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INFLUENCE OF SOIL PROPERTIES ON CROP RESPONSE TO PHOSPHATE FERTILIZER

by

© LEONARD MITCHELL KRYZANOWSKI

A THESIS

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J.A. Robertson

Supervisor

Robert T. Hardin

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Date 1982-04-26

DEDICATION

To my parents, in appreciatio [illegible] ne encouragement and support giv[illegible] me.

ABSTRACT

The objective of this study was to determine the influence of site properties on the response of barley, rapeseed, and wheat to phosphate fertilizer in Alberta. Yield and site data from 254 field experiments from the period of 1969 to 1975 were assembled. Additional information, including site classification (agro-climatic area, soil zone, and soil order), and laboratory analysis of particle size distribution, $CaCO_3$ equivalence, and organic matter content of the surface depth of the field sites were determined. Discriminant analysis was used to determine those site properties important for the separation of sites into responsive and unresponsive categories. Multiple regression procedures were used to determine those site variables which could significantly account for the variation in yield increase of the responsive sites. Principal component analysis was used to identify the interrelationships among site properties of the responsive sites.

Analyses of the pooled barley data for 125 site-years indicated that the soil test for phosphorus (ASFTL-P) was the most important site variable influencing site separation, and for the variation in yield increase of the responsive sites. Clay and $CaCO_3$ content of the soil and growing season precipitation were additional variables which appeared to be important for site separation, while soil pH, growing season precipitation and organic matter content of soils were additional co-variates that significantly accounted for the variation in yield increase of the responsive sites. Site classification had a significant influence on both site separation and variation in yield increase. Principal component analysis indicated an inverse relationship between the required phosphate fertilizer rate for "optimum" yield and each of ASFTL-P, soil pH, and organic matter content of soils.

Analyses of the pooled rapeseed data for 91 site-years indicated that the soil test for phosphorus (ASFTL-P) was the most important site parameter affecting site separation, and for the variation in yield increase of the responsive sites. Other site variables which appeared to be important for site separation were soil electrical conductivity (E.C.) and clay content of soils, while $CaCO_3$ was the only additional variable to significantly account for the variation in yield increase. Site classification appeared to be important for site separation, but did not significantly account for any of the variation in yield increase. Principal component analysis revealed an inverse relationship between the required phosphate fertilizer rate for "optimum" yield and each of ASFTL-P, soil pH, organic matter content of soils and growing season precipitation.

Results of the analyses of the pooled wheat data for 38 site-years indicated that a soil test for phosphorus was the most important site variable to influence site separation, and for the variation in percent yield increase of the

responsive sites. However, the specific soil test procedure varied among the results of the discriminant analyses. Other site properties influencing site separation included organic matter content of soils, and soil E.C., while soil E.C. was the only additional variable to significantly account for the variation in percent yield increase. Site classification did not appear to have a clear influence on either site separation or the variation in percent yield increase. Principal component analysis of the responsive sites indicated an inverse relationship between the phosphate fertilizer rate for "optimum" yield and each of soil pH, soil organic matter, and growing season precipitation, but the positive relationship with Olsen-P was contrary to the results of the barley and rapeseed sites, and the expected relationship.

The results of this study lack verification with data external to this study, but suggest that the phosphate fertilizer rate for "optimum" yield should decrease as the soil test for phosphorus (ASFTL-P), soil pH, organic matter content of soils and/or growing season precipitation increase.

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I. INTRODUCTION

For optimum crop growth and nutrition, the soils of western Canada have been generally considered to be low in plant available phosphorus. Phosphate fertilizer application has proven to be benefical in promoting flowering, seed formation, root growth, disease resistance, straw strength, and maturation, in addition to increasing yield. The major problem has been the prediction, by means of a soil test, of phosphate fertilizer requirements and the yield response to phosphate addition.

Numerous soil test procedures for measuring the available phosphorus status of the soil have been developed and used, with varying degrees of success. In western Canada, studies have been conducted to determine the best soil test procedure to measure available phosphorus, predict crop response to phosphate fertilizer, and to determine optimum phosphate fertilizer requirements. In general, greenhouse studies have resulted in better correlations between soil test phosphorus and yield response than have field studies. Field research in Manitoba found that the relationship between percent yield and extractable phosphorus by a number of methods was not very high regardless of how the crops or soils were selected (Soper, 1967). Poor correlations between percent yield for cereal crops and the available phosphorus were also found in field studies conducted in Alberta (Robertson, 1967). All three western Canadian prairie provinces have recognized differences among soils and among climatic areas in regards to soil test phosphorus levels and crop response to phosphate fertilizer. To improve predictions of phosphate fertilizer requirements, attempts have been made at developing new soil test procedures. Alternatively, as more researchers recognize the influence of environmental factors and soil properties other than the fertility status of soils on crop response to fertilizer, the use of more elaborate statistical and modelling techniques has become increasingly common.

The objectives of this study were, by means of discriminant analysis, multiple regression procedures, and principal component analysis,

1. to determine the best soil test procedure for predicting crop response to phosphate fertilizer and to aid in the prediction of "optimum" fertilizer rates.
2. to determine the influence of various chemical and physical soil properties on crop response to phosphate fertilizer.
3. to determine the value of site classification systems in predicting crop response to phosphate fertilizer.

II. LITERATURE REVIEW

A. INTRODUCTION

It has long been recognized that crop yield, both quantity and quality, is a function of the soil on which the crop is grown, the climate, management factors, and the crop itself (Fitts, 1974). The influence of each factor is difficult to discern since each is a broad category consisting of several components, each of which may be modifying or limiting. The fertility status of a soil is but one component of the soil factor, and is composed of several individual elements. Thus it is difficult to predict crop yield from only one variable such as the available soil phosphorus without taking into account the other growth factors. These other growth factors can exert strong influences on yields and fertilizer effects.

When compared with carbon, hydrogen, oxygen, and nitrogen, the phosphorus content of plants is small, in the range of 0.1 to 1.0 %, yet this element is essential for plant nutrition. Its most important function within the plant is that of energy storage and transfer as adenosine triphosphate (ATP) in biochemical processes such as photosynthesis, electron transport, active ion transport, and sucrose transport. In addition, it is an important structural component of numerous compounds, including phospholipids, nucleic acids, phytin, sugar phosphates, and coenzymes (Glass *et al.*, 1980; Wallingford, 1977). All of these compounds and processes are essential for plant metabolism which ultimately determines growth, development, and crop yield.

The phosphate content of plant material is controlled by two factors, the specific, genetically-fixed nutrient uptake potential of plants for phosphorus and the availability of phosphorus in the soil (Mengel and Kirkby, 1978). The ability of the soil to supply phosphorus to plants can be separated into several general factors. Omanwar (1970) defined these factors as (i) intensity, the properties of the soil phosphorus that affects the ease or difficulty of phosphorus withdrawal by plants, (ii) quantity, the total amount of the nutrient reserve in the soil that is available to the plant, and (iii) rate, the transport of phosphorus to roots. Numerous researchers have attempted to relate these factors, either individually or in combination with each other, to crop growth. Studies have shown that these factors are not independent of each other, nor are they independent of the chemical and physical properties of the soil. Recognizing this, various techniques for evaluating and modelling the influence of soil properties on crop response to fertilizer have been used. Therefore, the objectives of this literature review are:

1. to review the concepts of phosphate equilibria in soil and the influence of soil properties on the reactions of added

phosphate fertilizer.

2. to examine some of the techniques that have been used to evaluate the phosphorus fertility status of soils.
3. to review the mathematical models used for characterizing crop response to fertilizer.

B. SOIL PHOSPHORUS EQUILIBRIA AND REACTIONS OF ADDED PHOSPHATES WITH SOIL

The immediate source of phosphorus for the plant is the soil solution, but the phosphate concentration in this solution is very low, in the order of 1 to 0.1 $\mu g\ ml^{-1}$. Within the soil solution, the forms of phosphorus are in equilibrium governed by protonation reactions and ionic complex formations. The ionic species of phosphates that are commonly found in the soil solution include H_3PO_4, $H_2PO_4^-$, HPO_4^{-2}, and PO_4^{-3}, with the most abundant being $H_2PO_4^-$ and HPO_4^{-2} (Larsen, 1967). Also, many metallic ions form soluble complexes of varying stability with phosphorus but following the general order of $Fe^{+3} > Al^{+3} > Mn^{+2} > Ca^{+2}, Mg^{+2} > K^+, Na^+$ (Sillen and Martell, 1964). In addition to this solution equilibrium, solution phosphorus is also in equilibrium with the phosphorus in the solid phase, but such that it heavily favours the solid phase. Hence, it is this latter overall equilibrium which controls the phosphorus concentration in solution. As plant roots remove phosphorus from the soil solution, phosphorus from the solid phase enters the solution phase in an attempt to reestablish the overall equilibrium. The rate of phosphorus dissolution from the solid phase is controlled by the forms of phosphorus in the solid phase which in turn are a function of the physical and chemical properties of the soil.

The influence of the soil environment on the intensity factor, and the chemical properties of orthophosphates in the soil, particularly fertilizer phosphates has been well studied (Swenson *et al*., 1948; Dean, 1949; Wild, 1950; Kurtz, 1953; Olsen, 1953; Hemwall, 1957; Mattingly and Talibudeen, 1967; Williams, 1970; Soper and Racz, 1980). Phosphates added to soils react strongly with various soil components with the most commonly suggested reaction mechanisms being physical and chemical sorption, anion exchange, surface precipitation, and precipitation as separate solid phases. In a review of phosphorus fixation by soils, Hemwell (1957) indicated that the recovery of fertilizer phosphorus by crops amounts to only 10 to 30 % of the quantity added to the soil with the remaining 70 to 90 % being primarily chemically precipitated and physiochemically sorbed by the soil. The soil properties and components that play important roles in these reaction mechanisms include pH, aluminum and iron hydrous oxides, alumino-silicate minerals, carbonates, non-living organic matter, moisture, and the ionic nature of the soil solution.

Time is an important aspect of the reactions of added phosphates with soil and can be separated into initial and long term categories. Soper and Racz (1980) describe the dissolution of fertilizer phosphate granules in moist soils as being fairly rapid, forming a saturated phosphate solution around the granules. As this phosphate rich solution moves into the surrounding soil, alteration of soil constituents and solution composition occurs, resulting in precipitation and adsorption reactions. The initial reaction products are metastable and are altered to more stable and less water soluble products over time, with the rate of alteration being controlled by soil properties and environmental factors. Thomas and Peaslee (1973) found, from fractionation studies, that added phosphates will assume the pattern of native phosphates with time and that over a number of years, the various fractions merely build up, about in proportion to their original content.

The most important soil property which appears to control phosphate behavior in soils, in terms of ionic species, initial chemical reactions and final products, is soil reaction (pH). The prevailing soil pH has a definite relationship with some predominant reaction mechanisms of phosphate retention by soils. As indicated earlier, one of the reactions controlling the species of phosphate ions in solution is protonation. As a result, $H_2PO_4^-$ tends to be the dominant phosphate species under acidic conditions, while HPO_4^{-2} is dominant under alkaline conditions. It is difficult to separate the direct effects of pH on phosphate behavior from those of other soil properties such as mineralogy and exchangeable cations. Extensive reviews by Dean (1949), Wild (1950), Hemwall (1957), Smith (1965), Larsen (1967), Ryden *et al.* (1973), Parfitt (1978), and Soper and Racz (1980) have dealt with the mechanisms of phosphate retention and "fixation" by soils.

In soils with acidic pH, the reactions of added phosphates are dominated by Al, Fe, and, to some extent, Mn to produce basic reaction products. Al and Fe sesquioxides, which can occur as discrete compounds or as coatings on soil particles, have been implicated as playing a significant role in phosphate retention. Depending on time, temperature, pH and phosphate concentration in the soil solution, these compounds can retain large quantities of added phosphate (Wild, 1950). The suggested mechanism by which Fe and Al oxides retain phosphates has been separated into three stages of adsorption occurring at different solution phosphate concentrations: (i) a high energy chemisorption of small amounts of phosphate; (ii) precipitation of a separate phosphate phase; and (iii) a low energy sorption of phosphates onto the precipitate (Bache, 1964). Hingston *et al.*, (1967,1968) have suggested and shown a specific adsorption mechanism for hydrous Fe and Al oxides by which the phosphate is capable of exchanging with edge OH_2 and OH^- groups and becoming coordinated with the Fe or Al ion at the surface. Phosphate adsorption has been correlated with either extractable Al or Fe (Lopez-Hernandez and Burnhan, 1974; Evans and Smillie, 1976; Schwertmann and Knittel, 1973; Myszka and Janowska, 1973) and with exchangeable Al and Fe (Udo and Uzu, 1972). Precipitation of phosphorus by Al and Fe is also considered to be significant by Ghani and Islam (1946) but Hsu (1964) and Fitter and Sutton (1975) found this only in soils having pH less than 5, due to the low activities of Fe^{+3} and Al^{+3} in soil solution at pH values above 5.

In alkaline soils, the reaction of phosphate fertilizer and the solubility of phosphates is influenced by Ca^{+2} and/or Mg^{+2} and CaCO$_3$, resulting in more stable basic Ca and Mg phosphates being formed. Alkaline soils can be separated into calcareous and non-calcareous depending on the presence of carbonates. The reactions of phosphates in a non-calcareous soil would be dominated by exchangeable Ca^{+2} and/or Mg^{+2}. Olsen (1953) demonstrated that if the soil pH is raised by additions of NaOH, the solubility of calcium phosphate increases, but if Ca(OH)$_2$ is added to increase the pH, the solubility of the calcium phosphate decreases as a result of the commom-ion effect. He indicated that the mechanisms for this common-ion effect are precipitation reactions forming calcium phosphates, and adsorption reactions with calcium on clay minerals forming a monolayer. Larsen *et al*. (1965) found that pH was significantly correlated with the half-life of the labile phosphorus measured. They suggested the decrease in labile phosphorus was due to the formation of a crystalline basic calcium phosphate at a rate that increased with pH. The reactions of phosphates in a calcareous soil are again dominated by Ca^{+2} and/or Mg^{+2} with CaCO$_3$ and/or CaMg(CO$_3$)$_2$ acting as a source of calcium and/or magnesium and also as a pH buffer (Soper and Racz, 1980). Bell and Black (1970) found the change of the initial reaction products to more basic compounds was more rapid when CaCO$_3$ was present. Added phosphates also react with the carbonate particles themselves by forming a surface coating on the particles. With time, the layer of phosphate on the carbonate particles may be coated by more carbonates (Thomas and Peaslee, 1973). Parfitt (1978) suggested three steps involved in the reaction: (i) chemisorption of phosphate, accompanied by heterogeneous formation of nuclei of amorphous calcium phosphate; (ii) a slow transformation of these nuclei into crystalline calcium phosphate; and (iii) crystal growth of calcium phosphate. The result is a tendency for the solubility of the "adsorbed" phosphate to decline with time and thus decrease the phosphate availability.

The investigation of the retention of phosphates by alumino-silicate clay minerals have been extensive. Wild (1950) reported that silicate clays could sorb phosphorus by several mechanisms. These include an exchange reaction of phosphates with OH groups on an edge Al-OH (ligand exchange) and/or an anion exchange reaction at a positively charged site developed by the adsorption of protons on -OH groups. Dissolution of clay minerals to release Si and subsequent precipitation of phosphorus as alumino-phosphate compounds has also been proposed, but only at high phosphorus concentrations (Low and Black, 1948,1950; Rajan and Fox, 1975). The rate of phosphate retention by clay minerals generally increases with temperature, concentration of phosphorus, and decreasing pH, and follows a decreasing order of illite, kaolinite, and montmorillonite (Haseman, 1950). Exchangeable cations also influence the retention capacity of clay minerals. As already stated, exchangeable Fe and Al have been correlated with phosphate adsorption under acidic conditions. Kurtz (1953) pointed out that Ca clays retain more phosphates than do Na, NH_4, or K clays. It is possible that the linkage of phosphates to the clay particle may be through exchangeable Ca^{+2} or Mg^{+2} ions acting as a bridge. Blanchet (1974) illustrated the influence of physio-chemical properties of the soil (particularly particle size) on plant nutrition. He compared the amount of phosphate absorbed/gram of root with increasing phosphate additons for two soils, a sandy loam and a clay. The amount absorbed was greater for the sandy loam than the clay due to the higher adsorption properties of the clay.

The influence of organic matter on the retention of phosphates in soil has been studied by many workers. Soil organic matter, and more specifically, humus, is considered to have very little ability to retain phosphates due to its normal negative charge. However, because of this negative charge, it can hold many cations which can react with the phosphate ion. Doughty (1930, 1935) gave evidence that Fe^{+3}, Al^{+3}, and Ca^{+2} ions which are associated with the organic matter can react with phosphates. Several researchers have reported positive relationships between organic matter content of soils and phosphate adsorption (Rennie and McKercher, 1959; Harter, 1969; Hinga 1973; Lopez-Hernandez and Burnhan, 1974; Holford and Mattingly, 1975). By contrast, Moreno *et al.*, (1960) demonstrated that organic matte[illegible] complex Ca ions and thus increase the phosphate concentration in the soil solution from some of the calcium phosphates. Replacement of phosphate ions adsorbed by clay minerals by the humate ion has been shown by Mattson (1931). Nagarajah *et al.*, (1970) found that organic acids were capable of reducing the amount of phosphate adsorbed by kaolinite, gibbsite, and goethite by what they believed to be a ligand exchange mechanism on the mineral surfaces and thus the organic acids compete with phosphates for adsorption sites. Phosphate and organic matter competition has also been suggested for adsorption on $CaCO_3$ surfaces in calcareous soils (Holford and Mattingly, 1975). Thus, the evidence suggests that organic matter may either decrease or increase the ability of soils to adsorb phosphorus.

Soil moisture influences phosphorus nutrition of plants by affecting many soil factors and processes which control the supply of phosphorus to the plant. These include transport rates, adsorption-desorption rates, mineral and precipitate solubility, and mineralization and immobilization rates. As the moisture content of soil decreases, adsorption-desorption equilibria would favour adsorption, the solubility of phosphate minerals and precipitates would decrease, and biological activity would decrease, reducing mineralization of organic phosphorus (Sheppard and Racz, 1980). Olsen *et al.*, (1961) concluded that reducing the soil moisture content reduced phosphorus uptake because (i) it reduces the movement of phosphorus to the root by reducing the thickness of water films which increases the diffusion path length, and (ii) it reduces the amount of phosphorus absorption by the root by reducing the number of root hairs, elongation of roots and turgidity of roots. Simpson (1965), Reichman and Grunes (1966), and Strong and Barry (1980) found that the availability of native phosphorus is more sensitive to soil water content than the availability of fertilizer phosphorus. In additon, Strong and Barry (1980) suggested that the reduced utilization of native soil phosphorus under dry conditions was the result of the reduced soil volume exploited by the stunted root system. As a consequence of this and the relatively high availability of phosphorus in the fertilizer band, there may be a relatively large crop response to phosphorus under arid conditions.

The presence of soluble salts in association with phosphate fertilizer materials influences phosphate availability. The common-ion effects of Ca salts have already been cited as decreasing phosphate availability. An increase in phosphate availability may be accounted for by an increased stimulation of the plant due to the presence of the salts or by chemical effects on the phosphate reaction products in the soil. Addition of nitrogen to a phosphate fertlizer band has been reported by many workers to increase the phosphate absorption by the plant. This has been attributed to (i) increased root growth in the vicinity of the band (Duncan and Ohlrogge, 1956; Grunes *et al.*, 1958; Miller and Ohlrogge, 1958), (ii) increased solubility of the phosphate fertilizer (Bouldin and Sample, 1958, 1959; Starostka and Hill, 1955), (iii) increased metabolic activity of the plant (Cole *et al.*, 1963; Leonce and Miller, 1966; Minshall, 1964), and (iv) a reduction in pH at the soil-root interface, most likely caused by the exchange of H^+ ions from within the root for NH_4^+ or K^+ ions in soil (Miller *et al.*, 1970; Riley and Barber, 1971). Bouldin and Sample (1958), studying the influence of associated salts on plant availability of concentrated superphosphates, found the order of effectiveness to be generally $KNO_3 > (NH_4)_2SO_4 > NH_4NO_3 > NH_4Cl > KCl$. Whatever the mechanism, the literature does indicate a definite increase in phosphate absorption by plants when nitrogen is in close contact with the phosphate fertilizer. Several workers (Mitchell, 1957; Olsen *et al.*, 1954) have demonstrated an appreciable increase in plant availability of rock phosphate and other phosphate carriers from the use of sulphur, while no appreciable influence of potassium on phosphorus uptake could be demonstrated (Olsen *et al* ., 1954; Fine, 1955).

