treatments indicated that the L *GPY* and *NU* values were lower. Combined with lower observed median *GY* values in the L than in the U and M, this resulted in relatively consistent *GPC* values among LECs within all N treatments in 1998. The higher check yield in the U, coupled with the essentially uniform *GPY* and the greater *GY*, resulted in the lowest observed *GPC* of 12.5% (even though it was not significantly lower from the other LECs). Treatment effects were more apparent than landscape effects in a contour map of *GPC* (Figure 5.3).

Table 5.5 Median values of grain protein concentration, grain protein yield and total nitrogen uptake across and within LECs.

Year	Attribute	N Rate (kg/ha)	LEC			
			Overall	U	M	L
1997	*GPC*[1](%)	0	12.3	13.0b[2]	12.1a	12.7ab
	GPY(kg/ha)		210	213a	203a	222a
	NU(kg/ha)		53	53a	51a	53a
	GPC[1](%)	45	13.5	13.6b	13.5b	12.4a
	GPY(kg/ha)		285	282a	287a	288a
	NU(kg/ha)		74	73a	74a	74a
	GPC[1](%)	90	15.4	15.9b	15.7b	14.3a
	GPY(kg/ha)		335	312a	336ab	357b
	NU(kg/ha)		89	85a	87a	93a
	GPC[1](%)	135	16.4	16.2ab	16.5b	15.5a
	GPY(kg/ha)		371	354a	392a	357a
	NU(kg/ha)		100	87a	101a	99a
1998	*GPC*[1](%)	0	13.0	12.5a	13.0a	13.3a
	GPY(kg/ha)		198	198a	198a	195a
	NU(kg/ha)		53	51a	53a	55a
	GPC[1](%)	45	14.0	13.9a	14.0a	13.8a
	GPY(kg/ha)		316	334b	313ab	296a
	NU(kg/ha)		82	86b	82b	77a
	GPC[1](%)	90	15.8	15.4a	15.8a	15.8a
	GPY(kg/ha)		393	427b	412b	356a
	NU(kg/ha)		118	112ab	121b	97a
	GPC[1](%)	135	15.6	15.8a	15.6a	15.6a
	GPY(kg/ha)		461	476a	464a	442a
	NU(kg/ha)		143	143a	143a	141a

[1] GPC determined from grain N % x 5.7, adjusted to a grain moisture concentration of 13.5%.

[2] Median values followed by the same letter are not significantly different between LECs at α=0.20 (Kruskal-Wallis multiple comparison procedure).

Over all N rates, *GPC, GPY* and *NU* were strongly correlated with *EPANS* (r^2= 0.75, 0.79 and 0.82) in 1997 and 1998 (r^2= 0.75, 0.77 and 0.82) (Table 5.2). Within N treatments in 1997, significant correlations indicated that *GPC* was generally inversely related to convergent landscape character, solum development and soil moisture. Alternatively, *GPY* and *NU* were generally directly proportional to more moist, convergent landscape character in 1997. Specifically, *GPC* tended to be significantly and positively related to relative elevation, but significant correlations with soil profile descriptors (A horizon, solum thickness) and measures of *SOC* were inconsistent in direction in 1997. This may have indicated a landscape-based influence that was not reflected by segregation into treatments alone. Within N treatments in 1998, *GPC, GPY* and *NU* correlations were infrequent and somewhat inconsistent. *GPC* was most often proportional to moist, convergent character in the landscape, opposite to the trend observed in 1997.

In 1997, *GPC* was inversely correlated with grain yield within N treatments, although coefficients were significant only for the 90 and 135 kg/ha treatments (r^2= -0.32 and -0.63). Across N treatments, *GPC* and *GY* were significantly and positively correlated (r^2= 0.31). McKercher (1964) (and several authors since) observed negative correlations between *GPC* and *GY* at a uniform N supply level. McKercher also observed the influence of microclimatic characteristics of a soil profile type on *GPC*. *GPC* values of wheat grown on locally humid Solonetzic and Gleysolic soils in more convergent portions of toposequences were approximately 3% lower than that of wheat grown on more arid genetic soil types.

In 1998, *GPC* and *GY* were significantly correlated in the 45 kg/ha treatment only, and positively so (r^2= 0.33). There was no apparent relationship in the other treatments. Across N treatments, *GPC* and *GY* were again significantly and positively related (r^2= 0.60). The typical inverse relationship between *GPC* and *GY* (at a given N supply rate) did not manifest itself under conditions which were not moisture deficient. It is possible that in 1998, higher potential N losses detected in the L (described in a previous manuscript), coupled with the lower yields in the L, resulted in low variation in GPC values between LECs.

Protein content in winter wheat has itself been successfully used as an indicator of N fertilizer sufficiency (Goos et al., 1982). In Manitoba, a critical *GPC* of 13.5% has been established for red spring wheat (Flaten and Racz, 1997). Below this critical level, economic yield is sacrificed due to inadequate nitrogen fertility. In 1997, the more arid U required the least amount of applied N to surpass the critical *GPC* (Table 5.5). In 1998, *GPC* appeared to increase uniformly with N applied across all LECs, suggesting some uniform rate across LECs would suffice.

5.4.5 Water Use, Water Use Efficiency, and Moisture Deficits

Modeled yield responses to N fertilizer within LECs, upon which calculations of economic optima may be performed, varied considerably from 1997 to 1998. The optimum N requirement is largely determined by the soil and crop microclimate over the course of the growing season. The dynamic combination of moisture and temperature largely determines the size of the N sink in the growing crop, along with mineralization, losses, redistribution and accessibility of N. Moisture regimes were grossly different from 1997 to 1998, and both were quite different from the long-term average.

Historical growing season precipitation at the site is estimated at 21.0 cm with a standard deviation of 7.8 cm. The site was approximately equidistant between Hamiota and Birtle, and these statistics are averages of those for each location, as presented by Ash (1991). In 1997, growing season precipitation from the time of seeding to August 15 was 13.2 cm, and in 1998, 33.1 cm. 1997 precipitation was 37% lower than the long term average, whereas 1998 precipitation was 62% above average, and 150% greater than that of 1997. Assuming historical growing season precipitation is normally distributed, the risk of a year like 1997 or drier was estimated to be 16%. The risk of a year like 1998 or wetter was estimated to be 6%. This indicated that there is a greater chance that a dry year will occur than a wet year.

Water use (*WU*) was calculated as the sum of growing season precipitation and spring volumetric soil moisture to 120 cm, minus fall volumetric soil moisture to 120 cm (Steppuhn and Zentner, 1986). In both years, lateral redistribution was not fully accounted for, resulting in underestimated differences in water use among LECs. In 1998, there was the potential for deep leaching, which likely resulted in overestimates of water use. In 1997, *WU* did not vary consistently among LECs within N treatments (Table 5.6). In 1998, *WU* generally increased with convergent landscape character. Due to higher precipitation in 1998, *WU* was higher than 1997. There were no readily apparent *WU* trends over the range of N treatments in 1997, and *WU* was not significantly correlated with *EPANS*. However, *WU* and *EPANS* were significantly correlated in 1998 (r^2= 0.35), suggesting that more water was used at higher N rates (Table 5.2). Also, the highest median *WU* value in the L occurred at the 135 kg/ha rate (Table 5.6). Excluding the check treatment, the absolute yield difference between the highest-yielding U and L was least for the 135 kg/ha N rate in 1998. It is possible that the higher available N indirectly improved aeration and resultant yields in the L by promoting use of excess moisture. Under the moisture-deficient conditions of 1997, *WU* and *GY* were positively and significantly correlated when N was least limiting (r^2= 0.60) at the 135 kg/ha rate. In 1998, *WU* and *GY* were not significantly correlated within any one N treatment.

Table 5.6 Median values of water use, water use efficiency and water deficits across and within LECs.

Year	Attribute	N Rate (kg/ha)	LEC			
			Overall	U	M	L
1997	*WU*[1](cm)	0	22	21a[3]	22.6b	20.9ab
	WUE(kg/mm)		7.7	8.1a	7.3a	8.5a
	WD[2](cm)		-9.5	-10.5	-8.9	-10.6
	WU(cm)	45	21.5	20.9a	21.4a	23.4b
	WUE(kg/mm)		10	10a	10a	9.6a
	WD(cm)		-10	-10.6	-10.1	-8.1
	WU(cm)	90	20.9	24.5b	20.5a	21.3ab
	WUE(kg/mm)		10.8	9.5a	11.4b	11.8b
	WD(cm)		-10.6	-7	-11	-10.2
	WU(cm)	135	20.8	23.5ab	22.8b	18a
	WUE(kg/mm)		10.8	9.6a	10.3a	13.6b
	WD(cm)		-10.7	-8	-8.7	-13.5
1998	*WU*(cm)	0	30.8	28.7a	30.7a	34.6b
	WUE(kg/mm)		4.8	5.5b	4.9b	4.1a
	WD(cm)		1.3	-0.8	1.2	5.1
	WU(cm)	45	32.5	33.3a	31.9a	33.7a
	WUE(kg/mm)		7	6.9a	7.1a	6.3a
	WD(cm)		3	3.8	2.4	4.2
	WU(cm)	90	34.2	33.6a	34.2ab	35.7b
	WUE(kg/mm)		7.2	8.1b	7.3b	6.9a
	WD(cm)		4.7	4.1	4.7	6.2
	WU(cm)	135	34.7	31.6a	33.2a	39.4b
	WUE(kg/mm)		8.4	9.8b	8.7b	7.2a
	WD(cm)		5.2	2.1	3.7	9.9

[1] *WU* = [(precipitation + spring volumetric soil moisture to 120 cm) – (fall volumetric soil moisture to 120 cm)] (Steppuhn and Zentner, 1986)

[2] *WD* = *WU* – 31.5 cm (1997); *WU* – 29.5 cm (1998) (Raddatz, unpublished data).

[3] Median values followed by the same letter are not significantly different between LECs at α=0.20 (Kruskal-Wallis multiple comparison procedure).

Water use efficiency (*WUE*) was calculated as the amount of grain yield production per unit of water used, expressed here as kg grain/mm water (Table 5.6). *WUE* increased over the range of N treatments in 1997 and 1998, and was positively correlated with *EPANS* in both years (r^2=0.53 and 0.51, respectively)(Table 5.2). This was due mostly to the effect of N on yield in 1997, as *WU* did not vary with *EPANS*. *WUE* tended to increase from the U to the L in 1997, in the 90 and 135 kg/ha treatments, and decreased with convergent character within all N treatments in 1998. This reflected a greater yield increase with high N supply as convergent character increased in 1997. In 1998, it indicated that the amount of excess moisture, that was not of use for yield production or lowered production, increased with convergent character. Across the landscape, *WUE* values were higher in 1997, most likely due to overestimates of water use in 1998. Under the moisture-deficient conditions in 1997, in treatments where N was least limiting (within the 135 kg/ha treatment), the overall calculated *WUE* of 10.8 kg grain/mm *WU* was consistent with the value of 10.1 kg wheat/mm *WU* reported by Campbell et al. (1988b).

At the soft dough stage, historical moisture stress at the site is estimated at -3.1 cm with a standard deviation of 3.8 cm. Season-long moisture stress values for 1997 and 1998 were –5.5 and –1.3 cm respectively, at Virden, Manitoba (Raddatz, unpublished data). Total evaporative demand estimates (also from Virden) were 31.5 and 29.5 cm in 1997 and 1998. Site-specific water deficits (*WD*) were calculated for each LEC in each growing season by subtracting moisture use from total evaporative demand (Table 5.6). *WD* estimates were obviously subject to the same limitations as the *WU* calculation. *WD* was lower (less negative) in 1998, and within 1998, decreased with convergent landscape character. As for *WU* in 1997, no consistent landscape *WD* trend was evident.

While the relative distribution of soil moisture among LECs was shown to be consistent from year to year and varied systematically with temporally stable soil-landscape properties, the difference in moisture regimes between 1997 and 1998 was large. Due to the differences in absolute amounts of soil moisture, its relative distribution had very different implications for productivity in 1997 than in 1998, within LECs. Modeled yield responses to N fertilizer within LECs were very different from 1997 to 1998, such that

LEC-specific N management in 1998 based on observed 1997 responses would have been sub-optimal. Others have noted similar instability in productivity in a given area of a field from one year to the next due to changes in growing season conditions (Ciha, 1984; Wibawa et al., 1993). Hence, the gross variability in modeled yield response to N fertilizer within spatially fixed management units must therefore not only be sufficiently different among spatially homogenous LECs within a growing season to justify variable rate N application, but they must also be sufficiently *temporally* stable. Obviously, identical growing conditions from one growing season to the next cannot be expected. 'Sufficient' temporal stability infers that, based on probabilistic occurrence of growing season conditions, there is a typical modeled response to N fertilizer within each LEC which is more suitable (i.e., more efficient and profitable) than a single uniform rate for the entire field, over time. While risk may be reduced by assessing stored soil moisture, spring residual soil N and with predictions of net N mineralization, the necessary probabilistic information may only be obtained with long-term, empirical study. Based on precipitation data, growing season conditions in 1997 were more similar to the long-term average than those in 1998. History indicates that moisture-deficient conditions are most probable at this location, and therefore the effect of landscape redistribution of moisture on yield should most often manifest itself in the same way it did in 1997. Moisture conditions experienced in 1998 were aberrant. As a result, if one needed to rely on short-term information, the observed responses in 1997 would be superior to those obtained in 1998 for subsequent calculations of economic optima within LECs.

Variable applications geared to typical responses must be more profitable, considered in composite over the entire field, than a conventional whole-field fertilizer application. To this end, the areal percentage of the field occupied by each LEC may be as critical as the magnitude of any difference in yield response among LECs in any comparison of productive or economic benefits stemming from VRF. The U and the L behaved most differently in both growing seasons, but accounted for only 27 and 19% of the surveyed site area, respectively. The M, accounting for the remaining 54% of the site area, was virtually constant from 1997 to 1998 with respect to model coefficients, yield potential, and calculations of yield response. The remainder of the 65 ha field was not delineated into LECs, but Figure 3.2 suggests that the L would occupy a much greater areal percentage of the whole field than it does in the site, and that the U may occupy the lowest areal percentage overall. The greater area occupied by the L is important, as the modeled yield responses were significantly different only within the L in both years.

The uncertainty associated with crop prices and protein premiums adds to the challenge of variable rate N application. While the price of N is established at the time of fertilization, the price of wheat is not. As a result, 'characteristic' yield response to N must not only be sufficiently different among management units to account for productive variation among seasons, they must also be sufficiently large to justify variable-rate N application over a reasonable range of fertilizer:grain price ratios. Relevant prices must also include the value of protein premiums, which strongly affect predicted economic optima for N application in spring wheat. Protein premiums are not currently known within the window of fertilization of a wheat crop.

5.5 Summary and Conclusions

In both 1997 and 1998, median ABM values increased with N applied in each LEC. In 1998, the response to N was more diverse due to a greater supply of moisture, in addition to a divergence in the range of available N from the 0 to the 135 kg/ha treatments. While

ABM generally increased with convergent character within N rates in 1997, they decreased in 1998. *GY* and *SY* followed similar trends to that of *ABM*. The greater 1997 *GY*, *SY* and ABM values in the L were attributable to the greater soil moisture supply in this LEC in 1997. In 1998, *GY*, *SY* and ABM in the L were inhibited by excess moisture. In 1997, *GPC* increased with N fertilizer supplied in all LECs, and generally decreased with convergent character in the landscape. 1997 *GPC* was inversely correlated with grain yield, and the lower *GPC* in the L was attributed to dilution of assimilated grain protein in a larger pool of grain biomass. In 1998, *GPC* again responded strongly to applied N, but varied little among LECs. This may have been attributable to the fact that lower yields in the L paralleled greater potential losses of N within the excessively wet L. In each year, *GY*, *GPC* and *GPY* differences between the check and 135 kg/ha N treatments were larger than those among LECs. *GY* was predicted with a quadratic-plus-plateau model (Cerrato and Blackmer, 1990). Modeled 1997 *GY* maxima were 2077, 2261 and 2485 kg/ha in the U, M and L, where the L responded most strongly to fertilizer N. *EPANS* at *GY* maxima were 89, 130 and 130 kg N/ha, correspondingly. In 1998, the relative order of predicted *GY* maxima among LECs was reversed. *GY* values of 2501, 2355 and 2227 kg/ha were predicted in the U, M and L. Initial response to N was similar among LECs, but the response in the U was slightly greater than the M or L. *EPANS* at *GY* maxima were 146, 142 and 154 kg N/ha, correspondingly. It was concluded that modeled yield-N relationships from 1997 would be most characteristic of an average year, as the amount of precipitation in 1997 was closer to average than in 1998.

Ultimately, the feasibility of variable rate N fertilization depends on its profitability for the producer. There are a multitude of factors influencing profitability, but the minimum economic benefit required with variable rate N application is that the net return from the combined management units, fertilized to achieve economic optima within each, exceeds that of the economically optimal conventional N fertilization rate. If discrete, smoothed LECs are to be successfully employed as fixed management units, then yield response to N fertilizer must be sufficiently different among LECs. In addition, yield response to N fertilizer within a LEC must be sufficiently consistent and/or predictable among growing seasons. Finally, the modeled differences in productive potential must be sufficiently different such that differences in rates of fertilization are justified over a reasonable range of fertilizer:grain price ratios which include the value of protein premiums. To establish any "characteristic" *GY*-N response model within a LEC, long-term empirical study is required. If a LEC can be successfully characterized as such, then the areal extent of a LEC which has unique and consistent yield response to N must be large enough to justify variable rate application.

Table 5.7. Descriptive statistics for crop response attributes, across and within LECs and within N treatments.

(a) Overall

N Rate (kg/ha)	Attribute	Median	Mean	Std. De v.	Minimum	Maximum
Overall	*ABM 97*(kg/ha)	1739	1820	440	713	3819
0	*ABM 97*(kg/ha)	1606	1643	352	969	2993
45	*ABM 97*(kg/ha)	1682	1724	317	1121	2584
90	*ABM 97*(kg/ha)	2024	2018	534	713	3819
135	*ABM 97*(kg/ha)	2005	1914	416	1007	2708
Overall	*ABM 98*(kg/ha)	2491	2419	525	883	3740
0	*ABM 98*(kg/ha)	1892	1844	359	1002	3149
45	*ABM 98*(kg/ha)	2394	2357	380	883	3134
90	*ABM 98*(kg/ha)	2693	2660	381	1436	3426
135	*ABM 98*(kg/ha)	2977	3034	292	2506	3740
Overall	*Z 97*	55	55	3	45	59
0	*Z 97*	57	56	3	46	59
45	*Z 97*	56	55	4	45	59
90	*Z 97*	55	54	3	45	59
135	*Z 97*	54	54	3	46	58
Overall	*Z 98*	60	60	2	52	66
0	*Z 98*	62	61	1	58	64
45	*Z 98*	61	61	2	58	64
90	*Z 98*	59	60	2	52	66
135	*Z 98*	60	60	1	58	62
Overall	*GY 97*(kg/ha)	2140	2124	392	1110	3150
0	*GY 97*(kg/ha)	1640	1700	325	1110	2697
45	*GY 97*(kg/ha)	2142	2190	319	1452	3150
90	*GY 97*(kg/ha)	2275	2287	285	1385	3046
135	*GY 97*(kg/ha)	2405	2347	338	1461	3042
Overall	*GY 98*(kg/ha)	2257	2236	546	621	3416
0	*GY 98*(kg/ha)	1518	1497	284	621	1900
45	*GY 98*(kg/ha)	2240	2257	240	1702	2806
90	*GY 98*(kg/ha)	2534	2501	404	1582	3388
135	*GY 98*(kg/ha)	2954	2924	239	2400	3416
Overall	*SY 97*(kg/ha)	3316	3285	692	1739	5168
0	*SY 97*(kg/ha)	2437	2524	557	1739	4465
45	*SY 97*(kg/ha)	3192	3315	534	2280	4712
90	*SY 97*(kg/ha)	3563	3648	547	2537	5168
135	*SY 97*(kg/ha)	3648	3729	438	2898	4693
Overall	*SY 98*(kg/ha)	4361	4314	991	1363	6441
0	*SY 98*(kg/ha)	3099	2967	513	1363	3776
45	*SY 98*(kg/ha)	4327	4251	514	1378	5106
90	*SY 98*(kg/ha)	5106	4969	631	3696	6237
135	*SY 98*(kg/ha)	5349	5380	434	4365	6441
Overall	*HBM 97*(kg/ha)	5137	5120	995	2746	7803
0	*HBM 97*(kg/ha)	3748	3995	816	2746	6798
45	*HBM 97*(kg/ha)	5071	5210	730	3978	7266
90	*HBM 97*(kg/ha)	5550	5615	778	3925	7803
135	*HBM 97*(kg/ha)	5729	5759	679	4484	7086

N Rate (kg/ha)	Attribute	Median	Mean	Std. De v.	Minimum	Maximum
Overall	*HBM 98*(kg/ha)	6370	6248	1434	1900	9153
0	*HBM 98*(kg/ha)	4484	4261	738	1900	5334
45	*HBM 98*(kg/ha)	6337	6204	656	3149	7353
90	*HBM 98*(kg/ha)	7332	7133	934	5178	8802
135	*HBM 98*(kg/ha)	7904	7910	584	6441	9153
Overall	*HI 97*	0.36	0.36	0.03	0.16	0.46
0	*HI 97*	0.38	0.37	0.02	0.29	0.39
45	*HI 97*	0.37	0.37	0.03	0.23	0.46
90	*HI 97*	0.36	0.35	0.03	0.16	0.44
135	*HI 97*	0.35	0.35	0.02	0.28	0.38
Overall	*HI 98*	0.31	0.31	0.03	0.23	0.56
0	*HI 98*	0.31	0.30	0.02	0.25	0.33
45	*HI 98*	0.32	0.32	0.04	0.28	0.56
90	*HI 98*	0.30	0.30	0.02	0.23	0.34
135	*HI 98*	0.32	0.32	0.01	0.28	0.34
Overall	*GPC 97*(%)	13.5	13.9	1.7	11.0	19.1
0	*GPC 97*(%)	12.1	12.3	0.7	11.0	13.9
45	*GPC 97*(%)	13.2	13.2	1.1	11.3	17.0
90	*GPC 97*(%)	15.1	15.1	1.3	12.3	19.1
135	*GPC 97*(%)	16.1	15.9	0.8	14.4	17.3
Overall	*GPC 98*(%)	14.4	14.5	1.3	11.8	16.8
0	*GPC 98*(%)	13.0	13.1	0.7	11.8	14.7
45	*GPC 98*(%)	14.0	13.9	0.8	12.2	16.3
90	*GPC 98*(%)	15.8	15.6	0.7	13.6	16.8
135	*GPC 98*(%)	15.6	15.6	0.4	15.0	16.6
Overall	*GPY 97*(kg/ha)	298	296	72	132	489
0	*GPY 97*(kg/ha)	210	209	42	132	345
45	*GPY 97*(kg/ha)	285	289	42	195	401
90	*GPY 97*(kg/ha)	335	340	52	134	489
135	*GPY 97*(kg/ha)	371	373	44	247	437
Overall	*GPY 98*(kg/ha)	325	328	98	75	536
0	*GPY 98*(kg/ha)	198	196	40	75	260
45	*GPY 98*(kg/ha)	316	315	42	208	415
90	*GPY 98*(kg/ha)	393	390	63	251	514
135	*GPY 98*(kg/ha)	461	457	40	365	536
Overall	*NU 97*(kg/ha)	78	77	19	35	133
0	*NU 97*(kg/ha)	53	53	11	35	90
45	*NU 97*(kg/ha)	74	74	11	55	101
90	*NU 97*(kg/ha)	89	89	13	57	133
135	*NU 97*(kg/ha)	100	99	9	80	117
Overall	*NU 98*(kg/ha)	89	93	32	20	160
0	*NU 98*(kg/ha)	53	52	10	20	69
45	*NU 98*(kg/ha)	82	83	13	54	123
90	*NU 98*(kg/ha)	118	115	20	72	155
135	*NU 98*(kg/ha)	143	139	15	110	160
Overall	*WU 97*(cm)	21.4	21.5	3.3	13.2	29.7
0	*WU 97*(cm)	22.0	21.8	2.7	16.5	28.9
45	*WU 97*(cm)	21.5	21.8	3.2	13.2	29.7
90	*WU 97*(cm)	20.9	20.9	3.3	14.5	28.1
135	*WU 97*(cm)	20.8	21.4	4.1	14.4	29.6

N Rate (kg/ha)	Attribute	Median	Mean	Std. Dev.	Minimum	Maximum
Overall	*WU 98*(cm)	33.2	33.1	3.6	23.8	46.5
0	*WU 98*(cm)	30.8	31.4	3.3	24.4	40.2
45	*WU 98*(cm)	32.5	32.5	3.3	26.8	46.5
90	*WU 98*(cm)	34.2	34.6	3.2	23.8	43.2
135	*WU 98*(cm)	34.7	34.4	4.4	27.4	43.3
Overall	*WUE 97*(kg/mm)	98	101	24	51	196
0	*WUE 97*(kg/mm)	77	79	15	51	113
45	*WUE 97*(kg/mm)	100	103	21	57	160
90	*WUE 97*(kg/mm)	108	112	23	74	196
135	*WUE 97*(kg/mm)	108	112	21	71	144
Overall	*WUE 98*(kg/mm)	68	68	18	18	136
0	*WUE 98*(kg/mm)	48	48	11	18	68
45	*WUE 98*(kg/mm)	70	70	11	42	101
90	*WUE 98*(kg/mm)	72	73	16	39	136
135	*WUE 98*(kg/mm)	84	86	14	64	121
Overall	*WD 97*(cm)	-10.1	-10.0	3.3	-18.3	-1.8
0	*WD 97*(cm)	-9.5	-9.7	2.7	-15.0	-2.7
45	*WD 97*(cm)	-10.0	-9.7	3.2	-18.3	-1.8
90	*WD 97*(cm)	-10.6	-10.6	3.3	-17.0	-3.4
135	*WD 97*(cm)	-10.7	-10.1	4.1	-17.1	-1.9
Overall	*WD 98*(cm)	3.7	3.6	3.6	-5.7	17.0
0	*WD 98*(cm)	1.3	1.9	3.3	-5.1	10.7
45	*WD 98*(cm)	3.0	3.0	3.3	-2.7	17.0
90	*WD 98*(cm)	4.7	5.1	3.2	-5.7	13.7
135	*WD 98*(cm)	5.2	4.9	4.4	-2.2	13.8

(a) Upper Elevation LEC

N Rate (kg/ha)	Attribute	Median	Mean	Std. Dev.	Minimum	Maximum
Overall	*ABM 97*(kg/ha)	1710	1729	360	1007	2689
0	*ABM 97*(kg/ha)	1606	1594	190	1311	1891
45	*ABM 97*(kg/ha)	1796	1791	266	1292	2242
90	*ABM 97*(kg/ha)	1644	1842	533	1140	2689
135	*ABM 97*(kg/ha)	1577	1577	806	1007	2147
Overall	*ABM 98*(kg/ha)	2581	2448	531	1002	3359
0	*ABM 98*(kg/ha)	1952	1976	549	1002	3149
45	*ABM 98*(kg/ha)	2581	2454	275	2005	2730
90	*ABM 98*(kg/ha)	2917	2852	384	2139	3359
135	*ABM 98*(kg/ha)	3123	3123	26	3104	3142
Overall	*Z 97*	57	56	2	51	59
0	*Z 97*	57	57	2	53	59
45	*Z 97*	58	56	3	51	59
90	*Z 97*	55	56	2	54	58
135	*Z 97*	55	55	1	54	55
Overall	*Z 98*	62	62	2	58	66
0	*Z 98*	63	63	1	61	64
45	*Z 98*	61	61	2	58	64
90	*Z 98*	62	62	2	59	66
135	*Z 98*	61	61	1	60	62

N Rate (kg/ha)	Attribute	Median	Mean	Std. Dev.	Minimum	Maximum
Overall	*GY 97*(kg/ha)	1951	1956	294	1233	2493
0	*GY 97*(kg/ha)	1645	1640	204	1233	1916
45	*GY 97*(kg/ha)	2103	2082	209	1646	2424
90	*GY 97*(kg/ha)	2038	2065	226	1832	2493
135	*GY 97*(kg/ha)	2237	2237	247	2062	2411
Overall	*GY 98*(kg/ha)	2361	2206	592	621	3081
0	*GY 98*(kg/ha)	1582	1483	362	621	1834
45	*GY 98*(kg/ha)	2419	2364	173	1999	2553
90	*GY 98*(kg/ha)	2784	2632	444	1746	3081
135	*GY 98*(kg/ha)	3023	3023	27	3004	3042
Overall	*SY 97*(kg/ha)	3021	2974	527	1872	4123
0	*SY 97*(kg/ha)	2451	2456	343	1872	3069
45	*SY 97*(kg/ha)	3092	3031	316	2280	3439
90	*SY 97*(kg/ha)	3430	3423	469	2784	4123
135	*SY 97*(kg/ha)	3387	3387	692	2898	3876
Overall	*SY 98*(kg/ha)	4332	4110	1023	1363	5581
0	*SY 98*(kg/ha)	3040	2819	615	1363	3387
45	*SY 98*(kg/ha)	4391	4374	365	3615	5106
90	*SY 98*(kg/ha)	5225	4995	579	3848	5581
135	*SY 98*(kg/ha)	5235	5235	94	5168	5301
Overall	*HBM 97*(kg/ha)	4696	4665	706	2938	6024
0	*HBM 97*(kg/ha)	3744	3875	479	2938	4522
45	*HBM 97*(kg/ha)	4869	4832	401	4185	5498
90	*HBM 97*(kg/ha)	5074	5209	436	4682	6024
135	*HBM 97*(kg/ha)	5321	5321	905	4681	5962
Overall	*HBM 98*(kg/ha)	6337	6018	1521	1900	7952
0	*HBM 98*(kg/ha)	4479	4102	909	1900	4812
45	*HBM 98*(kg/ha)	6430	6418	476	5344	7263
90	*HBM 98*(kg/ha)	7667	7272	944	5358	7952
135	*HBM 98*(kg/ha)	7850	7850	118	7766	7933
Overall	*HI 97*	0.37	0.37	0.03	0.29	0.46
0	*HI 97*	0.37	0.37	0.02	0.32	0.39
45	*HI 97*	0.38	0.38	0.03	0.32	0.46
90	*HI 97*	0.34	0.35	0.05	0.29	0.44
135	*HI 97*	0.37	0.37	0.02	0.35	0.38
Overall	*HI 98*	0.32	0.32	0.02	0.27	0.34
0	*HI 98*	0.32	0.31	0.02	0.27	0.33
45	*HI 98*	0.32	0.32	0.01	0.29	0.34
90	*HI 98*	0.32	0.31	0.02	0.28	0.34
135	*HI 98*	0.31	0.33	0.00	0.33	0.33
Overall	*GPC 97*(%)	13.6	14.0	1.3	12.1	16.8
0	*GPC 97*(%)	12.8	12.8	0.6	12.1	13.9
45	*GPC 97*(%)	13.3	13.7	1.1	12.7	16.8
90	*GPC 97*(%)	15.6	15.4	0.6	14.2	15.9
135	*GPC 97*(%)	15.9	15.9	0.8	15.3	16.4
Overall	*GPC 98*(%)	13.9	14.1	1.3	12.1	16.3
0	*GPC 98*(%)	12.5	12.6	0.4	12.1	13.2
45	*GPC 98*(%)	13.9	14.1	0.9	13.2	16.3
90	*GPC 98*(%)	15.4	15.4	0.5	14.7	16.1
135	*GPC 98*(%)	15.8	15.8	0.5	15.4	16.1

N Rate (kg/ha)	Attribute	Median	Mean	Std. Dev.	Minimum	Maximum
Overall	*GPY 97*(kg/ha)	282	274	52	160	371
0	*GPY 97*(kg/ha)	213	210	24	160	235
45	*GPY 97*(kg/ha)	282	285	25	248	322
90	*GPY 97*(kg/ha)	312	317	27	289	371
135	*GPY 97*(kg/ha)	354	354	22	338	370
Overall	*GPY 98*(kg/ha)	328	316	105	75	490
0	*GPY 98*(kg/ha)	198	188	47	75	237
45	*GPY 98*(kg/ha)	334	334	29	286	376
90	*GPY 98*(kg/ha)	427	407	72	257	474
135	*GPY 98*(kg/ha)	476	476	19	463	490
Overall	*NU 97*(kg/ha)	73	71	15	42	95
0	*NU 97*(kg/ha)	53	53	6	42	62
45	*NU 97*(kg/ha)	73	72	7	62	86
90	*NU 97*(kg/ha)	85	87	4	83	92
135	*NU 97*(kg/ha)	87	87	10	80	95
Overall	*NU 98*(kg/ha)	86	85	32	20	152
0	*NU 98*(kg/ha)	51	48	12	20	59
45	*NU 98*(kg/ha)	86	87	13	70	113
90	*NU 98*(kg/ha)	112	112	23	74	146
135	*NU 98*(kg/ha)	143	143	13	133	152
Overall	*WU 97*(cm)	21.0	21.3	2.4	16.9	26.6
0	*WU 97*(cm)	21.0	20.2	2.3	16.9	23.3
45	*WU 97*(cm)	20.9	20.8	1.5	17.9	23.3
90	*WU 97*(cm)	24.5	23.2	2.2	19.8	25.2
135	*WU 97*(cm)	23.5	23.5	4.4	20.4	26.6
Overall	*WU 98*(cm)	31.8	32.0	3.2	26.6	37.3
0	*WU 98*(cm)	28.7	29.4	2.4	26.6	34.7
45	*WU 98*(cm)	33.3	33.2	3.0	28.6	37.3
90	*WU 98*(cm)	33.6	33.3	2.1	29.1	35.7
135	*WU 98*(cm)	31.6	31.6	6.0	27.4	35.8
Overall	*WUE 97*(kg/mm)	94	92	13	67	123
0	*WUE 97*(kg/mm)	81	82	10	67	97
45	*WUE 97*(kg/mm)	100	100	10	89	123
90	*WUE 97*(kg/mm)	95	90	13	74	105
135	*WUE 97*(kg/mm)	96	96	7	91	101
Overall	*WUE 98*(kg/mm)	68	69	17	18	111
0	*WUE 98*(kg/mm)	55	51	15	18	66
45	*WUE 98*(kg/mm)	69	72	8	59	85
90	*WUE 98*(kg/mm)	81	79	11	60	92
135	*WUE 98*(kg/mm)	98	98	19	84	111
Overall	*WD 97*(cm)	-10.5	-10.2	2.4	-14.6	-5.0
0	*WD 97*(cm)	-10.5	-11.3	2.3	-14.6	-8.2
45	*WD 97*(cm)	-10.6	-10.7	1.5	-13.6	-8.2
90	*WD 97*(cm)	-7.0	-8.3	2.2	-11.7	-6.3
135	*WD 97*(cm)	-8.0	-8.0	4.4	-11.1	-5.0
Overall	*WD 98*(cm)	2.3	2.5	3.2	-2.9	7.8
0	*WD 98*(cm)	-0.8	-0.1	2.4	-2.9	5.2
45	*WD 98*(cm)	3.8	3.7	3.0	-0.9	7.8
90	*WD 98*(cm)	4.1	3.8	2.1	-0.4	6.2
135	*WD 98*(cm)	2.1	2.1	6.0	-2.1	6.3

