UNIVERSITY OF ALBERTA

SPATIAL VARIABILITY OF WEEDS, SOILS AND CROPS IN FIELDS OF THE SOUTH PEACE RIVER REGION, ALBERTA

by

CHERYL FLORENCE FLETCHER ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of

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in

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FACULTY OF GRADUATE STUDIES AND RESEARCH

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DEDICATION

To my parents

ARTHUR WHITNEY FLETCHER
(January 6, 1911 - March 19, 1995)

&

FLORENCE ALEXANDRA SAZWAN FLETCHER
(October 31, 1924 - June 26, 1997)

the land was their life

ABSTRACT

Site specific management is feasible only if significant sub-field variability in weeds, soils or crops exists. The variability of weeds, crop yields, crop quality and soil fertility was assessed during one season, along transects across three fields in the South Peace River region of Alberta. Variability in weeds presented limited opportunities for the site specific application of herbicides. Site specific fertilizer application would: 1) increase fertilizer inputs by 4-10 kg/ha, 2) reduce inputs by 5-30 kg/ha, or 3) re-distribute the fertilizer used differently among nutrients and across the field depending on the field and the crop. Site specific harvesting on the basis of grade was feasible at two sites. Crop yield varied within fields at two sites, due primarily to sodicity, poor soil structure and excess moisture. Producers in the region recognize spatial patterns in their fields, consequently they may both use and participate in development of this technology.

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Dominus vobiscum

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LIST OF SYMBOLS AND ACRONYMS

Symbol	Designation
Ap	Surface mineral horizon that has been disturbed by cultivation
BA	Broadleaf annual weed species
Bnt	A mineral horizon enriched with silicate clay, that has a ratio of exchangeable calcium to exchangeable sodium that is 10 or less; structure is prismatic or columnar; peds have dark coatings, and consistence is hard to very hard when dry
BP	Broadleaf perennial weed species
C	Carbon
$CaCl_2$	Calcium chloride
CEC	Cation exchange capacity
CPS	Canadian Prairie Spring wheat
DGPS	Differential global positioning system
EC	Electrical conductivity
ES	Exchangeable sodium
GDD	Growing degree days
GA	Grassy annual weed species
GLM	General linear model
GP	Grassy perennial weed species
GPC	Grain protein content
HCl	Hydrochloric acid
HRS	Hard Red Spring wheat
K	Potassium
KCl	Potassium chloride
KM	Kelowna extractant for PO_4-P
K_2O	Potash
LFH	Sequence of organic horizons developed from the accumulation and decomposition of leaves, twigs and woody materials
M	Molar
MWD	Mean weight diameter
N	Nitrogen
N_2	Nitrogen gas
NH_4OAc	Ammonium acetate
NO_3-N	Nitrate-nitrogen (mass of N present as NO_3^-)
O_2	Oxygen gas
P	Phosphorus
P_2O_5	Phosphorus pentoxide
PO_4-P	Phosphate-phosphorus (mass of P present as extractable PO_4^{-3})
PR	Penetration resistance
PSA	Particle size analysis
SOM	Soil organic matter
SO_4-S	Sulfate-sulfur (mass of S present as $SO_4^{=}$)
S	Sulfur
SSA	Site specific application of fertilizers
SSM	Site specific management
TDR	Time domain reflectometry
TKW	Thousand kernel weight
TWA	Test weight apparatus
UA	Uniform application of fertilizers

CHAPTER I

INTRODUCTION

SOIL FERTILITY AND SOIL PRODUCTIVITY

Soil is "the unconsolidated material on the immediate surface of the earth that serves as a natural medium for plant growth" (Agriculture Canada, 1976). Soil fertility is the "ability of soil itself to provide nutrients and rooting conditions necessary for plant growth" (McGill, 1982). Soil productivity is the capacity of soil to produce plants that supply people with essential food and fiber. Soil productivity is measured in terms of crop yield and quality, and is a function of all factors of plant growth, including soil fertility (Hausenbuiller, 1985).

FACTORS OF SOIL FERTILITY

Numerous environmental (climate, topography, parent material, natural vegetation), plant (rhizosphere ecology, residues) and socioeconomic (inputs, choice of crops, cultivation) factors, and their interactions, determine the fertility of agricultural soils. However, the environmental factors are the most stable and the most difficult to change. Therefore, management decisions must address the environmental aspects of soil fertility if adequate soil fertility is to be maintained. Adequate soil fertility depends on the crop or group of crops to be grown, because nutrient requirements and optimum rooting conditions are crop-specific (Fageria *et al.* 1997).

Soil fertility derives from the physical, chemical and biological properties of the soil. Therefore, soil fertility is largely determined by the nature of these soil properties. Soil texture and soil structure are the primary physical properties affecting soil fertility. Soil texture refers to the relative portions of sand, silt and clay in a soil. Soil texture is an important property because it influences aeration, cation-exchange capacity, water-holding capacity, nutrient supply, and hence crop growth. Because soil texture can influence soil water content, and water content influences heat capacity and thermal conductivity, soil texture is also indirectly related to soil temperature (Fageria *et al.* 1997).

Soil structure refers to the binding of soil particles into aggregates. Soil structure, together with soil texture, determines soil porosity. Porosity is the total space (%) of soil, not occupied by soil particles. Therefore, soil structure influences aeration, water infiltration, root growth, the activities of soil organisms, and thus crop growth (Fageria *et al.* 1997).

Nutrient deficiencies and toxicities, soil pH, cation-exchange capacity (CEC), salinity and sodicity are the primary chemical properties affecting soil fertility (Fageria *et al.* 1997). Crop growth is restricted by inadequate nutrition. Inadequate nutrition occurs when essential elements are at insufficient (less than optimum) or deficient (severely limiting growth) concentrations, or when essential or nonessential elements, are at excessive (causing nutrient imbalances) or toxic (severely reducing growth) concentrations in the soil (Tisdale *et al.* 1985). Nutrient deficiencies and toxicities in soils, are related to parent material, weathering, erosion and management practices. Nitrogen and phosphorus are the most deficient nutrients in temperate soils. Aluminum and manganese are the most toxic nutrients in temperate soils (Fageria *et al.* 1997).

Soil pH indicates whether a soil is acid (pH < 7.0), neutral (pH 7.0) or alkaline (pH > 7.0). It is one of the most important soil chemical properties for crop growth, because it regulates the relative availability of nutrients, soil response to liming and the presence of phytotoxic ions in the soil (Fageria *et al.* 1997). CEC is the sum of exchangeable cations retained by soil. Exchangeable cations are cations that are reversibly attached to the solid phase of soil. Soil CEC is important to crop growth because it reflects the soil's ability to retain and supply cationic nutrients (Fageria *et al.* 1997).

Soil salinity refers to the amount of soluble salts in the soil. An excess of soluble salts reduces the availability of water for crop growth. Salinity may be accompanied by sodicity. Sodicity refers to the amount of exchangeable sodium (ES) in the soil. Excess ES is not conducive for crop growth because it encourages the breakdown of soil aggregates and the reduction of pore space. These changes in soil structure lower the permeability of soil to water and air, and create physical restrictions to root and shoot growth (Hausenbuiller, 1985).

Soil organisms and soil organic matter (SOM) are the primary biological factors of soil fertility. Soil organisms contribute to soil fertility in several ways. Soil populations increase nutrient availability through mineralization, nitrogen fixation and mycorrhizal processes. Soil organisms also improve soil physical conditions (aeration, structure, aggregation) through burrowing and mixing activities, and by transforming and synthesizing constituents of SOM. Soil organisms reduce soil fertility through processes of denitrification and immobilization, and by parasitizing plants or inducing plant disease (Fageria *et al.* 1997).

Soil organic matter refers to soil materials derived from "plant and animal residues, cells and tissues of soil organisms and substances synthesized by the soil population" (Agriculture Canada, 1976). SOM enhances soil fertility by contributing to the CEC of the soil and serving as a "revolving bank account" for soil nutrients (McGill, 1982). Some constituents of SOM also serve as binding agents in aggregation processes, thus contributing to soil structure and the soil's ability to provide crops with adequate water and rooting conditions (Fageria *et al.* 1997). Plant residues at the soil surface reduce windspeed and water runoff. Therefore, SOM also contributes to soil fertility by reducing erosion (McGill, 1982). SOM also influences soil fertility and crop growth, indirectly, through the attenuation or alteration of agricultural chemicals (fertilizers, pesticides).

SPATIAL VARIABILITY OF SOIL FERTILITY

Soil properties are not spatially independent. They have a spatial structure and are spatially correlated with each other (Hall and Olson, 1991). This is important for two reasons. First, these factors limit the ability of science to quantify soil properties (Parkin, 1993). Second, these factors interfere with traditional ways of developing models of predictive relationships between soil properties, soil fertility and soil productivity (Parkin, 1993). If spatial variability is addressed, the ability to quantify soil properties is improved, and the driving variables behind fertility and productivity related processes are more readily identified (Parkin, 1993).

Three questions arise when considering spatial variability of soil fertility: How large is it? What causes it? and how do you deal with it? The first question relates to the quantification of soil properties, and to the identification of factors controlling their variability (Parkin, 1993). The second question probes for insights into driving variables which will assist in developing predictive process models. The third question depends in part on the answers to the previous questions. For farmers, however, it is mainly a question of how to manage it (Parkin, 1993).

QUANTIFYING SPATIAL VARIABILITY

One way to quantify the spatial variability of soil fertility is to model the spatial structure of individual soil properties. When the spatial structure (variogram) is known, it can be used to predict soil properties at points that have not been sampled (Upchurch and Edmonds, 1991). It also provides a useful statistic called the "range." The range is the distance beyond which there is no spatial correlation between sample sites (Burrough, 1991). Range values are useful for managing spatial variability, because they can be used to develop optimum soil sampling plans (Burrough, 1991).

The ranges of many soil properties have been investigated (Boyer *et al.* 1991; Han *et al.* 1994; Miller *et al.* 1988; Mulla, 1988, 1992; Rochette *et al.* 1991; Samra *et al.* 1988; van Es *et al.* 1989; Vieira *et al.* 1981). Soil properties may have ranges as small as 0.15 m (microbial activity), and as large as 150 m (pH). However, a majority of properties have ranges between 30 and 90 m, with an overall average of about 65 m (Brubaker and Hallmark, 1991).

Variograms focus exclusively on distance between points, and ignore intervening landscape features. Soil properties, however, are controlled by landscape features. Consequently, another method for quantifying the spatial variability of soil fertility in agricultural fields is landscape modeling. This method is usually applied when topographic features are prominent. Landscapes are stratified into units based on significant changes in slope gradient and slope profile curvature. Soil properties are then assessed for each unit (Moore *et al.* 1992). Diverse landscape stratification schemes may be used. They include: toeslope-south backslope-ridgetop-north backslope (Miller *et al.* 1992); toeslope-footslope-backslope (shoulder)-(summit) ridgetop (Busacca and Montgomery, 1992; Pierson and Mulla, 1990); and convergent shoulder-divergent shoulder-convergent backslope-divergent backslope-convergent footslope-divergent footslope-level elements (Pennock *et al.* 1987).

Several landscape modeling studies have been conducted in the Palouse region of the Pacific Northwest. The area is characterized by highly variable topography, with slopes ranging from 0 to 45 % (Miller *et al.* 1992). Topsoil depth, organic matter, available moisture, aggregate stability, texture, soil nutrients, pH and bulk density varied significantly with landscape units (Miller *et al.* 1992; Pierson and Mulla, 1990). Aggregate stability and organic C were observed to be highest in the footslope and toeslope positions, and lowest at the summit. Clay content was highest at the summit and lowest at the toeslope. Erosional processes were used to explain these findings (Pierson and Mulla, 1990).

Similar studies have been conducted in Canada. In Saskatchewan, Pennock *et al.* (1987) reported that topsoil thickness and depth to carbonates, were consistently greater in convergent vs. divergent landscape elements; and followed the trend: shoulders < backslopes < level < footslope elements. The differences were attributed to characteristic water dynamics in the hill-slope systems of the region (Pennock et al, 1987). Landscape modeling studies in Alberta revealed significant differences in soil texture, organic matter, depth to the B horizon, pH, nitrate, and phosphate, between landscape positions (footslope, backslope, shoulder). When soils in these studies were formally classified, the difference in pedon classification from one landscape position to another, was at the Order level (Goddard *et al.* 1996).

THE ORIGIN OF SPATIAL VARIABILITY

Soils in landscapes, vary in both horizontal and vertical directions (McNeil and Goddard, 1996). This spatial variability can be attributed to interactions between the soil forming factors. They are: climate, topography, parent material, vegetation, time and human influence (McNeil and Goddard, 1996). The capability of these factors to induce soil heterogeneity is readily apparent. For example, regional differences in climate (temperature, precipitation) have resulted in the formation of Brown soils in south-eastern Alberta, and Black soils in central Alberta. The occurrence of thinner, drier, less fertile soils on hilltops, relative to lower-slope positions, illustrates one way that topography induces soil variability in landscapes (McNeil and Goddard, 1996).

Differences between soils which have formed in shale bedrock, and those formed in lake basin sediments demonstrate how parent material can induce soil variability. The texture of these soils is often the same, but the potential for salinity is substantially higher in the soils formed in the shale (McNeil and Goddard, 1996). The differences in soils formed under grassland vegetation and those formed under deciduous forest cover, exemplify vegetation induced heterogeneity (McNeil and Goddard, 1996). The typical Regosol-Brunisol-Luvisol pattern with increasing age of soils on fluvial fans, is a good example of how time induces spatial variability (Crown, 1996).

Human activity also has a large impact on the homogeneity of soil resources (Bouma and Finke, 1993). Perhaps the most drastic changes occur when native landscapes are first converted to agricultural uses. For example, Luvisolic soils lose most of their humus-rich LFH horizon, and Chernozemic soils experience a significant drop in organic carbon content (Izaurralde *et al.* 1992; Juma, 1993). Once landscapes are converted to agricultural use, soil variability is further manipulated by numerous combinations of tillage and cropping practices (Bouma and Finke, 1993).

Major disturbances such as land leveling, and the installation of drainage systems are examples of gross spatial manipulation of soil by humans. However, more subtle practices can also change the homogeneity of soil resources. For example, studies at the Rodale Research Center revealed that soil nitrate varies considerably with methods for supplying the crop with this nutrient. In early April, manure treatments had 52 kg/ha of nitrate in the top 30 cm of soil, whereas legume cover crop treatments had 9 kg/ha in this soil layer (Doran *et al.* 1994). By mid-June, the manure treatment had 113 kg/ha of nitrate and the legume treatment had 147 kg/ha of nitrate in this same soil layer (Doran *et al.* 1994).

MANAGING SPATIAL VARIABILITY

Once soil variability has been quantified, and its sources identified, the next step is to decide on its management. The recent practice, however, is to ignore it. In the latter half of this century, North American farmers have tended to manage their soil resources as large, homogeneous tracts of land (McNeil and Goddard, 1996). In Alberta, for example, farmers often manage their land as quarter section units, even though the boundaries for these units were arbitrarily established by legal land survey, and do not reflect natural patterns in the landscape (Crown, 1996).

Agricultural land in Canada and the US has not always been managed this way. When crop cultivation first began in North America, people had the resources to cultivate only small plots. Then, as animal and mechanical power developed, farmers were able to crop larger areas, and field sizes increased (Shueller, 1992). In recent years, socioeconomic factors and the advent of agribusiness have also encouraged larger field sizes (Luciuk and Pettapiece, 1994).

As field sizes increased, small plot techniques were abandoned in favor of more practical "blanket" strategies. The typical "blanket" approach is to apply all cropping practices in a uniform manner, across each production unit. Sub-field variability is usually considered only when fields are being sampled for nutrient recommendations. Soil cores are taken from at least 15 different areas in each field, and an effort is made to avoid "non-representative" areas (Norwest labs, 1998). However, these soil cores are usually bulked before they are submitted for analysis. Recommended rates for inputs, based on the "average" soil test results, are then applied over the entire area (McNeil and Goddard, 1996).

The problem with the blanket approach is that it does not account for sub-field variability in soil fertility. Composite samples provide some indication of average field characteristics, but there will always be areas within fields where soil fertility is far less than the field average, and areas where the opposite is true (Blackmore, 1994). When inputs (fertilizers, pesticides) are applied uniformly, at rates based on average requirements, some areas receive more inputs than they are capable of using, and some areas do not receive enough. As a result, inputs are not used efficiently; field productivity is not maximized, and the risk of non-point source pollution (nitrate and pesticide contamination of water resources) is increased (Shueller, 1992). In addition, there are often sites within cultivated fields which are not suitable for crop production at all; areas prone to erosion or salt accumulation for example. When these areas receive the same management treatments as the rest of the field, soil resources in these areas are degraded (Blackmore, 1994).

Farmers have long recognized that their large fields are not uniform, but since the days of small plot farming, they have not had the tools they need to address sub-field variability adequately (Shueller, 1992). Trends in agronomic research have discouraged the management of sub-field variability as well. Historically, the development of crop production technologies has been based on assumptions of homogeneity within field units (Shueller, 1992). These trends, however, are changing.

SITE SPECIFIC MANAGEMENT

Advances are currently being made toward site specific management (SSM). SSM is a system of crop production techniques, designed to manage agricultural fields as a series of smaller areas with differing characteristics. Spatial variability of soil, terrain, plant growth, or other properties within field boundaries, is measured and located geographically. Management zones are identified and delineated based on these spatial data. Decisions are then taken specifically to optimize production within each zone (Blackmore, 1994; Heaney *et al.* 1994; Shueller, 1992).

Practical applications for SSM are being developed. Real-time positioning systems, variable rate technologies, digital terrain models, geographic information systems, decision support systems, geostatistical methods, remote sensing technologies, aerial photography, computer guidance systems, yield sensors, soil sensors and other soil testing techniques are some of the applications under way (Blackmore, 1994; Borgelt, 1992; Shueller, 1992).

When these applications are field ready, farmers will have enormous capabilities for managing sub-field variability. They will be able to map soil, pest, and crop characteristics at large scales, within field boundaries. They will have the ability to combine these data into any format they desire. They will have the capability to model management scenarios and evaluate possible outcomes, before they take their management plans to the field. They will be able to develop optimum management prescriptions for each square meter of their field. They will have the technology to apply these prescriptions in one pass over large fields. They will have the option to carry out field operations at night, if necessary. They will have the ability to evaluate the performance of their SSM tools. And they will be able to keep accurate records of all of the above (McNeil and Goddard, 1996; Murray and Cook, 1992; Veseth *et al.* 1992).

The perceived benefits of SSM are many. Mulla (1998) divided them into four groups: increased profitability, improved productivity, reduced risk and environmental protection. Increased profit occurs when savings from reduced inputs and increased productivity, offset costs associated with SSM. Reduced risk arises when management practices are more closely matched to local site conditions (input requirements and micro-climate). Environmental protection arises from less erosion, less runoff and reduced leaching of agricultural chemicals (Mulla, 1998). The following statements illustrate the published rhetoric regarding the benefits of SSM:

> "Site specific management allows the manager a better understanding and a greater control over the treatments to the field" (Blackmore, 1994).

> "Matching N application rates to fertility levels and yield goals in specific management zones within a farm is a strategy that provides for efficient use of fertilizer resources and reduces the potential for non-point source pollution of surface and groundwater" (Mulla, 1992).

> "The most obvious benefits [of SSM] are higher net income or less environmental pollution due to the better matching of inputs to the productivity potential of a soil" (Voorhees *et al.* 1992).

> "If the management of within-field variability lessens the overall agrichemical load in both the agricultural and non-agricultural environments, then the value of such management increases appreciably" (Forcella, 1992).

"variable rate fertilization shows promise as a practice that will be profitable" (Wollenhaupt and Buchholz, 1992).

"The environmental impact was greater than the cost savings would indicate because of a redistribution of materials from areas where over application and waste were occurring, to areas where under application had been happening" (Macy, 1992).

"Site specific management has potential to reduce pollution at the source. Site specific techniques could enable farmers to better meet legislated obligations (record keeping, appropriate levels of application) for nutrient and pesticide use" (Gustafson, 1992).

"As farmers realize there is a more sustainable and profitable way to farm the landscape, the square patchwork of quarter sections will give way to field shapes based on optimizing production. Farmers will realize that there are areas in almost all landscapes where alternatives such as forage or wildlife habitat are more profitable or more sustainable than arable crops" (Heaney *et al.* 1994).

The possible benefits of SSM are impressive. However, they will be realized only if basic, underlying assumptions are correct. The entire premise for SSM is that different areas within agricultural fields require different management mixes to achieve optimum productivity. This will be true only if significant sub-field differences in soil fertility or weed growth exist.

SUB-FIELD VARIABILITY OF SOIL FERTILITY IN THE SOUTH PEACE RIVER REGION, ALBERTA

The South Peace River region of Alberta (Figure 1.1) extends from 116° west longitude to 120° west longitude, and from 55° north latitude to 56° north latitude. Climate in the region is temperate continental, with a mean annual air temperature of 2.0 °C. Mean annual precipitation is 452 mm. Dominant native vegetation is mixed tree cover (aspen, spruce) in the forested areas, and low shrub species and grasses in the parkland areas (Odynsky *et al.* 1961).

The South Peace River region consists mainly of the remnants of a former till plain and lower lying lake basins. Terrain ranges from undulating, with long gentle slopes (0-1.5 %) to rolling or hummocky, with steep slopes (6-15 %). Glaciofluvial, glaciolacustrine and till parent materials dominate in the region. Most of the soils in the area belong to either the Luvisolic, Solonetzic or Gleysolic Orders (Odynsky *et al.* 1961).

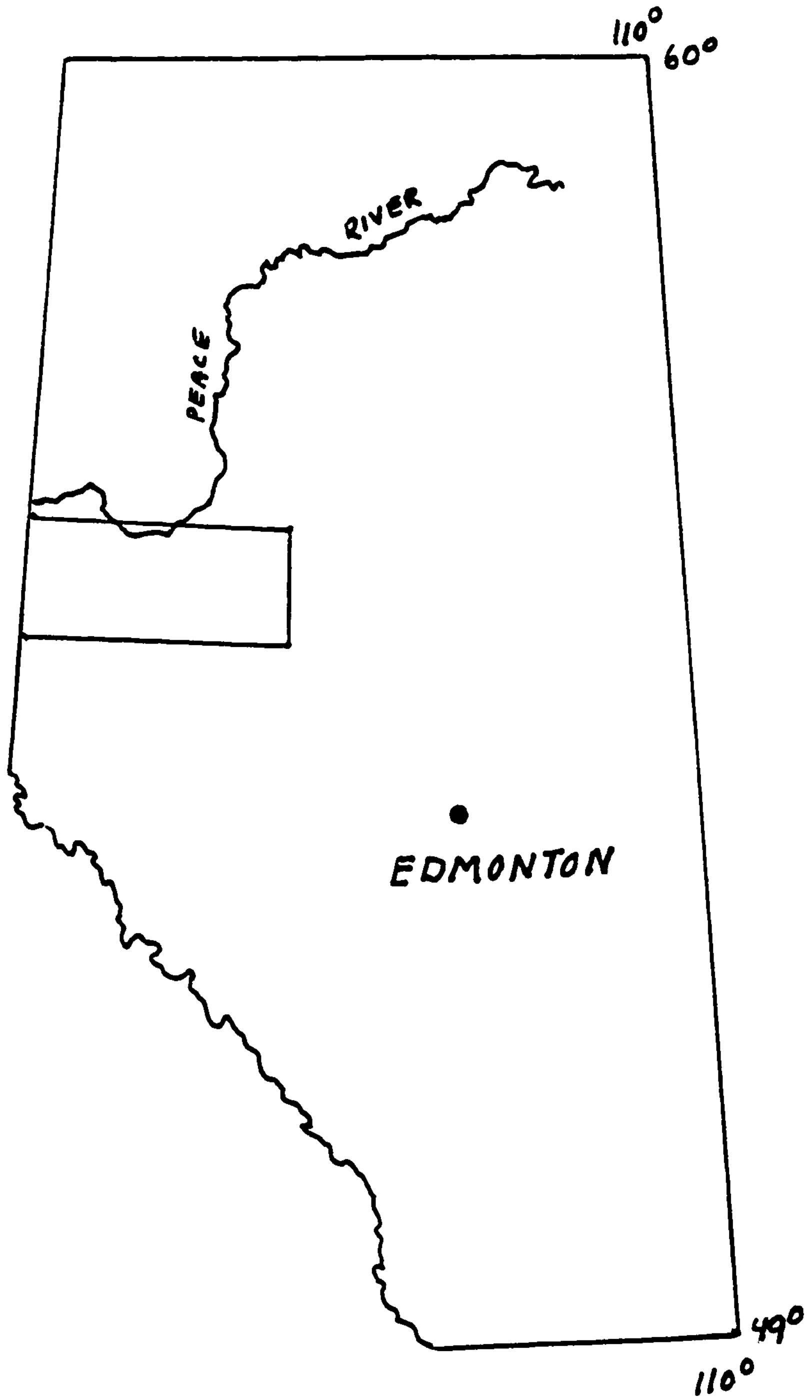

Figure 1.1 South Peace River Region of Alberta (scale 1: 6447368).

Significant sub-field variability in soil fertility may exist in fields of the South Peace River region. Particularly in those used to grow annual crops, in the south-westerly portion of the area. The inherent characteristics of these fields and the variety of management practices they have been exposed to, make them likely to contain large sub-field differences in soil fertility.

The typical undulating topography of the area encourages the formation of micro-climate. For example, significant differences in minimum temperature, between knolls and hollows, were observed in fields near Beaverlodge. Average differences of 6.9 ^{o}C were recorded. Extreme differences of 19 ^{o}C were observed during summer months. According to these data, the lower areas in these fields were more susceptible to frost than those at higher elevation (Odynsky *et al.* 1961).

The formation of micro-climate is also encouraged by typical vegetation patterns in the area. For example, the presence of trees and shrubs along field boundaries has been linked to large sub-field differences in evaporation. Odynsky *et al.* (1961) reported that moisture loss to evaporation near Beaverlodge, was about 34 % less near the edge of a sheltered field, than it was at 400 m in towards the center of the field.

South Peace fields often contain several different problem soils. This characteristic makes them good candidates for sub-field variability in soil fertility as well. Fields in the area are typically composed of a mixture of soils from the Luvisolic, Solonetzic, Gleysolic and Organic orders (Odynsky *et al.* 1961). Poor soil fertility is inherent in all these soils, but to different degrees and for different reasons (McGill, 1982; SSCAFF, 1984). If a mixture of these soils exist within field boundaries, it is reasonable to expect a mixture of soil fertility as well.

Fields in the area are prone to degradation by water erosion. This feature also increases the likelihood for sub-field differences in soil fertility. A combination of high snowfall, rapid spring runoff, intense summer storms, long sloping fields, and summer fallow use, puts soils in the area at risk (McGill, 1982; SSCAFF, 1984). Annual soil losses average 11.5 Mg/ha. Higher rates (27 Mg/ha) have been observed during single rainfall events (Chanasyk and Woytowich, 1987; SSCAFF, 1984). Given the extent of redistribution occurring in these landscapes, spatial patterns of soil fertility are to be expected.

Human activity has probably encouraged sub-field differences in soil fertility as well. For example, many fields in the South Peace River region were formed by the consolidation of several smaller fields (Odynsky *et al.* 1961). The results of human activity in the smaller landscapes are now patterns in these larger fields. Features like old fence lines, straw butts and farmyards have been incorporated into the larger mosaic.

Management practices vary in the South Peace River region. In the normal course of a year, fields are subjected to many different tillage, seeding, spraying and harvesting operations. In their efforts to improve and maintain soil fertility, farmers have applied numerous other practices as well. They have drained, limed, deep-ripped, contour-tilled, direct seeded and applied manure to their fields (Statistics Canada, 1996). They have subjected fields to legume plowdown, winter cover crops and changes in crop rotations. Some farmers have grassed in waterways and established shelter belts in their fields as well (Statistics Canada, 1996). Given the number and variety of management practices used, it is reasonable to expect that human activity has influenced the pattern of soil fertility in these fields.

Their inherent characteristics and the variety of management practices they have been exposed to, make fields of the South Peace River region likely to have sub-field variability in soil fertility. However, the nature and extent of this variability is not well known. Farmers in the area are aware of sub-field trends in crop yield, weed species, soil moisture, soil organic matter, soil texture, tilth and trafficability. However, most of this knowledge is anecdotal and incomplete. Research on the subject is also lacking. Some studies on the spatial variability of soil fertility have been conducted in central and southern Alberta (Goddard *et al.* 1996; Heaney *et al.* 1994; Penney *et al.* 1996), but no published data are currently available for the South Peace River region.

SITE SPECIFIC MANAGEMENT IN THE SOUTH PEACE RIVER REGION

Farmers in the region may be aware of sub-field trends in soil fertility, but they currently make little effort to manage for these trends. Some attention is given to field variability during soil sampling, and some site specific pesticide application does occur. About 25 % of farmers in the area have combines that will support yield monitoring equipment, but the number of farmers actually collecting yield data is unknown (Huffman, 1998). Very few other site specific techniques are being used. Traditional "blanket" management is still the most common crop production strategy in the South Peace River region.

PROBLEM STATEMENT AND OBJECTIVES

Farmers who grow annual crops in the south-westerly portion of the South Peace River region may be able to realize some of the benefits of SSM, by matching their management practices more closely to local conditions in their fields. The realization of these benefits, however, is dependent upon the nature and extent of differences in soil fertility, crop growth or weed populations, within field boundaries. There are reasons to believe that sub-field variability exists in these landscapes, but its nature and extent are not well known.

The purpose of this study is to investigate the spatial variability of weeds, crops and soil fertility, within these fields, and evaluate the implications of this variability for site specific management. The specific objectives are to:

1. measure sub-field variability in broadleaf, grassy, annual and perennial weed groups, and evaluate the implications of this variability for site specific application of post-emergent herbicides.

2. measure sub-field variability in soil test recommendations for macronutrients and evaluate the implications of this variability for site specific application of fertilizers.

3. measure sub-field variability in crop quality and evaluate the implications of this variability for site specific harvesting.

4. determine differences in selected soil properties and crop characteristics, between high yielding and low yielding areas within field boundaries, and evaluate the implications of these differences for the site specific management of annual crops.

There are five chapters in this thesis. Chapter two addresses sub-field variability in weed groups. Chapter three addresses sub-field variability in soil macronutrients. Chapter four is devoted to sub-field variability in crops and selected soil properties. Chapter five comprises a synthesis of my research results, including discussions regarding the potential use of my research results and the direction for future research.

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CHAPTER II

SPATIAL VARIABILITY OF WEEDS IN FIELDS OF THE SOUTH PEACE RIVER REGION, ALBERTA

INTRODUCTION

Effective weed management is essential to annual crop production. Left unchecked, weed infestations increase management costs, diminish crop quality and limit crop yields (Mortimer, 1990). Farmers who grow annual crops in the South Peace River region, typically use mechanical (tillage) and chemical (herbicides) methods to manage their weed populations. Post-emergent herbicide application is a common form of chemical weed control practiced in the area (Statistics Canada, 1996).

Chemical weed control is responsible for a large portion of the input costs associated with annual crop production. In the South Peace River region, input costs for weed control are about 20 to 25 % of variable costs, when conventional (residue incorporation) tillage systems are used (Statistics Canada, 1996). In addition to being expensive, chemical weed control is also controversial. The public is concerned that chemical weed control is contributing to surface and groundwater contamination (Marks and Ward, 1993). The site specific spraying of post-emergent herbicides may be one way to address both the environmental and economic concerns regarding herbicide use. Site specific spraying may also improve productivity through better weed control (Thomas, 1998).

The possibilities for using site specific spraying to reduce herbicide costs and the environmental loading of these chemicals, are related to reductions in the volume of herbicide applied. By spraying only where weeds are present in the crop (intermittent spraying), herbicides are not wasted and chemicals are not needlessly introduced into the field environment (Gustafson, 1992). The opportunity for improving productivity arises through reduced weed competition. When herbicides are closely matched to the weeds in the field (species specific application), better control and reduced competition can be expected.

Positioning and spraying technologies for the site specific application of post-emergent herbicides are available (Mackay, 1998). However, the successful implementation of these technologies in fields of the South Peace River region, is contingent upon the distribution of weeds in these fields (Zanin, *et al.* 1996). Weed distribution studies in other parts of the world indicate that weed species in cultivated fields are not uniformly or randomly distributed, but tend to be highly aggregated or clumped (Mortensen *et al.* 1993; Thornton *et al.* 1990). If weed distributions in fields of the South Peace River region reflect this general trend, opportunities for site specific spraying may exist.

Most of the weed species in fields planted to annual crops in the South Peace River region are grassy (Monocotyledons) or broadleaf (Dicotyledons) weeds. For the purpose of chemical control, it is useful to divide weeds into these two groups, because these groups tend to respond very differently to herbicides (Lakeland College, 1997). It is also useful to group weedy species according to their general life-cycle, because a weed's habit partially determines its distribution and the difficulty of its control. Weed species in fields of the South Peace River region have various life-cycles, but for present purposes they can be loosely grouped as annual or perennial weeds.

The purpose of this study was to measure the spatial variability of broadleaf, grassy, annual and perennial weeds, within fields used to grow annual crops in the South Peace River region, and evaluate the implications of this variability for the site specific application of post-emergent herbicides.

MATERIALS & METHODS

Site Characteristics

A one-season field study was conducted in the south-west portion of Soil Correlation Area #18 (Dark Gray and Black Soil Zone of the South Peace), in 1996 (Figure 2.1). Field scouting, soil survey data and producer interviews were used to locate three fields, representative of agricultural landscapes in the area. These fields differed in size, topography, parent material and soils, but were under similar management regimes (Table 2.1). For the purpose of this study, the fields were labeled as the Halcourt, Hythe and Huallen sites.

General management practices and field histories for each field were obtained by producer questionnaire. Conventional tillage systems (residue was incorporated in the fall; cultivation was used for seedbed preparation in the spring) were used, and annual crops of wheat (*Triticum aestivum*), barley (*Hordeum vulgare, H. distichum*), peas (*Pisum sativum*) and canola (*Brassica rapa*) were grown. Wheat (Hythe) and barley (Halcourt, Huallen) were grown in 1996. Questionnaire results are recorded in detail in Appendix B.

Climate in the study area is temperate continental, with a mean annual air temperature of 2.0 °C. Annual precipitation is 452 mm. Regional weather data (long term averages; 1996 growing season) for a central meteorological site (Beaverlodge) are tabulated in Table 2.2 and 2.3. The 1996 growing season was cooler, wetter and more overcast than normal. Precipitation was measured at each field site from June 1st to September 20th. Standard Environment Canada rain-gauges were installed in early June. Weekly observations were taken until the end of September. Seasonal totals are listed in Table 2.1.

Table 2.1 Site characteristics

Site features	Halcourt site	Hythe site	Huallen site
Legal land location	NW 28 70 10 W6	NW 17 73 10 W6	NW 16 70 9 W6
Field size	~ 33 ha	~ 55 ha	~18 ha
Elevation	697 m	744 m	694 m
Precipitation (June - Sept., 1996)	230.3 mm	250.7 mm	231.1 mm
Topography	0 - 1.5 % slope Level & undulating	0 - 5 % slope Level & undulating - Gently rolling	2 - 5 % slope Gently rolling
Soil Series* (described and correlated with nodes, in Appendix A)	a) Landry b) Albright	a) Landry b)Valleyview c) Goose d) Prestville	a) Culp b) Leith c) Wembley (Codner) d) Eaglesham
Residue Management	Residue incorporation	Residue incorporation	Residue incorporation
1995 Crop	Peas	Canola	Barley
1996 Crop	Barley (2 row; malting)	Wheat (CPS)	Barley (6 row; feed)
Cultivar	B1215	AC Taber	Brier

* Knapik and Brierley, 1993; Odynsky *et al.* 1961.

Table 2.2 Beaverlodge meteorological site long term averages (1916-1991).