The interaction of phosphorus with other elements in the soil may influence the crop response to phosphate fertilizer and the availability or utilization of many other elements. Nitrogen effects have already been cited, but in addition micronutrient-phosphorus interactions have been studied, as reviewed by Adams(1980). Micronutrient deficiencies, induced by phosphate application, have been noted. Racz and Haluschuk (1970) reported the effects of phosphorus levels on the utilization of Cu, Zn, Fe, and Mn by wheat and flax on Manitoba soils. They found that trace element content and uptake by these crops were reduced in many instances when large amounts of phosphorus were added to soils or nutrient solutions. They concluded that the reduction in trace element uptake was due to the inability of the plant, under high phosphorus levels, to absorb the trace elements. For soils having amounts of available micronutrients which could be considered as bordering on deficiency, addition of phosphate fertilizer could induce micronutrient deficiencies. In order to achieve maximum plant growth, both macro and micro nutrients must not be limiting. Leibig proposed in his Law of the Minimum that the amount of plant growth was controlled by the factor present in the minimum amount, and implied that if two factors are limiting, or nearly limiting growth, adding only one of them will have little effect on growth, while adding both together could have considerable effect (Russell, 1961). Therefore, if a soil is deficient in both phosphorus and a micronutrient, addition of phosphorus alone could result in a small degree of crop response or have no effect on crop growth.

C. EVALUATION OF PHOSPHORUS FERTILITY STATUS OF SOILS

The evaluation of the phosphorus fertility status or quantity factor of soils has been extensively studied (Olsen *et al.*, 1954; Miller and Axley, 1956; Robertson, 1962; Omanwar, 1970; Alexander, 1973; Gwyer, 1979). Omanwar (1970) stated that the use of the term "available" requires that some time limit be specified since all soil phosphorus could be mobilized and made available to plants over an infinite time period. In general, the term has been associated with one crop growth period, and implies that prior to crop growth, the soil has a particular level of phosphorus reserve which could be made available to plants during the growing season.

Various methods for determining the phosphorus fertility status of soils have been developed and used. These include anion exchange resins, radioisotope techniques, and equilibrium isotherm techniques, but the most common method is chemical extraction by one of a variety of solutions including water, acidic solutions, alkaline solutions, and neutral salt solutions. The original approach to the problem was to attempt a dissolution of the same amount of phosphate from the soil as would the plant roots (Russell, 1961). This concept was soon abandoned and the present approach involves selection of a method for which there is a high correlation between extractable soil phosphorus and phosphate uptake, yield, or yield response to phosphate fertilizer. Kamprath and Watson (1980) described the objectives of the phosphorus soil tests as being (i) grouping of soils into classes for the purpose of making phosphate fertilizer recommendations, (ii) prediction of the probability of getting a profitable response to application of phosphate fertilizer, and (iii) providing an index of the amount of phosphorus a soil can supply. These objectives can be restated as (i) separation of soils as responsive or unresponsive to phosphate fertilizer, (ii) prediction of an expected yield response to phosphate fertilizer, and (iii) prediction of the phosphate ferilizer rate that needs to be applied to attain an optimum yield.

The two chemical extraction methods used presently in western Canada are a modification of the acid fluoride solution used by Miller and Axley (1956), and a buffered sodium bicarbonate solution developed by Olsen *et al*., (1954). The Miller and Axley procedure uses a 0.03N NH_4F in 0.03N H_2SO_4 solution. The hydrogen of the H_2SO_4 greatly increases the solubility of all calcium phosphates; in addition it attacks aluminum and iron phosphates, although, the rate of dissolution of the aluminum and iron phosphates is somewhat slower than the calcium phosphates. Generally, it has been observed that the H^+ remove phosphates in the order Ca > Al > Fe. The SO_4^{-2} forms weak complexes with polyvalent metal cations but competes poorly with phosphates for iron and aluminum. Sulphate appears to prevent readsorption of phosphate released by hydrogen ions. Fluoride ions specifically precipitate soluble calcium as

CaF_2 and as a result will extract the more soluble calcium phosphates such as $CaHPO_4$ from the soil. Fluoride also complexes aluminum stongly and frees phosphates bonded to aluminum. The fluoride ion is rather harmless to basic calcium and iron phosphates unless the fluoride solution is acidified (Thomas and Peaslee, 1973). The Miller and Axley procedure is considered most suitable on neutral to slightly acidic soils (Olsen and Dean, 1965). Difficulties may arise when it is used on calcareous soils because of neutralization reaction between carbonates and the acid, resulting in low values for extractable phosphorus (Olsen *et al.*, 1954).

The Olsen procedure uses a 0.5M $NaHCO_3$ solution buffered at pH 8.5. The presence of HCO_3^- decreases the activity of Ca^{+2} by causing precipitation of calcium as $CaCO_3$. This results in increased solubility of calcium phosphates which are thought to be a major source of plant available phosphorus in calcareous soils. In addition, bicarbonate ions remove aluminum bound phosphates, probably by replacement and by aluminum precipitation because of the OH^- ion content in the solution (Thomas and Peaslee, 1973). Extractable phosphorus by the Olsen method is usually better correlated with plant response on calcareous soils than is extractable phosphorus by acidic extraction methods (Olsen *et al.*, 1954). This is thought to be a result of the buffered nature of the extracting solution making it more suitable for extracting calcium phosphates.

The amount of phosphorus extracted by both methods has been found to be highly correlated with "A" value measurements of plant available phosphorus (Olsen *et al*., 1954; Omanwar, 1970; Omanwar and Robertson, 1973). As well, extractable phosphorus by these methods has been shown to be highly correlated with yield response. Robertson (1962) in a greenhouse study of 79 Alberta soils, found that the response of barley was highly correlated with extractable phosphorus as measured by both methods. Correlations ranging from R = 0.73** to R = 0.79** for the Miller and Axley method and correlations of R = 0.73** to R = 0.82** for the Olsen method were found. Numerous other studies in the greenhouse have shown high correlations between phosphorus extracted by these methods and plant response (Olsen *et al*., 1954; Maclean *et al*., 1955; Miller and Axley, 1956; Martar and Samman, 1975). Holford (1980) compared several phosphate extraction procedures to determine the effects of phosphate buffer capacity of a soil under field conditons. The phosphate buffer capacity is the resistance of the soil solution concentration to change when phosphate is added to, or removed from the labile pool (Holford and Mattingly, 1976). Holford's results confirmed that the larger the negative effect of buffer capacity on extraction of labile phosphate by a soil test, the higher was the correlation between the soil test and plant response to phosphate. He found that the Bray (ammonium fluoride) method was the most sensitive to the buffer capacity of a soil while the sodium bicarbonate extraction was less sensitive. Whereas a previous study suggested that the ammonium fluoride test was over-sensitive to buffering, and hence underestimated available phosphate in strongly buffered soils, this field study showed that the test was correctly sensitive to buffering. Consequently critical levels for near-maximum wheat yields do not vary for the ammonium fluoride test, but increase with the increasing buffer capacity for the sodium bicarbonate tests. As a result, an additional measurement of buffer capacity is therefore required to give precision in the use of the sodium bicarbonate soil test.

D. MATHEMATICAL MODELS IN SOIL RESEARCH

Mathematical models are quantitative techniques for expressing the relationship between two or more variables. Numerous statistical procedures have been developed to evaluate, explain, and model experimental results, ranging from purely graphical to multiple regression and multivariate procedures. Probably the first method was by simple observation of the data and arbitrary separation. In an attempt to separate responsive and unresponsive sites to fertilizer application, Cate and Nelson (1965) developed a graphical method for partitioning a scatter of percentage yield versus soil test level into two groups (i) those for which probability of response to added fertilizer is large and (ii) those for which probability of response to added fertilizer is small. They attempted to find the "critical level" soil test value for separating the two groups. In 1971, these same authors outlined a statistical procedure for partitioning soil test correlation data into two classes of probable response to fertilizer (low and high), based upon maximization of the class sum of squares in a one-way analysis of variance. This sum of squares reflects the weighted sum of squares of the difference between the percentage yield means for the various classes and the grand mean. Using this procedure, one finds quantitatively the best divisions from the point of view of maximizing mean differences among classes. These, in turn, should be the best divisions from the point of view of prediction. The use of more elaborate techniques of data analysis have become increasingly common due to the recognization of the influence of many site properties on the results of field experiments or observations. These techniques include yield response functions, multiple regression analyses, simultaneous equations, discriminant function analyses, and principle component analyses. Many of these techniques have been used in soil fertility studies, while others show great promise.

As indicated earlier, crop yield is a function of many growth, or input factors. Dillon (1977) simplified this situation by using a theory of response based on the important input factors. His theory contained three simplifying assumptions,

1. there is a continuous smooth causal relation between the X's (inputs) and Y (outputs);
2. diminishing returns prevail with respect to each input factor, X, so that the additional output from succeeding units of X becomes less and less;
3. decreasing returns to scale prevail so that an equal proportionate increase in all inputs results in a less than proportionate increase in output.

Crop response to successive fertilizer nutrient increments, a single input variable, follows these assumptions.

Some researchers have attempted to develop models for the effect of nutrient application on crop yield on a theoretical basis so that biological and physical meanings can be attached to their parameters. However, care is needed since such models could be used to express a particular bias. Alternatively, models may be chosen for their computational convenience, the statisical estimation of functions from data or to permit calculation of optimal rates. As yet, there is no fundamental theoretical model for the effects of nutrient application on crop yield, but rather the model chosen is empirical, based on observations and experience (Colwell, 1978). In general, the mathematical expressions that have been used to relate crop growth to nutrient levels in the soil fall into three categories, namely; the straight line, the exponential, or the quadratic equation. Response functions for a single nutrient, such as phosphorus, have generally been either exponential or quadratic expressions. Characteristically, the exponential function never reaches a maximum and will never indicate a yield decrease. By contrast, the quadratic function does reach a maximum yield, followed by a yield decrease which could be due to a toxicity level of the factor, induced nutrient deficiency or a depletion of soil water by excessive early vegetative growth stimulated by high fertilizer applications (Melsted and Peck, 1977; Colwell, 1978). As a result, polynomial (quadratic) models are more popular than exponential models. Polynomial functions are easily fitted to data by standard multiple regression procedures and can be made flexible enough to describe most trends and rigid enough to smooth out most errors in data (Colwell, 1978). Johnson (1953) compared quadratic functions with exponential functions for fitting response curves and concluded that the quadratic polynomial model generally gave the better fit and the best results for purposes of interpolation. Anderson and Nelson (1975) however, concluded that the use of second order polynomial models may result in biases in the estimates of optimal fertilizer rates due to a ceiling on the crop yield imposed by environmental or management factors and type of crop.

Multiple regression analysis is an attempt to account for the variation in the dependent variable by a linear combination of independent variables. As mentioned in the previous discussion on yield response functions, multiple regression procedures are commonly used to fit equations to response data, but a more frequent use of multiple regression analysis in soil research has been the combining of a series of similar experiments. Studies using multiple regression analysis deal primarly with crop yield or compositon as influenced by fertility status of soils, fertilizer application, soil chemistry, site topography, and climate (Laird and Cady, 1969; Cady and Allen, 1972; Williams *et al*., 1975; Bole and Pittman, 1980a, 1980b). Agronomic experiments on the same factor or a group of factors are usually repeated for a number of years at one or more locations. Because of the variation in the effect of many factors due to location and year, the results obtained at a single site for a single year are not precise enough as a basis for generalization (Leonard, 1962). Yates and Cochran (1938) stated that it is impossible to lay down rules of procedure for combining several experiments for different years which will be applicable in all cases, and that the results usually require comprehensive examination with special emphasis on certain treatment effects.

The mathematical analysis of a complex problem can lead logically to a system of simultaneous equations (Heapy, 1971). If the model can be divided into specfic stages such that a multi-equation system can be used to describe the model and where such models involve jointly determined variables, simultaneous equations procedure should be used (Dillon, 1977). Heapy *et al.*, (1976a,1976b) used this system of multi-equations to develop a barley yield equation based on the effects of soil and fertilizer nitrogen and phosphorus. As part of this equation, a moisture stress term was included but calculated from a second equation derived from data external to the study.

A special type of statistical analysis that has been used in soil research, as well as geology and biology, to classify an individual into one of two or more groups is discriminant function analysis. The objective of this procedure is to find a linear combination of the variables that maximally discriminate among groups. The technique was first used by Fisher (1936) as a solution to a taxonomic problem and has since found limited application in soil science. Cox and Martin (1937) used the technique to predict the presence of *Azotobacter* on the basis of pH, available phosphorus, and total nitrogen content of the soil sample. Most of the recent applications of discriminant analysis in soil science has been in soil genesis and soil classification (Oertel, 1961; Norris and Loveday, 1971; Bracewell and Robertson, 1973; Berg, 1980; Henderson and Ragg, 1980).

Thus far, all the statistical techniques discussed have been of a single criterion and multiple predictor association, with the exception of the discriminant analysis, of which only the two group situation fits this association, but another type of analysis which has been proposed and used in soil fertility studies is an analysis of variable interdependence, principal component analysis (PCA). Ferrari (1965) illustrated the use of a system of simultaneous equations for modelling the magnesium content of herbage and suggested the use of factor anaylsis or PCA to obtain these equations. Kyuma and Kawaguchi (1973), and Kyuma (1973a,1973b) illustrated the use of PCA as a method of fertility evaluation and grading for paddy soils. Using the new components formed by PCA, they were able to develop a multiple regression equation to account for 57% of the yield variation. Principal component analysis has some advantages over multiple regression. Interpretation of multiple regression analysis is dependent upon the assumption that explanatory variables in the analysis are not strongly interrelated (Chatterjee and Price, 1977). However, the real world, particularly soils, does not behave in this fashion. Even when subjected to various analytical chemical procedures, the analytical results will be influenced by various soil and environmental properties, due to the empirical nature of some procedures. Therefore, use of PCA has potential in identifying and evaluating the interrelationships among soil properties.

III. MATERIALS AND METHODS

A. BACKGROUND OF FIELD DATA

1. Cooperators and Site Design

In 1971, the Risk Adjusted Yield Potential (RAYP) project was initiated in Alberta to collect data for the purpose of improving prediction of fertilizer requirements based on soil tests. It was a joint endeavor involving the University of Alberta, Alberta Agriculture, Western Co-operative Fertilizer Ltd., Sherritt Gordon Mines Ltd., and the Agriculture Canada research stations at Beaverlodge, Lacombe, and Lethbridge. Field plots were set out throughout the province to study both nitrogen and phosphorus fertilizer requirements for a number of years varying with cooperator. In most cases, a one-factor-at-a-time experimental design was used for both nutrients.[1] The exception was Lethbridge Research Station, which used a factorial design. In most cases, there were two test crops, barley and rapeseed.

In addition, data for wheat response to phosphate fertilizer in east-central Alberta were included in the present study.[2] These latter field experiments were conducted over the same years as those of the RAYP project using a similar one-factor-at-a-time experimental design.

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[1] Personal communication with Dr. M. Nyborg.
[2] Personal communication with Dr. J. A. Robertson.

2. Location of Test Sites

There were two main objectives of the RAYP project. The first was to find the potential yielding ability and the fertilizer needs of different textural classes of soils within each soil zone. The second objective was to compare crop response to fertilizer on stubble and fallowed fields.[3] With these objectives in mind, plot sites were selected by each individual cooperator. Legal location of plot sites used in this study and their cropping history are provided in Appendix A.

3. Seeding, Fertilizer Application, and Harvesting

Whenever possible, one crop, namely barley, was common to all experiments in the RAYP project. Galt barley was the most common variety, but some sites were seeded to Betzes or Conquest. Where rapeseed was used, Span was the most common variety but some sites were seeded to Echo or Torch. In general, both barley and rapeseed were grown at a site, but some sites had only one test crop. The wheat sites in east-central Alberta utilized Thatcher wheat. Crop varieties for each site are provided in Appendix A.

For the phosphorus block of each of the RAYP sites, blanket applications of nitrogen, potassium, and sulphur as NH_4NO_3, K_2SO_4, KCl, and Na_2SO_4 were applied either with the seed or side banded. The wheat sites had only a blanket application of nitrogen as NH_4NO_3. The phosphate fertilizer, in the form of treble superphosphate and/or ammonium

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[3] Personal Communication with Dr. M. Nyborg.

phosphate, was generally placed with the seed and/or banded. The number of treatments and phosphate fertilizer rates varied among cooperators, ranging from five to nine including a check, and the number of replicates also varied. Plots were harvested at maturity, air dried, threshed and the grain yield recorded. Yield means for each phosphate treatment at each site used in this study are provided in Appendix F.

4. Soil Sampling

Soil cores were generally taken on a site basis prior to seeding and divided into subdepths of 0-15 cm, 15-30 cm, 30-60 cm, and 60-90 cm. Samples were air dried and several analyses were conducted by the Alberta Agricultural Soil and Feed Testing Laboratory (ASFTL). At the initiation of the author's study, 1977, sites were revisited to collect additional surface samples for physical analysis and determination of organic matter and carbonate content.

5. Growing Season Precipitation

The precipitation during the growing season was recorded for most sites, but some sites lacked these data. For those sites lacking data, approximate values were estimated using meteorological data published by Alberta Environment and records of neighbouring sites. Precipitation values for each site used in the study are presented in Appendix C.

B. ANALYTICAL METHODS

1. Soil Physical Analysis

One composite sample of the 0-15 cm depth of each site was ground to 2 mm using a flail grinder. Particle-size analysis was performed on these samples by the hydrometer procedure (Bouycous, 1951; Toogood and Peters, 1953). Particle-size distribution and textural classification for each site used in the study are presented in Appendix D.

2. Soil Chemical Analysis

Most of the chemical analyses were done by the Alberta Agricultural Soil and Feed Testing Laboratory using composite site samples for each soil depth. $CaCO_3$ equivalence and organic matter content were determined at the University of Alberta on either original samples or subsequent samples.

Soil reaction (pH) was determined on a 1:2 soil:water suspension using a pH meter. Electrical conductivity (E.C.) was determined on the same 1:2 soil:water suspension using a conductivity meter. The conductivity reading was multiplied by a factor of 2.063 to express results on a saturated paste extract equivalent.

Nitrate-nitrogen was determined on a 0.02N $CuSO_4$ plus 0.007N $AgNO_3$ extract using the phenoldisulphonic acid method (Prince, 1945) as described by Heapy (1971). Extractable potassium was determined from a 1:5 soil:ammonium acetate extract using a flame photometer. Extractable phosphorus was determined using three procedures, the Miller and Axley, and

Olsen methods, as described by Alexander *et al*. (1972), and a modified Miller and Axley procedure. This modified procedure utilized a 5 cc (scoop) volume soil sample, 25 ml of the 0.03N NH_4F in 0.03N H_2SO_4 extracting solution and a shaking period of 10 minutes. After filtration, phosphorus in solution was determined on a auto-colorimeter set at 400 nm using a combined nitric vanadate molybdate procedure (Kitson and Mellon, 1947).

$CaCO_3$ equivalence was determined on the 0-15 cm samples using the calcimeter method (Bascomb, 1961). Organic matter content was obtained for the 0-15 cm sample by measuring total carbon by dry combustion using a Leco induction furnace, subtracting the portion that was inorganic carbon and multiplying by a factor of 1.71. Results of the soil chemical analyses are presented in Appendices C and E.

C. SOIL CLASSIFICATION

Many of the sites had been classified by some of the participants of the project. Those sites which were originally unclassified were revisited and classified according to the Canadian System of Classification (1978). Soil classification of each site used in the study are presented in Appendix B.

D. DATA ANALYSIS

1. Response Functions

For consistency in interpretation, only one type of mathematical expression was used for purposes of fitting a curve to the yield data. A second order polynomial equation of the form

$$Y = b_0 + b_1(X) + b_2(X^2)$$

was calculated for each site using the mean yield of each treatment as the Y term and the phosphate fertilizer rates as the X terms. The coefficient values (b_0, b_1, and b_2) for each site-equation are given in Appendix G. The effects of a nutrient application on yield are not immediately obvious from the yield functions. Therefore, a yield increase value was calculated for each site as follows: The maximum yield (Y-max) was calculated for each site by taking the first derivative of the equation, equating it to zero, solving for X (X-max, the fertilizer rate for Y-max) and inserting the value of X-max into the original equation to obtain the Y-max. Ninety percent of Y-max (Y-90%max) was selected as the "optimum yield" for each site since this value would likely be in the upper end of the "linear" portion of the quadratic curve, meaning that the fertilizer rate to obtain this yield should still be providing an economic return (Spencer and Glendinning, 1980). The rate of fertilizer (X-90%max) required for Y-90%max ("optimum" fertilizer rate) was calculated from the original equation. Yield increase was calculated by the difference between Y-90%max and the "b." value or yield at the zero phosphate fertilizer rate. Percent yield increase was calculated by dividing the yield increase by the Y-90%max and multiplying by 100. Percent yield increase was used to remove some of the variation in yield caused by environmental conditions and to take into account maximum yielding potential differences among sites (Colwell, 1978). The percent yield increase was used only for the wheat sites. The yield increase or percent yield increase was used to characterize the magnitude of the yield response to phosphate fertilizer and to provide a common yield term for each site for use in subsequent analyses. As a result of these procedures, sites could be separated into two groups, responsive and unresponsive. Responsive sites were those sites having a yield increase greater than 0.0 100kg/ha (quintal/ha) while unresponsive sites had a yield increase equal to or less than 0.0 100kg/ha. Yield increase and all intermediate values are presented in Appendix H.