(b) Mid Elevation LEC

N Rate (kg/ha)	Attribute	Median	Mean	Std. De v.	Minimum	Maximum
Overall	*ABM 97*(kg/ha)	1701	1772	383	969	2708
0	*ABM 97*(kg/ha)	1492	1543	277	969	2081
45	*ABM 97*(kg/ha)	1663	1679	291	1121	2299
90	*ABM 97*(kg/ha)	2024	2008	396	1292	2708
135	*ABM 97*(kg/ha)	1872	1852	419	1273	2708
Overall	*ABM 98*(kg/ha)	2506	2470	516	1227	3740
0	*ABM 98*(kg/ha)	1904	1841	262	1227	2267
45	*ABM 98*(kg/ha)	2386	2413	301	1848	3134
90	*ABM 98*(kg/ha)	2730	2724	360	1668	3426
135	*ABM 98*(kg/ha)	3142	3111	337	2506	3740
Overall	*Z 97*	56	55	3	48	59
0	*Z 97*	57	56	3	48	59
45	*Z 97*	57	56	3	48	59
90	*Z 97*	55	55	3	49	59
135	*Z 97*	54	55	2	52	58
Overall	*Z 98*	61	61	2	56	63
0	*Z 98*	62	61	1	59	63
45	*Z 98*	61	61	1	59	63
90	*Z 98*	60	60	1	56	63
135	*Z 98*	60	60	1	59	61
Overall	*GY 97*(kg/ha)	2141	2094	370	1110	2958
0	*GY 97*(kg/ha)	1598	1663	252	1110	2180
45	*GY 97*(kg/ha)	2156	2175	302	1452	2958
90	*GY 97*(kg/ha)	2198	2246	264	1385	2831
135	*GY 97*(kg/ha)	2406	2311	334	1461	2767
Overall	*GY 98*(kg/ha)	2284	2278	555	966	3416
0	*GY 98*(kg/ha)	1532	1532	260	966	1900
45	*GY 98*(kg/ha)	2260	2273	256	1702	2806
90	*GY 98*(kg/ha)	2619	2574	404	1741	3388
135	*GY 98*(kg/ha)	2954	2954	258	2400	3416
Overall	*SY 97*(kg/ha)	3263	3199	634	1786	4788
0	*SY 97*(kg/ha)	2366	2439	434	1786	3544
45	*SY 97*(kg/ha)	3240	3279	510	2461	4342
90	*SY 97*(kg/ha)	3482	3516	474	2537	4788
135	*SY 97*(kg/ha)	3544	3611	374	3221	4693
Overall	*SY 98*(kg/ha)	4422	4416	991	2171	6441
0	*SY 98*(kg/ha)	3187	3016	501	2171	3681
45	*SY 98*(kg/ha)	4358	4337	323	3634	4973
90	*SY 98*(kg/ha)	5118	5110	589	4076	6237
135	*SY 98*(kg/ha)	5520	5507	487	4365	6441
Overall	*HBM 97*(kg/ha)	5116	5000	913	2746	7237
0	*HBM 97*(kg/ha)	3748	3877	618	2746	5145
45	*HBM 97*(kg/ha)	5091	5160	683	3978	6900
90	*HBM 97*(kg/ha)	5470	5423	692	3925	7237
135	*HBM 97*(kg/ha)	5677	5609	612	4484	7086
Overall	*HBM 98*(kg/ha)	6415	6386	1446	3021	9153
0	*HBM 98*(kg/ha)	4565	4341	705	3021	5325
45	*HBM 98*(kg/ha)	6403	6303	515	5125	7353
90	*HBM 98*(kg/ha)	7453	7337	879	5824	8802
135	*HBM 98*(kg/ha)	8127	8063	645	6441	9153

N Rate (kg/ha)	Attribute	Median	Mean	Std. Dev.	Minimum	Maximum
Overall	*HI 97*	0.37	0.36	0.03	0.16	0.45
0	*HI 97*	0.38	0.37	0.03	0.29	0.39
45	*HI 97*	0.37	0.37	0.03	0.23	0.45
90	*HI 97*	0.36	0.35	0.04	0.16	0.39
135	*HI 97*	0.36	0.35	0.03	0.28	0.38
Overall	*HI 98*	0.31	0.31	0.02	0.23	0.35
0	*HI 98*	0.31	0.30	0.02	0.26	0.33
45	*HI 98*	0.31	0.31	0.02	0.28	0.35
90	*HI 98*	0.30	0.30	0.02	0.23	0.34
135	*HI 98*	0.32	0.32	0.02	0.28	0.34
Overall	*GPC 97*(%)	13.6	14.0	1.8	11.0	19.1
0	*GPC 97*(%)	11.8	12.0	0.7	11.0	13.7
45	*GPC 97*(%)	13.2	13.3	0.7	11.4	14.8
90	*GPC 97*(%)	15.4	15.4	1.3	12.5	19.1
135	*GPC 97*(%)	16.2	16.3	0.6	15.4	17.3
Overall	*GPC 98*(%)	14.4	14.5	1.2	11.8	16.8
0	*GPC 98*(%)	13.0	13.1	0.7	11.8	14.7
45	*GPC 98*(%)	14.0	13.9	0.7	12.2	15.5
90	*GPC 98*(%)	15.8	15.6	0.6	13.8	16.8
135	*GPC 98*(%)	15.6	15.6	0.5	15.0	16.6
Overall	*GPY 97*(kg/ha)	297	294	74	132	433
0	*GPY 97*(kg/ha)	203	200	32	132	295
45	*GPY 97*(kg/ha)	287	288	40	195	392
90	*GPY 97*(kg/ha)	336	338	54	134	418
135	*GPY 97*(kg/ha)	392	375	48	247	433
Overall	*GPY 98*(kg/ha)	327	334	100	114	536
0	*GPY 98*(kg/ha)	198	202	39	114	260
45	*GPY 98*(kg/ha)	313	317	46	208	415
90	*GPY 98*(kg/ha)	412	401	63	292	514
135	*GPY 98*(kg/ha)	464	462	46	365	536
Overall	*NU 97*(kg/ha)	77	76	19	35	117
0	*NU 97*(kg/ha)	51	52	8	35	76
45	*NU 97*(kg/ha)	74	74	10	57	101
90	*NU 97*(kg/ha)	87	88	12	57	113
135	*NU 97*(kg/ha)	101	101	9	85	117
Overall	*NU 98*(kg/ha)	90	95	33	37	160
0	*NU 98*(kg/ha)	53	53	9	37	69
45	*NU 98*(kg/ha)	82	84	13	54	123
90	*NU 98*(kg/ha)	121	121	19	85	155
135	*NU 98*(kg/ha)	143	139	17	110	160
Overall	*WU 97*(cm)	21.5	21.3	3.1	13.2	29.6
0	*WU 97*(cm)	22.6	22.5	2.2	17.1	28.7
45	*WU 97*(cm)	21.4	21.3	3.0	13.2	26.5
90	*WU 97*(cm)	20.5	20.1	3.0	14.5	26.0
135	*WU 97*(cm)	22.8	22.4	4.0	16.6	29.6
Overall	*WU 98*(cm)	32.5	32.6	3.3	23.8	43.2
0	*WU 98*(cm)	30.7	31.1	2.9	24.4	40.2
45	*WU 98*(cm)	31.9	32.0	2.8	26.8	42.7
90	*WU 98*(cm)	34.2	34.2	3.4	23.8	43.2
135	*WU 98*(cm)	33.2	32.7	3.2	27.4	38.3

N Rate (kg/ha)	Attribute	Median	Mean	Std. Dev.	Minimum	Maximum
Overall	*WUE 97*(kg/mm)	98	101	25	51	196
0	*WUE 97*(kg/mm)	73	75	14	51	101
45	*WUE 97*(kg/mm)	101	104	21	57	156
90	*WUE 97*(kg/mm)	114	115	23	81	196
135	*WUE 97*(kg/mm)	103	105	18	71	144
Overall	*WUE 98*(kg/mm)	70	70	18	28	136
0	*WUE 98*(kg/mm)	49	50	10	28	68
45	*WUE 98*(kg/mm)	71	72	11	49	101
90	*WUE 98*(kg/mm)	73	76	17	55	136
135	*WUE 98*(kg/mm)	87	91	12	77	121
Overall	*WD 97*(cm)	-10.0	-10.2	3.1	-18.3	-1.9
0	*WD 97*(cm)	-8.9	-9.0	2.2	-14.4	-2.8
45	*WD 97*(cm)	-10.1	-10.2	3.0	-18.3	-5.0
90	*WD 97*(cm)	-11.0	-11.4	3.0	-17.0	-5.5
135	*WD 97*(cm)	-8.7	-9.1	4.0	-14.9	-1.9
Overall	*WD 98*(cm)	3.0	3.1	3.3	-5.7	13.7
0	*WD 98*(cm)	1.2	1.6	2.9	-5.1	10.7
45	*WD 98*(cm)	2.4	2.5	2.8	-2.7	13.2
90	*WD 98*(cm)	4.7	4.7	3.4	-5.7	13.7
135	*WD 98*(cm)	3.7	3.2	3.2	-2.2	8.8

(a) Lower Elevation LEC

N Rate (kg/ha)	Attribute	Median	Mean	Std. Dev.	Minimum	Maximum
Overall	*ABM 97*(kg/ha)	2005	1997	562	713	3819
0	*ABM 97*(kg/ha)	2005	2010	477	1349	2993
45	*ABM 97*(kg/ha)	1615	1782	414	1273	2584
90	*ABM 97*(kg/ha)	2024	2110	750	713	3819
135	*ABM 97*(kg/ha)	2195	2160	107	2005	2261
Overall	*ABM 98*(kg/ha)	2338	2270	527	883	3015
0	*ABM 98*(kg/ha)	1747	1706	349	1242	2334
45	*ABM 98*(kg/ha)	2214	2090	561	883	2693
90	*ABM 98*(kg/ha)	2424	2453	351	1436	3015
135	*ABM 98*(kg/ha)	2831	2838	65	2768	2947
Overall	*Z 97*	54	53	4	45	59
0	*Z 97*	55	54	5	46	58
45	*Z 97*	53	53	4	45	58
90	*Z 97*	54	53	4	45	59
135	*Z 97*	52	52	4	46	56
Overall	*Z 98*	59	59	2	52	63
0	*Z 98*	60	60	1	58	62
45	*Z 98*	59	60	1	58	62
90	*Z 98*	59	58	3	52	63
135	*Z 98*	58	58	1	58	60
Overall	*GY 97*(kg/ha)	2354	2315	435	1189	3150
0	*GY 97*(kg/ha)	1834	1886	553	1189	2697
45	*GY 97*(kg/ha)	2214	2322	405	1850	3150
90	*GY 97*(kg/ha)	2478	2479	253	1974	3046
135	*GY 97*(kg/ha)	2345	2461	391	1962	3042

N Rate (kg/ha)	Attribute	Median	Mean	Std. De v.	Minimum	Maximum
Overall	*GY 98*(kg/ha)	2158	2157	492	939	3158
0	*GY 98*(kg/ha)	1452	1401	275	939	1801
45	*GY 98*(kg/ha)	2122	2126	196	1768	2548
90	*GY 98*(kg/ha)	2378	2301	331	1582	2790
135	*GY 98*(kg/ha)	2861	2826	225	2488	3158
Overall	*SY 97*(kg/ha)	3814	3707	750	1739	5168
0	*SY 97*(kg/ha)	2641	2864	935	1739	4465
45	*SY 97*(kg/ha)	3738	3653	592	2670	4712
90	*SY 97*(kg/ha)	4009	4026	566	3012	5168
135	*SY 97*(kg/ha)	3985	4101	294	3781	4541
Overall	*SY 98*(kg/ha)	4133	4205	956	1378	5681
0	*SY 98*(kg/ha)	3078	2980	464	2366	3776
45	*SY 98*(kg/ha)	3945	3926	835	1378	4964
90	*SY 98*(kg/ha)	4342	4676	666	3696	5681
135	*SY 98*(kg/ha)	5151	5153	264	4878	5600
Overall	*HBM 97*(kg/ha)	5919	5723	1098	2767	7803
0	*HBM 97*(kg/ha)	4227	4496	1406	2767	6798
45	*HBM 97*(kg/ha)	5829	5662	867	4330	7266
90	*HBM 97*(kg/ha)	6214	6199	777	4719	7803
135	*HBM 97*(kg/ha)	6004	6230	617	5478	7011
Overall	*HBM 98*(kg/ha)	5980	6070	1334	3149	8332
0	*HBM 98*(kg/ha)	4318	4192	690	3206	5334
45	*HBM 98*(kg/ha)	5776	5765	914	3149	7011
90	*HBM 98*(kg/ha)	6398	6666	923	5178	7966
135	*HBM 98*(kg/ha)	7548	7598	432	7049	8332
Overall	*HI 97*	0.36	0.35	0.02	0.28	0.39
0	*HI 97*	0.37	0.37	0.02	0.34	0.39
45	*HI 97*	0.36	0.36	0.03	0.28	0.39
90	*HI 97*	0.36	0.35	0.02	0.32	0.39
135	*HI 97*	0.34	0.34	0.02	0.31	0.37
Overall	*HI 98*	0.31	0.31	0.04	0.25	0.56
0	*HI 98*	0.29	0.29	0.02	0.25	0.31
45	*HI 98*	0.32	0.33	0.07	0.28	0.56
90	*HI 98*	0.30	0.30	0.02	0.26	0.32
135	*HI 98*	0.33	0.32	0.01	0.31	0.34
Overall	*GPC 97*(%)	13.3	13.6	1.5	11.3	17.0
0	*GPC 97*(%)	12.5	12.5	0.7	11.4	13.3
45	*GPC 97*(%)	12.2	12.7	1.5	11.3	17.0
90	*GPC 97*(%)	14.0	14.2	1.1	12.3	16.2
135	*GPC 97*(%)	15.2	15.3	0.8	14.4	16.8
Overall	*GPC 98*(%)	14.7	14.7	1.2	12.2	16.7
0	*GPC 98*(%)	13.3	13.4	0.7	12.2	14.2
45	*GPC 98*(%)	13.8	13.9	0.8	12.8	15.5
90	*GPC 98*(%)	15.8	15.6	0.8	13.6	16.7
135	*GPC 98*(%)	15.6	15.6	0.3	15.2	15.9
Overall	*GPY 97*(kg/ha)	331	317	74	158	489
0	*GPY 97*(kg/ha)	222	235	71	158	345
45	*GPY 97*(kg/ha)	288	294	56	224	401
90	*GPY 97*(kg/ha)	357	356	54	242	489
135	*GPY 97*(kg/ha)	357	373	43	329	437

N Rate (kg/ha)	Attribute	Median	Mean	Std. De v.	Minimum	Maximum
Overall	*GPY 98*(kg/ha)	322	319	88	119	480
0	*GPY 98*(kg/ha)	195	187	37	119	241
45	*GPY 98*(kg/ha)	296	295	35	251	367
90	*GPY 98*(kg/ha)	358	359	54	251	444
135	*GPY 98*(kg/ha)	442	439	28	396	480
Overall	*NU 97*(kg/ha)	86	82	21	37	133
0	*NU 97*(kg/ha)	53	59	19	37	90
45	*NU 97*(kg/ha)	74	75	15	55	100
90	*NU 97*(kg/ha)	93	93	16	59	133
135	*NU 97*(kg/ha)	99	100	7	92	110
Overall	*NU 98*(kg/ha)	84	91	31	33	150
0	*NU 98*(kg/ha)	55	51	10	33	63
45	*NU 98*(kg/ha)	77	78	13	58	106
90	*NU 98*(kg/ha)	97	105	20	72	140
135	*NU 98*(kg/ha)	141	138	12	118	150
Overall	*WU 97*(cm)	21.6	21.9	4.1	14.4	29.7
0	*WU 97*(cm)	20.9	21.7	4.0	16.5	28.9
45	*WU 97*(cm)	23.5	23.9	4.1	15.5	29.7
90	*WU 97*(cm)	21.3	21.6	3.8	15.1	28.1
135	*WU 97*(cm)	18.0	18.4	3.2	14.4	23.4
Overall	*WU 98*(cm)	35.0	35.2	3.9	27.8	46.5
0	*WU 98*(cm)	34.6	34.6	3.1	29.9	38.7
45	*WU 98*(cm)	33.7	33.3	4.5	27.8	46.5
90	*WU 98*(cm)	35.7	35.8	3.1	30.1	40.1
135	*WU 98*(cm)	39.4	39.0	3.1	35.0	43.3
Overall	*WUE 97*(kg/mm)	110	108	26	60	160
0	*WUE 97*(kg/mm)	85	87	21	60	113
45	*WUE 97*(kg/mm)	96	101	29	62	160
90	*WUE 97*(kg/mm)	118	117	20	95	156
135	*WUE 97*(kg/mm)	136	134	9	119	143
Overall	*WUE 98*(kg/mm)	63	62	15	30	84
0	*WUE 98*(kg/mm)	41	40	7	30	49
45	*WUE 98*(kg/mm)	63	65	11	42	82
90	*WUE 98*(kg/mm)	69	65	12	39	84
135	*WUE 98*(kg/mm)	72	73	7	64	82
Overall	*WD 97*(cm)	-9.9	-9.6	4.1	-17.1	-1.8
0	*WD 97*(cm)	-10.6	-9.8	4.0	-15.0	-2.7
45	*WD 97*(cm)	-8.0	-7.6	4.1	-16.0	-1.8
90	*WD 97*(cm)	-10.2	-9.9	3.8	-16.4	-3.4
135	*WD 97*(cm)	-13.5	-13.1	3.2	-17.1	-8.1
Overall	*WD 98*(cm)	5.5	5.7	3.9	-1.7	17.0
0	*WD 98*(cm)	5.1	5.1	3.1	0.4	9.2
45	*WD 98*(cm)	4.2	3.8	4.5	-1.7	17.0
90	*WD 98*(cm)	6.2	6.3	3.1	0.6	10.6
135	*WD 98*(cm)	9.9	9.5	3.1	5.5	13.8

6. GENERAL DISCUSSION

The objective of this research was to characterize spatial variation in productivity determinants and the resultant differences in yield response to N fertilizer in an undulating glacial till soil. Researchers have long recognized the fundamental relationship between soil-landscape morphology and productivity, and over the decades, several authors have investigated differences in productivity among discrete, visually identifiable landscape positions. Within the last decade, there has been a resurgence in interest in predicting production variability within traditional management units in order to apply soil amendments, e.g., N fertilizer, more judiciously. The interest in more management intensive, "site-specific agriculture" is largely due to an improved technological ability to characterize productive variability in the field and to apply N at variable rates. As a result of basic soil-landscape-productivity relationships, three-dimensional landform element complexes (LECs) have been investigated as management units for variable-rate N application. In this application, smoothed, three-dimensional LECs derived from a description program by MacMillan and Pettapiece (1997) were used to segment the soil landscape into discrete areas in which yield potential and response to N fertilizer were characterized.

Due to the long-term integration of pedogenic processes regulated by convergent and divergent character in the undulating glacial till parent material, predictable soil-landscape associations occurred within the site due to topographic control of moisture redistribution. Among LECs, convergent character increased in the order U < M < L, based on topographic attributes described by Pennock et al. (1987). Accordingly, there was an increase in median values of A horizon depth, solum depth, depth to carbonates and SOC moving from the U to the L. Median A horizon thickness, solum thickness, and depth of carbonate-free soil were 16, 29 and 26 cm in the U; 18, 34 and 32 cm in the M; and 26, 45 and 44 cm in the L, where most strongly eluviated profiles occurred. Pennock and de Jong (1990b) reported similar average values for Ap-horizon thickness and depth to carbonates in the Black soil zone. Median values for SOC were 1.94, 2.17 and 2.60 (%), and 35, 45 and 64 (Mg/ha) for the U, M and L, respectively. Pennock and Vreeken (1986) found that organic C accumulation was a function of more recent pedogenic episodes and corresponded well with present-day topography. SOC may also be higher in more convergent, depositional lower slope positions due to erosional redistribution (Verity and Anderson, 1990; Moulin et al., 1994). Median slope gradients at our site were low, ranging from 0.7 to 1.6° among LECs. Net *in-situ* SOC assimilation, rather than erosional redistribution, was more likely responsible for the observed differences among LECs.

While the LECs captured gross variation in soil morphological character, significant variability remained within LECs with respect to genetic soil types. For example, relatively shallow (Gleyed Rego Black) Varcoe soils occurred in the L, in close association with (Gleyed Eluviated Black) Angusville soils. Inclusions of Angusville soils occurred in the U and M, which were dominated by (Orthic Black) Newdale soils.

Nonetheless, division of the site into manageable, spatially homogenous LECs required that some information was lost due to scale.

Soil water and N fertility were the limiting factors most directly and functionally related to productivity. Spatial variability in productivity was determined by the relative distribution of soil moisture and nutrient supplying power; there was nothing inherently limiting about the relative distribution of topographic character and soil genetic variability. Nonetheless, static soil characteristics which result from topographic variability often regulate, or coincide with, variation in these more dynamic, immediate determinants of productivity throughout the soil-landscape continuum. For example, A horizon depth and SOC content, the result of local microclimatic regime and biomass production, and good indicators of historical productivity, influence moisture retention and inherent fertility. Accordingly, soil moisture and fertility gradients generally corresponded with those observed for more static soil attributes.

Soil water generally increased with convergent character in the landscape. In a 120 cm soil profile, the L had 4.6, 3.5 and 3.4 cm more water than the U at spring, anthesis and harvest in 1997, and correspondingly, 4.6, 2.3 and 2.5 cm in 1998. In both years, the systematic landscape influence on soil moisture was apparent, but absolute differences were attenuated by the growing crop as the season progressed. This characteristic redistribution with convergent character was expected (Sinai et al., 1981; Hanna et al., 1982), but a reduction in landscape control of soil moisture redistribution with dry conditions as observed by Halvorson and Doll (1991) and Miller et al. (1988) was not apparent. Relative differences among LECs were greatest in the spring of both growing seasons, when runoff and infiltration were probably influenced by the presence of frost.

The spatial variability in soil moisture was undoubtedly large enough to have influenced productivity within each of the two growing seasons. Under moisture-deficient conditions in the Western Canadian Prairie Ecozone, each additional millimeter of plant-available water will allow for an additional 10 kg/ha of wheat production (Henry et al., 1986). In our study, relative redistribution among LECs at all different sampling times was alike, as evidenced by median values and significant positive correlations among moisture contents measured in 1997 and those measured in 1998. Differences in soil moisture content were larger between 1997 and 1998 than among LECs within either growing season, due to the large differences in growing season precipitation between 1997 and 1998. Differences in median moisture content values within LECs varied from 3.1 to 14.9 cm between similar sampling times in 1997 and 1998.

Spring soil residual N also varied among LECs in each year, but the landscape-scale differences in nitrogen fertility were of minor agronomic significance. In spring of 1997, median residual nitrate amounts to a 90 cm depth varied from 44 kg/ha in the U to 52 kg/ha in the L. In 1998, median spring residual levels were again generally greater in the L; differences among median residual levels ranged from 14 to 19 kg/ha within the four N treatments. Malo and Worcester (1975) attributed similar trends to increases in organic matter content, soil moisture and sedimentation with increasing convergent character; trends in residual nitrate were likely due to slightly higher net mineralization in the more moist, carbon-rich L.

The differences in spring residual soil nitrate observed among N treatments in 1998 were of much greater significance to crop production. Differences of 46, 56 and 49 kg/ha in residual amounts were observed between the check and 135 kg/ha treatment in the U, M and L, respectively. The 1998 treatments were superimposed onto the same locations as in 1997; therefore the check treatments were increasingly N-depleted and the 135 kg/ha treatments were increasingly well-supplied with N. The landscape influence on nitrate concentrations was subtle, compared to that of fertilizer management.

Crop production was mostly influenced by landscape redistribution of soil moisture within each growing season, the absolute amount of available soil moisture within growing seasons, and by differences in available N as influenced by fertilizer treatment. The characteristic redistribution of soil moisture among LECs had markedly different effects on crop yield among growing seasons; relative rank of yield potential among LECs was reversed in 1997 compared to 1998. In the moisture-deficient 1997 growing season, in which growing season precipitation was 37% below average, modeled grain yield maxima of 2077, 2261 and 2485 kg/ha occurred in the U , M and L, respectively. Positive and significant correlations with yield and soil moisture (r^2= 0.35 to 0.67) indicated that this yield gradient was likely a result of greater soil moisture availability in the L. In 1998, growing season precipitation was 62% above average, and modeled yield maxima of 2501, 2355 and 2227 kg/ha were observed in the U , M and L. In 1998, all significant yield-soil moisture correlations were negative, suggesting that moisture in the L was excessive. Total above-ground harvest biomass and straw yields followed similar trends. Weed infestations in the L may have caused yield loss, but more likely the yield losses coincided with other limiting factors which were not quantified, such as anaerobic rooting conditions or pathogen pressure. Wibawa et al. (1993) observed similar temporal instability in productive potential among landscape positions; in a dry year, observed yields were highest in lower slope positions, and in a wet year, yields were depressed due to excessive moisture and weed growth.

In both growing seasons for our experiment, yield responses to N fertilizer were observed within each LEC. Modeled as a function of EPANS, responses were influenced by variation in moisture content among growing seasons and LECs. In 1997, a greater yield response was expressed in the L due to the higher amount of available soil water. It is unlikely that the small fertility gradients in 1997 significantly influenced modeled yield responses. Kachanoski et al. (1985) reasoned that each additional centimeter of soil water would offset the reduction in yield response to N fertilizer which would otherwise occur for each additional 10-15 kg/ha of residual soil N. In 1998, moisture supply ranged from adequate in the divergent U to excessive in the convergent L, which influenced observed yield maxima. However, grain yield responses to EPANS were essentially alike across the landscape in 1998. Increases in EPANS explained relatively less variation in yield in 1997 than in 1998 due to moisture-deficient conditions. In 1998, soil moisture was well supplied and N limitations were more apparent within all LECs. As a result, coefficients of determination were greater for 1998, where the range in EPANS explained relatively more variation in grain yield than in 1997.

Variation in GPC in 1997 was due to moisture gradients among LECs and by differences in available N among treatment levels. GPC increased with N supply within each LEC, and decreased with convergent landscape character within each N rate. Among reported medians, a maximum difference of 4.4% GPC occurred among N rates (in the M), and a maximum difference of 1.6% GPC occurred among LECs (at the 90 kg/ha rate). GPC was inversely correlated with grain yield within N treatments. McKercher (1964) observed a general negative correlation between GPC and GY. McKercher also observed a similar landscape influence on GPC; wheat grown on locally humid Solonetzic and Gleysolic soils in more convergent portions of toposequences had GPCs approximately 3% lower than that of wheat grown on more divergent, arid soils. In 1998, GPC was increased with N rate, but varied little among LECs. Among LECs, medians differed by a maximum of 0.8%, but from the check to the 135 kg/ha treatment, a maximum difference of 3.3% GPC was observed. While significantly and positively related over all N treatments, GPC and GY were essentially unrelated within individual treatments in 1998. The typical inverse relationship between *GPC* and *GY* (at a given N supply rate) did not manifest itself under conditions which were not moisture deficient. It is possible that in 1998, higher potential N losses detected in the L, coupled with the lower yields in the L, resulted in low variation in GPC values between LECs.

If the yield models are to be used to define economically optimum N fertilizer rates, then the year with closest to average conditions should be used. Of the two growing seasons, 1997 was most 'typical', and likely the better candidate from which to predict economic returns within LECs. History indicates that moisture-deficient conditions are most probable at this location, and therefore the effect of landscape redistribution of moisture on yield should most often manifest itself in the same way it did in 1997. In 1997, the L was determined to be statistically distinct, with the highest yield potential and yield response to EPANS. Additionally, protein contents were consistently lowest in the L. By these indications, variable rate fertilization with more N fertilizer applied in the L would have been beneficial.

In justifying and defining LEC-specific N rates, reality demands that two key requirements are met: 1) the differences among LECs with respect to net return to N application are sufficient, where the areal percentage of each LEC is taken into consideration, and 2) net return to N application is sufficiently predictable within LECs. The first requirement may be addressed using relevant costs and returns for a given growing season, including grain protein premiums, which are no less than crucial. It is the second requirement that would render any LEC-specific N prescriptions premature. Only further empirical study will ascertain the relevance of the LEC-based delineations and the scale at which they were created.

Of immediate utility is the fact that the model coefficients defined for the M, which accounted for just over half of site area, were very much alike for 1997 and 1998. It would be useful to compare net return to N application in this LEC from 1997 to 1998. Even if further study should indicate that net return to N application is temporally stable in the M alone, then at the very least, this information will be useful in re-evaluating whole-field fertility management practices. Until more information about *GY* response to N in the L and U is acquired, soil sampling and N fertilizer recommendations should be performed within the M if it can be shown that the remainder of the 65 ha field is dominated by this LEC.

7. SUMMARY AND CONCLUSIONS

The findings of this study are as follows:

1. Delineation of the soil-landscape into discrete and homogenous LECs, sufficiently large to manage uniquely for agricultural purposes, was useful in capturing pedogenic variability. 'A' horizon depth, solum depth, depth to carbonates, percent organic carbon, soil pH and the absolute amount of organic carbon in the 'A' horizon all increased with convergent character in the landscape (L>M>U).

2. The LEC delineations were useful in capturing variability in soil moisture. While relative distribution of volumetric soil moisture was consistent among LECs (L>M>U), the differences in precipitation received between growing seasons were much more influential, agronomically.

3. Differences in spring nitrate-N concentrations among LECs were negligible. Differences among the applied N treatments were much more influential, agronomically.

4. Within LECs, modeled grain yield responses to N fertilizer were strongly regulated by available moisture in this landscape, resulting in temporally unstable yield patterns from 1997 to 1998. Further study is required to determine if there exists a sufficiently

persistent moisture regime at the site to justify N fertilizer prescriptions for each of the LECs. Nonetheless, historical data indicates that moisture-deficient conditions are most likely to occur, such that yield in the L can most often be expected to respond to N more strongly than in the U or M at this site. Since the modeled yield response to EPANS varied little in the M from 1997 to 1998, soil sampling and fertility prescriptions should be directed to this LEC if it can be shown that it dominates the remainder of the quarter section. The information would then also be of use for evaluating profitability of whole-field N fertility management.

Issues that might be considered in future investigations include the following:

i. For several response attributes, response to N fertilizer was still evident up to the 135 kg/ha treatment, most notably for grain yield in 1998. Future experiments should increase the range of N application upward to ensure maximum economic yield response has been achieved. This is especially important when considering the large impact that grain protein premiums currently have on the profitability of higher N fertilization rates. In addition, it would be useful to investigate potentially detrimental effects of excess N on grain yield.

ii. N cycling is highly dynamic, and balance methods used to assess apparent mineralization were estimates at best. It would be useful to quantify variability in mineral N supply over the course of the growing season in order to better identify sources and losses of N, especially when there existed the potential for lateral redistribution in the landscape. To this end, both conventional soil tests or ion-exchange membranes could be used to develop a time series within season.

iii. Phenological timing of soil moisture stress can be as critical to grain yield and quality as the net amount of precipitation received over the course of the growing season. As a result, the relative distribution of precipitation over the course of the growing season is also important in seeking a sufficiently consistent economic return to N fertilization within a given LEC. A more intensified schedule of *available* soil moisture measurement is required to address this concern (future study should define the lower limit of water availability at each sample point, due to soil textural and genetic variability). To this end, the use of tensiometers and neutron attenuation should be considered.

8. CONTRIBUTION TO KNOWLEDGE

Variability in productive potential and response to crop amendments in the glacial depositional soil-landscapes of Western Canada has long been recognized. Interest in managing this variability has heightened, due to our recently improved ability to quantify yield variation and to precisely apply crop amendments.

In seeking more efficient application of crop inputs, including N fertilizer, it has become evident that agronomy, not technology, limits current efforts to implement variable rate fertilization (VRF) at a production scale. Problems include the inability to accurately quantify resource variability in the soil-landscape and the inability to relate to this variability to productivity and efficiency. Most importantly, only probabilistic predictions of growing season environmental conditions are available, but weather is the single largest source of variability in the relationship between crop production and underlying, systematic soil-landscape variability. We have asserted that long-term empirical research is required to evaluate within-field management units for VRF.

This study provides useful information for producers and agronomists interested in VRF. In undulating glacial till Black Chernozems, convergent LECs would most likely benefit from increased rates of N fertilizer under typically moisture-deficient growing season conditions. Nonetheless, it would be premature to create LEC-specific N fertilizer prescriptions without further study.

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10. APPENDICES

Appendix I. Detailed descriptions of soil series found within the study site, as classified by Fitzmaurice et al. (1999).

Angusville series:

"The Angusville series is characterized by a Gleyed Eluviated Black Chernozemic soil profile developed on a moderately to strongly calcareous, slightly stony, fine loamy (L-CL) morainal till of limestone, granitic and shale bedrock origin. These soils are imperfectly drained and occur in lower to mid slope positions of undulating to hummocky landscapes, in close association with the well drained Newdale, Rufford and Cordova soils, the imperfectly drained Varcoe series, and the poorly drained Drokan and Penrith series. Surface runoff is slow to moderately slow; permeability is moderately slow to slow within the solum and moderately slow in the subsoil. Vegetation on non-cultivated land consists of grasses and trembling aspen."

Newdale series:

"The Newdale series is characterized by an Orthic Black Chernozemic solum developed on moderately to strongly loamy (CL) morainal till of limestone, granitic rock and shale origin. These soils are well drained and occur in mid to upper slope positions of undulating to hummocky landscapes. Surface runoff is moderate to moderately rapid; permeability is moderately slow. Most of these soils are presently cultivated; they have formed under intermixed aspen grove and grassland vegetation.

The Newdale solum has a black to very dark gray Ah horizon, commonly 20 cm thick and ranging from 15 to 40 cm, a dark brown Bm horizon, 10 to 15 cm thick, may be present in shallower soils but is not evident in deeper profiles, Its solum depth averages 40 cm and ranges from 25 to 60 cm. Minor amounts of well drained Eluviated Black soils occur within the Newdale mapping units. These eluviated soils range from 75 cm to greater than 1 m in depth. They have thick A (combined Ah, Ahe) horizons, 30 to 60 cm and Bt horizons that are 40 cm thick.

The Newdale soils in the study area differ from the very similar Rufford and Cordova soils in being more strongly leached, thicker and free of lime carbonate in the A and B horizons."

Varcoe series:

"The Varcoe series is characterized by a Gleyed Rego Black (carbonated) Chernozemic solum on moderately to strongly calcareous, loamy (L, CL) morainal till of limestone, granitic rock and shale origins. These soils are imperfectly drained and occur in the lower slope positions of undulating to hummocky landscapes in close association with Angusville soils. They receive runoff from the upper slopes, and in some landscapes, may be influenced by seepage from adjacent lower lying areas. Permeability is slow and may be restricted during periods of subsoil saturation. In areas where seepage waters contain soluble salts, there may be a risk of soil salinization.

Varcoe profiles average 42 cm in thickness and range from 20 to 60 cm. The A horizon is usually 25 cm thick and ranges from 20 to 50 cm; very dark gray in color and is underlain by a dark gray transitional AC horizon, 4 to 8 cm thick. A lime accumulation horizon may be present, but is often thin and discontinuous."

Appendix IIa. Static soil properties observed at individual sampling points: Location and topographic attributes as described by Pennock et al. (1987).