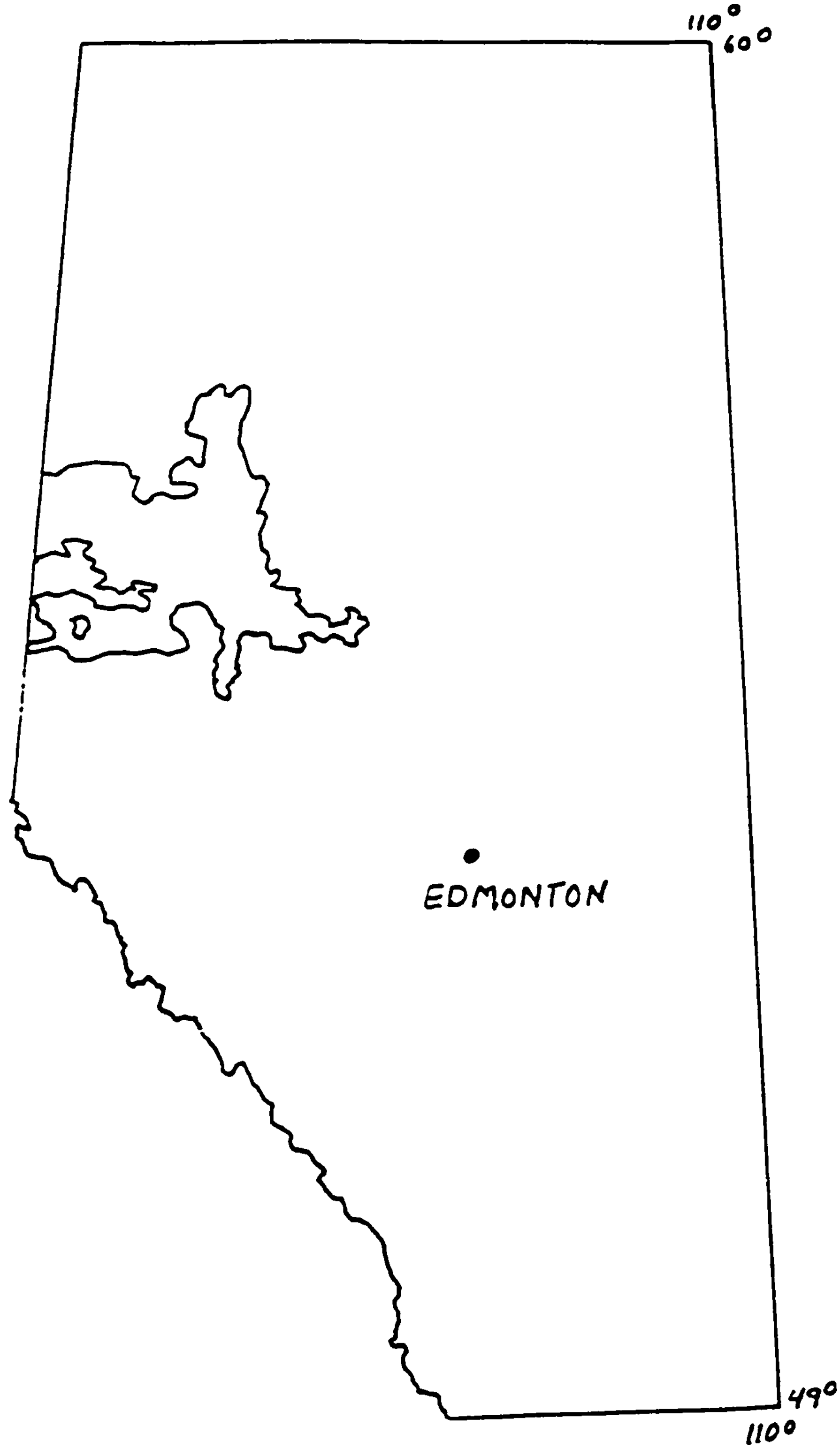
	MAY	JUN	JUL	AUG	SEP	OCT	YEAR
Air temperature (°C)							
Daily mean	9.6	13.2	15.4	14.3	9.8	4.1	2.0
Daily maximum	16.1	19.5	22.1	21.0	15.9	9.4	7.5
Daily minimum	3.1	6.8	8.8	7.7	3.7	-1.0	-3.5
G.D.D. (5° base)	157.1	247.3	324.3	290.8	162.5	65.6	1304.1
Sunshine (hrs)							
Bright sunshine	267.8	272.7	300.4	261.0	175.8	138.0	2096.9
Precipitation (mm)							
Total precipitation	39.3	61.8	63.7	54.7	43.2	27.8	452.2
Snowfall (cm)	3.8	1.1	0.0	0.8	4.6	12.9	182.0
Soil temperature (°C)							
5 cm depth	8.5	13.4	15.6	14.7	10.0	4.5	4.6
20 cm depth	7.1	11.8	14.4	14.1	10.2	5.4	4.6
50 cm depth	5.4	10.3	13.1	13.5	10.6	6.5	4.8
Evaporation (mm)							
"class a" pan	179.2	194.0	197.9	165.2	95.1	0.0	831.4
Windspeed (km/hr)							
10 meter windspeed	14.98	13.92	12.29	11.62	12.10	12.95	12.15
Mean date of last spring frost (0 °C)						MAY	25
Mean date of last spring frost (-2.2 °C)						MAY	10
Mean date of first fall frost (0 °C)						SEP	6
Mean date of first fall frost (-2.2 °C)						SEP	21
Frost free period (0 °C)						(days)	104
Frost free period (-2.2 °C)						(days)	133

Location: NW 36 71 10 W6
Elevation: 745 m
Source: P. F. Mills, Agrometeorologist
AAFC Research Station
Beaverlodge, AB
November 5, 1992

Table 2.3 Beaverlodge meteorological site averages (1996).

	MAY	JUN	JUL	AUG	SEP	OCT
Air temperature (°C)						
Daily mean	6.3	12.3	14.7	14.8	7.7	-
Daily maximum	11.5	18.1	20.9	21.9	12.8	-
Daily minimum	1.1	6.5	8.5	7.6	2.6	-
G.D.D. (5° base)	86.5	218.3	300.3	302.8	96.8	-
Sunshine (hrs)						
Bright sunshine	192.4	254.8	261.4	270.3	122.6	-
Precipitation (mm)						
Total precipitation	70.0	43.5	93.7	74.2	72.9	-
Snowfall (cm)	9.0	0.0	0.0	0.0	13.0	-
Soil temperature (°C)						
10 cm depth	7.4	12.5	14.8	14.8	10.3	-
Evaporation (mm)						
"class a" pan	133.3	184.9	198.2	186.9	77.7	-
Date of last spring frost (0 °C)					MAY	16
Date of last spring frost (-2.2 °C)					MAY	12
Date of first fall frost (0 °C)					SEP	20
Date of first fall frost (-2.2 °C)					SEP	22
Frost free period (0 °C)					(days)	126
Frost free period (-2.2 °C)					(days)	132

Location: NW 36 71 10 W6
Elevation: 745 m
Source: P. F. Mills, Agrometeorologist
AAFC Research Station
Beaverlodge, AB
November 5, 1992



Scale 1: 5986842

Figure 2.1 Soil Correlation Area # 18: Dark Gray and Black Soil Zone of the South Peace (Knapik and Brierley, 1993).

Experimental Design

A systematic transect design was used (Burrough, 1991). Aerial photographs were used to determine optimum transect placement at each site. The criterion for optimum placement was to position the transect across the photograph in such a way that maximum variation in tone (black, white, gray), texture (smooth, course) and spatial pattern, would fall along the length of the transect (Lohstraeter and Goddard, 1990). The most recent photographs (1:30,000) available (July 23, 1989, Halcourt; September 24, 1989, Hythe and Huallen), were enlarged to a scale of 1:5000. A single transect was drawn across the enlarged photograph of each site. The photographs were then used as base-maps (Plates 2.1-2.3) to position the transects across the fields (Alberta Environmental Protection, 1993).

Field transects were established in the spring of 1996. Marker stakes were placed at intervals of 65 m along each transect (Han *et al.* 1994). These markers served as sampling nodes for the duration of the study. A total of 29 sampling nodes were established: 12 at the Halcourt site, 10 at the Hythe site and 7 at the Huallen site. Five areas around each node, all located at 3 m from the node, were selected to serve as sampling units. These units were 2.25 m^2 in size, and were evenly spaced in a circular fashion around their respective nodes (Wollenhaupt and Wolkowski, 1994).

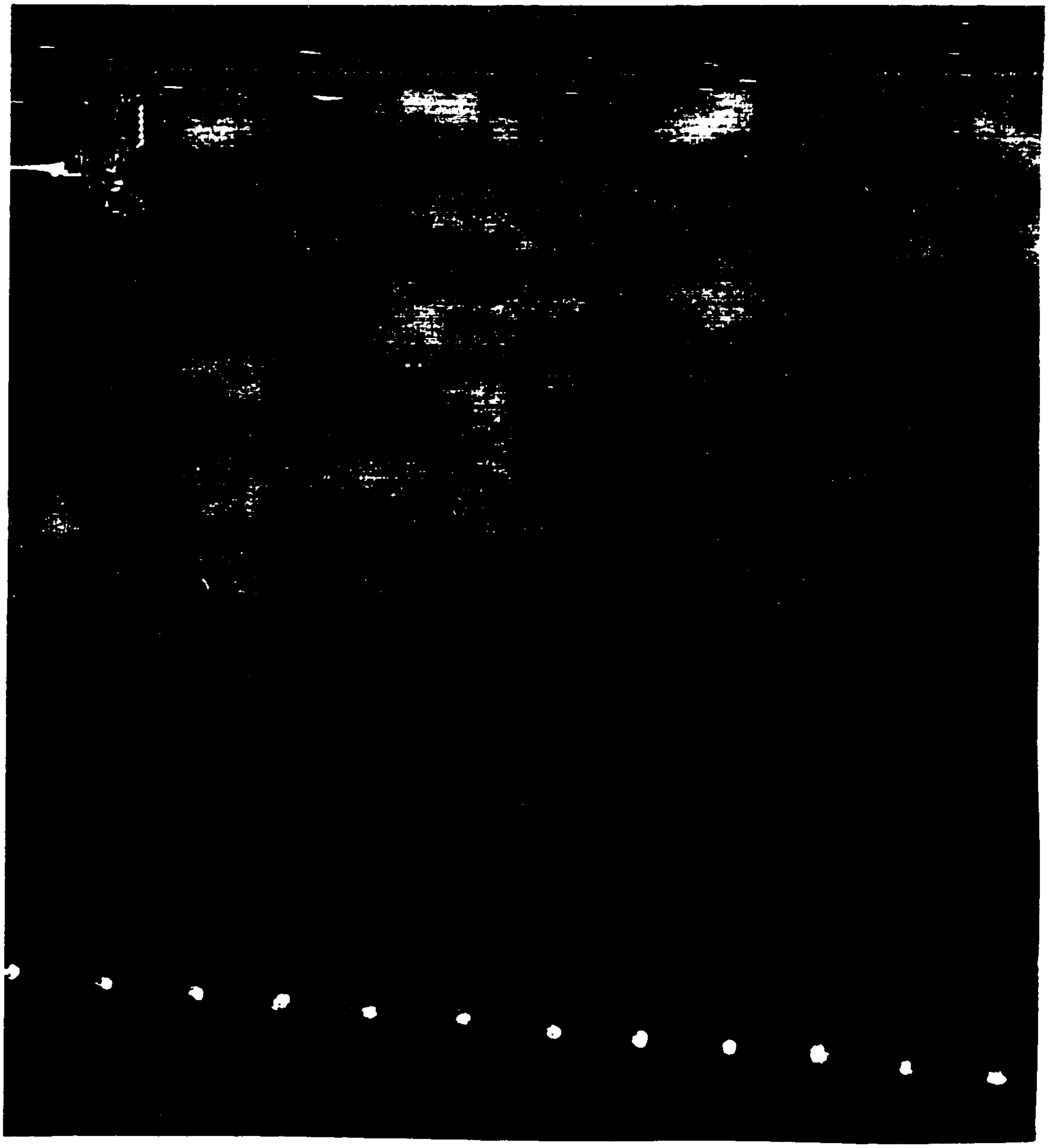


Plate 2.1 Base-map for the Halcourt site (scale 1:5000).

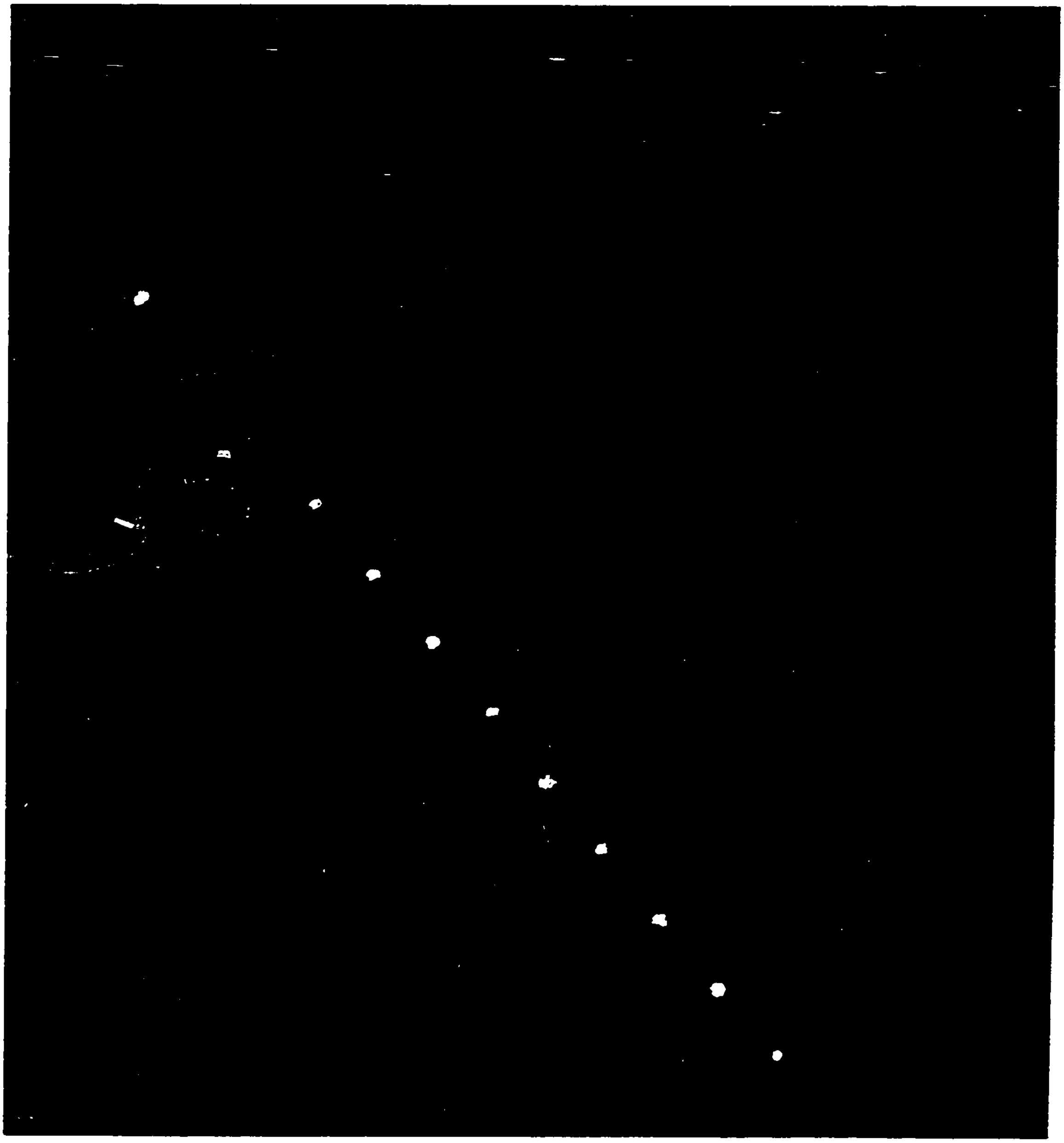


Plate 2.2 Base-map for the Hythe site (scale 1:5000).

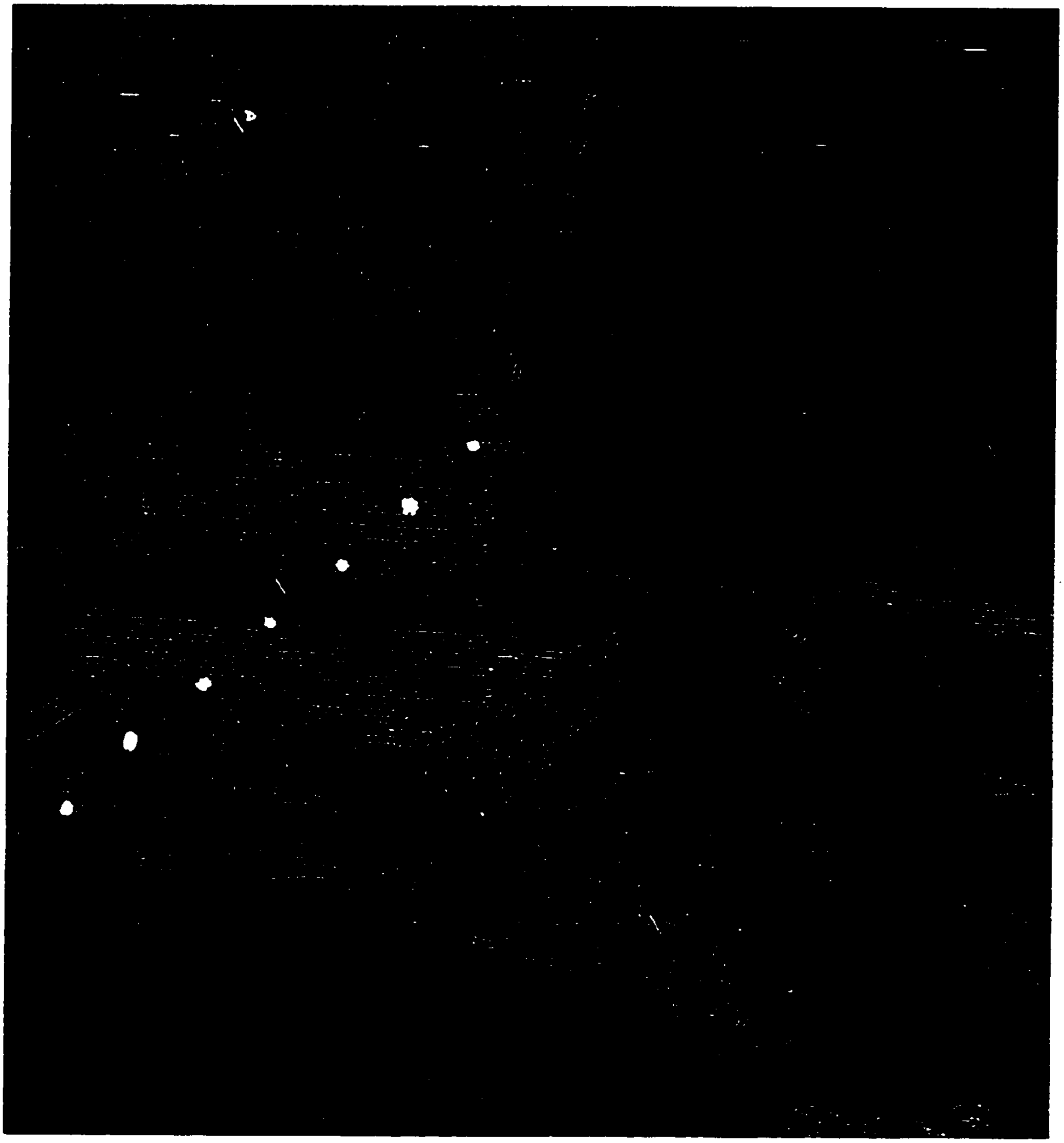


Plate 2.3 Base-map for the Huallen site (scale 1:5000).

Elevation

Elevation at each node was determined by differential global positioning (DGPS) and conventional survey methods. A DGPS base-station was established at a central, known survey point near Beaverlodge. Additional GPS receivers were used to obtain concurrent position readings for 2 sampling nodes at each research site. Base-station data were used to correct the signals obtained for the selected nodes. Elevation for the rest of the nodes was determined with a transit and an electronic distance meter, using the GPS nodes as references.

Weed Populations

Weed populations were surveyed at all sites, prior to spraying. Survey dates were June 10-11th (Hythe), June 12-13th (Halcourt) and June 27-28th (Huallen). Weed species were identified and counted, in 4 quadrants (.25 m^2) per sampling unit. Species were grouped (Kaulbars, 1998; Stearman, 1983) according to their general form (broadleaf or grassy) and habit (annual or perennial). Botanical classification was not strictly observed; grouping criteria were management based. Winter annuals were grouped with annuals, biennials were grouped with perennials and *Equisetum arvense* L. was classified as a broadleaf species.

The number of broadleaf species per sampling unit (broadleaf species frequency) was determined by assigning each broadleaf species, at a given site, a value of zero (if absent within the unit), or a value of one (if present within the unit), and then summing the assigned values. The number of grassy, annual and perennial species per sampling unit, was determined by the same method (Gill and Arshad, 1995). Group densities (number of weeds in each group per sampling unit) were calculated by summing densities for individual species within each group (Gill and Arshad, 1995).

Statistical Analyses

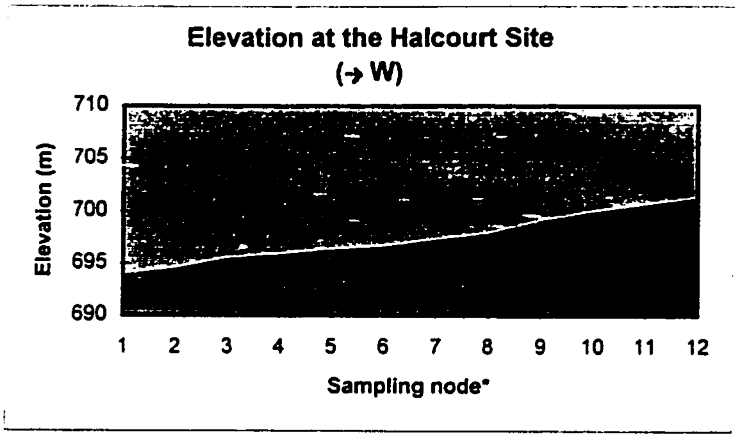
The SAS General linear model (GLM) procedure was used to analyze sub-field differences in weed variables (SAS Institute Inc., 1985). A one-way classification was used. Sources of variation were node and sampling error (Steel and Torrie, 1980). The Bonferroni procedure ($p = .05$) was used for mean separation (Snedecor and Cochran, 1989). Prior to analysis of variance, all data sets were tested for normal distribution of variance using SAS Univariate procedure. Outliers were removed from those data sets that failed the test. Adjusted data sets were then analyzed using the GLM procedure for missing values (SAS Institute Inc., 1985).

RESULTS

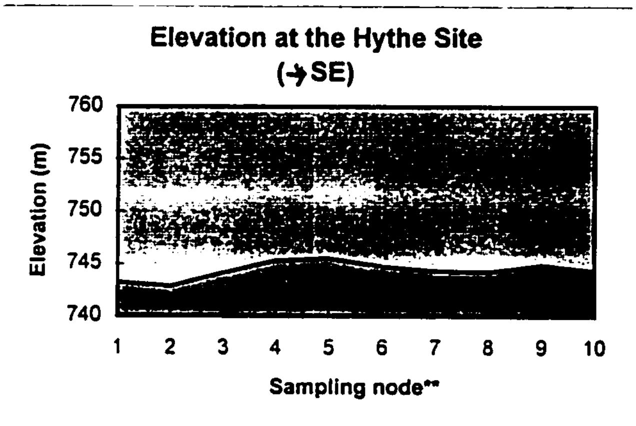
Elevation

Elevation data are illustrated in Figure 2.2. The Hythe site had the highest mean elevation (744 m), followed by the Halcourt site (697 m) and the Huallen site (694 m). Elevation at Halcourt ranged from 693.7 m at node 1, to 701.1 m at node 12 (difference of 7.4 m). Elevation at Hythe ranged from 742.9 m at node 2, to 745.5 m at node 5 (difference of 1.9 m). Elevation at Huallen ranged from 688.8 m at node 6, to 703.9 m at node 1 (difference of 15.1 m).

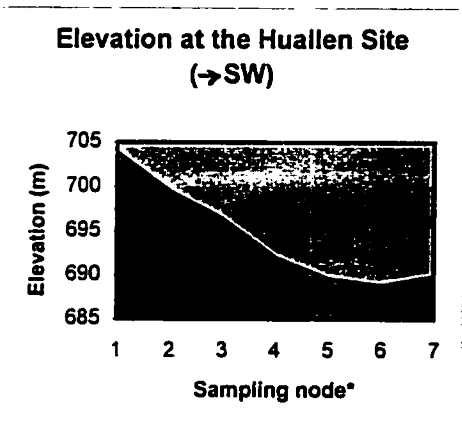
Node	Elevation (m)
1	693.7
2	694.3
3	695.3
4	695.6
5	696.1
6	696.4
7	697.1
8	697.6
9	698.9
10	699.7
11	700.4
12	701.1
mean	**697.2**



Node	Elevation (m)
1	743.2
2	742.9
3	744.2
4	745.3
5	745.5
6	744.8
7	744.3
8	744.2
9	744.9
10	744.3
mean	**744.4**



Node	Elevation (m)
1	703.9
2	699.5
3	696.4
4	692.0
5	689.6
6	688.8
7	689.8
mean	**694.3**



* Nodes are 65 m apart.
** Nodes 2-10 are 65 m apart; nodes 1 and 2 are ~ 200 m apart (see Plate 2.2).

Figure 2.2 Elevation along the transects at the Halcourt, Hythe and Huallen sites.

Weed Populations

Weed species form and habit, are summarized in Table 2.4. There was some uncertainty regarding the identification of wild mustard. Perhaps those plants identified as such, were really volunteer canola. The numbers listed under site notations refer to nodes at the respective sites, and indicate the presence of the weed species at the node. A total of 32 species were identified at the three sites. Hythe had the greatest number of species (23); the other two sites had fewer species (16, 15). The majority of weeds at all sites were broadleaf annuals.

Table 2.4 Weed species at the Halcourt, Hythe and Huallen sites in 1996.

Common Name	Botanical Name	Form	Habit	Halcourt	Hythe	Huallen
Bluebur*	*Lappula echinata* Gilib.	Broadleaf	Annual	all nodes	3,8	-
Buckwheat (Wild)	*Polygonum convolulus* L.	Broadleaf	Annual	all nodes	all nodes	1-3,5-7
Barley (Foxtail)	*Hordeum jubatum* L.	Grassy	**Perennial**	-	2-4,7,8,10	-
Canola (Volunteer)	*Brassica rapa* or *B. napus*	Broadleaf	Annual	2,3,6,8-12	all nodes	2-6
Chickweed (Common)*	*Stellaria media* (L.) Cyrill.	Broadleaf	Annual	-	-	all nodes
Cleavers	*Galium aparine* L.	Broadleaf	Annual	-	-	all nodes
Clover (Alsike)	*Trifolium hybridum*	Broadleaf	**Perennial**	3,5-12	3,4,8,9	-
Corn Spurry	*Spergula arvensis* L.	Broadleaf	Annual	12	-	1
Dandelion	*Taraxacum officinale* Weber	Broadleaf	**Perennial**	1,2,4-8,10,11	all nodes	2
Groundsel (Common)**	*Senecio vulgaris L.*	Broadleaf	Annual	all nodes	4,6-8	-
Hawk's beard (NL)	*Crepis tectorum* L.	Broadleaf	Annual	-	9,10	2
Hemp-nettle	*Galeopsis tetrahit* L.	Broadleaf	Annual	-	1-5,9	-
Horsetail (Field)	*Equisetum arvense* L.	Broadleaf	**Perennial**	1,3,4,9,11	-	1,4-7
Lady's-thumb	*Polygonum persicaria* L.	Broadleaf	Annual	-	9	-
Lamb's-quarters	*Chenopodium album* L.	Broadleaf	Annual	all nodes	1,2,4,5,7-10	all nodes
Mustard (Ball)*	*Neslia paniculata* (L.) Desv.	Broadleaf	Annual	1-6,8-12	-	1,3-7
Mustard (Wild)	*Sinapis arvensis* L. (aka *Brassica kaber* (D.C.) LC Wheeler)	Broadleaf	Annual	2,3,4,8,9,10	- -	1,2,6,7 -
Oats (Wild)	*Avena fatua* L.	Grassy	Annual	all nodes	2,3,4,9,10	1
Pineapple Weed	*Matricaria matricarioides* (Less.) Porter	Broadleaf	Annual	- -	7,8,10 -	- -
Peas (Volunteer)	*Pisum sativum* L.	Broadleaf	Annual	9	-	-
Plantain (Broad-leaved)	*Plantago major* L.	Broadleaf	**Perennial**	4,5,6	2-4,8,9	-
Purslane	*Portulaca oleracea* L.	Broadleaf	Annual	-	7,8,10	-
Quackgrass	*Agropyron repens* (L.) Beauv.	Grassy	**Perennial**	-	1,2,4-6,8	1,2,7
Rose (Wild)	*Rosa woodsii*	Broadleaf	**Perennial**	-	5,9	-
Scentless Chamomile***	*Matricaria maritima* L. (aka *M. inodora* L.)	Broadleaf	Annual	-	2,6-8,10	- -
Shepherd's-purse*	*Capsella bursa-pastoris* (L.) Medic	Broadleaf	Annual	-	6,9,10	-
Sow thistle (perennial)	*Sonchus arvensis* L.	Broadleaf	**Perennial**	-	-	6,7
Speedwell	*Veronica peregrina* L.	Broadleaf	Annual	6,7	-	-
Stinkweed*	*Thlaspi arvense* L.	Broadleaf	Annual	1,3,4,6-12	1-7,9	all nodes
Tansy	*Tanacetum vulgare* L.	Broadleaf	**Perennial**	-	7	-
Wormwood****	*Artemesia sp.*	Broadleaf	**Perennial**	-	3,8	-
Yarrow	*Achillea millefolium* L.	Broadleaf	**Perennial**	-	3,8	-
Total number of species: 32				**16**	**23**	**15**

* annual or winter annual; grouped as an annual.

** annual, winter annual or biennial; grouped as an annual.

*** annual, winter annual, biennial or short lived perennial; grouped as an annual.

**** biennial or perennial; grouped as a perennial.

Halcourt Site

Broadleaf and grassy weeds were present at all nodes. All nodes had a higher frequency and density of broadleaf weeds, relative to grassy ones. The frequency of broadleaf species varied from node to node, but the grassy species frequency did not. Sub-field variability in weed densities for both broadleaf and grassy species was observed. The density of broadleaf and grassy species varied more along the transect than did the frequency of these groups (Tables 2.5-2.6, Figure 2.3).

Annual and perennial weeds were present at all nodes. All nodes had a higher frequency and density of annual weeds, relative to perennial ones. Sub-field variability in frequency and density, for both annual and perennial species, was observed (Tables 2.7-2.8, Figure 2.4).

Table 2.5 ANOVA for broadleaf weeds at the Halcourt site in 1996.

Dependent Variable: Frequency of broadleaf weeds at Halcourt.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PFBD = node	11	48.00	4.36	3.36	0.0017
Error	48	62.40	1.30		
Corrected Total	59	110.40			
R-Square		C.V.	Root MSE		PFBD Mean
0.43		17.28	1.14		6.60

Dependent Variable: Density of broadleaf weeds at Halcourt.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PDBD = node	11	974258.45	88568.95	12.25	0.0001
Error	48	347133.20	7231.94		
Corrected Total	59	1321391.65			
R-Square		C.V.	Root MSE		PDBD Mean
0.74		39.80	85.04		213.65

Table 2.6 ANOVA for grassy weeds at the Halcourt site 1996.

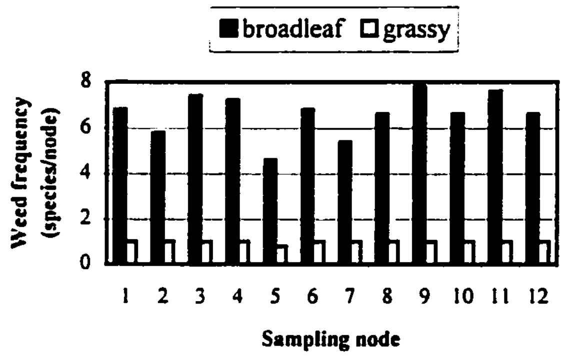
Dependent Variable: Frequency of grassy weeds at Halcourt.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PFGR = node	11	0.18	0.02	1.00	0.4604
Error	48	0.80	0.02		
Corrected Total	59	0.98			
R-Square		C.V.	Root MSE		PFGR Mean
0.19		13.13	0.13		0.98

Dependent Variable: Density of grassy weeds at Halcourt.

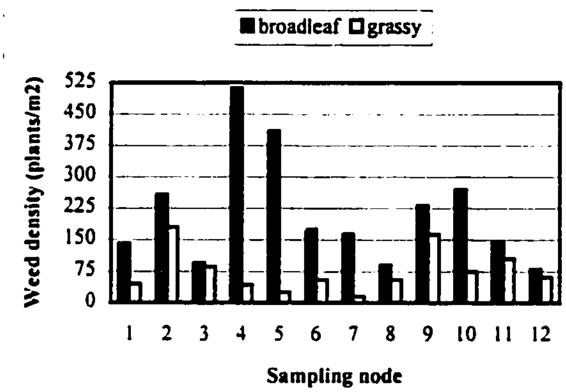
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PDGR = node	11	132217.67	12019.79	5.27	0.0001
Error	46	104830.35	2278.92		
Corrected Total	57	237048.02			
R-Square		C.V.	Root MSE		PDGR Mean
0.56		65.13	47.74		73.29

Node	Broadleaf (species/node)	Node	Grassy (species/node)
9	7.8 a	1	1.0 a
11	7.6 a	2	1.0 a
3	7.4 a	3	1.0 a
4	7.2 a	4	1.0 a
6	6.8 ab	9	1.0 a
1	6.8 ab	6	1.0 a
10	6.6 ab	7	1.0 a
8	6.6 ab	8	1.0 a
12	6.6 ab	11	1.0 a
2	5.8 ab	10	1.0 a
7	5.4 ab	12	1.0 a
5	4.6 b	5	0.8 a
MSD = 2.59			MSD = 0.29



(Bonferroni, p = .05)

Node	Broadleaf (plants/m2)	Node	Grassy (plants/m2)
4	513.2 a	2	179.0 a
5	408.6 ab	9	162.2 ab
10	268.6 bc	11	104.4 abc
2	257.2 bc	3	85.2 abc
9	231.2 bc	10	74.3 abc
6	174.4 c	12	61.0 bc
7	162.8 c	8	54.4 bc
11	143.2 c	6	54.4 bc
1	140.6 c	1	44.4 c
3	94.6 c	4	42.6 c
8	89.0 c	5	25.0 c
12	80.4 c	7	14.0 c
MSD = 193.49			MSD = 111.18



(Bonferroni, p = .05)

Figure 2.3 Frequency and density of broadleaf and grassy weeds along a transect at the Halcourt site in 1996.

Table 2.7 ANOVA for annual weeds at the Halcourt site in 1996.

Dependent Variable: Frequency of annual weeds at Halcourt.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PFAN = node	11	56.85	5.17	6.20	0.0001
Error	48	40.00	0.83		
Corrected Total	59	96.85			

R-Square	C.V.	Root MSE	PFAN Mean
0.59	14.15	0.91	6.45

Dependent Variable: Density of annual weeds at Halcourt.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PDAN = node	11	1224596.33	111326.94	9.53	0.0001
Error	48	560526.40	11677.63		
Corrected Total	59	1785122.73			

R-Square	C.V.	Root MSE	PDAN Mean
0.69	36.43	108.06	296.56

Table 2.8 ANOVA for perennial weeds at the Halcourt site in 1996.