2. Multiple Regression and Least Square Analyses of Covariance For Unequal Numbers

The multiple regression function is a linear combination of independent variables that attempts to account for the variation in a dependent variable. The multiple regression equation is expressed in the form

$$Y = b_0 + b_1(X_1) + b_2(X_2) + \ldots\ldots\ldots + bn(Xn)$$

where Y is the predicted value of the dependent variable, b_0 is the intercept of the regression line on the vertical axis; b_1, b_2, ... bn are the partial regression coefficients of Y on X; X_1, X_2, ...Xn are the observed values of the independent variables. The sequence of addition of the independent variables in the regression equation is controlled by the proportion of the variation (R^2) in the dependent variable that is accounted for by the independent variable. The greater the contribution to the overall R^2, the greater the importance that variable has in accounting for the variation in the dependent variable. The level of significance of the regression equation and the individual b values of the independent variables are determined from the calculated F ratio.

In multiple regression analysis, it is necessary to code qualitative variables with dummy values. An effect coding, which uses a 1, 0, -1 coded values, is one of the coding systems used to code qualitative variables. Although such systems of coding are valid for equal subclass numbers, they are most often used for unequal numbers.[4] The intercept, b_0, is an estimate of the grand mean of the dependent variable, Y, and each b is an estimate of the treatment effect for the group with which it is associated i.e., the deviation of the mean of the group from the grand

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[4] Personal communication with Dr. R. Hardin.

mean, Y. Subsequent to obtaining a significant R^2, the mean Y value for each qualitative variable is determined by an analysis of covariance. The effects of the covariates are removed from the analysis and the qualitative variable means are adjusted to a common value of the covariates, usually the mean of the covariates. This type of covariance analysis requires the assumption that the slopes of the regression lines are equal among the qualitative variables. Significant differences between the qualitative variable means are determined by an approximate multiple comparison test. The product difference between two means used in computing, now accounts for the variance and covariance between the qualitative variables and the covariates (Harvey, 1975; Mehlenbacher, 1978; Steel and Torrie, 1980).

In this study, stepwise multiple regression equations were computed for the "responsive" sites. Yield increase was used as the dependent term to determine the influence of soil properties on crop response to phosphate fertilizer using multiple regression procedures. Variables considered for inclusion were: three soil test procedures, a number of quantitative site variables, and qualitative site variables. The use of multiple regression is based on the assumption that the relationships between the dependent variable and the independent variables are linear. To determine whether or not this was in fact the case, the dependent variables (yield increase or percent yield increase) were plotted against each of the soil test phosphorus variables using a scattergram program. Visual examination of the scattergrams indicated that a nonlinear relationship did exist. The natural logarithmic transformation was regarded as best approximating a linear relationship where originally a nonlinear relationship existed. The effectiveness of the transformation was evaluated by the contribution to the overall correlation between the dependent variable and the best set of independent variables before and after transformation. The contribution to the overall correlation between the dependent variable and the set of independent variables should be greater for transformed independent variables than for the non-transformed independent variables. The natural logarithmic-transformed variables were subsequently used as separate independent variables in evaluating classification variables. It should be noted that if the non-transformed variable was equal to 0, then 0 was used for the value of the natural logarithmic transformation.

After establishing the best combination of quantitative variables, the classification dummy variables were inserted into the analysis using an effect coding (Appendix I).[5] Analysis of covariance for unequal numbers was used to calculate qualitative treatment means at the means of the quantitative covariates. Student-Newman-Keuls' test was used for approximate comparison of these means (Steel and Torrie, 1980).

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[5] Personal communication with Dr. R. Hardin.

3. Discriminant Analysis

In theory, the discriminant function is a linear combination of independent variables with a dependent variable that represents group membership. With only two groups, discriminant function analysis amounts to multiple regression analysis with the dependent variable taking the values of 1 and 0 (Kerlinger and Pedhazur, 1973). Stepwise discriminant analysis begins as a simple one-way analysis of variance, based on the highest F value of the variable that best discriminates between groups. A second discriminating variable is selected as the one best able to improve the power of discrimination in combination with the first variable. At each step, variables may be removed if they reduce discrimination when combined with more recently selected variables. Eventually, all variables which significantly contibute to the discriminating power are included. (Klecka, 1975; Berg, 1979).

The discriminant function is expressed in the form

$$D = d_0 + d_1Z_1 + d_2Z_2 + \ldots\ldots + dpZp$$

for unstandardized data and in the form

$$D = d_1Z_1 + d_2Z_2 + \ldots\ldots + dpZp$$

for standardized data. D represents the score on the discriminant function, d_0 is the constant, the d's are the weighting coefficients, and the Z's are the values of the p discriminanting variables used in the analysis. Ideally, the discriminant scores (D's) for the cases within a particular group will be fairly similar. At any rate, the function is formed in such a way as to maximize the separation of the groups. The sequential addition of the independent variables to the function is dependent upon their discriminating power. The greater its ability to separate the groups, the greater the importance that variable has in the function. The relative importance of each variable is determined from the standardized discriminant function coefficients. When the sign is ignored, each coefficient represents the relative contribution of its associated variable to that function. The sign merely denotes whether the variable in making a positive or negative contribution (Klecka, 1975).

The effectiveness of a discriminant function can be judged by two measurements. The total discriminatory power (TDP) which is a measure of the total variability of the function attributable to group differences can be calculated using the function eigenvalue which is a measure of the total variance existing in the discriminatory variables (Appendix J). A further aid in judging the importance of a discriminant function is its associated canonical correlation, a measure of how closely the function and the "group variable" are related. The canonical correlation squared can be interpreted as the proportion of variance in the discriminant function explained by the groups. The statistical significance of the function can be measured by the chi-square statistic.

The resulting equation indicates to which group each member probably "belongs". Thus the function can be used for predictive purposes to determine the membership of an unknown into one of the groups based on its measurement of certain properties as defined by the function (Kerlinger and Pedhazur, 1973). Classification is achieved through the use of a series of classification functions, one for each group. Classification equations are derived from the pooled within-groups covariance matrix and the centroids for the discriminating variables. The resulting classification coefficients are to be multiplied by the raw variable values, summed together, and added onto a constant. The equation for one group would appear as

$$Ci = ci_1V_1 + ci_2V_2 + \ldots\ldots + cipVp + ci_0$$

where Ci is the classification score for group i, the cij's are the classification coefficients with ci_0 being the constant, and the V's are the raw scores on the discriminating variables. There is always a separate equation for each group and a case would be classified into the group with highest score (Klecka, 1975).

For this study, a stepwise discriminant analysis program was used to compare three soil phosphorus test procedures, select the optimal set of discriminating variables and to compute discriminant functions to separate responsive and unresponsive sites. The responsive sites were coded as 1 and the unresponsive sites were coded as 0. The effect of the natural logarithmic transformation of the phosphorus soil tests was determined. The effectiveness of this transformation was evaluated by the contribution to the canonical correlation between group membership before and after transformation. The contribution to the overall correlation should be greater for the transformed variable than the non-transfromed variable. If this was the case, then the natural logarithmic transformed variable was subsequently used as a separate independent variable in evaluating classification variables. It should again be noted that if the non-transformed variable was equal to 0, then the natural logarithmic transformation was assigned a value of 0. The criterion used to select discriminating variables was to maximize the Mahalonobis distance between the two groups. The procedure is fairly straight forward for data composed of only measured variables, but data consisting of both measured and qualitative variables tend to be more troublesome. Krzanowski (1980) demonstrated a method of discriminant analysis for mixtures of categorical and continuous variables using a binary (1, 0) coding of the categorical variables. The overall error rate was reduced when compared to a weighted coding (0, 1, 2), but still remained high. Kendall (1975) stated that there appears as yet to be no satisfactory theory to deal with this situation. He proposed either a dummy coding system or alternatively, a separate discriminant function for each class of the qualitative classification. Both procedures were tried in the present study using the effect coding for the dummy system and a separate discriminant analysis for each qualitative class containing sufficient members. For the dummy system technique, the procedure used was to first find the optimum set of independent measured variables using the stepwise procedure based on maximizing the Mahalonobis distance. Then, using a direct computing program option which enters all independent variables into the analysis concurrently, the dummy variables were included with the optimum set of measured variables. This is to insure that all dummy variables were included in the discriminant function. The stepwise procedure was only used for determining a separate discriminant analysis for each class of the qualitative classification.

4. Principal Component Analysis

In theory, principal component analysis (PCA) or factor analysis is a statistical procedure used to interpret within the variance-covariance matrix of a multivariate data collection (Davies, 1973). Rummel (1967) described the working of factor analysis as taking numerous measurements and qualitative observations and resolving them into distinct patterns of occurrence. No particular assumption about the underlying structure of the variables is required. The process of principal component analysis can be separated into two steps. First a correlation matrix of the variables involved is computed as a measure of association. The second step is the extraction from the correlation matrix of initial components as eigenvalues and eigenvectors such that the components are orthogonal or independent of each other (Kim, 1975).

Principal component analysis transforms a given set of variables into a new set of composite variables that would account for more variance in the data as a whole than any other linear combination of variables. The second component is defined as the second best linear combination of variables, under the condition that the second component is orthogonal to the first, and therefore can be defined as the linear combination of variables that accounts for the most residual variance after the effect of the first component is removed from the data. Subsequent components are defined similarly until all the variance in the data is exhausted (Kim, 1975).

In this study, a principal component analysis program was used to determine the interrelationships present among the independent variables for the responsive sites. The variables were standardized such that each variable had a mean of zero and a unit variance to ensure a normal distribution. This allows one to compare the distribution of one variable to that of another when the two variables are expressed in different units of measurement (Davies, 1973).

5. Selection of Independent Variables

The variables chosen for the discriminant, multiple regression and principal component analyses were those considered to have an influence on the availability of soil phosphorus and crop response to phosphate fertilizer. These included soil chemical and physical properties, and qualitative classification variables. A problem that did arise during the study was missing data for Olsen-P, and Miller and Axley-P soil tests for some sites as a result of loss of original samples. Also, because of multicollinearity problems, % clay, % silt, and % sand variables could not all be used at the same time for the disciminant and principal component analyses. As a result, only % sand and/or % clay was used.

The qualitative variables used in this study included agro-climatic area, soil zone, and soil order classifications. Agro-climatic area classification was determined from the Agro-climatic Areas of Alberta map (Bowser, 1967) while soil zone classification of each site was based on the Soil Zones of Alberta map (Odynsky, 1962) and identification of the soil great group using the Canadian System of Soil Classification (1976). Soil order classification according to the Canadian System of Soil Classification (1976) was based on profile examination for each site.

IV. RESULTS AND DISCUSSION

This chapter is divided into four sections. The first three sections deal specifically with the results and discussion of the individual crops studied. Each crop section is further divided into the three statistical procedures used, discriminant analysis, multiple regression analysis, and principal component analysis. The final section deals with the potential sources of error within this study.

A. Barley

The results presented in this section represent the statistical analyses of the yield response of barley to phosphate fertilizer for 125 sites. A brief summary of the chemical and physical characteristics of the field sites used are presented in Tables 1 and 2, while frequency distribution of the sites in regards to three types of site classification and textural classes are presented in Table 3. In general, the sites used in this study represented a wide variety of site conditions for both the responsive and unresponsive groups. The means and standard deviations of each independent variable were almost equal between the two groups. The most noteworthy difference between the two groups was a lower mean value of all three soil test methods, ASFTL-P, M & A-P, and Olsen-P, for both depths of the responsive sites. The distribution of the responsive and unresponsive sites among the classification

Table 1. Mean, Standard Deviation, Maximum, and Minimum Values of the Independent Site Variables for the Unresponsive Barley Sites

Variables*	Mean	Std. Dev.	Max.	Min.	No. of Sites
pH (0-15)	6.91	0.60	8.0	5.4	60
pH (15-30)	7.07	0.74	8.4	5.0	60
E.C. (0-15)	0.41	0.30	2.3	0.2	60
E.C. (15-30)	0.48	0.63	4.5	0.2	60
% O.M. (0-15)	5.32	2.53	14.7	1.2	60
% $CaCO_3$ (0-15)	0.17	0.57	3.6	0.0	60
% sand (0-15)	32.23	18.85	78.6	3.3	60
% silt (0-15)	36.51	11.87	58.0	4.0	60
% clay (0-15)	31.24	16.67	81.7	8.2	60
Pptn.	22.29	7.80	41.9	7.4	60
ASFTL-P(0-15)	49.0	39.3	218.4	4.5	60
Ln ASFTL-P(0-15)	3.64	0.73	5.39	1.50	60
ASFTL-P(15-30)	22.5	43.5	213.9	0.0	60
Ln ASFTL-P(15-30)	1.97	1.48	5.37	0.0	60
M & A-P(0-15)	51.2	39.7	221.8	5.6	57
Ln M & A-P(0-15)	3.70	0.70	5.40	1.72	57
M & A-P(15-30)	26.1	43.4	207.2	0.0	57
Ln M & A-P(15-30)	2.50	1.19	5.33	0.0	57
Olsen-P(0-15)	37.1	18.3	122.1	11.2	57
Ln Olsen-P(0-15)	3.52	0.42	4.81	2.42	57
Olsen-P(15-30)	22.6	17.0	89.6	6.7	57
Ln Olsen-P(15-30)	2.93	0.58	4.50	1.91	57

* Variable	Units
E.C.	mmhos/cm
Pptn.	cm
ASFTL-P	kg/ha
M & A-P	kg/ha
Olsen-P	kg/ha

Table 2. Mean, Standard Deviation, Maximum, and Minimum Values of the Independent Site Variables for the Responsive Barley Sites

Variables*	Mean	Std. Dev.	Max.	Min.	No. of Sites
pH (0-15)	6.76	0.76	8.3	5.2	65
pH (15-30)	6.83	1.02	8.4	4.5	65
E.C. (0-15)	0.36	0.15	0.8	0.1	65
E.C. (15-30)	0.36	0.17	0.8	0.1	65
% O.M. (0-15)	5.71	2.26	11.7	2.5	65
% $CaCO_3$ (0-15)	0.37	2.14	16.9	0.0	65
% sand (0-15)	34.58	17.34	74.9	8.1	65
% silt (0-15)	38.61	10.85	59.2	14.1	65
% clay (0-15)	26.80	10.98	62.5	10.2	65
Pptn.	21.44	7.54	38.1	3.3	65
ASFTL-P(0-15)	26.2	20.6	125.7	0.0	65
Ln ASFTL-P(0-15)	2.98	0.82	4.85	0.0	65
ASFTL-P(15-30)	6.8	7.1	30.2	0.0	65
Ln ASFTL-P(15-30)	1.43	1.09	3.41	0.0	65
M & A-P(0-15)	27.6	22.7	134.4	4.5	55
Ln M & A-P(0-15)	3.06	0.72	4.90	1.50	55
M & A-P(15-30)	8.5	7.1	33.6	0.0	55
Ln M & A-P(15-30)	1.78	0.94	3.52	0.0	55
Olsen-P(0-15)	26.1	17.0	87.4	7.8	55
Ln Olsen-P(0-15)	3.09	0.57	4.47	2.06	55
Olsen-P(15-30)	14.7	7.8	43.7	4.5	55
Ln Olsen-P(15-30)	2.56	0.50	3.78	1.50	55
P_2O_5 (90% Max.Yld.)	27.5	15.0	70.6	4.5	65

* <u>Variable</u>	<u>Units</u>
E.C.	mmhos/cm^2
Pptn.	cm
ASFTL-P	kg/ha
M & A-P	kg/ha
Olsen-P	kg/ha
P_2O_5 (90% Max.Yld.)	kg/ha

Table 3. Frequency Distribution of Unresponsive and Responsive Barley Sites per Classification Class (Number of Sites)

Classification		Unresponsive	Responsive
Agro-climatic Area			
	1	23	21
	2A	8	8
	2H	15	19
	3H	1	8
	3Ha	13	9
Soil Zone			
	Gray	11	15
	Dark Gray	14	17
	Black	11	20
	Thin Black	14	5
	Dark Brown	10	8
Soil Order			
	Chernozemic	41	38
	Luvisolic	17	24
	Gleysolic	0	2
	Solonetzic	2	1
Texture (0-15)			
	HC	5	2
	C	3	3
	SiC	1	2
	SiCL	8	5
	CL	15	21
	SCL	3	0
	SiL	4	5
	L	12	15
	SL	8	12
	LS	1	0

classes was approximately equal (Table 3) suggesting that site classification may not be important in the separation of responsive sites from unresponsive sites. Finally, the general geographical distribution of the sites within the province was great enough to represent the major grain producing areas of the province.

1. Discriminant Analyses

The objective of the use of discriminant analysis is to determine those site variables important for distinguishing phosphate responsive and unresponsive sites. Based on the simple examination of the means in Tables 1 and 2, the most important variable for separation of the sites would appear be the soil test for phosphorus. Therefore, the first step was to determine the best soil test procedure for separating the sites. There appeared to be little difference among the three soil test procedures in their ability to separate responsive and unreponsive barley sites when the comparison was made using the same sites (Table 4). The only major difference was that for the Olsen-P, both depths were important based on the standardized coefficients, while for both the ASFTL-P and M & A-P, the 15-30 cm depth did not enter the function. Even when all 125 sites were used in the analysis the ASFTL-P(15-30) did not enter into the function. There was little difference in the total disciminatory power (TDP) or the canonical correlation among the functions. Because there is little difference among the three methods, further discriminant analyses of the barley sites involved only the ASFTL-P because the number of sites having this information was larger than those sites having the Olsen-P or M & A-P.

The overall discriminant function based on the quantitative variables only (Table 4) for all 125 barley sites indicated that the most important site variable for

Table 4. Discriminant Analysis for Barley Response to Phosphate Fertilizer: (1) Comparison of Soil Tests, and (2) Best Overall Function

Variables	Std. Coef.	Unstd. Coef.	Group Centroid Resp.	Group Centroid Unresp.	TDP	Chi-sq.	Canonical Correl.
1. Comparison of Soil Tests							
(112 sites)							
Ln ASFTL-P(0-15)	1.00	1.26					
constant		-4.18	-0.44	0.42	0.15	18.4	0.40**
Ln M & A-P(0-15)	1.00	1.41					
constant		-4.78	-0.46	0.44	0.16	20.5	0.41**
Ln Olsen-P(0-15)	0.79	1.59					
Ln Olsen-P(15-30)	0.33	0.61					
constant		-6.96	-0.46	0.44	0.16	20.6	0.41**
(125 sites)							
Ln ASFTL-P(0-15)	1.00	1.28					
constant		-4.23	-0.41	0.44	0.15	20.4	0.39**
2. Best Overall Function (125 sites)							
Ln ASFTL-P(0-15)	0.97	1.24					
% clay (0-15)	0.62	0.05					
pH (15-30)	0.53	0.59					
Pptn.	0.33	0.04					
% O.M. (0-15)	-0.31	-0.13					
constant		-9.70	-0.60	0.65	0.27	39.9	0.53**

** significant at $p \leq 0.01$

site separation was the ASFTL-P for the 0-15 cm depth. In addition, the other variables which were important included % clay, pH (15-30), growing season precipitation, and % O.M.. The total discriminatory power for the function was low (0.27) indicating a large amount of within group variation. The canonical correlation was also low and as a result a poor separation of the sites based on this function would be expected.

Inclusion of agro-climatic area, soil zone or soil order variables into the discriminant analysis along with the quantitative variables did not improve the function's ability to separate the sites (Table 5). The low values of the standardized coefficients for each of the classification variables indicated that these variables were not very important in separating the sites. In addition, the total discriminatory power and canonical correlation are not significantly improved with the inclusion of these classification variables.

Two possible reasons exist for the lack of improvement in the discriminant function with the inclusion of the classification variables: either the classification has no significant influence in determining barley response to phosphate fertilizer or, the important quantitative variables for discrimination differ among the classification classes. To check the latter possibility, individual discriminant analyses were conducted on each classification class having sufficient members.