Transect	Point	UTM E/W	UTM N/S	Relative Elevation (m)	Gradient (°)	Profile Curvature (°/m)	Plan Curvature (°/m)	Global Catchment (m^2x100)	Local Catchment (m^2x 100)
1	1	367595	5566139	4.2	0.7	0.1	3.0	0	0
1	2	367567	5566127	3.9	0.3	0.0	-2.2	0	0
1	3	367540	5566115	3.9	0.6	0.0	-7.2	14	3
1	4	367512	5566102	3.6	0.4	0.0	-11.4	4	4
1	5	367497	5566096	3.6	0.4	0.1	-3.0	0	0
1	6	367485	5566091	3.4	1.0	0.1	-1.6	0	0
1	7	367458	5566077	2.9	1.7	0.0	-0.7	3	3
1	8	367443	5566071	2.6	2.0	0.0	2.6	0	0
1	9	367430	5566065	2.1	2.1	0.0	2.9	0	0
1	10	367418	5566059	1.7	1.9	0.0	3.1	1	1
1	11	367403	5566052	1.2	1.8	0.0	0.9	3	3
1	12	367391	5566047	0.8	1.6	-0.1	-0.2	4	4
1	13	367376	5566040	0.5	0.4	-0.1	-5.1	44	44
1	14	367363	5566034	0.6	0.4	0.0	-5.2	60	35
1	15	367348	5566027	0.8	0.6	0.1	5.7	0	0
1	16	367321	5566015	0.9	0.6	0.0	-4.6	42	17
1	17	367294	5566002	1.3	0.7	0.0	-1.4	3	3
1	18	367266	5565990	1.5	0.9	0.0	-1.1	2	2
1	19	367239	5565978	1.9	0.9	0.0	-1.6	2	2
1	20	367212	5565966	2.2	0.4	0.0	3.1	0	0
1	21	367185	5565954	2.2	0.6	0.0	1.0	0	0
2	1	367602	5566129	4.0	1.2	0.1	0.2	1	1
2	2	367574	5566116	3.9	0.1	0.1	-30.9	0	0
2	3	367562	5566111	3.9	0.3	-0.1	-2.8	11	11
2	4	367547	5566104	3.9	0.6	0.0	2.4	0	0
2	5	367519	5566092	3.5	0.3	-0.1	-12.6	24	13
2	6	367491	5566079	3.6	0.4	0.1	8.0	0	0
2	7	367478	5566073	3.5	1.3	0.1	6.4	0	0
2	8	367464	5566067	3.2	1.4	-0.1	7.5	0	0
2	9	367449	5566059	2.8	2.0	0.1	4.6	0	0
2	10	367436	5566054	2.3	2.3	0.0	2.8	0	0
2	11	367423	5566048	1.7	1.7	0.0	2.5	0	0
2	12	367410	5566042	1.2	1.7	0.0	2.5	0	0
2	13	367397	5566036	0.8	1.7	0.0	1.3	1	1
2	14	367382	5566029	0.5	0.2	-0.1	-9.2	109	84
2	15	367355	5566017	0.8	0.6	0.1	-3.1	1	1
2	16	367328	5566005	0.9	0.6	0.0	-1.6	0	0
2	17	367301	5565993	1.2	0.5	0.0	-4.8	26	1
2	18	367274	5565980	1.4	0.5	0.0	-5.0	12	12
2	19	367246	5565968	1.8	0.9	0.0	1.1	4	4
2	20	367219	5565956	2.1	0.5	0.0	1.5	0	0
2	21	367191	5565943	2.2	0.5	0.0	-1.6	1	1
3	1	367604	5566119	3.7	1.3	0.0	-1.7	4	4
3	2	367576	5566106	4.0	0.6	0.1	5.2	0	0

Transect	Point	UTM E/W	UTM N/S	Relative Elevation (m)	Gradient (°)	Profile Curvature (°/m)	Plan Curvature (°/m)	Global Catchment (m^2x100)	Local Catchment (m^2 x 100)
3	3	367563	5566099	4.0	0.4	0.0	2.9	0	0
3	4	367549	5566095	4.0	0.6	0.1	6.5	0	0
3	5	367522	5566082	3.5	0.5	-0.1	-2.1	4	4
3	6	367495	5566069	3.6	0.7	0.1	4.7	0	0
3	7	367480	5566065	3.5	1.8	0.1	2.9	0	0
3	8	367468	5566057	3.1	2.1	0.1	1.7	0	0
3	9	367454	5566051	2.7	2.2	0.1	1.8	1	1
3	10	367440	5566045	2.0	2.6	0.0	0.9	1	1
3	11	367427	5566039	1.5	2.4	0.0	0.5	0	0
3	12	367414	5566033	1.1	1.5	0.0	2.8.	1	1
3	13	367400	5566026	0.8	1.6	0.0	1.5	0	0
3	14	367386	5566020	0.4	0.1	-0.2	2.3	124	95
3	15	367359	5566007	0.8	0.3	0.1	-1.5	4	0
3	16	367331	5565994	1.0	0.8	0.0	1.4	1	1
3	17	367304	5565982	1.3	0.4	0.1	5.0	0	0
3	18	367277	5565970	1.4	0.3	0.0	-5.1	0	0
3	19	367250	5565958	1.7	1.0	0.0	1.1	2	2
3	20	367222	5565945	2.0	0.9	0.1	-0.4	1	1
3	21	367195	5565933	2.1	0.5	0.0	-8.5	5	5
4	1	367611	5566107	3.5	0.9	-0.1	-2.3	5	5
4	2	367583	5566096	4.0	1.2	0.1	4.9	0	0
4	3	367569	5566090	4.1	0.6	0.1	4.0	0	0
4	4	367556	5566084	3.7	0.8	0.0	3.3	0	0
4	5	367529	5566071	3.6	0.6	0.0	7.7	0	0
4	6	367502	5566059	3.4	1.0	0.1	0.7	0	0
4	7	367488	5566053	3.1	1.9	0.1	-1.2	1	1
4	8	367475	5566047	2.7	2.5	0.0	-0.3	1	1
4	9	367462	5566041	2.3	2.5	0.0	0.2	1	1
4	10	367447	5566034	1.8	2.7	0.0	0.6	2	2
4	11	367432	5566027	1.2	1.9	-0.1	-0.3	1	1
4	12	367419	5566022	1.0	1.6	0.0	0.9	3	3
4	13	367405	5566015	0.7	1.2	-0.1	2.2	0	0
4	14	367391	5566009	0.4	0.5	-0.1	-4.7	126	97
4	15	367364	5565997	0.9	0.3	0.1	5.0	0	0
4	16	367337	5565985	1.0	0.9	0.0	5.1	0	0
4	17	367309	5565972	1.3	0.4	0.0	2.8	1	1
4	18	367282	5565960	1.5	0.1	0.1	24.2	0	0
4	19	367256	5565947	1.5	1.0	0.0	0.4	3	3
4	20	367229	5565935	1.7	1.3	-0.1	-1.2	9	9
4	21	367201	5565922	2.1	0.9	0.0	0.0	0	0
5	1	367614	5566098	3.4	0.5	0.0	-0.4	6	6
5	2	367587	5566085	3.6	1.9	0.0	1.1	1	1
5	3	367572	5566079	3.8	1.2	0.0	4.2	0	0
5	4	367559	5566073	3.7	1.1	0.0	1.2	1	1
5	5	367532	5566061	3.5	0.8	0.0	4.8	0	0
5	6	367505	5566048	3.3	1.0	0.1	0.8	35	24
5	7	367491	5566042	2.8	1.8	0.1	-2.9	37	26

Transect	Point	UTM E/W	UTM N/S	Relative Elevation (m)	Gradient (°)	Profile Curvature (°/m)	Plan Curvature (°/m)	Global Catchment (m^2x100)	Local Catchment (m^2 x 100)
5	8	367477	5566036	2.3	2.1	0.0	-2.8	2	2
5	9	367465	5566030	2.0	2.1	0.0	-1.4	2	2
5	10	367450	5566023	1.4	2.3	-0.1	-1.1	6	6
5	11	367435	5566016	1.0	1.6	-0.1	-2.5	3	3
5	12	367422	5566011	0.7	1.4	0.0	-1.8	2	2
5	13	367409	5566005	0.4	1.4	0.0	-0.6	4	4
5	14	367395	5565999	0.4	0.7	-0.1	-5.0	128	99
5	15	367368	5565986	0.7	0.8	0.0	5.1	0	0
5	16	367341	5565975	0.9	1.4	0.0	0.9	1	1
5	17	367313	5565962	1.2	0.5	0.0	-3.4	4	4
5	18	367286	5565949	1.4	0.4	0.1	3.3	0	0
5	19	367259	5565937	1.3	1.0	0.0	-1.1	4	4
5	20	367232	5565925	1.6	0.9	0.0	-6.3	28	28
5	21	367205	5565912	2.2	1.1	0.0	0.8	1	1
6	1	367620	5566086	3.3	1.0	0.1	3.1	4	4
6	2	367593	5566073	3.2	1.2	-0.1	-1.9	4	4
6	3	367566	5566061	3.6	1.0	0.0	5.8	0	0
6	4	367538	5566049	3.4	1.0	0.0	1.6	1	1
6	5	367525	5566044	3.2	0.9	0.0	0.3	1	1
6	6	367511	5566038	3.2	0.8	0.1	1.4	0	0
6	7	367498	5566032	2.9	1.7	0.1	-0.8	1	1
6	8	367483	5566025	2.2	1.7	0.0	-4.5	48	37
6	9	367471	5566020	1.4	1.6	0.0	-7.1	54	43
6	10	367456	5566014	0.9	1.9	0.0	-3.6	60	49
6	11	367440	5566007	0.6	1.4	0.0	-2.1	73	62
6	12	367429	5566002	0.3	1.1	0.0	-2.3	78	67
6	13	367415	5565995	0.3	1.0	0.0	-0.9	82	71
6	14	367401	5565989	0.5	0.7	-0.1	-0.4	129	100
6	15	367373	5565976	0.6	0.9	0.0	5.6	0	0
6	16	367346	5565963	0.6	1.4	0.0	0.7	2	2
6	17	367319	5565950	1.1	1.4	0.0	-0.1	1	1
6	18	367292	5565938	1.2	1.2	0.0	1.1	1	1
6	19	367264	5565925	1.2	0.5	0.0	-6.4	51	51
6	20	367236	5565913	1.6	1.7	-0.1	0.7	1	1
6	21	367210	5565901	2.3	1.9	0.0	0.7	1	1
7	1	367625	5566076	3.2	1.6	0.1	1.4	0	0
7	2	367597	5566063	3.0	1.0	0.0	-1.0	5	5
7	3	367569	5566051	3.4	1.0	0.0	6.7	0	0
7	4	367542	5566039	3.1	0.9	0.0	-2.0	2	2
7	5	367527	5566033	3.1	0.7	0.0	-2.2	7	7
7	6	367513	5566027	3.1	0.6	0.0	9.5	0	0
7	7	367501	5566021	2.9	1.5	0.0	5.0	0	0
7	8	367487	5566014	2.5	1.6	0.0	4.7	0	0
7	9	367476	5566009	2.0	1.8	0.0	3.2	1	1
7	10	367460	5566002	1.5	2.1	0.0	1.7	0	0
7	11	367443	5565995	0.8	1.4	0.0	-1.8	2	2
7	12	367432	5565990	0.6	1.2	0.0	-1.5	37	21

Transect	Point	UTM E/W	UTM N/S	Relative Elevation (m)	Gradient (°)	Profile Curvature (°/m)	Plan Curvature (°/m)	Global Catchment (m^2x100)	Local Catchment (m^2 x 100)
7	13	367417	5565983	0.3	0.6	-0.1	-2.8	39	23
7	14	367405	5565977	0.2	0.2	0.0	-6.6	232	192
7	15	367378	5565964	0.4	0.9	-0.1	2.2	1	1
7	16	367351	5565952	0.4	1.2	0.0	-0.3	10	10
7	17	367324	5565940	0.8	1.5	0.0	0.4	1	1
7	18	367297	5565927	1.0	0.7	-0.1	-1.5	2	2
7	19	367269	5565915	1.1	0.6	0.0	-1.1	5	5
7	20	367241	5565903	1.7	2.0	-0.1	0.3	2	2
7	21	367214	5565891	2.7	1.6	0.1	3.3	0	0
8	1	367629	5566066	2.8	1.6	-0.1	0.0	1	1
8	2	367616	5566059	3.0	1.4	-0.1	-3.1	33	33
8	3	367601	5566052	2.9	1.0	0.0	0.7	0	0
8	4	367574	5566040	3.1	1.1	0.0	2.5	0	0
8	5	367561	5566033	3.1	0.7	0.0	3.1	0	0
8	6	367547	5566027	2.9	0.9	0.0	-5.0	14	14
8	7	367520	5566016	3.0	1.1	0.1	2.9	0	0
8	8	367502	5566011	2.9	1.5	0.0	5.0	0	0
8	9	367492	5566004	2.5	1.7	0.0	1.8	0	0
8	10	367479	5565996	2.0	1.9	0.0	0.2	1	1
8	11	367465	5565991	1.5	1.8	0.0	-2.6	8	8
8	12	367452	5565984	1.0	1.6	0.0	-4.2	29	13
8	13	367439	5565978	0.7	1.4	0.0	-1.4	1	1
8	14	367411	5565965	0.2	0.3	0.0	-4.5	45	29
8	15	367383	5565954	0.1	0.0	0.0	-102.3	309	253
8	16	367356	5565943	0.2	0.8	-0.1	-4.2	132	132
8	17	367329	5565931	0.6	1.1	0.0	-5.8	108	108
8	18	367301	5565919	0.9	0.4	0.0	-9.7	97	97
8	19	367274	5565905	1.2	0.6	0.0	-0.1	5	5
8	20	367247	5565891	1.7	2.1	-0.1	2.0	2	2
8	21	367219	5565878	3.0	0.8	0.2	14.1	0	0
9	1	367633	5566055	2.4	0.9	-0.1	-2.2	7	7
9	2	367606	5566043	2.7	1.0	0.0	1.0	0	0
9	3	367593	5566036	2.7	1.1	0.0	-1.6	8	8
9	4	367579	5566030	2.9	1.0	0.0	-2.0	1	1
9	5	367565	5566023	3.0	0.6	0.0	4.0	0	0
9	6	367552	5566017	2.8	1.1	0.0	-0.6	1	1
9	7	367525	5566006	2.7	1.4	0.0	1.9	1	1
9	8	367511	5565999	2.6	1.6	0.0	1.7	0	0
9	9	367497	5565993	2.3	1.6	0.0	2.6	1	1
9	10	367483	5565987	1.9	1.6	0.0	2.9	0	0
9	11	367470	5565981	1.5	1.4	0.0	-1.5	19	3
9	12	367458	5565975	1.1	1.5	0.0	0.6	2	2
9	13	367442	5565969	0.9	1.4	0.1	2.9	0	0
9	14	367415	5565958	0.2	0.8	-0.1	-3.9	11	11
9	15	367387	5565947	0.2	0.5	0.0	2.8	0	0
9	16	367360	5565934	0.1	0.5	-0.1	-0.4	4	4
9	17	367332	5565921	0.5	1.0	0.0	0.7	1	1

Transect	Point	UTM E/W	UTM N/S	Relative Elevation (m)	Gradient (°)	Profile Curvature (°/m)	Plan Curvature (°/m)	Global Catchment (m^2x100)	Local Catchment (m^2 x 100)
9	18	367305	5565909	0.9	0.6	0.0	3.8	1	1
9	19	367277	5565896	1.2	0.4	0.0	1.6	1	1
9	20	367250	5565885	1.6	2.0	-0.1	-0.5	3	3
9	21	367223	5565872	2.8	1.6	0.0	3.0	0	0
10	1	367639	5566045	2.3	0.7	0.0	-3.7	10	10
10	2	367612	5566033	2.5	0.8	0.0	-1.1	1	1
10	3	367584	5566020	2.8	0.9	0.0	1.1	1	1
10	4	367571	5566014	2.9	0.7	0.0	7.9	0	0
10	5	367557	5566008	2.7	1.3	0.0	0.3	1	1
10	6	367544	5566002	2.5	1.0	0.0	-2.9	2	2
10	7	367530	5565996	2.4	1.0	-0.1	2.4	2	2
10	8	367516	5565990	2.3	1.4	0.0	-0.5	0	0
10	9	367503	5565984	2.0	1.2	-0.1	-0.8	5	5
10	10	367489	5565977	1.8	0.9	-0.1	0.2	0	0
10	11	367476	5565971	1.6	1.3	0.0	-1.7	1	1
10	12	367462	5565964	1.3	1.6	0.0	-0.1	1	1
10	13	367449	5565958	0.9	1.4	0.0	1.4	3	3
10	14	367421	5565945	0.4	0.8	0.1	-1.3	2	2
10	15	367394	5565933	0.3	0.3	0.0	15.3	0	0
10	16	367367	5565921	0.1	0.4	-0.1	0.7	4	4
10	17	367339	5565909	0.5	1.1	0.0	0.0	1	1
10	18	367311	5565897	0.8	0.7	0.0	1.9	1	1
10	19	367284	5565884	1.2	0.7	0.1	2.0	0	0
10	20	367258	5565873	1.6	1.7	-0.1	0.0	6	6
10	21	367229	5565861	2.5	1.2	0.0	-1.1	2	2

Appendix IIb. Static soil properties at individual sampling points: LEC membership, soil series and solum properties.

Transect	Point	LEC	Soil Series	A Horizon Depth (cm)	Solum Depth (cm)	Depth to Calcium Carbonate (cm)	Ap Horizon pH	Ap Horizon OC (%)	Ap Horizon OC (Mg/ha)
1	1	U	Newdale	25	25	25	6.5	2.2	69
1	2	U	Newdale	30	49	49	6.4	2.6	71
1	3	U	Newdale	15	57	57	5.6	2.9	46
1	4	U	Newdale	19	53	53	5.9	2.0	52
1	5	U	Newdale	15	26	26	5.9	2.1	39
1	6	U	Angusville	25	45	45	6.1	2.3	65
1	7	M	Newdale	27	50	50	6.6	2.2	63
1	8	M	Newdale	13	28	28	6.1	1.5	24
1	9	M	Newdale	13	28	28	6.1	2.0	37
1	10	M	Newdale	18	32	32	6.6	2.3	50
1	11	M	Varcoe	23	23	23	6.5	1.9	57
1	12	L	Newdale	32	51	57	6.3	2.5	89
1	13	L	Angusville	37	60	70	6.2	3.6	118
1	14	L	Angusville	41	82	82	6.0	3.4	125
1	15	L	Varcoe	12	25	12	6.6	2.6	36
1	16	M	Angusville	20	37	37	6.7	3.1	49
1	17	M	Newdale	22	45	45	6.6	2.7	69
1	18	M	Newdale	26	41	41	6.5	2.6	78
1	19	M	Newdale	20	26	26	6.6	2.0	51
1	20	M	Angusville	37	80	80	6.2	3.0	69
1	21	M	Angusville	32	56	56	6.3	3.7	106
2	1	U	Newdale	21	21	12	6.2	1.9	33
2	2	U	Angusville	26	80	80	6.0	2.4	54
2	3	U	Angusville	24	44	44	5.9	3.4	79
2	4	U	Newdale	13	22	22	5.9	2.3	35
2	5	U	Angusville	25	99	99	5.9	2.5	61
2	6	U	Newdale	10	29	29	6.3	1.6	15
2	7	U	Newdale	9	9	0	7.0	1.7	16
2	8	M	Newdale	13	23	23	7.2	2.1	26
2	9	M	Newdale	14	33	33	5.9	1.2	25
2	10	M	Newdale	14	14	14	6.0	1.8	27
2	11	M	Newdale	22	37	37	6.0	1.9	50
2	12	M	Newdale	12	22	12	6.1	1.7	21
2	13	M	Varcoe	23	23	23	6.8	2.1	57
2	14	L	Angusville	37	140	140	6.1	3.3	116
2	15	L	Varcoe	20	20	10	6.6	2.6	64
2	16	M	Newdale	25	68	68	6.2	3.9	109
2	17	M	Newdale	13	37	37	6.8	2.2	34
2	18	M	Angusville	36	74	74	6.6	3.1	70
2	19	M	Newdale	27	39	27	6.7	2.4	69
2	20	M	Newdale	26	40	26	6.6	2.4	67
2	21	M	Angusville	27	60	60	6.3	3.9	83
3	1	M	Newdale	15	37	37	6.1	1.6	35
3	2	U	Newdale	14	30	30	5.9	2.1	29
3	3	U	Newdale	7	21	21	6.0	1.0	6

Transect	Point	LEC	Soil Series	A Horizon Depth (cm)	Solum Depth (cm)	Depth to Calcium Carbonate (cm)	Ap Horizon pH	Ap Horizon OC (%)	Ap Horizon OC (Mg/ha)
3	4	U	Newdale	16	16	16	6.8	1.6	28
3	5	U	Angusville	45	78	112	5.7	2.2	80
3	6	U	Newdale	20	20	20	6.9	1.3	33
3	7	U	Newdale	25	25	0	.	1.7	48
3	8	U	Newdale	18	34	18	6.6	1.1	26
3	9	U	Newdale	17	25	25	5.8	1.8	31
3	10	M	Newdale	10	20	10	5.3	1.8	18
3	11	M	Newdale	18	29	29	5.7	1.6	40
3	12	M	Newdale	11	26	26	5.9	1.8	21
3	13	M	Varcoe	14	14	0	.	1.7	35
3	14	L	Angusville	42	69	79	6.0	2.6	100
3	15	L	Newdale	12	30	30	6.3	2.1	30
3	16	M	Newdale	21	27	27	6.4	2.9	67
3	17	M	Newdale	16	34	34	6.9	2.5	48
3	18	M	Angusville	31	49	49	6.6	3.6	101
3	19	M	Newdale	22	22	36	6.6	3.1	59
3	20	M	Newdale	22	36	36	6.6	2.9	66
3	21	M	Newdale	16	34	34	6.2	2.8	49
4	1	M	Angusville	32	52	62	6.3	2.3	83
4	2	U	Newdale	9	19	9	6.2	1.6	16
4	3	U	Newdale	17	29	17	6.2	1.1	24
4	4	U	Newdale	19	35	35	6.1	1.8	38
4	5	U	Newdale	12	24	24	6.3	2.0	30
4	6	U	Newdale	16	37	37	6.2	1.9	35
4	7	M	Newdale	22	37	37	6.8	1.8	40
4	8	M	Newdale	27	45	45	6.5	1.9	60
4	9	M	Newdale	26	39	26	6.3	2.2	65
4	10	M	Newdale	19	38	19	6.1	1.5	34
4	11	M	Newdale	12	26	26	6.1	2.0	31
4	12	L	Angusville	32	45	45	6.2	2.3	62
4	13	L	Varcoe	16	16	9	6.9	2.6	43
4	14	L	Angusville	60	80	80	6.7	2.1	106
4	15	L	Newdale	23	38	23	6.7	2.6	69
4	16	M	Newdale	12	22	32	6.4	1.9	29
4	17	M	Newdale	25	42	42	6.4	2.5	63
4	18	M	Newdale	20	20	13	6.5	2.6	62
4	19	M	Newdale	18	18	18	7.0	1.4	72
4	20	M	Newdale	18	48	48	6.3	3.0	56
4	21	M	Newdale	9	26	9	6.7	2.6	29
5	1	M	Newdale	13	24	24	6.3	2.2	31
5	2	M	Newdale	16	38	38	5.9	2.4	47
5	3	M	Newdale	12	25	25	5.7	1.9	26
5	4	U	Newdale	14	35	39	5.7	2.1	32
5	5	U	Newdale	21	29	29	6.6	2.8	66
5	6	M	Newdale	12	32	32	5.6	2.0	28
5	7	M	Newdale	12	29	29	5.2	1.9	25
5	8	M	Newdale	20	56	56	5.8	1.9	44
5	9	M	Newdale	11	29	29	6.0	2.0	28

Transect	Point	LEC	Soil Series	A Horizon Depth (cm)	Solum Depth (cm)	Depth to Calcium Carbonate (cm)	Ap Horizon pH	Ap Horizon OC (%)	Ap Horizon OC (Mg/ha)
5	10	M	Newdale	17	33	33	5.7	1.9	35
5	11	M	Newdale	29	50	50	5.8	2.6	76
5	12	L	Newdale	30	53	53	6.7	2.1	68
5	13	L	Varcoe	29	29	19	6.6	2.6	128
5	14	L	Newdale	37	48	48	7.2	2.8	100
5	15	M	Varcoe	14	14	0	7.0	2.5	31
5	16	M	Varcoe	19	19	25	6.6	2.0	52
5	17	M	Newdale	24	54	54	6.1	2.6	67
5	18	M	Newdale	19	19	19	6.7	2.5	54
5	19	M	Newdale	25	25	11	6.7	2.6	57
5	20	M	Newdale	18	38	38	6.5	2.1	47
5	21	M	Newdale	18	30	30	6.8	2.4	48
6	1	M	Newdale	26	44	44	6.7	2.0	67
6	2	M	Newdale	25	47	47	6.1	2.1	58
6	3	M	Newdale	20	36	20	7.0	1.9	46
6	4	M	Newdale	12	24	24	6.3	2.1	29
6	5	U	Newdale	22	44	44	6.2	2.7	69
6	6	U	Newdale	14	38	38	6.5	2.0	36
6	7	M	Newdale	18	28	18	6.2	2.2	43
6	8	M	Newdale	13	30	35	6.6	1.9	27
6	9	M	Newdale	9	30	30	5.9	2.1	20
6	10	M	Varcoe	21	21	21	6.4	2.1	49
6	11	L	Angusville	37	71	71	6.3	2.7	105
6	12	L	Varcoe	39	39	24	6.7	3.2	149
6	13	L	Newdale	16	60	60	6.6	2.9	63
6	14	L	Varcoe	15	27	15	6.9	2.1	32
6	15	L	Varcoe	19	29	19	7.1	1.9	45
6	16	L	Varcoe	18	39	23	6.7	2.3	47
6	17	M	Newdale	28	39	39	6.1	2.8	76
6	18	M	Newdale	17	36	36	6.7	2.6	49
6	19	M	Newdale	23	38	38	6.7	2.5	62
6	20	M	Newdale	13	27	27	6.5	2.7	35
6	21	M	Newdale	19	45	45	6.4	2.8	56
7	1	M	Newdale	15	23	15	6.9	2.4	42
7	2	M	Angusville	30	57	57	6.0	3.0	88
7	3	M	Newdale	11	27	27	6.4	2.0	23
7	4	M	Newdale	12	28	28	6.2	2.2	31
7	5	M	Angusville	19	35	58	6.0	2.1	30
7	6	U	Newdale	10	24	24	6.1	1.9	18
7	7	M	Newdale	11	29	21	6.3	2.0	26
7	8	M	Newdale	13	13	21	5.9	2.2	40
7	9	M	Newdale	15	27	15	6.6	1.7	22
7	10	M	Newdale	11	19	11	6.7	2.2	25
7	11	L	Newdale	35	50	50	6.4	3.2	101
7	12	L	Newdale	18	44	44	6.4	2.4	45
7	13	L	Varcoe	42	42	42	6.4	4.1	151
7	14	L	Angusville	29	52	52	6.5	3.4	104
7	15	L	Varcoe	26	26	12	7.0	2.7	70

Transect	Point	LEC	Soil Series	A Horizon Depth (cm)	Solum Depth (cm)	Depth to Calcium Carbonate (cm)	Ap Horizon pH	Ap Horizon OC (%)	Ap Horizon OC (Mg/ha)
7	16	L	Newdale	17	27	36	6.9	2.5	52
7	17	M	Newdale	23	41	41	6.9	3.0	80
7	18	M	Newdale	15	25	25	6.6	2.9	49
7	19	M	Newdale	22	35	35	6.7	3.0	78
7	20	M	Newdale	23	23	23	6.9	2.2	68
7	21	U	Newdale	16	16	33	6.9	1.5	58
8	1	M	Newdale	28	32	28	6.6	2.4	79
8	2	L	Angusville	21	50	50	6.2	2.2	57
8	3	M	Newdale	12	21	12	6.3	2.5	34
8	4	M	Newdale	11	18	18	6.1	2.3	31
8	5	M	Newdale	13	34	34	5.8	2.4	34
8	6	M	Angusville	20	40	40	5.6	2.6	33
8	7	M	Newdale	13	24	24	6.0	1.9	28
8	8	M	Newdale	11	20	20	6.3	1.6	19
8	9	M	Newdale	16	34	34	6.0	1.8	38
8	10	M	Newdale	23	36	36	6.2	2.1	54
8	11	M	Newdale	20	34	34	5.9	2.2	45
8	12	M	Newdale	25	39	39	6.1	2.4	66
8	13	L	Varcoe	21	21	11	6.6	2.5	57
8	14	L	Angusville	50	86	95	6.3	3.7	181
8	15	L	Angusville	38	75	75	6.6	3.5	147
8	16	L	Angusville	40	66	66	6.6	3.0	112
8	17	L	Newdale	17	50	50	6.7	1.9	38
8	18	M	Angusville	20	45	45	5.8	3.0	49
8	19	M	Newdale	25	42	42	6.2	3.5	87
8	20	M	Newdale	29	36	36	6.6	2.3	78
8	21	U	Newdale	13	13	0	6.9	1.2	25
9	1	L	Angusville	33	77	77	6.4	3.0	91
9	2	L	Newdale	13	22	13	6.2	2.6	41
9	3	L	Newdale	20	56	56	6.0	3.2	62
9	4	M	Angusville	19	39	39	5.8	2.6	40
9	5	M	Newdale	8	15	8	6.3	1.5	14
9	6	M	Newdale	13	34	34	5.9	1.4	20
9	7	M	Newdale	11	24	24	5.8	1.9	26
9	8	M	Newdale	13	21	21	5.6	1.3	17
9	9	M	Newdale	14	34	34	5.7	1.9	28
9	10	M	Newdale	18	31	31	5.7	1.7	34
9	11	M	Newdale	20	20	24	5.9	1.5	41
9	12	M	Newdale	21	30	30	6.0	2.2	55
9	13	L	Varcoe	9	9	9	6.5	1.8	17
9	14	L	Angusville	48	80	80	6.5	3.4	141
9	15	L	Varcoe	31	46	20	6.7	3.1	101
9	16	L	Angusville	50	90	112	6.7	3.1	152
9	17	L	Varcoe	20	20	0	7.3	1.6	41
9	18	M	Newdale	16	36	36	6.0	2.4	39
9	19	M	Newdale	31	46	46	6.1	3.2	95
9	20	M	Angusville	34	48	48	6.7	1.9	69
9	21	U	Newdale	11	22	11	6.7	1.7	20

Transect	Point	LEC	Soil Series	A Horizon Depth (cm)	Solum Depth (cm)	Depth to Calcium Carbonate (cm)	Ap Horizon pH	Ap Horizon OC (%)	Ap Horizon OC (Mg/ha)
10	1	L	Angusville	33	53	53	6.3	2.7	86
10	2	L	Angusville	28	45	45	5.9	3.2	59
10	3	L	Newdale	11	26	39	6.4	2.0	27
10	4	M	Newdale	8	18	23	6.4	1.8	12
10	5	M	Newdale	12	33	33	5.9	2.7	35
10	6	M	Angusville	33	42	42	5.8	1.8	57
10	7	M	Angusville	25	47	60	5.6	2.2	45
10	8	M	Newdale	14	29	29	5.4	1.9	28
10	9	M	Newdale	19	41	41	5.8	2.1	45
10	10	M	Newdale	27	48	48	5.8	1.7	57
10	11	M	Newdale	15	31	15	6.4	1.8	34
10	12	M	Newdale	16	39	16	6.1	2.1	42
10	13	L	Newdale	15	27	27	6.4	1.9	37
10	14	L	Newdale	16	24	24	6.5	2.8	49
10	15	L	Varcoe	22	22	22	6.7	1.7	47
10	16	L	Angusville	34	65	74	6.5	2.7	114
10	17	L	Newdale	10	32	32	6.6	1.8	19
10	18	M	Newdale	15	35	41	6.6	2.7	42
10	19	M	Newdale	29	36	18	6.3	2.6	66
10	20	M	Newdale	15	28	28	6.4	2.1	39
10	21	U	Newdale	10	21	10	6.5	1.8	17

Appendix IIc. Composite bulk density calculated for each 30 cm increment based on overall average bulk densities of soil genetic profiles (g soil/cm^3).

Transect	Point	0-30 cm	30-60 cm	60-90 cm	90-120 cm
1	1	1.17	1.43	1.43	1.43
1	2	1.19	1.39	1.43	1.43
1	3	1.26	1.30	1.43	1.43
1	4	1.23	1.32	1.43	1.43
1	5	1.27	1.43	1.43	1.43
1	6	1.21	1.36	1.43	1.43
1	7	1.20	1.36	1.43	1.43
1	8	1.28	1.43	1.43	1.43
1	9	1.28	1.43	1.43	1.43
1	10	1.25	1.42	1.43	1.43
1	11	1.25	1.43	1.43	1.43
1	12	1.19	1.35	1.43	1.43
1	13	1.23	1.31	1.45	1.43
1	14	1.19	1.27	1.34	1.43
1	15	1.30	1.43	1.43	1.43
1	16	1.27	1.43	1.43	1.43
1	17	1.22	1.36	1.43	1.43
1	18	1.20	1.38	1.43	1.43
1	19	1.25	1.43	1.43	1.43
1	20	1.21	1.40	1.35	1.43
1	21	1.19	1.30	1.43	1.43
2	1	1.26	1.43	1.43	1.43
2	2	1.24	1.29	1.35	1.43
2	3	1.21	1.37	1.43	1.43
2	4	1.30	1.43	1.43	1.43
2	5	1.24	1.31	1.31	1.39
2	6	1.29	1.43	1.43	1.43
2	7	1.36	1.43	1.43	1.43
2	8	1.29	1.43	1.43	1.43
2	9	1.24	1.42	1.43	1.43
2	10	1.32	1.43	1.43	1.43
2	11	1.23	1.41	1.43	1.43
2	12	1.31	1.43	1.43	1.43
2	13	1.25	1.43	1.43	1.43
2	14	1.31	1.31	1.31	1.31
2	15	1.27	1.43	1.43	1.43
2	16	1.21	1.33	1.40	1.43
2	17	1.25	1.40	1.43	1.43
2	18	1.24	1.31	1.37	1.43
2	19	1.21	1.41	1.43	1.43
2	20	1.21	1.41	1.43	1.43
2	21	1.24	1.31	1.43	1.43
3	1	1.24	1.40	1.43	1.43
3	2	1.26	1.43	1.43	1.43
3	3	1.33	1.43	1.43	1.43
3	4	1.30	1.43	1.43	1.43
3	5	1.22	1.32	1.38	1.47

Transect	Point	0-30 cm	30-60 cm	60-90 cm	90-120 cm
3	6	1.27	1.43	1.43	1.43
3	7	1.23	1.43	1.43	1.43
3	8	1.26	1.42	1.43	1.43
3	9	1.27	1.43	1.43	1.43
3	10	1.33	1.43	1.43	1.43
3	11	1.25	1.43	1.43	1.43
3	12	1.29	1.43	1.43	1.43
3	13	1.32	1.43	1.43	1.43
3	14	1.20	1.31	1.41	1.43
3	15	1.27	1.43	1.43	1.43
3	16	1.24	1.43	1.43	1.43
3	17	1.26	1.42	1.43	1.43
3	18	1.19	1.34	1.43	1.43
3	19	1.25	1.42	1.43	1.43
3	20	1.23	1.41	1.43	1.43
3	21	1.26	1.42	1.43	1.43
4	1	1.19	1.35	1.43	1.43
4	2	1.33	1.43	1.43	1.43
4	3	1.27	1.43	1.43	1.43
4	4	1.24	1.41	1.43	1.43
4	5	1.28	1.43	1.43	1.43
4	6	1.25	1.40	1.43	1.43
4	7	1.23	1.41	1.43	1.43
4	8	1.20	1.37	1.43	1.43
4	9	1.21	1.41	1.43	1.43
4	10	1.25	1.41	1.43	1.43
4	11	1.27	1.43	1.43	1.43
4	12	1.19	1.35	1.43	1.43
4	13	1.30	1.43	1.43	1.43
4	14	1.19	1.19	1.35	1.43
4	15	1.25	1.43	1.43	1.43
4	16	1.32	1.43	1.43	1.43
4	17	1.21	1.39	1.43	1.43
4	18	1.27	1.43	1.43	1.43
4	19	1.27	1.43	1.43	1.43
4	20	1.25	1.37	1.43	1.43
4	21	1.32	1.43	1.43	1.43
5	1	1.28	1.43	1.43	1.43
5	2	1.25	1.40	1.43	1.43
5	3	1.29	1.43	1.43	1.43
5	4	1.25	1.42	1.43	1.43
5	5	1.24	1.43	1.43	1.43
5	6	1.27	1.42	1.43	1.43
5	7	1.27	1.43	1.43	1.43
5	8	1.24	1.34	1.43	1.43
5	9	1.26	1.43	1.43	1.43
5	10	1.25	1.42	1.43	1.43
5	11	1.20	1.36	1.43	1.43
5	12	1.19	1.35	1.43	1.43
5	13	1.19	1.41	1.43	1.43

Transect	Point	0-30 cm	30-60 cm	60-90 cm	90-120 cm
5	14	1.19	1.34	1.43	1.43
5	15	1.32	1.43	1.43	1.43
5	16	1.27	1.43	1.43	1.43
5	17	1.22	1.35	1.43	1.43
5	18	1.28	1.43	1.43	1.43
5	19	1.23	1.43	1.43	1.43
5	20	1.25	1.40	1.43	1.43
5	21	1.25	1.43	1.43	1.43
6	1	1.21	1.38	1.43	1.43
6	2	1.21	1.36	1.43	1.43
6	3	1.25	1.42	1.43	1.43
6	4	1.29	1.43	1.43	1.43
6	5	1.23	1.38	1.43	1.43
6	6	1.24	1.39	1.43	1.43
6	7	1.26	1.43	1.43	1.43
6	8	1.25	1.44	1.43	1.43
6	9	1.29	1.43	1.43	1.43
6	10	1.26	1.43	1.43	1.43
6	11	1.19	1.28	1.39	1.43
6	12	1.19	1.34	1.43	1.43
6	13	1.25	1.31	1.43	1.43
6	14	1.28	1.43	1.43	1.43
6	15	1.25	1.43	1.43	1.43
6	16	1.26	1.40	1.43	1.43
6	17	1.20	1.40	1.43	1.43
6	18	1.25	1.41	1.43	1.43
6	19	1.22	1.40	1.43	1.43
6	20	1.28	1.43	1.43	1.43
6	21	1.24	1.36	1.43	1.43
7	1	1.29	1.43	1.43	1.43
7	2	1.19	1.40	1.43	1.43
7	3	1.29	1.43	1.43	1.43
7	4	1.28	1.43	1.43	1.43
7	5	1.23	1.41	1.43	1.43
7	6	1.29	1.43	1.43	1.43
7	7	1.29	1.43	1.43	1.43
7	8	1.22	1.43	1.43	1.43
7	9	1.28	1.43	1.43	1.43
7	10	1.32	1.43	1.43	1.43
7	11	1.19	1.34	1.43	1.43
7	12	1.25	1.39	1.43	1.43
7	13	1.19	1.33	1.43	1.43
7	14	1.19	1.32	1.43	1.43
7	15	1.22	1.43	1.43	1.43
7	16	1.27	1.44	1.43	1.43
7	17	1.22	1.39	1.43	1.43
7	18	1.28	1.43	1.43	1.43
7	19	1.23	1.41	1.43	1.43
7	20	1.24	1.43	1.43	1.43
7	21	1.29	1.43	1.43	1.43

Transect	Point	0-30 cm	30-60 cm	60-90 cm	90-120 cm
8	1	1.20	1.43	1.43	1.43
8	2	1.30	1.38	1.43	1.43
8	3	1.31	1.43	1.43	1.43
8	4	1.32	1.43	1.43	1.43
8	5	1.27	1.42	1.43	1.43
8	6	1.23	1.39	1.43	1.43
8	7	1.28	1.43	1.43	1.43
8	8	1.31	1.43	1.43	1.43
8	9	1.26	1.42	1.43	1.43
8	10	1.22	1.41	1.43	1.43
8	11	1.24	1.42	1.43	1.43
8	12	1.21	1.40	1.43	1.43
8	13	1.26	1.43	1.43	1.43
8	14	1.19	1.26	1.33	1.45
8	15	1.19	1.28	1.40	1.43
8	16	1.19	1.27	1.41	1.43
8	17	1.23	1.34	1.43	1.43
8	18	1.27	1.40	1.43	1.43
8	19	1.21	1.29	1.43	1.43
8	20	1.19	1.41	1.43	1.43
8	21	1.22	1.43	1.43	1.43
9	1	1.20	1.35	1.37	1.43
9	2	1.31	1.43	1.43	1.43
9	3	1.24	1.33	1.43	1.43
9	4	1.23	1.39	1.43	1.43
9	5	1.35	1.43	1.43	1.43
9	6	1.27	1.42	1.43	1.43
9	7	1.30	1.43	1.43	1.43
9	8	1.30	1.43	1.43	1.43
9	9	1.26	1.42	1.43	1.43
9	10	1.25	1.43	1.43	1.43
9	11	1.27	1.43	1.43	1.43
9	12	1.23	1.43	1.43	1.43
9	13	1.36	1.43	1.43	1.43
9	14	1.19	1.32	1.35	1.43
9	15	1.19	1.39	1.43	1.43
9	16	1.19	1.30	1.31	1.47
9	17	1.27	1.43	1.43	1.43
9	18	1.24	1.40	1.43	1.43
9	19	1.19	1.37	1.43	1.43
9	20	1.19	1.33	1.43	1.43
9	21	1.32	1.43	1.43	1.43
10	1	1.19	1.33	1.43	1.43
10	2	1.20	1.37	1.43	1.43
10	3	1.28	1.35	1.43	1.43
10	4	1.33	1.43	1.43	1.43
10	5	1.27	1.42	1.43	1.43
10	6	1.22	1.29	1.43	1.43
10	7	1.21	1.39	1.43	1.43
10	8	1.25	1.43	1.43	1.43

Transect	Point	0-30 cm	30-60 cm	60-90 cm	90-120 cm
10	9	1.24	1.39	1.43	1.43
10	10	1.20	1.37	1.43	1.43
10	11	1.28	1.43	1.43	1.43
10	12	1.27	1.41	1.43	1.43
10	13	1.27	1.43	1.43	1.43
10	14	1.28	1.43	1.43	1.43
10	15	1.25	1.43	1.43	1.43
10	16	1.19	1.29	1.43	1.43
10	17	1.28	1.42	1.43	1.43
10	18	1.24	1.42	1.43	1.43
10	19	1.20	1.42	1.43	1.43
10	20	1.27	1.43	1.43	1.43
10	21	1.32	1.43	1.43	1.43

Appendix IIIa. Dynamic soil properties at individual sampling points: 1997 volumetric soil moisture content (cm).