Dependent Variable: Frequency of perennial weeds at Halcourt.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PFPER = node	11	15.73	1.43	3.99	0.0004
Error	48	17.20	0.36		
Corrected Total	59	32.93			

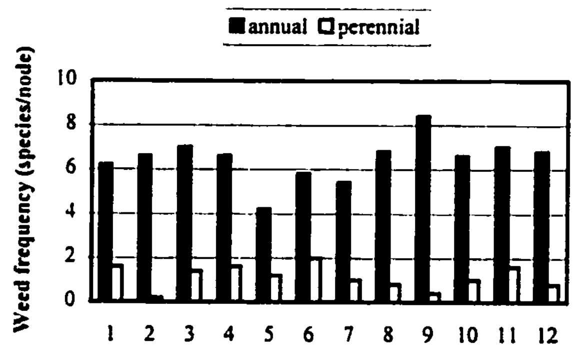
R-Square	C.V.	Root MSE	PFPER Mean
0.48	52.82	0.60	1.13

Dependent Variable: Density of perennial weeds at Halcourt.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PDPER = node	11	383.09	34.83	11.80	0.0001
Error	46	135.75	2.95		
Corrected Total	57	518.85			

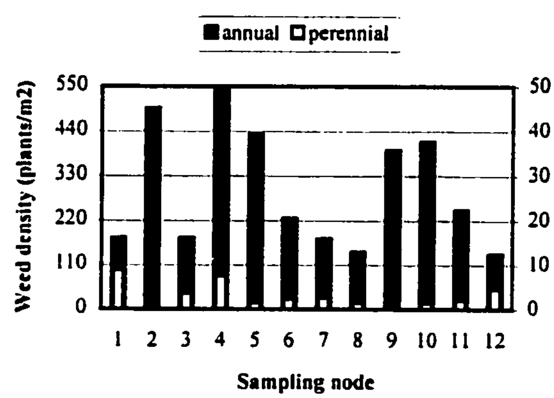
R-Square	C.V.	Root MSE	PDPER Mean
0.74	58.27	1.72	2.95

Node	Annual (species/node)	Node	Perennial (species/node)
9	8.4 a	6	2.0 a
3	7.0 ab	1	1.6 ab
11	7.0 ab	11	1.6 ab
12	6.8 ab	4	1.6 ab
8	6.8 ab	3	1.4 abc
2	6.6 ab	5	1.2 abc
10	6.6 ab	10	1.0 abc
4	6.6 ab	7	1.0 abc
1	6.2 bc	8	0.8 abc
6	5.8 bc	12	0.8 abc
7	5.4 bc	9	0.4 bc
5	4.2 c	2	0.2 c
MSD = 2.08		MSD = 1.36	



(Bonferroni, p = .05)

Node	Annual (plants/m2)	Node	Perennial (plants/m2)
4	546.0 a	1	8.8 a
2	496.8 a	4	7.5 ab
5	432.2 ab	12	4.6 bc
10	414.4 abc	3	3.6 bc
9	393.0 abc	7	2.6 cd
11	245.6 bcd	6	2.3 cd
6	225.4 bcd	11	2.0 cd
3	176.2 cd	10	1.4 cd
1	176.2 cd	5	1.4 cd
7	174.2 cd	8	1.4 cd
8	142.0 cd	9	0.4 d
12	136.8 d	2	0.2 d
MSD = 245.87		MSD = 4.0	



(Bonferroni, p = .05)

Figure 2.4 Frequency and density of annual and perennial weeds along a transect at the Halcourt site in 1996.

Hythe Site

Broadleaf and grassy weeds were present at all nodes at this site. All nodes had a higher frequency of broadleaf weeds, relative to grassy ones. Grassy weed density was higher than broadleaf weed density at node 2, but was lower than broadleaf density at all other nodes. Sub-field variability in weed density and frequency, for both broadleaf and grassy species, was observed (Tables 2.9-2.10, Figure 2.5).

Annual and perennial weeds were present at all nodes. Perennial weed frequency was higher than annual weed frequency at node 8, but was lower than annual weed frequency at all other nodes. Perennial weed density was higher than annual weed density at node 2, but was lower than annual weed density at all other nodes. Sub-field variability in frequency and density for both annual and perennial species, was observed (Tables 2.11-2.12, Figure 2.6). Annual weed densities tended to be higher on the knolls (nodes 1, 4, 5, 9), whereas perennial weed densities tended to be higher in the hollows (Figure 2.2 and 2.6).

Table 2.9 ANOVA for broadleaf weeds at the Hythe site in 1996.

Dependent Variable: Frequency of broadleaf weeds at Hythe.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PFBD = node	9	69.62	7.74	3.68	0.0020
Error	40	84.00	2.10		
Corrected Total	49	153.62			

R-Square	C.V.	Root MSE	PFBD Mean
0.45	27.55	1.45	5.26

Dependent Variable: Density of broadleaf weeds at Hythe.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PDBD =node	9	163440.07	18160.01	9.35	0.0001
Error	39	75720.75	1941.56		
Corrected Total	48	239160.82			

R-Square	C.V.	Root MSE	PDBD Mean
0.68	43.17	44.06	102.06

Table 2.10 ANOVA for grassy weeds at the Hythe site in 1996.

Dependent Variable: Frequency of grassy weeds at Hythe.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PFGR = node	9	17.67	1.96	5.63	0.0001
Error	39	13.60	0.35		
Corrected Total	48	31.27			

R-Square	C.V.	Root MSE	PFGR Mean
0.57	67.29	0.59	0.88

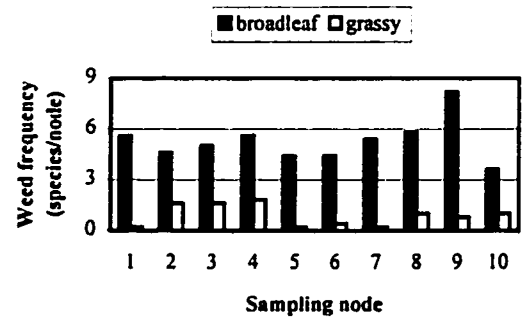
Dependent Variable: Density of grassy weeds at Hythe.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PDGR = node	9	23228.09	2580.90	229.18	0.0001
Error	26	292.80	11.26		
Corrected Total	35	23520.89			

R-Square	C.V.	Root MSE	PDGR Mean
0.99	24.76	3.36	13.56

Node	Broadleaf (species/node)
9	8.2 a
8	5.8 ab
1	5.6 ab
4	5.6 ab
7	5.4 ab
3	5.0 ab
2	4.6 b
6	4.4 b
5	4.4 b
10	3.6 b

MSD = 3.22



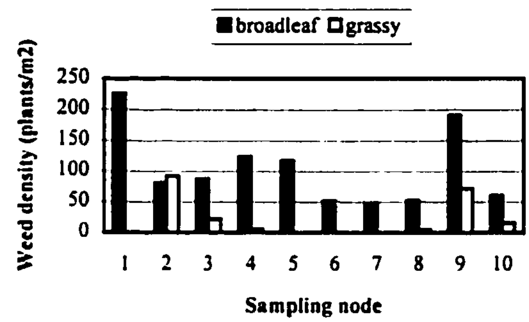
(Bonferroni, p = .05)

Node	Grassy (species/node)
4	1.8 a
3	1.6 ab
2	1.6 ab
10	1.0 abc
8	1.0 abc
9	0.8 abc
6	0.4 bc
5	0.2 c
7	0.2 c
1	0.2 c

MSD = 1.33

Node	Broadleaf (plants/m2)
1	226.0 a
9	190.8 ab
4	124.2 bc
5	117.0 bc
3	87.2 c
2	80.4 c
10	60.4 c
8	52.8 c
6	51.6 c
7	48.0 c

MSD = 99.35



(Bonferroni, p = .05)

Node	Grassy (plants/m2)
2	92.0 a
9	72.0 b
3	21.8 c
10	15.5 c
4	5.0 d
8	4.4 d
6	0.8 d
5	0.2 d
1	0.2 d
7	0.0 d

MSD = 9.82

Figure 2.5 Frequency and density of broadleaf and grassy weeds along a transect at the Hythe site in 1996.

Table 2.11 ANOVA for annual weeds at the Hythe site in 1996.

Dependent Variable: Frequency of annual weeds at Hythe.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PFAN = node	9	67.70	7.52	4.25	0.0006
Error	40	70.80	1.77		
Corrected Total	49	138.50			

R-Square	C.V.	Root MSE	PFAN Mean
0.49	32.45	1.33	4.10

Dependent Variable: Density of annual weeds at Hythe.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PDAN = node	9	302763.32	33640.37	14.84	0.0001
Error	39	88432.35	2267.50		
Corrected Total	48	391195.67			

R-Square	C.V.	Root MSE	PDAN Mean
0.77	47.11	47.62	101.08

Table 2.12 ANOVA for perennial weeds at the Hythe site in 1996.

Dependent Variable: Frequency of perennial weeds at Hythe.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PFPER = node	9	32.00	3.56	5.08	0.0001
Error	40	28.00	0.70		
Corrected Total	49	60.00			

R-Square	C.V.	Root MSE	PFPER Mean
0.53	41.83	0.84	2.00

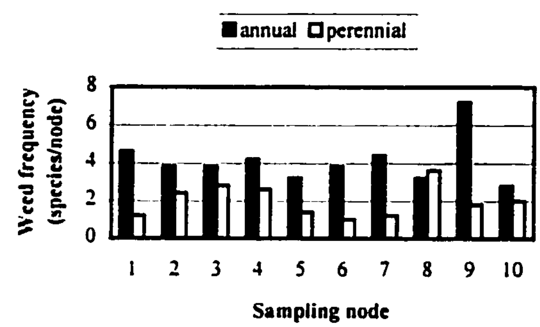
Dependent Variable: Density of perennial weeds at Hythe.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PDPER = node	9	12760.88	1417.88	31.95	0.0001
Error	34	1508.67	44.37		
Corrected Total	43	14269.55			

R-Square	C.V.	Root MSE	PDPER Mean
0.89	48.69	6.66	13.68

Node	Annual (species/node)
9	7.2 a
1	4.6 ab
7	4.4 ab
4	4.2 b
2	3.8 b
6	3.8 b
3	3.8 b
8	3.2 b
5	3.2 b
10	2.8 b

MSD = 2.96



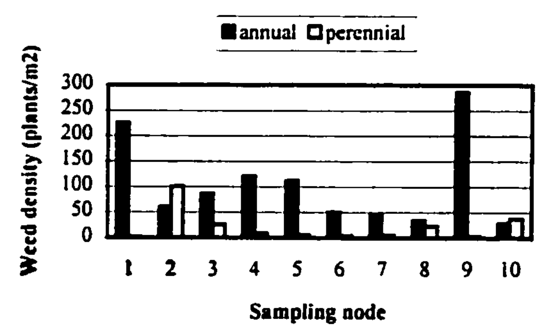
(Bonferroni, p = .05)

Node	Perennial (species/node)
8	3.6 a
3	2.8 ab
4	2.6 ab
2	2.4 ab
10	2.0 ab
9	1.8 ab
5	1.4 b
7	1.2 b
1	1.2 b
6	1.0 b

MSD =1.86

Node	Annual (plants/m2)
9	286.3 a
1	224.8 ab
4	120.6 bc
5	111.4 c
3	86.4 c
2	60.0 c
6	50.0 c
7	46.0 c
8	34.0 c
10	28.4 c

MSD = 107.45



(Bonferroni, p = .05)

Node	Perennial (plants/m2)
2	100.0 a
10	37.3 b
3	25.6 bc
8	23.2 bcd
4	8.4 cde
5	5.8 de
7	5.6 de
6	4.2 e
9	3.8 e
1	1.4 e

MSD = 18.18

Figure 2.6 Frequency and density of annual and perennial weeds along a transect at the Hythe site in 1996.

Huallen Site

Broadleaf weeds were present at all nodes at this site. Grassy weeds were present only at nodes 1, 2 and 7. Broadleaf frequency and density were higher than grassy weed frequency and density, at all nodes. Sub-field variability in weed density and frequency for both broadleaf and grassy species, was observed (Tables 2.13-2.14, Figure 2.7). Grassy weeds were associated with upper-slope position (Figures 2.2 and 2.7).

Annual weeds were present at all nodes. Perennial weeds were present at all nodes except number 3. Annual weed frequency and density were higher than perennial weed frequency and density, at all nodes. Node 2 had an exceptionally high density of annual broadleaf weeds. Sub-field variability in frequency and density for both annual and perennial species was observed (Tables 2.15-2.16, Figure 2.8).

Table 2.13 ANOVA for broadleaf weeds at the Huallen site in 1996.

Dependent Variable: Frequency of broadleaf weeds at Huallen.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PFBD = node	6	33.54	5.59	10.03	0.0001
Error	28	15.60	0.56		
Corrected Total	34	49.14			

R-Square	C.V.	Root MSE	PFBD Mean
0.68	11.87	0.75	6.29

Dependent Variable: Density of broadleaf weeds at Huallen.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PDBD = node	6	3626156.34	604359.39	23.67	0.0001
Error	28	714962.40	25534.37		
Corrected Total	34	4341118.74			

R-Square	C.V.	Root MSE	PDBD Mean
0.84	31.06	159.79	514.51

Table 2.14 ANOVA for grassy weeds at the Huallen site in 1996.

Dependent Variable: Frequency of grassy weeds at Huallen.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PFGR = node	6	5.54	0.92	16.17	0.0001
Error	28	1.60	0.06		
Corrected Total	34	7.14			

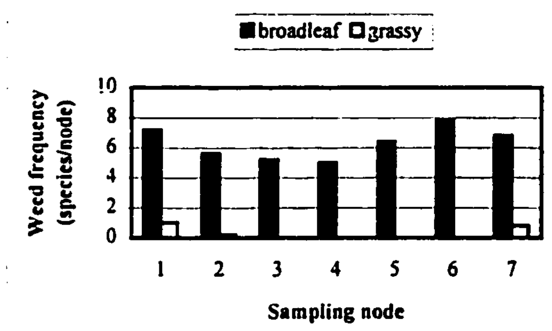
R-Square	C.V.	Root MSE	PFGR Mean
0.78	83.67	0.24	0.29

Dependent Variable: Density of grassy weeds at Huallen.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PDGR = node	6	237.09	39.51	5.92	0.0004
Error	28	186.80	6.67		
Corrected Total	34	423.89			

R-Square	C.V.	Root MSE	PDGR Mean
0.56	155.87	2.58	1.66

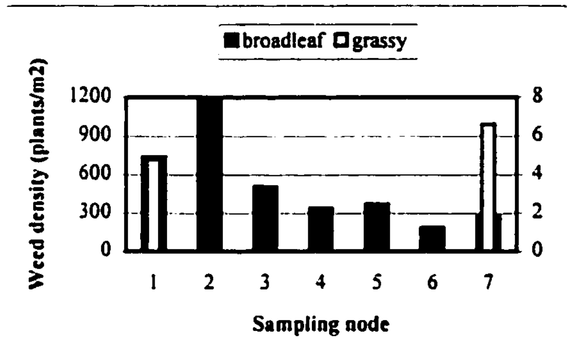
Node	Broadleaf (species/node)
6	7.8 a
1	7.2 a
7	6.8 ab
5	6.4 abc
2	5.6 bc
3	5.2 c
4	5.0 c



Node	Grassy (species/node)
1	1.0 a
7	0.8 a
2	0.2 b
4	0.0 b
5	0.0 b
6	0.0 b
3	0.0 b

MSD = 1.58 (Bonferroni, p = .05) MSD = 0.50

Node	Broadleaf (plants/m2)
2	1191.6 a
1	735.8 b
3	507.0 bc
5	369.0 c
4	337.2 c
7	274.2 c
6	186.8 c



Node	Grassy (plants/m2)
7	6.6 a
1	4.8 ab
2	0.2 b
4	0.0 b
5	0.0 b
6	0.0 b
3	0.0 b

MSD = 337.59 (Bonferroni, p = .05) MSD = 5.46

Figure 2.7 Frequency and density of broadleaf and grassy weeds along a transect at the Huallen site in 1996.

Table 2.15 ANOVA for annual weeds at the Huallen site in 1996.

Dependent Variable: Frequency of annual weeds at Huallen.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PFAN = node	6	8.61	1.44	2.56	0.0430
Error	27	15.15	0.56		
Corrected Total	33	23.76			

R-Square	C.V.	Root MSE	PFAN Mean
0.36	13.26	0.75	5.65

Dependent Variable: Density of annual weeds at Huallen.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PDAN = node	6	3767302.74	627883.79	24.85	0.0001
Error	28	707358.00	25262.78		
Corrected Total	34	4474660.74			

R-Square	C.V.	Root MSE	PDAN Mean
0.84	31.28	158.94	508.08

Table 2.16 ANOVA for perennial weeds at the Huallen site in 1996.

Dependent Variable: Frequency of perennial weeds at Huallen.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PFPER = node	6	16.57	2.76	9.21	0.0001
Error	28	8.40	0.30		
Corrected Total	34	24.97			

R-Square	C.V.	Root MSE	PFPER Mean
0.66	66.10	0.55	0.83

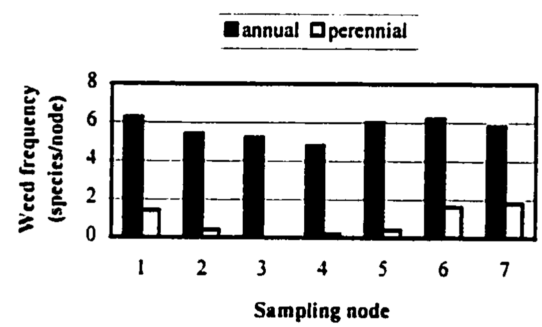
Dependent Variable: Density of perennial weeds at Huallen.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PDPER = node	6	5992.74	998.79	19.86	0.0001
Error	28	1408.00	50.28		
Corrected Total	34	7400.74			

R-Square	C.V.	Root MSE	PDPER Mean
0.81	87.70	7.09	8.08

Node	Annual (species/node)
1	6.3 a
6	6.2 a
5	6.0 a
7	5.8 a
2	5.4 a
3	5.2 a
4	4.8 a

MSD = 1.62



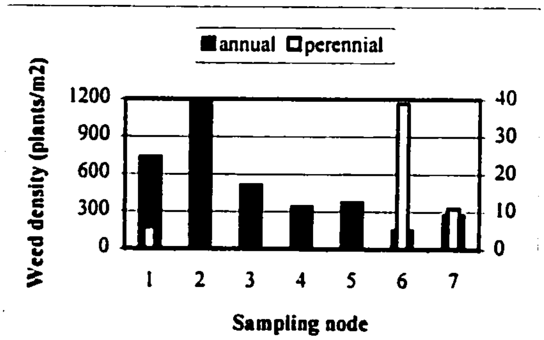
(Bonferroni, p = .05)

Node	Perennial (species/node)
7	1.8 a
6	1.6 a
1	1.4 ab
2	0.4 bc
5	0.4 bc
4	0.2 c
3	0.0 c

MSD = 1.16

Node	Annual (plants/m2)
2	1191.4 a
1	734.8 b
3	507.0 bc
5	368.6 cd
4	336.8 cd
7	270.0 cd
6	148.0 d

MSD = 335.79



(Bonferroni, p = .05)

Node	Perennial (plants/m2)
6	38.8 a
7	10.8 b
1	5.8 b
4	0.4 b
5	0.4 b
2	0.4 b
3	0.0 b

MSD = 14.98

Figure 2.8 Frequency and density of annual and perennial weeds along a transect at the Huallen site in 1996.

DISCUSSION

Implications of Weed Variability for the Site Specific Application of Post-emergent Herbicides

Integrated threshold models for weed groups are not available, and the exclusion of economic principles from the study did not allow for the calculation of economic thresholds for individual weed species. Therefore, general guidelines were used to evaluate weed patterns and their implications for the site specific application of post-emergent herbicides.

Crop production guides for Alberta suggest that post-emergent weed control in cereal crops should be considered when weed infestations are medium to heavy. The lower limit of the medium class is taken as the spray threshold density. Wild oats, stinkweed, wild buckwheat, lamb's-quarters, hemp-nettle, smartweed, volunteer canola, wild mustard and shepherd's-purse have a spray threshold density of 10 plants/m^2; chickweed and corn spurry have a spray threshold density of 20 plants/m^2, and Canada thistle, perennial sow thistle and dandelion have a spray threshold of 2 plants/m^2. Noxious weeds (cleavers, tansy, scentless chamomile) are controlled if present at all (Dorrance, 1994; McLelland, 1989; Rourke, 1993).

Halcourt site

The distribution of broadleaf annuals (BA), along the transect at the Halcourt site, presented limited opportunities for the site specific application of BA post-emergent herbicides. BA densities were higher than spray thresholds at all nodes, thus opportunities to reduce herbicide use through intermittent spraying of these weeds did not exist (Dorrance, 1994).

Different BA species were present at different nodes, and since it is not yet possible to control all BA weeds with any one post-emergent herbicide (at least not before harvest), opportunities for targeting different species at different nodes were suggested by these data. However, examination of the BA species present at each node, and review of products available for their control (Ali, 1998) revealed only one node (node 12) where more than one post-emergent product was required to control all the BA species present. The unique BA species at node 12 was corn spurry. Because corn spurry is an aggressive weedy species in cultivated fields (Dorrance, 1994), the site specific application at node 12, of a post-emergent specific to corn spurry, would have been useful.

The distribution of grassy annuals (GA) along the transect at the Halcourt site, did not present any opportunities for species specific application or intermittent spraying. Wild oats was the only grassy annual observed. Wild oats was present at all nodes, and densities were higher than spray thresholds at all nodes (Dorrance, 1994).

The sub-field variability in broadleaf perennials (BP) at the Halcourt site, did not present definite opportunities for site specific control either. Species varied from node to node, but densities were too low along most of the transect to warrant spraying. Perennial weed densities at node 1 and 4 were high enough to warrant inspection. If the higher BP densities at node 1 and 4 were related to dandelion populations, a species specific application for their control might have been useful at these nodes. However, if the higher numbers of BP at these nodes were related to horsetail and plantain populations, a species specific application at these node would not have been worth while (Dorrance, 1994). No grassy perennials (GP) were observed along the transect at the Halcourt site.

Hythe Site

BA densities were higher than spray thresholds at all nodes, at the Hythe site. Therefore, opportunities to reduce herbicide use through intermittent spraying of these weeds did not exist (Dorrance, 1994). Different BA species were present at different nodes, but there were only two nodes (nodes 9 and 10) where more than a common tank-mix was required to control all the BA species present (Ali, 1998). The unique BA species at nodes 9 and 10, was hawk's beard. If hawk's beard was present at these two nodes in sufficient numbers, it would provide an opportunity for the site specific application of a post-emergent herbicide.

The only GA present along the transect at the Hythe site was wild oats. Wild oats were present only at nodes 2, 3, 4, 9 and 10 (half the nodes along the transect), and thus presented an opportunity for intermittent spraying. The grouping criteria did not allow for a complete evaluation of wild oat densities because there were several grassy species present at these nodes. However, sub-field differences in grassy and perennial weed densities, suggested that wild oat densities at nodes 2, 3, 4 and 10 were below the spray threshold. If this was true, wild oat populations along the transect could have been effectively controlled with a site specific herbicide application at node 9.

Tansy and dandelion were the principle BP weeds of concern at the Hythe site. Tansy is a noxious weed that must be controlled if present at all, and dandelion requires control at low densities (Dorrance, 1994). Tansy was present only at node 7, but because there are no post-emergent herbicides available for its control, its distribution did not provide an opportunity for site specific herbicide application (Ali, 1998). Dandelions were present at all nodes, thereby eliminating the obvious possibility for intermittent spraying of this species. However, the low density of perennial weeds at node 1, suggested that dandelion control was not required at this node.

Quackgrass was the principle GP species of concern at the Hythe site. Quackgrass distribution along the transect, presented a good opportunity for intermittent spraying because it was present only at nodes 1, 2, 4, 5, 6 and 8. Densities were high enough at all these nodes to warrant control.

Huallen

The distribution of BA weeds along the transect at the Huallen site, presented limited opportunities for the site specific application of BA post-emergent herbicides. BA densities were higher than spray thresholds at all nodes. Therefore, opportunities to reduce herbicide use through intermittent spraying of these weeds, did not exist at this site (Dorrance, 1994). Different BA species were present at different nodes, but there were only two nodes (nodes 1 and 2) where more than one post-emergent product was required to control all the BA species present (Ali, 1998). The unique BA species at node 1 was corn spurry. The unique species at node 2 was hawk's beard. If the densities of these two species at their respective nodes, were higher than spray thresholds, site specific applications of post-emergent herbicides would have been useful. No GA species were present along the transect at the Huallen site. This was expected because a wild oat herbicide had been applied at this site in the fall of 1995 (Appendix B).

Sow thistle and dandelion were the BP weeds at the Huallen site. Sow thistle is a noxious weed that must be controlled if present at all, and dandelion requires control at low densities (Dorrance, 1994). Sow thistle was present only at nodes 6 and 7, thereby presenting a good opportunity for the site specific control of this species with a post-emergent herbicide. Dandelion was present only at node 2, but perennial weed densities at this node suggested that dandelion numbers were below the spray threshold, and did not warrant site specific attention. Quackgrass was the only GP weed present along the transect at the Huallen site. Its distribution presented a good opportunity for site specific control, because it was present only at nodes 1, 2 and 7.

Weed - landscape Associations

The window for post-seeding weed counts is short, and it is not usually possible to scout entire fields. Therefore, it would be useful if the weed species that present opportunities for site specific spraying, were associated with obvious landscape features, such as knolls or depressions. Corn spurry was the only species that presented an opportunity for site specific spraying at the Hythe site. It was associated with the highest point along the transect (node 12). However, topography at the Halcourt site was subtle, and since this species was only present at one node, a trend was not evident.

Hawk's beard, wild oats and quackgrass were the species that warranted site specific spraying at the Hythe site. These species did not show a trend with elevation. Scentless chamomile and tansy did not present opportunities for site specific spraying, but since they are noxious weeds and must be controlled if present at all, it would be useful if their presence was associated with slope position. Tansy was observed at a low spot in the field, but since it was only present in one spot, a trend was not evident.

Scentless chamomile, however, tended to be present at low spots along the transect (nodes 2, 6, 7, 8, 10). This finding correlates with general knowledge of this weed's distribution. Scentless chamomile tends to inhabit lower, wetter areas in cultivated fields and is associated with Solonetzic soils (Dorrance, 1994). Solonetzic soils (Solodized Solonetz) were present in the low spots long the transect at this site (Appendix A). Perhaps the control of scentless chamomile at this site, could be improved by scouting low spots in this field.

Corn spurry, hawk's beard, sow thistle and quackgrass were the species that warranted site specific spraying at the Huallen site. Corn spurry and hawk's beard were only present at one node, therefore associations with landscape position were not evident. Sow thistle was present at nodes 6 and 7. Node 6 was in a low spot, and node 7 was located at an adjacent upper slope position, therefore an association of sow thistle with slope position was not evident. The Huallen site, however, drops more than 14 m from node 1 to node 7, and node 6 is lower than node 7. Thus on the field scale, sow thistle was associated with lower areas along the transect. Sow thistle is known to inhabit lower areas in cultivated fields so this association was not unexpected (Stearman, 1983).

Quackgrass was present at nodes 1, 2 and 7. It is not readily apparent in Figure 2.2, but these nodes were situated at mid to upper slope positions in the field. Quackgrass' reproductive strategy is mostly vegetative. It is known to inhabit all slope positions in cultivated fields, provided adequate moisture is available and there has been sufficient soil disturbance to allow its establishment (Dorrance, 1994). Hence it is difficult to interpret its association with mid to upper slopes at this site. It may be that this association reflects better soil moisture conditions for this species along the transect, or quackgrass may be absent from other nodes just because it hasn't been introduced.

SUMMARY & CONCLUSIONS

Spatial variability in corn spurry (BA; Halcourt, Huallen), hawk's beard (BA; Hythe, Huallen), wild oats (GA, Hythe), sow thistle (BP, Huallen) and quackgrass (GP; Hythe, Huallen) populations, presented limited opportunities for the site specific application of post-emergent herbicides, along field transects in 1996. All weed groups were variable enough to present some opportunities for intermittent spraying, but not all weed groups presented opportunities at every site. This leads to the conclusion that sub-field variability in the frequency and density of broadleaf, grassy, perennial and annual weeds, presents limited opportunities for the site specific application of post-emergent herbicides in fields of the South Peace River region. However, the nature and extent of these opportunities are field and group specific.

Distributions of sow thistle (Huallen), scentless chamomile (Hythe) and quackgrass were associated with landscape position. When present along a transect, sow thistle and scentless chamomile were associated with low spots. It follows that it may be possible to improve the control of noxious weeds like sow thistle and scentless chamomile in fields of the South Peace River region, by scouting for these weeds in low spots in the field. Quackgrass was associated with upper slope positions along the transect at the Huallen site, but was not associated with slope position at the Hythe site. These results suggest that quackgrass - landscape associations are field specific, and the use of these associations to improve scouting for quackgrass, requires that associations in specific fields be known.

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CHAPTER III

SPATIAL VARIABILITY OF NUTRIENT REQUIREMENTS IN FIELDS OF THE SOUTH PEACE RIVER REGION, ALBERTA

INTRODUCTION

Effective nutrient management is essential to annual crop production. Crops require balanced nutrition for healthy growth, optimum yields and high quality (Fageria, 1997). Farmers who grow annual crops in the South Peace River region, typically use chemical fertilizers to meet the nutritional needs of these crops. Commercial sources of N, P, K and S are used to compensate for inadequate nutrient concentrations in the soil. The common practice is to apply these fertilizers uniformly across fields, at rates based on average soil test values for each field (McNeil and Goddard, 1996).

Chemical fertilizers represent a large portion of the input costs associated with annual crop production. In the South Peace River region nutrient costs are about 30 to 35 % of variable costs, when cereal and canola crops are grown (Statistics Canada, 1996). In addition to being expensive, uniform nutrient application may be inefficient. Average soil test values provide a general indication of nutrient conditions in the field, but there will be areas within fields where soil nutrients are lower than average and areas where the opposite is true (Blackmore, 1994). When fertilizers are applied uniformly, at rates based on average requirements, some areas receive more inputs than needed and other areas do not receive enough. As a result, expensive fertilizers are wasted and nutritional imbalances for field crops may be induced (Shueller, 1992).

Site specific fertilizer application may be one way to address both the economical and ecological problems associated with inefficiencies in uniform nutrient application. In the site specific approach, fields are overlain with sampling grids that have cell sizes of one hectare or smaller. A composite sample of five to eight soil cores is taken at points where gridlines intersect (nodes). Nutrient recommendations for each composite sample are obtained, and requirements for areas between nodes are interpolated to generate a prescription map for the field. Nutrients are then applied according to the map. Since inputs are better matched with nutrient requirements, site specific fertilizer application may reduce the wastage and nutritional risks associated with uniform application (Reetz, 1994; Wollenhaupt and Wolkowski, 1994).

Positioning and variable rate technologies for the site specific application of fertilizers are available (Mackay, 1998). However, the successful implementation of these technologies in fields of the South Peace River region, is contingent upon the spatial variability of nutrient requirements within the boundaries of these fields. Opportunities to conserve fertilizer resources and improve crop nutrition with site specific fertilizer application, exist in fields used to grow annual crops in Washington, Ontario and southern Alberta (Hammond, 1994; Kachanoski and Fairchild, 1994; Penney *et al.* 1996). Farmers in the South Peace River region may be able to realize these benefits as well. However, no published data on the spatial variability of nutrient requirements are available for the region.

The purpose of this study was to measure sub-field variability in soil test recommendations for N, P_2O_5, K_2O, and S, in three fields in the South Peace River region and evaluate the implications of this variability for the site specific application of fertilizers.

MATERIALS & METHODS

Site Characteristics

A one-season field study was conducted in the south-west portion of Soil Correlation Area #18 (Dark Gray and Black Soil Zone of the South Peace), in 1996. Spatial variability of soil macronutrients was investigated in three fields in the area. The fields differed in size, topography, parent material and soils, but were under similar management regimes. Conventional tillage systems were used, and annual crops of wheat (*Triticum aestivum*), barley (*Hordeum vulgare, H. distichum*), peas (*Pisum sativum*) and canola (*Brassica rapa*) were grown. Site characteristics and experimental design are described in detail, in Chapter II (Table 2.1).

For study purposes, the fields were labeled as the Halcourt, Hythe and Huallen sites. Wheat (Hythe) and barley (Halcourt, Huallen) were grown in 1996. Sites were not fertilized in the fall of 1995. The Halcourt site was fertilized with N (70.6 kg/ha) and P (32 kg/ha, P_2O_5 equivalent), as a granular blend (35-16-0-0), on May 22, 1996. The Hythe site was fertilized with N, applied as anhydrous ammonia (67 kg/ha) and granular 12-51-0-0 (5 kg/ha), on May 18, 1996. P (22 kg/ha, P_2O_5 equivalent) was applied as 12-51-0-0 (May 18, 1996). The Huallen site was fertilized with N, applied as anhydrous ammonia (50.5 kg/ha) on May 30, 1996, and granular 11-55-0-0 (5.5 kg/ha), on June 10, 1996. P (30.8 kg/ha, P_2O_5 equivalent) was applied as 11-55-0-0, on June 10, 1996. No K or S applications were made at any of these sites in 1996. Management practices are recorded in detail in Appendix B.

Soil Sampling

All soil samples were collected during the 1996 field season. Sampling dates were May 14th -16th at Halcourt; May 27th at Huallen; and October 12th-15th at Hythe. Samples were composites of 3 cores (2.5 cm dia.) from each sampling unit, that were divided into 0 to 15 cm and 15 to 30 cm depth increments. Conventional soil samples were also taken at Hythe and Huallen, on their respective sampling dates. Conventional samples were composites of fifteen cores (2.5 cm dia, 0-30 cm), taken at random from the entire field, and subsequently bulked for analyses. All samples were air-dried and ground to pass a 2 mm sieve.

Soil Analyses

Soil NO_3-N

Soil NO_3-N was determined by KCl (1 M) extraction and colorimetric methods (Maynard and Kalra, 1993). Two gram (Huallen site, 0 to 15 cm depth at Halcourt), or five gram (Hythe site, 15 to 30 cm depth at Halcourt) sub-samples (air-dried, 2 mm) were measured into Erlenmeyer flasks (50 ml). KCl (20 ml, 1 M) was added and the samples were shaken for one hr (orbital shaker, 180 oscillations/min). The suspensions were filtered through pre-washed (1M KCl) filter paper (Whatman #5, qualitative). The concentration of NO_3-N in each extract was determined colorimetrically, with an autoanalyzer (Maynard and Kalra, 1993). Soil NO_3-N was expressed as mg/kg (oven dry, 105 °C, 48 hr). A sample calculation for soil NO_3-N is provided in Appendix D.

Soil PO_4-P

Soil PO_4-P was determined by Kelowna (KM) extraction and colorimetric methods (van Lierop, 1988). Soil (2 g, air-dried, 2 mm) was measured into Erlenmeyer flasks (50 ml). KM extracting solution (20 ml; 0.015 M acetic acid, 0.3 M ammonium fluoride) was added, and the samples were shaken for 5 minutes (orbital shaker, 180 oscillations/min). The suspensions were filtered through pre-washed (KM solution) filter paper (Whatman #5, qualitative). The concentration of PO_4-P in the extracts was determined colorimetrically, with an autoanalyzer (van Lierop, 1988). Soil PO_4-P was expressed as mg/kg (oven dry, 105 °C, 48 hr).

Soil K

Exchangeable K was determined by the NRC-13 method (Knudsen *et al.* 1982) and flame emission spectrophotometry (Rottiery, 1980). Soil (2 g, air-dried, 2 mm) was measured into Erlenmeyer flasks (50 ml). NRC-13 extracting solution (20 ml, ammonium acetate, 1 M, pH 7.0) was added, and the samples were shaken for 5 minutes (orbital shaker, 210 oscillations/min). The suspensions were filtered through pre-washed (NRC-13 solution) filter paper (Whatman #5, qualitative). The concentration of potassium in the extracts was determined by flame emission spectrophotometry (Knudsen *et al.* 1982; Rottiery, 1980). Soil K was expressed as mg/kg (oven dry, 105 °C, 48 hr).

Soil SO_4-S

Soil SO_4-S was determined by $CaCl_2$ extraction and colorimetric (methylthymol blue) methods (Hamm *et al.* 1973). Analysis was restricted to the first depth (0-15 cm), and only two samples from each node were analyzed. Soil (10 g, air-dried, 2 mm) was measured into Erlenmeyer flasks (250 ml). Extracting solution (50 ml, $CaCl_2$, .001 M) was added, and the samples were shaken for 30 minutes (flat bed shaker). The suspensions were filtered (Whatman #42), and then passed through Dowex 50W-X8 ion-exchange resin to remove interfering cations. The concentration of SO_4-S in the extracts was determined colorimetrically (methylthymol blue), with an autoanalyzer (Hamm *et al.* 1973). Soil SO_4-S was expressed as mg/kg (oven dry, 105 °C, 48 hr).

Statistical Analyses

The SAS General linear model (GLM) procedure was used to analyze sub-field differences in soil macronutrients (SAS Institute Inc., 1985). A one-way classification was used. Sources of variation were node and sampling error (Steel and Torrie, 1980). The Bonferroni procedure ($p = .05$) was used for mean separation (Snedecor and Cochran, 1989). Prior to analysis of variance, all data sets were tested for normal distribution of variance, using SAS Univariate procedure. Outliers were removed from those data sets that failed the test. Adjusted data sets were then analyzed using the GLM procedure for missing values (SAS Institute Inc., 1985).