Table 5. Discriminant Analyses for Barley Response to Phosphate Fertilizer: Quantitative and Classification Variables (125 sites)

	Std.	Unstd.	Group Centroid				Canonical
Variables	Coef.	Coef.	Resp.	Unresp.	TDP	Chi-sq.	Correl.
Agro-climatic Area							
Ln ASFTL-P(0-15)	0.89	1.14					
% clay (0-15)	0.69	0.05					
pH (15-30)	0.53	0.59					
Pptn.	0.28	0.04					
% O.M. (0-15)	-0.35	-0.15					
Agro-climatic Area							
1	0.18	0.26					
2A	-0.24	-0.43					
2H	0.07	0.11					
3H	-0.19	-0.39					
constant		-9.41	-0.62	0.67	0.29	41.6	0.54**
Soil Zone							
Ln ASFTL-P(0-15)	0.91	1.16					
% clay (0-15)	0.59	0.04					
pH (15-30)	0.47	0.53					
Pptn.	0.39	0.05					
% O.M. (0-15)	-0.23	-0.10					
Soil Zone							
Gray	-0.06	-0.10					
Black	-0.26	-0.42					
Dark Gray	0.02	0.35					
Dark Brown	-0.11	-0.19					
constant		-9.25	-0.63	0.68	0.30	43.1	0.55**
Soil Order							
Ln ASFTL-P(0-15)	0.95	1.22					
% clay (0-15)	0.61	0.43					
pH (15-30)	0.54	0.60					
Pptn.	0.33	0.04					
% O.M. (0-15)	-0.29	-0.12					
Soil Order							
Chernozemic	0.08	0.16					
Luvisolic	0.08	0.15					
Solonetzic	0.05	0.26					
constant		-9.84	-0.60	0.65	0.28	39.7	0.53**

** significant at $p \leq 0.01$

For all three of these classifications, each individual class analyzed varied as to which quantitative variables were important for site discrimination (Table 6, 7, and 8). The most common variables were ASFTL-P(0-15), ASFTL-P(15-30), % clay, and precipitation. With two exceptions, the individual class disciminant analysis was more effective in distinguishing responsive and unresponsive sites than the effect coded analyses. Both total discriminatory power and canonical correlation were improved in many instances, and as a result, a high degree of correct classification can be anticipated. In general, the classes for which it was difficult to separate sites by means of a discriminant function were those sites belonging to the agro-climatic area '1', the Black soil zone, and the Chernozemic soil order. For these sites there were possibly other site parameter(s) controlling the response of barley to phosphate fertilizer. These could include micronutrient deficiency, experimental technique, pests and/or disease. By contrast, the best expected prediction of site responsiveness would be for those sites belonging to the Gray soil zone (Table 7), Luvisolic soil order (Table 8), or agro-climatic areas '2H' and '3Ha' (Table 6).

Examination of the standardized coefficients for each of the functions presented in this section indicates a number of general trends for the influence of the site variables on barley response to phosphate fertilizer. The importance of each variable within a given function is shown

Table 6. Discriminant Analyses for Barley Response to Phosphate Fertilizer for Four Agro-climatic Areas

	Std.	Unstd.	Group Centroid				Canonical
Variables	Coef.	Coef.	Resp.	Unresp.	TDP	Chi-sq.	Correl.
Area '1' (54 sites)							
Ln ASFTL-P(0-15)	1.12	1.63					
Ln ASFTL-P(15-30)	-0.82	-0.81					
% clay (0-15)	0.89	0.08					
% sand (0-15)	0.62	0.05					
% $CaCO_3$ (0-15)	0.32	0.98					
constant		-8.25	-0.69	0.63	0.29	14.7	0.56**
Area '2A' (16 sites)							
E.C. (15-30)	-1.38	-9.23					
% clay (0-15)	1.57	0.07					
constant		1.53	-0.76	0.76	0.34	6.6	0.63**
Area '2H' (34 sites)							
ASFTL-P(0-15)	0.85	0.05					
pH (15-30)	0.82	0.81					
Pptn.	0.68	0.10					
constant		-9.30	-0.86	1.09	0.48	21.2	0.71**
Area '3Ha' (22 sites)							
Ln ASFTL-P(0-15)	0.54	0.58					
% clay (0-15)	1.23	0.08					
Ln ASFTL-P(15-30)	1.37	1.03					
% sand (0-15)	-0.88	-0.04					
% O.M. (0-15)	-0.54	-0.19					
Pptn.	0.34	0.04					
constant		-5.24	-2.16	1.49	0.76	25.8	0.88**

** significant at $p \leq 0.01$

Table 7. Discriminant Analyses for Barley Response to Phosphate Fertilizer in Five Soil Zones

Variables	Std. Coef.	Unstd. Coef.	Group Centroid		TDP	Chi-sq.	Canonical Correl.
			Resp.	Unresp.			
Gray Soil Zone (24 sites)							
Ln ASFTL-P(15-30)	1.45	1.17					
% clay (0-15)	0.90	0.08					
E.C. (0-15)	0.32	2.50					
constant		-5.20	-1.15	1.57	0.64	24.4	0.81**
Dark Gray Soil Zone (31 sites)							
ASFTL-P(15-30)	0.73	0.03					
% clay (0-15)	1.06	0.08					
pH (0-15)	0.50	0.66					
E.C. (0-15)	-0.74	-7.77					
% $CaCO_3$ (0-15)	0.58	9.24					
ASFTL-P(0-15)	0.46	0.01					
constant		-5.31	-0.76	0.92	0.40	14.5	0.65**
Black Soil Zone (31 sites)							
Pptn.	0.84	0.13					
ASFTL-P(0-15)	0.50	0.03					
E.C. (15-30)	0.45	0.58					
constant		-4.36	-0.58	1.05	0.36	13.8	0.63**
Thin Black Soil Zone (19 sites)							
ASFTL-P(15-30)	-0.79	-0.11					
pH (15-30)	-1.32	-3.94					
% O.M. (0-15)	1.05	0.65					
% $CaCO_3$ (0-15)	0.89	1.80					
% sand (0-15)	0.78	0.09					
E.C. (0-15)	-0.53	-1.10					
constant		24.19	-1.70	0.61	0.50	10.8	0.73**
Dark Brown Soil Zone (18 sites)							
Pptn.	0.54	0.10					
% clay (0-15)	0.93	0.41					
E.C. (15-30)	-0.79	-5.23					
ASFTL-P(0-15)	0.67	0.04					
% O.M. (0-15)	-0.51	-0.24					
constant		-1.07	-1.18	0.95	0.12	11.0	0.75**

** significant at $p \le 0.01$

Table 8. Discriminant Analyses for Barley Response to Phosphate Fertilizer for Two Soil Orders

Variables	Std. Coef.	Unstd. Coef.	Group Centroid Resp.	Group Centroid Unresp.	TDP	Chi-sq.	Canonical Correl.
Chernozemic (79 sites)							
Ln ASFTL-P(0-15)	1.15	1.72					
pH (15-30)	0.56	0.77					
% clay (0-15)	0.90	0.06					
Pptn.	0.64	0.08					
% O.M. (0-15)	-0.37	-0.16					
Ln ASFTL-P(15-30)	-0.62	-0.55					
% sand (0-15)	0.64	0.04					
constant		-14.09	-0.63	0.59	0.26	23.4	0.53**
Luvisolic (41 sites)							
Ln ASFTL-P(0-15)	0.55	0.63					
Ln ASFTL-P(15-30)	0.99	0.77					
% clay (0-15)	0.89	0.08					
% $CaCO_3$ (0-15)	0.26	3.43					
constant		-5.79	-1.05	1.39	0.59	35.3	0.78**

** significant at $p \leq 0.01$

by the magnitude of the standardized coefficient, while the sign, when considered along with the group centroids for each group, indicates the behavior of the variable in relation to the separation of the sites. Whenever ASFTL-P(0-15), % $CaCO_3$, % clay, or growing season precipitation appeared in the function, the sign associated with the coefficient was consistently positive, while the value of the group centroid for the responsive group was lower than the unresponsive group. Therefore, as the value of these variables increased, the site tended to be unresponsive to phosphate fertilizer. Other variables that appeared in the various functions, but were not consistent in their behavior among the classification classes, included ASFTL-P(15-30), pH(15-30), E.C., % O.M. and % sand. The results presented indicate that the critical soil test value varies depending upon the soil and environmental properties of the site. Therefore, contrary to the approach of Cate and Nelson (1965), it would be difficult to use one soil test value as the critical soil test value for all soils.

2. Multiple Regression Analysis

The yield increase for each responsive site was dependent on the phosphate fertilizer rate calculated to attain 90% maximum yield for that site. Therefore, the variation of this relationship among all sites would be due primarily to the differences of the soil and environmental properties. Multiple regression analysis should identify and quantify those variables.

A comparison of the three soil test procedures indicated that ASFTL-P was the best soil test procedure in accounting for the greatest amount of variation in yield increase (Table 9). The ASFTL-P(0-15) accounted for 15% of the yield increase variation with an additional 3% accounted by ASFTL-P(15-30). By contrast, for both M & A-P and Olsen-P, only the 0-15 cm. depth soil test was significant, accounting for only 8% and 4% of the variation respectively. For all three methods, the natural logarithmic form of the soil test was better than the untransformed soil test values. As a result of this comparison, the ASFTL-P was used in the succeeding analyses. The best combination of quantitative variables accounted for 73% of the variation in yield increase (Table 9). These variables, and the approximate additional variation each explained, include the phosphate fertilizer rate needed to reach 90% of the maximum site yield (47%), ASFTL-P(0-15) (15%), ASFTL-P(15-30) (5%), pH (0-15) (3%), the growing season precipitation (2%), and the % O.M. (0-15) (2%).

Table 9. Stepwise Multiple Regression Analyses for Responsive Barley Sites: (1) Comparison of Soil Tests, and (2) Best Combination of Quantitative Variables for Yield Increase Equation

Variables	b Value	Std.Err. b	F Value	R^2 Change	Overall		
					Std.Err. Est.	F Value	R^2
1. Comparison of Soil Tests (55 sites)							
P_2O_5 (90% Max.Yld.)	0.23**	0.03	54.98	0.54			
Ln ASFTL-P(0-15)	-3.56**	0.65	29.91	0.15			
Ln ASFTL-P(15-30)	1.03**	0.49	4.49	0.03			
constant	9.60				3.36	41.62	0.71**
P_2O_5 (90% Max.Yld.)	0.25**	0.04	51.19	0.54			
Ln M & A-P(0-15)	-2.55**	0.76	11.34	0.08			
constant	7.65				3.81	42.59	0.62**
P_2O_5 (90% Max.Yld.)	0.26**	0.04	46.70	0.54			
Ln Olsen-P(0-15)	-2.39**	1.03	5.37	0.04			
constant	7.06				4.00	36.12	0.58**
2. Best Combination of Quantitative Variables (65 sites)							
P_2O_5 (90% Max.Yld.)	0.19**	0.03	32.36	0.47			
Ln ASFTL-P(0-15)	-4.46**	0.64	48.95	0.15			
Ln ASFTL-P(15-30)	1.48**	0.43	11.81	0.05			
pH (0-15)	-1.64**	0.63	6.85	0.03			
Pptn.	-0.11**	0.06	3.87	0.02			
% O.M. (0-15)	-0.34**	0.18	3.49	0.02			
constant	28.46				3.29	26.06	0.73**

** significant at $p \leq 0.01$

The influence of each variable can be determined by examining the magnitude and sign of its coefficients. As expected, the phosphate rate had a positive effect on yield increase, but unexpectedly, so did the ASFTL-P(15-30). The other variables in the analysis all had negative effects on yield increase, that is, the yield increase was depressed as the the value of these variables increased. Thus, an increase in the ASFTL-P(0-15) reduced the yield increase from applied phosphate fertilizer as would be expected if the ASFTL-P(0-15) provided a measure of the available phosphorus in the soil. A similar trend can be observed for pH, precipitation, and organic matter content, except that the magnitude and the yield increase variation accounted by these variables was smaller. Even though the influence of pH, precipitation, and organic matter content were significant, these variables combined accounted for only an additional 6% of the variation in yield increase to phosphate fertilizer.

As noted, an increase in pH appeared to depress barley yield increase to phosphate fertilizer. If the same rate of phosphate fertilizer was required to reach "optimum" yield, the yield increase for an alkaline soil would be less than that of an acidic soil. This could possibly be due to a greater availability of the phosphate fertilizer under acidic soil conditions and/or a lower yielding potential of the crop on alkaline soils. Because of the lower yield increase on alkaline soils, the "optimum" rate of phosphate fertilizer will be lower. Hallsworth (1969), commenting on work by Colwell and Esdaile (1968), makes a similar conclusion: "for soils containing say 5 ppm available P, the phosphate dressing for most profitable response is twice as high on an acid soil (pH 5.5) as it is on an alkaline soil (pH 8.0)". This suggests that, as the pH of a soil increases, the phosphate fertilizer application rate required to obtain the optimum yield for a site should be reduced.

The influence of precipitation on crop response to phosphate fertilizer tended to be negative, that is, as precipitation increased, the crop response to phosphate fertilizer was reduced (Table 9). Strong and Barry (1980) found a relatively large crop response to phosphorus under arid conditions due to a reduced volume of soil exploited by the crop's root system and the relatively high availability of phosphorus in the fertilizer band. Thus under arid conditions, the crop made more use of the fertilizer phosphorus than under non-arid conditions where the crop made more use of native soil phosphorus. Hutcheon and Rennie (1960) reported a significant decrease in the availability of soil phosphorus to wheat as the moisture stress increased, and an increase in the relative availability of the fertilizer phosphorus banded with the seed.

Organic matter content of the soil appeared to have a negative effect on yield increase (Table 9). As the organic matter content increased, yield increase to added phosphate fertilizer was depressed. This could suggest that the crop obtained phosphates from organic sources through mineralization (Stewart *et al*, 1980), or that phosphate sorption increased with increasing organic matter (Rennie and McKercher, 1959; Harter, 1969; Hinga, 1973; Lopez-Hernandez and Burnhan, 1974; Holford and Mattingly, 1975).

Having established the effects of the quantitative variables, the next step was to assess whether the prediction of yield response would be improved by including site classification variables. The inclusion of agro-climatic area, soil zone, or soil order classification variables into the regression procedure resulted in a small increase in the equation's overall correlation (Table 10). Agro-climatic area accounted for an additional 3% of the variation in barley response, with all previously determined covariates remaining significant. Soil zone accounted for an additional 5% of the variation while soil order accounted for an additional 4% variation. However, for both soil zone and soil order equations, the organic matter variable became nonsignificant and was discarded prior to inclusion of soil zone or soil order variables. Thus, the variation accounted for by organic matter content was accounted for by the soil zone or soil order variables.

To determine whether a significant difference existed among the classes for each classification system, an approximate multiple range test was conducted on the

Table 10. Yield Increase Equations for 65 Responsive Barley Sites with Site Classification Using Stepwise Multiple Regression Analysis

Variables	b Value	Std.Err. b	F Value	R^2 Change	Overall Std.Err. Est.	Overall F Value	Overall R^2
Agro-climatic Area							
P_2O_5 (90% Max.Yld.	0.[illegible]**	0.03	25.99	0.47			
Ln ASFTL-P(0-15)	-4.1[illegible]**	0.63	44.15	0.15			
Ln ASFTL-P(15-30)	1.40**	0.44	10.09	0.05			
pH (0-15)	-1.57**	0.68	5.29	0.03			
Pptn.	-0.14**	0.06	5.93	0.02			
% O.M. (0-15)	-0.29*	0.19	2.32	0.02			
Agro-climatic Area							
1	-0.80	0.78					
2A	-1.61	1.13					
2H	-0.63	0.80					
3H	1.19	1.06					
constant	28.17				3.16	16.96	0.76**
Soil Zone							
P_2O_5 (90% Max.Yld.)	0.20**	0.03	39.25	0.47			
Ln ASFTL-P(0-15)	-3.95**	0.61	42.24	0.15			
Ln ASFTL-P(15-30)	1.52**	0.41	13.91	0.05			
Pptn.	-0.17**	0.06	8.48	0.03			
pH (0-15)	-1.06**	0.62	2.92	0.02			
Soil Zone							
Gray	3.31	0.83					
Black	-0.27	0.71					
Dark Gray	-0.17	0.79					
Dark Brown	-1.18	1.05					
constant	21.53				3.00	21.55	0.78**
Soil Order							
P_2O_5 (90% Max.Yld.)	0.19**	0.03	36.43	0.47			
Ln ASFTL-P(0-15)	-4.27**	0.61	49.23	0.15			
Ln ASFTL-P(15-30)	1.49**	0.41	13.05	0.05			
Pptn.	-0.15**	0.05	8.07	0.02			
pH (0-15)	-1.48**	0.59	6.21	0.03			
Soil Order							
Chernozemic	-1.71	1.60					
Luvisolic	1.83	1.06					
Solonetzic	1.12	2.45					
constant	25.84				3.08	23.45	0.77**

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* significant at $p \le 0.05$

** significant at $p \le 0.01$

estimated class means (see Material and Methods). No significant differences were found among the agro-climatic area class means, but a significant difference existed within both the soil zone and soil order classifications (Table 11). Within the soil zone classification, the Gray zone had a significantly greater yield increase than the other soil zones, with no significant difference among the other four zones. Within the soil order classification, there was a significant difference between Luvisolic and Chernozemic sites with the Luvisolic sites having a greater response to phosphate fertilizer. Solonetzic and Gleysolic sites showed no significant difference from either the Luvisolic or Chernozemic sites, probably due to the low number of sites within each class and the resulting high standard errors for the means. The results of the soil zone and soil order were in agreement with each other which might be expected since most Luvisolic sites were within the Gray soil zone.

Table 11. Comparison of Mean Yield Increase (100 kg/ha) for Responsive Barley Sites in Various Classes

Classification	Mean	Std. Error
Agro-climatic Area		
1	6.34 a	0.75
2A	5.53 a	1.28
2H	6.51 a	0.81
3H	8.32 a	1.22
3Ha	8.97 a	1.10
$\bar{x}$	7.14	0.44
Soil Zone		
Gray	9.87 a	0.83
Dark Gray	6.38 b	0.78
Black	6.30 b	0.70
Dark Brown	5.39 b	5.39
Thin Black	4.86 b	4.86
$\bar{x}$	6.56	0.44
Soil Order		
Luvisolic	8.98 a	0.67
Solonetzic	8.23 ab	3.20
Gleysolic	6.61 ab	2.29
Chernozemic	5.81 b	0.51
$\bar{x}$	7.41	0.99

Means within a classification having different letters are significantly different ($P \le 0.05$)

3. Principal Component Analysis

The results presented in this section are those principal components accounting for the majority of the variation in the responsive site data. The independent variables (eigenvectors) are listed along with their factor loadings for each component. These loadings measure the degree each variable is involved in each factor pattern, and can be interpreted like correlation coefficients (Rummel, 1967).

The sum of the five largest eigenvalues explained about 75% of the total variance within the data (Table 12). Principal component number 1 accounted for about 25% of the variation and was heavily loaded, positively, by pH and E.C. variables and moderately loaded, but negatively, by precipitation and the phosphate fertilizer calculated for optimum yield. As the pH and E.C. of a soil increased, the phosphate fertilizer rate for "optimum" yield decreased. This relationship between pH and phosphate fertilizer was noted previously in the results of the multiple regression and the discriminant analyses. The relationship between E.C. and phosphate fertilizer could represent an effect of the soil solution (including NO_3-N) concentration, on crop utilization of phosphate fertilizer. This group of variables reflect the chemical potential of the soil solution and can be labelled the "soil solution component".

The second principal component accounted for about 17% of the variation in the data, and was loaded heavily by

Table 12. Principal Component Analysis of Responsive Barley Sites: The Five Largest Eigenvalues

Principal Component No.	1	2	3	4	5
Eigenvalue	2.796	1.897	1.696	1.123	0.834
(cumulative percentage)	25.4	42.7	58.1	68.3	75.9
Eigenvectors					
pH (0-15)	0.780	-0.380	-0.223	0.251	-0.064
pH (15-30)	0.874	-0.205	-0.129	0.149	0.258
E.C. (0-15)	0.720	0.144	0.313	0.113	-0.245
E.C. (15-30)	0.608	0.189	0.467	-0.216	0.245
% O.M. (0-15)	0.193	0.423	0.264	0.502	0.266
% $CaCO_3$ (0-15)	0.240	-0.525	-0.106	-0.485	-0.137
% clay (0-15)	-0.081	0.225	0.814	-0.002	-0.209
Pptn.	-0.428	-0.129	-0.181	0.644	-0.151
Ln ASFTL-P(0-15)	0.061	0.828	-0.175	-0.231	-0.211
Ln ASFTL-P(15-30)	0.087	0.578	-0.584	-0.121	0.378
P_2O_5 (90% Max.Yld.)	-0.488	-0.335	0.408	-0.088	0.547

ASFTL-P(0-15), moderately by ASFTL-P(15-30), carbonate content of the soil, organic matter content of the soil, pH (0-15) and the phosphate fertilizer rate. Again the fertilizer rate displayed a negative loading, that is it had an inverse relationship with the ASFTL-P variables. This can be interpreted as meaning that as the value of the ASFTL-P increased, fertilizer requirement decreased. The inverse relationship between organic matter content of soils and the fertilizer rate suggests a possible mineralization of organic phosphorus to supply phosphate to the crop. This component can be labelled the "available phosphorus component".