		Spring Sample Depths (cm)				Anthesis Sample Depths (cm)				Harvest Sample Depths (cm)			
Transect	**Point**	**0-30**	**30-60**	**60-90**	**90-120**	**0-30**	**30-60**	**60-90**	**90-120**	**0-30**	**30-60**	**60-90**	**90-120**
1	1	9.8	7.8	6.2	6.0	7.3	4.4	5.3	5.4	4.6	4.8	5.0	5.3
1	2	6.8	6.1	7.6	5.5	7.0	4.5	5.7	6.4	5.8	3.0	5.3	6.0
1	3	8.0	6.8	5.7	5.2	7.3	3.8	4.8	6.0	7.0	3.2	5.0	5.8
1	4	8.6	6.7	5.8	5.9	7.9	5.1	5.7	5.7	4.0	3.5	4.2	5.5
1	5	8.5	7.8	7.3	6.1	6.8	6.6	6.1	6.0	4.3	3.7	5.5	6.5
1	6	8.2	7.2	5.9	6.4	6.7	4.7	6.0	5.5	5.6	4.0	5.0	6.3
1	7	8.9	7.2	6.6	5.5	8.8	7.0	5.9	5.8	4.4	4.1	5.3	6.3
1	8	8.7	7.1	6.9	6.8	7.9	5.8	6.5	5.9	5.4	4.8	5.6	7.3
1	9	9.9	8.0	6.7	6.7	7.7	6.8	6.6	6.6	3.5	4.2	6.2	6.5
1	10	7.7	7.2	6.4	7.0	9.0	6.8	6.8	7.4	6.4	3.6	5.5	6.5
1	11	8.0	7.9	7.5	7.5	7.2	5.5	6.5	6.4	4.3	4.1	5.9	6.8
1	12	9.7	8.5	6.8	7.1	7.9	6.3	7.6	7.2	4.4	3.5	6.3	7.2
1	13	10.8	8.2	8.1	8.5	9.3	6.3	7.1	8.9	6.3	4.4	5.1	6.7
1	14	9.9	7.4	7.5	7.9	9.5	6.8	5.3	7.3	6.0	4.7	6.8	7.3
1	15	9.1	12.2	6.6	6.9	8.8	7.1	7.4	7.2	4.8	4.4	6.2	6.9
1	16	10.5	5.0	4.5	5.0	9.2	7.3	4.0	5.1	6.6	5.3	4.3	4.9
1	17	8.4	6.3	6.1	6.2	7.6	5.3	5.6	6.2	5.3	4.2	5.1	5.4
1	18	7.7	7.4	3.4	2.1	6.7	5.0	2.9	6.4	3.4	3.6	3.2	3.5
1	19	8.0	6.6	4.9	5.6	7.6	5.0	6.8	5.7	5.6	2.2	2.9	6.4
1	20	7.3	4.8	5.3	5.8	5.8	5.9	6.1	6.4	4.7	3.1	5.2	8.5
1	21	7.2	4.5	5.6	5.8	7.9	5.4	6.4	7.1	4.1	3.8	3.8	5.9
2	1	8.5	8.1	5.9	5.9	6.6	6.1	6.2	5.8	4.9	6.8	5.1	5.6
2	2	6.5	4.6	6.7	6.6	8.7	4.6	7.5	7.5	5.0	4.0	5.8	6.8
2	3	11.1	7.2	6.1	6.3	8.2	6.4	5.3	6.6	6.3	6.4	5.7	6.0
2	4	9.4	8.6	6.0	6.3	7.9	6.4	6.4	6.1	7.3	6.0	5.0	6.2
2	5	7.2	8.8	6.1	5.9	8.1	7.0	5.6	6.2	5.3	5.0	6.2	6.2
2	6	7.6	7.6	6.8	5.3	6.9	6.7	6.4	6.7	4.6	4.1	6.0	6.6
2	7	10.6	9.1	7.1	7.4	9.4	8.0	7.8	6.0	7.0	5.2	6.9	7.4
2	8	7.4	8.4	7.6	7.5	8.2	7.1	7.2	6.3	6.5	4.7	6.5	7.0
2	9	7.4	7.6	6.7	7.0	6.4	6.3	7.2	6.6	5.5	4.6	6.8	6.5
2	10	7.8	7.4	6.5	7.6	6.5	4.0	5.5	5.6	6.9	4.0	5.9	6.6
2	11	11.0	7.2	5.9	6.1	6.9	5.5	5.4	7.2	6.7	3.3	5.9	5.7
2	12	9.1	8.8	7.8	7.9	8.1	6.9	7.6	7.7	6.1	4.6	6.8	7.1
2	13	9.6	10.3	10.6	8.0	8.0	8.6	8.2	8.2	7.3	5.4	7.9	7.4
2	14	13.4	8.1	8.7	5.3	9.6	6.8	6.6	4.4	6.5	3.7	4.0	7.5
2	15	8.6	5.6	8.2	7.8	9.6	6.8	7.2	7.2	8.2	3.8	6.2	6.9
2	16	11.8	5.6	7.3	5.7	9.6	6.4	6.0	6.3	8.4	5.2	7.2	10.2
2	17	8.3	8.2	6.8	3.7	9.0	6.1	7.1	6.8	7.4	4.7	6.2	7.0
2	18	9.3	6.1	5.9	6.9	7.2	4.5	2.2	6.6	7.8	3.5	4.9	6.4
2	19	9.8	5.3	4.9	4.1	8.1	6.1	6.6	4.5	7.6	5.2	5.1	5.2
2	20	8.2	5.3	5.1	6.1	7.7	6.5	6.8	9.9	7.9	4.4	2.9	5.0
2	21	9.2	7.4	8.0	7.8	7.8	6.2	6.4	6.4	7.2	4.7	4.6	5.9
3	1	8.5	7.2	6.6	6.3	8.1	7.2	6.7	5.8	5.1	4.7	4.8	6.8
3	2	7.3	5.9	6.1	6.8	7.7	5.3	7.1	6.0	7.0	3.7	6.4	6.6
3	3	7.3	5.8	5.8	5.7	9.3	5.6	6.3	5.7	5.6	4.5	5.3	5.3
3	4	7.2	7.9	7.0	6.6	7.4	4.9	6.3	6.1	6.7	4.6	5.5	6.0

		Spring Sample Depths (cm)				Anthesis Sample Depths (cm)				Harvest Sample Depths (cm)			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
3	5	9.6	6.8	5.1	6.6	7.7	6.3	5.3	5.6	5.0	5.2	5.4	6.2
3	6	6.8	6.7	5.3	6.1	5.8	5.6	3.4	7.6	5.0	3.2	2.9	5.6
3	7	7.8	7.6	6.8	6.6	7.2	5.3	6.0	6.3	4.8	4.1	5.9	6.4
3	8	7.2	7.1	6.1	6.7	6.6	6.6	6.2	6.3	4.7	3.5	5.9	6.5
3	9	7.0	6.7	5.2	6.5	7.4	5.1	6.4	6.2	5.9	4.9	6.4	6.4
3	10	8.4	7.7	6.4	6.4	6.8	6.7	5.9	6.1	4.7	5.1	6.1	6.5
3	11	8.4	7.7	4.8	6.6	6.8	4.6	6.4	6.4	5.2	2.6	5.8	7.0
3	12	7.9	7.2	7.4	7.2	7.4	6.3	6.8	6.8	5.7	2.9	7.3	7.1
3	13	9.4	8.8	8.8	7.4	8.5	8.3	8.2	7.3	7.7	5.5	7.3	6.9
3	14	9.1	8.9	9.2	9.0	8.2	7.3	8.8	7.4	7.0	5.1	7.4	7.1
3	15	8.0	8.8	7.4	6.8	8.0	5.8	7.4	7.6	4.7	4.6	6.1	7.0
3	16	9.8	8.4	6.4	6.7	9.4	6.2	6.4	6.4	6.1	4.4	6.3	6.5
3	17	8.4	7.8	7.9	7.2	8.8	6.3	7.0	6.2	6.7	3.7	5.9	7.0
3	18	11.3	6.7	5.4	7.0	9.6	6.7	6.4	6.8	7.7	4.7	5.8	6.7
3	19	9.9	7.6	4.3	6.0	8.3	6.6	6.4	5.7	4.9	4.3	4.6	6.3
3	20	4.7	8.7	10.0	6.3	8.6	5.5	8.3	6.9	7.1	4.8	5.4	6.6
3	21	8.3	8.3	7.8	7.6	6.9	6.4	6.9	7.4	5.2	3.9	6.2	6.1
4	1	10.5	6.9	5.2	5.5	6.3	6.8	5.7	5.4	5.8	4.7	5.3	5.5
4	2	7.5	8.1	6.2	6.0	7.5	6.2	6.3	6.4	5.7	4.6	5.8	6.2
4	3	5.8	5.2	2.4	2.4	5.5	4.8	6.4	6.3	3.5	1.7	3.3	3.9
4	4	6.2	7.2	6.1	6.1	5.3	5.5	6.5	6.2	4.6	3.9	5.7	6.1
4	5	8.6	7.1	7.0	6.5	7.2	5.9	6.6	6.1	6.0	4.6	5.1	6.4
4	6	5.9	7.6	7.4	6.6	6.7	5.8	6.2	6.3	4.8	2.8	5.8	6.1
4	7	8.1	6.7	6.3	6.0	7.1	6.4	6.9	6.5	5.2	4.3	6.0	6.5
4	8	7.5	7.7	6.4	6.2	6.2	5.4	5.8	6.4	5.0	4.3	5.6	6.0
4	9	7.5	5.6	4.6	6.0	6.9	4.8	6.5	6.6	3.6	3.4	5.4	5.7
4	10	6.4	6.4	6.5	6.4	6.7	5.6	5.8	7.0	3.7	4.1	5.7	6.5
4	11	7.8	8.0	7.0	6.6	7.1	6.8	7.5	6.7	5.3	3.9	5.5	6.3
4	12	7.8	7.2	6.2	7.0	7.4	6.3	8.0	7.7	5.3	2.8	4.8	4.0
4	13	8.8	9.1	7.6	7.0	7.8	6.8	7.5	7.0	5.4	6.6	7.2	6.9
4	14	8.7	7.5	8.6	9.2	7.9	5.8	7.4	7.7	7.2	4.5	9.1	7.9
4	15	8.8	8.5	6.8	7.0	7.0	6.4	6.9	7.0	5.4	4.3	6.3	6.6
4	16	6.3	6.0	5.9	6.6	7.9	6.0	6.7	6.6	4.0	4.0	5.7	6.3
4	17	8.0	6.4	5.3	4.8	8.2	6.2	8.4	6.9	6.2	3.6	6.1	5.3
4	18	10.9	8.1	5.5	7.0	7.7	5.7	6.2	6.6	5.7	4.2	6.4	6.3
4	19	9.0	7.8	5.1	5.8	7.6	4.9	4.1	6.7	5.8	4.3	6.3	7.0
4	20	9.6	6.5	5.1	5.6	7.6	5.3	6.4	5.3	5.3	4.2	5.1	5.9
4	21	9.5	8.3	6.5	6.3	8.0	4.5	4.4	4.0	6.4	4.1	6.7	7.0
5	1	9.4	7.4	6.7	5.8	8.6	7.0	5.6	5.4	7.1	5.6	5.2	5.4
5	2	7.0	7.0	5.4	6.4	6.5	5.3	6.5	5.9	6.7	3.9	5.0	5.3
5	3	8.6	7.7	6.3	6.1	7.7	5.7	5.9	6.3	6.1	3.9	5.1	6.5
5	4	7.1	6.7	5.7	5.9	7.5	5.2	5.8	5.6	6.3	5.0	5.4	6.3
5	5	7.4	7.8	6.5	6.2	7.3	5.5	5.3	5.9	7.2	4.0	5.3	6.3
5	6	6.5	7.3	6.0	6.2	7.6	5.8	6.4	6.7	6.4	4.1	6.1	5.8
5	7	6.3	7.9	7.4	7.0	6.9	6.9	7.2	5.9	5.1	4.2	6.9	7.0
5	8	7.8	4.4	5.2	6.5	6.5	5.1	5.7	6.8	5.6	3.7	5.9	5.9
5	9	7.1	8.1	6.1	6.5	6.5	5.4	5.9	6.3	6.0	4.8	5.4	5.6
5	10	6.1	5.9	9.0	6.2	4.5	2.4	3.3	3.4	6.1	4.1	4.1	4.4
5	11	8.3	6.8	4.8	5.8	7.6	5.6	5.4	5.0	6.7	4.3	6.8	7.3

		Spring Sample Depths (cm)				Anthesis Sample Depths (cm)				Harvest Sample Depths (cm)			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
5	12	8.7	7.1	5.2	7.0	6.9	3.9	4.0	6.2	3.8	4.3	4.9	6.5
5	13	10.1	10.5	8.0	5.6	7.4	6.5	7.4	7.7	7.5	5.8	4.9	4.9
5	14	8.8	8.8	10.7	8.2	9.5	8.4	8.2	7.7	6.4	7.3	8.9	7.8
5	15	8.8	6.6	4.0	6.6	7.3	6.0	7.6	6.1	7.1	4.3	6.7	7.2
5	16	8.0	7.2	5.8	6.1	6.4	5.5	5.5	5.3	6.5	4.6	4.4	5.4
5	17	8.3	3.9	5.0	5.9	7.3	4.6	3.3	6.1	6.0	4.2	4.9	5.1
5	18	8.6	8.9	7.1	6.2	6.6	6.9	6.7	5.8	7.1	4.5	5.6	6.3
5	19	8.0	4.6	2.4	2.9	5.9	4.7	3.0	4.5	5.0	3.3	4.7	4.8
5	20	8.0	7.1	6.7	6.7	6.5	5.1	7.0	7.3	6.7	2.8	5.8	5.9
5	21	8.9	6.4	6.7	6.5	7.7	4.1	7.0	6.5	7.3	4.1	5.8	5.9
6	1	8.4	7.3	5.9	6.2	7.7	6.1	6.3	6.3	5.5	4.2	3.4	5.0
6	2	8.1	3.5	4.5	4.7	8.4	5.3	5.0	5.6	3.8	3.9	4.9	5.4
6	3	8.8	8.7	6.6	6.3	8.2	5.7	6.9	6.1	6.7	4.8	5.5	6.3
6	4	9.0	7.5	5.9	6.3	7.4	6.2	6.5	6.4	5.7	4.0	5.0	6.4
6	5	8.3	5.4	3.0	5.5	6.5	7.1	2.3	2.4	4.2	3.9	1.5	6.1
6	6	8.4	7.0	5.8	6.1	7.8	6.0	7.2	6.2	5.4	5.1	5.2	5.8
6	7	8.1	6.7	6.1	6.7	7.1	5.1	6.2	2.3	5.3	4.0	6.2	6.2
6	8	7.0	7.1	6.2	6.3	5.8	3.3	5.5	6.5	4.1	4.4	6.1	6.4
6	9	9.7	6.3	5.2	6.6	6.9	5.7	6.6	6.0	4.5	3.8	6.6	5.9
6	10	7.6	7.3	6.3	6.5	8.5	6.3	3.8	4.7	5.0	3.7	3.7	4.7
6	11	9.6	6.2	6.4	5.6	8.5	5.6	6.3	6.4	7.3	3.6	4.8	6.1
6	12	9.1	5.5	6.8	7.6	10.1	10.0	8.3	7.1	7.1	5.8	8.1	7.7
6	13	11.9	15.7	8.7	6.0	9.5	6.1	5.1	6.4	5.5	3.9	8.8	9.9
6	14	10.1	10.6	9.2	9.8	8.8	7.5	7.8	7.5	5.6	4.7	7.7	7.1
6	15	8.7	8.1	7.7	7.4	7.8	6.8	4.9	7.0	5.8	4.8	5.5	6.0
6	16	8.4	6.9	7.5	6.9	8.2	5.2	6.0	6.4	5.9	3.1	5.9	6.5
6	17	8.5	7.9	7.6	7.5	6.3	3.5	5.5	6.9	5.1	3.9	6.2	6.0
6	18	9.1	8.1	6.6	6.2	7.0	6.0	7.7	6.4	6.1	4.6	5.2	5.5
6	19	8.6	6.2	7.6	7.5	7.4	4.7	6.6	7.7	6.1	3.5	4.0	5.0
6	20	7.9	5.6	6.5	7.8	7.9	5.4	6.8	9.9	5.7	2.4	5.4	6.5
6	21	9.3	6.8	5.7	5.8	7.2	5.8	6.3	5.9	5.6	3.9	5.3	5.9
7	1	8.1	6.0	6.1	6.3	7.2	4.5	5.4	6.3	5.8	3.3	5.4	6.2
7	2	9.4	6.9	4.1	5.6	7.1	5.4	5.9	6.3	4.7	4.1	5.4	6.3
7	3	8.9	8.6	6.4	4.7	7.3	5.0	5.6	5.9	6.3	4.2	4.8	5.8
7	4	7.9	8.2	6.5	6.2	7.7	7.2	6.7	6.1	5.3	3.9	5.5	5.9
7	5	7.7	7.0	7.6	7.2	5.1	4.3	7.7	7.9	5.5	4.3	4.6	5.0
7	6	6.9	7.1	6.4	6.7	7.1	6.8	7.5	6.8	5.6	3.8	6.3	6.1
7	7	7.8	7.9	6.8	6.8	6.9	5.8	6.3	7.1	5.1	4.0	5.7	6.7
7	8	7.6	7.7	7.0	7.1	7.4	6.3	6.8	6.8	5.0	4.2	5.8	6.7
7	9	5.0	7.7	4.3	6.0	7.0	5.2	5.8	5.4	5.6	4.1	5.8	6.0
7	10	6.2	7.9	4.1	7.2	7.7	6.3	7.4	6.4	6.2	3.9	6.2	7.0
7	11	7.5	4.2	3.8	5.1	6.9	4.8	4.3	3.6	6.4	3.1	5.9	5.9
7	12	7.5	7.5	5.1	6.9	8.0	5.9	6.3	6.5	7.3	4.5	7.0	6.5
7	13	7.9	9.4	8.1	5.8	9.2	7.1	5.1	4.3	8.3	5.7	7.5	5.5
7	14	10.6	7.2	4.0	3.8	8.1	7.3	7.4	7.3	6.1	5.0	4.8	8.0
7	15	8.7	10.7	8.4	7.2	7.8	8.5	8.3	7.9	7.8	5.5	6.4	6.9
7	16	7.9	8.2	7.8	6.6	8.3	6.4	6.9	6.7	6.7	3.6	8.0	7.5
7	17	7.3	6.8	5.4	5.7	6.8	5.5	5.1	5.9	6.5	4.0	6.1	6.9
7	18	9.5	7.2	6.2	8.1	6.7	3.2	6.5	9.1	4.8	3.6	3.5	4.8

		Spring Sample Depths (cm)				Anthesis Sample Depths (cm)				Harvest Sample Depths (cm)			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
7	19	10.3	9.0	6.1	5.1	8.5	6.0	5.4	5.3	6.8	4.9	4.3	5.2
7	20	8.9	9.5	8.7	7.0	7.8	7.5	7.2	7.6	5.4	4.4	4.8	6.5
7	21	6.7	7.3	5.3	4.2	6.5	5.4	7.2	7.7	4.4	3.3	2.4	2.0
8	1	7.8	8.2	7.0	6.6	7.6	5.7	7.3	6.2	4.6	4.4	5.9	6.4
8	2	8.6	6.1	3.5	7.3	7.7	5.4	6.9	6.4	4.5	4.3	3.4	6.2
8	3	8.3	7.1	5.9	6.0	8.2	4.3	6.7	5.9	4.7	4.5	6.2	6.9
8	4	9.3	8.4	6.1	6.5	7.7	6.4	6.6	6.2	5.4	5.4	5.7	6.1
8	5	8.9	7.5	5.6	5.6	6.3	3.2	2.8	2.8	2.7	2.1	6.5	7.0
8	6	8.4	8.3	8.7	7.3	7.4	6.6	6.9	6.3	4.5	3.0	5.3	6.3
8	7	8.2	7.3	7.8	6.9	6.6	6.0	6.5	6.1	5.5	4.5	6.2	6.5
8	8	7.7	8.7	6.9	7.0	7.1	6.0	6.4	5.8	4.8	3.7	6.0	6.5
8	9	7.2	6.6	5.1	5.3	6.9	5.9	6.2	5.9	5.3	3.0	4.4	6.0
8	10	7.9	7.5	4.8	5.5	7.3	5.7	6.2	5.7	4.5	3.0	4.8	5.7
8	11	8.3	6.2	6.0	5.9	7.3	5.8	7.0	6.9	3.8	3.9	5.2	5.7
8	12	8.9	7.2	7.0	6.5	8.2	5.0	5.9	6.7	5.8	2.9	5.5	6.3
8	13	8.3	8.2	6.9	6.0	6.6	6.1	6.9	6.9	5.9	6.3	6.8	7.0
8	14	11.9	11.0	8.9	5.7	9.9	7.1	7.3	9.0	6.8	4.2	6.6	6.2
8	15	11.5	6.7	7.8	7.5	9.8	6.6	8.0	7.9	7.7	5.6	8.3	7.8
8	16	10.0	7.3	4.3	6.3	7.9	5.0	4.4	7.1	6.1	4.7	7.8	7.8
8	17	8.0	4.8	4.0	4.6	6.4	3.9	5.9	6.1	4.9	3.1	4.0	4.6
8	18	11.1	6.3	3.8	4.8	8.0	7.3	7.1	6.4	6.8	4.4	5.1	5.7
8	19	9.5	8.7	7.0	5.7	10.3	7.3	6.9	5.8	6.2	4.9	6.3	6.9
8	20	6.3	5.2	5.0	5.0	6.0	4.3	5.7	6.1	5.3	3.4	5.4	5.4
8	21	4.6	4.3	2.9	1.9	4.9	3.8	2.1	2.4	3.4	2.0	2.5	2.1
9	1	9.3	7.8	6.2	5.6	7.7	6.3	7.2	4.2	5.9	4.9	6.9	8.2
9	2	6.6	6.4	5.1	5.7	6.9	6.4	6.6	6.3	3.9	5.9	5.4	6.0
9	3	8.2	4.0	6.6	3.6	7.4	5.8	5.2	5.7	7.4	5.1	5.2	4.6
9	4	8.3	6.2	5.9	6.1	7.4	6.2	6.3	6.3	6.1	4.0	4.5	5.8
9	5	5.8	7.0	6.3	6.5	7.6	6.5	6.4	6.6	5.9	5.4	5.4	6.9
9	6	7.1	7.1	5.3	6.9	6.1	5.2	5.8	6.1	7.7	4.1	5.9	6.5
9	7	6.8	6.5	6.2	6.0	6.8	5.5	6.2	6.1	7.3	5.0	5.8	6.4
9	8	7.9	6.0	5.6	5.8	6.7	6.0	6.5	6.4	7.4	4.5	4.8	6.2
9	9	6.2	6.7	5.9	6.2	5.9	6.1	6.7	6.1	6.3	4.0	6.0	6.3
9	10	7.2	6.3	5.6	5.4	5.7	4.3	5.9	6.4	6.2	4.2	6.3	6.4
9	11	7.6	9.9	5.7	6.4	7.9	5.2	6.9	6.6	5.6	4.5	6.1	6.5
9	12	7.3	7.4	6.8	6.3	7.2	5.3	6.6	6.5	7.5	4.0	6.4	5.8
9	13	8.7	7.7	8.7	6.9	7.4	6.9	7.2	7.0	7.3	5.5	6.3	6.6
9	14	12.1	6.7	8.1	4.9	10.6	7.8	8.1	7.4	7.4	5.2	6.8	7.8
9	15	8.7	8.4	8.7	8.9	10.1	7.3	7.9	9.5	6.9	5.0	7.8	9.4
9	16	10.3	7.9	7.4	7.6	9.3	6.7	5.3	6.8	8.7	4.2	5.2	5.2
9	17	10.1	8.6	7.5	7.5	7.3	6.6	7.1	7.3	6.6	6.3	5.5	6.5
9	18	8.0	5.7	6.1	5.8	7.2	5.7	5.9	5.8	4.2	4.6	5.2	5.7
9	19	8.5	5.9	5.4	5.2	7.4	3.4	4.7	5.5	5.3	4.0	4.8	5.5
9	20	7.2	5.6	6.7	7.6	6.3	4.3	4.7	6.6	5.5	3.8	5.1	5.2
9	21	6.5	6.4	6.8	8.4	5.7	3.8	5.5	4.5	4.8	4.0	5.1	4.9
10	1	9.8	9.3	6.3	6.6	8.4	6.9	6.2	6.4	6.2	4.6	6.7	6.6
10	2	7.7	6.4	6.3	6.4	7.2	5.3	4.5	5.9	7.0	4.4	5.8	6.4
10	3	7.6	6.1	6.4	6.2	7.4	7.1	7.7	6.8	6.8	4.0	5.8	6.6
10	4	7.4	6.9	6.1	5.9	8.1	6.9	7.3	6.9	6.6	5.9	5.8	6.7

		Spring Sample Depths (cm)				Anthesis Sample Depths (cm)				Harvest Sample Depths (cm)			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
10	5	6.8	5.1	5.4	5.0	7.3	5.0	6.4	6.5	5.6	3.9	4.6	5.3
10	6	7.5	5.0	6.2	5.7	7.0	6.6	6.1	6.3	5.2	5.3	5.8	6.6
10	7	7.5	5.9	3.3	5.2	7.1	5.7	4.3	6.4	6.2	3.9	3.9	2.8
10	8	7.4	6.0	5.3	6.6	7.4	6.1	7.0	6.4	4.8	4.1	5.0	5.7
10	9	7.5	5.6	4.2	3.6	6.3	5.7	8.2	6.4	5.1	4.1	5.2	8.3
10	10	7.6	4.7	5.6	5.6	6.4	5.9	7.0	5.9	7.4	4.8	6.3	6.4
10	11	7.4	7.4	6.6	5.9	5.6	5.0	6.4	6.7	6.7	3.0	6.1	6.6
10	12	7.2	5.7	5.1	4.9	8.1	4.7	3.2	3.9	3.9	4.6	6.2	7.2
10	13	8.4	6.4	6.2	6.7	8.5	6.1	7.1	6.6	7.7	5.1	6.7	6.7
10	14	9.9	10.3	9.4	7.4	8.5	5.7	8.1	7.6	6.9	4.7	6.9	6.6
10	15	8.9	8.1	8.7	7.1	9.6	8.9	8.7	8.3	6.1	4.9	7.6	7.2
10	16	10.0	6.5	7.2	7.4	8.8	5.6	8.0	8.4	6.4	5.6	6.7	7.0
10	17	8.6	8.9	8.0	7.1	7.5	6.1	7.2	7.8	6.7	5.2	5.6	6.4
10	18	8.1	7.7	6.4	5.8	7.0	6.1	6.5	5.8	6.8	4.2	5.7	6.0
10	19	8.8	5.7	6.0	6.4	7.4	5.9	6.3	6.1	5.8	4.3	5.0	5.6
10	20	8.3	6.2	6.3	6.4	8.3	6.1	5.5	6.3	6.0	4.3	5.4	5.9
10	21	7.6	8.4	6.8	6.5	7.2	6.9	7.6	7.7	6.3	4.0	7.2	6.8

Appendix IIIb. Dynamic soil properties at individual sampling points: 1998 volumetric soil moisture content (cm).

		Spring Sample Depths (cm)				Anthesis Sample Depths (cm)				Harvest Sample Depths (cm)			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
1	1	6.0	4.7	5.0	5.3	10.2	8.8	8.3	6.4	6.7	5.3	5.4	6.0
1	2	8.3	7.4	5.3	6.0	10.5	8.3	8.2	8.4	8.3	7.1	5.9	6.9
1	3	7.4	4.3	5.0	5.8	12.4	8.1	7.7	8.5	8.0	4.7	6.0	6.9
1	4	7.5	6.7	4.2	5.5	8.8	7.8	8.2	7.4	7.3	6.5	6.9	6.6
1	5	6.8	5.3	5.4	6.5	8.3	7.0	7.7	7.5	6.7	7.3	6.9	7.3
1	6	7.0	5.2	5.0	6.3	10.1	7.7	7.9	7.5	7.6	6.3	6.5	6.5
1	7	7.9	4.9	5.3	6.3	9.2	7.8	7.6	8.0	8.1	7.4	6.7	6.9
1	8	7.9	6.4	5.6	7.3	10.4	8.2	7.5	7.8	8.2	5.3	6.5	5.8
1	9	8.1	8.2	6.2	6.5	8.7	9.6	7.9	7.7	7.4	7.1	6.9	7.8
1	10	8.2	7.3	5.5	6.5	9.0	9.5	8.9	7.7	8.0	7.1	7.5	7.6
1	11	7.5	6.2	5.9	6.8	10.0	10.0	8.6	7.3	8.4	7.6	6.6	7.4
1	12	8.8	3.7	6.3	7.2	10.5	8.3	8.8	8.4	7.0	5.9	7.0	7.4
1	13	9.9	5.5	5.1	6.7	13.3	8.9	7.4	7.3	9.7	5.8	9.0	9.6
1	14	10.1	9.6	6.8	7.3	10.3	7.6	7.8	7.7	8.6	8.0	7.0	8.1
1	15	9.3	6.7	6.2	6.9	9.5	9.4	9.0	8.4	8.3	9.2	7.6	6.9
1	16	10.0	5.8	4.3	4.9	12.4	9.1	7.7	8.4	8.8	8.3	4.7	6.5
1	17	7.4	5.3	5.1	5.4	11.3	8.9	7.7	7.9	8.7	7.0	6.5	7.1
1	18	8.4	5.5	3.2	3.5	8.9	8.8	7.2	7.1	8.1	4.6	4.7	5.4
1	19	8.4	6.4	2.9	6.4	9.4	9.2	7.5	7.6	7.1	6.2	4.2	5.8
1	20	7.6	2.1	5.2	8.5	10.1	4.7	8.3	8.0	7.0	4.3	6.2	7.0
1	21	6.3	3.8	3.8	5.9	11.1	9.2	7.0	7.3	7.0	4.9	6.1	6.6
2	1	7.3	4.7	5.1	5.6	9.8	9.5	8.3	7.1	7.8	6.9	7.1	6.8
2	2	8.8	4.3	5.8	6.8	11.2	7.6	8.0	8.8	8.9	5.5	7.1	6.8
2	3	7.1	4.4	5.6	6.0	12.4	9.2	9.2	8.1	8.2	6.7	6.7	7.4
2	4	8.8	4.6	5.0	6.2	9.5	9.0	8.7	7.1	6.8	6.8	6.6	7.3
2	5	9.2	6.2	6.2	6.2	10.1	10.7	9.2	7.7	8.2	7.6	6.3	7.1
2	6	5.5	5.2	6.0	6.6	9.1	8.6	10.2	8.1	7.8	8.4	7.9	7.5
2	7	8.4	7.8	6.9	7.4	11.3	10.4	9.3	7.9	9.7	8.7	8.4	8.1
2	8	7.1	6.5	6.5	7.0	10.6	8.8	8.5	8.0	7.5	8.7	8.2	7.7
2	9	6.8	4.5	6.8	6.5	8.6	9.1	7.9	7.4	7.1	7.1	6.8	7.3
2	10	7.4	6.0	5.9	6.6	9.0	8.1	8.8	7.9	7.8	8.0	7.2	7.3
2	11	7.4	6.6	5.9	5.7	9.4	7.7	8.7	7.8	7.2	6.5	7.7	7.7
2	12	7.4	6.3	6.8	7.1	10.9	8.9	8.1	8.2	8.0	7.7	7.2	7.3
2	13	8.2	7.9	7.9	7.4	10.7	9.6	10.0	8.7	8.6	8.6	8.4	8.2
2	14	11.0	8.3	4.0	7.5	12.7	9.4	9.6	11.5	11.0	8.7	7.9	6.4
2	15	7.6	6.1	6.2	6.9	11.5	9.9	8.9	8.3	8.4	7.8	7.9	7.3
2	16	9.5	8.5	7.2	10.2	12.6	10.4	8.8	8.3	9.4	5.8	6.4	7.5
2	17	7.7	6.7	6.2	7.0	10.5	9.4	8.8	8.2	8.2	6.4	6.4	7.3
2	18	9.1	4.4	4.9	6.4	12.2	8.4	8.6	8.4	7.5	4.5	8.1	7.7
2	19	6.8	5.2	5.0	5.2	10.5	9.5	9.0	7.6	8.5	6.7	6.2	4.9
2	20	7.8	3.8	2.8	5.0	9.4	7.3	6.2	6.7	8.3	7.5	6.8	9.9
2	21	8.8	4.1	4.6	5.9	12.6	8.3	10.0	8.3	8.2	7.9	7.5	6.4
3	1	6.7	2.2	4.8	6.8	9.5	7.9	7.5	8.2	7.3	5.2	7.3	7.3
3	2	7.5	3.7	6.4	6.6	12.5	9.3	9.2	9.1	9.3	8.7	7.5	7.9
3	3	6.8	6.2	5.3	5.3	10.1	9.2	8.0	8.1	8.5	8.0	8.2	7.3
3	4	7.0	6.1	5.5	6.0	10.7	8.7	7.8	6.2	7.9	8.8	8.4	7.9