Nutrient Recommendations

Macronutrient recommendations were prepared by Norwest Labs, using the results from soil nutrient analyses (NO_3-N, PO_4-P, K, SO_4-S) that were provided to the lab. Norwest technicians processed these data through their soil test software, and generated recommendations for the crop that was grown at each site in 1996. Recommendations for canola were also generated for each site. A field composite for the Halcourt site was not analyzed. Average nutrient values for the transect at Halcourt were submitted to the lab instead.

RESULTS

Soil Macronutrients

Halcourt Site

Sub-field variability in NO_3-N, PO_4-P and K was significant (Tables 3.1-3.3). SO_4-S did not vary significantly at this site (Table 3.4, Figure 3.4). Concentrations of NO_3-N and PO_4-P, decreased with depth (Figures 3.1- 3.2). K increased with depth at nodes 2, 3, 4 and 12, but decreased with depth at all other nodes (Figure 3.3). Soil NO_3-N tended to be lower towards the lower end of the transect (Figure 3.1). PO_4-P and K tended to be lower at nodes 2, 9 and 10, and higher through the central portion of the transect (Figure 3.2-3.3).

Table 3.1 ANOVA for KCl extractable NO_3-N at the Halcourt site (sampled May 14-16, 1996).

Dependent Variable: NO_3-N (0-15 cm; mg/kg)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model N1 = node	11	404.12	36.74	12.90	0.0001
Error	46	130.97	2.85		
Corrected Total	57	535.09			

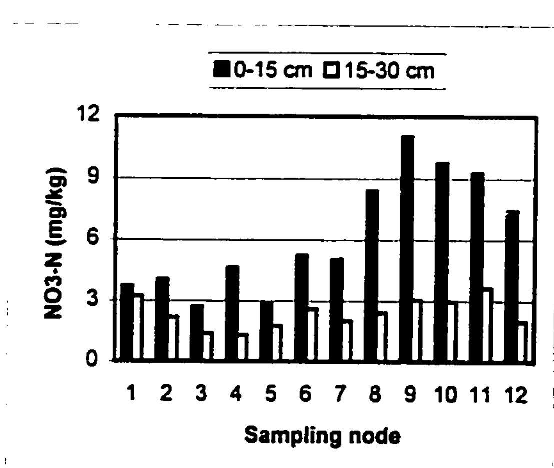
R-Square	C.V.	Root MSE	N1 Mean
0.76	28.09	1.69	6.01

Dependent Variable: NO_3-N (15-30 cm; mg/kg))

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model N2 = node	11	29.96	2.72	8.00	0.0001
Error	48	16.34	0.34		
Corrected Total	59	46.30			

R-Square	C.V.	Root MSE	N2 Mean
0.65	24.64	0.58	2.37

Node	NO3-N (mg/kg) 0-15 cm	
9	11.0	a
10	9.8	a
11	9.3	a
8	8.4	ab
12	7.4	abc
6	5.2	bcd
7	5.0	bcd
4	4.6	bcd
2	4.0	cd
1	3.7	cd
5	2.9	d
3	2.7	d
MSD = 4.0		



(Bonferroni, p = .05)

Node	NO3-N (mg/kg) 15-30 cm	
11	3.6	a
1	3.2	ab
9	3.0	abc
10	3.0	abc
6	2.6	abcd
8	2.4	abcd
2	2.2	bcd
7	2.0	bcd
12	2.0	bcd
5	1.8	cd
3	1.4	d
4	1.3	d
MSD = 1.3		

Figure 3.1 KCl extractable NO_3-N across a transect at the Halcourt site (sampled May 14-16, 1996).

Table 3.2 ANOVA for Kelowna extractable PO_4-P at the Halcourt site (sampled May 14-16, 1996).

Dependent Variable: PO_4-P (0-15 cm; mg/kg))

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model P1 = node	11	587.08	53.37	7.10	0.0001
Error	48	360.65	7.51		
Corrected Total	59	947.74			

R-Square	C.V.	Root MSE	P1 Mean
0.62	14.23	2.74	19.26

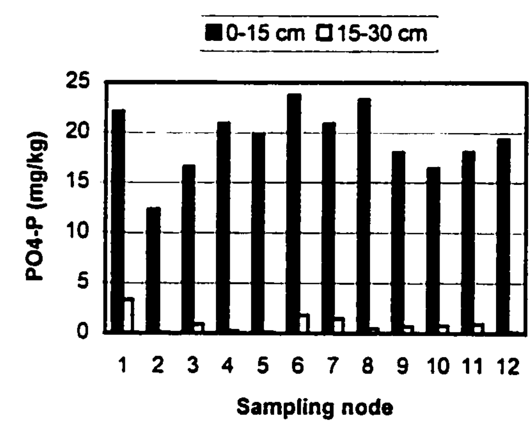
Dependent Variable: PO_4-P (15-30 cm; mg/kg)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model P2 = node	11	35.84	3.26	10.62	0.0001
Error	45	13.80	0.31		
Corrected Total	56	49.65			

R-Square	C.V.	Root MSE	P2 Mean
0.72	67.82	0.55	0.82

Node	PO4-P (mg/kg) 0-15 cm	
6	23.8	a
8	23.3	a
1	22.1	ab
4	20.9	ab
7	20.9	ab
5	19.7	ab
12	19.3	ab
11	18.0	abc
9	18.0	abc
3	16.5	bc
10	16.4	bc
2	12.3	c

MSD = 6.2



(Bonferroni, p = .05)

Node	PO4-P (mg/kg) 15-30 cm	
1	3.3	a
6	1.8	b
7	1.4	bc
11	0.9	bc
3	0.9	bc
10	0.8	bc
9	0.7	bc
8	0.4	c
4	0.2	c
12	0.1	c
5	0.1	c
2	0.1	c

MSD = 1.3

Figure 3.2 Kelowna extractable PO_4-P across a transect at the Halcourt site (sampled May 14-16, 1996).

Table 3.3 ANOVA for NH_4OAc extractable K at the Halcourt site (sampled May 14-16, 1996).

Dependent Variable: K (0-15 cm; mg/kg)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model K1 = node	11	162511.42	14773.77	30.68	0.0001
Error	48	23112.50	481.51		
Corrected Total	59	185623.92			

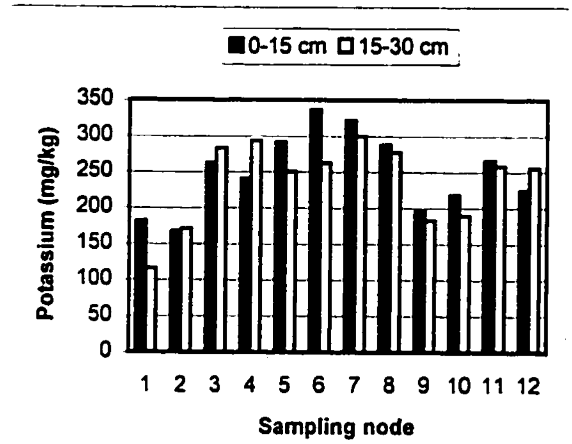
R-Square	C.V.	Root MSE	K1 Mean
0.88	8.80	21.94	249.49

Dependent Variable: K (15-30 cm; mg/kg)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model K2 = node	11	183651.86	16695.62	13.02	0.0001
Error	47	60280.54	1282.56		
Corrected Total	58	243932.40			

R-Square	C.V.	Root MSE	K2 Mean
0.75	15.17	35.81	236.12

Node	K (mg/kg) 0-15 cm	
6	336.4	a
7	322.1	a
5	291.6	ab
8	287.7	abc
11	266.1	bcd
3	262.3	bcd
4	240.6	cde
12	224.5	def
10	218.1	def
9	196.1	efg
1	181.3	fg
2	167.0	g
MSD = 49.9		



(Bonferroni, p = .05)

Node	K (mg/kg) 15-30 cm	
7	299.4	a
4	293.5	a
3	283.3	a
8	277.1	a
6	262.4	ab
11	257.8	ab
12	255.2	ab
5	250.5	abc
10	189.2	bcd
9	182.0	bcd
2	170.9	cd
1	115.8	d
MSD = 82.5		

Figure 3.3 NH_4OAc extractable K across a transect at the Halcourt site (sampled May 14-16, 1996).

Table 3.4 ANOVA for $CaCl_2$ extractable SO_4-S at the Halcourt site

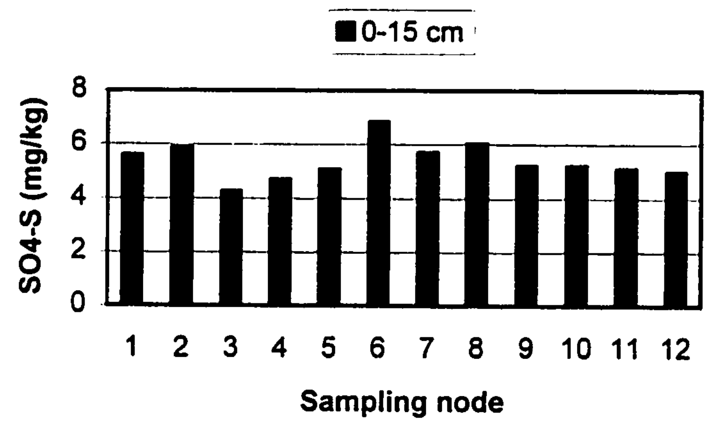
Dependent Variable: SO_4-S (0-15 cm; mg/kg)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model S = node	11	10.08	0.92	1.98	0.1279
Error	12	5.55	0.46		
Corrected Total	23	15.63			

R-Square	C.V.	Root MSE	S Mean
0.64	12.65	0.68	5.38

Node	SO4-S (mg/kg) 0-15 cm
6	6.8 a
8	6.0 a
2	5.9 a
7	5.7 a
1	5.6 a
9	5.2 a
10	5.2 a
11	5.1 a
5	5.1 a
12	5.0 a
4	4.7 a
3	4.3 a

MSD = 3.1



(Bonferroni, p = .05)

Figure 3.4 $CaCl_2$ extractable SO_4-S across a transect at the Halcourt site (sampled May 14-16, 1996).

Hythe Site

Significant sub-field variability in NO_3-N, PO_4-P, K and SO_4-S, was observed (Tables 3.5-3.8). Soil NO_3-N and PO_4-P decreased with depth at all nodes (Figure 3.5-3.6). K increased with depth at nodes 2, 5 and 10, and decreased with depth at the other nodes (Figure 3.7).

Soil NO_3-N (0-15 cm) was highest at nodes 9, 1 and 4 (4 mg/kg); all other nodes had less than 3 mg/kg. NO_3-N (15-30 cm) held in a narrow range, with all values were between 1.0 and 2.5 mg/kg (Figure 3.5). Soil PO_4-P (0-15 cm) was higher along the second half of the transect, and at node 2. In the 15-30 cm depth, PO_4-P was significantly higher at nodes 2 and 8, but uniform across the rest of the nodes (Figure 3.6). K (0-15 cm) was significantly higher at nodes 2 and 8, relative to all other nodes (Figure 3.7).

SO_4-S was lower along the first half of the transect. It increased at nodes 6 and 7, dropped off again at nodes 8 and 9, and then increased significantly at node 10 (Figure 3.8). High SO_4-S values at node 10 suggested a saline soil. EC values (1:1 soil: water) were 1.3 dS/m (0-15 cm) and 3.1 dS/m (15-30 cm) at node 10. All other nodes had lower EC values than node 10.

Table 3.5 ANOVA for KCl extractable NO_3-N at the Hythe site (sampled October 12-15, 1996).

Dependent Variable: NO_3-N (0-15 cm; mg/kg)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model N1 = node	9	45.90	5.10	11.03	0.0001
Error	39	18.03	0.46		
Corrected Total	48	63.92			

R-Square	C.V.	Root MSE	N1 Mean
0.72	25.70	0.68	2.65

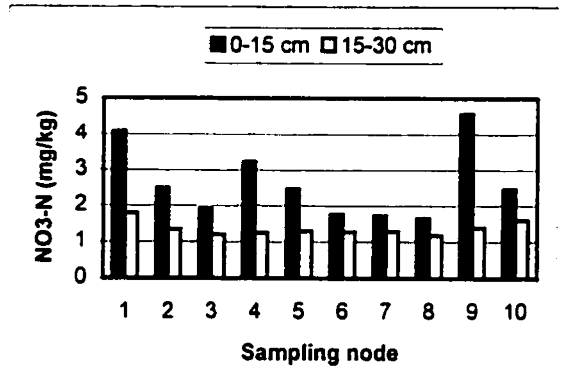
Dependent Variable: NO_3-N (15-30 cm; mg/kg)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model N2 = node	9	1.63	0.18	13.20	0.0001
Error	40	0.55	0.014		
Corrected Total	49	2.18			

R-Square	C.V.	Root MSE	N2 Mean
0.75	8.66	0.12	1.35

Node	NO3-N (mg/kg) 0-15 cm	
9	4.6	a
1	4.1	a
4	3.2	ab
2	2.5	b
10	2.5	b
5	2.5	b
3	1.9	b
6	1.8	b
7	1.7	b
8	1.7	b

MSD = 1.5



(Bonferroni, p = .05)

Node	NO3-N (mg/kg) 15-30 cm	
1	1.8	a
10	1.6	ab
9	1.4	bc
2	1.3	bc
5	1.3	bc
7	1.3	bc
6	1.3	bc
4	1.2	c
3	1.2	c
8	1.2	c

MSD = 0.3

Figure 3.5 KCl extractable NO_3-N across a transect at the Hythe site (sampled October 12-15, 1996).

Table 3.6 ANOVA for Kelowna extractable PO_4-P at the Hythe site (sampled October 12-15, 1996).

Dependent Variable: PO_4-P (0-15 cm; mg/kg)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model P1 = node	9	1571.95	174.66	12.71	0.0001
Error	40	549.54	13.74		
Corrected Total	49	2121.48			

R-Square	C.V.	Root MSE	P1 Mean
0.74	19.22	3.71	19.28

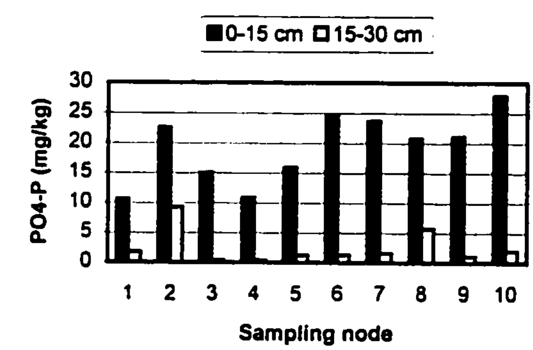
Dependent Variable: PO_4-P (15-30 cm; mg/kg)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model P2 = node	9	359.36	39.93	69.61	0.0001
Error	40	22.94	0.57		
Corrected Total	49	382.31			

R-Square	C.V.	Root MSE	P2 Mean
0.94	30.97	0.76	2.45

Node	PO4-P (mg/kg) 0-15 cm	
10	27.8	a
6	24.6	a
7	23.7	ab
2	22.5	abc
9	21.1	abc
8	20.8	abc
5	15.9	bcd
3	15.0	cd
4	10.8	d
1	10.6	d

MSD = 8.2



(Bonferroni, p = .05)

Node	PO4-P (mg/kg) 15-30 cm	
2	9.2	a
8	5.7	b
10	1.9	c
1	1.8	c
7	1.6	c
6	1.3	c
5	1.2	c
9	1.0	c
3	0.4	c
4	0.4	c

MSD = 1.7

Figure 3.6 Kelowna extractable PO_4-P across a transect at the Hythe site (sampled October 12-15, 1996).

Table 3.7 ANOVA for NH_4OAc extractable K at the Hythe site (sampled October 12-15, 1996).

Dependent Variable: K (0-15 cm: mg/kg)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model K1 = node	9	421091.20	46787.91	141.35	0.0001
Error	40	13240.51	331.01		
Corrected Total	49	434331.71			

R-Square	C.V.	Root MSE	K1 Mean
0.97	7.38	18.19	246.38

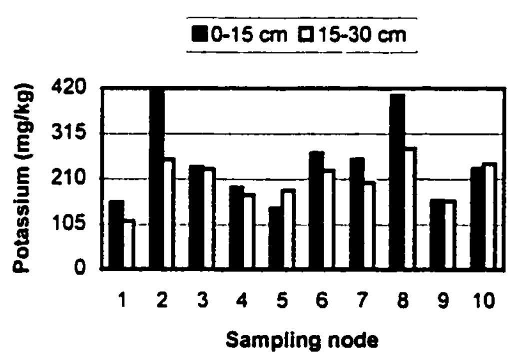
Dependent Variable: K (15-30 cm; mg/kg)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model K2 = node	9	116238.12	12915.35	19.64	0.0001
Error	40	26300.64	657.52		
Corrected Total	49	142538.76			

R-Square	C.V.	Root MSE	K2 Mean
0.82	12.41	25.64	206.66

Node	K (mg/kg) 0-15 cm	
2	416.7	a
8	403.5	a
6	269.5	b
7	255.1	b
3	237.0	b
10	234.0	b
4	190.0	c
9	160.4	cd
1	155.8	cd
5	141.9	d

MSD = 40.4



Node	K (mg/kg) 15-30 cm	
8	279.7	a
2	254.2	ab
10	244.9	ab
3	232.3	abc
6	229.2	abcd
7	200.4	bcde
5	183.3	cde
4	172.3	de
9	158.2	ef
1	112.2	f

MSD = 57.0

(Bonferroni, p = .05)

Figure 3.7 NH_4OAc extractable K across a transect at the Hythe site (sampled October 12-15, 1996).

Table 3.8 ANOVA for $CaCl_2$ extractable SO_4-S at the Hythe site (sampled October 12-15, 1996).

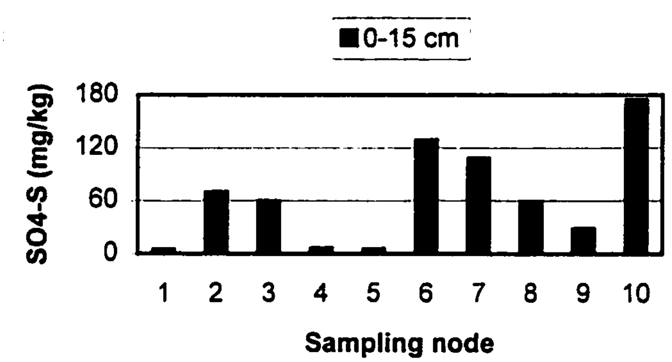
Dependent Variable: SO_4-S (0-15 cm; mg/kg)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model S = node	9	59634.37	6626.04	38.70	0.0001
Error	10	1711.94	171.19		
Corrected Total	19	61346.31			

R-Square	C.V.	Root MSE	S Mean
0.97	20.34	13.08	64.31

Node	SO4-S (mg/kg) 0-15 cm	
10	174.4	a
6	128.4	ab
7	107.6	bc
2	69.4	bcd
3	59.3	cde
8	58.7	cde
9	28.5	de
4	6.0	e
5	5.6	e
1	5.2	e

MSD = 59.1



(Bonferroni, p = .05)

Figure 3.8 $CaCl_2$ extractable SO_4-S across a transect at the Hythe site (sampled October 12-15, 1996).

Huallen Site

Significant sub-field variability in all soil macronutrients, was observed at the Huallen site (Tables 3.9-3.12). Soil NO_3-N and PO_4-P decreased with depth, at all nodes (Figures 3.9-3.10). Soil K increased with depth at nodes 2 and 7; it decreased with depth at all other nodes (Figure 3.11). Soil NO_3-N (0-15 cm) at node 6 was significantly higher than all other nodes (Figure 3.9). Soil PO_4-P (0-15 cm) extremes occurred at adjacent nodes (Figure 3.10). Soil K (0-15 cm) was significantly higher at node 5, relative to all other nodes; and was significantly lower at node 7, relative to all other nodes (Figure 3.11). Soil SO_4-S was significantly higher at node 6, relative to all other nodes (Figure 3.12).

Table 3.9 ANOVA for KCl extractable NO_3-N at the Huallen site (sampled May 27, 1996).

Dependent Variable: NO_3-N (0-15 cm; mg/kg)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model N1 = node	6	754.13	125.69	52.85	0.0001
Error	27	64.21	2.38		
Corrected Total	33	818.34			

R-Square	C.V.	Root MSE	N1 Mean
0.92	20.07	1.54	7.68

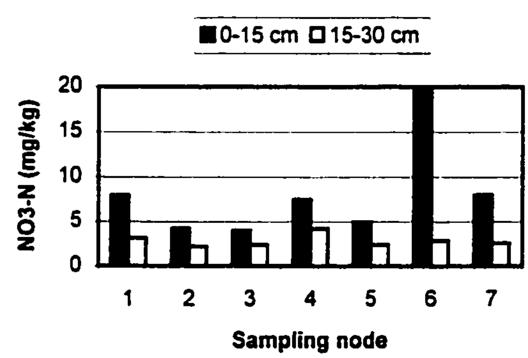
Dependent Variable: NO_3-N (15-30 cm; mg/kg)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model N2 = node	6	13.78	2.30	5.98	0.0004
Error	27	10.36	0.38		
Corrected Total	33	24.14			

R-Square	C.V.	Root MSE	N2 Mean
0.57	22.17	0.62	2.79

Node	NO3-N (mg/kg) 0-15 cm	
6	19.8	a
7	8.0	b
1	7.9	b
4	7.5	bc
5	4.9	bcd
2	4.2	cd
3	4.0	d

MSD = 3.3



(Bonferroni, p = .05)

Node	NO3-N (mg/kg) 15-30 cm	
4	4.1	a
1	3.1	ab
6	2.8	ab
7	2.6	b
3	2.4	b
5	2.4	b
2	2.2	b

MSD = 1.3

Figure 3.9 KCl extractable NO_3-N across a transect at the Huallen site (sampled May 27, 1996).

Table 3.10 ANOVA for Kelowna extractable PO_4-P at the Huallen site (sampled May 27, 1996).

Dependent Variable: PO_4-P (0-15 cm; mg/kg)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model P1 = node	6	791.72	131.95	10.37	0.0001
Error	27	343.72	12.73		
Corrected Total	33	1135.45			

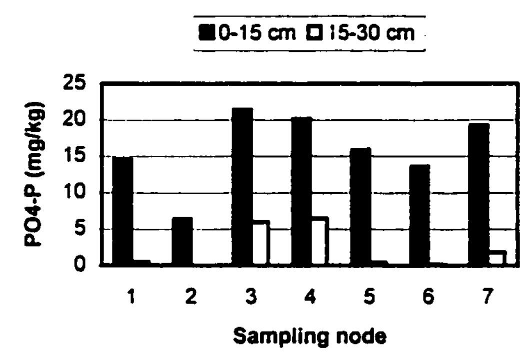
R-Square	C.V.	Root MSE	P1 Mean
0.70	22.46	3.57	15.89

Dependent Variable: PO_4-P (15-30 cm; mg/kg)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model P2 = node	6	234.48	39.08	97.44	0.0001
Error	27	10.83	0.40		
Corrected Total	33	245.30			

R-Square	C.V.	Root MSE	P2 Mean
0.96	28.97	0.63	2.19

Node	PO4-P (mg/kg) 0-15 cm
3	21.5 a
4	20.1 ab
7	19.3 ab
5	15.9 ab
1	14.5 ab
6	13.6 bc
2	6.4 c



Node	PO4-P (mg/kg) 15-30 cm
4	6.4 a
3	5.9 a
7	1.8 b
1	0.5 bc
5	0.4 bc
6	0.1 c
2	0.0 c

MSD = 7.7 (Bonferroni, p = .05) MSD = 1.4

Figure 3.10 Kelowna extractable PO_4-P across a transect at the Huallen site (sampled May 27, 1996).

Table 3.11 ANOVA for NH_4OAc extractable K at the Huallen site (sampled May 27, 1996).

Dependent Variable: K (0-15 cm; mg/kg)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model K1 = node	6	104383.84	17397.31	53.66	0.0001
Error	28	9078.44	324.23		
Corrected Total	34	113462.28			

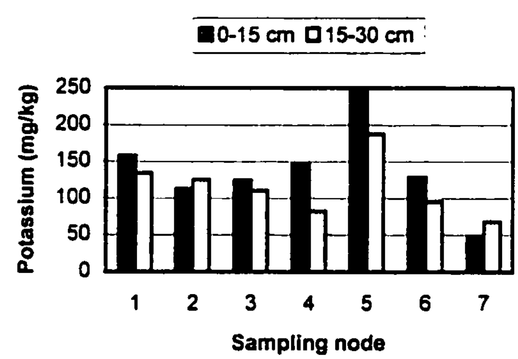
R-Square	C.V.	Root MSE	K1 Mean
0.92	13.11	18.01	137.37

Dependent Variable: K (15-30 cm; mg/kg)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model K2 = node	6	46979.73	7829.95	38.65	0.0001
Error	28	5672.58	202.59		
Corrected Total	34	52652.31			

R-Square	C.V.	Root MSE	K2 Mean
0.89	12.46	14.23	114.23

Node	K (mg/kg) 0-15 cm	
5	244.9	a
1	157.5	b
4	146.1	bc
6	128.2	bc
3	124.0	bc
2	112.6	c
7	48.2	d



Node	K (mg/kg) 15-30 cm	
5	187.0	a
1	133.8	b
2	124.7	bc
3	109.9	bcd
6	94.7	cde
4	82.0	de
7	67.6	e

MSD = 38.0 (Bonferroni, p = .05) MSD = 30.1

Figure 3.11 NH_4OAc extractable K across a transect at the Huallen site (sampled May 27, 1996).

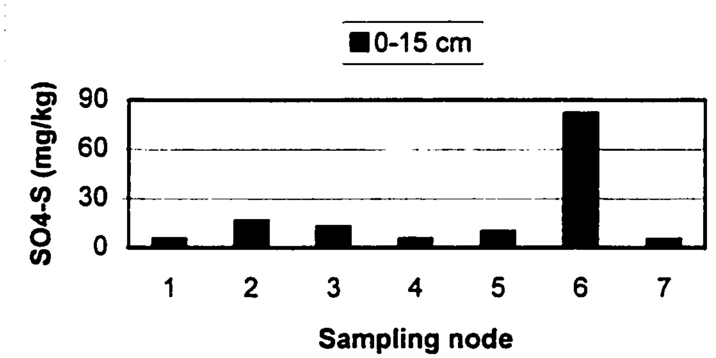
Table 3.12 ANOVA for $CaCl_2$ extractable SO_4-S at the Huallen site (sampled May 27, 1996).

Dependent Variable: SO_4-S (0-15 cm; mg/kg)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model S = node	6	9344.38	1557.40	248.19	0.0001
Error	7	43.92	6.27		
Corrected Total	13	9388.30			

R-Square	C.V.	Root MSE	S Mean
0.99	12.84	2.50	19.51

Node	SO4-S (mg/kg) 0-15 cm	
6	82.0	a
2	16.3	b
3	12.7	b
5	9.9	b
4	5.3	b
1	5.3	b
7	5.0	b



MSD = 11.6 (Bonferroni, p = .05)

Figure 3.12 $CaCl_2$ extractable SO_4-S across a transect at the Huallen site (sampled May 27, 1996).

Nutrient Recommendations

The spatial variability in soil macronutrients was reflected in the differences in soil test recommendations for each node. Sub-field variability in recommendations for N, P_2O_5, K_2O and S, was observed at all sites (Tables 3.13-3.18). Sub-field variability in recommendations for S was minimal at the Halcourt site (Tables 3.13-318).

Table 3.13 Soil macronutrient recommendations (kg/ha) for malting barley across a transect at the Halcourt site (sampled May 14-16, 1996).

Node	1	2	3	4	5	6	7	8	9	10	11	12	RR
N	56	56	58	58	58	56	56	54	47	52	54	54	56
Difference	0	0	-2	-2	-2	0	0	2	9	4	2	2	
P_2O_5	27	40	35	28	30	25	28	25	32	35	32	30	30
Difference	3	-10	-4	2	0	6	2	6	-2	-4	-2	0	
K_2O	21	21	0	21	0	0	0	0	21	21	0	21	0
Difference	-21	-21	0	-21	0	0	0	0	-21	-21	0	-21	
S	11	11	12	11	11	11	11	11	11	11	11	11	11
Difference	0	0	-1	0	0	0	0	0	0	0	0	0	

Applied N (kg/ha)	22	34	45	56	67	78	
Yield response (kg/ha)	3012	3335	3496	3604	3658	3712	*

Expected growing conditions: excellent
RR = recommended rate for transect mean (kg/ha)
* Estimated yield increase from the base yield (yield without N fertilizer) for this crop and region
(-) = under application

Table 3.14 Soil macronutrient recommendations (kg/ha) for canola across a transect at the Halcourt site (sampled May 14-16, 1996).

Node	1	2	3	4	5	6	7	8	9	10	11	12	RR
N	85	85	87	87	87	85	85	81	72	81	81	83	83
Difference	-2	-2	-4	-4	-4	-2	-2	2	11	2	2	0	
P_2O_5	21	36	30	24	26	19	24	20	28	30	28	26	26
Difference	4	-10	-4	2	0	7	2	6	-2	-4	-2	0	
K_2O	17	17	0	0	0	0	0	0	17	0	0	0	0
Difference	-17	-17	0	0	0	0	0	0	-17	0	0	0	
S	18	18	20	20	19	17	18	18	19	19	19	19	19
Difference	1	1	-1	-1	0	2	1	1	0	0	0	0	

Applied N (kg/ha)	45	56	67	78	90	101	
Yield response (kg/ha)	1849	1905	1905	1961	1961	1961	*

Expected growing conditions: excellent
RR = recommended rate for transect mean (kg/ha)
* Estimated yield increase from the base yield (yield without N fertilizer) for this crop and region.
(-) = under application

Table 3.15 Soil macronutrient recommendations (kg/ha) for wheat across a transect at the Hythe site (sampled October 12-15, 1996).

Node	1	2	3	4	5	6	7	8	9	10	RR
N	78	81	81	81	81	83	83	83	78	81	78
Difference	0	-2	-2	-2	-2	-4	-4	-4	0	-2	
P_2O_5	41	25	36	41	34	22	24	27	27	18	31
Difference	-10	7	-4	-10	-2	9	8	4	4	13	
K_2O	20	0	0	20	20	0	0	0	20	0	20
Difference	0	20	20	0	0	20	20	20	0	20	
S	11	0	0	11	11	0	0	0	0	0	0
Difference	-11	0	0	-11	-11	0	0	0	0	0	

Applied N (kg/ha)	67	78	90	101	
Yield response (kg/ha)	3496	3564	3631	3698	*

Expected growing conditions: excellent
RR = recommended rate for field composite (kg/ha)
* Estimated yield increase from the base yield (yield without N fertilizer) for this crop and region.
(-) = under application

Table 3.16 Soil macronutrient recommendations (kg/ha) for canola across a transect at the Hythe site (sampled October 12-15, 1996).

Node	1	2	3	4	5	6	7	8	9	10	RR
N	87	90	90	87	87	90	90	90	87	90	87
Difference	0	-2	-2	0	0	-2	-2	-2	0	-2	
P_2O_5	38	21	32	38	30	18	19	24	24	15	28
Difference	-10	7	-4	-10	-2	10	9	4	4	13	
K_2O	17	0	0	17	17	0	0	0	17	0	17
Difference	0	17	17	0	0	17	17	17	0	17	
S	19	0	0	18	18	0	0	0	0	0	0
Difference	-19	0	0	-18	-18	0	0	0	0	0	

Applied N (kg/ha)	45	56	67	78	90	101	
Yield response (kg/ha)	1849	1905	1905	1961	1961	1961	*

Expected growing conditions: excellent
RR = recommended rate for field composite (kg/ha)
* Estimated yield increase from the base yield (yield without N fertilizer) for this crop and region.
(-) = under application

Table 3.17 Soil macronutrient recommendations (kg/ha) for feed barley across a transect at the Huallen site (sampled May 27, 1996).

Node	1	2	3	4	5	6	7	RR
N	72	78	78	72	76	58	72	76
Difference	4	-2	-2	4	0	18	4	
P_2O_5	34	46	25	26	24	35	27	37
Difference	3	-9	12	11	13	2	10	
K_2O	18	34	25	18	18	20	90	44
Difference	26	10	19	26	26	24	-46	
S	11	0	0	11	0	0	11	11
Difference	0	11	11	0	11	11	0	

Applied N (kg/ha)	45	56	67	78	89	101	
Yield response (kg/ha)	3712	3927	4034	4142	4196	4249	*

Expected growing conditions: excellent
RR = recommended rate for field composite (kg/ha)
* Estimated yield increase from the base yield (yield without N fertilizer) for this crop and region.
(-) = under application

Table 3.18 Soil macronutrient recommendations (kg/ha) for canola across a transect at the Huallen site (sampled May 27, 1996).

Node	1	2	3	4	5	6	7	RR
N	81	85	85	81	85	69	81	83
Difference	2	-2	-2	2	-2	13	2	
P_2O_5	32	44	22	25	22	34	26	36
Difference	3	-8	13	11	13	2	10	
K_2O	17	31	22	17	0	19	87	41
Difference	25	10	19	25	41	22	-46	
S	19	0	11	19	11	0	19	19
Difference	0	19	8	0	8	19	0	

Applied N (kg/ha)	45	56	67	78	90	101	
Yield response (kg/ha)	1849	1905	1905	1961	1961	1961	*

Expected growing conditions: excellent
RR = recommended rate for field composite (kg/ha)
* Estimated yield increase from the base yield (yield without N fertilizer) for this crop and region.
(-) = under application

Uniform recommendations for N and P_2O_5 differed from site specific recommendations for these nutrients at the majority of nodes, at all three sites. Both over and under fertilization contributed to the discrepancies in N, however, over fertilization tended to be associated with barley, while under fertilization tended to be associated with canola and wheat (Table 3.19). At the Halcourt site, over and under fertilization contributed equally to the discrepancies in P_2O_5 recommendations, for both crops (barley, canola). At the Hythe and Huallen sites, discrepancies in P_2O_5 recommendations, at more nodes, were due to over fertilization. This trend was consistent across crops, at both these sites (Table 3.19).

Discrepancies between uniform recommendations and site specific recommendations for K_2O, were field specific. At the Halcourt site, uniform K_2O recommendations matched site specific recommendations at most of the nodes, whereas they did not match site specific recommendations at the majority of nodes at the other sites. Discrepancies in K_2O recommendations were associated with under fertilization at the Halcourt site, but were associated more with over fertilization at the other sites (Table 3.19).

Uniform recommendations matched site specific recommendations for S, at the majority of nodes at all three sites. The discrepancies in recommendations for S were due mostly to the over fertilization of canola at the Halcourt site. However, uniform S recommendations under fertilized some of the nodes at this site, for both canola and barley. Discrepancies in S recommendations were associated with under fertilization of wheat and canola at the Hythe site, but were associated with over fertilization of barley and canola at the Huallen site. Overall, uniform recommendations under fertilized for N>P_2O_5>K_2O>S, over fertilized for P_2O_5>K_2O>N>S and matched requirements at more nodes for S>K_2O>N>P_2O_5 (Table 3.19).

Table 3.19 Inconsistencies between uniform and site specific recommendations for N, P_2O_5, K_2O and S along transects at the Halcourt, Hythe and Huallen sites.

Site	Crop	Nutrient	Nodes	Matched	Over	Under
Halcourt	**Barley**	**N**	**12**	**4**	**5**	**3**
Halcourt	Canola	N	12	1	4	7
Hythe	**Wheat**	**N**	**10**	**2**	**0**	**8**
Hythe	Canola	N	10	4	0	6
Huallen	**Barley**	**N**	**7**	**1**	**4**	**2**
Huallen	Canola	N	7	0	3	4
Total			**58**	**12**	**16**	**30**
Halcourt	**Barley**	**P_2O_5**	**12**	**2**	**5**	**5**
Halcourt	Canola	P_2O_5	12	2	5	5
Hythe	**Wheat**	**P_2O_5**	**10**	**0**	**6**	**4**
Hythe	Canola	P_2O_5	10	0	6	4
Huallen	**Barley**	**P_2O_5**	**7**	**0**	**6**	**1**
Huallen	Canola	P_2O_5	7	0	6	1
Total			**58**	**4**	**34**	**20**
Halcourt	**Barley**	**K_2O**	**12**	**6**	**0**	**6**
Halcourt	Canola	K_2O	12	9	0	3
Hythe	**Wheat**	**K_2O**	**10**	**4**	**6**	**0**
Hythe	Canola	K_2O	10	4	6	0
Huallen	**Barley**	**K_2O**	**7**	**0**	**6**	**1**
Huallen	Canola	K_2O	7	0	6	1
Total			**58**	**23**	**24**	**11**
Halcourt	**Barley**	**S**	**12**	**11**	**0**	**1**
Halcourt	Canola	S	12	5	5	2
Hythe	**Wheat**	**S**	**10**	**7**	**0**	**3**
Hythe	Canola	S	10	7	0	3
Huallen	**Barley**	**S**	**7**	**3**	**4**	**0**
Huallen	Canola	S	7	3	4	0
Total			**58**	**36**	**13**	**9**

Site specific methods required more fertilizer (total) than uniform methods at the Halcourt site, but required less fertilizer (total) at the Hythe and Huallen sites (Table 3.20). Requirements for K_2O had the largest coefficient of variation overall, followed by those for S>P_2O_5>N. K_2O also had the largest application range, followed by P_2O_5>N=S (Table 3.21).