The third principal component accounted for about 15% of the variation in the data, and was loaded heavily by the clay content of the soil, and moderately loaded by ASFTL-P(15-30), E.C.(15-30), and the optimum phosphate fertilizer rate. The most important relationship that should be noted was between clay content of the soil and phosphate fertilizer rate. As clay content increased, the phosphate fertilizer rate required for 90% of maximum yield also increased suggesting an adsorption reaction between clay and phosphate fertilizer. Component 3 could be labelled the "phosphate adsorption component".

Principal component number 4 was composed primarily of precipitation, organic matter content of the soil, and carbonate content of the soil and accounted for about 10% of the variation. Precipitation and organic matter content had positive loadings, while carbonate content of the soil had a negative loading. Thus, as precipitation increased, organic matter also increased, while carbonate content decreased. This relationship reflects the trend seen in the soil and climate for the province as one goes from the Brown soil zone to the Black soil zone. Therefore, this component can be labelled as the "soil zonation component".

The final component, number 5, accounted for about 7% of the variation, and was loaded moderately by the ASFTL-P(15-30) and the optimum fertilizer rate, both positively. The positive loadings of these two variables in this component correspond to the positive coefficients observed in the multiple regression analysis. Since the majority of the crop roots are found in the top 15 cm of the soil, utilization of the available phosphorus in the second 15 cm could have an effect similar to fertilizer on crop response. This component can therefore be labelled the "phosphate fertilizer rate component".

The principal component analysis served to illustrate the complex interrelationships among soil variables and in particular the relationships between "optimum" phosphate fertilizer rate and other soil properties. In order to use the soil test as the criterion for predicting phosphate fertilizer requirements for optimum yield, the relationships between phosphate fertilizer rate for optimum yield and soil properties must be taken into account.

4. Summary

The results of the discriminant analyses of the barley sites indicated that there was very little difference among the three soil test procedures. Overall, the most important quantitative site variable determining the response of barley to phosphate fertilizer was the soil test for phosphorus; as this variable increased, the site tended to be unresponsive. Other variables which occurred commonly in the discriminant functions of the barley sites included % clay, % $CaCO_3$, and growing season precipitation. A quantitative increase of any of these site variables tended to categorize a site as unresponsive to phosphate fertilizer. Site classification did enhance the separation of the sites, but only when individual classification class discriminant functions were determined.

Multiple regression analysis of the responsive barley sites indicated that the soil test best accounting for the variation in yield increase was the ASFTL-P. The best combination of quantitative site variables that were significant in accounting for the variation in yield increase to phosphate fertilizer was the calculated optimum fertilizer rate, ASFTL-P(0-15), ASFTL-P(15-30), pH (0-15), growing season precipitation, and the organic matter content of the soil. Yield increase from phosphate fertilizer was depressed by an increase in ASFTL-P(0-15), pH (0-15), precipitation, and % organic matter. Inclusion of site classification variables into the analysis did improve the prediction ability of the equation. Multiple comparison tests of the estimated means indicated no significant difference among the agro-climatic areas, but within the soil zone and soil order classifications, significant differences existed among the class means. The Gray soil zone and the Luvisolic soil order were significantly more responsive to phosphate fertilizer than the remaining classification classes.

Principal component analysis of the responsive sites illustrated the complex interrelationships among the site properties, and with the calculated optimum fertilizer rate. The site variables measured can be reduced to five components representing (1) the soil solution, (2) the available phosphorus, (3) phosphate adsorption, (4) soil zonation, and (5) the phosphate fertilizer rate. The most noteworthy interrelationships were the inverse relations of "optimum" phosphate fertilizer rate and each of pH, ASFTL-P, and organic matter, and the direct relation between clay content and phosphate fertilizer rate within certain components.

B. Rapeseed

The results presented in this section represent the statistical analyses of the yield response of rapeseed to phosphate fertilizer for 91 sites. A brief summary (means, standard deviations, maximum and minimum values) of the chemical and physical characteristics of the field sites is presented in Tables 13 and 14, while a frequency distribution of the sites in each of three site classifications is presented in Table 15. In general, the sites used in this study represented a wide variety of site conditions for both responsive and unresponsive groups. The most noteworthy difference between the two groups was a lower mean value of the soil test levels of phosphorus for the responsive sites, especially in the surface depth and a higher mean preciptation for the responsive sites. The distribution of responsive and unresponsive sites among the classification classes was unequal for some classes (Table 15), suggesting a greater importance of site classification in the separation of rapeseed sites than that observed for the barley sites. Finally, the general geographic distribution of the sites in the province was representative of the major dryland crop producing areas of the province as well as the major soil and climatic groups.

Table 13. Mean, Standard Deviation, Maximum, and Minimum Values of the Independent Variables for the Unresponsive Rapeseed Sites

Variables*	Mean	Std. Dev.	Max.	Min.	No. of Sites
pH (0-15)	6.87	0.75	8.2	5.4	39
pH (15-30)	7.05	0.95	8.4	4.5	39
E.C. (0-15)	0.40	0.17	0.9	0.2	39
E.C. (15-30)	0.51	0.68	4.5	0.2	39
% O.M. (0-15)	5.20	2.47	11.7	1.8	39
% $CaCO_3$ (0-15)	0.25	0.77	3.8	0.0	39
% sand (0-15)	30.82	18.00	74.4	3.1	39
% silt (0-15)	39.24	12.60	72.8	4.0	39
% clay (0-15)	29.95	11.40	63.1	10.3	39
Pptn.	18.71	8.03	35.8	3.3	39
ASFTL-P(0-15)	49.7	40.1	218.4	6.7	39
Ln ASFTL-P(0-15)	3.68	0.68	5.39	1.91	39
ASFTL-P(15-30)	14.8	37.8	213.9	0.0	39
Ln ASFTL-P(15-30)	1.68	1.22	5.37	0.0	39
M & A-P(0-15)	55.3	42.0	221.8	7.8	36
Ln M & A-P(0-15)	3.80	0.66	5.40	2.06	36
M & A-P(15-30)	18.2	38.0	207.2	0.0	36
Ln M & A-P(15-30)	2.13	1.12	5.33	0.0	36
Olsen-P(0-15)	41.1	18.5	76.2	9.0	36
Ln Olsen-P(0-15)	3.61	0.49	4.33	2.19	36
Olsen-P(15-30)	15.7	13.9	71.7	4.5	36
Ln Olsen-P(15-30)	2.53	0.61	4.27	1.50	36

* Variable	Units
E.C.	mmhos/cm^{3}
Pptn.	cm
ASFTL-P	kg/ha
M & A-P	kg/ha
Olsen-P	kg/ha

Table 14. Mean, Standard Deviation, Maximum, and Minimum Values of the Independent Variables for the Responsive Rapeseed Sites

Variables*	Mean	Std. Dev.	Max.	Min.	No. of Sites
pH (0-15)	6.69	0.71	8.1	5.2	52
pH (15-30)	6.74	0.91	8.2	4.6	52
E.C. (0-15)	0.34	0.14	0.8	0.2	52
E.C. (15-30)	0.36	0.25	1.5	0.1	52
% O.M. (0-15)	5.47	2.58	14.7	1.2	52
% $CaCO_3$ (0-15)	0.19	1.12	8.1	0.0	52
% sand (0-15)	33.50	19.14	78.6	2.9	52
% silt (0-15)	38.27	11.26	59.2	12.2	52
% clay (0-15)	28.21	14.10	71.6	8.2	52
Pptn.	23.12	7.72	38.1	5.8	52
ASPTL-P(0-15)	28.0	26.8	134.4	0.0	52
Ln ASPTL-P(0-15)	2.97	0.90	4.90	0.0	52
ASPTL-P(15-30)	15.1	33.3	201.6	0.0	52
Ln ASPTL-P(15-30)	1.65	1.38	5.31	0.0	52
M & A-P(0-15)	29.3	26.0	131.0	4.5	52
Ln M & A-P(0-15)	3.08	0.78	4.88	1.50	50
M & A-P(15-30)	17.4	34.5	200.5	0.0	50
Ln M & A-P(15-30)	2.09	1.15	5.30	0.0	50
Olsen-P(0-15)	24.4	12.5	62.7	7.8	50
Ln Olsen-P(0-15)	3.07	0.52	4.14	2.06	50
Olsen-P(15-30)	17.3	14.9	89.6	4.5	50
Ln Olsen-P(15-30)	2.62	0.65	4.50	1.50	50
P_2O_5-90% (Max.Yld.)	30.6	46.7	67.2	2.2	52

* Variable	Units
E.C.	mmhos/cm^2
Pptn.	cm
ASPTL-P	kg/ha
M & A-P	kg/ha
Olsen-P	kg/ha
P_2O_5 (90% Max.Yld.)	kg/ha

Table 15. Frequency Distribution of Unresponsive and Responsive Rapeseed Sites per Classification Class (Number of Sites)

Classification		Unresponsive	Responsive
Agro-climatic Area			
	1	16	13
	2A	7	0
	2H	12	16
	3H	0	6
	3Hm	4	17
Soil Zone			
	Gray	3	14
	Dark	6	24
	Black	11	13
	Thin Black	11	1
	Dark Brown	5	0
	Brown	3	0
Soil Order			
	Chernozemic	29	27
	Luvisolic	8	23
	Gleysolic	0	1
	Solonetzic	2	1
Texture (0-15)			
	HC	2	3
	C	0	2
	SiC	3	1
	SiCL	5	8
	CL	11	14
	SCL	2	0
	SiL	2	4
	L	9	11
	SL	5	8
	LS	0	1

1. Discriminant Analyses

The objective of this series of analyses was to determine those site variables important for separating responsive sites from unresponsive sites for the phosphate fertilizer response of rapeseed. Simple examination of the mean values (Tables 13 and 14) indicated that the major difference between the two groups was the soil test for available phosphorus.

There was a slight difference among the three soil test procedures in separating responsive and unresponsive sites (Tables 16). M & A-P and Olsen-P had the greatest success in distinguishing these groups. For all three procedures, both depths were important in the function. There was no improvement in the correlation of the discriminant function when a larger data set was used (Table 16). Since there is a close procedural relationship between M & A-P and ASFTL-P, but there was a larger sample/population having ASFTL-P information, ASFTL-P was used to determine the best overall function (Table 16). In addition to the ASFTL-P, the other variables which were important for site distinction were pH (15-30), and growing season precipitation. However, the effectiveness of the function to separate sites was still poor as indicated by the low total discriminatory power and canonical correlation. Inclusion of soil order into the analysis with the quantitative variables did not improve the ability of the function to separate sites, however, inclusion of agro-climatic area or soil zone did improve the

Table 16. Discriminant Analyses for Rapeseed Response to Phosphate Fertilizer: (1) Comparison of Soil Tests, and (2) Best Overall Function

Variables	Std. Coef.	Unstd. Coef.	Group Centroid Resp.	Group Centroid Unresp.	TDP	Chi-sq.	Canonical Correl.
1. Comparison of Soil Tests							
(86 sites)							
ASFTL-P(0-15)	1.81	0.05					
ASFTL-P(15-30)	-1.52	-0.04					
constant		-1.42	-0.53	0.73	0.27	27.8	0.53**
Ln M & A-P(0-15)	1.61	2.21					
Ln M & A-P(15-30)	-1.24	-1.09					
constant		-5.17	-0.65	0.90	0.36	38.9	0.61**
Olsen-P(0-15)	1.25	0.08					
Olsen-P(15-30)	-0.83	-0.06					
constant		-1.61	-0.61	0.85	0.34	35.2	0.59**
(91 sites)							
ASFTL-P(0-15)	1.76	0.05					
ASFTL-P(15-30)	-1.46	-0.04					
constant		-1.37	-0.50	0.67	0.25	26.4	0.51**
2. Best Overall Function (91 sites)							
Ln ASFTL-P(0-15)	1.32	1.62					
Ln ASFTL-P(15-30)	-0.94	-0.71					
pH (15-30)	0.58	0.62					
Pptn.	-0.38	-0.05					
constant		-7.34	-0.65	0.87	0.36	40.0	0.61**

** significant at $p \leq 0.01$

function's correlation, with the latter classification showing the greatest improvement (Table 17).

As with the barley sites, the individual classes for each classification were analyzed to determine variable differences among the classes for site discrimination. Results indicated that not only did the quantitative variables vary among the classes, but so did their importance and behavior (Tables 18, 19, and 20). The most common variables were the ASFTL-P(0-15) and ASFTL-P(15-30), while the other variables seem to appear at random in the functions. In general, the individual class discriminant analysis was more effective in separating responsive and unresponsive sites than the effect coded analysis. Both total discriminatory power and canonical correlation were improved in many instances for the individual class analyses and as a result, a high degree of correct classification of the sites could be expected. The exceptions were agro-climatic area '2H' and the black soil zone. Thus, it would appear that some additional unmeasured site parameter(s) was controlling phosphate response of rapeseed in these classification classes. These could include deficiency of micronutrients, experimental technique of the individual coordinators, pests, and/or disease.

The behavior of the site variables is determined by examination of the standardized coefficients of the discriminant function in relation to the group centroids. Only the ASFTL-P for both depths, E.C. for both depths and

Table 17. Discriminant Analyses for Rapeseed Response to Phosphate Fertilizer: Quantitative and Site Classification Variables (91 sites)

Variables	Std. Coef.	Unstd. Coef.	Group Centroid Resp.	Group Centroid Unresp.	TDP	Chi-sq.	Canonical Correl.
Agro-climatic Area							
Ln ASFTL-P(0-15)	1.13	1.39					
Ln ASFTL-P(15-30)	-0.69	-0.53					
pH (15-30)	0.32	0.34					
Pptn.	-0.22	-0.03					
Agro-climatic Area							
1	0.16	0.22					
2A	0.79	1.59					
2H	0.13	-0.18					
3H	-0.42	-0.80					
constant		-5.33	-0.77	1.03	0.44	50.2	0.67**
Soil Zone							
Ln ASFTL-P(0-15)	-0.98	-1.20					
Ln ASFTL-P(15-30)	0.71	0.54					
pH (15-30)	-0.08	-0.08					
Pptn.	-0.08	-0.01					
Soil Zone							
Gray	0.83	1.60					
Black	0.30	0.50					
Dark Gray	0.97	1.64					
Dark Brown	-0.55	-1.28					
Brown	-0.67	-1.72					
constant		3.04	0.90	-1.20	0.52	63.0	0.73**
Soil Order							
Ln ASFTL-P(0-15)	1.29	1.58					
Ln ASFTL-P(15-30)	-0.91	-0.69					
pH (15-30)	0.54	0.58					
Pptn.	-0.33	0.04					
Soil Order							
Gleysolic	-0.33	-0.66					
Luvisolic	0.09	0.09					
Solonetzic	0.01	0.02					
constant		-7.52	-0.67	0.90	0.37	41.2	0.62**

** significant at $p \leq 0.01$

Table 18. Discriminant Analyses for Rapeseed Response to Phosphate Fertilizer for Three Agro-climatic Areas

Variables	Std. Coef.	Unstd. Coef.	Group Centroid Resp.	Group Centroid Unresp.	TDP	Chi-sq.	Canonical Correl.
Area '1' (29 sites)							
ASFTL-P(0-15)	-1.15	-0.07					
E.C. (0-15)	-1.07	-6.32					
% $CaCO_3$ (0-15)	-0.62	-5.49					
% sand (0-15)	2.37	0.20					
% clay (0-15)	2.19	0.34					
% O.M. (0-15)	-0.47	-0.22					
E.C. (15-30)	0.55	0.71					
ASFTL-P(15-30)	0.37	0.05					
constant		-10.27	1.98	-1.61	0.76	34.3	0.88**
Area '2H' (28 sites)							
Ln ASFTL-P(0-15)	1.21	1.83					
pH (0-15)	0.77	0.99					
Ln ASFTL-P(15-30)	-0.68	-0.58					
constant		-11.67	-0.47	0.63	0.21	6.8	0.49**
Area '3Ha' (21 sites)							
Ln ASFTL-P(0-15)	-3.90	-4.24					
pH (0-15)	3.32	5.66					
Ln ASFTL-P(15-30)	2.46	1.48					
pH (15-30)	-1.56	-2.07					
E.C. (15-30)	0.99	2.87					
Pptn.	-1.17	-0.15					
constant		-11.34	1.03	-4.39	0.82	28.7	0.91**

** significant at $p \leq 0.01$

Table 19. Discriminant Analyses for Rapeseed Response to Phosphate Fertilizer for Three Soil Zones

Variables	Std. Coef.	Unstd. Coef.	Group Centroid Resp.	Group Centroid Unresp.	TDP	Chi-sq.	Canonical Correl.
Gray Soil Zone (17 sites)							
pH (0-15)	-2.77	-4.92					
ASFTL-P(0-15)	2.72	0.05					
Pptn.	1.13	0.18					
% sand (0-15)	-1.34	-0.07					
pH (15-30)	0.74	0.74					
constant		23.97	-1.21	5.63	0.87	27.0	0.94**
Dark Gray Soil Zone (30 sites)							
Ln ASFTL-P(0-15)	1.49	2.05					
Ln ASFTL-P(15-30)	-0.69	-0.54					
pH (0-15)	2.47	3.09					
pH (15-30)	-1.74	-1.75					
E.C. (0-15)	0.54	3.95					
% sand (0-15)	-0.86	-0.05					
% clay (0-15)	-0.63	-0.05					
constant		-12.64	-0.82	3.29	0.73	33.3	0.86**
Black Soil Zone (24 sites)							
ASFTL-P(15-30)	1.06	0.12					
ASFTL-P(0-15)	-0.69	-0.04					
% clay (0-15)	0.61	0.05					
constant		-1.23	0.51	-0.61	0.21	6.0	0.50**

** significant at $p \leq 0.01$

Table 20. Discriminant Analyses for Rapeseed Response to Phosphate Fertilizer for Two Soil Orders

Variables	Std. Coef.	Unstd. Coef.	Group Centroid		TDP.	Chi-sq.	Canonical Correl.
			Resp.	Unresp.			
Chernozemic (56 sites)							
pH (15-30)	0.75	0.94					
ASFTL-P(0-15)	0.94	0.06					
ASFTL-P(15-30)	-0.57	-0.07					
% sand (0-15)	0.31	0.02					
Pptn.	-0.28	-0.04					
E.C. (0-15)	0.38	2.49					
% $CaCO_3$ (0-15)	-0.30	-0.24					
E.C. (15-30)	-0.28	-1.24					
constant		-8.02	-0.98	0.91	0.47	32.9	0.69**
Luvisolic (31 sites)							
ASFTL-P(0-15)	2.38	0.05					
pH (0-15)	-0.96	-1.52					
ASFTL-P(15-30)	-1.30	-0.02					
Pptn.	0.78	0.11					
% sand (0-15)	-0.56	-0.03					
E.C. (15-30)	-0.30	-1.43					
constant		7.34	-0.93	2.67	0.71	33.7	0.85**

** significant at $p \leq 0.01$

% clay exhibit a constant behavior when all functions were examined. The behavior of the ASFTL-P(0-15) and ASFTL-P(15-30) were opposite so that as ASFTL-P(0-15) increased, the site tended to be unresponsive, while an increase in the ASFTL-P(15-30) tended to result in the site being responsive to phosphate fertilizer. E.C. also displayed this type of behavior; as the E.C.(0-15) increased, the site tended to be unresponsive while an increase in the E.C.(15-30) tended to result in the site being responsive. The % clay of the soil appeared only few functions but where it did, an increase resulted in the site tending to be responsive to phosphate fertilizer remaining variables appearing in the functions were inconsistant in their behavior probably due to the small sample sizes used in many analyses.

2. Multiple Regression Analysis

As in the case of barley, for each responsive rapeseed site, yield increase was dependent upon the calculated phosphate fertilizer rate to produce a yield that was 90% of the maximum site yield. Therefore, the variation in this relationship from site to site should be due to the differences among the sites' soil properties. Multiple regression analysis techniques were used to identify those variables responsible for this among-site variation in crop response.