		Spring Sample Depths (cm)				Anthesis Sample Depths (cm)				Harvest Sample Depths (cm)			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
3	5	8.2	5.9	5.4	6.2	8.6	8.3	9.1	8.9	8.5	8.2	8.6	8.5
3	6	7.1	4.5	2.9	5.6	10.3	9.0	7.4	8.0	6.6	6.9	6.3	6.3
3	7	7.2	5.1	5.9	6.4	6.6	7.2	8.3	7.8	7.9	9.2	9.0	9.0
3	8	6.3	4.9	5.9	6.5	9.3	10.0	8.3	7.6	7.2	8.6	8.0	7.9
3	9	6.3	5.3	6.3	6.4	7.9	8.9	7.7	8.1	6.9	8.7	7.5	7.5
3	10	6.9	5.2	6.1	6.5	9.4	8.7	8.4	8.2	7.4	8.0	8.2	7.6
3	11	6.9	5.6	5.8	7.0	9.0	8.7	8.5	7.8	6.7	7.1	7.5	7.7
3	12	7.6	7.4	7.2	7.1	9.8	7.2	9.0	7.8	6.9	8.2	9.4	7.7
3	13	8.6	7.9	7.3	6.9	9.7	7.5	9.6	9.5	8.8	9.1	8.6	8.1
3	14	9.4	6.1	7.4	7.1	9.3	8.8	10.4	13.7	9.5	7.7	8.8	8.5
3	15	4.8	5.8	6.1	7.0	10.4	11.5	8.6	7.8	6.4	8.1	8.0	8.1
3	16	7.7	5.9	6.3	6.5	8.4	10.1	9.5	8.2	9.6	7.8	7.8	8.0
3	17	7.2	6.6	5.9	7.0	10.8	7.4	9.5	9.1	7.4	8.2	10.3	7.9
3	18	7.9	4.7	5.8	6.7	8.9	9.3	10.3	9.1	8.5	7.5	7.3	7.2
3	19	9.1	6.8	4.6	6.3	13.3	9.3	9.4	8.6	9.7	9.5	7.5	8.3
3	20	8.2	5.1	5.4	6.6	11.6	10.2	9.0	7.7	8.4	8.1	7.6	7.3
3	21	8.1	5.0	6.2	6.1	10.8	9.3	10.3	9.8	6.9	6.9	9.9	8.6
4	1	9.8	4.5	5.2	5.5	9.6	9.0	8.2	9.2	7.6	6.9	7.4	6.7
4	2	7.6	4.5	5.8	6.2	10.0	8.9	8.4	7.5	7.0	7.2	7.1	7.1
4	3	4.5	3.0	3.3	3.9	9.0	8.1	6.8	8.6	6.6	3.9	4.2	6.0
4	4	5.2	4.6	5.7	6.1	7.8	7.4	7.9	7.2	6.9	7.5	7.3	7.0
4	5	6.5	5.0	5.1	6.4	9.4	7.6	8.3	7.8	9.0	7.1	7.5	7.6
4	6	6.5	7.3	5.8	6.1	11.4	7.8	7.7	7.4	4.7	7.1	6.8	7.0
4	7	6.1	5.1	6.0	6.5	7.6	5.3	8.4	7.3	7.9	7.4	7.2	6.7
4	8	7.3	4.1	5.6	6.0	8.0	8.8	7.7	7.4	6.8	5.9	6.8	6.5
4	9	3.9	4.5	5.4	5.7	10.1	8.3	8.8	8.5	7.0	6.6	7.2	6.9
4	10	6.2	5.4	5.7	6.5	9.2	8.5	8.4	7.3	6.0	7.5	7.3	7.3
4	11	7.3	5.5	5.4	6.3	8.9	8.6	8.2	7.5	7.1	8.7	8.2	7.9
4	12	7.5	4.0	4.8	4.0	8.3	8.0	7.2	8.6	7.6	5.5	7.5	7.5
4	13	8.7	8.2	7.2	6.9	11.2	8.4	9.2	9.4	9.6	8.9	8.5	7.8
4	14	6.8	6.5	9.1	7.9	9.1	8.8	10.8	9.4	9.3	7.3	8.5	8.2
4	15	7.9	5.1	6.2	6.6	11.6	10.1	8.7	7.6	8.0	8.0	7.8	7.9
4	16	7.2	5.6	5.7	6.3	11.8	8.2	8.8	7.9	6.8	8.2	7.3	6.9
4	17	6.1	4.8	6.1	5.3	11.0	9.4	8.7	8.2	7.5	6.9	6.6	6.7
4	18	7.6	5.1	6.4	6.3	9.9	9.0	11.6	10.3	9.0	7.9	7.2	7.1
4	19	7.8	3.6	6.2	7.0	12.7	10.9	7.5	7.5	9.2	10.9	8.1	6.6
4	20	7.9	4.3	5.1	5.9	10.4	8.4	8.5	8.2	8.4	7.1	7.4	7.8
4	21	8.7	7.9	6.7	7.0	11.1	8.1	9.5	8.2	8.1	7.8	8.1	7.7
5	1	7.3	4.9	5.2	5.4	9.9	9.5	9.0	9.3	7.3	6.2	5.8	6.6
5	2	7.1	5.0	5.0	5.3	9.5	8.8	8.4	8.2	6.7	5.1	5.6	5.7
5	3	7.7	4.3	5.1	6.4	11.0	9.4	8.4	8.1	6.3	4.8	5.8	6.4
5	4	7.8	5.0	5.4	6.3	9.1	9.6	9.4	8.0	6.5	5.5	5.7	6.1
5	5	8.0	6.5	5.3	6.3	8.4	9.6	8.3	8.1	6.1	5.8	6.3	6.6
5	6	7.2	5.5	6.1	5.8	10.4	9.4	8.1	7.9	5.5	5.9	6.0	6.2
5	7	7.6	6.5	6.9	7.0	10.4	10.0	8.5	8.2	6.4	6.8	5.5	6.0
5	8	5.2	4.1	5.9	5.9	8.6	8.9	7.7	8.2	6.4	4.6	5.3	5.2
5	9	4.2	4.9	5.4	5.6	11.5	8.0	9.1	8.0	6.7	5.6	5.8	6.3
5	10	5.1	3.3	4.1	4.4	7.9	6.8	4.5	5.7	5.2	7.0	6.3	6.7
5	11	6.8	5.2	6.8	7.3	7.8	7.0	7.0	7.5	7.5	6.6	6.3	7.4

		Spring Sample Depths (cm)				Anthesis Sample Depths (cm)				Harvest Sample Depths (cm)			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
5	12	8.5	3.9	4.9	6.5	9.9	8.7	6.3	9.2	8.7	6.9	6.2	6.9
5	13	8.7	7.1	4.9	4.9	11.7	8.1	7.3	9.0	8.1	8.2	7.1	6.6
5	14	8.3	8.7	8.9	7.8	11.0	12.7	11.9	10.2	7.9	7.6	8.4	7.9
5	15	7.8	6.5	6.6	7.2	11.2	10.6	12.7	11.3	8.0	6.1	6.4	6.5
5	16	5.5	4.3	4.4	5.4	10.3	10.4	9.6	10.5	7.7	7.2	6.1	6.5
5	17	5.8	4.0	4.9	5.1	8.5	8.5	8.9	8.6	7.4	4.6	6.1	6.2
5	18	6.2	5.1	5.6	6.3	12.1	9.9	8.1	10.3	8.5	6.3	6.9	7.2
5	19	6.9	5.1	4.6	4.8	11.3	11.9	9.9	8.3	6.6	5.3	2.3	6.1
5	20	5.2	3.9	5.8	5.9	8.8	8.2	6.4	9.4	6.8	7.3	7.3	7.6
5	21	8.4	4.5	5.7	5.9	9.5	8.6	11.7	9.2	7.9	7.0	7.4	7.5
6	1	8.3	3.5	3.4	5.0	10.4	9.6	10.2	8.3	7.0	7.0	6.8	6.9
6	2	8.0	3.5	4.9	5.4	8.3	8.1	7.1	8.3	7.3	5.6	5.4	6.8
6	3	7.5	4.7	5.5	6.3	10.6	7.2	8.5	6.3	7.4	7.7	7.3	7.1
6	4	7.6	4.4	4.9	6.4	9.8	9.1	9.6	8.0	6.9	7.5	7.2	7.2
6	5	7.6	2.0	1.5	6.1	10.2	8.2	8.8	8.2	5.6	4.2	1.5	5.5
6	6	6.6	10.2	5.2	5.8	10.4	6.9	5.6	8.4	7.0	7.0	6.9	6.8
6	7	6.7	5.4	6.2	6.1	8.4	8.8	8.6	7.8	7.1	7.4	7.8	7.5
6	8	6.5	6.8	6.1	6.4	8.8	8.8	8.6	7.6	6.9	7.9	6.9	7.3
6	9	6.6	6.2	6.6	5.9	8.6	8.6	9.0	8.1	7.3	7.7	7.9	7.6
6	10	9.8	6.9	3.7	4.7	9.6	8.3	10.1	8.2	8.7	7.3	6.2	6.8
6	11	7.8	4.0	4.8	6.1	11.0	8.8	8.9	8.8	8.3	7.1	8.4	8.1
6	12	9.6	9.9	8.1	7.7	10.1	6.8	7.5	8.1	10.1	11.5	9.7	9.9
6	13	9.3	9.2	8.7	9.9	13.0	13.6	11.6	10.3	9.8	5.8	7.2	4.7
6	14	7.6	7.3	7.7	7.1	11.5	10.9	9.7	0.0	7.2	7.3	8.8	8.3
6	15	7.8	5.7	5.5	6.0	11.0	7.9	10.8	8.5	7.3	8.9	8.8	7.9
6	16	8.6	6.5	5.9	6.5	10.6	6.7	8.8	8.1	7.8	8.1	9.0	5.6
6	17	8.0	3.9	6.2	6.0	9.9	7.8	9.0	8.3	8.8	8.3	8.5	8.4
6	18	7.9	7.1	5.2	5.5	10.5	9.3	10.0	8.8	7.1	8.1	8.2	9.7
6	19	8.1	4.4	3.9	5.0	9.5	8.8	9.1	8.7	6.9	6.7	6.1	7.0
6	20	8.3	5.4	5.4	6.5	9.8	7.7	8.6	9.3	5.7	5.8	9.5	8.9
6	21	8.2	4.1	5.3	5.9	9.6	10.2	10.2	9.8	7.9	6.8	8.3	7.3
7	1	7.5	4.7	5.4	6.2	9.1	8.6	9.5	8.7	7.6	4.6	6.5	6.8
7	2	7.4	6.3	5.4	6.3	10.3	8.3	9.2	8.0	7.6	4.6	4.7	7.1
7	3	8.3	6.4	4.8	5.8	9.5	8.7	8.7	7.4	8.4	7.1	7.0	6.5
7	4	5.0	4.9	5.5	5.9	9.1	7.1	9.3	7.0	6.3	6.0	6.4	6.4
7	5	5.6	4.2	4.6	5.0	9.8	8.9	9.0	8.0	6.7	6.6	6.0	6.8
7	6	6.4	6.3	6.3	6.1	7.7	9.0	8.4	8.8	6.9	6.0	6.2	7.0
7	7	7.0	5.0	5.7	6.7	7.8	8.2	9.2	7.9	6.8	6.7	6.0	6.9
7	8	6.5	4.7	5.8	6.7	8.1	9.5	8.3	8.0	6.2	6.4	6.3	7.4
7	9	7.6	5.7	5.8	6.0	9.1	8.7	8.5	8.6	7.2	7.2	6.0	6.9
7	10	7.9	6.2	6.2	7.0	8.7	9.3	9.1	8.1	7.5	7.5	7.1	7.5
7	11	7.6	5.6	5.9	5.9	8.9	9.6	8.1	8.0	7.5	5.0	4.5	5.0
7	12	8.2	6.1	7.0	6.5	10.4	8.5	6.9	8.4	7.7	6.9	7.3	6.9
7	13	10.5	9.5	7.5	5.5	10.8	8.0	10.0	8.4	9.8	8.8	8.1	4.3
7	14	8.8	7.2	4.7	8.0	12.6	11.4	12.5	9.7	9.1	5.7	3.8	6.5
7	15	8.3	7.1	6.4	6.9	11.4	11.2	9.9	10.7	8.6	8.7	7.3	6.0
7	16	8.8	9.3	8.0	7.4	10.6	11.2	10.4	8.9	6.9	7.3	6.8	6.0
7	17	6.9	3.6	6.1	6.9	8.9	10.3	8.2	8.0	6.2	7.0	7.4	7.5
7	18	6.5	5.6	3.5	4.8	9.8	8.3	8.3	8.9	6.4	4.7	11.5	5.6

		Spring Sample Depths (cm)				Anthesis Sample Depths (cm)				Harvest Sample Depths (cm)			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
7	19	9.2	4.2	4.3	5.2	10.5	6.3	5.9	6.7	9.5	7.9	6.3	7.8
7	20	7.3	4.6	4.8	6.5	11.0	11.7	9.7	8.3	8.1	8.2	8.4	7.9
7	21	5.4	4.1	2.4	2.0	9.9	8.2	9.8	8.9	6.1	5.6	5.6	6.1
8	1	7.0	6.1	5.9	6.4	6.9	9.3	6.8	6.5	7.1	8.3	8.2	7.3
8	2	8.0	5.5	3.4	6.2	11.7	9.6	8.3	5.7	7.8	5.1	4.9	7.5
8	3	7.2	7.0	6.2	6.9	10.8	8.4	7.9	7.5	6.3	8.0	7.7	7.9
8	4	6.1	4.8	5.7	6.1	11.0	9.4	10.5	7.9	8.2	8.3	7.7	7.7
8	5	7.7	5.8	6.5	7.0	11.0	9.3	8.6	8.0	7.1	7.1	4.6	5.0
8	6	6.4	4.9	5.3	6.3	9.2	9.0	8.9	8.1	8.2	8.7	7.9	10.6
8	7	6.9	5.8	6.2	6.5	9.9	9.2	9.2	8.2	7.1	7.9	7.6	7.7
8	8	7.3	5.4	6.0	6.5	9.0	7.8	8.8	8.4	7.5	8.3	8.2	7.7
8	9	6.9	5.9	4.4	6.0	9.1	8.2	8.3	8.4	7.2	7.4	7.4	7.4
8	10	7.8	4.1	4.8	5.7	9.2	8.8	8.9	8.1	6.8	7.7	7.5	7.7
8	11	8.0	4.9	5.2	5.6	9.6	6.0	8.5	8.1	7.3	7.4	7.6	6.6
8	12	7.5	7.4	5.5	6.3	8.7	9.0	7.8	8.2	6.9	6.0	7.9	7.8
8	13	8.8	8.1	6.8	7.0	9.0	7.5	8.7	7.9	8.5	9.0	6.8	7.7
8	14	12.2	7.8	6.6	6.2	9.5	7.4	7.7	7.6	11.0	7.6	7.8	8.6
8	15	9.6	8.2	8.2	7.8	9.3	8.6	9.9	7.6	9.9	6.0	8.5	7.6
8	16	9.5	7.1	7.8	7.8	13.2	16.1	9.6	9.5	9.1	6.7	7.8	6.9
8	17	6.2	4.4	4.0	4.6	12.7	9.7	10.6	14.1	6.5	4.9	4.8	7.6
8	18	7.9	4.8	5.1	5.7	12.5	9.3	8.6	10.4	7.1	7.2	7.9	7.0
8	19	9.4	6.1	6.3	6.9	8.1	9.0	10.3	10.3	8.8	8.7	9.5	8.6
8	20	6.6	4.2	5.4	5.4	9.5	8.3	8.2	8.6	6.2	8.8	7.8	7.4
8	21	5.3	2.9	2.5	2.1	12.8	11.5	10.1	9.6	5.1	3.3	2.6	4.0
9	1	9.6	6.0	6.9	8.2	7.9	8.6	8.7	10.8	8.0	6.9	6.4	7.1
9	2	8.7	6.3	5.4	6.0	8.2	7.0	5.3	5.0	8.5	7.2	6.7	6.9
9	3	9.1	7.8	5.2	4.6	12.0	9.5	8.8	7.5	8.4	6.4	5.1	6.1
9	4	6.9	4.8	4.5	5.8	9.2	8.3	7.4	6.1	8.1	7.1	6.0	7.2
9	5	7.5	7.9	5.3	6.9	9.0	9.6	8.7	8.6	7.8	6.8	7.5	6.8
9	6	6.5	5.7	5.9	6.5	8.4	7.8	8.2	8.3	8.8	7.2	6.6	6.4
9	7	7.5	4.7	5.8	6.4	9.4	8.4	8.6	7.9	7.4	6.9	6.7	6.6
9	8	7.0	5.0	4.8	6.2	10.5	9.8	9.5	7.9	7.5	6.8	6.6	6.7
9	9	8.5	5.1	6.0	6.3	8.1	9.0	8.6	8.3	7.8	5.9	6.5	6.5
9	10	9.7	5.4	6.3	6.4	9.0	8.5	8.8	8.2	7.4	6.6	6.4	6.7
9	11	7.3	7.2	6.1	6.5	9.7	8.6	9.5	8.9	6.8	6.4	5.9	6.6
9	12	7.6	6.6	6.4	5.8	9.1	7.6	8.8	8.0	7.6	6.8	6.7	6.7
9	13	8.9	6.8	6.3	6.6	10.1	9.0	8.6	8.4	8.0	6.3	6.9	6.9
9	14	9.2	9.7	6.8	7.8	11.8	8.9	8.9	8.4	8.9	6.9	7.4	7.2
9	15	9.4	8.4	7.8	9.4	11.3	9.7	11.4	8.9	8.2	8.6	7.9	8.0
9	16	10.5	8.6	5.2	5.2	12.1	10.0	7.6	7.8	8.7	7.4	6.7	7.9
9	17	7.2	6.0	5.5	6.4	9.9	8.9	9.7	9.5	8.1	8.1	7.5	6.8
9	18	8.7	5.6	5.2	5.7	9.6	9.7	8.2	8.1	7.7	7.0	5.7	6.1
9	19	7.6	4.6	4.8	5.5	11.7	8.1	8.3	8.2	7.3	5.4	5.9	6.5
9	20	6.2	4.6	5.1	5.2	9.8	8.7	8.7	8.1	6.7	5.6	5.9	6.6
9	21	5.3	3.7	5.1	4.8	8.3	10.3	11.7	9.5	6.1	6.0	6.2	8.3
10	1	8.3	6.8	6.7	6.6	11.6	8.2	9.2	8.0	8.1	6.6	7.2	7.0
10	2	8.4	5.2	5.8	6.4	9.9	7.9	7.6	7.9	9.3	4.9	6.5	6.8
10	3	7.2	5.8	5.8	6.6	7.3	7.6	7.9	6.9	6.9	7.0	6.2	7.4
10	4	7.7	7.2	5.8	6.7	8.9	7.5	7.9	8.1	5.2	7.9	7.4	7.4

		Spring Sample Depths (cm)				Anthesis Sample Depths (cm)				Harvest Sample Depths (cm)			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
10	5	6.5	5.1	4.5	5.3	8.5	8.9	9.0	7.3	7.4	7.0	7.1	6.6
10	6	7.7	5.8	5.8	6.6	11.0	9.3	8.9	9.1	8.3	5.9	7.7	6.7
10	7	6.6	4.7	3.9	2.7	8.8	8.7	6.3	6.9	7.6	6.1	5.4	6.8
10	8	7.4	5.6	5.0	5.6	9.2	8.4	8.2	6.8	8.2	6.6	6.8	7.0
10	9	7.1	6.7	5.1	8.3	10.7	9.0	9.0	10.0	6.4	4.7	3.8	6.6
10	10	7.0	4.9	6.3	6.4	9.3	8.9	8.2	9.2	6.5	6.5	6.0	7.2
10	11	7.2	5.0	6.1	6.6	8.7	9.3	8.8	9.3	6.5	6.0	5.6	7.1
10	12	6.8	6.4	6.2	7.2	8.6	7.4	9.0	10.1	7.5	7.4	5.1	6.9
10	13	8.2	7.0	6.6	6.7	9.2	8.5	9.1	8.4	6.1	6.8	6.8	7.1
10	14	9.0	8.5	6.9	6.6	9.0	8.5	10.0	9.0	8.5	9.6	8.3	7.7
10	15	8.2	8.3	7.6	7.2	9.6	10.1	9.6	8.7	8.2	8.8	7.9	8.2
10	16	8.5	7.6	6.7	7.0	11.2	9.2	10.9	13.0	8.9	6.7	7.8	9.4
10	17	9.0	6.5	5.6	6.4	9.4	10.1	10.2	9.2	7.4	8.3	9.2	7.7
10	18	9.3	1.6	5.7	6.0	9.2	7.7	9.8	9.8	9.0	7.4	7.4	7.3
10	19	7.1	5.6	5.0	5.6	10.3	9.5	9.1	8.7	7.5	6.9	6.2	5.6
10	20	6.4	4.5	5.4	5.9	10.9	11.0	9.5	9.2	8.0	7.1	6.5	7.0
10	21	6.9	8.4	7.2	6.8	9.8	10.1	10.2	8.6	6.5	7.4	6.5	6.5

Appendix IIIc. Dynamic soil properties at individual sampling points: Residual soil nitrate, 1997 and 1998 (kg/ha).

		Spring 1997				Spring 1998				Harvest 1998			
Transect	**Point**	**0-30**	**30-60**	**60-90**	**90-120**	**0-30**	**30-60**	**60-90**	**90-120**	**0-30**	**30-60**	**60-90**	**90-120**
1	1	28.1	11.2	4.3	4.3	20.7	6.9	4.3	4.3	16.2	6.5	4.6	5.4
1	2	26.4	12.9	8.6	4.3	28.6	14.2	9.9	5.2	25.2	15.2	5.5	10.4
1	3	30.6	10.1	4.3	4.3	39.7	8.9	4.3	4.3	24.8	9.2	5.6	7.2
1	4	28.7	9.9	4.3	4.3	39.0	20.2	7.3	6.0	20.0	8.2	4.1	5.7
1	5	22.9	11.2	5.2	4.3	30.9	7.3	4.7	4.3	20.8	8.0	4.4	4.3
1	6	33.8	13.5	4.3	4.3	33.8	5.3	4.3	6.9	22.1	7.5	5.7	5.3
1	7	23.8	8.2	4.3	4.3	45.0	19.6	4.7	6.9	36.0	13.4	6.2	10.9
1	8	28.8	13.3	4.3	4.3	33.0	17.2	4.3	4.3	16.2	7.4	4.7	4.8
1	9	42.6	13.3	4.3	4.3	54.9	15.1	6.0	5.6	35.2	7.1	4.3	4.8
1	10	31.1	7.2	4.3	4.3	48.0	18.3	5.6	5.1	29.0	8.7	14.0	5.6
1	11	28.9	10.7	4.3	4.3	39.0	6.4	4.3	4.3	26.0	12.3	5.2	6.5
1	12	30.4	15.4	6.0	4.3	45.3	8.9	4.3	6.9	28.7	4.6	4.3	4.3
1	13	21.4	7.9	7.8	4.3	33.2	14.5	9.6	8.2	21.0	5.5	4.8	6.3
1	14	33.2	9.5	5.6	4.3	25.0	11.8	4.0	4.3	34.1	8.5	4.0	4.4
1	15	28.5	8.6	4.3	4.3	38.2	9.0	4.3	4.3	15.8	4.7	4.3	6.1
1	16	49.2	4.3	4.3	5.6	46.5	16.3	4.3	5.1	65.3	10.0	6.3	10.0
1	17	32.6	6.5	4.3	4.3	59.7	25.7	8.6	6.4	33.2	7.9	4.8	5.8
1	18	33.5	12.0	4.3	4.3	39.6	14.1	4.3	5.1	21.1	27.7	23.7	13.1
1	19	29.3	7.3	4.3	4.3	23.3	6.4	4.3	6.9	21.1	6.2	4.3	4.3
1	20	37.0	4.6	5.7	9.0	66.4	22.7	10.5	23.6	21.7	13.3	4.4	7.9
1	21	49.3	6.2	4.3	4.7	37.8	3.9	4.3	4.3	21.2	3.9	6.0	5.4
2	1	29.5	9.0	4.3	4.3	16.6	4.3	4.3	4.3	19.1	4.3	4.3	4.3
2	2	27.9	9.7	5.3	4.3	23.1	3.9	4.1	4.3	27.0	4.1	4.1	4.3
2	3	32.7	7.8	4.3	4.7	15.2	4.1	4.3	6.0	17.8	4.1	4.3	4.3
2	4	41.7	10.7	4.3	4.3	14.0	4.3	4.3	4.3	8.6	4.7	4.3	4.3
2	5	39.1	3.9	3.9	7.1	26.8	8.6	3.9	4.2	33.5	3.9	3.9	4.2
2	6	31.4	18.5	4.3	4.3	13.2	4.3	4.3	4.3	11.3	4.3	4.3	4.3
2	7	24.5	5.6	4.3	5.6	19.2	4.3	7.3	8.2	39.2	6.8	4.3	4.3
2	8	25.9	5.2	4.3	4.3	16.6	4.3	4.3	4.3	30.6	4.3	4.3	4.3
2	9	21.6	7.7	4.3	4.3	13.8	4.3	4.3	4.3	11.8	4.3	4.3	4.3
2	10	27.3	15.0	4.3	4.3	20.2	8.6	4.3	4.3	27.3	4.3	4.3	4.3
2	11	34.0	12.3	6.4	4.3	14.8	4.2	4.3	5.1	26.3	6.9	4.3	4.3
2	12	38.9	15.0	4.3	4.3	26.7	6.4	4.3	4.3	28.9	7.2	4.3	4.3
2	13	30.0	8.2	5.2	6.0	39.4	12.4	7.3	8.6	17.8	4.3	4.3	4.3
2	14	44.8	17.7	7.9	4.7	31.8	11.4	3.9	3.9	46.5	6.2	3.9	3.9
2	15	38.5	9.9	4.3	4.3	26.3	8.2	4.3	4.3	18.2	6.1	4.3	4.3
2	16	41.8	16.4	5.0	6.0	45.0	14.0	7.6	7.3	222.5	88.3	71.0	43.5
2	17	31.1	7.1	4.3	4.3	22.1	5.9	4.3	4.3	39.0	10.3	5.1	9.0
2	18	36.1	9.4	4.5	7.7	32.7	8.6	12.7	11.6	21.2	7.2	11.5	9.5
2	19	29.4	6.8	4.3	4.3	14.5	5.9	5.6	7.3	30.7	8.5	5.0	4.6
2	20	31.6	10.2	4.3	47.2	36.3	4.7	18.4	4.3	23.1	12.1	5.4	4.3
2	21	29.4	8.7	4.3	6.0	31.6	3.9	4.3	4.3	31.2	7.3	8.3	7.2
3	1	28.3	6.7	4.3	4.3	12.3	4.2	4.3	4.3	12.8	11.8	4.9	4.3
3	2	20.8	5.2	4.3	4.3	14.7	4.3	4.3	4.3	32.6	8.2	4.3	5.1
3	3	31.9	5.6	4.3	4.3	13.2	4.3	4.3	4.3	22.1	6.0	4.6	4.3
3	4	31.2	12.0	4.3	4.3	42.5	100.0	152.7	84.1	21.8	10.1	7.8	5.2

		Spring 1997				Spring 1998				Harvest 1998			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
3	5	21.2	4.4	4.1	4.4	29.6	5.9	4.1	4.4	39.5	7.9	10.4	7.7
3	6	40.0	24.9	8.2	5.6	19.4	6.4	4.3	4.3	37.6	12.6	8.1	5.2
3	7	53.5	24.9	5.2	4.3	22.5	7.7	4.3	4.3	27.9	15.6	5.2	4.3
3	8	29.1	10.2	4.3	4.3	12.5	4.3	4.3	4.3	17.6	6.4	4.3	4.3
3	9	25.5	5.6	4.3	4.3	15.2	4.3	4.3	4.3	22.9	5.0	4.3	4.3
3	10	45.1	7.3	4.3	4.3	10.4	4.3	4.3	4.3	24.5	4.3	4.3	4.3
3	11	28.5	8.2	4.3	6.0	11.6	4.3	4.3	4.3	13.0	4.3	4.3	4.3
3	12	25.9	6.9	4.3	5.6	24.0	5.1	4.3	4.7	22.4	4.3	4.3	4.3
3	13	29.3	9.4	4.3	4.3	15.4	4.3	4.3	4.3	13.1	4.3	4.3	4.3
3	14	24.5	12.2	13.1	4.3	20.9	7.5	4.2	4.3	38.6	3.9	4.2	4.3
3	15	38.9	11.2	4.3	4.3	8.0	4.3	4.3	4.3	17.2	4.3	4.3	4.3
3	16	47.6	8.2	4.3	4.3	35.0	7.7	5.1	4.3	35.8	4.3	4.3	4.3
3	17	54.1	11.9	4.3	4.3	33.3	8.5	4.3	5.1	21.5	4.3	4.3	4.3
3	18	33.9	8.4	4.3	4.3	26.8	4.0	4.3	4.3	32.0	7.5	4.3	4.3
3	19	25.5	9.4	4.3	4.3	22.9	10.2	4.3	4.7	53.5	10.7	4.3	6.7
3	20	31.0	11.8	4.3	4.3	27.7	4.2	4.3	4.3	30.0	7.7	4.3	4.3
3	21	30.2	12.4	4.3	4.3	19.7	4.3	4.3	4.3	17.7	5.8	4.3	4.3
4	1	23.9	20.7	4.3	4.3	32.1	7.3	4.3	4.3	14.9	4.1	4.3	4.3
4	2	29.5	7.3	4.3	4.3	18.8	4.7	4.3	4.3	6.4	4.3	4.3	4.3
4	3	28.2	18.5	4.3	4.3	28.2	12.9	7.3	6.4	21.0	4.3	4.3	4.3
4	4	15.3	7.2	4.3	4.3	14.5	4.2	4.3	4.3	20.3	4.2	4.3	4.3
4	5	18.1	5.6	4.3	4.3	13.8	4.3	4.3	4.3	18.2	4.3	4.3	4.3
4	6	33.4	14.7	4.3	4.3	27.0	21.0	5.6	6.0	11.7	4.2	4.3	4.3
4	7	31.0	7.6	4.3	4.3	17.0	4.2	4.3	4.3	23.8	4.5	4.3	4.3
4	8	34.6	12.7	4.7	4.3	26.6	9.9	4.3	4.3	22.4	4.6	4.3	4.3
4	9	18.2	12.7	4.7	4.3	8.7	4.2	4.3	4.3	17.8	4.2	4.3	4.3
4	10	28.9	14.0	4.3	4.3	20.3	4.7	4.7	7.3	13.2	4.2	4.3	4.3
4	11	37.0	10.3	4.3	4.3	18.7	4.3	4.3	4.3	33.1	4.3	4.3	4.3
4	12	30.0	9.7	4.7	4.3	21.4	14.2	4.3	6.9	17.6	4.1	4.3	4.3
4	13	19.5	8.6	4.3	4.3	18.3	4.7	4.3	4.3	31.6	5.0	4.3	4.3
4	14	40.7	18.9	8.5	4.3	12.1	3.6	6.5	5.1	45.4	4.5	4.1	4.3
4	15	31.1	7.3	4.3	4.3	18.8	4.3	4.3	4.3	23.6	8.9	4.3	4.3
4	16	30.5	6.9	4.3	4.3	28.9	4.7	4.3	4.3	21.8	4.2	4.3	4.3
4	17	30.9	7.1	4.3	4.3	25.4	4.2	4.3	4.3	28.4	6.8	4.3	4.3
4	18	40.0	10.7	4.3	8.2	23.6	4.3	4.3	5.6	43.6	4.3	4.3	4.3
4	19	31.2	12.9	4.3	4.3	6.9	41.2	10.3	4.3	23.2	9.7	4.3	4.3
4	20	38.3	7.8	4.3	4.3	3.8	4.1	4.3	34.7	31.2	4.1	4.3	4.3
4	21	31.7	11.2	4.3	4.3	28.5	8.6	4.3	4.7	18.5	5.5	4.3	4.3
5	1	30.0	8.6	4.3	4.3	25.7	8.2	4.3	4.3	37.9	9.3	12.1	8.3
5	2	25.9	10.5	4.3	4.3	43.1	7.1	4.3	4.3	19.4	5.5	8.5	6.9
5	3	32.5	8.6	4.3	4.3	44.9	17.6	4.3	4.3	22.8	5.6	7.3	4.5
5	4	24.4	8.5	4.3	4.3	20.3	4.3	4.3	4.3	31.3	7.6	6.6	6.2
5	5	22.0	8.2	4.3	4.3	58.4	49.8	4.3	4.3	25.7	6.0	6.1	4.6
5	6	16.4	6.0	4.3	4.3	23.6	7.2	6.0	6.0	21.5	6.3	5.1	5.5
5	7	23.6	6.0	4.3	4.3	11.0	4.3	4.3	4.3	33.1	10.5	6.0	4.3
5	8	26.0	4.0	4.3	4.3	43.2	20.5	12.4	13.3	22.5	5.1	5.4	8.1
5	9	26.5	4.7	4.3	4.3	28.0	4.3	4.3	5.6	31.3	5.0	4.4	4.3
5	10	30.0	14.5	4.3	4.3	16.1	6.8	4.3	4.3	28.0	6.5	4.3	4.3
5	11	25.9	4.9	4.3	4.3	74.2	61.2	9.0	5.6	28.6	21.8	14.2	14.2