Table 3.20 Fertilizer requirements (kg/ha) for the transect area at the Halcourt, Hythe and Huallen sites (uniform versus site specific application).

Site	Crop	Method	N	P_2O_5	K_2O	S	Total
Halcourt	Barley	Uniform	56.0	30.0	0.0	11.0	97.0
		Site specific	**54.9**	**30.6**	**10.5**	**11.1**	**107.1**
	Canola	Uniform	83.0	26.0	0.0	19.0	128.0
		Site specific	**83.3**	**26.0**	**4.3**	**18.7**	**132.2**
Hythe	Wheat	Uniform	78.0	31.0	20.0	0.0	129.0
		Site specific	**81.0**	**29.5**	**8.0**	**3.3**	**121.8**
	Canola	Uniform	87.0	28.0	17.0	0.0	132.0
		Site specific	**88.8**	**25.9**	**6.8**	**5.5**	**127.0**
Huallen	Barley	Uniform	76.0	37.0	44.0	11.0	168.0
		Site specific	**72.3**	**31.0**	**31.9**	**4.7**	**139.9**
	Canola	Uniform	83.0	36.0	41.0	19.0	179.0
		Site specific	**81.0**	**29.3**	**27.6**	**11.3**	**149.1**
Average		Uniform	77.2	31.3	20.3	10.0	138.8
		Site specific	**71.3**	**28.7**	**14.9**	**9.1**	**129.5**

Table 3.21 Variability in Soil macronutrient recommendations for barley, wheat and canola, along transects at the Halcourt, Hythe and Huallen sites in 1996.

		Coefficients of Variation (%)			
Site	Crop	N	P_2O_5	K_2O	S
Halcourt	barley	5.72	11.41	73.85	2.51
Halcourt	canola	4.86	13.22	52.22	4.77
Hythe	wheat	3.35	20.16	81.65	57.74
Hythe	canola	1.83	22.38	81.65	55.73
Huallen	barley	10.20	22.24	32.65	81.65
Huallen	canola	6.67	23.40	36.32	62.64
Average		**5.44**	**18.80**	**59.73**	**44.17**

		Application Range Across the Transect (kg/ha)			
Site	Crop	N	P_2O_5	K_2O	S
Halcourt	barley	11	16	21	1
Halcourt	canola	15	17	17	3
Hythe	wheat	4	23	20	11
Hythe	canola	2	23	17	19
Huallen	barley	20	22	72	11
Huallen	canola	15	21	87	19
Average		**11.17**	**20.33**	**39.00**	**10.67**

DISCUSSION

Farmers who grow annual crops in the South Peace River region may be able to conserve inputs and improve crop nutrition, by matching fertilizer applications more closely to nutrient requirements in the field. Such opportunities would be reflected in the differences between nutrient recommendations (amount, distribution) for site specific application (SSA) and those for uniform application (UA).

Site specific recommendations for N, P_2O_5 and S, differed from uniform recommendations for these nutrients, at the majority of nodes at the Halcourt site. However, the total amount of N, P_2O_5 and S required to fertilize the transect was about the same for both methods. Therefore, SSA did not significantly change the amount of N, P_2O_5 and S fertilizer required at this site, but simply redistributed it among the nodes. According to the uniform method, K was not required at any of the nodes at this site. Site specific methods, however, added K_2O to the fertility regime, thereby increasing the total amount of fertilizer required at this site by 10 kg/ha for barley or 4 kg/ha for canola.

Site specific recommendations for P_2O_5 and K_2O differed from the uniform recommendations for these nutrients, at the majority of nodes at the Hythe site. SSA also recommended more N (3.0 kg/ha, 1.8 kg/ha), but less P_2O_5 (1.5 kg/ha, 2.1 kg/ha) and K_2O (12.0 kg/ha, 10.2 kg/ha) than the uniform method in total. The site specific method then, increased the amount of N applied at this site by about 2.5 kg/ha, but redistributed the conventional amount of P_2O_5 and K_2O fertilizer for savings of about 2 (P_2O_5) and 12 (K_2O) kg/ha.

According to the uniform method, S was not required at any of the nodes at the Hythe site. The site specific method, however, indicated that S fertilizer was required at 3 nodes (for both crops) along the transect. SSA, therefore, increased the amount of S fertilizer required at this site, by adding this nutrient to the fertility regime. However, the additional amount of S and N fertilizer required by this method was offset by the reduction in other nutrients, and the net result was less fertilizer (7 kg/ha, wheat; 5 kg/ha, canola) required in total at this site.

Site specific requirements (all nutrients) were different from uniform requirements, at the majority of nodes at the Huallen site. Site specific application, therefore, redistributed all nutrients among the nodes at this site for total savings of 28 kg/ha for barley or 30 kg/ha for canola.

To benefit by converting to site specific fertilizer application, increased revenue from better crop nutrition and savings from reduced input costs, would have to be large enough to offset the additional costs for soil sampling and variable rate equipment (Mulla, 1998). Farmers are more likely to realize such benefits in fields where the implementation of SSA adjusts several nutrients, by substantial amounts, in many areas of the field; and reduces the total amount of fertilizer required overall.

SSA adjusted the amount of fertilizer required for more nutrients, at more nodes, at the Huallen site (87 %, 4 nutrients), followed by the Hythe (65 %, 3 nutrients) and Halcourt sites (58 %, 2 nutrients). This method also adjusted nutrients by the largest amount at the Huallen site (33.4 kg/ha), followed by the Hythe (14.6 kg/ha) and Halcourt (12.6 kg/ha) sites. SSA also reduced the total amount of fertilizer required, to a greater extent at the Huallen site (-28 kg/ha, -30 kg/ha), followed by the Hythe (-7 kg/ha, -5 kg/ha) and Halcourt sites (+10 or +4 kg/ha). Therefore, the Huallen site would likely benefit the most from site specific fertilizer application, followed by the Hythe and Halcourt sites.

Nutrient requirements at these sites were not consistently associated with slope position, therefore the relative performance of SSA from site to site, was not related to anything obvious in these fields. However, application patterns suggested that discrepancies in fertilizer rates, between the two methods, were related to the presence of extremely high testing areas and extremely low testing areas in these fields, and the relative contribution these areas made to the field average.

For example, most of the discrepancies between UA and SSA rates at the Hythe and Halcourt sites, were related to the way areas in the field that did not require any additions of S and K, were factored into the field average. At the Hythe site, areas that did not require S, made an extensive contribution to the field average and eliminated recommendations for S at this site. However, areas that tested high for K at this site, did not make a substantial enough contribution to the field average to eliminate the recommendation for K_2O. As a result, UA grossly under fertilized several nodes for S (11-18 kg/ha) and grossly over fertilized several nodes for K (17-20 kg/ha) at this site.

At the Halcourt site, areas of the field that did not require K, made an extensive contribution to the field average, resulting in no recommendations for K_2O at this site. Consequently, UA grossly under fertilized several nodes for K (17-21 kg/ha) at this site as well. Site specific methods, however, recognized and corrected for the large sub-field differences in S and K_2O requirements at the Hythe and Halcourt sites, thereby resulting in large adjustments to the application of these nutrients. These results were consistent with those of Fixen (1994) and Penney *et al.* (1996), who reported large differences between UA and SSA rates, in fields that contained areas where UA rates approach zero.

Discrepancies between UA and SSA rates for S at the Huallen site, were also related to the fact that this site had areas in the field where recommended rates approached zero. However, this site also had larger extremes in N, P_2O_5 and K_2O recommendations, than the other sites did, and the more extensive redistribution and conservation of nutrients by SSA at this site was related to the way the large extremes for these nutrients were factored into the field average.

For example, N requirements were much lower at node 6, than they were at other nodes along the transect at the Huallen site. However, the area of the field represented by node 6 did not make a substantial contribution to the field composite, either because it was a low spot in the field and was avoided during conventional sampling, or because its contribution to the field average was diluted by higher N requirements in other parts of the field. Consequently, UA substantially over applied N at this node, whereas SSA recognized that much less N was required and reduced rates accordingly. Because this adjustment occurred only in one area of the field, the overall conservation of N was small (2-3 kg/ha), but since it was a large adjustment, it resulted in a much larger application range for N at the Huallen site.

Site specific methods also redistributed nutrients to a larger extent at the Huallen site, by adjusting for situations where extremely low testing areas over contributed to the field average. For example, requirements for P_2O_5 at node 2, and K_2O at node 7, were much higher than they were at the other nodes. The areas of the field represented by node 2 and 7, however, made a substantial contribution to the field composite, either because they were highly "representative" and contributed several samples, or because their large requirements for P_2O_5 or K_2O diluted contributions from other parts of the field, or both. Consequently, average rates for these nutrients were high, and UA over fertilized most of the nodes at this site for P_2O_5 and K_2O, but still under fertilized node 2 for P_2O_5 and node 7 for K_2O. SSA, however, adjusted for these large sub-field differences and conserved 6-7 kg/ha of P_2O_5 and 12-13 kg/ha of K_2O in the process.

Site specific fertilizer practices can be adopted on a nutrient by nutrient basis, therefore, it would be useful to know if one nutrient was more likely than another to be sensitive to field variability. Nutrient variability (CVs for 0-15 cm depth) in the field followed the trend NO_3-N (24.9 %) > PO_4-P (18.6 %) > SO_4-S (15.3 %) > K (9.8 %). SSA, however, adjusted UA rates at more nodes for P_2O_5 (93.1 %) > N (79.3 %) > K_2O (60.3 %) > S (37.9 %), and adjusted nutrients by larger amounts for K_2O (221.8 %) > S (111.7 %) > P_2O_5 (67.8 %) > N (15.0 %). Overall adjustments in nutrient requirements (CVs) were greater for K_2O (59.7 %) > S (44.2 %) > P_2O_5(18.8 %) > N (5.4 %).

According to these data, NO_3-N and PO_4-P were more variable than SO_4-S and K in the field, and SSA adjusted UA rates for N and P_2O_5 more frequently than it did for S and K_2O. However, the magnitude of the adjustments to S and K_2O was much larger than it was for N and P_2O_5, resulting in more extensive adjustments to K_2O and S overall. Therefore, requirements for K_2O were the most sensitive to field variability, followed by those for S, P_2O_5 and N.

SUMMARY & CONCLUSIONS

At the Huallen site, SSA redistributed all nutrients, and resulted in net savings of 28-30 kg/ha. At the Hythe site, SSA redistributed the uniform amounts of P_2O_5 and K_2O, increased the requirements for N and added S to the nutrient regime, but still resulted in net savings of 5-7 kg/ha. At the Halcourt site, SSA redistributed the uniform requirements for N, P_2O_5 and S, but also added K_2O to the nutrient regime at this site, and thus resulted in additional total fertilizer requirements of 4-10 kg/ha.

According to these findings, farmers who grow annual crops in the South Peace River region, could reduce the amount of fertilizer wasted and increase nutrition where needed, in some of their fields, by simply distributing the total amount of fertilizer required for uniform application, differently among nutrients and across the field. In other fields, however, additional fertilizer would be required to achieve optimum crop nutrition. These findings also suggest that the implementation of SSA could increase fertilizer inputs by 4-10 kg/ha or reduce inputs by 5-30 kg/ha, depending on the field and what crop is grown.

SSA conserved the most fertilizer, and adjusted uniform rates for more nutrients, by greater amounts, in more areas of the field at the Huallen site, followed by the Hythe and Halcourt sites. Therefore, the Huallen site was the most likely site to benefit from SSA. The extent of redistribution and conservation of fertilizer by SSA, was not consistently associated with anything obvious (like slope position) in the field, but was related to the presence of high testing and low testing areas in the field and their relative contribution in the field average.

NO_3-N and PO_4-P were more variable than SO_4-S and K in the field, and SSA adjusted UA rates for N and P_2O_5 more frequently than it did for S and K_2O. However, the magnitude of the adjustments to S and K_2O was much larger than it was for N and P_2O_5, resulting in more extensive adjustments to K_2O and S overall. Therefore, requirements for K_2O were the most sensitive to field variability, followed by those for S, P_2O_5 and N.

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CHAPTER IV

SPATIAL VARIABILITY OF CROP CHARACTERISTICS AND SOIL PROPERTIES IN FIELDS OF THE SOUTH PEACE RIVER REGION, ALBERTA

INTRODUCTION

Site specific herbicide and fertilizer application address sub-field variability in required inputs, but farmers who grow annual crops may be able to benefit from addressing sub-field variability in outputs as well. Outputs are major determinants of returns to the farmer, and in annual cropping systems they are measured in terms of grain yield and quality. Grain yield is simply the amount of grain produced, whereas grain quality refers to the desirability of the grain, and includes various physical and chemical factors depending on the intended use of the crop (Stoskopf, 1985).

Most of the factors of grain quality are embodied in the standard grades for cereal grains established by the Canadian Grain Commission. Therefore, returns for good quality are largely determined by crop grade (Jones, 1998). However, for those farmers who grow wheat or malting barley, optimum grain protein content (GPC) is an additional aspect of quality that factors into the profit margin. If farmers can produce a good grade of malting barley or wheat, that is also in the optimum range for protein, they will receive a better price for their crop (Jones, 1998). If they can produce large quantities of this high quality grain, they will optimize returns overall.

In dryland cropping, grain yield and quality are the results of interactive responses of crop plants to weather and soil conditions, modified by the occurrence of weeds, pests and disease (Spiertz, 1983). When the crop is adequately protected, climate (solar radiation, precipitation, air temperature) and soil fertility factors (nutrient and water availability) prevail. Producing large yields of high quality grain under dryland conditions, however, can be difficult. Crop yield and quality are controlled by the same factors, but outcomes for these characteristics can be unique, depending on how the controlling factors interact over the growing season.

For example, in the first part of the growing season when dry matter accumulation is underway, the potential for high yields and good grades (photosynthetic capacity), and the potential for high GPC (N accumulation), both increase with increasing nutrient and water supply (McMullan *et al.* 1988). From anthesis to maturity, however, yield and quality responses partially diverge. During grain filling, yields and grades will continue to increase, but GPC tends to decrease, with increasing nutrient and water supply. Conversely, yields and grades decline, but GPC increases, if nutrients and water become limiting during this period (McMullan *et al.* 1988).

Managing for grain yield and quality in dryland systems is also difficult because many of the determinants are out of the farmer's control. Farmers can protect their crops and manage soil fertility to some degree, but there is little they can do about the weather. The best opportunities for management come in the first half of the growing season when farmers can prepare the seedbed, fertilize and protect the crop. Consequently, management tends to be geared more towards optimizing dry matter production, and after anthesis the fate of the crop is basically left to be determined by the field environment.

Grain yield and quality are likely to change from location to location within the field, because these outputs are largely controlled by environmental factors. Crop yield and quality vary considerably within fields in western Canada (Elliot and De Jong, 1992). Nolan *et al.* (1995) reported sub-field differences of 260 kg/ha in yields of spring wheat, in southern Alberta. Penney (1998) reported yield differences of 1284 kg/ha (spring wheat) and 2670 kg/ha (barley) within fields in central Alberta.

Mckercher (1964) evaluated the spatial variability of GPC in wheat fields in Saskatchewan. He reported that changes in GPC across slope positions, within individual fields, were often greater than differences in mean GPC for widely separated fields. Penney (1998) assessed GPC at benchmark locations within grain fields in south central Alberta. He reported GPC ranges as large as three percentage points, in wheat and barley fields in that area. Large sub-field differences in other quality characteristics (test weight, thousand kernel weight) were observed in these fields as well (Penney, 1998).

Dryland cereal growers may not be able to manage all the determinants of crop yield and quality, but perhaps they can benefit to a greater extent than they currently do by addressing sub-field variability in outputs. For example, sub-field variability in crop yield has been linked to sub-field variability in soil fertility. Factors like salinity (McKenzie *et al.* 1983), nutrient concentrations (Fiez *et al.* 1994; Mulla *et al.* 1992), water holding capacity (Finke and Goense, 1993), soil organic matter (Jones *et al.* 1989) and depth of topsoil (Verity and Anderson, 1990) have been reported as yield limiting factors at the sub-field level.

Many of these factors can either be corrected or managed for, on a site specific basis (Kachanoski *et al.* 1985; Nolan *et al.* 1995; Penney *et al.* 1996). If farmers could locate areas of lower productivity within their fields, and identify the factors that are limiting productivity at these sites, they may be able to enhance future production by correcting or at least factoring limitations into management decisions. Farmers may also be able to capitalize on spatial variability in grain quality. If sub-field differences in quality are substantial, farmers could increase the market value of their crops by separating grain on the basis of protein or grade, at harvest (Penney, 1998).

Recent advances in site specific harvesting technology will soon provide farmers with the ability to address sub-field differences in outputs. Combine-mounted yield monitors and the positioning systems required to provide accurate combine location in the field, are already available and used on a commercial basis (Mulla, 1998). Proto-types of combine-mounted protein sensors are now being tested (Penney, 1998). When these sensors are field ready, growers will be able to monitor grain protein as they harvest, and deposit grain with different GPC into compartmentalized hoppers on their combines (Penney, 1998).

Technologies for separating on the basis of grade are not as close to being ready. However, remote sensing techniques (aerial infra red photography, satellite and microwave imagery) have related well to crop patterns, and show promise as methods to map sub-field differences in grain quality prior to harvest (Heard, 1998). If remotely sensed quality information can be geo-referenced with the positioning system on the combine, fields could be harvested site specifically, on the basis of expected crop grade.

The successful implementation of site specific harvesting technologies in fields of the South Peace River region, however, is contingent upon the spatial variability of crop yield and quality within the boundaries of these fields. Opportunities to manage for better yield and quality at the sub-field level, exist in other areas where these crops are grown (Mckercher, 1964; Nolan *et al.* 1995; Penney *et al.* 1996; Penney, 1998). If sub-field variability in outputs exists in fields of the South Peace River region, farmers in this area may also be able to realize these benefits. However, no published data on the sub-field variability of grain yield and quality are available for this region.

The purpose of this study was to (1) measure sub-field variability in crop quality in three fields in the South Peace River region and evaluate the implications of this variability for site specific harvesting, and (2) determine differences in selected soil properties and crop characteristics between high yielding and low yielding areas, within three fields in the South Peace River region, and evaluate the implications of these differences for the site specific management of annual crops.

MATERIALS & METHODS

Site Characteristics

Site characteristics are described in detail in Chapter II, Appendix A and Appendix B.

Crop Characteristics

Weeds

Weed populations were surveyed at all sites prior to spraying. Survey dates were June 10-11th (Hythe), June 12-13th (Halcourt) and June 27th-28th (Huallen). The number of weed plants within four quadrants (0.25 m^2) per sampling unit were recorded (refer to Chapter II).

Crop Density

Crop density and weed data were collected concurrently. The number of crop plants and the average leaf-stage of the crop within each quadrant were recorded.

Crop Development

Crop development was quantitatively assessed using the Haun method (Haun, 1973). Five plants per sampling unit were randomly selected and tagged (late June). When crops reached the stage of boot enlargement (late July), the development of each pre-selected plant was rated according to the Haun scale. Assessment dates were July 22nd (Halcourt, Hythe) and August 2nd (Huallen).

Grain Yield

Crop samples were collected on September 11-12th (Halcourt), September 23rd (Huallen) and September 24th (Hythe). Just prior to swathing, 1 m^2 of above-ground plant mass (straw and grain) was harvested from each sampling unit. Samples were bagged (cloth sacks), and hung on outside drying racks for several weeks. Samples were dried (forced-air drier, 22 ^{0}C, 48 hr), and then threshed with a Wintersteiger Nurserymaster combine. Grain samples were passed through a clipper to remove dockage, and then weighed. Grain moisture content was determined from oven-dried sub-samples (70 ^{0}C, 72 hr). Grain yields (kg/ha), based on 14.8 % moisture (barley) or 14.5 % moisture (wheat), were calculated from sample masses and moisture contents.

Total Dry Matter

Total dry matter was determined by weighing the air-dried crop samples just before they were threshed. Total dry matter was not determined for the Halcourt site because the crop samples were contaminated with wild oats straw.

Thousand Kernel Weight (TKW)

TKW was determined by hand-counting. Two sub-samples (100 seeds per sub-sample) from each grain sample, were counted out and weighed. TKW, based on 14.8 % moisture (barley) or 14.5 % moisture (wheat), was calculated from the average mass of the sub-samples and the moisture content of the grain samples.

Test Weight

Test weight was determined using the Seedburo 151 standard test weight apparatus (TWA). Grain samples were placed into the TWA hopper and the spout was opened. The grain was allowed to fall (standard 5 cm drop) into the container (500 ml) below, until it was overflowing. The spout was closed and the excess volume of grain was removed by passing a metal rod across the mouth of the container. Test weight (kg/hl), based on 14.8 % moisture (barley) or 14.5 % moisture (wheat), was calculated from the container volume, the mass of the grain in the container, and the moisture content of the grain.

Commercial Grades (grain)

Grain samples were graded, according to Canadian Grain Commission standards, by commercial graders at the local grain elevator. Details regarding the grades and classes used for evaluation, are tabulated in Appendix E.

Percent Protein (grain)

Protein (%) in the grain was determined from total N analysis, performed using the Dumas combustion method (LECO Corp., 1996). Grain samples were ground to 20 mesh; formed into pellets; and then oxidized in the LECO FP-428 furnace. Nitrogen (%), based on the thermal conductivity of the separated combustion product in the analysis (N_2), was determined by the LECO system. Grain protein (%), based on 14.8 % moisture (barley) or 14.5 % moisture (wheat), was calculated from nitrogen percentages (% N x 6.25) and grain moisture contents.

Soil Properties

Soil Sampling

Three different sets of soil samples were taken at each site, during the 1996 field season. The first set of samples were collected for chemical and physical soil analyses. Collection dates were May 14^{th} -16^{th} at Halcourt; May 27^{th} at Huallen; and October 12^{th}-15^{th} at Hythe. Soil samples were composites of 3 cores (2.54 cm dia.) from each sampling unit, that were divided into 0 to 15 cm and 15 to 30 cm depth increments. All samples were air-dried and ground to 2 mm standard size.

A second set of samples, for soil bulk density, was collected at Halcourt on October 5^{th}-6^{th}; at Huallen on October 8^{th}; and at Hythe on October 12^{th}-15^{th}. The sampling method was the same as that used to collect the first set.

A third set of samples, for water stable aggregate analysis, was collected at Hythe on July 27^{th}; at Huallen on July 31^{st}; and at Halcourt on August 1^{st}. A single soil core (7.62 cm dia., 0-7.5 cm depth) was taken from each sampling unit. Samples were stored at 4 ^{0}C until they could be processed.

Soil Bulk Density

Soil samples were weighed directly from the field, oven-dried at 105 ^{0}C for 48 hr and weighed again. Soil bulk density was calculated from the volume of the soil probe and the mass of the oven-dried samples (Blake and Hartge, 1986). Gravimetric water content was calculated from wet and dry sample masses, and expressed on a dry soil basis.

Soil Moisture

Time domain reflectometry (TDR) was used to measure soil moisture in the field (Soil Moisture equipment Corp., 1989). Buriable wave guides connected to the TDR system, were inserted vertically into the top 20 cm of soil within each sampling unit, and two readings were recorded. TDR measurements were taken twice during the 1996 field season; once in July and once in September. Sampling dates were: July 23rd (Hythe), July 24th (Halcourt, Huallen), September 19th (Halcourt), September 20th (Huallen) and September 25th (Hythe).

Penetration Resistance

Penetration resistance (PR) was measured on October 16th (Halcourt) and October 17th (Hythe, Huallen). An Eijkelkamp penetrometer, with a base surface cone of 1 cm^2 was used. One measurement, to a depth of greater than 30 cm, was taken for each sampling unit. PR values (MPa) at 2.5 cm, 7.5 cm, 12.5 cm, 17.5 cm, and 25cm depths were recorded from the penetrometer charts.

Soil moisture data were collected concurrently with PR. Two soil cores (2.54 cm dia.), one from the first and one from the third sampling unit at each node, were divided into 0 to 5 cm, 5 to 10 cm, 10 to 15 cm, 15 to 20 cm, and 20 to 30 cm depth increments, and composited. Gravimetric soil moisture content was determined by mass loss during drying (105 °C, 48 hr), and reported on a dry soil basis.

Water Stable Aggregates

Water stable aggregation was determined by the wet sieving method (Kemper and Rosenau, 1986). Soil cores were gently broken by hand into aggregates that would pass through an 8 mm sieve. A sub-sample (30 g) from each broken core was weighed, oven-dried (105 °C, 48 hr) and then weighed again, to determine the oven-dry mass of the sample being analyzed.

Water stable aggregation was determined from a moist sub-sample (30 g) sprinkled evenly on a nest of submerged sieves (175 mm dia.) with 4.0 mm (top sieve), 2.0 mm, 1.0 mm, 0.5 mm, 0.25 mm and 0.125 mm (bottom sieve) openings. The surface of the water was made flush with the screen of the top sieve, before the soil was placed on it. The sample was allowed to sit undisturbed, for 10 minutes. Then it was immersed and the sieves raised and lowered (35-mm stroke length) 160 times during the next 10 minutes. When wet sieving was complete, the sieve nest was dismantled and the individual sieves, containing their respective aggregates, were oven-dried at 105 °C for 1 hr and then weighed.

The fraction of soil on each sieve was determined from it's respective sieve mass, oven-dry sieve + aggregate mass and the initial oven-dry sample mass. The fraction of soil < 0.125 mm was calculated as the difference between the initial sample mass and the summed masses of the other fractions. Mean weight diameter was determined by summing the products of each fraction and the mean diameter of its class. A sample calculation is provided in Appendix D.

Particle Size Analysis (PSA)

Prior to PSA, all samples with a pH of 7.0 or greater, were tested for reaction with 0.1 M HCl. Samples from nodes 5 and 6 (15 to 30 cm depth), at the Huallen site showed strong effervescence. They were treated with 1 M HCl to remove carbonates (Sheldrick, 1984). Sub-samples (40 g) were weighed into 250 ml centrifuge bottles. Nanopure H_2O (100 ml) was added, and the samples were shaken. HCl (1 M) was added dropwise until the pH fell to between 3.4 and 4.0, and remained there for 10 minutes. The samples were centrifuged (10 min, 3,440 rcf) and the clear liquid poured off. Each sample was washed twice by shaking with nanopure water (50 ml), centrifuging and discarding the clear liquid. Samples were allowed to air-dry before PSA was carried out.

Soil texture was determined by the hydrometer method (McKeague, 1978). Ten grams (Halcourt, Hythe) or forty grams (Huallen) of soil (air-dried, 2 mm) was measured into fleakers (500 ml). Reverse osmosis (RO) water (250 ml) and dispersing solution (100 ml, Sodium metaphosphate and Sodium carbonate) was added to the fleakers, and they were left to sit for 12 hrs. Treated samples were then transferred to an electric mixer dispersing cup, and mixed (5 min, low speed). Dispersed suspensions were transferred to glass cylinders (1 L) and made to volume with RO water. A reagent blank and temperature blank were prepared in the same way.

Cylinders were stoppered and repeatedly inverted (30 inversions) for 1 minute, and then left to settle in a constant temperature room. The concentration of the suspension in each cylinder (including the blank) was determined at 270 and 1080 minutes, by inserting a hydrometer and reading the upper edge of the meniscus. Suspension temperatures (°C) were recorded concurrently with hydrometer readings. The suspensions were then washed through a sieve (53 microns), and the sand retained was oven-dried (105 °C, 48 hr) and weighed.

The mineral mass (oven-dry) of each sample was determined by subtracting organic C mass from oven-dried (105 °C, 48 hr) mass. The percent clay in the mineral fraction was interpolated from summation percentages and particle sizes, that were calculated from hydrometer and temperature readings. Percent sand was calculated from the mineral mass of the sample and the mass of the sand retained on the sieve (53 microns). Percent silt was calculated as the difference between the mineral mass of the sample and the summed masses of sand and clay. Soil texture was determined from the texture triangle (Hausenbuiller, 1985). A sample calculation is provided in Appendix D. Note that this method may underestimate percent silt relative to percent clay if organic matter remains in suspension. This method may overestimate percent silt relative to percent clay if aggregates are not completely dispersed.

Soil pH

Soil pH was measured in water (1:1, soil:water ratio) and in 0.01 M $CaCl_2$ (1:2, soil:solution ratio). Samples from node 6 (0 to 15 cm depth) at the Huallen site had a high organic matter content so a 1:4 ratio was used. Soil (20 g, air-dried, 2 mm) was measured into disposable paper cups. Nanopure water (20 ml) was added, and the suspensions were stirred several times during the next 30 minutes. The suspensions were then allowed to settle for 30 minutes. Suspension pH was measured with a Fisher Accumet 815Mp pH meter. $CaCl_2$ (20 ml, 0.02 M) was added to the suspensions, and the procedure was repeated (Fisher Scientific, 1986; Sheldrick, 1984).

Electrical Conductivity (EC)

Electrical conductivity was measured using a 1:1 soil:water ratio (Sheldrick, 1984). Soil (15 g, air-dried, 2mm) and nanopure water (15 ml) were measured into centrifuge tubes (50 ml) and stoppered. Tubes were shaken at high speed on a reciprocating shaker for 30 minutes; centrifuged (10 min, 13,800 rcf) and then filtered (Whatman #1 qualitative paper) into test tubes (15 ml). The extracts were covered with parafilm and left on the lab bench to equilibrate with room temperature. Once equilibrated, extracts were vortexed and their EC was measured with a YSI Model 35 conductance meter. The temperature of the extracts was also recorded, and conductivity values were converted to 25 °C.

Soil Organic Carbon

Soil organic carbon (SOC) was determined using the modified Mebius method (Nelson and Sommers, 1982). About 0.2 to 0.4 g of soil (air-dried, 0.5 mm) was measured into digestion tubes (75 ml). Potassium dichromate (5 ml, 0.1667 M) and concentrated ($\geq$ 96 %) sulfuric acid (10 ml) was added to each tube. The samples were digested (150 °C, 30 min); allowed to cool in the fumehood; and then transferred into Erlenmeyer flasks (250 ml). Indicator solution (5 drops; 1, 10 phenanthroline ferrous sulfate complex) was added to the digestions, and they were titrated with a solution of ferrous ammonium sulfate hexahydrate (~ 0.2 M) and sulfuric acid (0.9 M). Four reagent blanks were included with each set of digestions; two were heated with the digestions (boiled blanks) and two were not (unboiled blanks). SOC was calculated from titration volumes, and expressed on an oven dry basis (105 °C, 48 hr). A sample calculation is provided in Appendix D.

Statistical Analyses

The SAS General linear model (GLM) procedure was used to analyze sub-field differences in crop, soil and weed variables (SAS Institute Inc., 1985). A one-way classification was used. Sources of variation were node and sampling error (Steel and Torrie, 1980). The Bonferroni procedure ($p = .05$) was used for mean separation (Snedecor and Cochran, 1989). Prior to analysis of variance, all data sets were tested for normal distribution of variance, using SAS Univariate procedure. Outliers were removed from those data sets that failed the test. Adjusted data sets were then analyzed using the GLM procedure for missing values (SAS Institute Inc., 1985).

When F values for yield were significant ($p \leq .05$), orthogonal contrasts were used to test for differences in soil, weed, and crop variables, between the highest and lowest yielding groups of nodes within the field (Steel and Torrie, 1980). When F values for yield were not significant ($p > .05$), orthogonal contrasts were used to test the range of soil, weed and crop variables that did not result in sub-field differences in crop yield. Statistical details are tabulated in Appendix E.

RESULTS

Crop Quality

Halcourt Site

Crop quality at the Halcourt site was nearly uniform (Figure 4.1). No differences in commercial grades were observed. Barley protein ranged from 7.3 % at node 3, to 9.8 % at node 1. However, only one node (1) was significantly different from any of the other nodes at this site (Figure 4.1).

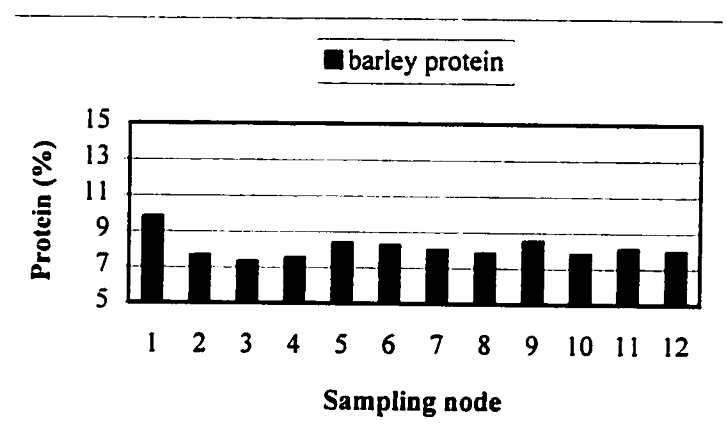
Table 4.1 ANOVA for barley protein (grain) at the Halcourt site in 1996.

Dependent Variable: Protein (%)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PROT = node	11	22.52	2.048	5.47	0.0001
Error	48	17.97	0.37		
Corrected Total	59	40.49			

R-Square	C.V.	Root MSE	PROT Mean
0.56	7.57	0.612	8.08

Grade	Node	Protein (%)
X 1CW	1	9.79 a
X 1CW	9	8.50 ab
X 1CW	5	8.37 b
X 1CW	6	8.24 b
X 1CW	11	8.10 b
X 1CW	7	8.00 b
X 1CW	12	7.96 b
X 1CW	8	7.80 b
X 1CW	10	7.79 b
X 1CW	2	7.63 b
X 1CW	4	7.53 b
X 1CW	3	7.29 b
	mean	8.08



Minimum significant difference = 1.39 %
Mean separation: Bonferroni, p = .05

Figure 4.1 Barley protein (grain) across a transect at the Halcourt site in 1996.

Hythe Site

Crop quality was variable at the Hythe site (Figure 4.2). Commercial grades were poor (CWFEED) along the first half of the transect (nodes 1-5), and at node 9. Node 8 had a better grade (2CPRS). Nodes 6, 7 and 10 made top grade (1CRPS). Wheat protein ranged from 10.2 % at node 5, to 13.5 % at node 10. Wheat protein was significantly higher at Node 10 than it was at nodes 2, 4, 5 and 7. Nodes 6 and 10 had protein percentages that would make them eligible for premiums (i.e. ≥ 12 %).

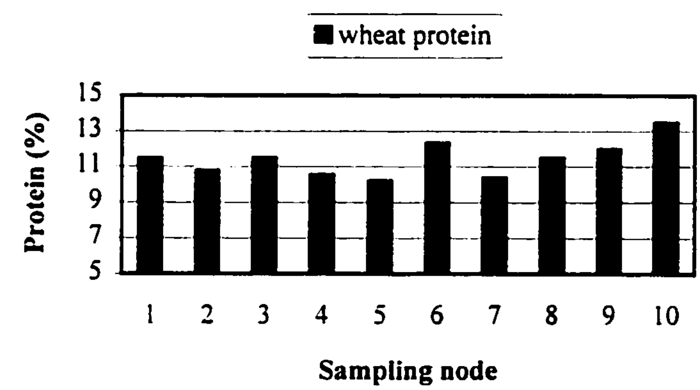
Table 4.2 ANOVA for wheat protein (grain) at the Hythe site in 1996.

Dependent Variable: Protein (%)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PROT = node	9	45.51	5.06	4.57	0.0004
Error	40	44.30	1.11		
Corrected Total	49	89.81			

R-Square	C.V.	Root MSE	PROT Mean
0.51	9.24	1.05	11.39

Grade	Node	Protein (%)	
1CRPS	10	13.45	a
1CRPS	6	12.30	ab
CWFEED	9	11.97	ab
CWFEED	3	11.47	ab
2CRPS	8	11.47	ab
CWFEED	1	11.46	ab
CWFEED	2	10.75	b
CWFEED	4	10.52	b
1CRPS	7	10.37	b
CWFEED	5	10.18	b
	mean	11.39	



Minimum significant difference = 2.34 %
Mean separation: Bonferroni, p = .05

Figure 4.2 Wheat protein (grain) across a transect at the Hythe site in 1996.