A stepwise multiple regression analysis was first computed for each of three soil test procedures, after which the best combination of quantitative variables to explain the variation in yield increase was determined. The comparison of the three soil test procedures indicated that there was very little difference among them (Table 21). ASFTL-P(0-15) accounted for 6% of the yield increase variation, M & A-P(0-15) explained 5% of the variation while Olsen-P(0-15) accounted for 9% of the variation. For all three methods, the natural logarithmic transformation of the soil test accounted for a larger portion of the variation than the untransformed values. Also, the soil test for the 15-30 cm depth was nonsignificant for all methods. Since there was very little difference among the soil test procedures, and because of a larger sample size, the ASFTL-P was used in the next step to determine the best combination of quantitative variables. The stepwise procedure indicated

Table 21. Stepwise Multiple Regression Analyses for Responsive Rapeseed Sites: (1) Comparison of Soil Tests, and (2) Best Combination of Quantitative Variables for Yield Increase Equation

Variables	b Value	Std.Err. b	F Value	R^2 Change	Overall Std.Err. Est.	Overall F Value	Overall R^2
1. Comparison of Soil Tests (50 sites)							
P_2O_5 (90% Max.Yld.)	0.08**	0.02	29.35	0.47			
Ln ASPTL-P(0-15)	-0.68**	0.28	5.94	0.06			
constant	2.60				1.66	26.20	0.53**
P_2O_5 (90% Max.Yld.)	0.08**	0.02	28.77	0.47			
Ln M & A-P(0-15)	-0.71**	0.34	4.51	0.05			
constant	2.73				1.68	24.86	0.51**
P_2O_5 (90% Max.Yld.)	0.08**	0.02	33.88	0.47			
Ln Olsen-P(0-15)	-1.40**	0.47	9.10	0.09			
constant	4.84				1.61	29.18	0.55**
2. Best Combination of Quantitative Variables (52 sites)							
P_2O_5 (90% Max.Yld.)	0.09**	0.01	40.18	0.48			
Ln ASPTL-P(0-15)	-0.79**	0.27	8.88	0.06			
% $CaCO_3$ (0-15)	-0.53**	0.20	6.85	0.06			
constant	2[illegible]8				1.58	23.28	0.59**

** significant at $p \leq 0.01$

that the best combination of quantitative variables accounted for 59% of the variation in yield increase of rapeseed (Table 21). These variables and the approximate amount of additional variation each explained were the phosphate rate to attain 90% maximum yield (48%), Ln ASFTL-P(0-15) (6%), and the % $CaCO_3$(0-15) (6%).

The coefficients for the quantitative variables indicated the specific influence each variable had on rapeseed response to phosphate fertilizer. The phosphate fertilizer rate for 90% maximum yield had a positive influence, so that as the phosphate fertilizer rate increased, yield response also increased. Meanwhile, both ASFTL-P(0-15) and % $CaCO_3$ had negative influences, so that as the value of these variables increased, the yield increase was depressed. This result suggested that the soil test procedure did provide an index of the amount of plant available phosphorus present in the soil, and as this measure increased, less fertilizer phosphate was required to attain the optimum yield. The negative influence of $CaCO_3$ indicated a possible chemical precipitation and/or adsorption reaction of the added phosphates by $CaCO_3$ reducing the availability of the added phosphate (Thomas and Peaslee, 1973). Since the presence of carbonates is resticted to alkaline soils, the results of the analysis would tend to support the statement made by Hallsworth (1969) referred to earlier in the chapter.

To determine if knowledge of agro-climatic area, soil zone, or soil order could improve yield response prediction, effect coded variables of these site classifications were entered into the multiple regression analysis. The inclusion of these classification variables did not significantly improve the explanation of the yield response variation of rapeseed to phosphate fertilizer (Table 22). As a result, estimated means for the classification classes and the corresponding multiple range test were not calculated.

Table 22. Yield Increase Equations for 52 Responsive Rapeseed Sites with Site Classification Using Stepwise Multiple Regression Analysis

Variables	b Value	Std.Err. b	F Value	R^2 Change	Overall		
					Std.Err. Est.	F Value	R^2
Agro-climatic Area							
P_2O_5 (90% Max.Yld.)	0.09**	0.02	34.91	0.48			
Ln ASFTL-P(0-15)	-0.76**	0.29	6.86	0.06			
% $CaCO_3$ (0-15)	-0.51**	0.21	5.71	0.06			
Agro-climatic Area							
1	-0.41	0.41					
2H	-0.19	0.39					
3H	0.43	0.54					
constant	2.87				1.62	11.21	0.60**
Soil Zone							
P_2O_5 (90% Max.Yld.)	0.09**	0.02	32.37	0.48			
Ln ASFTL-P(0-15)	-0.82**	0.28	8.68	0.06			
% $CaCO_3$ (0-15)	-0.54**	0.22	6.13	0.06			
Soil Zone							
Gray	0.52						
Black	0.23						
Dark Gray	0.97						
constant	2.71				1.61	11.34	0.60**
Soil Order							
P_2O_5 (90% Max.Yld.)	0.09**	0.02	37.59	0.48			
Ln ASFTL-P(0-15)	-0.86**	0.27	9.89	0.06			
% $CaCO_3$ (0-15)	-0.54**	0.21	6.86	0.0[illegible]			
Soil Order							
Chernozemic	-1.71	1.31					
Luvisolic	0.63	0.63					
Solonetzic	0.52	1.31					
constant	2.53				1.60	11.72	0.61**

** significant at $p \leq 0.01$

3. Principal Component Analysis

To determine the interrelationships among the independent site variables of the responsive rapeseed sites, principal component analysis was conducted. The sum of the five largest components explained about 82% of the total variance of the data (Table 23).

Principal component number 1 accounted for about 25% of the variation and was heavily loaded by pH, E.C., and $CaCO_3$, with a moderate loading by % clay and ASFTL-P(0-15). Of these variables, only ASFTL-P(0-15) had a negative effect while the other variables had positive effects so that there was an inverse relationship between soil test phosphorus and the other major variables of this component. As pH increased, the availability of soil phosphorus, as measured by the soil test, decreased. This could be due to several reasons, including the nature of the chemical extracting procedure and a lower concentration of readily available phosphorus in the soil solution and on the soil colloids. As the E.C. increased, indicating a greater ionic concentration in the soil solution, the availability of the soil phosphorus decreased possibly due to chemical precipitation reactions with cations in solution. The inverse relation between the soil test phosphorus and carbonates or clay content could reflect adsorption equilibrium reations of soil phosphates with carbonates and clay particles. This component represents the soil solution equilibrium and can be labelled the "soil solution component".

Table 23. Principal Component Analysis of Responsive Rapeseed Sites: The Five Largest Eigenvalues

Principal Component No.	1	2	3	4	5
Eigenvalue	2.812	2.401	1.590	1.313	0.923
(cumulative percentage)	25.6	47.4	61.8	73.8	82.2
Eigenvectors					
pH (0-15)	0.614	0.539	-0.425	-0.107	-0.224
pH (15-30)	0.649	0.509	-0.295	-0.223	-0.161
E.C. (0-15)	0.798	0.198	0.212	0.233	0.214
E.C. (15-30)	0.644	0.218	0.494	0.113	0.398
% O.M. (0-15)	0.165	0.084	0.720	-0.328	-0.305
% $CaCO_3$ (0-15)	0.620	-0.210	-0.280	0.436	-0.197
% clay (0-15)	0.453	-0.570	0.416	0.299	-0.188
Pptn.	-0.019	0.549	0.274	-0.541	0.178
Ln ASFTL-P(0-15)	-0.446	0.545	0.247	0.570	0.147
Ln ASFTL-P(15-30)	-0.294	0.787	-0.101	0.380	0.053
P_2O_5 (90% Max.Yld.)	0.243	-0.415	-0.342	-0.186	0.648

The second principal component accounted for about 22% of the variation in the independent site data, and was heavily loaded by pH, clay content of the soil, precipitation, and ASFTL-P, and moderately loaded by the phosphate fertilizer rate. The fertilizer rate exhibited an inverse relationship with soil test phosphorus, precipitation, and pH, and a direct relationship with clay content. The soil test apparently provided some measure of the amount of soil phosphorus available to the plant since with an increase of the soil test, there was a decreased need for fertilizer phosphorus, as indicated by their inverse relationship in this component. There was an inverse relationship between the phosphate fertilizer rate and precipitation. This relationship might occur because growing season precipitation would tend to increase root development of the crop and a greater volume of soil would be utilized by the crop to obtain nutrients. As a result, added phosphate fertilizer may not have been used as extensively by the crop as it would be under arid conditions (Strong and Barry, 1980). Hallsworth (1969) suggested a greater need of fertilizer phosphate under acidic conditions. A similar result appeared in the second component as an inverse relationship between pH and the fertilizer rate; that is, as pH increased, the optimum fertilizer rate decreased. Since phosphate sorption generally increases with clay content, one might expect the phosphate fertilizer requirement to increase directly with clay content, as was observed in this component. This component can be labelled the "available phosphorus component".

Principal component number 3 accounted for about 14% of the independent variable variation and was heavily loaded by organic matter content of the soil, and moderately by a number of other variables, the most noteworthy being the phosphate fertilizer rate. There was an inverse relationship between organic matter and fertilizer rate so that as organic matter increased fertilizer rate decreased indicating a possible mineralization of organic phosphate to satisfy crop requirements. Therefore this component can be labelled the "soil organic matter component".

The fourth component accounted for about 12% of the variation of the independent variables. The most important variables in this component were organic matter and carbonate content of the soil, precipitation, and soil test phosphorus. Organic matter content, carbonate content, and precipitation illustrated a soil zone relationship. In general, as precipitation decreases, organic matter content of soils also decreases, while carbonate content of the soil increases. It is possible that soil test phosphorus may also follow a zonal trend. Thus, this component could be labelled the "soil zone component".

The fifth component accounted for about 8% of the variation in the independent variables and was controlled primarily by the phosphate fertilizer rate for optimum yield. Therefore, this component can be labelled the "phosphate fertilizer component". The loading of phosphate fertilizer rate as the only variable in this component would tend to suggest that there are other undetermined site variables which may influence the optimum phosphate fertilizer rate.

The complex relationships among the independent variables for the responsive rapeseed sites were illustrated by this analysis. The variation of the phosphate fertilizer for optimum crop response was related to many soil properties and environmental conditions which control the phosphate supply to the crop.

4. Summary

The results of the discriminant analyses of the rapeseed sites indicated that there was a slight difference among the soil test procedures. The M & A-P appeared to best separate the sites, but ASFTL-P had the advantage of a larger number of sites available for analysis. Overall, the most important quantitative site variable that separated responsive and unresponsive sites were the ASFTL-P tests for the 0-15 cm and the 15-30 cm depth. As ASFTL-P(0-15) increased the site tended to be unresponsive, whereas, ASFTL-P(15-30) had the opposite effect. Other variables which were consistent in their behavior in the various functions included E.C. for both depths, and clay content. Site classification did influence the separation of the sites. Inclusion of either agro-climatic area or soil zone variables into the function improved the correlation. Individual classification class discriminant functions provided potentially the most effective means of separating sites.

Multiple regression analysis of the responsive rapeseed sites indicated very little difference among the three soil test procedures in accounting for the variation in yield increase from phosphate fertilizer. The best combination of significant quantitative variables was ASFTL-P(0-15) and % $CaCO_3$. Yield increase was depressed by an increase of either or both of these variables. Inclusion of site classification variables into the analysis did not improve the equation's prediction ability.

Principal component analysis of the responsive sites illustrated the complex interrelationships among the site properties, and with the calculated optimum fertilizer rate. The site variables measured can be reduced to five components representing (1) the soil solution, (2) the available phosphorus, (3) the soil organic matter, (4) soil zone, and (5) the phosphate fertilizer rate. The most noteworthy relationships were the inverse relationships between phosphate fertilizer rate and each of pH, ASFTL-P, precipitation, and soil organic matter content, and the direct relationship between clay content and phosphate fertilizer rate within certain components.

C. Wheat

The wheat sites used in this study were outside the RAYP project but were used as experimental sites during the same period of time in a project having similar objectives. This project was designed to determine the response of wheat to phosphate fertilizer on Chernozemic and Solonetzic soil orders. The results presented in this section represent the statistical analysis of wheat response to phosphate fertilizer for 38 sites. A brief description of the site charateristics (means, standard deviations, maximum and minimum values) are presented in Tables 24 and 25, while frequency distribution of the sites according to site classification are presented in Table 26. In general, the sites were restricted to acidic pH values and to only a few classification classes. In addition, site chemical and physical data are available for only the 0-15 cm soil depth. The major difference between the unresponsive and responsive groups was a higher mean soil test level for phosphorus and a higher mean precipitation for the unresponsive sites. Finally, the general distribution of the sites was restricted to the east-central portion of the province.

Table 24. Mean, Standard Deviation, Maximum, and Minimum Values of the Independent Variables for the Unresponsive Wheat Sites

Variables*	Mean	Std. Dev.	Max.	Min.	No. of Sites
pH (0-15)	5.70	0.35	6.3	5.1	13
E.C. (0-15)	0.43	0.13	0.7	0.3	13
% O.M. (0-15)	6.65	1.64	10.1	5.1	13
% sand (0-15)	32.49	7.76	44.5	20.8	13
% silt (0-15)	40.12	4.21	47.6	34.7	13
% clay (0-15)	27.42	5.59	38.6	18.5	13
Pptn.	30.54	10.61	44.7	14.7	13
ASFTL-P(0-15)	63.5	35.0	116.5	22.4	13
Ln ASFTL-P(0-15)	4.00	0.59	4.76	3.11	13
M & A-P(0-15)	68.7	34.5	128.8	25.8	13
Ln M & A-P(0-15)	4.11	0.52	4.86	3.25	13
Olsen-P(0-15)	43.1	16.1	71.7	22.4	13
Ln Olsen-P(0-15)	3.70	0.37	4.27	3.11	13

* Variable	Units
E.C.	mmhos/cm
Pptn.	cm
ASFTL-P	kg/ha
M & A-P	kg/ha
Olsen-P	kg/ha

Table 25. Mean, Standard Deviation, Maximum, and Minimum Values of the Independent Variables for the Responsive Wheat Sites

Variables*	Mean	Std. Dev.	Max.	Min.	No. of Sites
pH (0-15)	5.63	0.28	6.3	5.0	25
E.C. (0-15)	0.40	0.14	0.7	0.2	25
% O.M. (0-15)	5.71	1.60	8.0	2.2	25
% sand (0-15)	40.29	10.04	69.5	25.9	25
% silt (0-15)	34.63	6.12	41.1	16.2	25
% clay (0-15)	25.10	5.94	37.4	14.2	25
Pptn.	24.18	7.49	40.4	14.5	25
ASFTL-P(0-15)	37.2	16.9	70.6	7.8	25
Ln ASFTL-P(0-15)	3.48	0.58	4.26	2.06	25
M & A-P(0-15)	43.3	16.3	84.0	13.4	25
Ln M & A-P(0-15)	3.69	0.42	4.43	2.60	25
Olsen-P(0-15)	28.7	9.3	49.3	13.4	25
Ln Olsen-P(0-15)	3.30	0.34	3.90	2.60	25
P_2O_5 (90% Max.Yld.)	26.93	21.17	106.4	1.1	25

* Variable	Units
E.C.	mmhos/cm
Pptn.	cm
ASFTL-P	kg/ha
M & A-P	kg/ha
Olsen-P	kg/ha
P_2O_5 (90% Max.Yld.)	kg/ha

Table 26. Frequency Distribution of Responsive and Unresponsive Wheat Sites per Classification Class (Number of Sites)

Classification		Unresponsive	Responsive
Agro-climatic Area			
	1	12	18
	2A	1	9
Soil Zone			
	Black	4	11
	Thin Black	8	5
	Dark Brown	1	9
Soil Order			
	Chernozemic	5	13
	Solonetzic	8	12
Texture (0-15)			
	CL	7	8
	SCL	0	1
	L	6	14
	SL	0	2

1. Discriminant Analyses

The objective of this series of analyses was to determine those site variables important for distinguishing responsive and unresponsive wheat sites to phosphate fertilizer. There appeared to be very little difference among the soil test procedures for purposes of separating responsive and unresponsive sites (Table 27). In general, separation was very poor. The best overall functions were determined using Olsen-P and ASFTL-P in separate functions (Table 27). Again there was very little difference between the two procedures for separating sites into unresponsive and responsive. The function using Olsen-P also included % O.M. and E.C., while the function using ASFTL-P had only % O.M. as an additional variable important for discrimination. Since the function using ASFTL-P only required one additional variable to obtain the same degree of separation as that for the function using Olsen-P, it was much easier to use. Therefore, comparison of site classification was made using the ASFTL-P function.

Inclusion of the site classification variables into the function did not improve the function correlation (Table 28). As a result, individual class discriminant analyses were determined. These functions varied as to the number and types of variables important for site separation (Table 29 and 30). Even the best phosphorus soil test procedure varied among the classes. For separating the sites, the best functions were within the soil zone and soil

Table 27. Discriminant Analyses for Wheat Response to Phosphate Fertilizer:, (1) Comparison of Soil Tests, and (2) Best Overall Function

Variables	Std. Coef.	Unstd. Coef.	Group Centroid		TDP	Chi-sq.	Canonical Correl.
			Resp.	Unresp.			
1. Comparison of Soil Tests							
(38 sites)							
ASFTL-P(0-15)	1.00	0.04					
constant		-1.89	-0.37	0.71	0.19	8.6	0.46**
M & A-P(0-15)	1.00	0.04					
constant		-2.17	-0.36	0.70	0.18	8.4	0.46**
Olsen-P(0-15)	1.00	0.08					
constant		-2.80	-0.41	0.79	0.23	10.4	0.50**
2. Best Overall Functions (38 sites)							
Ln Olsen-P(0-15)	1.01	2.89					
% O.M. (0-15)	0.54	0.34					
E.C. (0-15)	-0.39	-2.89					
constant		-10.77	-0.47	0.91	0.29	13.0	0.56**
ASFTL-P(0-15)	1.00	0.04					
% O.M. (0-15)	0.77	0.48					
constant		-4.76	-0.52	1.00	0.33	15.4	0.60**

** significant at $p \leq 0.01$

Table 28. Discriminant Analyses for Wheat Response to Phosphate Fertilizer: Quantitative and Site Classification Variables (38 sites)

Variables	Std. Coef.	Unstd. Coef.	Group Centroid		TDP	Chi-sq.	Canonical Correl.
			Resp.	Unresp.			
Agro-climatic Area							
ASFTL-P(0-15)	0.99	0.04					
% O.M. (0-15)	0.74	-0.46					
Argo-climatic Area							
1	0.04	0.04					
constant		-4.67	-0.52	1.00	0.33	15.1	0.60**
Soil Zone							
ASFTL-P(0-15)	0.90	0.04					
% O.M. (0-15)	0.69	0.43					
Soil Zone							
Black	-0.13	-0.15					
Dark Brown	-0.09	-0.12					
constant		-4.30	-0.53	1.02	0.34	15.3	0.60**
Soil Order							
ASFTL-P(0-15)	1.10	0.05					
% O.M. (0-15)	0.79	0.49					
Soil Order							
Chernozemic	0.31	0.30					
constant		-5.00	-0.54	1.04	0.35	16.2	0.61**

** significant at $p \leq 0.01$

Table 29. Discriminant Analyses for Wheat Response to Phosphate Fertilizer for One Agro-climatic Area and Two Soil Zones

Variables	Std. Coef.	Unstd. Coef.	Group Centroid		TDP	Chi-sq.	Canonical Correl.
			Resp.	Unresp.			
Agro-climatic Area '1' (26 sites)							
ASFTL-P(0-15)	1.24	0.05					
% O.M. (0-15)	0.82	0.65					
constant		-6.52	-0.66	0.88	0.35	12.0	0.62**
Black Soil Zone (15 sites)							
Pptn.	0.83	0.10					
% clay (0-15)	3.96	0.73					
% sand (0-15)	3.10	0.45					
Ln M & A-P(0-15)	0.93	1.95					
E.C. (0-15)	0.83	5.29					
constant		-47.28	0.76	-2.10	0.61	11.0	0.81**
Thin Black Soil Zone (13 sites)							
Pptn.	1.53	0.36					
% clay (0-15)	2.20	0.38					
% sand (0-15)	4.13	0.57					
Ln Olsen-P(0-15)	3.87	13.47					
% O.M. (0-15)	2.39	1.41					
E.C. (0-15)	-1.36	-11.23					
pH (0-15)	-0.70	-1.90					
constant		-84.11	-7.22	4.51	0.97	27.6	0.99**

** significant at $p \leq 0.01$

Table 30. Discriminant Analyses for Wheat Response to Phosphate Fertilizer for Two Soil Orders

Variables	Std. Coef.	Unstd. Coef.	Group Centroid		TDP	Chi-sq.	Canonical Correl.
			Resp.	Unresp.			
Chernozemic Sites (18 sites)							
Ln Olsen-P(0-15)	-2.04	-6.16					
% O.M. (0-15)	-1.38	-0.66					
Pptn.	1.79	0.19					
E.C. (0-15)	1.77	13.94					
pH (0-15)	0.77	2.29					
% sand (0-15)	1.91	0.17					
% clay (0-15)	1.26	0.19					
constant		-10.42	1.02	-2.64	0.72	17.4	0.87**
Solonetzic Sites (20 sites)							
% sand (0-15)	2.90	0.41					
pH (0-15)	-2.08	-8.11					
% O.M. (0-15)	1.31	1.18					
% clay (0-15)	2.21	0.45					
M & A-P(0-15)	-0.91	-0.04					
constant		13.87	1.02	-1.54	0.60	15.7	0.80**

** significant at $p \leq 0.01$

order classes, while the function for agro-climatic area '1' had a poor ability to separate sites as indicated by the relatively low total discriminatory power and canonical correlation. However, care must be exercised when examining these functions because of the small sample size which may have resulted in a general inconsistant behavior of the site variables among the functions presented.