		Spring 1997				Spring 1998				Harvest 1998			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
5	12	30.0	9.3	4.3	4.3	83.2	25.9	4.3	4.3	51.6	33.5	17.6	14.1
5	13	27.5	8.0	4.3	4.3	41.8	14.8	4.3	4.3	35.5	13.3	7.0	8.0
5	14	24.6	4.4	4.3	4.3	26.8	15.3	4.3	4.3	38.2	10.8	4.7	5.7
5	15	9.1	4.3	4.3	4.7	30.5	7.3	6.0	7.3	43.5	18.6	16.8	18.8
5	16	30.1	9.9	4.3	4.3	17.1	4.3	4.3	4.3	39.2	17.5	16.4	5.8
5	17	38.1	6.9	4.3	4.3	38.4	4.1	4.3	6.4	32.8	9.4	9.6	11.0
5	18	29.2	4.7	4.3	4.3	14.6	4.3	4.3	5.6	49.7	9.9	4.9	5.3
5	19	36.5	8.6	4.3	4.3	38.4	19.7	6.4	10.3	49.8	10.2	7.4	10.6
5	20	22.5	7.6	4.3	4.3	30.8	4.2	4.3	4.3	24.9	7.7	17.7	7.8
5	21	35.6	6.4	4.3	4.3	48.0	8.2	4.3	4.3	21.5	7.6	5.1	9.7
6	1	28.0	7.9	4.3	4.3	32.3	4.1	4.3	4.3	22.4	4.7	4.3	4.3
6	2	38.1	4.5	4.3	4.3	34.5	4.1	4.3	4.3	21.9	4.7	4.3	4.3
6	3	27.0	14.9	4.7	4.3	22.5	4.3	4.3	4.3	27.6	4.3	4.3	4.3
6	4	24.4	6.9	4.3	4.3	23.2	5.6	4.3	4.7	17.2	4.3	4.3	4.3
6	5	32.5	5.8	4.3	4.3	37.6	6.2	4.3	4.3	22.1	4.1	4.3	4.3
6	6	18.2	7.5	4.3	4.3	24.2	5.4	4.3	4.3	13.9	7.7	4.1	4.5
6	7	32.9	9.9	4.3	4.3	28.4	9.9	4.7	4.3	39.9	9.6	4.3	4.3
6	8	26.3	8.6	4.3	4.3	34.1	9.5	4.3	4.3	30.3	7.9	4.3	4.3
6	9	36.0	10.3	4.3	4.3	18.2	6.0	4.3	4.3	24.5	7.4	4.3	4.3
6	10	40.5	11.2	4.3	4.3	28.7	15.4	4.3	4.3	22.9	4.7	4.3	4.6
6	11	35.0	7.3	4.6	4.3	35.7	8.4	4.2	4.3	29.1	4.7	4.2	4.3
6	12	32.5	4.0	4.3	4.3	39.3	19.7	8.2	7.7	33.8	9.4	4.9	4.5
6	13	43.5	9.8	4.3	4.3	36.0	15.3	6.4	8.2	30.9	4.6	4.3	4.3
6	14	23.0	7.7	4.3	4.3	21.9	7.3	4.3	4.3	17.0	4.8	4.3	4.3
6	15	35.3	7.7	4.3	4.3	22.5	4.3	4.3	4.3	18.7	5.4	4.3	4.3
6	16	32.1	10.1	4.3	4.3	26.5	7.1	4.3	4.3	13.8	4.7	4.3	4.3
6	17	35.3	10.1	4.3	4.3	38.5	11.8	4.3	4.3	26.9	7.8	4.3	6.6
6	18	24.0	8.5	4.3	4.3	33.4	9.7	4.3	4.3	24.1	9.2	4.3	4.3
6	19	29.7	9.2	4.3	4.3	38.4	10.9	4.3	4.3	24.2	5.8	4.3	4.3
6	20	28.8	6.4	4.3	4.3	31.9	12.4	4.3	4.3	15.9	4.3	4.3	4.3
6	21	38.7	8.2	4.3	4.3	23.8	4.1	4.3	4.3	19.9	4.9	4.3	4.3
7	1	40.3	14.2	5.6	4.3	36.8	15.4	4.3	4.7	55.1	6.1	4.1	4.9
7	2	36.1	9.2	4.3	4.3	65.3	31.9	10.7	5.1	37.4	8.0	10.5	10.6
7	3	32.5	9.0	4.3	4.3	60.4	21.0	4.3	5.6	40.7	11.2	12.8	4.3
7	4	35.7	15.9	4.3	4.3	59.1	34.3	4.7	9.4	45.2	15.9	32.6	13.7
7	5	30.6	14.0	4.3	4.3	38.4	18.6	4.3	4.7	45.9	4.7	4.3	4.3
7	6	34.8	9.9	4.3	4.3	39.1	23.6	4.7	4.3	27.4	6.0	5.4	4.3
7	7	32.9	10.7	4.3	4.3	46.1	30.0	4.7	4.3	22.9	5.5	4.1	4.3
7	8	34.4	13.7	4.3	4.3	49.8	10.7	4.3	4.3	26.4	5.8	14.9	14.1
7	9	36.5	9.4	4.3	4.3	58.4	33.0	6.0	6.0	50.0	7.9	6.9	9.3
7	10	32.1	6.9	4.3	4.3	68.1	16.3	6.9	5.1	29.3	6.0	6.7	7.5
7	11	49.3	14.5	4.3	4.3	84.6	53.9	13.3	9.0	31.0	6.2	5.4	4.3
7	12	50.3	15.0	4.3	4.3	72.4	31.3	10.3	8.2	41.3	7.0	10.2	4.4
7	13	48.9	21.2	4.3	4.3	66.8	29.9	7.3	8.2	49.3	7.3	11.6	9.2
7	14	42.8	9.1	4.3	4.3	33.9	31.3	8.2	4.3	26.0	5.5	4.3	4.3
7	15	43.6	9.0	4.3	4.3	42.5	12.9	5.1	4.3	34.6	5.2	4.3	4.3
7	16	58.3	12.5	5.2	4.3	50.7	18.6	5.1	4.3	25.1	4.3	4.3	4.3
7	17	40.3	11.7	4.3	4.3	77.2	12.1	4.3	7.3	46.0	8.0	46.4	14.4
7	18	48.4	14.6	6.9	4.3	71.8	33.9	4.3	4.7	15.2	4.3	17.4	12.1

		Spring 1997				Spring 1998				Harvest 1998			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
7	19	41.7	14.8	4.3	4.3	91.5	5.1	5.6	4.3	34.1	16.1	15.8	10.6
7	20	34.6	10.7	4.3	5.2	48.0	4.3	4.3	5.1	49.7	10.2	13.6	5.6
7	21	35.6	25.7	15.4	42.5	23.2	45.0	4.3	4.3	62.3	26.5	19.1	8.5
8	1	34.6	18.0	4.3	6.9	27.4	4.3	4.3	4.3	12.2	5.6	4.3	4.3
8	2	39.0	12.8	4.3	4.7	35.1	6.6	4.3	4.3	16.4	4.1	4.3	4.3
8	3	38.9	12.4	6.0	5.6	25.9	4.3	4.3	4.3	18.5	4.3	4.3	4.3
8	4	43.2	11.6	4.3	4.3	11.1	4.3	4.3	4.3	25.3	4.3	4.3	4.3
8	5	35.4	12.8	4.3	4.3	27.1	4.3	4.3	9.0	7.2	4.3	4.3	4.3
8	6	31.0	5.4	4.3	4.3	31.7	4.2	4.3	4.3	12.0	4.2	4.3	4.3
8	7	40.3	9.0	4.3	4.3	19.2	4.3	4.3	4.3	11.5	5.0	4.3	4.3
8	8	36.9	6.4	4.3	4.3	20.4	4.3	4.3	4.3	16.5	4.3	4.3	4.3
8	9	28.4	16.6	5.2	4.3	29.5	4.3	4.3	4.3	8.0	4.3	4.3	4.3
8	10	34.0	11.0	4.3	4.3	23.8	11.0	4.3	4.3	11.2	5.7	4.3	4.3
8	11	14.9	4.3	4.3	4.3	26.4	4.3	4.3	4.3	16.2	4.3	4.3	4.3
8	12	31.6	8.4	4.3	4.3	25.8	4.2	4.3	4.3	8.5	4.2	4.3	4.3
8	13	31.4	6.9	4.3	4.3	25.3	4.3	4.3	4.3	22.9	4.3	4.3	4.3
8	14	35.7	15.1	7.6	7.4	43.6	20.0	4.0	4.4	19.0	3.8	4.0	4.4
8	15	40.7	13.4	4.6	4.3	30.7	6.9	4.2	4.3	26.2	3.8	4.2	4.3
8	16	40.7	10.3	4.2	4.3	26.8	13.0	4.2	4.7	12.4	3.8	4.2	4.3
8	17	39.1	8.0	4.3	4.3	30.6	4.0	4.3	4.3	9.3	4.0	4.3	4.3
8	18	42.7	12.6	4.3	4.3	36.2	4.2	4.3	4.3	13.9	4.2	4.3	4.3
8	19	74.1	29.0	7.7	4.3	38.8	4.3	4.3	4.3	19.6	5.2	4.3	4.3
8	20	45.7	9.3	4.3	5.2	28.2	4.2	5.1	5.6	19.8	6.6	4.3	4.3
8	21	50.1	26.2	8.6	5.2	3.7	4.3	4.3	4.3	13.2	4.3	4.3	4.3
9	1	40.0	11.3	4.1	4.3	49.7	15.0	4.5	4.7	22.2	4.1	4.1	4.3
9	2	38.5	8.6	4.3	4.3	36.5	8.6	4.3	4.3	10.3	4.3	4.3	4.3
9	3	38.7	9.2	4.3	4.3	50.6	11.6	4.3	4.3	10.7	4.0	4.3	4.3
9	4	31.4	7.9	4.3	6.0	50.6	5.4	5.6	5.1	34.4	4.2	4.3	7.0
9	5	33.2	10.3	4.3	4.3	25.9	4.3	4.3	4.3	14.4	4.3	4.3	4.3
9	6	24.0	9.0	4.3	4.3	38.5	17.0	4.3	4.3	32.8	7.2	4.3	4.3
9	7	35.5	11.6	4.3	4.3	27.3	4.3	4.3	4.3	22.7	7.2	4.3	4.3
9	8	25.7	7.7	4.3	4.3	31.6	7.3	4.3	4.3	13.3	5.3	4.3	4.3
9	9	40.1	8.5	4.3	4.3	41.6	14.9	4.3	4.3	26.3	7.8	4.3	4.3
9	10	38.3	12.9	4.3	4.3	25.1	4.3	4.3	4.3	20.8	4.4	4.3	4.7
9	11	79.6	57.9	8.2	4.3	33.5	46.8	6.4	5.6	28.2	5.7	13.6	13.8
9	12	37.3	13.7	4.3	4.3	36.5	16.7	4.3	4.3	20.6	6.6	4.3	4.3
9	13	47.3	8.6	4.3	4.3	20.0	4.3	4.3	4.3	16.4	4.3	4.3	4.3
9	14	68.2	47.1	13.8	9.4	53.2	48.7	10.5	5.1	40.6	9.1	10.4	20.0
9	15	46.8	12.1	4.3	6.0	52.1	16.3	4.3	4.3	24.7	4.8	4.3	4.3
9	16	35.3	21.1	5.9	4.4	38.2	24.2	4.7	5.3	20.6	5.6	3.9	4.4
9	17	38.1	9.4	4.3	4.3	34.3	4.7	4.3	4.3	13.4	5.4	4.3	4.3
9	18	45.8	8.4	4.3	4.3	51.0	13.0	4.3	4.3	13.6	5.0	4.3	4.3
9	19	43.9	9.5	4.3	4.3	52.8	9.0	6.0	8.2	15.0	3.9	4.5	10.9
9	20	36.1	10.0	6.9	4.7	44.6	5.6	5.6	5.6	20.0	5.9	4.3	6.2
9	21	46.7	14.6	7.7	7.7	8.7	4.3	4.3	4.3	11.5	5.6	4.3	5.9
10	1	47.1	22.3	5.2	4.3	35.7	10.4	4.3	4.3	22.9	4.0	4.3	4.3
10	2	23.8	7.4	4.3	4.3	42.8	9.5	4.3	4.3	21.1	4.1	4.3	4.3
10	3	32.3	5.7	4.3	4.3	18.4	4.1	4.3	4.3	7.5	4.1	4.3	4.3
10	4	32.7	6.9	4.3	4.3	21.5	4.3	4.3	4.3	9.1	4.3	4.3	4.3

		Spring 1997				Spring 1998				Harvest 1998			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
10	5	25.5	8.1	4.3	4.3	27.8	8.5	4.3	4.3	10.5	4.3	4.3	4.3
10	6	32.2	10.1	4.3	4.3	28.9	3.9	4.3	4.3	11.7	3.9	4.3	4.3
10	7	31.9	4.6	4.3	4.3	22.5	4.2	4.3	4.3	7.5	4.2	4.3	4.3
10	8	45.0	10.3	4.3	4.3	16.9	4.3	4.3	4.3	28.6	4.8	4.3	4.3
10	9	63.6	14.2	4.3	4.3	32.0	11.3	4.3	4.3	12.8	4.2	4.3	4.3
10	10	29.2	4.1	4.3	4.3	3.6	4.1	23.6	4.3	6.7	4.1	4.3	4.3
10	11	46.5	18.5	9.9	5.6	25.7	4.3	4.3	4.3	17.9	4.3	4.3	4.3
10	12	36.2	6.8	4.3	4.3	31.6	5.5	4.3	4.3	29.8	4.2	4.3	4.3
10	13	35.4	9.4	4.3	4.3	25.9	5.6	4.3	4.3	16.1	4.3	4.3	4.3
10	14	57.6	28.3	4.7	4.3	41.1	6.0	4.3	4.3	13.5	4.3	4.3	4.3
10	15	41.6	9.4	4.3	4.3	32.6	9.4	4.3	4.3	14.4	4.3	4.3	4.3
10	16	37.1	7.4	4.3	4.3	39.6	15.9	4.3	4.3	24.7	3.9	4.3	4.3
10	17	63.0	23.9	4.3	4.3	35.3	8.9	4.3	4.3	18.0	5.0	4.3	5.3
10	18	33.9	10.2	4.3	4.3	46.1	15.8	4.3	4.3	20.6	4.3	4.3	5.1
10	19	55.1	11.5	4.3	9.9	36.7	6.0	4.3	6.9	13.0	5.2	4.3	10.7
10	20	45.7	12.9	4.3	4.7	11.0	4.3	4.3	4.3	18.7	4.5	5.9	8.5
10	21	32.5	7.3	4.3	4.3	6.3	4.3	4.3	4.3	10.3	4.3	4.3	4.3

Appendix IIId. Dynamic soil properties at individual sampling points: Residual exchangeable soil ammonium, 1997 and 1998 (kg/ha).

		Spring 1997				Spring 1998				Harvest 1998			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
1	1	6.7	15.1	9.9	12.1	7.7	14.2	14.2	15.9	28.1	54.6	34.5	25.0
1	2	5.0	4.6	16.8	9.9	7.1	12.9	13.8	17.6	32.1	39.3	30.8	35.5
1	3	5.7	8.9	8.2	9.0	6.8	10.9	11.2	10.8	32.6	29.4	46.8	36.5
1	4	12.5	15.9	9.9	13.3	10.3	13.5	10.8	13.3	39.3	27.5	32.0	43.8
1	5	6.1	12.9	18.9	19.4	9.9	14.6	18.9	18.9	20.4	27.8	40.0	34.1
1	6	8.3	11.4	9.5	12.9	9.1	17.1	15.1	20.2	19.5	24.2	35.6	41.2
1	7	3.2	9.0	6.9	6.5	11.9	13.5	13.8	16.8	18.3	29.6	28.5	27.2
1	8	5.4	6.0	5.2	6.9	11.5	14.2	18.5	15.9	28.0	20.9	30.0	30.1
1	9	0.8	5.2	5.6	5.6	9.6	12.5	14.6	15.1	28.8	34.1	36.2	38.3
1	10	4.9	6.4	4.7	4.7	10.5	11.5	12.0	13.3	20.0	22.5	24.5	28.9
1	11	5.3	4.3	4.7	9.0	9.4	10.7	11.2	13.3	16.6	25.3	15.7	17.9
1	12	0.4	4.1	5.1	4.7	8.2	10.1	9.9	11.2	23.0	14.6	27.1	26.9
1	13	5.5	7.9	3.9	3.0	12.5	14.9	8.7	10.7	21.8	29.2	23.8	24.7
1	14	0.7	5.7	10.5	8.2	8.9	13.3	14.5	12.9	22.1	27.4	12.8	18.0
1	15	5.9	12.0	11.2	15.0	12.1	19.3	21.9	21.9	18.7	24.2	39.8	46.8
1	16	8.0	14.6	9.4	8.6	13.3	17.6	15.4	12.9	30.6	53.8	51.4	34.5
1	17	5.9	13.9	12.0	12.0	11.3	13.1	19.3	16.7	37.0	50.3	33.6	21.2
1	18	6.8	7.9	5.6	4.7	11.2	14.5	9.4	11.2	15.4	32.4	19.0	27.3
1	19	6.8	5.1	5.6	6.0	18.0	17.2	12.9	24.9	28.1	29.6	27.5	22.5
1	20	4.7	5.0	5.3	4.7	11.3	9.2	9.3	9.9	35.6	25.9	22.6	28.4
1	21	6.8	26.9	18.4	11.2	10.0	15.2	15.4	14.6	36.4	38.0	38.5	30.1
2	1	7.2	14.6	9.9	15.9	11.0	15.0	15.0	15.9	31.0	27.9	35.5	36.0
2	2	6.3	8.5	10.9	10.7	11.9	12.0	12.2	10.7	53.5	41.4	37.2	50.8
2	3	6.2	9.9	7.3	7.3	11.3	12.7	13.7	13.7	38.8	43.9	46.3	40.4
2	4	8.6	11.6	10.7	10.7	10.1	13.7	12.4	15.0	34.7	29.6	35.3	44.7
2	5	6.3	10.2	10.2	19.6	8.2	9.0	9.0	9.6	30.4	35.6	32.5	32.8
2	6	8.9	15.9	15.4	12.4	9.7	16.3	17.6	19.3	23.6	33.0	29.6	37.1
2	7	16.7	21.0	18.4	16.3	13.5	15.9	18.4	19.3	27.6	31.0	56.1	36.2
2	8	8.9	17.6	23.2	22.7	18.2	21.9	15.9	16.3	24.2	25.2	23.3	20.6
2	9	10.8	14.5	15.0	14.2	14.9	15.3	19.3	21.9	19.9	28.6	29.5	30.0
2	10	7.9	8.6	7.3	9.4	11.1	17.2	12.0	18.9	26.2	25.2	34.6	34.8
2	11	4.4	5.9	10.7	12.4	10.7	14.0	12.4	16.3	29.3	28.5	30.7	29.3
2	12	4.3	9.4	3.9	6.9	11.0	12.0	13.3	13.3	31.3	30.0	29.3	28.4
2	13	6.8	11.2	4.7	11.2	14.3	14.6	11.6	15.4	29.9	19.4	27.8	28.6
2	14	1.2	5.9	6.3	7.5	9.0	10.2	6.3	7.5	25.3	26.4	20.5	22.3
2	15	4.2	5.1	4.7	8.6	7.6	9.9	11.6	15.9	21.0	15.4	20.7	29.5
2	16	5.8	12.0	7.6	9.4	6.5	9.2	8.4	6.9	26.2	46.7	32.0	31.5
2	17	6.4	8.0	9.4	11.6	16.9	19.7	16.3	17.6	26.3	47.6	39.8	38.2
2	18	6.3	7.9	10.3	8.2	10.8	13.8	17.7	18.4	43.7	54.5	71.3	50.5
2	19	12.7	15.7	13.7	10.7	16.0	15.2	12.0	15.0	59.2	48.9	41.5	41.8
2	20	6.9	9.3	10.7	12.0	17.8	13.1	21.0	14.2	37.2	76.0	70.4	79.2
2	21	8.6	11.0	5.1	6.0	13.0	11.4	9.9	10.7	73.2	87.2	42.2	31.3
3	1	10.4	12.6	9.9	11.6	13.0	8.0	16.7	22.3	27.2	37.3	42.5	40.3
3	2	4.9	12.4	15.4	15.0	15.5	16.7	17.2	21.5	46.2	35.4	27.9	34.8
3	3	9.2	12.4	10.7	12.4	12.0	15.9	16.3	16.3	17.6	20.2	24.1	26.1
3	4	9.0	13.3	9.9	12.4	7.4	13.3	16.3	21.5	20.2	40.7	49.2	48.8

Transect	Point	Spring 1997				Spring 1998				Harvest 1998			
		0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
3	5	4.8	11.1	9.5	10.6	9.2	15.8	14.5	13.7	38.1	33.9	53.4	33.5
3	6	5.3	4.7	8.2	7.3	9.5	11.2	26.6	16.7	15.6	26.7	27.5	42.9
3	7	6.3	9.9	9.4	10.7	8.1	12.4	15.0	17.6	50.9	55.6	49.0	48.7
3	8	6.8	9.8	13.3	12.4	11.3	14.5	14.2	13.7	38.3	51.1	45.0	48.6
3	9	8.4	9.9	8.2	9.4	13.3	10.7	13.3	12.4	33.4	37.3	29.0	n/a
3	10	11.6	15.0	12.0	13.3	9.2	12.0	20.2	19.7	27.7	32.6	27.9	29.1
3	11	6.0	10.7	12.4	16.3	9.8	14.2	12.0	14.2	27.2	34.6	37.5	33.7
3	12	10.1	11.2	10.3	11.2	15.5	17.6	13.7	17.6	20.5	25.5	30.4	27.5
3	13	5.5	13.3	9.4	10.3	11.5	18.9	20.6	16.3	27.9	39.0	33.5	36.5
3	14	6.8	9.8	3.8	3.9	6.8	9.0	6.3	7.7	21.8	26.6	23.8	21.1
3	15	6.1	9.9	8.2	10.7	14.5	16.7	17.2	21.9	29.8	41.9	36.3	28.4
3	16	10.0	10.7	7.7	8.2	8.6	13.3	22.3	24.5	40.0	39.9	37.5	29.5
3	17	6.0	7.2	9.9	12.4	11.3	17.0	12.0	18.9	42.5	35.7	29.7	32.7
3	18	5.7	7.6	6.4	4.3	13.6	19.3	15.0	15.4	29.5	44.6	29.0	33.3
3	19	6.0	10.7	9.4	6.0	5.6	8.5	15.4	14.6	18.3	28.1	27.4	29.5
3	20	3.0	5.5	8.2	10.7	8.1	11.4	9.9	12.0	30.3	38.6	37.1	46.3
3	21	5.7	9.4	7.7	8.6	9.5	14.1	22.7	22.7	25.7	27.8	37.5	30.0
4	1	11.8	11.7	9.4	9.9	8.9	13.0	12.0	11.6	19.2	25.6	25.1	26.5
4	2	8.4	13.7	18.0	18.0	12.4	13.3	14.6	14.6	19.6	39.1	39.6	35.4
4	3	7.2	8.2	5.6	5.6	6.5	7.3	9.9	10.7	14.4	39.2	17.3	34.1
4	4	11.5	16.9	14.6	14.6	11.9	15.7	12.0	16.7	14.6	22.9	29.3	35.8
4	5	10.0	16.3	14.6	17.2	16.9	17.2	28.3	24.9	27.5	33.5	17.5	22.8
4	6	7.1	16.4	8.2	15.0	12.8	20.2	17.2	20.2	19.1	36.1	43.1	40.6
4	7	8.9	13.5	9.9	11.2	8.9	14.0	12.4	14.6	23.9	34.3	16.2	17.4
4	8	7.9	15.6	11.2	10.7	6.5	11.5	9.9	8.2	14.1	28.1	23.7	19.7
4	9	7.6	8.0	9.4	11.2	9.1	11.0	11.2	12.4	23.3	18.3	21.1	24.9
4	10	7.1	8.9	12.4	12.4	8.6	11.0	11.6	14.2	28.5	24.6	37.9	36.3
4	11	11.8	14.6	10.3	12.0	9.5	12.0	13.7	15.0	17.3	18.7	28.8	39.0
4	12	7.9	8.9	33.9	18.4	7.9	8.9	9.4	9.0	12.3	10.4	17.2	16.7
4	13	12.1	15.9	15.0	17.2	9.8	13.7	15.0	17.6	29.3	24.2	19.6	20.7
4	14	33.6	26.1	14.2	15.0	8.6	9.3	9.3	11.2	13.7	26.3	37.6	22.6
4	15	10.9	17.2	13.7	15.9	10.5	13.7	15.9	16.3	50.7	45.0	28.5	33.6
4	16	6.7	9.9	9.9	9.9	9.5	13.7	13.3	12.0	24.0	29.6	28.5	30.9
4	17	7.3	9.6	8.2	10.7	8.3	12.9	15.9	22.3	35.8	46.3	35.8	27.8
4	18	7.6	12.4	13.7	15.9	12.6	17.2	17.2	20.2	47.8	38.7	49.5	48.3
4	19	6.1	8.2	8.6	13.3	17.5	15.9	11.2	11.2	26.3	33.9	31.3	40.6
4	20	9.8	14.4	9.9	10.7	12.0	7.8	13.3	13.7	32.6	33.5	28.7	32.0
4	21	9.9	13.7	29.2	18.9	17.0	19.3	26.6	24.9	31.5	42.1	40.5	31.7
5	1	11.1	20.6	15.0	15.4	11.1	16.3	15.9	17.2	43.6	42.0	60.2	35.9
5	2	16.1	18.1	13.7	14.6	10.9	13.0	12.9	12.0	29.6	33.6	28.2	61.9
5	3	13.2	16.3	27.5	23.2	10.1	14.6	15.4	15.4	57.4	48.9	64.7	56.0
5	4	14.3	18.3	16.3	18.0	9.4	13.6	13.3	15.9	56.4	63.9	54.9	50.3
5	5	28.3	36.0	16.3	22.7	8.6	13.3	13.7	16.7	23.9	39.6	40.3	46.3
5	6	13.3	16.2	18.4	22.7	13.0	12.8	12.9	16.3	29.9	36.6	30.5	33.4
5	7	12.2	18.4	12.9	15.0	9.5	13.7	12.0	14.6	23.7	28.9	30.8	13.9
5	8	15.3	13.7	12.0	12.4	7.1	14.1	11.2	10.7	23.9	28.1	24.4	28.7
5	9	9.5	14.2	10.7	9.9	18.9	9.4	10.7	14.2	32.0	32.6	20.4	21.6
5	10	12.8	13.6	10.7	13.3	9.8	11.5	9.9	10.7	19.2	44.5	23.2	27.5
5	11	8.6	9.0	6.9	6.0	9.0	7.8	8.2	7.7	31.4	44.7	26.6	12.5

		Spring 1997				Spring 1998				Harvest 1998			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
5	12	6.4	9.3	8.2	8.6	6.8	7.7	8.2	9.0	25.8	25.9	19.4	13.3
5	13	6.4	8.5	6.0	9.0	8.2	8.0	8.2	7.7	39.6	38.2	22.0	27.8
5	14	11.8	15.7	10.3	12.4	9.3	12.9	9.0	14.2	40.7	47.4	31.4	27.8
5	15	7.5	9.4	7.3	10.7	9.9	16.3	17.6	18.9	30.3	46.3	34.0	35.5
5	16	6.1	10.7	12.0	12.0	14.1	21.0	18.4	21.0	36.9	52.6	52.0	71.4
5	17	5.1	11.3	8.6	8.2	8.1	14.6	14.6	12.9	22.2	31.3	29.7	29.1
5	18	5.8	10.7	14.2	19.3	12.3	22.7	20.2	18.4	29.2	30.2	31.8	38.0
5	19	6.6	8.6	6.0	5.6	9.2	7.3	6.0	6.9	23.4	24.0	26.0	19.3
5	20	13.1	18.5	11.2	12.9	10.9	11.3	10.7	12.0	26.3	41.5	35.4	36.5
5	21	9.4	15.0	15.9	15.9	20.3	21.5	14.2	17.2	34.6	43.8	34.8	34.2
6	1	8.0	10.4	9.4	10.7	7.3	9.5	6.9	7.7	25.7	25.4	33.8	26.8
6	2	9.4	11.4	9.9	10.7	6.9	8.2	8.2	8.2	21.7	28.5	29.4	26.8
6	3	7.5	14.1	14.2	18.9	8.6	11.5	12.0	14.6	21.2	32.0	27.9	35.3
6	4	8.9	12.4	10.3	12.4	9.7	9.4	8.2	10.7	26.5	40.0	25.8	38.8
6	5	9.2	13.2	6.9	11.6	6.6	6.6	6.9	13.3	24.8	20.1	40.6	38.8
6	6	7.1	11.7	12.4	18.0	6.3	11.7	8.6	12.4	19.7	34.4	31.7	42.8
6	7	6.4	12.0	11.6	15.0	11.0	12.0	10.7	15.0	24.9	37.8	33.7	34.2
6	8	8.6	17.3	9.9	12.0	7.5	9.9	6.0	11.2	40.4	52.0	28.2	33.5
6	9	6.6	6.9	10.3	12.4	8.9	8.2	8.2	11.2	31.4	41.8	24.2	24.8
6	10	7.6	10.7	9.0	11.2	7.9	7.3	9.9	9.4	26.6	35.6	17.8	22.6
6	11	6.1	9.6	8.3	8.6	6.4	6.9	7.9	7.3	45.4	28.6	34.3	31.3
6	12	6.4	10.1	7.7	9.4	8.2	7.6	4.3	7.3	28.0	29.3	30.5	30.8
6	13	9.4	11.8	6.4	7.3	10.5	9.8	5.1	7.7	22.1	32.7	28.5	25.4
6	14	9.6	13.7	5.6	8.2	8.4	12.0	10.7	10.3	22.8	30.0	30.7	32.2
6	15	6.8	12.0	30.5	28.3	7.5	8.2	9.4	12.0	18.7	34.6	33.9	45.9
6	16	10.6	13.9	10.7	15.0	11.7	7.1	8.2	11.2	22.2	29.5	27.8	30.1
6	17	16.9	18.9	10.7	13.3	5.8	8.8	9.0	9.4	20.8	28.6	21.4	29.7
6	18	9.4	13.1	10.7	12.0	6.4	4.7	7.3	9.9	13.3	18.4	20.1	21.8
6	19	6.6	10.5	9.4	8.2	9.2	9.2	10.3	8.2	20.4	26.3	28.8	25.1
6	20	8.4	12.4	11.6	11.6	9.2	7.7	11.6	14.2	19.7	19.9	22.2	25.3
6	21	9.3	13.1	13.7	14.2	11.2	14.3	16.3	17.6	26.6	31.5	30.9	39.3
7	1	9.7	7.7	10.7	11.2	10.8	11.2	9.9	15.0	19.9	28.5	45.5	41.7
7	2	10.0	14.7	10.7	9.4	7.9	8.4	6.4	9.0	32.7	41.0	31.1	26.7
7	3	8.5	10.3	13.7	14.6	8.5	12.4	12.0	13.7	27.1	47.4	38.0	37.1
7	4	5.4	9.4	8.2	7.7	6.5	6.9	7.3	8.2	23.9	36.8	47.8	39.9
7	5	6.3	11.0	12.4	10.7	4.8	7.6	8.6	8.2	38.3	58.7	78.2	74.9
7	6	8.9	9.9	12.0	15.4	7.0	7.7	9.9	14.2	52.1	53.3	55.9	60.6
7	7	10.8	12.9	12.0	14.2	7.7	9.9	9.9	13.7	32.8	37.8	38.2	41.1
7	8	7.3	12.0	9.4	9.9	8.1	13.3	12.0	12.4	33.3	39.7	29.6	34.0
7	9	5.0	7.7	12.0	12.9	6.9	6.9	11.6	15.0	28.4	34.8	27.8	36.3
7	10	9.1	10.7	10.7	14.2	9.1	10.7	11.2	13.3	28.4	29.2	40.3	35.1
7	11	24.6	16.1	8.6	8.6	11.1	11.3	8.2	8.2	28.5	34.7	34.1	33.5
7	12	7.5	10.4	15.4	16.3	8.6	9.2	8.6	9.9	17.5	23.2	14.7	14.1
7	13	16.1	14.8	7.7	7.3	8.9	6.8	5.1	5.6	18.3	3.3	5.4	6.2
7	14	24.6	19.0	10.7	6.0	10.4	16.2	4.3	8.2	9.7	12.6	7.0	10.3
7	15	11.3	21.0	52.3	35.6	8.4	10.7	15.0	20.2	9.0	19.4	20.5	23.3
7	16	14.1	17.7	13.3	15.0	10.7	14.3	12.0	13.7	16.4	24.2	22.3	29.1
7	17	17.9	19.6	12.4	14.6	8.4	10.4	9.0	9.9	21.2	19.2	13.9	14.2
7	18	9.6	10.3	13.7	9.9	5.0	3.9	3.9	5.6	35.4	24.4	27.7	23.6

		Spring 1997				Spring 1998				Harvest 1998			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
7	19	9.2	14.4	14.6	13.7	4.8	11.8	13.7	9.0	22.6	30.5	36.9	21.9
7	20	16.4	19.3	16.3	17.2	6.0	7.7	8.6	9.9	19.6	31.4	11.5	26.0
7	21	8.1	9.9	16.3	23.2	10.4	9.4	9.0	9.9	16.8	20.2	27.1	35.4
8	1	11.9	14.6	12.4	12.0	6.8	7.3	6.0	6.0	17.0	19.9	21.8	22.7
8	2	16.8	24.4	10.7	12.4	4.3	3.7	3.4	3.0	19.5	19.7	19.2	6.8
8	3	14.5	16.3	21.0	24.9	3.5	7.7	9.4	10.7	16.3	30.9	24.7	29.6
8	4	14.7	15.9	17.2	18.4	3.6	4.3	7.3	9.0	14.5	18.1	20.7	22.3
8	5	6.1	8.9	8.2	7.3	7.2	8.5	6.4	6.0	19.4	22.5	16.1	19.7
8	6	5.9	13.8	9.0	10.3	5.9	7.1	7.3	6.9	25.6	28.2	25.0	27.2
8	7	8.8	12.4	13.7	11.2	6.5	8.6	7.7	9.0	26.2	36.7	34.7	34.1
8	8	11.0	15.0	12.4	14.6	4.3	7.3	7.7	8.2	18.9	30.0	28.4	27.4
8	9	8.3	9.8	13.7	14.6	6.0	6.0	6.0	6.0	23.2	33.4	31.1	27.6
8	10	8.4	10.2	8.6	9.9	4.0	2.5	5.1	4.3	15.2	16.5	22.9	24.7
8	11	13.0	14.9	12.0	13.3	4.8	6.0	6.0	6.4	29.4	27.1	26.3	18.0
8	12	7.3	13.0	12.9	12.0	8.7	8.0	6.0	6.9	13.0	18.0	19.2	14.8
8	13	9.8	14.2	13.3	15.9	4.2	15.9	8.2	8.2	13.0	25.0	24.7	26.3
8	14	16.4	16.3	13.2	12.2	3.6	3.4	5.6	4.8	12.5	14.4	10.9	7.8
8	15	9.6	11.9	13.9	13.3	3.2	4.6	3.8	2.6	13.1	16.0	25.5	22.6
8	16	8.6	14.1	13.5	13.3	2.9	6.5	7.2	4.7	15.5	26.7	26.5	33.4
8	17	11.8	14.1	10.7	6.0	3.0	4.8	3.9	3.9	23.7	26.6	13.9	10.6
8	18	9.9	12.2	12.0	12.0	4.6	8.0	4.3	6.9	24.0	29.6	33.1	31.3
8	19	9.1	13.2	12.9	15.0	3.3	7.0	6.0	6.4	20.8	25.2	31.5	27.3
8	20	15.4	13.5	12.0	15.9	4.6	5.9	6.0	6.4	27.0	47.4	29.8	28.9
8	21	7.0	6.4	10.3	10.7	9.2	11.2	9.4	7.3	14.6	19.6	21.9	22.9
9	1	9.0	17.4	10.7	9.9	8.6	17.4	10.7	12.4	13.1	26.0	21.7	16.7
9	2	13.4	19.7	15.0	16.3	9.4	15.9	16.7	16.3	14.2	24.1	22.7	25.6
9	3	8.6	12.4	6.0	6.0	9.3	12.4	10.7	8.6	23.1	24.7	24.8	22.6
9	4	6.3	6.7	6.0	8.2	13.3	15.8	13.7	14.2	22.6	28.0	23.1	28.1
9	5	5.7	12.0	7.3	11.2	13.0	15.0	21.9	24.9	29.1	24.9	23.5	29.3
9	6	6.1	8.1	10.3	11.6	13.3	15.8	15.0	18.0	23.6	29.5	24.6	21.9
9	7	5.5	10.3	7.3	9.0	16.8	19.3	15.4	17.6	25.3	23.9	43.8	38.0
9	8	16.8	16.7	16.3	15.0	15.6	16.3	17.2	17.6	30.0	34.3	34.9	41.6
9	9	8.7	14.1	12.4	13.7	10.6	12.8	12.4	15.0	28.9	29.2	33.0	40.0
9	10	6.8	9.0	9.9	13.7	13.5	14.6	18.0	21.5	23.7	32.3	35.2	45.7
9	11	7.2	12.0	7.3	9.9	13.7	18.4	16.3	19.7	27.5	22.2	19.7	19.6
9	12	6.3	8.2	7.3	12.0	10.7	22.3	18.4	24.0	15.9	24.7	26.1	29.7
9	13	6.1	9.4	9.9	12.4	17.5	18.0	16.7	21.0	16.5	26.4	22.1	30.6
9	14	6.1	5.5	5.7	4.3	13.6	16.2	15.4	17.6	20.4	13.5	23.3	25.0
9	15	6.1	10.8	4.7	5.1	14.6	21.3	15.4	14.2	16.4	29.0	23.1	14.8
9	16	5.0	6.6	5.9	4.0	18.2	21.5	12.6	14.1	12.7	14.9	13.0	10.1
9	17	8.4	10.7	8.2	12.0	12.6	13.7	28.3	24.9	18.4	22.2	29.4	28.6
9	18	6.0	10.1	10.7	9.0	19.0	19.3	15.9	14.2	22.3	29.1	28.1	24.0
9	19	6.4	14.0	12.0	9.9	26.1	29.2	9.4	21.0	19.1	120.7	30.0	23.9
9	20	8.2	12.0	10.7	9.9	14.3	18.0	15.0	17.6	17.2	25.9	22.3	25.6
9	21	7.1	6.9	11.2	12.0	8.7	8.2	12.0	14.6	15.9	22.8	23.0	23.7
10	1	6.8	12.4	9.4	9.4	15.7	15.2	12.4	12.0	22.9	42.0	26.0	19.6
10	2	11.2	11.1	10.3	10.7	11.5	17.3	15.9	11.2	20.6	27.6	24.2	18.3
10	3	8.1	11.3	12.9	12.4	12.7	9.3	11.2	17.6	17.6	22.8	25.4	26.6
10	4	8.0	11.6	10.7	13.7	16.0	10.7	15.4	12.9	19.7	25.7	18.5	21.9

		Spring 1997				Spring 1998				Harvest 1998			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
10	5	8.4	8.1	8.2	8.2	11.8	14.1	20.2	15.9	21.2	25.9	28.7	28.1
10	6	3.7	8.9	9.4	9.4	11.3	13.2	11.2	16.3	22.4	23.6	26.9	22.4
10	7	5.1	11.3	7.7	7.3	13.8	13.3	15.0	12.0	23.8	39.4	33.8	31.9
10	8	9.0	8.6	9.9	9.0	13.9	21.0	23.6	20.6	20.9	20.9	22.1	29.1
10	9	6.3	5.4	7.7	8.6	18.2	18.3	15.9	21.0	30.7	20.7	19.7	29.3
10	10	9.0	10.3	10.7	9.4	25.9	23.8	27.5	16.3	22.7	25.5	26.9	27.6
10	11	10.8	12.9	13.7	15.0	15.4	21.5	16.3	21.5	29.6	23.3	29.2	25.6
10	12	8.4	9.7	8.2	10.7	15.6	11.0	13.7	24.0	26.9	21.2	16.9	24.3
10	13	8.0	8.2	7.7	10.7	23.6	15.0	17.2	14.6	24.9	23.7	17.6	19.9
10	14	6.9	9.4	10.7	12.9	16.9	24.9	30.5	27.0	19.8	26.1	36.4	35.3
10	15	6.8	6.9	9.4	10.7	17.3	10.7	14.2	19.7	19.8	15.7	12.6	27.2
10	16	3.2	6.6	5.6	3.9	18.9	11.2	12.4	9.9	18.4	20.9	24.8	17.6
10	17	7.3	7.7	4.7	7.7	15.0	14.5	17.2	15.4	18.0	17.4	18.2	23.7
10	18	4.8	7.7	6.0	12.0	12.3	17.0	13.3	15.0	22.0	25.9	20.8	26.3
10	19	5.0	9.8	6.9	7.3	11.5	22.6	15.0	17.6	16.2	21.2	22.8	21.2
10	20	6.9	13.3	9.4	12.9	9.9	14.2	16.3	21.0	21.3	27.5	36.6	33.5
10	21	7.1	9.0	13.7	17.2	9.1	11.2	12.9	17.2	14.3	22.6	28.3	38.1

Appendix IIIe. Dynamic soil properties at individual sampling points: Residual extractable soil phosphorus, 1997 and 1998 (kg/ha).