Huallen Site

Crop quality was variable at the Huallen site. Four different grades were observed. They ranged from poor (SCWLW) at nodes 5 and 6, to excellent (X1CW) at nodes 3 and 7 (Figure 4.3). Significant differences in barley protein were also observed (Table 4.3). However, only the extreme means (nodes 3 and 6) were significantly different from each other (Figure 4.6). Barley grain at node 3 had the lowest protein content (7.51 %) but graded well (X1CW). Barley grain at node 6 had the highest protein content (9.23 %) but graded poorly (SCWLW).

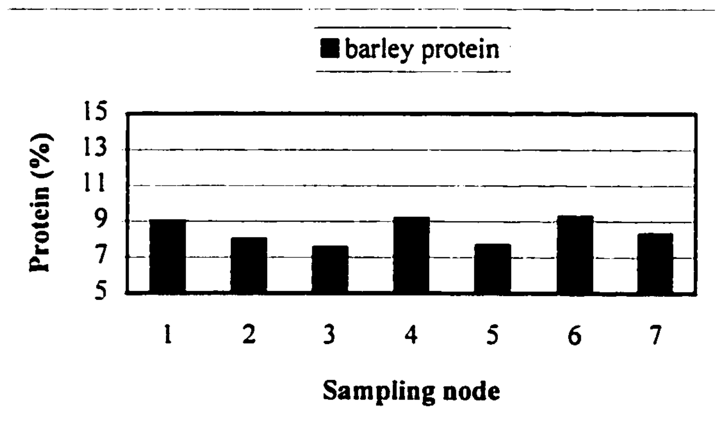
Table 4.3 ANOVA for barley protein (grain) at the Huallen site in 1996.

Dependent Variable: Protein (%)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model PROT = node	6	15.67	2.61	4.15	0.0042
Error	28	17.63	0.63		
Corrected Total	34	33.30			

R-Square	C.V.	Root MSE	PROT Mean
0.47	9.46	0.79	8.39

Grade	Node	Protein (%)
SCWLW	6	9.23 a
2CW	4	9.14 ab
1CW	1	8.97 ab
X1CW	7	8.26 ab
1CW	2	7.98 ab
SCWLW	5	7.64 ab
X1CW	3	7.51 b
	mean	8.39



Minimum significant difference = 1.68 %

Mean separation: Bonferroni, p = .05

Figure 4.3 Barley protein (grain) across a transect at the Huallen site in 1996.

Crop Yield

Halcourt Site

Yield of barley grain at the Halcourt site ranged from 3584.2 kg/ha at node 5, to 5259.7 kg/ha at node 1 (Figure 4.4). Yields tended to be lower through the middle section of the transect (nodes 3 - 8), and higher toward each end (nodes 1 - 2 and nodes 9 - 12). However, these differences were not significant (Table 4.4).

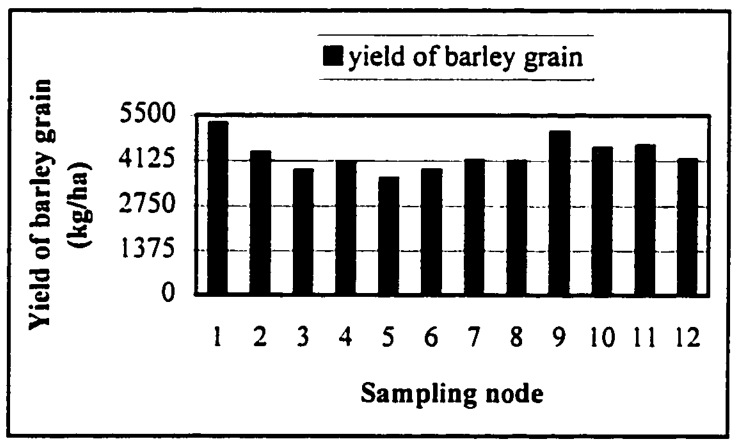
Table 4.4 ANOVA for yield of barley grain at the Halcourt site in 1996.

Dependent Variable: Yield of barley grain(kg/ha)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model GYLD = node	11	13087356.40	1189759.67	1.81	0.0790
Error	48	31606303.68	658464.66		
Corrected Total	59	44693660.08			

R-Square	C.V.	Root MSE	GYLD Mean
0.29	18.93	811.46	4285.88

Node	Yield (kg/ha)
1	5259.7 a
9	4991.3 a
11	4589.3 a
10	4517.2 a
2	4359.4 a
12	4162.6 a
7	4123.3 a
8	4094.3 a
4	4080.5 a
6	3839.2 a
3	3829.6 a
5	3584.2 a
mean	4285.9



Minimum significant difference = 1846.3 kg/ha
Mean separation: Bonferroni, p = .05

Figure 4.4 Yield of barley grain across a transect at the Halcourt site in 1996.

Hythe Site

Significant differences in yields of wheat grain were observed at the Hythe site (Table 4.5). Yields ranged from 1206 kg/ha at node 8, to 3693.7 kg/ha at node 4 (Figure 4.5). Nodes 1, 4 and 5 made up the high yielding group at this site. All other nodes were included in the low yielding group (Figure 4.5). Mean yield was 3232.6 kg/ha for the high yielding group, and 1828.4 kg/ha for the low yielding group (Figure 4.5).

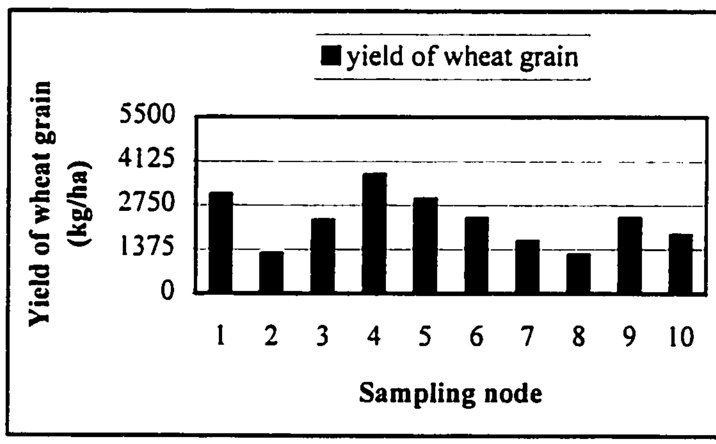
Table 4.5 ANOVA for yield of wheat grain at the Hythe site in 1996.

Dependent Variable: Yield of wheat grain (kg/ha)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model GYLD = node	9	29794177.55	3310464.17	11.44	0.0001
Error	40	11576585.55	289414.64		
Corrected Total	49	41370763.10			

R-Square	C.V.	Root MSE	GYLD Mean
0.72	23.91	537.97	2249.65

Node	Yield (kg/ha)	
4	3693.7	a
1	3070.6	ab
5	2933.4	abc
9	2333.8	bcd
6	2330.4	bcd
3	2269.3	bcd
10	1811.7	cd
7	1614.8	d
2	1232.8	d
8	1206.0	d
mean	**2249.7**	



Minimum significant difference = 1195.7
Mean separation: Bonferroni, p = .05

Figure 4.5 Yield of wheat grain across a transect at the Hythe site in 1996.

Huallen Site

Significant differences in yield of barley grain were observed at the Huallen site (Table 4.6). Yield ranged from 664.7 kg/ha at node 6, to 4280.3 at node 3 (Figure 4.6). Nodes 3 and 7 made up the high yielding group at this site. All other nodes belonged to the low yielding group (Figure 4.6). Nodes 1 and 4 turned out to be located in yield transition zones in the field, and were excluded from group comparisons. The remaining members of the low group were divided into two subgroups (nodes 5 and 6; node 2), based on position along the transect. The mean yield for the subgroup of nodes 5 and 6 was 741.8 kg/ha. The yield for the other low yielding node (node 2) was 1258.4 kg/ha. Mean yield for the high yielding group (node 3 and 7) was 4182.7 kg/ha (Figure 4.6).

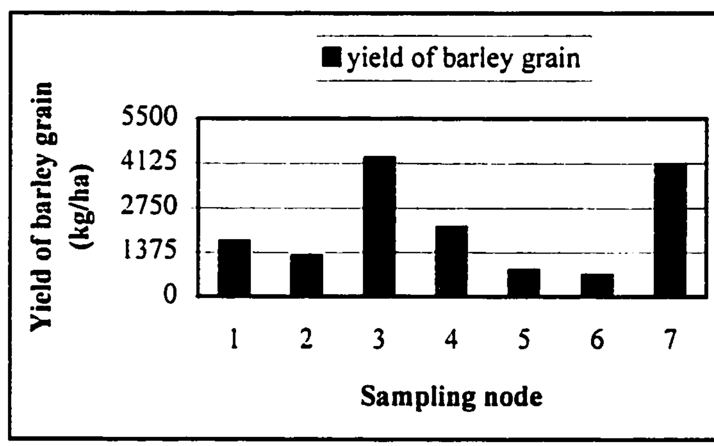
Table 4.6 ANOVA for yield of barley grain at the Huallen site in 1996.

Dependent Variable: Yield of barley grain (kg/ha)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model GYLD = node	6	66262777.22	11043796.20	21.73	0.0001
Error	28	14231389.98	508263.93		
Corrected Total	34	80494167.21			

R-Square	C.V.	Root MSE	GYLD Mean
0.82	33.37	712.93	2136.41

Node	Yield (kg/ha)	
3	4280.3	a
7	4085.1	a
4	2142.9	b
1	1704.7	b
2	1258.4	b
5	818.8	b
6	664.7	b
mean	2136.4	



Minimum significant difference = 1506.2 kg/ha
Mean separation: Bonferroni, p = .05

Figure 4.6 Yield of barley grain across a transect at the Huallen site in 1996.

Differences in Crop and Soil Variables between High and Low Yielding Groups of Nodes

Halcourt Site

Yield of barley grain was not significantly different between nodes at the Halcourt site in 1996. Therefore, differences in crop and soil variables, between high and low yielding nodes, were not tabulated for this site. The ranges for crop and soil variables were tabulated instead (Table 4.7). No differences in commercial grades were observed. The ranges for penetration resistance (all depths) and percent sand (15-30 cm) were not significant; ranges for all other variables were significant (Table 4.7).

Table 4.7 Ranges for crop and soil variables at the Halcourt site in 1996.

Variable		High	Node	Low	Node	Difference	Pr > F*
Barley grain yield (kg/ha)		5259.68	1	3584.22	5	1675.46	0.0790
Commercial Grade				X1CW - all nodes			-
Grain protein (%)		9.79	1	7.29	3	2.50	**0.0001**
Thousand kernel weight (g)		45.61	12	42.89	4	2.72	**0.0003**
Test weight (kg/hl)		77.90	10	75.29	5	2.61	**0.0004**
Crop density (plants/m^2)							
4=3 leaf stage; 12=3-4 leaf stage		166.20	4	81.00	12	85.20	**0.0001**
Crop development (Haun units)		10.70	10	9.52	5	1.18	**0.0001**
Weed density (plants/m^2)		555.80	4	141.40	12	414.40	**0.0001**
Elevation (m)		701.07	12	693.72	1	7.35	-
Soil moisture	July	29.80	4	21.60	9	8.20	**0.0111**
(θ)	September	42.50	11	32.65	1	9.85	**0.0001**
Bulk density (Mg/m^3)							
0-15 cm (w3=29.3; w9 =38.0)		1.31	3	1.05	9	0.26	**0.0001**
15-30 cm (w1=21.9; w11=21.9)		1.50	1	1.27	11	0.23	**0.0001**
Penetration resistance (MPa)							
0-5 cm (w7=33.1; w2 =30.4)		2.17	7	0.32	2	1.85	0.0544
5-10 cm (w7=32.2; w2 =28.6)		2.99	7	1.26	2	1.73	0.3031
10-15 cm (w1=27.0; w11=37.6)		3.36	1	2.30	11	1.06	0.1688
15-20 cm (w4=27.2; w11=31.6)		3.63	4	2.66	11	0.97	0.4650
20-30 cm (w1=21.3; w11=33.9)		3.96	1	2.91	11	1.05	0.2145
Soil aggregates (MWD, mm)		4.02	4	2.88	11	1.14	**0.0205**
Soil texture	0-15 cm	Silty Clay Loam - Clay Loam - Silty Clay - Clay**					
	15-30 cm	Silty Clay Loam - Silty Clay - Clay**					
% sand	0-15 cm	20.82	9	16.42	11	4.40	**0.0001**
	15-30 cm	15.08	10	8.61	11	6.47	0.0516
% clay	0-15 cm	50.12	7	28.15	1	21.97	**0.0001**
	15-30 cm	67.31	12	27.18	1	40.13	**0.0001**
pH (water)	0-15 cm	5.70	3	5.26	5	0.44	**0.0001**
	15-30 cm	5.92	2	5.18	5	0.74	**0.0001**
pH ($CaCl_2$)	0-15 cm	5.35	3	4.76	5	0.59	**0.0001**
	15-30 cm	5.56	2	4.72	5	0.84	**0.0001**
EC	0-15 cm	0.32	9	0.20	3	0.12	**0.0001**
(dS/m)	15-30 cm	0.24	8	0.16	4	0.08	**0.0001**
SOC	0-15 cm	50.39	9	25.39	3	25.00	**0.0001**
(mg/g)	15-30 cm	22.01	11	9.25	4	12.76	**0.0001**

MWD = mean weight diameter.
w = gravimetric water content.
θ = volumetric water content.
* statistical significance (p = .05) is indicated by bold font.
** range of textural classes observed along the transect.

Hythe Site

Differences in crop and soil variables, between the high and low yielding groups at the Hythe site, are summarized in Table 4.8. Crop development, penetration resistance (0-15 cm, 20-30 cm) and soil organic carbon (15-30 cm), were not significantly different between groups; differences for all other variables were significant. EC increased with depth for both groups (Table 4.8).

Table 4.8 Differences in crop and soil variables at the Hythe site in 1996 (high yielding group versus low yielding group).

Variable		High Group	Low Group	Difference	Pr > F*
Wheat grain yield (kg/ha)		3232.57	1828.40	1404.17	**0.0001**
Commercial grade		-	-	-	-
Grain protein (%)		10.72	11.68	0.96	**0.0051**
Thousand kernel weight (g)		37.43	42.19	4.76	**0.0001**
Test weight (kg/hl)		72.29	75.05	2.76	**0.0001**
Crop density (plants/m^2)					
H=2-3 leaf stage;L=1-3 leaf stage		125.47	86.93	38.54	**0.0001**
Total dry matter (Mg/ha)		7.82	3.95	3.87	**0.0001**
Crop development (Haun units)		9.20	9.26	0.06	0.5304
Weed density (plants/m^2)		157.47	118.83	36.64	**0.0481**
Elevation (m)		744.68	744.21	0.47	-
Soil moisture	July	23.52	31.66	8.14	**0.0001**
(θ)	September	34.55	45.09	10.54	**0.0001**
Bulk density (Mg/m^3)					
0-15 cm (wH=38.1; wL=40.31)		1.00	1.16	0.16	**0.0001**
15-30 cm (wH=30.5; wL=28.01)		1.25	1.36	0.11	**0.0001**
Penetration resistance (MPa)					
0-5 cm (wH=38.5; wL=44.9)		1.81	1.72	0.09	0.7817
5-10 cm (wH=37.2; wL=37.0)		3.09	2.75	0.34	0.0626
10-15 cm (wH=36.2; wL=34.5)		3.30	3.48	0.18	0.3187
15-20 cm (wH=27.4; wL=29.3)		3.35	3.75	0.40	**0.0219**
20-30 cm (wH=30.9; wL=26.5)		3.58	3.96	0.38	0.0539
Soil aggregates (MWD, mm)		3.55	3.21	0.34	**0.0082**
Soil texture	0-15 cm	-	-	-	-
	15-30 cm	-	-	-	-
% sand	0-15 cm	25.87	17.39	8.48	**0.0001**
	15-30 cm	17.60	12.51	5.09	**0.0001**
% clay	0-15 cm	23.12	39.12	16.00	**0.0001**
	15-30 cm	39.56	58.16	18.60	**0.0001**
pH (water)	0-15 cm	5.32	5.55	0.23	**0.0001**
	15-30 cm	5.46	6.65	1.19	**0.0001**
pH ($CaCl_2$)	0-15 cm	4.97	5.02	0.05	**0.0323**
	15-30 cm	4.97	6.26	1.29	**0.0001**
EC	0-15 cm	0.20	0.74	0.54	**0.0001**
(dS/m)	15-30 cm	0.28	1.75	1.47	**0.0001**
SOC	0-15 cm	45.74	40.53	5.21	**0.0001**
(mg/g)	15-30 cm	20.02	21.49	1.47	0.1764

High group (H) = mean of nodes 1, 4 and 5.
Low group (L) = mean of nodes 2, 3, 6, 7, 8, 9 and 10.
MWD = mean weight diameter.
w = gravimetric water content.
θ = volumetric water content.
* statistical significance (p = .05) is indicated by bold font.

Huallen

Differences in crop and soil variables, between the high yielding group (nodes 3 and 7), and low yielding group (nodes 5 and 6) at the Huallen site, are summarized in Table 4.9. Grain protein, crop density, weed density and penetration resistance were not significantly different between these two groups; differences for all other variables were significant. There were major differences in soil texture (> 55 % sand, >30 % clay) between these two groups of nodes (Table 4.9).

Table 4.9 Differences in crop and soil variables at the Huallen site in 1996 (nodes 3 and 7 versus nodes 5 and 6).

Variable		Nodes 3 and 7	Nodes 5 and 6	Difference	Pr > F*
Barley grain yield (kg/ha)		4182.66	741.79	3440.87	**0.0001**
Grade		XICW	SCWLW	-	-
Grain protein (%)		7.88	8.44	0.56	0.1291
Thousand kernel weight (g)		34.25	23.69	10.56	**0.0001**
Test weight (kg/hl)		63.50	41.49	22.01	**0.0001**
Crop density ($plants/m^2$)					
H=3-4 leaf stage; L=2-3 leaf stage		168.60	168.40	0.20	0.9783
Total dry matter (Mg/ha)		9.04	3.89	5.15	**0.0001**
Crop development (Haun units)		11.10	9.49	1.61	**0.0001**
Weed density ($plants/m^2$)		393.90	277.90	58.00	0.1154
Elevation (m)		693.11	689.22	3.89	-
Soil moisture	July	17.23	44.90	27.67	**0.0001**
(θ)	September	28.98	54.97	25.99	**0.0001**
Bulk density (Mg/m^3)					
0-15 cm (wH=20.2; wL=53.5)		1.28	0.99	0.29	**0.0001**
15-30 cm (wH=16.2; wL=29.6)		1.53	1.32	0.21	**0.0001**
Penetration resistance (MPa)					
0-5 cm (wH=18.3; wL=56.6)		0.71	0.86	0.15	0.7057
5-10 cm (wH=19.4; wL=48.6)		2.40	1.96	0.44	0.2070
10-15 cm (wH=19.0; wL=45.5)		3.46	2.40	1.06	**0.0001**
15-20 cm (wH=15.7; wL=45.3)		3.44	2.51	0.93	**0.0001**
20-30 cm (wH=15.9; wL=25.1)		3.84	2.72	1.12	**0.0002**
Soil aggregates (MWD, mm)		2.20	4.24	2.04	**0.0001**
Soil texture	0-15 cm	Sandy Loam	Silty Clay	-	-
	15-30 cm	Sandy Loam	Silty Clay	-	-
% sand	0-15 cm	69.86	13.64	56.22	**0.0001**
	15-30 cm	68.00	8.73	59.27	**0.0001**
% clay	0-15 cm	7.62	41.72	49.34	**0.0001**
	15-30 cm	14.94	48.32	33.38	**0.0001**
pH (water)	0-15 cm	5.94	7.33	1.39	**0.0001**
	15-30 cm	6.64	7.76	1.12	**0.0001**
pH ($CaCl_2$)	0-15 cm	5.64	7.26	1.62	**0.0001**
	15-30 cm	6.11	7.45	1.34	**0.0001**
EC	0-15 cm	0.22	0.69	0.47	**0.0001**
(dS/m)	15-30 cm	0.17	0.66	0.49	**0.0001**
SOC	0-15 cm	16.86	58.48	41.62	**0.0001**
(mg/g)	15-30 cm	7.93	12.56	4.63	**0.0001**

MWD = mean weight diameter.
w = gravimetric water content.
θ = volumetric water content.
* statistical significance (p = .05) is indicated by bold font.
H = mean of nodes 3 and 7.
L = mean of nodes 5 and 6.

Differences in crop and soil variables, between the high yielding group (nodes 3 and 7), and node 2 at the Huallen site, are summarized in Table 4.10. Grain protein, test weight, crop density, penetration resistance (0-20 cm) and soil organic carbon (0-30 cm) were not significantly different between these two groups; differences for all other variables were significant (Table 4.10).

Table 4.10 Differences in crop and soil variables at the Huallen site in 1996 (nodes 3 and 7 versus node 2).

Variable		Nodes 3 and 7	Node 2	Difference	Pr > F*
Barley grain yield (kg/ha)		4182.66	1258.36	2924.3	**0.0001**
Commercial grade		X1CW	1CW	-	-
Grain protein (%)		7.88	7.98	0.10	0.8215
Thousand kernel weight (g)		34.25	31.34	2.91	**0.0202**
Test weight (kg/hl)		63.50	61.68	1.82	0.2999
Crop density (plants/m^2)					
H=3-4 leaf stage; 2=2-3 leaf stage		168.60	177.00	8.40	0.3547
Total dry matter (Mg/ha)		9.04	2.95	6.09	**0.0001**
Crop development (Haun units)		11.10	9.82	1.28	**0.0001**
Weed density (plants/m^2)		393.90	1191.80	797.90	**0.0001**
Elevation (m)		693.11	699.49	6.38	-
Soil moisture	July	17.23	34.68	17.45	**0.0001**
(θ)	September	28.98	37.90	8.92	**0.0001**
Bulk density (Mg/m^3)					
0-15 cm (wH=20.2; w2=24.0)		1.28	1.51	0.23	**0.0001**
15-30 cm (wH=16.2; w2=20.0)		1.53	1.64	0.11	**0.0011**
Penetration resistance (MPa)					
0-5 cm (wH=18.3; w2=25.6)		0.71	0.19	0.52	0.2771
5-10 cm (wH=19.4; w2=22.1)		2.40	2.35	0.05	0.9086
10-15 cm (wH=19.0; w2=21.2)		3.46	3.23	0.23	0.3700
15-20 cm (wH=15.7; w2=22.6)		3.44	3.07	0.37	0.1575
20-30 cm (wH=15.9; w2=18.8)		3.84	3.08	0.76	**0.0250**
Soil aggregates (MWD, mm)		2.20	3.57	1.37	**0.0001**
Soil texture	0-15 cm	Sandy Loam	Sandy Clay Loam	-	-
	15-30 cm	Sandy Loam	Sandy Clay Loam	-	-
% sand	0-15 cm	69.86	63.47	6.39	**0.0001**
	15-30 cm	68.00	59.79	8.21	**0.0001**
% clay	0-15 cm	7.62	16.99	9.37	**0.0001**
	15-30 cm	14.94	25.62	10.68	**0.0001**
pH (water)	0-15 cm	5.94	7.52	1.58	**0.0001**
	15-30 cm	7.76	7.70	0.06	**0.0001**
pH ($CaCl_2$)	0-15 cm	5.64	7.36	1.72	**0.0001**
	15-30 cm	6.11	7.38	1.27	**0.0001**
EC	0-15 cm	0.22	0.44	0.22	**0.0001**
(dS/m)	15-30 cm	0.17	0.30	0.13	**0.0001**
SOC	0-15 cm	16.86	15.90	0.96	0.2772
(mg/g)	15-30 cm	7.93	8.73	0.80	0.4717

MWD = mean weight diameter.
w = gravimetric water content.
θ = volumetric water content.
* statistical significance (p = .05) is indicated by bold font.
H = mean of nodes 3 and 7.

DISCUSSION

One of the perceived benefits of site specific harvesting is that it would allow farmers to increase the market value of their crops by separating grain on the basis of quality at harvest. Farmers who grow annual crops in the South Peace River region may be able to benefit in this way if sub-field differences in crop grade or percent protein, exist in their crops.

Producers in the region may also be able to increase productivity by matching management practices more closely to local soil conditions in their fields. To realize site specific benefits of this nature, however, sub-field differences in yields must exist, and producers must be able to identify the factors of soil fertility that are limiting productivity at low yielding sites. Yield monitoring is the first step in this process. If yield monitoring reveals significant differences, then these farmers may be able to identify limiting factors by comparing soil and crop characteristics at low and high yielding sites within the field.

Halcourt Site

Opportunities to use site specific harvesting to increase the market value of the barley crop at the Halcourt site, did not exist. A 2-row malting barley was grown at this site in 1996. Crop grades were consistently good (X1CW) along the length of the transect, therefore no opportunities to separate on the basis of grade were presented. The acceptable grain protein content (GPC) for 2-row malting barley is 10.0-12.5 % (Agrium, 1997). Malting companies will reject barley with a GPC outside of this range. Percent protein was below 10.0 % at all nodes, thereby eliminating any benefit to site specific harvesting on the basis of protein at this site.

Significant sub-field differences in yield were not observed at the Halcourt site in 1996. Therefore, sub-field variability in soil and crop characteristics, is not addressed here. However, many of the soil and crop variables at this site had significant ranges (Table 4.7), and although yields were not significantly different along the transect, a trend was suggested (Figure 4.4). Therefore, it may be worthwhile for the producer at this site to continue to monitor yields in this field. Perhaps under different growing conditions, or if a different crop is grown, yield differences that are worth addressing may materialize.

Hythe Site

Opportunities to use site specific harvesting were present at the Hythe site in 1996. Three grades of wheat (1CRPS, 2CRPS, CWFEED) were observed along the transect. The 1996 crop at this site was graded as CWFEED (Appendix B). If the crop could have been separated on the basis of grade when it was harvested, a portion of the grain in this field would have made a better grade, and brought in larger returns. Since technologies for separating grain on the basis of grade in the field are not yet available, it would be useful if grades varied predictably with percent protein or yield. These crop variables, however, were not consistently associated with each other, along the transect at this site.

Opportunities to increase market value by separating on the basis of protein were minimal at this site, but they did exist. Nodes 6 and 10 had protein percentages that were greater than 12.0 %, which would make them eligible for premiums (Jones, 1998). However, protein percentages presented here were determined by multiplying total N in the grain by a factor of 6.25. For wheat products used for human consumption, a conversion factor of 5.7 is used (Williams *et al.* 1998). If protein percentages at nodes 6 and 10 are adjusted to standards for human consumption, protein percentages at these nodes drop to 11.22 % and 12.27 %, respectively. As a result, node 6 is no longer eligible, and minimal premiums would be realized at node 10.

Significant yield differences were observed along the transect at the Hythe site. Nodes 1, 4 and 5 made up the high yielding group, and the rest of the nodes belonged to the low yielding group. Soil properties and crop characteristics for each group are summarized in Table 4.7. These data indicate that less productive areas along the transect were lower, wetter, more compact, not as well structured, finer textured, and lower in organic matter, than the more productive areas along the transect. Less productive areas also had higher pH and EC values. Growing conditions at lower yielding nodes along the transect resulted in poorer stands and reduced crop growth. The grain that was produced at these nodes, however, was of better quality.

Sodicity and the physical soil conditions that accompany it, were likely the most limiting factors of soil fertility at this site. Exchangeable sodium was not measured in this study, but the soil survey report indicated that Solonetzic soils (Solods and Solodized Solonetz) were present in this field (Appendix A). The Solods were likely present at the higher nodes along the transect, while the Solodized Solonetz likely occurred at the lower nodes (Agriculture Canada, 1987). The differences in soil properties, between the high yielding group and low yielding group of nodes, reflected the differences in these soils, and coincided with their expected pattern in the landscape (Lickacz, 1993).

All Solonetzic soils have subsurface layers (Bnt horizons) that are very hard when dry, but swell to sticky, low permeable masses when wet. In Solodized Solonetz, however, the Bnt is still intact, and tends to be closer to the soil surface (Agriculture Canada, 1987). Since members of the low yielding group tended to be located at lower positions in the landscape where Solodized Solonetz were likely present, the higher bulk density (15-30 cm) and penetration resistance (15-20 cm) for this group were likely due to a better developed, shallower Bnt at these nodes. The much higher clay content for the low yielding group, would attest to a shallower Bnt as well.

Characteristics of the Bnt at the lower yielding nodes probably contributed to their lower productivity. Penetration resistance (PR) at the 15-20 cm depth, in the low yielding group was 3.75 MPa, which is well above the critical threshold (2.0 MPa) for optimum root growth in annual crops (Arshad *et al.* 1996). Bulk density in the subsoil (15-30 cm) was also significantly higher for the low yielding group, and approached the threshold (1.4 Mg/m^3) for root restricting compaction (Arshad *et al.* 1996). Given these conditions, nodes in the lower yielding group likely had a smaller rooting volume, and therefore, less soil available for the exploration and extraction of water and nutrients by crop roots (Oussible *et al.* 1992).

On wet years, like the 1996 season, a shallower, less permeable Bnt is also likely to cause water-logging in the rooting zone. Water-logging limits the supply of O_2 to soil microbes and crop roots. As a result, root growth is inhibited, and nitrogen may be lost to the crop through denitrification (Lickacz, 1993). The Ap in the lower yielding group of nodes was saturated (65 %) beyond optimum aerobic conditions (60 %) in July, and in September it was highly saturated (93 %). Perhaps, the lower productivity at these nodes, was due in part to water-logging caused by physical restrictions in the soil (Arshad *et al.* 1996).

In addition to poorer subsoil permeability, soils at the low yielding nodes at this site were likely to have higher percentages of exchangeable sodium in the Ap. These soils were formed at lower positions in the landscape, in closer proximity to the water table, and in parent materials abundant in sodium salts (Appendix A). Therefore, they likely had higher percentages of exchangeable sodium in the profile to begin with, and have probably not been leached as extensively as the soils at higher elevation (Agriculture Canada, 1987).

Since less leaching has occurred, the soils at the low yielding nodes were likely to have a higher EC and pH, and this trend was reflected in the data. EC and pH, however, were not likely limiting factors at the lower yielding nodes. EC was higher at these nodes (0.74-1.75 dS/m), but it was lower than the critical threshold for wheat (6.0 dS/m). Soil pH at the lower yielding nodes (5.6-6.7) was actually in a more favorable range (5.5-7.0) for wheat than it was at the higher yielding nodes (Fageria *et al.* 1997).

Exchangeable sodium does not bind soil particles together sufficiently to form stable aggregates. When soils high in exchangeable sodium receive moisture, soil particles separate and disperse. As a result, structure is destroyed, and crusting occurs as the puddled soils dry. Poorly structured soils tend to be more compact as well (Hausenbuiller, 1985). The poorer aggregate stability and higher bulk density in the Ap of the lower yielding group, were likely the physical symptoms of higher exchangeable sodium percentages at these nodes (Lickacz, 1993).

The poorer aggregation in the Ap at the lower yielding nodes, probably contributed to their lower productivity. It is difficult to prepare a good seedbed for annual crops in soils that are prone to puddling and crusting. If cultivated when too wet or too dry, they form large clods that are difficult to break down. As a result, seedbeds are lumpy, and optimum seed-soil contact is not attained. Once crops have been seeded, poor structure (puddled, crusted) in the Ap can physically impede emergence. The poorer crop and weed stands, at the lower yielding nodes were likely a result of poorer seedbed conditions at these nodes (Haller, 1984).

Poor structure in the Ap can limit growth once the crop has emerged as well. Poorer aggregation results in less pore space, which reduces the permeability of the soil to water and air. This in turn, limits the supply of O_2, water and nutrients to the crop. The poorer crop growth (total dry matter) and lower yields at the less productive nodes were likely due in part, to poorer structure in the Ap that restricted water and air movement, throughout the growing season (Fageria *et al.* 1997).

The low yielding group of nodes at this site also had significantly lower concentrations of organic carbon. However, the difference in organic carbon translated into a difference of less than 1 % soil organic matter, and although it was lower, organic matter content for the low yielding group was still close to 7 %. The physical benefits of soil organic matter (tilth, aggregation, moisture holding capacity, erosion resistance), are generally realized at 3-4 %, therefore, it is not likely that this factor was a major contributor to the lower productivity at these nodes (Lickacz, 1985). Total organic matter is not an absolute indicator of the nutrient supplying power of the soil organic fraction, however, at 7 % organic matter, it is not likely that nutrient supply was substantially limited by the lower amount of organic matter present at the lower yielding nodes either (Lickacz, 1985).

GPC in wheat is a post-harvest indicator of whether or not N supply was sufficient for optimum yield (Grant and Flaten, 1998). GPC in the lower yielding group (11.68 %) was below the critical concentration that indicates N sufficiency (13.5 %), however, it was still higher than that of the high yielding group (10.72 %). These findings suggested that factors other than N supply were larger contributors to lower yields at these nodes (Grant and Flaten, 1998).

Differences in other crop characteristics suggested that limiting factors at the less productive nodes, were most limiting during the first part of the growing season. Crop establishment (crop density) and growth (total dry matter) were poorer at the lower yielding nodes, however, the grain that was produced at these nodes had higher test weights and higher kernel weights, than the better yielding nodes. Since test weight and kernel weight are largely determined by adequate moisture and N supply during grain filling (Stoskopf, 1985), the higher test weights and kernel weights for the lower yielding nodes, indicated that moisture and N were not as limiting at these nodes during the last part of the season. Apparently soil conditions at the lower yielding nodes could not support the crop growth that the higher yielding nodes could, but were better able to meet the needs of what little crop was present, during the grain filling stage.

Correcting limiting soil factors at this site, could be challenging. Improving the soils at the low yielding nodes by deep plowing or subsoiling is not an option. The soils at these nodes were formed in sodic bedrock (Appendix A), and mechanical treatments would likely incorporate an abundance of these materials into the Ap, thereby augmenting instead of alleviating soil physical problems in the topsoil. Surface drainage to prevent temporary water ponding, may be an option. However, the low yielding areas in the field were also the lower spots in the field, so attaining desired drainage patterns could be difficult. For smaller problem areas, however, amendments such as manure or compost, to improve tilth, may be feasible. Keeping spring tillage shallow and minimal, and returning residues to the soil would help as well. For extreme problem areas, alternative crops (forages) may have to be considered (Lickacz, 1993).

Huallen Site

Opportunities to use site specific harvesting were presented at the Huallen site in 1996. Four grades of feed barley (X1CW, 1CW, 2CW, SCWLW) were observed along the transect. The 1996 crop at this site was graded as 2CW (Appendix B). If it could have been separated on the basis of grade when it was harvested, the market value of this crop would have been increased. Protein premiums are not paid on feed barley so they were not considered here (Jones, 1998). As at the Hythe site, outputs did not vary consistently with each other along the transect.

Significant yield differences were observed along the transect at the Huallen site. Nodes 3 and 7 made up the high yielding group at this site. All other nodes belonged to the low yielding group (Figure 4.6). Nodes 1 and 4 were located in yield transition zones in the field, and were excluded from group comparisons. The remaining members of the low group were divided into two subgroups (nodes 5 and 6; node 2), based on position along the transect.

Differences in crop and soil variables, between the high yielding group (nodes 3 and 7), and low yielding group (nodes 5 and 6), are summarized in Table 4.8. These data indicate that the lower yielding area of the field represented by nodes 5 and 6, was lower, wetter, less compact, better structured, finer textured and much higher in organic matter, than the more productive areas of the field. EC and pH were also higher in the lower yielding area. Soil conditions in the lower yielding area provided for good crop establishment, but resulted in slower crop development, less vegetative growth and poorer crop quality.

Nodes 5 and 6 were much wetter than the more productive nodes. The wetter conditions at these nodes were likely due in part to their position in the landscape. They were located in the lowest portion of the transect, with a 5-6 % gradient in one direction, and a 1-2 % gradient in the other direction. These nodes were also situated downslope from sandy areas of the field where water holding capacity was low (Lowery *et al.* 1996). Consequently, these nodes were poorly drained to start with, and water was probably redistributed to them from other areas of the field, throughout the wetter than normal 1996 season. The higher organic matter content and finer textured subsoil at these nodes likely contributed to wet conditions. Once water arrived at these nodes, these soil materials, with their high water holding capacity, would tend to retain it (Hausenbuiller, 1985).