2. Multiple Regression Analysis

As in the case of the barley and rapeseed sites, the calculation of wheat response to phosphate fertilizer meant that yield increase was dependent upon a calculated fertilizer rate. The variation of this relationship among all sites should be due to variation in the site properties, and multiple regression procedures could be used to identify those site variables responsible for this variation.

It should be noted that the dependent variable used in these analyses was percent yield increase (see Material and Methods). This was done because of the very large variation in yield increase that could not be explained by the independent site variables other than the phosphate fertilizer rate. Percent yield increase was used in an attempt to remove some of the unmeasured environmental factors which may have influenced the variation in crop response. No comparison of the soil test procedures was necessary since only the Olsen-P proved to be significant in accounting for variation of percent yield increase. The best combination of quantitative variables as determined by a stepwise multiple regression analysis, and the approximate additional variation each explained, included: the phosphate fertilizer rate for optimum yield (31%), E.C.(0-15) (10%), and Ln Olsen-P(0-15) (20%) (Table 31). An increase in E.C. tended to enhance the percent yield increase, while an increase in Olsen-P depressed the percent yield increase. Altogether, this function was able to explain 61% of the

Table 31. Percent Yield Increase Equations for 25 Responsive Wheat Sites: (1) Best Combination of Quantitative Variables, and (2) Site Classification Using Stepwise Multiple Regression Anaylsis

Variables	b Value	Std.Err. b	F Value	R^2 Change	Overall Std.Err. Est.	Overall F Value	Overall R^2
(1) Best Combination of Quantitative Variables							
P_2O_5 (90% Max.Yld.)	0.46**	0.09	29.69	0.31			
E.C. (0-15)	56.87**	14.58	15.21	0.10			
Ln Olsen-P(0-15)	-20.14**	6.17	10.65	0.20			
constant	48.01				7.56	10.85	0.61**
(2) Site Classification							
Agro-climatic Area							
P_2O_5 (90% Max.Yld.)	0.39**	0.09	21.14	0.31			
E.C. (0-15)	63.04**	13.68	21.23	0.10			
Ln Olsen-P(0-15)	-21.14**	5.69	13.82	0.20			
Agro-climatic Area							
1	-3.76	1.70					
constant	51.86				6.95	10.86	0.69**
Soil Zone							
P_2O_5 (90% Max.Yld.)	0.40**	0.09	21.59	0.31			
E.C. (0-15)	63.66**	13.72	21.54	0.10			
Ln Olsen-P(0-15)	-20.69**	5.71	13.12	0.20			
Soil Zone							
Dark Brown	5.42	2.31					
Black	-0.85	2.05					
constant	48.26				6.96	8.85	0.70**
Soil Order							
P_2O_5 (90% Max.Yld.)	0.46**	0.09	24.49	0.30			
E.C. (0-15)	55.58**	18.11	9.42	0.10			
Ln Olsen-P(0-15)	-20.56**	7.17	8.22	0.20			
Soil Order							
Chernozemic	-0.35	2.81					
constant	50.04				7.75	7.76	0.61**

** significant at $p \leq 0.01$

variation in percent yield increase.

To determine if inclusion of site classification would improve percent yiel[illegible]rease prediction, effect coded classification var[illegible]es were forced into the function (Table 31). The inclusion of agro-climatic area or soil zone accounted respectively for an additional 8% and 9% of the percent yield increase variation. However, inclusion of soil order variables did not improve the regression correlation. To determine if a significant difference existed among the agro-climatic areas or soil zones, an approximate multiple range test was used on the estimated class means (see Material and Methods). The results indicated no significant difference among the means within either agro-climatic area or soil zone classifications (Table 32), even though a relatively large percentage of the variation in percent yield increase was accounted for by these variables. This was probably due to the large variation in the estimated means as indicated by the high standard errors.

Table 32. Comparison of Mean Percent Yield Increase for Responsive Wheat Sites in Various Classes

Classification		Mean	Std. Error
Agro-climatic Area			
	1	15.33 a	1.96
	2A	16.32 a	2.61
	$\bar{X}$	15.82	1.63
Soil Zone			
	Black	15.23 a	2.44
	Thin Black	15.54 a	3.76
	Dark Brown	16.31 a	2.68
	$\bar{X}$	15.70	1.71

Means within a classification having different letters are significantly different ($P \leq 0.05$)

3. Principal Component Analysis

The interrelationships among the measured independent site variables of the responsive wheat sites were determined using principal compnent analysis. The sum of the four largest components explained about 85% of the total variance of the data (Table 33)

Principal component number 1 accounted for about 34% of the variation. It was heavily loaded by pH, % organic matter, and the calculated optimum fertilizer rate and moderately loaded by % clay, precipitation, and Olsen-P. The phosphate fertilizer rate had an inverse relationship with pH, % organic matter, % clay, and precipitation, and a direct relationship with Olsen-P. This suggested that as pH, % organic matter and/or precipitation increased, the optimum fertilizer rate decreased. This would imply a mineralization process or a phosphate sorption mechanism by the soil organic matter, a greater importance of fertilizer phosphorus under arid conditions, plus a greater need for phosphate fertilizer by wheat as soil pH decreased. The direct relationship of the fertilizer phosphate requirement with the soil test for phosphorus (Olsen-P) is contrary to the definition of a soil test, and suggests that the soil test did not provide a measure of the available phosphorus in the soil. The inverse relationship between % clay and the phosphate fertilizer rate is again contrary to that found in the literature. This component could be labelled as the "phosphate fertilizer component".

Table 33. Principal Component Analysis of Responsive Wheat Sites: The Four Largest Eigenvalues

Principal Component No.	1	2	3	4
Eigenvalue	2.412	1.741	0.996	0.809
(cumulative percentage)	34.5	59.3	73.6	85.1
Eigenvectors				
pH (0-15)	0.855	-0.026	-0.207	-0.226
E.C. (0-15)	0.121	0.771	-0.442	0.371
% O.M. (0-15)	0.675	0.407	0.248	0.111
% clay (0-15)	0.537	-0.176	0.423	0.655
Pptn.	0.367	0.564	0.485	-0.423
Ln Olsen-P(0-15)	-0.473	0.783	0.132	0.026
P_2O_5 (90% Max.Yld.)	-0.751	-0.133	0.515	0.028

The second principal component accounted for about 25% of the variation and was heavily loaded by E.C. and Olsen-P, and moderately loaded by % organic matter and precipitation. The direct relationship between organic matter and precipitation suggested a soil zone trend, but the domination of the component by E.C. and Olsen-P suggested a minor role of the zone trend. Both E.C. and Olsen-P are an indication of the ionic potential of the soil solution, E.C. for ionic concentation and Olsen-P for solution and adsorbed phosphorus. Therefore, this component was labelled the "soil solution component".

Principal component number 3 accounted for about 14% of the variation and was loaded moderately by E.C., % clay, precipitation and the optimum phosphate fertilizer rate. A sorption relationship was indicated by this component, i.e., as clay content increased, the salt content of the soil solution (E.C.) decreased and the phosphate fertilizer rate needed for optimum growth increased to overcome phosphate sorption by the clay. Therefore, this component was labelled the "clay sorption component".

Principal component number 4 accounted for about 11% of the variation with the important variables being E.C., % clay and precipitation. No explanation for the relationship of these three variables can be offered.

Principal component analysis was meant for data reduction of large data sets and not for small data sets as was the case here. A number of unidentifiable or contrary relationships was found which may be due to the relatively small size of the data matrix.

4. Summary

The results of the discriminant analyses of the wheat sites indicated that there was very little difference among the soil test procedures for separation of responsive and unresponsive sites. In addition to the soil test for phosphorus, organic matter content of soils was an important discriminating variable, as was E.C., depending upon the soil test procedure used in the analysis. A high soil test for phosphorus and/or organic matter tended to allocate a site into the unresponsive group, whereas, a high E.C. tended to allocate a site into the responsive group. Individual classification class discriminant analyses resulted in more highly correlated functions than the function using the effect coded variables. This was due to the difference in the list of discriminant variables and their importance and behavior among the classes.

Multiple regression analysis of the responsive wheat sites indicated that the Olsen-P was the only soil test procedure able to significantly account for variation in the percent yield increase of wheat to phosphate fertili[illegible]. The only other measured quantitative variable which was significant was E.C.. Inclusion of either agro-climatic area or soil zone into the analysis increased the correlation coefficients of the equations. Soil order did not have the same effect. However, even with the improved correlation, there was no significant difference among the classification class means.

Principal component analysis of the responsive wheat sites revealed some recognizable relationships among site properties, and with the calculated optimum fertilizer rate. The site variables measured can be reduced to three components representing (1) phosphate fertilizer rate, (2) soil solution, and (3) clay adsorption. The most noteworthy relationships were the inverse relation between phosphate fertilizer rate and each of pH, % organic matter, and precipitation. Contradictory results were also noted, possibly being due to small sample size.

D. Sources of Variation

Several potential sources of variation exist in the study of crop response to fertilizer. These are discussed with reference to the present study.

1. The general field designs used in this study varied among the cooperators and were quite unique when compared to those found in the literature. As a result of careful examination, the procedure outlined in the Materials and Methods appeared to be the only route open to satisfy the objectives. Some of the problems encountered included:

   (a) In the original design of the project, a basic assumption was made concerning the relationship between cropping history of a site and nitrogen levels in the soil. It was assumed that fallowed sites would contain more plant available nitrogen than previously cropped sites, and as a result, blanket rates of nitrogen fertilizer differed depending on cropping history. Sites cropped the previous year received more nitrogen fertilizer than sites fallowed the previous year. This was compounded by use of different blanket nitrogen fertilizer rates among the cooperators. Therefore, cropping history as a site variable became related to nitrogen fertilizer rates. Separation of these variables was not possible and a combined variable was used. Analysis of covariance using an effect coding indicated no significant effect of this combined variable on yield response to phosphate fertilizer for all three crops.

(b)The plot design, number of treatments and replication varied not only among cooperators, but also from year to year for a particular cooperator.

(c) In a number of cases, the highest phosphate fertilizer treatment was not great enough to establish a true maximum yield for a site. For these sites, calculation of 90% maximum yield was based on the highest fertilizer rate and not on an extrapolation of the response function.

(d) The design of most of the experimental sites provided no information on possible interactions of plant nutrients.

2. The type of equation used for calculating the response function for each site was chosen based on visual examination of the plotted yield data for each site, ease of calculation, and ease of mathematical manipulation. Only one type of function (second order polynomial) was used, and in some cases the equation was forced to fit the data such that the fit was poor. Poor fits were due primarily to insufficient number of treatments to adequately define the response curve and to possible lack of uniformity within the plot site.
3. The lack of precipitation data for some sites forced the use of estimated values based on the nearest meteorological station. These estimated values may not have reflected the actual rainfall for the plot sites in

question. The influence of the distribution of precipitation over the growing season and the initial soil moisture conditions were not determined due to a lack of data.

4. Incomplete data for the M & A-P and Olsen-P procedures for some sites, due to the loss of original soil samples, forced comparison of soil test procedures being made on a reduced data set.
5. Site soil analyses were based on a composite soil sample for the site and not on individual treatments and/or replicates. This resulted in the assumption that the soil samples were representative of the plot site, and that the plot was uniform in terms of soil properties.
6. One or more of the variables investigated may have been truly unrelated to crop response but remained correlated due to chance. In the present study, attempts were made to give plausible explanations for significant correlations between independent and dependent variables. Definite causal relationships were however, difficult to determine. The validity of certain factors should be checked by analysis of new data.
7. The correlation between dependent and independent variables may have been nonlinear. This source of error was minimized in the present study by making scattergrams of dependent versus independent variables as described in the Material and Methods chapter, and applying the appropriate transformation to the

independent variable to approximate a linear relationship.

8. The number of sites, or sample population, in many analyses was quite small, thus possibly influencing the reliability of the results.
9. Multicollinearity exists when any independent variable is correlated with another independent variable or with a linear combination of other independent variables. Multicollinearity is common and even inevitable in much of the data in soil science. Correlation among the independent variables causes three main problems: (i) the standard errors of the regression coefficients are increased, (ii) as the extreme case of (i) is approached, computational difficulties arise, (iii) the omission of variables may result in biased estimators for the regression parameters of the remaining variables if the missing variables are correlated with those remaining. In general, there is little that can be done about multicollinearity except to take a larger sample, preferably in a way that decreases multicollinearity (Wesolowsky, 1976).
10. The basic difficulty with data derived from a series of fertilizer experiments is that the sources of variation differ between and within experiments. If these are not recognized, it is easy to obtain invalid tests of significance by using inappropriate estimates of error variance. The source of error affecting between site

relationships are primarily due to factors varying in an unknown or unidentified manner throughout the region. Since these error effects vary with both location and time, the error variance cannot be estimated by replication. Rather it must be estimated indirectly, as by the residual mean square of an appropriate regression analysis of variance.(Colwell, 1978).

11. The selection of 90% maximum yield for a site as the optimum yield may not have been valid. This selection was based on the examination of a general response curve which indicated that potential yield values near the maximum yield for the site changed very little, depending on the partial regression coefficients for the site, while the fertilizer rate could change quite dramatically. To provide a standard procedure, 90% of the maximum was arbitrarily selected as a yield that approximated an economic optimum as well as a biological optimum.
12. In this study, a simple separation of sites into 2 categories, responsive and unresponsive, was used. This separation did not take into account different levels of responsiveness (high, medium, and low).
13. With a few exceptions, analyses using effect coded variables (discriminant and multiple regression) were unable to indicate differences among the classes of a classification. This could be due to the assumption that the slope of the regression lines are equal among the

classes when effect coding is used. If this assumption was not correct, then a weighted coding may have been necessary.

14. The results of the statistical analyses in this study were not verified with data external to this study.

V. SUMMARY AND CONCLUSIONS

The aim of this study was to determine the influence of various soil properties and site classifications on the crop response to phosphate fertilizer in Alberta. As noted, rather poor correlations exist between the soil test for phosphorus and percent yield from combined field experiments in Alberta ($R^2 = 0.53$).[4] Good correlations between yield and the nitrogen and phosphate fertilizer rates were found for individual site-years by Heapy (1971) when soil tests for available nitrogen and phosphorus were included in the response function. However, when the individual site-years were combined, correlations were poor. Greenhouse studies have shown high correlations between yield response and soil test phosphorus (Robertson, 1962). Significant differences among cereal crops with respect to crop response to phosphate fertilizer was noted by Robertson *et al* (1968). In addition, numerous studies have noted the influence of various soil properties on the chemical reactions and availability of phosphate fertilizer within soils. Since (i) the correlations from greenhouse studies have been considerably better than those for field studies, and (ii) the correlations from individual site-year field experiments were better than those for which site-years were combined, there would appear to be an influence of the site environment (soil and climate) on the crop response to phosphate fertilizer. Therefore, rather than attempt to

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[4] Personal communication with Dr. J. A. Robertson.

develop and/or test new soil test procedures, the influence of soil and climatic properties on the yield response to phosphate fertilizer was examined.

The analyses of crop response in this study were broken down into two fundamental questions based on the purpose of a soil test: (1) Will a crop respond to phosphate fertilizer application at a particular site? and (2) If the answer to (1) is yes, then what is the magnitude of the response? To answer these questions, this study attempted to determine the influence of various site properties using two separate but related analyses: (1) discriminant analysis to separate sites into responsive and unresponsive categories, and (2) multiple regression analysis to account for the variation in yield increase of the responsive sites. In addition, principal component analysis was used to determine the interrelationships among site variables of the responsive sites. The results of these statistical techniques were used to try to understand the variation in site response to phosphate fertilizer application.

Results of the analyses of the barley sites indicated that the most important site property influencing both site response and yield increase to phosphate fertilizer was the soil test (ASFTL-P). Other site variables that were important for site separation included clay and $CaCO_3$ content of the soil, and growing season precipitation while, soil pH, growing season precipitation, and organic matter content of soils significantly accounted for variation in yield increase of the responsive sites. Site classification improved the correlation coefficients of both the discriminant and multiple regression analyses, indicating significant differences in crop response to phosphate fertilizer among some classes, particularly those sites in the gray soil zone or members of the Luvisolic soil order. Principal component analysis indicated that the required phosphate fertilizer rate for "optimum" yield response was inversely related to ASFTL-P, soil pH, and the organic matter content of soils. Thus for barley, the phosphate fertilizer rates should be reduced as ASFTL-P, pH, and/or % organic matter increase.

Results of the analyses of the rapeseed sites suggested that the crop response to phosphate fertilizer was influenced by site properties different from those for the barley sites. Again, the most important site parameter influencing crop response to phosphate fertilizer was the soil test for phosphorus (ASFTL-P). The other site variables that significantly influenced site separation were E.C. and clay content of the soil, while $CaCO_3$ content of the soil was the only other site parameter that accounted for variation in yield increase of the responsive sites. Site classification was important for site separation but not for explaining variation in yield increase. Principal component analysis of the responsive sites indicated trends similar to those found for the responsive barley sites. The required phosphate fertilizer rate for "optimum" yield was inversely related to ASFTL-P, soil pH, and soil organic matter content, but also, to growing season precipitation. Therefore, phosphate fertilizer rates for "optimum" yield response of rapeseed should be reduced as ASFTL-P, soil pH, organic matter content of soils and/or growing season precipitation increase.

Unfortunately, the locations of the wheat sites differed considerably from those of either barley or rapeseed, making crop comparisons almost impossible. The results of the analyses of the wheat sites indicate that a soil test for phosphorus was the most important site variable influencing crop response. The other site properties influencing site separation were organic matter content of soils and soil E.C., while only the additions of soil E.C. explained variation in percent yield increase of the responsive sites. Site classification had a variable influence. For site separation, site classfication appeared to be important, especially for individual class functions and for determining the best soil test procedure for phosphorus. For the variation in percent yield increase of the responsive sites, inclusion of site classification resulted in a large improvement in the correlation coefficient of the percent yield increase equation, but there was no significant difference among the class means when compared. Principal component analysis showed a number of the same trends as observed for the responsive barley and rapeseed sites, that is, the required phosphate fertilizer rate for "optimum" yield was inversely related to soil pH, soil organic matter, and growing season precipitation. However, the relationship between the soil test for phosphorus (Olsen-P) and phosphate fertilizer rate was contrary to the barley and rapeseed results, and to the commonly expected relationship. This contradiction could be due to either the small number of sites or to the inability of the soil test to provide an indication of the available phosphorus status for these sites, especially those classed as Solonetzic.

In conclusion, the soil test for phosphorus does not, by itself, provide a satisfactory measurement for separation of responsive and unresponsive sites, nor for the variation in yield increase of the responsive sites. The inclusion of other site properties did improve the correlation coefficients, but their contribution to the overall function R^2 was generally smaller than that of the soil test. Site classification using either effect coding or analysis of individual classes did improve on the correlations, with the individual analyses having the better results for site separation. It would be preferred that the coded function was more successful because of the difficulty in using individual class functions. The results of this study cannot be considered as conclusive and they need to be verified with external data. They do suggest that the phosphate fertilizer rate for "optimum" yield response should be reduced as ASFTL-P, soil pH, organic matter content, and/or growing season precipitation increase. The properties identified as influencing crop response to phosphate fertilizer can be used in further modelling designed to derive more specific calibration curves for predicting phosphate fertilizer requirements. Additional work is needed to determine the influence of meteorological variation, cropping history, soil and fertilizer nitrogen levels and micronutrient levels on the crop response to phosphate fertilizer. Alternative approaches to measuring the phosphorus fertility status of soils may also have to be examined.