		Spring 1997				Spring 1998			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
1	1	42.2	12.9	4.3	4.3	56.2	30.1	21.5	17.2
1	2	28.6	8.3	8.6	4.3	53.6	20.8	17.2	17.2
1	3	52.9	15.6	25.8	12.9	90.7	27.2	43.0	30.1
1	4	81.0	19.8	8.6	4.3	58.9	35.7	25.8	21.5
1	5	34.4	12.9	12.9	4.3	61.1	25.8	21.5	17.2
1	6	58.1	12.2	25.8	17.2	47.2	40.8	30.1	25.8
1	7	61.2	20.4	38.7	21.5	61.2	32.6	30.1	21.5
1	8	65.3	8.6	8.6	4.3	38.4	30.1	17.2	17.2
1	9	80.6	8.6	4.3	4.3	49.9	25.8	21.5	17.2
1	10	37.5	12.8	8.6	4.3	48.8	29.8	25.7	21.5
1	11	30.0	8.6	4.3	4.3	41.3	30.0	21.5	17.2
1	12	21.4	12.2	12.9	4.3	67.8	24.3	30.0	25.7
1	13	99.6	35.4	8.7	4.3	114.4	66.8	21.8	25.7
1	14	92.8	38.1	20.1	8.6	96.4	45.7	28.1	25.7
1	15	50.7	8.6	4.3	4.3	42.9	34.3	25.7	21.5
1	16	38.1	21.5	12.9	8.6	106.7	38.6	34.3	30.0
1	17	58.6	8.2	8.6	4.3	47.6	28.6	30.0	25.7
1	18	46.8	12.4	21.5	8.6	32.4	37.3	25.7	21.5
1	19	33.8	8.6	4.3	4.3	30.0	30.0	25.7	25.7
1	20	43.6	4.2	4.1	4.3	145.2	25.2	20.3	25.7
1	21	110.7	23.4	8.6	4.3	64.3	19.5	17.2	17.2
2	1	37.8	8.6	4.3	4.3	30.2	30.0	25.7	25.7
2	2	81.8	11.6	4.1	4.3	40.9	23.2	32.4	30.0
2	3	101.6	12.3	30.0	8.6	39.9	20.6	34.3	25.7
2	4	74.1	8.6	4.3	4.3	39.0	25.7	25.7	17.2
2	5	67.0	11.8	11.8	37.5	78.1	47.2	23.6	29.2
2	6	34.8	8.6	4.3	4.3	38.7	21.5	17.2	17.2
2	7	16.3	4.3	4.3	4.3	28.6	21.5	17.2	17.2
2	8	15.5	4.3	4.3	4.3	31.0	25.7	21.5	12.9
2	9	81.8	8.5	4.3	4.3	26.0	21.3	17.2	17.2
2	10	15.8	4.3	4.3	4.3	27.7	25.7	17.2	17.2
2	11	88.6	12.7	8.6	4.3	33.2	29.6	21.5	17.2
2	12	82.5	8.6	4.3	4.3	27.5	25.7	21.5	17.2
2	13	56.3	8.6	4.3	4.3	37.5	25.7	21.5	17.2
2	14	82.5	66.8	62.9	27.5	94.3	74.7	47.2	11.8
2	15	41.9	12.9	4.3	4.3	30.5	21.5	21.5	12.9
2	16	54.5	27.9	12.6	4.3	79.9	43.9	29.4	30.0
2	17	105.0	8.4	4.3	4.3	30.0	16.8	12.9	8.6
2	18	55.8	31.4	8.2	4.3	40.9	23.6	24.7	17.2
2	19	43.6	16.9	8.6	4.3	14.5	21.2	12.9	8.6
2	20	58.1	12.7	4.3	4.3	47.2	12.7	30.0	12.9
2	21	70.7	31.4	21.5	8.6	107.9	47.2	25.7	21.5
3	1	78.1	12.6	8.6	4.3	44.6	33.6	21.5	17.2
3	2	34.0	8.6	4.3	4.3	56.7	21.5	21.5	21.5
3	3	51.9	8.6	4.3	4.3	35.9	25.7	21.5	21.5
3	4	23.4	4.3	4.3	4.3	46.8	34.3	25.7	25.7

		Spring 1997				Spring 1998			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
3	5	128.1	43.6	16.6	8.8	98.8	59.4	29.0	35.3
3	6	34.3	12.9	4.3	4.3	30.5	30.0	25.7	25.7
3	7	33.2	12.9	4.3	4.3	33.2	34.3	25.7	25.7
3	8	37.8	4.3	4.3	4.3	30.2	29.8	21.5	25.7
3	9	61.0	8.6	4.3	4.3	38.1	30.0	25.7	25.7
3	10	59.9	8.6	4.3	4.3	31.9	30.0	25.7	21.5
3	11	37.5	12.9	4.3	4.3	67.5	34.3	30.0	21.5
3	12	81.3	8.6	4.3	4.3	46.4	34.3	30.0	17.2
3	13	31.7	8.6	4.3	4.3	39.6	38.6	34.3	25.7
3	14	104.4	35.4	12.7	4.3	108.0	70.7	50.8	34.3
3	15	49.5	8.6	4.3	4.3	38.1	38.6	34.3	25.7
3	16	63.2	8.6	8.6	4.3	93.0	47.2	38.6	30.0
3	17	86.9	4.3	4.3	4.3	52.9	38.3	30.0	25.7
3	18	125.0	24.1	21.5	8.6	89.3	60.3	47.2	38.6
3	19	18.8	12.8	8.6	8.6	63.8	46.9	38.6	47.2
3	20	114.4	8.5	4.3	4.3	70.1	50.8	42.9	34.3
3	21	79.4	8.5	4.3	4.3	113.4	21.3	21.5	21.5
4	1	75.0	32.4	25.7	25.7	92.8	52.7	68.6	72.9
4	2	27.9	4.3	4.3	4.3	39.9	34.3	34.3	30.0
4	3	19.1	8.6	4.3	4.3	45.7	34.3	34.3	34.3
4	4	14.9	12.7	8.6	8.6	55.8	50.8	38.6	30.0
4	5	23.0	4.3	4.3	4.3	23.0	17.2	17.2	12.9
4	6	120.0	8.4	8.6	4.3	75.0	16.8	17.2	17.2
4	7	48.0	4.2	8.6	8.6	55.4	21.2	17.2	12.9
4	8	64.8	12.3	8.6	4.3	32.4	20.6	21.5	17.2
4	9	29.0	8.5	4.3	4.3	14.5	16.9	17.2	17.2
4	10	30.0	8.5	4.3	4.3	33.8	21.2	17.2	17.2
4	11	80.0	8.6	4.3	4.3	26.7	25.7	21.5	17.2
4	12	42.8	16.2	8.6	4.3	42.8	24.3	21.5	21.5
4	13	15.6	8.6	4.3	4.3	35.1	25.7	17.2	17.2
4	14	82.1	25.0	8.1	4.3	50.0	14.3	28.4	21.5
4	15	56.3	12.9	4.3	4.3	67.5	30.0	25.7	21.5
4	16	79.2	8.6	8.6	4.3	35.6	25.7	21.5	17.2
4	17	54.5	12.5	4.3	4.3	72.6	29.2	25.7	21.5
4	18	64.8	8.6	4.3	4.3	41.9	25.7	17.2	17.2
4	19	68.6	17.2	8.6	4.3	15.2	42.9	25.7	21.5
4	20	153.8	16.4	8.6	4.3	15.0	20.6	25.7	124.4
4	21	23.8	12.9	8.6	4.3	67.3	21.5	21.5	17.2
5	1	76.8	17.2	8.6	4.3	88.3	30.0	25.7	17.2
5	2	41.3	8.4	4.3	4.3	97.5	25.2	25.7	21.5
5	3	81.3	8.6	4.3	4.3	73.5	30.0	21.5	8.6
5	4	60.0	21.3	17.2	8.6	45.0	21.3	17.2	17.2
5	5	22.3	8.6	4.3	4.3	67.0	34.3	21.5	17.2
5	6	30.5	4.3	4.3	4.3	30.5	21.3	21.5	17.2
5	7	57.2	8.6	4.3	4.3	26.7	25.7	17.2	17.2
5	8	48.4	20.1	8.6	4.3	40.9	20.1	25.7	21.5
5	9	79.4	8.6	8.6	4.3	34.0	25.7	21.5	17.2
5	10	45.0	12.8	4.3	4.3	18.8	21.3	17.2	12.9
5	11	50.4	12.2	21.5	4.3	46.8	16.3	25.7	21.5

		Spring 1997				Spring 1998			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
5	12	50.0	8.1	8.6	4.3	82.1	16.2	17.2	12.9
5	13	42.8	12.7	4.3	4.3	64.3	33.8	17.2	17.2
5	14	67.8	8.0	4.3	4.3	39.3	24.1	25.7	17.2
5	15	15.8	8.6	4.3	4.3	39.6	25.7	17.2	17.2
5	16	22.9	4.3	4.3	4.3	22.9	21.5	17.2	17.2
5	17	40.3	12.2	8.6	8.6	36.6	20.3	12.9	17.2
5	18	15.4	4.3	4.3	4.3	23.0	21.5	21.5	12.9
5	19	59.0	8.6	8.6	4.3	44.3	34.3	21.5	17.2
5	20	33.8	8.4	4.3	4.3	45.0	21.0	21.5	12.9
5	21	30.0	8.6	4.3	4.3	82.5	21.5	17.2	17.2
6	1	21.8	4.1	4.3	4.3	29.0	16.6	8.6	8.6
6	2	79.9	8.2	4.3	4.3	54.5	16.3	17.2	12.9
6	3	11.3	4.3	4.3	4.3	22.5	12.8	12.9	8.6
6	4	38.7	4.3	4.3	4.3	19.4	12.9	12.9	12.9
6	5	51.7	4.1	4.3	4.3	88.6	29.0	17.2	8.6
6	6	18.6	4.2	4.3	4.3	70.7	12.5	12.9	17.2
6	7	26.5	4.3	4.3	4.3	79.4	21.5	21.5	12.9
6	8	30.0	4.3	4.3	4.3	75.0	21.6	21.5	17.2
6	9	15.5	8.6	4.3	4.3	31.0	21.5	17.2	12.9
6	10	56.7	8.6	4.3	4.3	83.2	30.0	30.0	17.2
6	11	21.4	3.8	4.2	4.3	89.3	23.0	16.7	21.5
6	12	46.4	8.0	4.3	4.3	89.3	24.1	21.5	12.9
6	13	105.0	19.7	4.3	4.3	131.3	7.9	17.2	17.2
6	14	53.8	8.6	4.3	4.3	57.6	25.7	21.5	12.9
6	15	30.0	12.9	4.3	4.3	30.0	21.5	17.2	17.2
6	16	18.9	4.2	4.3	4.3	34.0	29.4	17.2	12.9
6	17	28.8	4.2	4.3	4.3	64.8	12.6	21.5	12.9
6	18	26.3	4.2	4.3	4.3	183.8	12.7	30.0	17.2
6	19	36.6	4.2	4.3	4.3	69.5	21.0	17.2	17.2
6	20	15.4	4.3	4.3	4.3	57.6	30.0	21.5	17.2
6	21	93.0	8.2	8.6	4.3	63.2	28.6	21.5	12.9
7	1	42.6	8.6	4.3	4.3	23.2	25.7	17.2	17.2
7	2	117.8	21.0	4.3	4.3	107.1	12.6	21.5	21.5
7	3	46.4	4.3	4.3	4.3	61.9	25.7	21.5	21.5
7	4	61.4	4.3	4.3	4.3	57.6	21.5	25.7	21.5
7	5	95.9	8.5	4.3	4.3	125.5	12.7	12.9	12.9
7	6	54.2	4.3	4.3	4.3	31.0	12.9	8.6	8.6
7	7	27.1	4.3	4.3	4.3	54.2	17.2	12.9	8.6
7	8	25.6	4.3	4.3	4.3	25.6	12.9	12.9	12.9
7	9	42.2	4.3	4.3	4.3	26.9	17.2	12.9	12.9
7	10	39.6	4.3	4.3	4.3	35.6	17.2	12.9	17.2
7	11	28.6	4.0	4.3	4.3	60.7	16.1	21.5	17.2
7	12	116.3	12.5	4.3	4.3	33.8	20.9	17.2	12.9
7	13	121.4	16.0	4.3	4.3	149.9	27.9	17.2	12.9
7	14	114.2	27.7	4.3	4.3	85.7	39.6	17.2	12.9
7	15	40.3	4.3	4.3	4.3	69.5	17.2	12.9	12.9
7	16	45.7	4.3	4.3	4.3	38.1	17.3	12.9	12.9
7	17	40.3	4.2	4.3	4.3	124.4	25.0	25.7	12.9
7	18	76.8	17.2	8.6	4.3	134.4	30.0	12.9	12.9

		Spring 1997				Spring 1998			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
7	19	40.6	12.7	8.6	4.3	29.5	25.4	12.9	12.9
7	20	48.4	8.6	4.3	4.3	52.1	17.2	12.9	8.6
7	21	38.7	4.3	8.6	4.3	54.2	17.2	4.3	4.3
8	1	25.2	4.3	4.3	4.3	32.4	17.2	12.9	12.9
8	2	89.7	16.6	4.3	4.3	101.4	20.7	17.2	8.6
8	3	51.1	4.3	4.3	4.3	35.4	17.2	12.9	8.6
8	4	126.7	4.3	8.6	4.3	23.8	8.6	4.3	8.6
8	5	49.5	8.5	8.6	4.3	57.2	34.1	30.0	17.2
8	6	51.7	8.3	8.6	4.3	88.6	25.0	21.5	12.9
8	7	30.7	4.3	4.3	4.3	38.4	12.9	8.6	8.6
8	8	7.9	4.3	4.3	4.3	35.4	12.9	8.6	12.9
8	9	26.5	4.3	8.6	4.3	52.9	12.8	8.6	4.3
8	10	58.6	4.2	4.3	4.3	62.2	12.7	4.3	4.3
8	11	18.6	4.3	4.3	4.3	130.2	12.8	12.9	4.3
8	12	36.3	4.2	4.3	4.3	87.1	16.8	12.9	4.3
8	13	34.0	4.3	4.3	4.3	98.3	8.6	4.3	4.3
8	14	85.7	71.8	51.9	8.7	132.1	136.1	59.9	52.2
8	15	146.4	53.8	4.2	4.3	185.6	34.6	16.8	4.3
8	16	92.8	7.6	4.2	4.3	64.3	45.7	21.2	17.2
8	17	51.7	16.1	4.3	4.3	51.7	12.1	4.3	4.3
8	18	148.6	33.6	8.6	4.3	125.7	12.6	8.6	8.6
8	19	79.9	15.5	8.6	4.3	43.6	15.5	12.9	12.9
8	20	42.8	4.2	4.3	4.3	78.5	12.7	12.9	12.9
8	21	54.9	17.2	8.6	12.9	18.3	8.6	12.9	4.3
9	1	64.8	16.2	8.2	4.3	93.6	36.5	24.7	17.2
9	2	19.7	4.3	4.3	4.3	55.0	12.9	8.6	8.6
9	3	37.2	16.0	12.9	4.3	107.9	23.9	42.9	60.1
9	4	44.3	4.2	4.3	4.3	59.0	29.2	21.5	12.9
9	5	24.3	4.3	4.3	4.3	52.7	12.9	12.9	8.6
9	6	26.7	4.3	4.3	4.3	61.0	17.0	12.9	12.9
9	7	11.7	4.3	4.3	4.3	31.2	12.9	12.9	12.9
9	8	15.6	12.9	17.2	8.6	35.1	21.5	12.9	12.9
9	9	64.3	12.8	8.6	8.6	41.6	21.3	17.2	8.6
9	10	37.5	12.9	8.6	8.6	52.5	17.2	12.9	12.9
9	11	83.8	8.6	8.6	8.6	80.0	21.5	17.2	17.2
9	12	62.7	12.9	12.9	8.6	92.3	21.5	21.5	8.6
9	13	28.6	12.9	8.6	12.9	36.7	25.7	17.2	17.2
9	14	164.2	47.5	32.4	8.6	135.7	43.6	20.3	21.5
9	15	50.0	8.3	21.5	17.2	146.4	16.7	25.7	34.3
9	16	92.8	70.2	35.4	13.2	164.2	70.2	59.0	75.0
9	17	22.9	17.2	17.2	12.9	106.7	25.7	21.5	17.2
9	18	70.7	12.6	17.2	12.9	37.2	8.4	8.6	8.6
9	19	42.8	8.2	17.2	12.9	92.8	8.2	17.2	17.2
9	20	82.1	12.0	17.2	17.2	46.4	31.9	21.5	8.6
9	21	43.6	21.5	17.2	12.9	23.8	21.5	8.6	4.3
10	1	67.8	27.9	17.2	17.2	57.1	8.0	38.6	12.9
10	2	32.4	8.2	30.0	17.2	90.0	16.4	34.3	12.9
10	3	42.2	16.2	12.9	12.9	53.8	12.2	12.9	8.6
10	4	12.0	17.2	12.9	12.9	51.9	12.9	8.6	4.3

		Spring 1997				Spring 1998			
Transect	**Point**	**0-30**	**30-60**	**60-90**	**90-120**	**0-30**	**30-60**	**60-90**	**90-120**
10	5	22.9	12.8	17.2	12.9	30.5	12.8	8.6	8.6
10	6	32.9	7.7	17.2	12.9	47.6	15.5	17.2	12.9
10	7	43.6	16.7	25.7	12.9	36.3	16.7	17.2	17.2
10	8	63.8	17.2	12.9	12.9	15.0	12.9	8.6	8.6
10	9	63.2	8.3	8.6	8.6	40.9	12.5	12.9	17.2
10	10	39.6	8.2	8.6	12.9	10.8	20.6	55.8	12.9
10	11	38.4	21.5	17.2	12.9	34.6	12.9	8.6	4.3
10	12	26.7	21.2	8.6	4.3	49.5	16.9	12.9	8.6
10	13	26.7	12.9	8.6	8.6	49.5	8.6	8.6	4.3
10	14	61.4	12.9	8.6	4.3	65.3	21.5	8.6	8.6
10	15	33.8	21.5	12.9	4.3	56.3	21.5	12.9	8.6
10	16	85.7	38.7	8.6	12.9	157.1	92.9	55.8	25.7
10	17	145.9	17.0	8.6	8.6	34.6	17.0	12.9	8.6
10	18	29.8	8.5	8.6	8.6	55.8	12.8	12.9	12.9
10	19	32.4	12.8	8.6	8.6	61.2	21.3	17.2	12.9
10	20	30.5	8.6	8.6	4.3	38.1	21.5	17.2	12.9
10	21	31.7	17.2	12.9	4.3	19.8	21.5	8.6	4.3

Appendix IIIf. Dynamic soil properties at individual sampling points: Residual exchangeable soil potassium, 1997 and 1998 (kg/ha).

		Spring 1997				Spring 1998			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
1	1	1023	663	745	904	707	745	818	865
1	2	732	483	749	663	1071	683	719	934
1	3	737	610	538	577	911	677	727	672
1	4	872	611	715	801	898	829	745	801
1	5	753	654	616	702	787	814	887	900
1	6	624	530	495	538	624	694	749	749
1	7	443	498	512	461	803	726	706	715
1	8	672	426	456	538	695	697	732	689
1	9	745	362	413	426	726	680	775	771
1	10	536	409	395	390	698	592	652	511
1	11	480	322	369	493	765	553	635	622
1	12	343	462	403	382	793	555	571	579
1	13	642	523	374	43	801	668	592	536
1	14	796	488	563	455	821	815	671	515
1	15	1088	532	609	674	932	776	794	819
1	16	739	678	450	463	1082	841	678	626
1	17	977	543	498	502	930	588	639	644
1	18	1562	1312	532	480	1138	505	463	532
1	19	1343	798	412	420	1448	1171	519	725
1	20	755	508	535	661	1212	521	636	798
1	21	1050	714	626	682	1042	554	639	626
2	1	730	592	648	656	839	755	759	751
2	2	926	461	591	656	833	708	725	695
2	3	835	629	498	519	824	760	785	742
2	4	1229	562	601	613	686	764	716	721
2	5	625	782	566	1017	714	790	668	542
2	6	519	476	596	639	553	674	656	661
2	7	579	695	759	802	604	862	918	897
2	8	581	592	661	755	581	691	716	832
2	9	900	533	579	635	573	728	781	746
2	10	455	352	553	549	570	541	575	605
2	11	520	364	438	532	494	512	553	583
2	12	1171	438	339	472	597	502	596	656
2	13	705	390	343	468	668	536	553	558
2	14	601	633	503	295	1002	739	389	413
2	15	895	416	493	631	831	536	596	665
2	16	1245	926	643	626	1209	962	802	631
2	17	885	533	669	562	709	630	588	583
2	18	1235	983	744	596	789	656	559	575
2	19	809	486	532	463	672	601	523	536
2	20	1314	529	528	592	1267	698	952	746
2	21	1149	872	399	403	1183	495	541	571
3	1	1071	487	571	592	777	475	691	734
3	2	518	583	639	656	680	764	759	776
3	3	630	592	558	566	774	785	798	781
3	4	683	605	613	652	897	704	764	811

		Spring 1997				Spring 1998			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
3	5	772	776	625	392	831	1152	907	820
3	6	762	326	485	781	518	455	837	957
3	7	557	493	605	691	624	686	802	845
3	8	578	486	613	609	597	758	785	811
3	9	644	562	553	609	697	785	862	811
3	10	670	596	592	626	658	738	781	644
3	11	506	472	442	579	675	656	699	746
3	12	631	498	553	622	739	665	751	832
3	13	554	583	644	695	804	854	867	785
3	14	673	519	368	343	702	735	774	613
3	15	933	536	579	734	732	802	854	927
3	16	1254	738	613	661	1205	764	772	764
3	17	1062	426	459	622	839	711	695	759
3	18	1449	720	502	382	1278	699	678	1283
3	19	851	579	429	382	690	626	592	644
3	20	1487	546	746	901	1188	850	952	914
3	21	1399	716	832	991	1334	814	1227	1253
4	1	1075	867	768	691	1057	1102	978	970
4	2	591	558	678	674	750	785	832	832
4	3	453	356	416	408	472	459	511	622
4	4	539	533	588	596	644	732	746	734
4	5	699	652	721	644	768	815	854	789
4	6	848	685	652	639	701	769	807	824
4	7	517	567	515	549	653	694	721	721
4	8	598	600	558	549	565	732	699	686
4	9	624	431	463	545	446	719	686	665
4	10	581	376	596	592	559	677	652	665
4	11	632	511	536	553	636	639	622	665
4	12	607	474	412	476	578	551	442	425
4	13	569	626	776	807	706	875	948	909
4	14	896	603	522	450	721	625	482	601
4	15	1103	695	854	952	881	794	1017	1017
4	16	1030	656	721	734	851	772	832	759
4	17	1067	592	631	519	958	696	708	699
4	18	1109	721	824	781	808	746	841	828
4	19	1185	442	425	639	667	1360	502	596
4	20	1316	670	528	553	626	674	691	1025
4	21	903	699	901	1081	1129	665	901	970
5	1	1321	819	768	734	1179	901	905	824
5	2	585	592	583	575	795	659	729	686
5	3	774	682	704	583	851	755	794	626
5	4	559	567	532	648	649	780	789	768
5	5	658	661	613	609	870	742	781	738
5	6	659	707	824	746	819	895	798	841
5	7	686	515	528	592	602	682	639	704
5	8	606	434	532	506	539	659	665	626
5	9	639	579	502	489	643	493	502	489
5	10	563	354	425	545	398	426	408	472
5	11	497	384	266	287	533	404	275	386

		Spring 1997				Spring 1998			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
5	12	464	433	262	335	557	409	463	429
5	13	710	393	266	347	650	431	365	317
5	14	1035	515	420	485	893	511	468	485
5	15	685	416	442	656	677	669	789	815
5	16	659	549	631	644	671	729	734	725
5	17	1065	608	613	549	670	636	644	635
5	18	684	515	661	661	561	635	695	682
5	19	1391	849	579	498	1000	605	759	721
5	20	765	651	794	772	821	752	721	729
5	21	848	575	545	618	1309	725	704	716
6	1	737	588	523	609	661	546	450	493
6	2	584	473	403	498	613	514	532	549
6	3	638	720	686	751	679	656	674	712
6	4	650	541	558	605	670	579	545	613
6	5	731	613	433	661	716	501	601	832
6	6	666	667	686	725	837	776	686	738
6	7	624	609	579	618	692	635	618	699
6	8	563	605	523	562	761	575	438	622
6	9	639	425	579	523	573	532	506	609
6	10	639	502	420	425	624	622	476	335
6	11	403	392	388	365	657	564	542	532
6	12	471	458	369	373	760	579	227	249
6	13	844	507	339	339	1290	778	399	455
6	14	718	549	347	399	695	519	549	553
6	15	1013	613	892	940	1294	523	794	824
6	16	677	517	592	635	847	445	566	644
6	17	792	697	476	386	832	546	493	571
6	18	1635	728	463	549	2798	1548	609	592
6	19	1127	407	360	343	1182	512	498	459
6	20	810	335	455	468	876	502	601	648
6	21	852	608	532	583	770	579	656	622
7	1	1269	515	566	532	759	553	519	721
7	2	960	798	545	476	1292	731	493	678
7	3	937	665	489	571	913	631	592	639
7	4	776	583	532	553	710	468	506	506
7	5	1613	1282	807	661	1443	757	583	558
7	6	1014	678	631	635	600	498	601	665
7	7	697	665	674	661	789	489	579	661
7	8	732	622	648	665	754	686	729	751
7	9	772	472	562	601	584	519	605	656
7	10	673	523	601	708	618	583	631	785
7	11	878	764	382	468	803	527	442	485
7	12	803	571	489	480	578	575	463	545
7	13	1032	630	395	305	893	543	386	429
7	14	1182	796	416	253	900	982	360	571
7	15	1398	661	858	884	988	742	935	922
7	16	1021	510	532	609	892	631	601	631
7	17	1021	600	489	536	963	534	498	558
7	18	3107	2801	2287	837	2596	2458	1523	1060

		Spring 1997				Spring 1998			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
7	19	982	791	682	712	679	601	656	699
7	20	859	575	558	652	573	506	562	562
7	21	774	403	403	429	724	459	365	386
8	1	1080	699	571	566	1105	489	476	442
8	2	1977	869	420	480	2071	687	317	313
8	3	1002	553	841	884	645	639	734	686
8	4	4594	2595	734	669	3330	1433	794	776
8	5	1158	528	373	352	644	558	485	485
8	6	664	771	536	558	579	450	455	528
8	7	864	566	661	566	572	601	511	613
8	8	735	605	678	729	574	515	592	609
8	9	578	541	558	631	597	405	450	433
8	10	1815	1282	506	558	1695	1079	395	450
8	11	591	469	442	592	621	396	403	433
8	12	653	559	498	485	639	643	408	438
8	13	801	622	661	648	813	558	592	566
8	14	796	934	1269	909	925	835	1337	1248
8	15	1160	657	559	425	896	511	454	296
8	16	1035	762	656	558	771	644	618	416
8	17	697	414	322	313	734	390	330	317
8	18	2031	1676	884	695	1246	643	360	433
8	19	1314	975	571	588	1165	608	450	476
8	20	778	470	553	639	603	334	416	429
8	21	787	356	450	446	256	339	438	403
9	1	1170	879	510	506	1105	1053	686	708
9	2	817	438	661	618	790	785	755	686
9	3	856	750	395	412	1328	750	558	545
9	4	1590	609	412	485	1137	671	691	669
9	5	652	562	468	562	693	648	699	712
9	6	533	473	416	493	667	622	678	716
9	7	644	502	472	536	839	669	708	686
9	8	690	635	656	682	753	708	695	704
9	9	809	635	605	661	745	673	682	674
9	10	836	519	536	652	679	644	699	738
9	11	953	699	558	558	800	644	686	682
9	12	579	489	412	588	827	661	704	755
9	13	1102	588	605	648	783	661	656	678
9	14	1071	772	1308	759	1000	1200	960	618
9	15	996	817	429	433	1242	1001	746	626
9	16	1071	667	483	467	1517	764	703	736
9	17	1082	631	566	665	1314	541	691	716
9	18	1101	609	515	523	949	840	579	656
9	19	1057	678	566	498	1239	707	558	661
9	20	607	519	519	485	571	583	652	669
9	21	1061	463	596	802	578	429	438	476
10	1	903	858	528	493	814	770	644	669
10	2	763	662	536	545	828	810	656	588
10	3	799	595	575	601	718	587	626	721
10	4	622	468	463	609	678	613	652	656

		Spring 1997				Spring 1998			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
10	5	564	460	468	511	632	486	588	644
10	6	501	557	545	579	641	631	609	596
10	7	483	659	429	472	635	613	502	506
10	8	818	515	566	592	608	665	686	699
10	9	897	513	420	459	718	809	588	631
10	10	778	526	558	502	497	633	759	558
10	11	829	592	515	639	676	498	579	695
10	12	629	321	313	386	754	427	412	579
10	13	701	360	438	519	819	511	596	553
10	14	1175	811	678	734	1440	729	935	828
10	15	1200	463	635	678	986	528	609	669
10	16	1067	534	506	347	1467	646	626	420
10	17	1336	545	373	506	826	588	575	622
10	18	1038	528	446	523	1109	814	644	609
10	19	1177	584	506	489	983	656	631	609
10	20	682	553	523	613	602	601	639	712
10	21	606	425	579	652	665	450	571	618

Appendix IIIg. Dynamic soil properties at individual sampling points: Residual soil sulphate-sulphur, 1997 and 1998 (kg/ha).