The excess soil moisture at these nodes likely contributed to their lower productivity. In July, the Ap at nodes 5 and 6 was 72 % saturated, and in September it was 88 % saturated. Since optimum aerobic conditions for microbial activity and root growth occur at about 60 % saturation, soil moisture at these nodes was excessive for good crop growth, during the 1996 season (Arshad *et al.* 1996). The significantly higher organic matter content at nodes 5 and 6, further suggested that wetter conditions were the norm at these nodes. In depressional areas, organic matter tends to accumulate in greater amounts because excess moisture restricts O_2 supply for decay processes (Hausenbuiller, 1985).

Soils at nodes 5 and 6 were also less compact, better aggregated, and less resistant to penetration than soils at the higher yielding group of nodes. Therefore, it is not likely that soil compaction or poor structure were major contributors to lower productivity at these nodes. Nodes 5 and 6 also had higher EC and pH values, than the more productive nodes. EC, however, was still well below the critical value (6.0 dS/m) for barley, and the pH was still in the acceptable range (6.5-7.8) for this crop (Fageria *et al.* 1997). Therefore it was not likely that these factors were major contributors to lower productivity either. Apparently excess soil moisture was the most limiting factor at nodes 5 and 6, during the 1996 growing season.

Differences in crop and soil variables, between the high yielding group of nodes (nodes 3 and 7), and node 2, are summarized in Table 4.9. These data indicate that the lower yielding area of the field represented by node 2, was higher, wetter, more compact, less resistant to penetration below the plow layer, better structured, finer textured and higher in pH and EC. The soil conditions at node 2 resulted in slower crop development, less vegetative growth and poorer crop quality.

Since the soil at node 2 was better aggregated than soils at the higher yielding group of nodes, poor structure was not likely a major contributor to the lower productivity at this node. Penetration resistance (PR) at node 2 was above the critical threshold (2.0 MPa) for optimum root growth (below 5 cm), however, it was less than PR at the more productive nodes, so restricted root growth was not clearly a major contributor to lower productivity. Bulk density was significantly higher at node 2, however, it was still below the critical threshold (1.70 Mg/m^3) for root restricting compaction in sandy clay loams (Arshad *et al.* 1996). Therefore, it is not likely that soil compaction was a major problem at node 2 either.

The Ap at node 2 was wetter than soils at the more productive nodes, however, saturation at this node was optimum in July (60 %), and it was not overly saturated in September (67%). Apparently excess moisture was not a major contributor to the lower productivity at this node either. EC was also higher at node 2, but it was well below the critical threshold (6.0 dS/m) for barley (Fageria *et al.* 1997). Soil pH, in the Ap, was higher at node 2 (7.52), but it was still within the acceptable range (6.5-7.8) for barley as well.

The limiting factors at node 2 then, were not readily identified by comparing the differences in soil properties between this node and the high yielding nodes. Perhaps part of the problem at node 2 was greater weed competition, inadequate mineral nutrition or some other factor of soil fertility that was not presented in Table 4.9. P nutrition, for example, may have been limiting. When pH is greater than 7.22, secondary orthophosphate (HPO_4^{2-}) is the dominant ion providing P nutrition. Uptake of secondary orthophosphate is much slower than uptake of primary orthophosphate (Tisdale *et al.* 1985). Results from Chapter III indicated that P nutrition was poor at node 2, and since the pH at this node was 7.52, the crop in this area if the field may have suffered from inadequate P nutrition during the 1996 season. To confirm nutritional problems of this sort, however, crop tissue analyses would be required.

Correcting or managing for the limiting factors of soil fertility in this field would not be straightforward. Nodes 5 and 6 were located in extremely low spots in the field, and the limiting factor at these nodes was excess moisture. The usual method for reducing soil moisture in discharge areas, is to grow deep rooted perennials on adjacent recharge areas of the field (Wentz, 1997). This would mean taking the high yielding areas of this field out of annual crop production. Perhaps it would be more feasible to seed down the extremely low lying areas of this field to a flood tolerant forage. Additions of manure or compost in recharge areas might also help. These additions would increase the water holding capacity of the sandy soils upslope, and slow the redistribution of water to low spots in the field.

As for node 2, it is not possible to manage problems that are not discernable. Pending further investigation, all the farmer can do to manage for limiting factors at this node is step up weed control and make sure the crop is adequately fertilized.

SUMMARY & CONCLUSIONS

Opportunities to use site specific harvesting to increase the market value of crops, existed at two (Hythe, Huallen) of the three sites studied. Separating grain on the basis of grade would have been beneficial at both of these sites. Separating grain on the basis of percent protein would have been beneficial at one node at the Hythe site. It follows that farmers in the South Peace River region may be able to increase the market value of their crops by harvesting them site specifically, however, opportunities to separate on the basis of grade may be more extensive than opportunities to separate on the basis of protein, in this region.

Yield monitoring revealed significant sub-field differences in crop yield at two of the three sites studied, and some insight into what was limiting yield at the less productive nodes could be gained by comparing soil fertility at low and high yielding spots within the field. The limiting factors at the lower yielding nodes, however, were not always readily apparent. These findings indicate that sub-field differences in yields are not necessarily present in all fields of the South Peace River region, and when they are present, it may not be that easy to discern their source.

When limiting factors were discernable, they tended to be things like sodicity, physical conditions in the soil, and excess moisture. If farmers in the region are to realize any benefit from matching cropping practices to local conditions in the field, the limiting factors at the low yielding nodes will have to be corrected, or at least factored into management decisions. Given the nature of the limiting factors identified in this study, correcting them may be a challenge.

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CHAPTER V

SYNTHESIS

THE PROBLEM

Farmers who grow annual crops in the south-westerly portion of the South Peace River region, may be able to realize some of the benefits of site specific management, by matching their management practices more closely to local conditions in their fields. The realization of these benefits, however, is dependent upon the nature and extent of differences in soil fertility, crop growth or weed populations, within field boundaries. There are reasons to believe that sub-field variability exists in these fields, but its nature and extent are not well known.

THE PROJECT

The purpose of this study was to investigate the spatial variability of weeds, crops and soil fertility, within these fields, and evaluate the implications of this variability for site specific management. The specific objectives were to:

1. measure sub-field variability in broadleaf, grassy, annual and perennial weed groups, and evaluate the implications of this variability for site specific application of post-emergent herbicides.
2. measure sub-field variability in soil test recommendations for macronutrients and evaluate the implications of this variability for site specific application of fertilizers.
3. measure sub-field variability in crop quality and evaluate the implications of this variability for site specific harvesting.
4. determine differences in selected soil properties and crop characteristics, between high yielding and low yielding areas within field boundaries, and evaluate the implications of these differences for the site specific management of annual crops.

THE FINDINGS & IMPLICATIONS

The results of this study imply that sub-field variability does indeed exist in fields used to grow annual crops in the South Peace River region. The findings also indicate that the nature and extent of differences in soil fertility, crop growth and weed populations do provide some opportunities for farmers in this region, to match herbicide applications, fertilizer applications, harvesting technology and other management practices, more closely to local conditions in their fields.

The nature and extent of these opportunities, however, varied with the particular practice, crop and field. These findings imply that a particular site specific application may not be beneficial in every field that is used to grow annual crops in the region, and the extent of site specific benefits may also change from year to year. Since not all site specific practices would be useful in every field, every year, farmers in the region may benefit the most by treating site specific technologies as tools in a toolbox, to be used and adapted as needed, rather than adopting these technologies as a complete system, as they would something like direct seeding for example (Green, 1996).

Several of the findings in this study also imply that general expectations regarding soil fertility, or relationships between soil fertility and productivity in the South Peace River region, do not necessarily hold at the sub-field level. For example, soil acidity is generally accepted as one of the major contributors to lower productivity in the Gray Soil Zone of Alberta (Penney, 1996). At two of the sites (Hythe, Huallen) in this study, however, areas of the field with lower pH, were more productive than areas of the field where pH was higher. Soil acidity then, may result in reduced productivity on the regional scale, but it was not the major factor that reduced the average yield of these two fields during the 1996 growing season.

The results for soil K, further support this implication. K nutrition is not generally considered to be a major problem in soils used to grow annual crops in the South Peace River region, and when it is a problem in other regions of the Province, it is expected to occur on soils that are "light to medium textured, alkaline, carbonated and imperfectly to poorly drained" (McKenzie, 1996). In this study, however, exchangeable K was marginal (<200 mg/kg) at about 45 % of the sampling nodes, and at one of these nodes it was in the deficient (<100 mg/kg) range for crop production (Norwest Labs, 1998).

Soil texture was medium to light at all of these nodes, but only three of the nodes had a pH greater than 7.0, and none of these soils appeared to have a carbonated Ap (i.e. did not effervesce in response to HCl). Trends in exchangeable K also contradicted expected correlations with drainage. At the Hythe site, K was marginal in higher, better drained spots, and optimum in lower, poorly drained spots in the field. Inconsistencies also occurred along the transect at the Huallen site. For example, K was marginal at a reasonably well drained upper slope position (node 3), was optimum at a poorly drained lower slope position (node 5), and was deficient at a well to imperfectly drained mid-slope position (node 7).

The trends in soil organic matter also support this implication. Higher organic matter content is generally associated with more productive soils (Janzen *et al.* 1992). This trend was reflected in one of the fields studied (Hythe), but the difference in organic matter between the high yielding group of nodes and the low yielding group of nodes was less than 1 %, and the low yielding nodes still had 7 % organic matter content, which is generally considered to be a sufficient amount (Lickacz, 1985). At the Huallen site, one of the lower yielding areas along the transect had much higher organic matter content than the more productive areas along the transect, and another of the lower yielding areas had the same amount of soil organic matter as the more productive areas, and yet the yield was lower.

The findings for crop quality provide yet another example. The South Peace River region is not considered to have even marginal opportunities for grain protein premiums (Sawatzky and Finn, 1998), however, grain protein content was high enough in portions of the wheat field in this study, to be eligible for a premium. If the season had been drier, and if a HRS cultivar had been grown instead of a CPS variety, the opportunities to harvest high protein wheat in this field may have also been more extensive (Fowler, 1998).

These contradictions, however, are not surprising because the general expectations regarding soil fertility, or relationships between soil fertility and productivity in the South Peace River region, are indeed generalizations, and are likely to have contradictory inclusions. The point is, if management is going to be successfully resolved to the sub-field level, supporting research and dissemination of agronomic information will need to be adapted to this level as well. If farmers in the region embrace site specific management, they will be seeking site specific solutions to site specific problems, and general approaches and recommendations will have to be refined.

The results of this study certainly imply that agronomic problems could, and perhaps should be addressed on smaller scales, but they also emphasize the need to keep the bigger management picture in focus as well. For example, to correct limiting factors like sodicity and excess moisture, a good understanding of what is going on in other parts of the field, or even outside field boundaries is required, and alternatives to annual crops may have to be considered (Lickacz, 1993; Wentz, 1997). There is also a caveat to this implication, in that once site specific practices are implemented, activities in one area of the field may change the productive potential in other areas of the field. Integrated management, therefore, is an essential component of site specific management.

The results of this study also emphasize the need for an integrated system of diagnostic techniques. Many of the environmental factors of soil fertility were assessed in this study, and still it was not possible to completely discern limiting factors at some of the low yielding areas within these fields. Farmers in the region will only be able to increase productivity with site specific practices if the factors that are limiting productivity at the sub-field level can be identified and corrected, or at least factored into management decisions. It will likely be necessary to integrate many technologies and areas of expertise to meet this challenge successfully.

One source of information that should not be overlooked is the farmers themselves. The cooperators in this study were well aware of general spatial patterns within their fields, and how these patterns change from year to year (Appendix B). For example, the cooperator at the Hythe site indicated that the north half of that field usually yields better, and the data for 1996 confirm this expectation. The mean grain yield along the northern portion of the transect (nodes 1-5) was 2639.96 kg/ha, whereas the mean grain yield along the southern portion of the transect (nodes 6-10) was 1859.34 kg/ha.

Similarly, the cooperator at the Halcourt site indicated that crop yields are generally higher towards the west end of the field. Although it was not significant, this trend was apparent in 1996. The mean grain yield along the west half of the transect at this site was 5295.6 kg/ha, whereas the mean grain yield along the east half of the transect was 4990.52 kg/ha. The cooperator at the Huallen site suggested that yield patterns in this field tend to be correlated with landscape features and reflect changes in moisture patterns from year to year. The findings of this study concur with the farmer's experience. 1996 was a wet season, and the wetter areas along the transect (nodes 2, 5 and 6) tended to be lower yielding.

The cooperators in this study were also aware of sub-field differences in weed populations and soil properties. For example, the cooperator at the Halcourt site indicated that wild oats was a problem in his field, and that it was a problem throughout the field. The results of this study supported the farmer's observation. Wild oats was present, and present in substantial numbers at all nodes at this site. Similarly, the cooperator at the Hythe site indicated that soils were heavier textured in the south half of the quarter, and the results of this study support this indication as well.

Since farmers in the area are knowledgeable of spatial patterns in their fields, the costs for field mapping and developing the data bases associated with site specific initiatives could be reduced by taking the farmers' knowledge into account. The information farmers can provide could be used to determine what site specific initiatives would be beneficial in the particular fields they manage. Their input could also provide a solid basis for determining how these activities are actually implemented as well. In addition to being end users then, farmers could make a contribution to the development of site specific technologies as well.

THE CONSENSUS

Significant sub-field variability exists in fields used to grow annual crops in the South Peace River region. The nature and extent of sub-field differences in soil fertility, crop growth and weed populations provide some opportunities for farmers in this region, to match herbicide applications, fertilizer applications, harvesting technology and other management practices, more closely to local conditions in their fields. Such opportunities vary among practices, crops and fields, therefore if farmers in the area are going to realize any of the benefits of site specific management, flexible and adaptable site specific tools will have to be developed. An integrated approach will be required in both the development and application of these tools, and research methods and agronomic information will have to be resolved to the sub-field level. Farmers in the region are knowledgeable of spatial patterns in their fields, therefore in addition to being end users of site specific management technology, they can make a contribution to its development.

THE APPLICATIONS

The results of this study could be applied in several ways. These data, for example, can be taken directly to the field. The information compiled for each site will be provided to its respective manager. These farmers then, will have at their disposal the aerial photographs and all the weeds, soils and crop data collected for their field, to adapt and use as they wish. If they choose to do so, these farmers can integrate this information immediately, in part or in whole, into site specific management plans for their field.

These data can also be used to encourage other farmers in the region to think about managing for field variability. Farmers will only consider site specific management if they think that the variability in their fields warrants attention. Since the results of this study provide some quantitative information regarding the nature and extent of field variability in the region, these data may generate some interest in site specific concepts among other growers in the area.

The results of this study could also be applied to further research. These data were collected with the intent of answering specific questions regarding sub-field variability and the implications of this variability for site specific management. This intent was realized, but in the process a large data set of basic soil and crop variables was compiled and linked to known locations in the field. This data set could be used to further explore relationships between management, soil fertility and productivity in this region.

These data could also be used to develop decision support systems for farmers in the region, or validate models currently available for their use. The results of this study could also make a useful contribution to the provincial database for field variability. Most of the studies involving field variability in Alberta have been located in south-central regions of the province. This study, however, provides information for the Gray soil zone.

THE ADDITIONAL NEEDS

The current study answered some of the basic questions regarding the potential for site specific management in the South Peace River region. However, additional studies would be useful. For example, results indicated that opportunities for site specific herbicide application exist in fields of the region, but the window for post-seeding weed assessment is short and field scouting is time consuming. Therefore, practical ways to construct spray maps are needed.

Similarly, opportunities to increase the market value of crops by separating grain on the basis of crop grade also existed in the fields studied, however, methods to do this are not currently available and need to be developed. Nutrient requirements were also significantly variable at the sub-field level, and farmers in the region could benefit from site specific fertilizer application. Grid sampling, however, is costly. Therefore less expensive methods for determining nutrient requirements are also needed.

Geographic information systems are available for handling site specific information, but the interpretation of agronomic information still needs to be resolved to the sub-field level. Models for integrating components of complex soil and crop systems into practical decision support systems need to be developed. Such models will need to be validated for the region (Kryzanowski, 1998). The costs and returns also need to be set to the concepts. New management tools are interesting and exciting, but if they do not pay, farmers cannot afford to use them.

In conclusion, farmers require practical, affordable tools, and site specific technologies need to be developed around these requirements. Farmers are the end users of the information and knowledge that research provides. Farmers are also the ones that put their livelihood on the line when they adopt and apply the technical information we make available to them. Scientists and advisors, therefore, must ensure that the information and knowledge that they provide is accurate, sound and meets current needs. In the South Peace River region, the fields are variable and the farmers are aware of it. The current need is for the tools to manage this variability.

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APPENDICES

APPENDIX A - Soil Descriptions*

Site	Halcourt	Hythe	Huallen
Soil series	**Landry**	**Landry**	**Culp**
Soil order	Solonetzic	Solonetzic	Luvisolic
Subgroup	Black Solod	Black Solod	Orthic Gray
Parent material (PM)	glaciolacustrine	glaciolacustrine	glaciofluvial
PM texture	silt loam & clay loam	silt loam & clay loam	loamy sand & sandy loam
Nodes**	1-9	1, 3, 4, 5, 6, 9	1, 2, 7
Soil series	**Albright**	**Valleyview**	**Leith**
Soil order	Luvisolic	Solonetzic	Luvisolic
Subgroup	Gleyed Dark Gray	Dark Gray Solodized Solonetz	Dark Gray
Parent material (PM)	till (morainal)	Softrock, fine, saline - sodic (paralithic)	glaciofluvial
PM texture	loam and clay loam	silt loam and clay loam	sand & sandy loam
Nodes**	10-12	2, 3, 6, 7, 8, 10	3, 4
Soil series		**Goose*** **	**Wembley (Codner)**
Soil order		Gleysolic	Gleysolic
Subgroup		Orthic Humic	Orthic Humic
Parent material (PM)		glaciolacustrine	glaciofluvial
PM texture		silty clay loam & clay	sandy loam & silt loam
Nodes**		-	5, 6
Soil series		**Prestville*** **	**Eaglesham*** **
Soil order		Gleysolic	Organic
Subgroup		Orthic Gleysol	Typic Mesisol
Parent material (PM)		glaciolacustrine	fen peat
PM texture		clay	fibrous peat

* Knapik and Brierley, 1993; Odynsky *et al.* 1961.

** Only roughly correlated with soils (based on 1: 190,000 soils map).

*** Present at the site, but not likely present along the transect.

APPENDIX B - Producer Questionnaires

Producer Questionnaire -Halcourt Site

Section I: Research Site Identification

General location: Halcourt
Legal land location: NW 28 70 10 W6

Section II: Fall (1995) Field Activities

Soil sampling: _x_ yes __ no
Tillage operations (implements used, number of passes, approximate dates):
- Fall-worked, 1 pass with the heavy-duty cultivator and harrows

Weed control (herbicides used, rates, methods of application, approximate dates):
- None

Fertility (fertilizers used, rates, methods of application):
- None

Other:
- N/A

Section III: The 1996 Field Season

Soil sampling: __yes _x_ no
Spring tillage operations (implements used, number of passes, approximate dates):
- May 22: banded fertilizer with air-seeder.
- May 22: harrow-packed; one pass.

Seeding operations (crop, variety, seed treatment, seeding rate, seeding depth, row spacing, implement used, seeding date, post-seeding packing/harrowing):
- May 23: seeded 2 row barley (B1215) with air-seeder (Flexicoil 800 cultivator).
- 80.7 kg/ha; no seed treatment; 3.8 cm deep.
- 23 cm spacing (spreads seed so that rows are indistinguishable).
- May 24: harrow-packed (1 pass).

Fertility (fertilizers used, rates, methods of application):
- 201.6 kg/ha of 35-16-0-0 (blend). Banded with air-seeder at approximately 7.6 cm deep.

Weed control (herbicides used, rates, methods of application, approximate dates and crop stages):
- June 15: sprayed Assert and Refine (tank mix); ¾ recommended rates. Crop: 3-4 leaf stage.

Pesticides and/or desiccants (products used, rates, methods of application, approximate dates and crop stages):
- None

Harvest operations (methods, implements used, dates, average yield, quality of yield):
- Swathed on September 12th; combined in October.
- Average yield: 3899.8 kg/ha.
- #1 feed.

Other: N/A

Section IV: General Management Practices and Field History

Crop rotation:
- Barley (1996); Peas (1995); Wheat (1994); Canola (1993); Fallow (1992); Barley (1991); Wheat (1990).

Yield history (average yields for previous years - as many as possible):
- 1996: 3899.8 kg/ha.
- 1995: 2017.2 kg/ha.
- 1994: 3025.7 kg/ha.

Herbicide history (products and rates used for as many previous field seasons as possible):
- 1996: Assert and Refine (Group 2 and Group 2)
- 1995: Sencor and Poast (Group 5 and Group 1)
- 1994: Assert and MCPA (Group 2 and Group 4)
- 1993: Hoegrass 284 (Group 1)
- 1992: None
- 1991: Hoegrass and Refine (Group 1 and maybe Group 6 if was Hoegrass II; and Group 2)

Major changes in field activities (relative to 1996) due to crop rotation:
- None

Soil Amendments such as manure or lime (product, rates, dates, methods of application):
- None

Physical soil amendments such as deep-ripping or drainage (methods, dates, implements used):
- None

Other: N/A

Section V: Manager's Comments and Concerns

Do you have any particular soil and/or cropping problems in this field?

- Wild oats became a problem when the chemical did not work properly in 1995 and 1996.

Are these problems spatially variable (i.e. do they vary from place to place in the field)?

- Wild oats were well established throughout this field, in 1996.

Which problem is of the most concern to you and? Why?

- Wild oats, because of the yield loss.

Does your crop yield vary from place to place within this field? If yes, do you notice any particular patterns, or specific areas where yield is particularly high or low?

- Yes, the west end of the field usually yields higher than the east end.

What sources of help or information do you utilize most often, when you require assistance with your management decisions, or need technical information (for example, other producers, publications, crop specialists etc.)? Other producers, elevator managers, DAs or Crop specialists, and the Research Station.

How many hectares do you farm? 532 cultivated.

Any other management concerns or comments (please use backside of page)? N/A

Producer Questionnaire - Hythe Site

Section I: Research Site Identification

General location: Hythe

Legal land location: NW 17 73 10 W6

Section II: Fall (1995) Field Activities

Soil sampling: _x_ yes __no

Tillage operations (implements used, number of passes, approximate dates):

- None.

Weed control (herbicides used, rates, methods of application, approximate dates):

- None.

Fertility (fertilizers used, rates, methods of application):

- None.

Other: N/A

Section III: The 1996 Field Season

Soil sampling: __yes _x_ no

Spring tillage operations (implements used, number of passes, approximate dates):

- May 17th: cultivated with shovels (3.8-5 cm deep).
- May 18th: Knifed in NH_3 (later learned of the uneven application).

Seeding operations (crop, variety, seed treatment, seeding rate, seeding depth, row spacing, implement used, seeding date, post-seeding packing/harrowing):

- CPS wheat (AC Taber).
- Seeded May 18th; 100 +/- lb/ac; 1 inch seeding depth.
- No seed treatment.
- John Deer DD press drill with 18 cm spacings.
- Harrowed on May 19th with chain harrows.

Fertility (fertilizers used, rates, methods of application):

- May 18th: Knifed in NH_3; 67.2 kg/ha. (actual N)
- May 18th: Applied 12-51-0-0 with the seed; 22.4 kg/ha. (actual P_2O_5)

Weed control (herbicides used, rates, methods of application, approximate dates and crop stages):

- May 25th: .2.024 L Roundup (Group 9) and 141.68 ug MCPA (Group 4) per ha; (pre-emergent).
- June 20th: 1.21g/ha Ally (Group 2).

Pesticides and/or desiccants (products used, rates, methods of application, approximate dates and crop stages):

- Sept 15th: 0.4 L/ha of Roundup (Group 9); pre-harvest.

Harvest operations (methods, implements used, dates, average yield, quality of yield):

- Straight combined some. Swathed and combined the rest after the snow (after Thanks-giving).
- Grade: CW feed.
- Average yield: 2689.5 kg/ha.

Other: N/A

Section IV: General Management Practices and Field History

Crop rotation: This is the first year this cooperator has managed this field.

- Intends to grow peas (south part) and canola (north part) in 1997.
- Canola was grown in 1995.
- See file for some management notes from the previous owners.

Yield history (average yields for previous years - as many as possible):

- N/A, see above.
- Previous owners mentioned that their canola yields were highly variable (112 kg/ha-1681kg/ha).

Herbicide history (products and rates used for as many previous field seasons as possible):

- 1996: Roundup (Group 9); MCPA (Group 4); Ally (Group 2).
- Before 1995: Unknown.

Major changes in field activities (relative to 1996) due to crop rotation: (intended)

- Tillage to get rid of harvest ruts.
- Use air drill instead of DD press drill.

Soil Amendments such as manure or lime (product, rates, dates, methods of application):

- None.

Physical soil amendments such as deep-ripping or drainage (methods, dates, implements used):

- If time allows, improve drainage with D7 cat, on the south-west corner.

Other: N/A

Section V: Manager's Comments and Concerns

Do you have any particular soil and/or cropping problems in this field?

- Clay soil in the south half of quarter is less productive. Lower OM?
- Some wet and low spots.

Are these problems spatially variable (i.e. do they vary from place to place in the field)?

- Yes

Which problem is of the most concern to you and? Why?

- Drainage in some areas.
- Where do I drain to, as field is low.

Does your crop yield vary from place to place within this field? If yes, do you notice any particular patterns, or specific areas where yield is particularly high or low?

- Yes
- North side is best.

What sources of help or information do you utilize most often, when you require assistance with your management decisions, or need technical information (for example, other producers, publications, crop specialists etc.)? All the help I can get!

How many hectares do you farm? 223 in crop in 1996; 494 in crop in 1997.

Any other management concerns or comments (please use backside of page)? N/A

Producer Questionnaire - Huallen Site

Section I: Research Site Identification

General location: Huallen

Legal land location: SW and NW 16 70 9 W6

Section II: Fall (1995) Field Activities

Soil sampling: __yes _X_ no

Tillage operations (implements used, number of passes, approximate dates):

- Fall-worked; deep tillage cultivator; one pass.

Weed control (herbicides used, rates, methods of application, approximate dates):

- None

Fertility (fertilizers used, rates, methods of application):

- None

Other: N/A

Section III: The 1996 Field Season

Soil sampling: __yes _x_ no

Spring tillage operations (implements used, number of passes, approximate dates):

- Chisel-plow; one pass; May.
- Light-duty cultivator; 15 cm spacing; 23 cm sweeps; 2 passes; May.

Seeding operations (crop, variety, seed treatment, seeding rate, seeding depth, row spacing, implement used, seeding date, post-seeding packing/harrowing):

- Seeded barley (6 row feed; Brier)
- Treated with formaldehyde.
- 15 cm; 5 cm seeding depth.
- 107.6 kg/ha rate.
- Nodes 1-3 were seeded June 7th; nodes 4-7 were seeded June 10th.
- DD press drill.
- Harrowed after seeding (1 pass)

Fertility (fertilizers used, rates, methods of application):

- 61.6 kg/ha anhydrous NH_3; knife-banded in the spring; 12-inch spacing. (product) May 30.
- 56 kg/ha 11-55-0-0; through the drill, with the seed. (product)

Weed control (herbicides used, rates, methods of application, approximate dates and crop stages):

- Avadex BW; 13.44 kg/ha; spring-applied; chisel-plow.
- MCPA amine (Group 4) and Ally (Group 2); 60% of label rates; 3L stage; sprayed sometime near the end of June (after the 27th).

Pesticides and/or desiccants (products used, rates, methods of application, approximate dates and crop stages):

- None.

Harvest operations (methods, implements used, dates, average yield, quality of yield):

- Swathed in October 1996; combined in the spring of 1997.
- Average yield: 1344.8-1613.7 kg/ha.
- Grade: #2 feed

Other: N/A

Section IV: General Management Practices and Field History

Crop rotation:

- Seven years of barley (1990-1996).

Yield history (average yields for previous years - as many as possible):

- 3227.4 kg/ha.

Herbicide history (products and rates used for as many previous field seasons as possible):

- 1996: Avadex BW (Group 8), MCPA amine (Group 4) and Ally (Group 2)
- 1995: Avadex BW (Group 8)
- 1994: MCPA amine (Group 4) and Ally (Group2)
- 1993; Avadex BW (Group 8)
- 1990-1992: no chemical used.

Major changes in field activities (relative to 1996) due to crop rotation:

- None, except reduced spring tillage when Avadex was not used.

Soil Amendments such as manure or lime (product, rates, dates, methods of application):

- None.

Physical soil amendments such as deep-ripping or drainage (methods, dates, implements used):

- None.

Other: N/A

Section V: Manager's Comments and Concerns

Do you have any particular soil and/or cropping problems in this field?

- The hollows often stay too wet and the knolls dry out too quickly.

Are these problems spatially variable (i.e. do they vary from place to place in the field)?

- Yes, see above.

Which problem is of the most concern to you and? Why?

- During dry years, we have a tough time growing a decent crop on the sandy knolls. Yields are reduced.

Does your crop yield vary from place to place within this field? If yes, do you notice any particular patterns, or specific areas where yield is particularly high or low?

- Yes.
- It all depends on the weather, but during drier years, the yield is lower on the sandy ridges/knolls; and higher in the flatter and lower lying areas. On drier years, yields are also higher around the spring in the middle of the field.
- On wet years it is difficult to get a crop established on parts of this field.

What sources of help or information do you utilize most often, when you require assistance with your management decisions, or need technical information (for example, other producers, publications, crop specialists etc.)? Publications and other producers.

How many hectares do you farm? 405-607 hectares.

Any other management concerns or comments (please use backside of page)? N/A

APPENDIX C - Commercial Grades

Halcourt Site
(B1215 Barley, Two-row)

Grades

1. Malting, Special Select, Canadian Western, Two-row (MSSCW2R)
2. Malting, Select, Canadian Western, Two-row (MSCW2R)
3. Extra Number one, Canadian Western (X1CW)
4. Number one, Canadian Western (1CW)
5. Number two, Canadian Western (2CW)
6. Sample, Canadian Western (SCW)

Hythe Site
(AC Taber Wheat)

Grades

1. Number one, Canada Prairie Spring Red (1CRPS)
2. Number two, Canada Prairie Spring Red (2CRPS)
3. Feed, Canadian Western (CWFEED)
4. Sample, Canadian Western (SCW)

Huallen Site
(Brier Barley, Six-row)

Grades

1. Extra Number one, Canadian Western (X1CW)
2. Number one, Canadian Western (1CW)
3. Number two, Canadian Western (2CW)
4. Sample, Canadian Western, Light weight (SCWLW)

SOURCE: Hartman Nagel
Canadian Grain Commission
August 26, 1997

APPENDIX D - Sample Calculations for Selected Soil Properties

Sample calculation of Soil NO_3-N

1. Calculate the net peak height (NPH) for the sample extract, from the autoanalyzer chart.

   NPH = peak height for the sample - base line
   Sample extract peak height (from chart) = **16.4**
   Baseline (from chart) = **11.4**

   NPH for sample extract = **16.4 - 11.4**
   = **5.0**

2. Calculate the concentration of NO_3-N in the sample extract from the standard curve (generated by linear regression of peak height on standard concentrations of NO_3-N).

   Y = NPH
   X = [NO_3-N] ug/ml
   Standard Curve: Y = **-.083 + 7.403(X)**

   Rearrange: Extract [NO_3-N] ug/ml = $\frac{\text{NPH - (-.083)}}{7.403}$

   Sample extract: Extract [NO_3-N] ug/ml = $\frac{\textbf{5.0 - (-.083)}}{\textbf{7.403}}$
   = **0.687** ug/ml

3. Calculate the [NO_3-N] mg/kg in the soil.

   Mass of soil (air dry) = **2** g
   Volume of extractant = **20** ml
   Soil [NO_3-N] mg/kg = Extract [NO_3-N] $\frac{\text{ug}}{\text{ml}} \times \frac{\text{ml of extractant}}{\text{g of soil}} \times \frac{10^3 \text{ g}}{\text{kg}} \times \frac{\text{mg}}{10^3 \text{ ug}}$
   Soil sample: Soil [NO_3-N] mg/kg = **0.687** ug/ml x (**20** ml/**2** g) x (10^3 g/kg) x (mg/10^3 ug)
   = **6.87** mg/kg

4. Express on an oven dry basis.

   Soil [NO_3-N] mg/kg on an oven dry basis = Soil [NO_3-N] mg/kg x $(1 + \frac{\text{\% water}}{100})$
   Water content of the air dry soil sample = **3.4** %

   Soil sample: Soil [NO_3-N] mg/kg, oven dry = **6.87** mg/kg x (**1.034**)
   = **7.1** mg/kg

Note: Calculations for other soil macronutrients were similar to these for NO_3-N.

Sample Calculation of Mean Weight Diameter (MWD) for Water Stable Aggregate Analysis

Sieve	Class	Midpoint of class	Percent of sample
a	0-0.125 mm	0.063 mm	27.5022
A	0.125-0.246 mm	0.186 mm	3.7534
B	0.246-0.495 mm	0.370 mm	5.0589
C	0.495-0.991 mm	0.743 mm	7.5884
D	0.991-1.981 mm	1.486 mm	8.4860
E	1.981-3.962 mm	2.972 mm	16.6047
F	3.962-7.924 mm	5.943 mm	31.0064
			total = 100

MWD = [(a x 0.063) + (A x 0.186) + (B x 0.37) + (C x 0.743) + (D x 1.486) + (E x 2.972) + (F x 5.943)]/ 100

MWD of the sample = [(27.5022 x 0.063) + (3.7534 x 0.186) + (5.0589 x 0.37) + (7.5884 x 0.743) + (8.4860 x 1.486) + (16.6047 x 2.972) + (31.0064 x 5.943)]/ 100
= 2.56 mm

Sample Calculation of Percent Sand, Silt and Clay

1. Calculate percent sand in the mineral fraction of the sample.

Percent sand in the sample = (oven dry mass of sand retained on the sieve/oven dry mass of the mineral portion of the sample) x 100
Oven dry mass of sand retained on the sieve = 2.016 g
Oven dry mass of the mineral portion of the sample = 9.255 g
Percent sand in the sample = (2.016 g/9.255 g) x 100
= 21.78 %

2. Calculate the summation percentages (P) for the sample, at 270 and 1080 minutes.

Co = Oven dry mass of the mineral portion of the sample in the cylinder (g/l)
R = Hydrometer reading for sample (g/l in suspension)
R_L = Hydrometer reading for reagent blank (g/l in suspension)

P = summation percentage (i.e. percent of sample in suspension)
= 100 x [(R-R_L)/Co]

__270 minutes__
Co = 9.255 g/l
R = 8.00 g/l
R_L = 5.00 g/l
Temperature = 22.5 °C
P = 100 x [(8.00 g/l -5.00 g/l)/9.255 g/l]
= 32.415 %

__1080 minutes__
Co = 9.255 g/l
R = 7.50 g/l
R_L = 5.00 g/l
Temperature = 21.5 °C
P = 100 x [(7.50 g/l -5.00 g/l)/9.255 g/l]
= 27.012 %

3. Determine the particle size (X) that corresponds with the hydrometer and temperature readings at 270 and 1080 minutes (directly from tables in McKeaque, 1978).

X at 270 minutes = 3.1 microns
X at 1080 minutes = 1.6 microns

4. Plot summation percentages (P) against particle size (X), and interpolate to read percent of particles less than 2 microns (i.e. percent clay in the sample)

$X1 = 1.6$ microns
$X2 = 3.1$ microns
$Y1 = 27.012\ \%$
$Y2 = 32.415\ \%$

Enter these data into "two-point form" of the line between these points:

$$Y - Y1 = \frac{Y2 - Y1}{X2 - X1}(X - X1)$$

$$Y - 27.012 = \left(\frac{32.415 - 27.012}{(3.1 - 1.6)}\right)(X - 1.6)$$

Simplify and rearrange into "slope-intercept form"

$$Y = 3.6X + 21.25$$

Solve for X = 2 microns

$$Y = 3.6(2) + 21.25$$
$Y = 28.45\ \%$ clay in the mineral fraction of the sample

5. Calculate percent silt in the mineral fraction of the sample.

Percent silt = 100 - (percent sand + percent clay)
Percent silt = 100 - (21.78 + 28.45)
= 49.77 %

Sample Calculation of Soil Organic Carbon

PDC = Potassium dichromate (0.1667 Molar $\simeq$ 1 Normal)
FASH = ferrous ammonium sulfate hexahydrate
(exact normality determined by standardization procedure)

ml_{BB} = mean ml of FASH required to titrate the boiled blanks
ml_{UB} = mean ml FASH required to titrate the unboiled blanks
ml_{SAMP} = ml FASH required to titrate the sample

Soil mass = 0.2039 g
ml_{BB} = 24.08 ml
ml_{UB} = 25.23 ml
ml_{SAMP} = 14.18 ml

1. Standardize the normality of FASH (B).

$$B = \frac{\text{(ml of PDC in unboiled blank) x (Normality of PDC)}}{ml_{UB}}$$

$$= \frac{(5\text{ ml}) \times (1\text{Normal})}{25.23\text{ ml}}$$

= 0.1982 Normal

2. Calculate the ml of FASH equivalent to the amount of PDC reduced (A).

$$A = [(ml_{BB} - ml_{SAMP}) \times (ml_{UB} - ml_{BB})/ml_{UB}] + (ml_{BB} - ml_{SAMP})$$

$$A = [(24.08 - 14.18) \times (25.23 - 24.08)/25.23] + (24.08 - 14.18)$$
$$= 10.35 \text{ ml}$$

3. Calculate SOC (formula on p. 572 of Nelson and Sommers, 1982).

$$\% \text{ SOC} = \frac{A \times B \times 0.003 \times 100}{\text{g air dry soil}}$$

$$\% \text{ SOC} = \frac{10.35 \times 0.1982 \times 0.003 \times 100}{.2039}$$

$$= 3.018 \%$$

4. Convert % SOC to mg/g.

$$\% \text{ SOC} = \frac{\text{g SOC}}{\text{g soil}} \times 100$$

$$\text{SOC g} = \frac{\% \text{ SOC}}{100} \times \text{g soil}$$

$$\text{SOC mg} = \frac{\% \text{ SOC}}{100} \times \text{g soil} \times \frac{10^3 \text{ mg SOC}}{\text{g SOC}}$$

$$\frac{\text{SOC mg}}{\text{g soil}} = \frac{3.018}{100} \times \frac{10^3 \text{ mg SOC}}{\text{g SOC}}$$

$$= 30.18 \text{ mg/g}$$

5. Express on an oven dry basis.

Water content of the air dry soil sample = 2.4 %

$$\text{Oven dry SOC mg/g} = \text{SOC mg/g} \times \left(1 + \frac{\% \text{ water}}{100}\right)$$
$$= 30.18 \text{ mg/g} \times (1 + 0.024)$$
$$= 30.91 \text{ mg/g}$$

APPENDIX E - Statistical Tables

Halcourt Crop Variables
(Model: *variable* = node)

Dependent Variable: Grain yield (kg/ha)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	13087356.40000000	1189759.67272728	1.81	0.0790
Error	48	31606303.67600040	658464.65991668		
Corrected Total	59	44693660.07600050			

R-Square	C.V.	Root MSE	GYLD Mean
0.292824	18.93330	811.45835378	4285.88000000

Dependent Variable: Grain protein (%)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	22.52300000	2.04754545	5.47	0.0001
Error	48	17.97136000	0.37440333		
Corrected Total	59	40.49436000			

R-Square	C.V.	Root MSE	PROT Mean
0.556201	7.570961	0.61188507	8.08200000

Dependent Variable: Thousand kernel weight (g)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	43.39253833	3.94477621	4.05	0.0003
Error	48	46.73112000	0.97356500		
Corrected Total	59	90.12365833			

R-Square	C.V.	Root MSE	KWT Mean
0.481478	2.239136	0.98669397	44.06583333

Dependent Variable: Test weight (kg/hl)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	31.20868880	2.83715353	3.97	0.0004
Error	46	32.90991830	0.71543301		
Corrected Total	57	64.11860710			

R-Square	C.V.	Root MSE	TESTWT Mean
0.486734	1.098165	0.84583273	77.02234483

Dependent Variable: Crop density (plants/m2)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	55857.90169492	5077.99106317	5.90	0.0001
Error	47	40442.20000000	860.47234043		
Corrected Total	58	96300.10169492			

R-Square	C.V.	Root MSE	CPDEN Mean
0.580040	23.15001	29.33380883	126.71186441

Dependent Variable: Crop development (Haun units)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	6.21152000	0.56468364	9.15	0.0001
Error	48	2.96192000	0.06170667		
Corrected Total	59	9.17344000			

R-Square	C.V.	Root MSE	CPDEV Mean
0.677120	2.436331	0.24840827	10.19600000

Dependent Variable: Weed density (plants/m2)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	1222842.93333333	111167.53939394	9.54	0.0001
Error	48	559284.00000000	11651.75000000		
Corrected Total	59	1782126.93333333			

R-Square	C.V.	Root MSE	TPD Mean
0.686171	35.99709	107.94327214	299.86666667

Halcourt Soil Variables
(Model: *variable* = node)

Dependent Variable: Soil moisture (July; θ)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	256.45783333	23.31434848	2.60	0.0111
Error	48	430.23200000	8.96316667		
Corrected Total	59	686.68983333			

R-Square	C.V.	Root MSE	MOISTJU Mean
0.373470	11.98421	2.99385482	24.98166667

Dependent Variable: Soil moisture (September; θ)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	278.84545614	25.34958692	9.82	0.0001
Error	45	116.17700000	2.58171111		
Corrected Total	56	395.02245614			

R-Square	C.V.	Root MSE	MOISTSP Mean
0.705898	4.062540	1.60677040	39.55087719

Dependent Variable: Bulk density (0-15 cm; Mg/m3)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.28552500	0.02595682	20.04	0.0001
Error	48	0.06216000	0.00129500		
Corrected Total	59	0.34768500			

R-Square	C.V.	Root MSE	BLKDEN1 Mean
0.821217	3.077051	0.03598611	1.16950000

Dependent Variable: Bulk density (15-30 cm; Mg/m3)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.22540500	0.02049136	15.90	0.0001
Error	48	0.06188000	0.00128917		
Corrected Total	59	0.28728500			

R-Square	C.V.	Root MSE	BLKDEN2 Mean
0.784604	2.591481	0.03590497	1.38550000

Dependent Variable: Penetration resistance (0-5 cm; MPa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	17.16405333	1.56036848	1.96	0.0544
Error	48	38.21432000	0.79613167		
Corrected Total	59	55.37837333			

R-Square	C.V.	Root MSE	PR05 Mean
0.309941	90.98526	0.89226211	0.98066667

Dependent Variable: Penetration resistance (5-10 cm; MPa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	9.10152000	0.82741091	1.22	0.3031
Error	48	32.68472000	0.68093167		
Corrected Total	59	41.78624000			

R-Square	C.V.	Root MSE	PR510 Mean
0.217811	38.09722	0.82518584	2.16600000

Dependent Variable: Penetration resistance (10-15 cm; MPa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	5.73049924	0.52095448	1.49	0.1688
Error	47	16.47895500	0.35061606		
Corrected Total	58	22.20945424			

R-Square	C.V.	Root MSE	PR1015 Mean
0.258021	20.31729	0.59212842	2.91440678

Dependent Variable: Penetration resistance (15-20 cm; MPa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	4.12753833	0.37523076	0.99	0.4650
Error	48	18.11136000	0.37732000		
Corrected Total	59	22.23889833			

R-Square	C.V.	Root MSE	PR1520 Mean
0.185600	18.66969	0.61426379	3.29016667

Dependent Variable: Penetration resistance (20-30 cm; MPa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	5.48200500	0.49836409	1.38	0.2145
Error	48	17.37288000	0.36193500		
Corrected Total	59	22.85488500			

R-Square	C.V.	Root MSE	PR2030 Mean
0.239861	17.41023	0.60161034	3.45550000

Dependent Variable: Mean weight diameter of soil aggregates (mm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	6.64125333	0.60375030	2.35	0.0205
Error	48	12.31032000	0.25646500		
Corrected Total	59	18.95157333			

R-Square	C.V.	Root MSE	MWD Mean
0.350433	14.63370	0.50642374	3.46066667

Dependent Variable: Percent sand (0-15 cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	93.01662398	8.45605673	6.07	0.0001
Error	47	65.45591500	1.39267904		
Corrected Total	58	158.47253898			

R-Square	C.V.	Root MSE	SAND1 Mean
0.586957	6.158954	1.18011823	19.16101695

Dependent Variable: Percent sand (15-30 cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	190.94992364	17.35908397	1.99	0.0516
Error	47	410.82879500	8.74103819		
Corrected Total	58	601.77871864			

R-Square	C.V.	Root MSE	SAND2 Mean
0.317309	24.71485	2.95652468	11.96254237

Dependent Variable: Percent clay (0-15 cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	2285.62511492	207.78410136	34.59	0.0001
Error	47	282.36538000	6.00777404		
Corrected Total	58	2567.99049492			

R-Square	C.V.	Root MSE	CLAY1 Mean
0.890044	6.170597	2.45107610	39.72186441

Dependent Variable: Percent clay (15-30 cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	7533.51148364	684.86468033	12.68	0.0001
Error	47	2539.22003500	54.02595819		
Corrected Total	58	10072.73151864			

R-Square	C.V.	Root MSE	CLAY2 Mean
0.747911	14.25087	7.35023525	51.57745763

Dependent Variable: pH in water (0-15 cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.91133333	0.08284848	15.53	0.0001
Error	48	0.25600000	0.00533333		
Corrected Total	59	1.16733333			

R-Square	C.V.	Root MSE	PHW1 Mean
0.780697	1.341635	0.07302967	5.44333333

Dependent Variable: pH in water (15-30 cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	1.92983333	0.17543939	5.61	0.0001
Error	48	1.50000000	0.03125000		
Corrected Total	59	3.42983333			

R-Square	C.V.	Root MSE	PHW2 Mean
0.562661	3.244601	0.17677670	
5.44833333			

Dependent Variable: pH in $CaCl_2$ (0-15 cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	1.90324138	0.17302194	59.40	0.0001
Error	46	0.13400000	0.00291304		
Corrected Total	57	2.03724138			

R-Square	C.V.	Root MSE	PHCC1 Mean
0.934225	1.059720	0.05397262	5.09310345

Dependent Variable: pH in $CaCl_2$ (15-30 cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	2.44183333	0.22198485	7.61	0.0001
Error	48	1.40000000	0.02916667		
Corrected Total	59	3.84183333			

R-Square	C.V.	Root MSE	PHCC2 Mean
0.635591	3.367384	0.17078251	5.07166667

Dependent Variable: EC (0-15 cm; mmohs/cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.04827017	0.00438820	6.67	0.0001
Error	47	0.03094000	0.00065830		
Corrected Total	58	0.07921017			

R-Square	C.V.	Root MSE	EC1 Mean
0.609394	9.978785	0.02565732	0.25711864

Dependent Variable: EC (15-30 cm; mmohs/cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.03384310	0.00307665	16.17	0.0001
Error	46	0.00875000	0.00019022		
Corrected Total	57	0.04259310			

R-Square	C.V.	Root MSE	EC2 Mean
0.794568	6.907876	0.01379193	0.19965517

Dependent Variable: Soil organic carbon (0-15 cm; mg/g)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	3672.23583333	333.83962121	51.00	0.0001
Error	48	314.22140000	6.54627917		
Corrected Total	59	3986.45723333			

R-Square	C.V.	Root MSE	SOC1 Mean
0.921178	6.604181	2.55856975	38.74166667

Dependent Variable: Soil organic carbon (15-30 cm; mg/g)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	661.53864475	60.13987680	16.04	0.0001
Error	47	176.24804000	3.74995830		
Corrected Total	58	837.78668475			

R-Square	C.V.	Root MSE	SOC2 Mean
0.789627	13.54134	1.93648091	14.30050847

Hythe Crop Variables
(Model: *variable* = node)

Note: Contrast "E" = nodes (1,4,5) vs. nodes (2,3,6,7,8,9,10)

Dependent Variable: Grain yield (kg/ha)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	29794177.55280000	3310464.17253334	11.44	0.0001
Error	40	11576585.55199990	289414.63880000		
Corrected Total	49	41370763.10479990			

R-Square	C.V.	Root MSE	GYLD Mean
0.720175	23.91364	537.97271195	2249.64800000

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	20702766.54175230	20702766.54175230	71.53	0.0001

Dependent Variable: Grain protein (%)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	45.50913000	5.05657000	4.57	0.0004
Error	40	44.30272000	1.10756800		
Corrected Total	49	89.81185000			

R-Square	C.V.	Root MSE	PROT Mean
0.506716	9.237344	1.05241057	11.39300000

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	9.74411667	9.74411667	8.80	0.0051

Dependent Variable: Thousand kernel weight (g)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	711.05188800	79.00576533	18.00	0.0001
Error	40	175.60084000	4.39002100		
Corrected Total	49	886.65272600			

R-Square	C.V.	Root MSE	KWT Mean
0.801951	5.140577	2.09523770	40.75880000

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	237.35296038	237.35296038	54.07	0.0001

Dependent Variable: Test weight (kg/hl)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	382.16592858	42.46288095	17.97	0.0001
Error	40	94.52243400	2.36306085		
Corrected Total	49	476.68836258			

R-Square	C.V.	Root MSE	TESTWT Mean
0.801710	2.072033	1.53722505	74.18922000

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	77.63587921	77.63587921	32.85	0.0001

Dependent Variable: Crop density (plants/m2)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	37169.17959184	4129.90884354	12.95	0.0001
Error	39	12433.80000000	318.81538462		
Corrected Total	48	49602.97959184			

R-Square	C.V.	Root MSE	CPDEN Mean
0.749334	18.03204	17.85540211	99.02040816

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	15429.12815077	15429.12815077	48.40	0.0001

Dependent Variable: Total dry matter (Mg/ha)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	213.53017800	23.72557533	20.41	0.0001
Error	40	46.49080000	1.16227000		
Corrected Total	49	260.02097800			

R-Square	C.V.	Root MSE	TDM Mean
0.821204	21.11328	1.07808627	5.10620000

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	157.35034371	157.35034371	135.38	0.0001

Dependent Variable: Crop development (Haun units)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	3.71026449	0.41225161	4.52	0.0004
Error	39	3.55896000	0.09125538		
Corrected Total	48	7.26922449			

R-Square	C.V.	Root MSE	CPDEV Mean
0.510407	3.267587	0.30208506	9.24489796

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	0.03657282	0.03657282	0.40	0.5304

Dependent Variable: Weed density (plants/m2)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	329370.58000000	36596.73111111	9.70	0.0001
Error	40	150861.60000000	3771.54000000		
Corrected Total	49	480232.18000000			

R-Square	C.V.	Root MSE	TPD Mean
0.685857	47.08853	61.41286510	130.42000000

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	15675.47523810	15675.47523810	4.16	0.0481

Hythe Soil Variables

(Model: *variable* = node)

Dependent Variable: Soil moisture (July; θ)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	1096.17200000	121.79688889	5.75	0.0001
Error	40	847.62800000	21.19070000		
Corrected Total	49	1943.80000000			

R-Square	C.V.	Root MSE	MOISTJU Mean
0.563933	15.75406	4.60333575	29.22000000

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	696.21428571	696.21428571	32.85	0.0001

Dependent Variable: Soil moisture (September; θ)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	1843.20020000	204.80002222	21.93	0.0001
Error	40	373.59600000	9.33990000		
Corrected Total	49	2216.79620000			

R-Square	C.V.	Root MSE	MOISTSP Mean
0.831470	7.289331	3.05612500	41.92600000

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	1166.88343810	1166.88343810	124.94	0.0001

Dependent Variable: Bulk density (0-15 cm; Mg/m3)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	0.43823510	0.04869279	33.72	0.0001
Error	39	0.05632000	0.00144410		
Corrected Total	48	0.49455510			

R-Square	C.V.	Root MSE	BLKDEN1 Mean
0.886120	3.415382	0.03800135	1.11265306

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	0.24882214	0.24882214	172.30	0.0001

Dependent Variable: Bulk density (15-30 cm; Mg/m3)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	0.32384800	0.03598311	14.70	0.0001
Error	40	0.09792000	0.00244800		
Corrected Total	49	0.42176800			

R-Square	C.V.	Root MSE	BLKDEN2 Mean
0.767834	3.717859	0.04947727	1.33080000

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	0.13532038	0.13532038	55.28	0.0001

Dependent Variable: Penetration resistance (0-5 cm; MPa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	12.95400200	1.43933356	1.23	0.3062
Error	40	46.90704000	1.17267600		
Corrected Total	49	59.86104200			

R-Square	C.V.	Root MSE	PR05 Mean
0.216401	62.04318	1.08290166	1.74540000

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	0.09128010	0.09128010	0.08	0.7817

Dependent Variable: Penetration resistance (5-10 cm; MPa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	7.89420200	0.87713356	2.62	0.0175
Error	40	13.39256000	0.33481400		
Corrected Total	49	21.28676200			

R-Square	C.V.	Root MSE	PR510 Mean
0.370850	20.28434	0.57863114	2.85260000

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	1.22812200	1.22812200	3.67	0.0626

Dependent Variable: Penetration resistance (10-15 cm; MPa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	5.62528200	0.62503133	1.96	0.0710
Error	40	12.77436000	0.31935900		
Corrected Total	49	18.39964200			

R-Square	C.V.	Root MSE	PR1015 Mean
0.305728	16.50174	0.56511857	3.42460000

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	0.32560010	0.32560010	1.02	0.3187

Dependent Variable: Penetration resistance (15-20 cm; MPa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	10.67001800	1.18555756	4.14	0.0008
Error	40	11.45268000	0.28631700		
Corrected Total	49	22.12269800			

R-Square	C.V.	Root MSE	PR1520 Mean
0.482311	14.74147	0.53508597	3.62980000

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	1.62997800	1.62997800	5.69	0.0219

Dependent Variable: Penetration resistance (20-30 cm; MPa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	11.25373000	1.25041444	3.26	0.0046
Error	40	15.33752000	0.38343800		
Corrected Total	49	26.59125000			

R-Square	C.V.	Root MSE	PR2030 Mean
0.423212	16.10465	0.61922371	3.84500000

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	1.51240238	1.51240238	3.94	0.0539

Dependent Variable: Mean weight diameter of soil aggregates (mm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	15.66616800	1.74068533	10.96	0.0001
Error	40	6.35228000	0.15880700		
Corrected Total	49	22.01844800			

R-Square	C.V.	Root MSE	MWD Mean
0.711502	12.02057	0.39850596	3.31520000

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	1.22880610	1.22880610	7.74	0.0082

Dependent Variable: Percent sand (0-15 cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	1082.07628200	120.23069800	96.83	0.0001
Error	40	49.66436000	1.24160900		
Corrected Total	49	1131.74064200			

R-Square	C.V.	Root MSE	SAND1 Mean
0.956117	5.589429	1.11427510	19.93540000

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	753.68606486	753.68606486	607.02	0.0001

Dependent Variable: Percent sand (15-30 cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	673.46014939	74.82890549	24.15	0.0001
Error	39	120.86092000	3.09899795		
Corrected Total	48	794.32106939			

R-Square	C.V.	Root MSE	SAND2 Mean
0.847844	12.51316	1.76039710	14.06836735

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	257.66660067	257.66660067	83.15	0.0001

Dependent Variable: Percent clay (0-15 cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	4982.92892000	553.65876889	80.12	0.0001
Error	40	276.40668000	6.91016700		
Corrected Total	49	5259.33560000			

R-Square	C.V.	Root MSE	CLAY1 Mean
0.947445	7.659886	2.62871965	34.31800000

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	2686.08034286	2686.08034286	388.71	0.0001

Dependent Variable: Percent clay (15-30 cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	6069.46596500	674.38510722	30.78	0.0001
Error	39	854.51463500	21.91063167		
Corrected Total	48	6923.98060000			

R-Square	C.V.	Root MSE	CLAY2 Mean
0.876586	8.867941	4.68087937	52.78428571

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	3431.82304455	3431.82304455	156.63	0.0001

Dependent Variable: pH in water (0-15 cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	1.36876087	0.15208454	61.17	0.0001
Error	36	0.08950000	0.00248611		
Corrected Total	45	1.45826087			

R-Square	C.V.	Root MSE	PHW1 Mean
0.938626	0.910160	0.04986092	5.47826087

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	0.46904236	0.46904236	188.67	0.0001

Dependent Variable: pH in water (15-30 cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	26.38320000	2.93146667	49.35	0.0001
Error	40	2.37600000	0.05940000		
Corrected Total	49	28.75920000			

R-Square	C.V.	Root MSE	PHW2 Mean
0.917383	3.871048	0.24372115	6.29600000

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	14.97634286	14.97634286	252.13	0.0001

Dependent Variable: pH in $CaCl_2$ (0-15 cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	1.57178261	0.17464251	39.79	0.0001
Error	36	0.15800000	0.00438889		
Corrected Total	45	1.72978261			

R-Square	C.V.	Root MSE	PHCC1 Mean
0.908659	1.325550	0.06624869	4.99782609

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	0.02176569	0.02176569	4.96	0.0323

Dependent Variable: pH in $CaCl_2$ (15-30 cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	28.96820000	3.21868889	61.08	0.0001
Error	40	2.10800000	0.05270000		
Corrected Total	49	31.07620000			

R-Square	C.V.	Root MSE	PHCC2 Mean
0.932167	3.908151	0.22956481	5.87400000

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	17.38286667	17.38286667	329.85	0.0001

Dependent Variable: EC (0-15 cm; mmohs/cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	4.98624625	0.55402736	90.58	0.0001
Error	38	0.23243500	0.00611671		
Corrected Total	47	5.21868125			

R-Square	C.V.	Root MSE	EC1 Mean
0.955461	13.98157	0.07820940	0.55937500

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	3.01901586	3.01901586	493.57	0.0001

Dependent Variable: EC (15-30 cm; mmohs/cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	36.10489125	4.01165458	70.66	0.0001
Error	38	2.15734000	0.05677211		
Corrected Total	47	38.26223125			

R-Square	C.V.	Root MSE	EC2 Mean
0.943617	18.37255	0.23826898	1.29687500

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	22.07119909	22.07119909	388.77	0.0001

Dependent Variable: Soil organic carbon (0-15 cm; mg/g)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	1130.01192367	125.55688041	16.34	0.0001
Error	39	299.58646000	7.68170410		
Corrected Total	48	1429.59838367			

R-Square	C.V.	Root MSE	SOC1 Mean
0.790440	6.599662	2.77158873	41.99591837

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	269.22983183	269.22983183	35.05	0.0001

Dependent Variable: Soil organic carbon (15-30 cm; mg/g)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	512.61648800	56.95738756	4.73	0.0003
Error	40	482.09024000	12.05225600		
Corrected Total	49	994.70672800			

R-Square	C.V.	Root MSE	SOC2 Mean
0.515344	16.49327	3.47163593	21.04880000

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
E	1	22.82784038	22.82784038	1.89	0.1764

Huallen Crop Variables
(Model: *variable* = node)

Note: Contrast "A" = nodes (3,7) vs. nodes (5,6)
Contrast "B" = nodes (3,7) vs. node (2)

Dependent Variable: Grain yield (kg/ha)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	66262777.22342860	11043796.20390470	21.73	0.0001
Error	28	14231389.98399990	508263.92800000		
Corrected Total	34	80494167.20742850			

R-Square	C.V.	Root MSE	GYLD Mean
0.823200	33.37032	712.92631316	2136.40857143

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	59197931.78450000	59197931.78450000	116.47	0.0001
B	1	28505101.63333330	28505101.63333330	56.08	0.0001

Dependent Variable: Grain protein (%)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	15.67103429	2.61183905	4.15	0.0042
Error	28	17.63032000	0.62965429		
Corrected Total	34	33.30135429			

R-Square	C.V.	Root MSE	PROT Mean
0.470582	9.456490	0.79350758	8.39114286

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	1.54012500	1.54012500	2.45	0.1291
B	1	0.03267000	0.03267000	0.05	0.8215

Dependent Variable: Thousand kernel weight (g)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	684.16162857	114.02693810	24.49	0.0001
Error	28	130.38840000	4.65672857		
Corrected Total	34	814.55002857			

R-Square	C.V.	Root MSE	KWT Mean
0.839926	7.224803	2.15794545	29.86857143

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	557.56800000	557.56800000	119.73	0.0001
B	1	28.22700000	28.22700000	6.06	0.0202

Dependent Variable: Test weight (kg/hl)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	3263.67191455	543.94531909	54.95	0.0001
Error	27	267.28929195	9.89960341		
Corrected Total	33	3530.96120650			

R-Square	C.V.	Root MSE	TESTWT Mean
0.924301	5.555854	3.14636352	56.63150000

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	2279.10187930	2279.10187930	230.22	0.0001
B	1	11.05832653	11.05832653	1.12	0.2999

Dependent Variable: Crop density (plants/m2)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	10952.74285714	1825.45714286	6.87	0.0001
Error	28	7434.80000000	265.52857143		
Corrected Total	34	18387.54285714			

R-Square	C.V.	Root MSE	CPDEN Mean
0.595661	9.412884	16.29504745	173.11428571

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	0.20000000	0.20000000	0.00	0.9783
B	1	235.20000000	235.20000000	0.89	0.3547

Dependent Variable: Total dry matter (Mg/ha)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	199.86594857	33.31099143	13.21	0.0001
Error	28	70.58264000	2.52080857		
Corrected Total	34	270.44858857			

R-Square	C.V.	Root MSE	TDM Mean
0.739016	29.25798	1.58770544	5.42657143

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	132.45804500	132.45804500	52.55	0.0001
B	1	123.62700000	123.62700000	49.04	0.0001

Dependent Variable: Crop development (Haun units)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	15.24150857	2.54025143	42.31	0.0001
Error	28	1.68128000	0.06004571		
Corrected Total	34	16.92278857			

R-Square	C.V.	Root MSE	CPDEV Mean
0.900650	2.426298	0.24504227	10.09942857

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	12.92832000	12.92832000	215.31	0.0001
B	1	5.42725333	5.42725333	90.39	0.0001

Dependent Variable: Weed density (plants/m2)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	3622508.57142857	603751.42857143	23.69	0.0001
Error	28	713704.40000000	25489.44285714		
Corrected Total	34	4336212.97142857			

R-Square	C.V.	Root MSE	TPD Mean
0.835408	30.93045	159.65413511	516.17142857

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	67280.00000000	67280.00000000	2.64	0.1154
B	1	2122148.03333333	2122148.03333333	83.26	0.0001

Huallen Soil Variables
(Model: *variable* = node)

Dependent Variable: Soil moisture (July; θ)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	4438.64267647	739.77377941	234.32	0.0001
Error	27	85.24350000	3.15716667		
Corrected Total	33	4523.88617647			

R-Square	C.V.	Root MSE	MOISTJU Mean
0.981157	5.792753	1.77684177	30.67352941

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	3828.14450000	3828.14450000	1212.53	0.0001
B	1	1015.00833333	1015.00833333	321.49	0.0001

Dependent Variable: Soil moisture (September; θ)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	3646.89369697	607.81561616	141.10	0.0001
Error	26	112.00266667	4.30779487		
Corrected Total	32	3758.89636364			

R-Square	C.V.	Root MSE	MOISTSP Mean
0.970203	5.676467	2.07552279	36.56363636

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	2893.42976190	2893.42976190	671.67	0.0001
B	1	265.22133333	265.22133333	61.57	0.0001

Dependent Variable: Bulk density (0-15 cm; Mg/m3)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	1.55062000	0.25843667	205.35	0.0001
Error	27	0.03398000	0.00125852		
Corrected Total	33	1.58460000			

R-Square	C.V.	Root MSE	BLKDEN1 Mean
0.978556	2.793355	0.03547560	1.27000000

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	0.39986941	0.39986941	317.73	0.0001
B	1	0.16725333	0.16725333	132.90	0.0001

Dependent Variable: Bulk density (15-30 cm; Mg/m3)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	0.66323429	0.11053905	31.76	0.0001
Error	28	0.09744000	0.00348000		
Corrected Total	34	0.76067429			

R-Square	C.V.	Root MSE	BLKDEN2 Mean
0.871903	3.972111	0.05899152	1.48514286

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	0.21840500	0.21840500	62.76	0.0001
B	1	0.04563000	0.04563000	13.11	0.0011

Dependent Variable: Mean weight diameter of soil aggregates (mm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	24.54062857	4.09010476	22.38	0.0001
Error	28	5.11800000	0.18278571		
Corrected Total	34	29.65862857			

R-Square	C.V.	Root MSE	MWD Mean
0.827436	13.48082	0.42753446	3.17142857

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	20.88968000	20.88968000	114.29	0.0001
B	1	6.23808000	6.23808000	34.13	0.0001

Dependent Variable: Penetration resistance (0-5 cm; MPa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	6.87749714	1.14624952	1.59	0.1880
Error	28	20.22892000	0.72246143		
Corrected Total	34	27.10641714			

R-Square	C.V.	Root MSE	PR05 Mean
0.253722	97.28321	0.84997731	0.87371429

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	0.10512500	0.10512500	0.15	0.7057
B	1	0.88752000	0.88752000	1.23	0.2771

Dependent Variable: Penetration resistance (5-10 cm; MPa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	14.47538647	2.41256441	4.22	0.0040
Error	27	15.42384000	0.57125333		
Corrected Total	33	29.89922647			

R-Square	C.V.	Root MSE	PR510 Mean
0.484139	29.31179	0.75581303	2.57852941

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	0.95484500	0.95484500	1.67	0.2070
B	1	0.00768000	0.00768000	0.01	0.9086

Dependent Variable: Penetration resistance (10-15 cm; MPa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	14.43652647	2.40608775	11.85	0.0001
Error	27	5.48170000	0.20302593		
Corrected Total	33	19.91822647			

R-Square	C.V.	Root MSE	PR1015 Mean
0.724790	13.78553	0.45058398	3.26852941

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	5.56512500	5.56512500	27.41	0.0001
B	1	0.16875000	0.16875000	0.83	0.3700

Dependent Variable: Penetration resistance (15-20 cm; MPa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	13.20901714	2.20150286	10.34	0.0001
Error	28	5.95960000	0.21284286		
Corrected Total	34	19.16861714			

R-Square	C.V.	Root MSE	PR1520 Mean
0.689096	14.25551	0.46134895	3.23628571

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	4.29664500	4.29664500	20.19	0.0001
B	1	0.44896333	0.44896333	2.11	0.1575

Dependent Variable: Penetration resistance (20-30 cm; MPa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	10.35155429	1.72525905	5.15	0.0011
Error	28	9.38720000	0.33525714		
Corrected Total	34	19.73875429			

R-Square	C.V.	Root MSE	PR2030 Mean
0.524428	16.82621	0.57901394	3.44114286

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	6.20498000	6.20498000	18.51	0.0002
B	1	1.88000333	1.88000333	5.61	0.0250

Dependent Variable: Mean weight diameter of soil aggregates (mm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	24.54062857	4.09010476	22.38	0.0001
Error	28	5.11800000	0.18278571		
Corrected Total	34	29.65862857			

R-Square	C.V.	Root MSE	MWD Mean
0.827436	13.48082	0.42753446	3.17142857

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	20.88968000	20.88968000	114.29	0.0001
B	1	6.23808000	6.23808000	34.13	0.0001

Dependent Variable: Percent sand (0-15 cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	21888.65991429	3648.10998571	621.79	0.0001
Error	28	164.28024000	5.86715143		
Corrected Total	34	22052.94015429			

R-Square	C.V.	Root MSE	SAND1 Mean
0.992551	4.607885	2.42222035	52.56685714

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	15800.06898000	15800.06898000	2692.97	0.0001
B	1	136.06440333	136.06440333	23.19	0.0001

Dependent Variable: Percent sand (15-30 cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	23146.11010857	3857.68501810	665.01	0.0001
Error	28	162.42672000	5.80095429		
Corrected Total	34	23308.53682857			

R-Square	C.V.	Root MSE	SAND2 Mean
0.993031	4.905473	2.40851703	49.09857143

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	17566.44264500	17566.44264500	3028.20	0.0001
B	1	224.78981333	224.78981333	38.75	0.0001

Dependent Variable: Percent clay (0-15 cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	8250.26246857	1375.04374476	388.10	0.0001
Error	28	99.20320000	3.54297143		
Corrected Total	34	8349.46566857			

R-Square	C.V.	Root MSE	CLAY1 Mean
0.988119	10.24903	1.88227825	18.36542857

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	5816.77832000	5816.77832000	1641.78	0.0001
B	1	293.09376333	293.09376333	82.73	0.0001

Dependent Variable: Percent sand (15-30 cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	23146.11010857	3857.68501810	665.01	0.0001
Error	28	162.42672000	5.80095429		
Corrected Total	34	23308.53682857			

R-Square	C.V.	Root MSE	SAND2 Mean
0.993031	4.905473	2.40851703	49.09857143

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	17566.44264500	17566.44264500	3028.20	0.0001
B	1	224.78981333	224.78981333	38.75	0.0001

Dependent Variable: pH in water (0-15 cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	18.41485714	3.06914286	142.28	0.0001
Error	28	0.60400000	0.02157143		
Corrected Total	34	19.01885714			

R-Square	C.V.	Root MSE	PHW1 Mean
0.968242	2.227264	0.14687215	6.59428571

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	9.66050000	9.66050000	447.84	0.0001
B	1	8.32133333	8.32133333	385.76	0.0001

Dependent Variable: pH in water (15-30 cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	8.42220588	1.40370098	123.25	0.0001
Error	27	0.30750000	0.01138889		
Corrected Total	33	8.72970588			

R-Square	C.V.	Root MSE	PHW2 Mean
0.964775	1.481599	0.10671874	7.20294118

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	5.92944118	5.92944118	520.63	0.0001
B	1	3.61250000	3.61250000	317.20	0.0001

Dependent Variable: pH in $CaCl_2$ (0-15 cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	21.10171429	3.51695238	189.37	0.0001
Error	28	0.52000000	0.01857143		
Corrected Total	34	21.62171429			

R-Square	C.V.	Root MSE	PHCC1 Mean
0.975950	2.117042	0.13627703	6.43714286

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	13.12200000	13.12200000	706.57	0.0001
B	1	9.86133333	9.86133333	530.99	0.0001

Dependent Variable: pH in CaCl2 (15-30 cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	12.58685714	2.09780952	118.42	0.0001
Error	28	0.49600000	0.01771429		
Corrected Total	34	13.08285714			

R-Square	C.V.	Root MSE	PHCC2 Mean
0.962088	1.961400	0.13309503	6.78571429

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	8.97800000	8.97800000	506.82	0.0001
B	1	5.37633333	5.37633333	303.50	0.0001

Dependent Variable: EC (0-15 cm; mmohs/cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	1.77282853	0.29547142	132.97	0.0001
Error	27	0.05999500	0.00222204		
Corrected Total	33	1.83282353			

R-Square	C.V.	Root MSE	EC1 Mean
0.967266	12.59991	0.04713849	0.37411765

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	1.02960029	1.02960029	463.36	0.0001
B	1	0.15265333	0.15265333	68.70	0.0001

Dependent Variable: EC (15-30 cm; mmohs/cm)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	1.21289188	0.20214865	369.42	0.0001
Error	25	0.01368000	0.00054720		
Corrected Total	31	1.22657188			

R-Square	C.V.	Root MSE	EC2 Mean
0.988847	8.477393	0.02339231	0.27593750

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	0.89460364	0.89460364	1634.88	0.0001
B	1	0.05985333	0.05985333	109.38	0.0001

Dependent Variable: Soil organic carbon (0-15 cm; mg/g)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	13609.41681250	2268.23613542	920.59	0.0001
Error	25	61.59767500	2.46390700		
Corrected Total	31	13671.01448750			

R-Square	C.V.	Root MSE	SOC1 Mean
0.995494	6.169383	1.56968373	25.44312500

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	7046.92911076	7046.92911076	2860.06	0.0001
B	1	3.04008333	3.04008333	1.23	0.2772

Dependent Variable: Soil organic carbon (15-30 cm; mg/g)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	288.34910424	48.05818404	12.20	0.0001
Error	26	102.41172000	3.93891231		
Corrected Total	32	390.76082424			

R-Square	C.V.	Root MSE	SOC2 Mean
0.737917	19.33405	1.98466932	10.26515152

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
A	1	91.67410714	91.67410714	23.27	0.0001
B	1	2.10145333	2.10145333	0.53	0.4717

THE END
DEO GRATIAS!