		Spring 1997				Spring 1998			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
1	1	51	25	16	27	17	13	13	22
1	2	18	21	15	12	14	14	5	7
1	3	20	11	7	20	22	14	29	43
1	4	21	9	10	23	22	18	15	17
1	5	19	10	16	34	14	12	12	14
1	6	14	13	6	12	11	6	8	12
1	7	30	13	6	19	19	11	12	20
1	8	18	10	7	9	20	9	7	14
1	9	14	7	2	4	23	8	6	10
1	10	14	6	5	8	17	16	10	11
1	11	18	10	59	224	39	12	182	201
1	12	37	14	16	141	24	17	59	55
1	13	16	14	13	9	15	29	10	9
1	14	37	18	21	61	156	67	38	52
1	15	20	18	665	4007	48	64	841	5320
1	16	49	9	16	88	33	20	91	68
1	17	8	9	8	12	49	20	12	12
1	18	40	16	13	19	50	17	37	35
1	19	34	11	145	410	204	41	86	187
1	20	12	10	10	12	52	282	28	27
1	21	22	10	166	166	13	10	63	46
2	1	11	10	9	13	31	14	15	17
2	2	19	11	8	7	17	9	14	24
2	3	13	9	17	69	13	10	61	57
2	4	16	12	9	15	21	8	10	13
2	5	18	8	18	9	15	9	7	12
2	6	12	9	10	23	10	5	14	24
2	7	16	8	9	13	25	11	14	16
2	8	24	9	10	12	22	11	13	17
2	9	11	7	7	9	13	6	6	8
2	10	13	9	7	6	9	5	7	12
2	11	15	10	6	9	8	8	37	49
2	12	23	30	20	76	32	19	177	450
2	13	68	59	90	401	19	375	901	528
2	14	20	16	9	6	72	9	11	7
2	15	22	15	1330	1416	45	59	1000	1236
2	16	171	16	12	154	29	21	42	144
2	17	22	13	16	27	15	8	14	29
2	18	25	11	14	12	20	12	23	33
2	19	22	11	29	2621	52	1337	1034	708
2	20	30	12	7	7	45	14	24	13
2	21	30	11	184	202	26	15	151	42
3	1	23	13	9	21	23	9	21	27
3	2	15	8	6	7	13	6	7	11
3	3	18	8	11	30	17	12	16	16
3	4	21	9	8	12	23	20	19	31

		Spring 1997				Spring 1998			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
3	5	15	5	9	16	18	15	26	23
3	6	15	9	7	6	18	18	9	9
3	7	43	18	9	15	16	10	12	17
3	8	12	6	5	10	11	13	12	14
3	9	14	6	5	6	24	10	16	14
3	10	16	6	6	13	10	8	11	21
3	11	42	9	28	79	24	13	37	79
3	12	144	86	100	105	24	14	36	52
3	13	21	442	1943	6607	28	1334	2608	6564
3	14	26	19	64	79	684	417	88	34
3	15	55	29	498	2145	45	1060	1592	2063
3	16	37	21	18	30	33	19	31	48
3	17	27	11	34	83	22	21	33	66
3	18	45	17	58	202	27	10	43	66
3	19	76	20	300	1973	30	32	1244	1828
3	20	49	26	15	24	28	27	66	51
3	21	17	10	6	11	17	9	7	9
4	1	47	14	22	110	31	19	26	46
4	2	13	10	8	8	15	10	12	16
4	3	18	7	6	6	26	16	9	8
4	4	15	9	9	12	11	17	21	23
4	5	15	6	8	6	13	5	8	6
4	6	24	12	8	10	16	27	11	9
4	7	15	9	7	7	11	12	21	21
4	8	21	9	5	10	10	7	7	16
4	9	7	6	5	4	9	6	9	9
4	10	11	6	4	5	20	11	18	22
4	11	18	8	4	11	18	9	13	32
4	12	24	9	11	46	11	11	6	7
4	13	35	198	185	95	15	75	146	163
4	14	19	11	8	22	17	21	17	23
4	15	43	19	380	1077	21	93	1330	1330
4	16	17	15	36	62	29	12	30	60
4	17	81	10	7	6	16	13	48	45
4	18	18	6	32	60	14	54	172	142
4	19	18	9	10	45	103	60	40	184
4	20	41	9	7	23	26	32	11	27
4	21	34	11	30	56	16	16	17	41
5	1	19	9	5	15	16	13	47	133
5	2	20	10	6	17	31	12	12	16
5	3	17	7	6	6	14	7	11	9
5	4	19	9	9	41	13	10	18	24
5	5	19	12	8	9	15	15	9	13
5	6	11	8	7	20	9	11	28	27
5	7	18	8	17	15	21	45	34	31
5	8	12	5	4	5	13	10	8	9
5	9	14	9	9	20	10	12	17	10
5	10	20	23	5	3	11	5	4	5
5	11	15	9	9	37	17	10	41	48

		Spring 1997				Spring 1998			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
5	12	17	13	66	172	24	18	35	52
5	13	16	14	9	10	24	20	12	9
5	14	20	12	6	7	21	14	6	6
5	15	23	34	340	961	26	1459	2231	2660
5	16	15	16	18	52	24	10	62	154
5	17	37	11	9	25	25	18	39	30
5	18	28	9	19	32	26	38	116	69
5	19	51	10	7	12	16	13	16	18
5	20	15	8	7	15	11	12	50	58
5	21	39	9	12	32	21	10	12	19
6	1	33	10	47	298	31	10	11	69
6	2	4	11	30	66	22	9	36	89
6	3	13	11	8	12	14	9	8	12
6	4	26	8	6	18	35	14	15	36
6	5	17	7	5	6	14	7	6	6
6	6	17	13	11	17	10	10	21	35
6	7	21	12	9	10	14	8	9	12
6	8	16	9	6	6	12	18	6	9
6	9	21	6	5	9	17	14	62	238
6	10	25	9	14	85	18	22	33	58
6	11	21	8	10	23	23	14	52	48
6	12	20	8	73	97	25	89	30	19
6	13	35	53	18	11	17	13	7	10
6	14	26	12	7	7	25	56	166	136
6	15	23	63	1459	3157	21	156	940	1137
6	16	45	30	17	55	43	26	142	236
6	17	20	13	314	230	20	21	511	383
6	18	16	13	18	57	39	29	56	79
6	19	16	14	5	27	18	11	6	24
6	20	25	10	9	19	21	41	30	30
6	21	54	12	12	35	12	6	17	25
7	1	19	12	45	459	27	15	74	239
7	2	17	21	17	97	17	33	12	28
7	3	27	15	7	20	24	15	8	21
7	4	19	17	9	43	23	12	20	60
7	5	33	13	9	21	16	11	4	6
7	6	12	9	9	13	9	5	4	8
7	7	15	9	9	9	12	8	5	6
7	8	15	9	9	17	23	9	8	15
7	9	27	9	9	21	13	8	18	21
7	10	20	13	17	56	26	10	27	57
7	11	64	16	9	77	50	36	50	100
7	12	56	25	674	397	35	41	682	429
7	13	40	24	26	13	25	16	13	11
7	14	7	20	13	9	12	11	6	6
7	15	28	38	92	49	14	26	54	35
7	16	85	12	10	44	20	14	95	85
7	17	20	10	19	100	23	13	254	112
7	18	76	25	18	53	21	19	11	16

		Spring 1997				Spring 1998			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
7	19	17	10	5	20	14	6	15	57
7	20	32	19	29	73	31	10	101	157
7	21	20	10	6	7	10	8	5	2
8	1	28	18	142	442	19	23	463	644
8	2	72	33	9	43	28	26	18	18
8	3	17	10	8	18	13	7	16	53
8	4	29	19	51	343	34	14	241	384
8	5	18	13	12	20	30	14	295	154
8	6	20	9	19	34	14	6	16	21
8	7	30	12	9	6	12	7	8	22
8	8	31	7	9	9	23	9	15	10
8	9	12	8	6	7	12	6	9	17
8	10	29	12	18	41	15	14	9	33
8	11	16	8	13	38	13	7	25	59
8	12	33	13	53	142	22	20	82	98
8	13	70	24	811	1330	22	41	888	987
8	14	28	20	20	61	21	17	9	10
8	15	33	15	8	6	21	15	13	15
8	16	19	9	6	21	14	10	11	18
8	17	28	12	498	326	18	11	56	44
8	18	50	16	9	10	18	9	24	35
8	19	50	20	12	65	33	17	89	91
8	20	59	13	22	48	19	10	37	57
8	21	14	9	6	6	7	3	3	6
9	1	28	9	39	33	176	61	46	40
9	2	22	14	10	27	32	16	18	38
9	3	28	14	98	249	34	16	417	369
9	4	61	16	596	944	34	13	57	205
9	5	22	11	10	11	17	10	8	23
9	6	11	9	9	20	14	10	15	31
9	7	41	11	7	11	28	13	19	20
9	8	17	6	4	6	13	8	8	10
9	9	18	7	6	16	23	13	18	21
9	10	11	8	33	207	18	16	195	278
9	11	28	9	6	9	20	12	25	37
9	12	15	6	8	27	15	21	12	12
9	13	32	10	31	138	17	13	66	176
9	14	21	15	10	9	22	13	15	18
9	15	36	8	35	48	37	37	63	88
9	16	22	15	10	25	24	17	8	10
9	17	27	11	27	218	30	28	103	275
9	18	20	9	22	54	15	11	14	45
9	19	24	10	55	80	31	13	8	60
9	20	20	9	41	31	29	10	14	24
9	21	19	10	71	233	12	14	90	82
10	1	32	19	54	145	17	11	19	47
10	2	31	13	485	1154	41	690	644	24
10	3	21	9	10	18	17	11	15	28
10	4	13	7	7	13	14	11	13	12

		Spring 1997				Spring 1998			
Transect	Point	0-30	30-60	60-90	90-120	0-30	30-60	60-90	90-120
10	5	20	9	16	136	24	20	37	102
10	6	26	13	6	9	44	17	17	23
10	7	42	10	91	118	16	9	68	80
10	8	26	9	7	15	20	9	8	9
10	9	15	8	11	6	23	16	8	9
10	10	19	5	7	12	7	13	18	13
10	11	49	19	13	15	44	22	42	59
10	12	21	7	12	39	16	67	208	234
10	13	16	10	189	296	19	15	99	227
10	14	23	31	204	172	48	27	101	127
10	15	65	187	944	1158	20	1918	2681	3286
10	16	39	41	24	46	27	18	13	26
10	17	47	32	978	1403	46	40	1180	1000
10	18	130	13	57	96	21	23	46	88
10	19	66	17	14	44	36	12	25	42
10	20	18	11	28	58	16	8	24	42
10	21	17	9	20	41	15	17	39	37

Appendix IVa. Response attributes observed at individual sampling points: 1997

Transect	Point	N Treatment (kg/ha)	Anthesis Biomass (kg/ha)	Grain Yield (kg/ha)	Straw Yield (kg/ha)	Grain N (%)	Straw N (%)
1	1	90	1644	2038	3477	2.85	0.70
1	2	90	2280	2198	4123	2.54	0.79
1	3	90	1482	1901	3430	2.81	0.78
1	4	90	1140	1832	3895	2.82	0.93
1	5	90	1568	1909	3031	2.78	0.96
1	6	90	2090	2084	3221	2.77	0.72
1	7	90	2062	2245	3848	2.87	0.69
1	8	90	1682	2309	3553	2.73	0.80
1	9	90	1530	2137	3753	2.77	0.73
1	10	90	1463	2322	3477	2.52	0.66
1	11	90	1511	2168	3249	2.58	0.67
1	12	90	2090	2539	4038	2.55	0.53
1	13	90	2261	2760	4199	2.50	0.66
1	14	90	2822	n/a	4551	2.42	0.67
1	15	90	1758	2596	4161	2.44	0.68
1	16	90	1834	2388	3857	2.98	0.69
1	17	90	1701	n/a	3743	2.96	0.78
1	18	90	1815	2162	3401	2.84	0.69
1	19	90	1909	2389	3477	2.68	0.70
1	20	90	1663	1385	2727	3.30	0.94
1	21	90	1928	2027	3050	2.95	0.81
2	1	45	1682	1872	2888	2.36	0.60
2	2	45	1853	2202	2280	2.50	0.59
2	3	45	1986	2146	3116	2.46	0.65
2	4	45	1720	1963	3012	2.27	0.60
2	5	45	1948	2091	3439	2.53	0.69
2	6	22	1178	1829	2660	2.31	0.46
2	7	22	1777	1807	2708	2.13	0.42
2	8	45	1644	1842	2812	2.34	0.68
2	9	45	1720	1799	2575	2.29	0.59
2	10	45	1815	2158	3306	2.40	0.61
2	11	45	1606	2138	2964	2.21	0.63
2	12	90	1644	2198	3240	2.39	0.76
2	13	45	1967	2644	4066	2.65	0.70
2	14	45	2584	2924	4095	2.41	0.62
2	15	90	713	2454	3392	2.32	0.68
2	16	90	2508	2831	4788	2.58	0.75
2	17	90	2024	2327	3696	2.37	0.59
2	18	90	2708	2177	3800	3.41	0.83
2	19	90	2166	2108	2983	2.86	0.61
2	20	90	2584	2445	3829	2.59	0.70
2	21	90	2090	2028	3468	2.83	0.71
3	1	0	1311	1602	2147	2.06	0.59
3	2	0	1387	1616	2347	2.29	0.64
3	3	0	1492	1680	3069	2.27	0.44
3	4	0	1311	1658	2632	2.48	0.73
3	5	0	1720	1484	2451	2.27	0.56

Transect	Point	N Treatment (kg/ha)	Anthesis Biomass (kg/ha)	Grain Yield (kg/ha)	Straw Yield (kg/ha)	Straw N (%)	Grain N (%)
3	6	0	1891	1894	2613	2.16	0.48
3	7	0	1758	1916	2679	2.19	0.61
3	8	0	1482	1634	2242	2.41	0.68
3	9	0	1701	1645	2204	2.28	0.53
3	10	0	1311	1393	1995	2.16	0.72
3	11	0	1387	1834	2641	2.10	0.52
3	12	0	1644	1110	1786	2.13	0.60
3	13	0	1482	1581	2147	2.01	0.54
3	14	0	2147	2585	3753	2.32	0.74
3	15	0	2005	1796	2499	2.15	0.46
3	16	0	1482	1683	2385	2.15	0.77
3	17	0	1216	2180	3088	2.42	0.69
3	18	0	1853	2082	2983	2.11	0.55
3	19	0	1758	1852	3544	2.05	0.57
3	20	0	2024	1763	2537	2.12	0.50
3	21	0	2062	2059	2755	2.07	0.55
4	1	45	1739	2203	3202	2.25	0.53
4	2	45	1292	1939	2679	2.37	0.55
4	3	45	1796	1646	3078	3.00	0.75
4	4	45	2109	2147	3107	2.36	0.60
4	5	45	1606	2099	2964	2.38	0.78
4	6	45	1796	2349	3268	2.45	0.80
4	7	45	1777	1754	2461	2.43	0.66
4	8	45	1644	1907	2860	2.62	0.69
4	9	45	1463	2017	2822	2.40	0.81
4	10	45	1796	2385	2575	2.38	0.57
4	11	45	1530	2311	3382	2.26	0.70
4	12	45	1644	2102	3164	2.27	0.62
4	13	45	2147	2062	3126	2.09	0.56
4	14	45	2470	3150	4541	2.28	0.58
4	15	45	1549	1920	2670	2.18	0.45
4	16	45	1254	1875	2546	2.26	0.60
4	17	45	1872	2154	3031	2.37	0.58
4	18	45	1720	2173	3088	2.63	0.74
4	19	45	2204	2754	4323	2.31	0.54
4	20	45	2062	2266	3183	2.28	0.81
4	21	45	1872	1996	2926	2.34	0.72
5	1	135	1739	2117	3297	2.84	0.79
5	2	135	1549	1765	2993	2.97	0.81
5	3	135	2204	1898	3116	3.06	0.84
5	4	135	2081	n/a	n/a	2.81	0.72
5	5	135	2546	n/a	n/a	2.60	0.66
5	6	135	931	2277	3705	2.86	0.95
5	7	135	1606	2006	3249	2.68	0.67
5	8	135	1482	2046	3287	2.90	0.79
5	9	135	1568	2236	3449	2.79	0.69
5	10	135	1891	1950	3078	3.02	0.78
5	11	135	2043	1918	3126	2.89	0.79

Transect	Point	N Treatment (kg/ha)	Anthesis Biomass (kg/ha)	Grain Yield (kg/ha)	Straw Yield (kg/ha)	Straw N (%)	Grain N (%)
5	12	135	2128	n/a	n/a	2.87	0.68
5	13	135	2299	2689	4142	2.70	0.57
5	14	135	1511	2821	4484	2.48	0.76
5	15	135	2081	n/a	n/a	2.35	0.56
5	16	135	2185	2116	3211	3.15	0.74
5	17	135	2223	2250	4332	3.08	1.02
5	18	135	1758	2331	3658	2.69	0.59
5	19	135	2822	3060	3544	3.04	0.66
5	20	135	2413	2632	3848	2.85	0.64
5	21	135	2024	2253	3591	2.86	0.70
6	1	45	1368	1915	2936	2.30	0.44
6	2	45	1663	1927	3382	2.59	0.65
6	3	45	1644	1852	2822	2.34	0.61
6	4	45	1568	2330	3382	2.29	0.50
6	5	45	2242	2424	3401	2.36	0.58
6	6	45	1463	2107	3135	2.37	0.61
6	7	45	2024	2272	3325	2.38	0.64
6	8	45	1701	2324	3525	2.28	0.75
6	9	45	2081	1995	3116	2.24	0.54
6	10	45	1530	1452	4313	2.40	0.51
6	11	45	1834	2421	3705	2.18	0.55
6	12	45	1463	2473	4000	2.15	0.48
6	13	45	1511	2326	3848	2.15	0.73
6	14	45	1482	1850	3050	2.23	0.47
6	15	45	1587	1976	3040	2.02	0.51
6	16	45	1682	2789	3857	2.10	0.44
6	17	45	1663	2415	3382	2.43	0.69
6	18	45	1663	2285	3420	2.26	0.70
6	19	45	2024	2958	4342	2.04	0.49
6	20	45	1606	2118	3838	2.44	0.58
6	21	45	2299	2524	4066	2.55	0.57
7	1	135	1511	2123	3297	2.88	0.69
7	2	135	2043	1461	3221	3.03	1.14
7	3	135	1815	2480	3534	2.88	0.74
7	4	135	1682	2406	3648	3.07	0.94
7	5	135	1425	2449	3430	2.90	0.80
7	6	135	1007	2062	2898	2.93	0.63
7	7	135	1311	2390	3610	2.95	0.80
7	8	135	1273	2147	3411	2.90	0.82
7	9	135	2299	2047	3354	2.94	1.05
7	10	135	1928	2143	3582	3.09	0.89
7	11	135	2147	1962	3781	3.00	0.82
7	12	135	2005	2405	3933	2.73	0.73
7	13	135	2261	2285	4019	2.70	0.68
7	14	135	2062	2277	3952	2.72	0.99
7	15	135	2242	3042	4380	2.57	0.67
7	16	135	2242	2795	4541	2.65	0.53
7	17	135	1948	2434	3705	2.85	0.88

Transect	Point	N Treatment (kg/ha)	Anthesis Biomass (kg/ha)	Grain Yield (kg/ha)	Straw Yield (kg/ha)	Straw N (%)	Grain N (%)
7	18	135	2261	2767	4693	2.80	0.78
7	19	135	2708	2649	3914	2.76	0.79
7	20	135	1872	2543	3544	2.75	0.88
7	21	135	2147	2411	3876	2.74	0.67
8	1	0	1682	1533	2299	2.10	0.58
8	2	0	1815	1465	2423	2.37	0.67
8	3	0	1444	1477	1967	2.09	0.78
8	4	0	1387	1590	2176	2.11	0.51
8	5	0	1739	1280	2641	2.26	0.59
8	6	0	1549	1457	1957	2.10	0.67
8	7	0	1492	1486	2052	2.28	0.57
8	8	0	1349	1545	2242	2.15	0.54
8	9	0	1425	1573	2119	2.45	0.73
8	10	0	1530	1783	2689	2.17	0.49
8	11	0	969	1524	2043	2.19	0.68
8	12	0	1140	1909	2584	1.97	0.60
8	13	0	1349	1369	1900	2.15	0.56
8	14	0	2993	2697	4465	2.28	0.50
8	15	0	2005	2117	3354	2.04	0.30
8	16	0	2109	1871	2784	2.17	0.60
8	17	0	1663	1189	1739	2.37	0.45
8	18	0	1606	1852	2765	2.06	0.65
8	19	0	1663	1822	3078	2.00	0.50
8	20	0	2081	1598	2366	2.41	0.58
8	21	0	1606	1233	1872	2.31	0.64
9	1	90	2527	n/a	n/a	2.84	0.59
9	2	90	2005	2275	3563	2.61	0.67
9	3	90	2128	2354	3553	2.89	0.64
9	4	90	2024	2513	3848	2.80	0.82
9	5	90	1511	2174	2964	2.60	0.71
9	6	90	1720	1875	2537	2.71	0.93
9	7	90	2043	2329	3439	2.61	0.85
9	8	90	2223	2151	3012	2.57	0.66
9	9	90	2204	2141	3164	2.60	0.59
9	10	90	2147	1976	2926	2.75	0.78
9	11	90	2413	2505	3895	2.94	0.66
9	12	90	2280	2717	4038	2.74	0.72
9	13	90	2024	2606	4133	2.47	0.65
9	14	90	3819	3046	5168	2.87	0.80
9	15	90	2955	2478	4522	2.32	0.65
9	16	90	2917	2642	4893	2.63	0.77
9	17	90	2024	2378	3610	2.50	0.69
9	18	90	2489	2043	3040	2.79	0.74
9	19	90	2689	2175	3487	2.96	0.78
9	20	90	2508	2043	3420	2.90	0.95
9	21	90	2689	2493	2784	2.66	0.78
10	1	90	1777	2570	3971	2.65	0.59
10	2	90	1292	2259	3981	2.68	0.81

Transect	Point	N Treatment (kg/ha)	Anthesis Biomass (kg/ha)	Grain Yield (kg/ha)	Straw Yield (kg/ha)	Straw N (%)	Grain N (%)
10	3	22	637	1624	2451	2.17	0.57
10	4	22	1045	1941	2917	2.26	0.59
10	5	45	1235	2377	3553	2.38	0.50
10	6	45	1891	2384	3895	2.49	0.67
10	7	45	1121	2553	2860	2.23	0.63
10	8	45	1254	2108	3354	2.39	0.67
10	9	45	1178	2061	3126	2.44	0.62
10	10	45	1273	2077	3278	2.34	0.59
10	11	90	1292	2524	3781	2.24	0.53
10	12	90	1701	2371	3563	2.54	0.50
10	13	90	1197	1974	3012	2.19	0.49
10	14	45	1463	2086	4712	2.63	0.57
10	15	45	1273	2480	3772	2.02	0.38
10	16	45	2261	1951	3572	3.05	0.82
10	17	90	1568	2250	3677	2.37	0.47
10	18	90	1606	2396	4133	2.71	0.66
10	19	90	2622	2551	4380	2.93	0.68
10	20	22	1928	1630	2708	2.77	0.69
10	21	22	1967	2476	3582	2.32	0.62

Appendix IVb. Response attributes observed at individual sampling points: 1998.

Transect	Point	Na Treatment (kg/ha)	Anthesis Biomass (kg/ha)	Grain Yield (kg/ha)	Straw Yield (kg/ha)	Grain N (%)	Straw N (%)
1	1	90	2992	2383	4636	3.25	0.67
1	2	90	3067	2823	5225	3.18	0.66
1	3	90	2139	2718	5581	3.27	1.24
1	4	90	2865	2784	5149	3.11	0.62
1	5	90	3359	2888	5239	3.00	0.93
1	6	90	2917	3081	5287	3.13	0.73
1	7	90	2730	2839	5168	3.13	1.00
1	8	90	3044	2647	4893	3.20	1.17
1	9	90	3254	2669	5106	3.24	0.95
1	10	90	3426	2542	5277	3.30	1.15
1	11	90	2835	2696	5315	3.31	0.79
1	12	90	2611	2564	5121	3.35	1.17
1	13	90	2304	2438	4992	3.29	1.12
1	14	90	2349	2790	5553	3.22	0.73
1	15	90	2678	2581	5505	2.98	0.56
1	16	90	2588	3223	5838	3.13	1.17
1	17	90	3000	2899	6237	3.27	1.17
1	18	90	3329	3103	5786	3.07	1.01
1	19	90	2596	2883	5140	3.03	1.02
1	20	90	3119	2389	6113	2.79	1.28
1	21	90	2700	2592	5667	3.20	0.88
2	1	45	2611	2339	4299	2.73	0.44
2	2	45	2132	2279	4365	2.81	0.71
2	3	45	2551	2537	4617	2.99	0.96
2	4	45	2005	2197	4674	2.69	0.76
2	5	45	2416	2493	5106	3.06	0.91
2	6	22	2027	1905	3624	2.63	0.48
2	7	22	2035	1829	3629	2.63	0.44
2	8	45	2379	1851	3867	2.70	0.92
2	9	45	2424	2251	4470	2.70	0.52
2	10	45	2394	2383	4323	2.62	0.54
2	11	45	2296	2608	4736	3.02	1.15
2	12	90	2656	2685	5106	3.22	0.95
2	13	45	2147	2674	4973	3.15	0.80
2	14	45	883	1768	3952	2.88	0.96
2	15	90	1436	2724	4969	3.04	0.85
2	16	90	1668	2812	5106	3.25	0.87
2	17	90	1885	3174	5743	3.11	1.20
2	18	90	2483	2954	5520	3.24	0.68
2	19	90	2723	3388	5615	3.05	1.07
2	20	90	2656	3251	5990	3.21	0.75
2	21	90	2244	1741	5087	3.41	0.99
3	1	0	2267	1433	3525	2.53	0.64
3	2	0	1885	1466	2560	2.45	0.32
3	3	0	1922	1669	3192	2.50	0.40
3	4	0	3149	1664	3040	2.53	0.56
3	5	0	1952	1834	3225	2.62	0.53

Transect	Point	N Treatment (kg/ha)	Anthesis Biomass (kg/ha)	Grain Yield (kg/ha)	Straw Yield (kg/ha)	Grain N (%)	Straw N (%)
3	6	0	1735	1444	3387	2.65	0.54
3	7	0	2065	1757	3173	2.62	0.46
3	8	0	2072	1582	2807	2.53	0.79
3	9	0	2005	1312	2627	2.67	0.71
3	10	0	1930	1461	2845	2.58	0.49
3	11	0	1773	1439	2622	2.78	0.69
3	12	0	1526	1312	2399	2.47	0.61
3	13	0	1578	1367	2351	2.47	0.66
3	14	0	1788	1499	3230	2.67	0.49
3	15	0	1242	939	2394	2.57	0.49
3	16	0	2012	1779	3648	2.80	0.56
3	17	0	n/a	1301	2280	2.73	0.60
3	18	0	2027	1900	3681	2.72	0.67
3	19	0	1900	1895	3453	2.75	0.40
3	20	0	2102	1521	3073	2.64	0.43
3	21	0	1691	983	2171	2.70	0.78
4	1	45	2207	2229	4536	2.95	0.73
4	2	45	2259	2449	4185	2.79	0.79
4	3	45	2730	2405	4256	2.84	0.62
4	4	45	2700	1999	3615	3.30	0.58
4	5	45	2656	2433	4418	2.76	0.47
4	6	45	2693	2515	4456	2.90	0.51
4	7	45	n/a	2224	4332	2.69	0.69
4	8	45	2506	2273	4351	2.91	0.52
4	9	45	2102	2197	3952	2.95	0.55
4	10	45	2663	2054	3995	2.85	0.74
4	11	45	2282	2229	4152	2.77	0.48
4	12	45	2670	2180	4033	2.75	0.64
4	13	45	2169	2098	3938	2.64	0.77
4	14	45	2551	2048	3558	3.15	0.49
4	15	45	n/a	2389	4242	2.74	0.48
4	16	45	n/a	2339	4551	2.92	0.47
4	17	45	2917	2411	4318	2.93	0.55
4	18	45	2124	2806	4926	2.90	0.45
4	19	45	2760	2702	4603	2.83	0.76
4	20	45	n/a	2553	4399	2.86	0.59
4	21	45	2184	2268	4408	2.84	0.43
5	1	135	3635	2317	4394	3.38	0.91
5	2	135	3546	2416	4327	3.13	1.04
5	3	135	3059	2784	5182	3.14	1.26
5	4	135	3000	2153	3985	3.06	1.26
5	5	135	3620	2795	4802	3.20	0.95
5	6	135	3598	2564	5140	3.19	1.05
5	7	135	3179	2054	3800	3.20	0.86
5	8	135	2940	2229	4161	3.29	1.22
5	9	135	n/a	2147	3995	3.20	0.93
5	10	135	2760	2180	3924	3.16	1.12
5	11	135	3187	1944	3886	2.23	1.36
5	12	135	3276	2482	4845	3.29	0.93

Transect	Point	N Treatment (kg/ha)	Anthesis Biomass (kg/ha)	Grain Yield (kg/ha)	Straw Yield (kg/ha)	Grain N (%)	Straw N (%)
5	13	135	2566	2674	5045	3.30	1.19
5	14	135	2633	2054	3843	3.29	1.08
5	15	135	3418	2136	3871	3.14	1.29
5	16	135	2850	2597	4864	3.24	0.92
5	17	135	2753	2136	4494	3.15	1.00
5	18	135	3149	2564	4494	3.24	1.27
5	19	135	3493	2477	4750	3.39	1.31
5	20	135	3082	2328	4019	3.20	0.91
5	21	135	2843	2010	3686	3.23	0.90
6	1	45	2356	2422	3933	2.69	0.51
6	2	45	2326	2372	4584	2.77	0.53
6	3	45	2491	1702	3681	2.47	0.49
6	4	45	2356	2570	4551	2.67	0.75
6	5	45	2656	2553	4475	2.82	0.60
6	6	45	2035	2164	4019	2.67	0.49
6	7	45	2528	2361	4361	2.66	0.81
6	8	45	1885	1724	3634	2.61	0.47
6	9	45	1848	2098	4061	2.80	0.95
6	10	45	2005	2021	4118	2.86	0.52
6	11	45	1765	2158	3905	2.82	0.52
6	12	45	1504	2548	4807	2.92	0.79
6	13	45	n/a	1949	3772	2.62	0.51
6	14	45	2506	1900	3848	2.67	0.71
6	15	45	n/a	2197	4080	2.84	0.67
6	16	45	1765	2147	3924	2.78	0.47
6	17	45	3134	2449	4422	2.93	0.57
6	18	45	2985	2295	4570	2.58	0.62
6	19	45	2259	2581	4665	3.04	0.69
6	20	45	2573	2142	3995	2.77	0.64
6	21	45	2573	2378	4356	3.14	0.59
7	1	135	3740	2954	5572	3.26	1.07
7	2	135	2820	2954	5349	3.37	1.39
7	3	135	2506	2905	5116	3.08	0.74
7	4	135	3157	3136	6441	3.16	0.68
7	5	135	3336	2630	5881	3.19	1.10
7	6	135	3142	3004	5168	3.12	1.37
7	7	135	2865	2773	5353	3.05	0.77
7	8	135	3269	2998	5192	3.06	1.36
7	9	135	2977	2899	5800	3.23	1.21
7	10	135	3142	2993	5463	3.15	0.92
7	11	135	2865	2855	5130	3.21	1.26
7	12	135	2843	2905	5239	3.13	1.00
7	13	135	2947	2488	4897	3.22	0.99
7	14	135	2783	2685	5173	3.22	1.46
7	15	135	2820	2866	4878	3.09	1.46
7	16	135	2768	3158	5600	3.09	0.95
7	17	135	3082	3201	5762	3.24	1.10
7	18	135	3232	3141	5520	3.17	1.27
7	19	135	2745	3416	5786	3.18	1.02

Transect	Point	N Treatment (kg/ha)	Anthesis Biomass (kg/ha)	Grain Yield (kg/ha)	Straw Yield (kg/ha)	Grain N (%)	Straw N (%)
7	20	135	3568	2400	4365	3.08	1.05
7	21	135	3104	3042	5301	3.27	0.89
8	1	0	2094	1532	3240	2.62	0.72
8	2	0	2334	1466	2779	2.86	0.66
8	3	0	2012	1768	3244	2.68	0.67
8	4	0	1474	1142	2389	2.82	0.65
8	5	0	2102	1823	3525	2.61	0.68
8	6	0	1825	1653	3088	2.55	0.39
8	7	0	1758	1516	2902	2.57	0.45
8	8	0	1908	1691	3187	2.59	0.44
8	9	0	1952	1571	3572	2.61	0.67
8	10	0	2057	1620	3411	2.65	0.72
8	11	0	1661	1367	2556	2.58	0.78
8	12	0	1481	966	2223	2.40	0.77
8	13	0	1518	1076	2366	2.88	0.49
8	14	0	1893	1395	3140	2.84	0.73
8	15	0	1840	1439	3045	2.67	0.74
8	16	0	1706	1801	3776	2.72	0.56
8	17	0	1324	1592	3111	2.48	0.68
8	18	0	1653	1691	3235	2.81	0.61
8	19	0	2177	1768	3515	2.98	0.50
8	20	0	1227	1796	3259	2.86	0.48
8	21	0	1002	621	1363	2.46	0.51
9	1	90	2738	2037	4266	3.21	0.87
9	2	90	2341	2378	4342	3.04	0.80
9	3	90	2738	2032	4313	3.37	1.34
9	4	90	2371	2510	5054	3.17	0.99
9	5	90	2730	2213	4185	3.03	1.17
9	6	90	2371	2317	4342	3.06	0.80
9	7	90	2917	2405	4769	3.04	0.94
9	8	90	2932	1900	4318	3.16	1.00
9	9	90	2513	2218	4422	3.20	1.04
9	10	90	2730	2059	4636	3.06	1.08
9	11	90	2573	2257	4646	3.16	1.28
9	12	90	2798	2021	4076	3.24	0.70
9	13	90	2252	1905	4133	2.96	0.57
9	14	90	2611	1582	3810	3.22	1.15
9	15	90	2267	1927	3696	3.15	0.84
9	16	90	2184	2169	4028	3.34	0.86
9	17	90	2311	2103	4080	3.24	0.58
9	18	90	2902	2197	4479	3.11	0.77
9	19	90	2738	2175	4389	3.33	0.70
9	20	90	2925	2328	4289	3.21	0.89
9	21	90	2626	1746	3848	2.99	0.74
10	1	90	2685	2526	5681	3.38	1.17
10	2	90	2424	2592	5467	3.12	1.01
10	3	22	1885	1801	3216	2.67	0.43
10	4	22	2214	1636	3506	2.57	0.98
10	5	45	n/a	2048	4133	2.66	0.95

Transect	Point	N Treatment (kg/ha)	Anthesis Biomass (kg/ha)	Grain Yield (kg/ha)	Straw Yield (kg/ha)	Grain N (%)	Straw N (%)
10	6	45	2154	2186	4513	2.84	0.69
10	7	45	2798	2142	4826	2.84	0.87
10	8	45	2424	2213	4508	2.93	0.73
10	9	45	2573	2092	4318	2.85	0.72
10	10	45	2551	1971	4028	2.78	0.56
10	11	90	2641	2707	5216	2.87	1.01
10	12	90	2992	2312	5130	3.27	0.91
10	13	90	2760	2367	4318	2.75	0.79
10	14	45	2267	2076	4565	2.89	0.70
10	15	45	2693	2048	1378	2.59	0.87
10	16	45	2214	2251	4964	3.08	0.92
10	17	90	3015	2405	5216	3.18	0.74
10	18	90	2573	2696	5581	3.26	0.74
10	19	90	2985	2724	5510	3.24	1.14
10	20	22	2124	2350	4707	3.05	0.81
10	21	22	2304	2026	4380	3.18	1.01

Appendix V. Site growing season precipitation, 1997 and 1998 (mm).

1997			1998		
Month	**Day**	**Precipitation (mm)**	**Month**	**Day**	**Precipitation (mm)**
May	18	4	May	6	6
	21	13		9	4
				10	4
				28	30
				29	1
	Total	*17*		*Total*	*45*
June	14	7	June	1	3
	17	23		2	1
	20	4		4	1
	21	1		10	3
	24	8		13	1
				17	25
				18	31
				19	32
				20	20
				21	1
				23	3
				25	11
				26	11
				28	10
	Total	*43*		*Total*	*153*
July	1	30	July	2	6
	4	2		4	4
	7	5		5	3
	11	3		6	5
				11	2
				17	9
				20	5
				21	3
				26	2
	Total	*40*		*Total*	*39*
August	2	1	August	1	19
	9	1		2	58
	15	30		3	7
	19	4		15	10
	20	3		18	21
	29	12		22	16
				23	1
	Total	*51*		*Total*	*132*

Appendix VI. Table of abbreviations. Example provided below.

Abbreviation	**Time of Sampling (Prefix)**'
ES	Early season (prior to seeding)
MS	Mid season (near anthesis)
H	Harvest (immediately subsequent to crop removal)
	Soil or Crop Attribute
	Topographic Attributes
E (m)	Relative elevation
G (°)	Gradient
Kh (°/m)	Plan curvature
Kv (°/m)	Profile curvature
Cg (m^2*x100)*	Global catchment
Cl (m^2*x100)*	Local catchment
	Static Soil Attributes
A d (cm)	Total A horizon depth
Solum d	A horizon depth plus B horizon depth
CO3 d	Depth to calcium carbonates
Ap pH	Soil pH of the surface Ap horizon
SOC (%)	Soil organic carbon % w/w in the surface Ap horizon
SOC (Mg/ha)	Soil organic carbon mass per unit area for all of the A horizon
PDI	Profile Development Index
	Dynamic Soil Attributes
V (cm)	Volumetric soil moisture content
NO_3 *(kg/ha)*	Soil residual nitrate nitrogen
NH_4 *(kg/ha)*	Soil residual ammonium nitrogen
P (kg/ha)	Soil residual extractable phosphate phosphorus
K (kg/ha)	Soil residual exchangeable potassium
S (kg/ha)	Soil residual sulphate-sulphur
EPANS (kg/ha)	Estimated plant available N supply
	Crop Response Attributes
ABM (kg/ha)	Total above-ground biomass near anthesis
Z	Zadoks decimal growth stage
GY (kg/ha)	Grain yield
SY (kg/ha)	Straw yield
HBM (kg/ha)	Total above-ground harvest biomass
HI	Harvest index
GPC (%)	Grain protein concentration
GPY (kg/ha)	Grain protein yield
NU (kg/ha)	Total above-ground nitrogen at harvest
N BAL (kg/ha)	Nitrogen balance
WU (cm)	Water use
WUE (kg GY/mm WU)	Water use efficiency
WD (cm)	Water deficit

Abbreviation	Sample Depth Under Consideration (Suffix)
w	0-30
x	30-60
y	60-90
z	90-120
90	0-90
120	0-120
	Growing Season (Suffix)
97	1997
98	1998
	Landform Elevation Complexes (LECs)
U	Upper elevation LEC
M	Mid elevation LEC
L	Lower elevation LEC

[1] The absence of a sampling time prefix for NO_3, NH_4, *P*, *K* or *S* indicates that the nutrient was sampled at *ES*. Sampling time prefixes are used only for dynamic soil attributes.

Example 1.

Abbreviation: $H\,NO_3\,x\,98$
Meaning: Harvest 1998 soil residual nitrate nitrogen in the 30-60 cm depth increment.

Example 2.

Abbreviation: $NO_3\;90\;97$
Meaning: Spring 1997 soil residual nitrate nitrogen from 0-90 cm.

Appendix VII. Glossary.

convergent landscape character: reflects tendency for concentration of water flow on the surface and within the soil, primarily due to land surface morphology with relatively low gradients and negative curvature

divergent landscape character: reflects tendency for dispersion of water flow on the surface and within the soil, primarily due to land surface morphology with relatively high gradients and positive curvature

facies: the sum of all primary lithologic and paleontologic characteristics of sediments or sedimentary rock that are used to infer its origin and environment; the general nature of appearance of sediments or sedimentary rock produced under a given set of conditions; a distinctive group of characteristics that distinguishes one group from another within a stratigraphic unit; e.g., contrasting river-channel facies and overbank-flood-plain facies in alluvial valley fills

landform: the various shapes of the land surface resulting from a variety of actions such as deposition or sedimentation (eskers, lacustrine basins), erosion (gullies, canyons), and earth crust movements

landform element: zone of a hillslope with a defined range of morphological attributes (e.g., profile curvature, plan curvature, gradient) derived from a digital elevation model

landform element complex (LEC): assemblage of individual landform elements or facets providing larger, more homogeneous delineations of the landscape

landscape: all the natural features such as fields, hills, forests, and water that distinguish one part of the earth's surface from another part; usually it is the portion of land or territory that the eye can see in a single view, including all its natural characteristics

lower elevation LEC (L): (as defined in this study) assemblage of elements/facets including level lowerslope, lowerslope depression, toeslope and lowerslope mounds

mid elevation LEC (M): (as defined in this study) assemblage of elements/facets including backslope, divergent backslope, convergent backslope, midslope terrace, saddle, midslope depression, lowerslope fan and footslope

soil association: a natural grouping of soil associates based on similarities in climatic or physiographic factors and soil parent materials; may include a number of soil associates provided that they are all present in significant proportions

soil-landscape: a collection of soil types associated with particular landscape features within a given area

soil series: the basic unit of soil classification, consisting of soils that are essentially alike in all major profile characteristics except the texture of the surface *toposequence:* a sequence of related soils that differ, one from the other, primarily because of topography as a soil-formation factor

upper elevation LEC (U): (as defined in this study) assemblage of elements/facets including level crest, divergent shoulder and upper depression