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APPENDICES

Site Identification Code

Code	Cooperator
B	Agriculture Canada, Beaverlodge
E	Alberta Agriculture, Edmonton
L	Agriculture Canada, Lacombe
W	Western Co-operative Fertilizer Ltd., Calgary
T	Agriculture Canada, Lethbridge
J	Dr. J.A. Robertson, University of Alberta

APPENDIX A

Experimental Year, Crop Variety, Cropping History, and Legal Location of Experimental Sites

NA indicates data were Not Available

Table A-1. Barley Sites

Site	Year	Variety	Past Cropping History	Legal Location
B01	1971	Galt	1970-Fallow	LSD 11-26-073-10-W6
B02	1971	Galt	1970-Fallow	NW 13-081-02-W6
B03	1971	Galt	1970-Oats 1969-Wheat	NE 35-108-12-W5
B04	1971	Galt	1970-Cropped	NE 15-110-19-W5
B05	1971	Galt	1970-Barley	LSD 06-26-073-10-W6
B06	1971	Galt	1970-Barley 1969-Barley	LSD 05-34-071-09-W6
B07	1971	Galt	1970-Wheat	SW 02-078-20-W5
B08	1971	Galt	1970-Fallow	SE 17-078-19-W6
B09	1971	Galt	1970-Fallow	NW 16-072-11-W6
B10	1971	Galt	1970-Fallow	SE 23-083-01-W6
B11	1972	Galt	1971-Fallow	NE 09-070-10-W6
B12	1972	Galt	1971-Fallow 1970-Barley	NW 16-072-11-W6
B13	1972	Galt	1971-Fallowed Fescue 1970-Fescue	LSD 23-078-10-W6
B14	1972	Galt	1971-Fallow	SE 01-109-12-W5
B15	1972	Galt	1971-Fallow	NW 01-108-13-W5
B16	1972	Galt	1971-Barley 1970-Rapeseed	LSD 07-072-07-W6
B17	1972	Galt	1971-Rapeseed	SW 32-072-11-W6
B18	1972	Galt	1971-Barley 1970-Fallow	SE 17-078-19-W6
B19	1972	Galt	1971-Rapeseed	NW 21-110-19-W5
B20	1972	Galt	1971-Barley	NE 02-108-13-W5
B21	1973	Galt	1972-Barley 1971-Barley	LSD 08-07-072-07-W6
B22	1973	Galt	1972-Fallow	LSD 16-36-083-24-W5
B23	1973	Galt	1972-Fallow	LSD 02-17-107-15-W5
B24	1973	Galt	1972-Fallow	NW 09-109-17-W5
B25	1973	Galt	1972-Fallow	NE 02-108-13-W5
B26	1973	Galt	1972-Fallow	NW 05-109-07-W5
B27	1973	Galt	1972-Wheat 1971-Fallow	LSD 03-22-080-02-W6
B28	1973	Galt	1972-Partial Fallow	LSD 09-26-073-10-W6
B29	1973	Galt	1972-Cropped	NW 01-108-13-W5
B30	1973	Galt	1972-Cropped	NW 16-110-19-W5
B31	1973	Galt	1972-Cropped	SW 16-107-15-W5
B32	1973	Galt	1972-Cropped	SW 24-107-13-W5
B33	1974	Galt	1973-Fallow	NE 14-108-13-W5
B34	1974	Galt	1973-Fallow	SW 04-107-12-W5
B35	1974	Galt	1973-Fallow	NW 16-107-15-W5
B36	1974	Galt	1973-Fallow	NE 01-108-13-W5
B37	1974	Galt	1973-Cropped	SE 17-107-15-W5
B38	1974	Galt	1973-Cropped	NW 01-108-13-W5
B39	1974	Galt	1973-Cropped	NW 08-108-17-W5
B40	1974	Galt	1973-Cropped	NW 16-110-19-W5

Table A-1. Barley Sites (cont.)

Site	Year	Variety	Past Cropping History	Legal Location	
E01	1971	Galt	1970-Oats and Barley 1969-Sod-Breaking	SW	18-055-23-W4
E02	1971	Galt	1970-Barley	NE	29-056-27-W4
E03	1971	Galt	1970-Fallow 1969-Oats	SW	24-055-24-W4
E04	1971	Galt	1970-Fallow	SW	18-062-26-W4
E06	1971	Galt	1970-Barley	SW	25-032-04-W5
E07	1971	Galt	1970-Barley and Oats	SE	25-046-27-W4
E08	1971	Galt	1970-Barley	NW	16-058-25-W4
E09	1971	Galt	1970-Barley	SE	29-033-01-W5
E10	1971	Galt	1970-Fallow	NE	16-063-26-W4
E11	1971	Galt	1970-Fallow 1969-Sweet-Clover	NW	27-046-25-W4
E13	1972	Galt	1971-Barley	NW	04-049-27-W4
E14	1972	Galt	1971-Fallow 1970-Hay-Sod	NW	01-049-22-W4
E15	1972	Galt	1971-Barley	SE	05-049-19-W4
E17	1972	Galt	1971-Oats and Barley	NE	04-049-19-W4
E20	1972	Galt	1971-Barley	SE	30-032-02-W5
E21	1972	Galt	1971-Barley	NW	26-033-01-W5
E22	1972	Galt	1971-Wheat	SE	03-033-27-W4
E23	1973	Galt	1972-Barley	SW	25-059-20-W4
E24	1973	Galt	1972-Barley	SE	17-059-21-W4
E25	1973	Galt	1972-Barley	NW	13-054-24-W4
E26	1973	Galt	1972-Wheat 1971-Rapeseed	SW	05-059-13-W4
E27	1973	Galt	1972-Barley	NE	07-057-24-W4
E29	1973	Galt	1972-Fallow 1971-Rapeseed	NE	31-058-21-W4
E30	1973	Galt	1972-Wheat 1971-Wheat	SE	20-060-17-W4
E32	1973	Galt	1972-Barley	SW	21-058-21-W4
E33	1973	Galt	1972-Barley 1971-Barley	SW	09-059-18-W4
E34	1973	Galt	1972-Barley 1971-Rapeseed	NE	24-059-17-W4

Table A-1. Barley Sites (cont.)

Site	Year	Variety	Past Cropping History	Legal Location	
L01	1971	Galt	1970-Barley	SE	02-055-08-W4
L03	1971	Galt	1970-Barley	NE	08-054-11-W4
L04	1971	Galt	1970-Rapeseed	SE	06-037-28-W4
L05	1971	Galt	1970-Wheat	NW	12-054-09-W4
L06	1971	Galt	1970-Fallow	NE	08-054-11-W4
L08	1971	Galt	1970-Barley	NW	35-052-08-W4
L10	1972	Galt	1971-Oats	SE	36-053-11-W4
L11	1972	Galt	1971-Sweet Clover	SW	14-053-08-W4
L12	1972	Galt	1971-Rapeseed	NE	34-054-07-W4
L13	1972	Galt	1971-Oats	SW	33-053-11-W4
L14	1972	Galt	1971-Sweet Clover	SE	32-054-13-W4
L15	1972	Galt	1971-Sweet Clover	SE	36-053-11-W4

Table A-1. Barley Sites (cont.)

Site	Year	Variety	Past Cropping History	Legal	Location
W01	1971	Conquest	1970-Fallow	SW	14-026-23-W4
W02	1971	Betzes	1970-Fallow	SW	29-027-19-W4
W03	1971	Conquest	1970-Fallow	NW	07-024-26-W4
W04	1971	Betzes	1970-Fallow	NE	20-023-23-W4
W05	1971	Betzes	1970-Fallow	NE	06-031-21-W4
W06	1971	Conquest	1970-Fallow	SW	11-022-25-W4
W07	1972	Betzes	1971-Fallow	NE	33-023-28-W4
W08	1972	Betzes	1971-Fallow	SW	02-023-27-W4
W09	1972	Galt	1971-Barley 1970-Cereal	NE	02-030-01-W5
W10	1972	Betzes	1971-Barley 1970-Cereal	SW	34-031-27-W4
W12	1972	Betzes	1971-Fallow	SW	09-024-21-W4
W13	1972	Betzes	1971-Fallow	SW	26-011-27-W4
W14	1972	Galt	1971-Fallow	SE	18-027-28-W4
W15	1972	Betzes	1971-Fallow	SE	04-027-21-W4
W16	1972	Betzes	1971-Fallow	NE	24-025-23-W4
W17	1972	Betzes	1971-Cereal	SW	17-032-01-W5
W18	1972	Betzes	1971-Fallow	NW	14-017-02-W5
W19	1972	Galt	1971-Cereal	NE	14-031-02-W5
W20	1972	Betzes	1971-Grazed Crop Cover 1970-Cereal	SE	16-018-29-W4
W22	1972	Betzes	1971-Fallow	NE	26-024-27-W4
W23	1972	Betzes	1972-Fallow	SW	26-011-27-W4
W24	1973	Betzes	1972-Fallow	SW	01-024-28-W4
W25	1973	NA	1972-Fallow	SW	07-032-23-W4
W26	1973	NA	1972-Fallow	SE	15-033-25-W4
W27	1973	Betzes	1972-Fallow	SW	05-028-22-W4
W28	1973	Galt	1972-Fallow	SW	18-027-21-W4
W29	1973	Betzes	1972-Barley	NW	26-024-27-W4
W31	1973	Betzes	1972-Rapeseed	NW	09-026-23-W4
W34	1973	Betzes	1972-Wheat 1971-Fallow	SW	26-011-27-W4
W36	1973	Galt	1972-Barley 1971-Barley	SE	30-029-25-W4
W37	1973	Galt	1972-Barley 1971-Cropped	SE	36-029-29-W4
W38	1973	Galt	1972-Barley 1971-Barley	NE	17-032-01-W5
W41	1973	Betzes	1973-Barley	SE	13-032-24-W4
W42	1974	Galt	1973-Wheat	SW	15-033-25-W4
W43	1974	Galt	1973-Oats and Barley	SE	23-029-01-W5
W44	1974	Galt	1973-Cropped	NW	12-034-01-W5
W46	1974	Galt	1973-Barley	NW	22-038-28-W4
W47	1974	Galt	1973-Barley	NE	31-038-01-W5

Table A-1. Barley Sites (cont.)

Site	Year	Variety	Past Cropping History	Legal	Location
T01	1973	Galt	1972-Rapeseed	SW	06-021-23-W4
T02	1973	Galt	1972-Fallow	SE	14-022-26-W4
T03	1973	Galt	1972-Barley	NE	02-023-28-W4
T07	1974	Galt	1973-Fallow	SW	06-021-23-W4
T08	1974	Galt	1973-Wheat	SE	02-023-28-W4
T09	1974	Galt	1973-Fallow	NW	14-022-26-W4
T10	1975	Galt	1974-Fallow	SW	06-021-23-W4
T12	1975	Galt	1974-Fallow	SE	14-022-26-W4

Table A-2. Rapeseed Sites

Site	Year	Variety	Past Cropping History	Legal Location	
B41	1971	Span	1970-Fallow	SE	23-083-01-W6
B42	1971	Span	1970-Oats 1969-Wheat	NE	35-108-12-W5
B43	1971	Span	1970-Cropped	NE	15-110-19-W5
B44	1971	Span	1970-Barley	LSD	06-26-073-10-W6
B45	1971	Span	1970-Barley 1969-Barley	SW	34-071-09-W6
B46	1971	Span	1970-Wheat	SW	02-078-20-W5
B47	1971	Span	1970-Fallow	LSD	11-26-073-10-W6
B48	1971	Span	1970-Fallow	SE	17-078-19-W6
B49	1971	Span	1970-Fallow	NW	13-081-02-W6
B50	1972	Span	1971-Rapeseed	NW	21-110-19-W5
B51	1972	Span	1971-Barley	NE	02-108-13-W5
B52	1972	Span	1971-Fallow	NE	09-070-10-W6
B53	1972	Span	1971-Fallow	NW	01-108-13-W5
B54	1972	Span	1971-Fallow		23-078-10-W6
B55	1972	Span	1971-Barley 1970-Fallow	SE	17-078-19-W6
B56	1972	Span	1971-Barley 1970-Rapeseed		07-072-07-W6
B57	1972	Span	1971-Fallow	NW	16-072-11-W6
B58	1972	Span	1971-Rapeseed 1970-Volunteer Barley	SW	32-072-11-W6
B59	1973	Span	1972-Barley 1971-Barley	LSD	08-07-072-07-W6
B60	1973	Span	1972-Barley	LSD	16-36-083-24-W5
B61	1973	Span	1972-Fallow	LSD	02-17-107-15-W5
B62	1973	Span	1972-Fallow	NW	09-109-17-W5
B63	1973	Span	1972-Fallow	NE	02-108-13-W5
B64	1973	Span	1972-Fallow	NW	05-109-07-W5
B65	1973	Span	1972-Wheat 1971-Fallow	LSD	03-22-080-02-W6
B66	1973	Span	1972-Partial Fallow 1971-Fescue	LSD	09-26-073-10-W6
B67	1973	Span	1972-Cropped	NW	01-108-13-W5
B68	1973	Span	1972-Cropped	NW	16-110-19-W5
B69	1973	Span	1972-Cropped	SW	16-107-15-W5
B70	1973	Span	1972-Cropped	SW	24-107-13-W5
B71	1974	Span	1973-Fallow	NE	14-108-13-W5
B72	1974	Span	1973-Fallow	SW	04-107-12-W5
B73	1974	Span	1973-Fallow	NW	16-107-15-W5
B74	1974	Span	1973-Fallow	NE	01-108-13-W5
B75	1974	Span	1973-Cropped	SE	17-107-15-W5
B76	1974	Span	1973-Cropped	NW	01-108-13-W5
B77	1974	Span	1973-Cropped	NW	08-108-17-W5
B78	1974	Span	1973-Cropped	NW	16-110-19-W6

Table A-2. Rapeseed Sites (cont.)

Site	Year	Variety	Past Cropping History	Legal	Location
E37	1971	Span	1970-Barley	NW	18-049-27-W4
E38	1971	Span	1970-Barley	NW	16-058-25-W4
E39	1971	Span	1970-Barley	SE	29-033-01-W5
E40	1971	Span	1970-Barley and Oats	SE	24-046-27-W4
E41	1971	Span	1970-Fallow	NE	09-049-26-W4
E42	1971	Span	1970-Barley	SW	25-032-04-W5
E44	1971	Span	1970-Fallow	SW	24-055-24-W4
E45	1971	Span	1970-Oat and Barley 1969-Sod-Breaking	SW	18-055-23-W4
E46	1972	Span	1971-Barley	NW	04-049-27-W4
E47	1972	Span	1971-Fallow 1970-Hay(Sod)	NW	01-049-22-W4
E48	1972	Span	1971-Barley	SE	05-049-19-W4
E49	1972	Span	1971-Oats and Barley	NE	04-049-19-W4
E53	1972	Span	1971-Cereal	SE	30-032-02-W5
E54	1972	Span	1971-Cereal	NW	26-033-01-W5
E55	1972	Span	1971-Wheat	SE	03-033-27-W4
E57	1973	Span	1972-Fallow	NE	31-058-21-W4
E58	1973	Span	1972-Barley	NW	13-054-24-W4
E60	1973	Span	1972-Barley	SE	17-059-21-W4
E61	1973	Span	1972-Barley 1971-Barley	SW	09-059-18-W4
E62	1973	Span	1972-Barley 1971-Rapeseed	NE	07-057-24-W4
E63	1973	Span	1972-Barley 1971-Rapeseed	NE	24-059-17-W4
E64	1973	Span	1972-Wheat 1971-Wheat	SE	20-060-17-W4
E65	1973	Span	1972-Barley	SW	25-059-20-W4
E66	1973	Span	1972-Barley	SW	21-058-21-W4

Table A-2. Rapeseed Sites (cont.)

Site	Year	Variety	Past Cropping History	Legal	Location
L48	1971	Span	1970-Rapeseed	SE	06-037-28-W4
L49	1971	Span	1970-Barley	SE	02-055-08-W4
L50	1971	Span	1970-Wheat	NW	12-054-09-W4
L51	1972	Span	1971-Sweet Clover	SE	35-053-11-W4
L52	1972	Span	1971-Oats	SE	36-053-11-W4
L53	1972	Span	1971-Rapeseed	NE	34-054-07-W4
L54	1972	Span	1971-Sweet Clover	SE	32-054-14-W4

Table A-2. Rapeseed Sites (cont.)

Site	Year	Variety	Past Cropping History	Legal	Location
W49	1972	Echo	1971-Fallow	NW	09-026-23-W4
W50	1973	Span	1972-Barley	NW	26-024-27-W4
W52	1973	Span	1972-Barley	SE	18-033-23-W4
W53	1973	Span	1972-Barley	SE	36-029-01-W5
W54	1973	Span	1972-Barley	NE	17-032-01-W5

Table A-2. Rapeseed Sites (cont.)

Site	Year	Variety	Past Cropping History	Legal	Location
T19	1971	Span	1970-Fallow	SE	34-018-24-W4
T20	1971	Span	1970-Fallow	SW	33-016-27-W4
T21	1971	Span	1970-Fallow	SE	33-005-27-W4
T22	1971	Span	1970-Fallow	NE	27-002-14-W4
T17	1972	Span	1971-Fallow	NW	26-002-14-W4
T18	1972	Span	1971-Fallow	SW	33-005-27-W4
T13	1973	Torch	1972-Fallow	SE	14-022-26-W4
T14	1973	Span	1972-Fallow	NE	05-008-01-W5
T15	1973	Span	1972-Fallow	SW	33-005-27-W4
T16	1973	Torch	1972-Barley	NE	02-023-28-W4
T26	1974	Span	1973-Fallow	SW	06-021-23-W4
T27	1974	Span	1973-Fallow	NE	28-002-14-W4
T28	1974	Span	1973-Fallow	SW	33-005-27-W4
T29	1974	Span	1973-Wheat	SE	02-023-28-W4
T30	1974	Span	1973-Fallow	NW	14-022-26-W4
T31	1975	Span	1974-Fallow	SE	14-022-26-W4
T32	1975	Span	1974-Fallow	SW	06-021-23-W4

Table A-3. Wheat Sites

Site	Year	Variety	Past Cropping History	Legal	Location
J01	1969	Thatcher	1968-Fallow	NW	03-046-17-W4
J02	1969	Thatcher	1968-Fallow	SW	25-032-17-W4
J03	1969	Thatcher	1968-Fallow	NW	36-038-14-W4
J04	1969	Thatcher	1968-Fallow	NW	21-039-28-W4
J06	1970	Thatcher	1969-Fallow	SE	15-039-19-W4
J07	1970	Thatcher	1969-Fallow	NW	03-046-17-W4
J08	1970	Thatcher	1969-Fallow	SW	25-032-17-W4
J09	1970	Thatcher	1969-Fallow	NW	36-038-14-W4
J10	1970	Thatcher	1969-Fallow	NW	21-039-18-W4
J11	1971	Thatcher	1970-Fallow	NE	07-031-17-W4
J12	1971	Thatcher	1970-Fallow	NW	21-039-18-W4
J13	1971	Thatcher	1970-Fallow	NW	12-032-18-W4
J14	1971	Thatcher	1970-Fallow	NW	36-038-14-W4
J15	1971	Thatcher	1970-Fallow	SW	25-032-17-W4
J16	1971	Thatcher	1970-Fallow	SE	18-039-18-W4
J17	1971	Thatcher	1970-Fallow	NW	15-047-17-W4
J18	1972	Thatcher	1971-Fallow	W	29-050-19-W4
J19	1972	Thatcher	1971-Fallow	SE	31-050-19-W4
J20	1972	Thatcher	1971-Cropped	NE	36-050-20-W4
J22	1972	Thatcher	1971-Greenfeed 1970-Cropped	NW	21-039-18-W4
J23	1972	Thatcher	1971-Fallow	SE	15-039-19-W4
J24	1972	Thatcher	1971-Fallow	NW	36-038-14-W4
J25	1972	Thatcher	1971-Cropped	SW	13-049-17-W4
J26	1972	Thatcher	1971-Cropped 1970-Fallow	SE	25-050-17-W4
J27	1972	Thatcher	1971-Cropped 1970-Cropped	NE	09-050-17-W4
J28	1972	Thatcher	1971-Fallow	NW	24-049-17-W4
J29	1973	Thatcher	1972-Cropped	SE	18-049-17-W4
J30	1973	Thatcher	1972-Fallow	NW	09-050-19-W4
J31	1973	Thatcher	1972-Fallow	SE	29-050-19-W4
J32	1973	Thatcher	1972-Fallow	SE	31-050-19-W4
J33	1973	Thatcher	1972-Fallow	SE	18-039-18-W4
J34	1973	Thatcher	1972-Barley 1971-Fallow	NW	03-046-17-W4
J35	1973	Thatcher	1972-Fallow	NW	36-038-14-W4
J36	1973	Thatcher	1972-Greenfeed	SE	20-029-18-W4
J37	1973	Thatcher	1972-Fallow	SW	25-050-17-W4
J38	1973	Thatcher	1972-Cropped	NW	09-050-17-W4
J39	1973	Thatcher	1972-Fallow	SE	15-050-19-W4
J40	1973	Thatcher	1972-Fallow	SE	26-049-17-W4

APPENDIX B

Classification of Experimental Sites

List of Classification Abbreviations

Soil Zone

G.	Gray
D.G.	Dark Gray
BL.	Black
TBL.	Thin Black
D.B.	Dark Brown
B.	Brown

Parent Material

Lac	Lacustrine
Lac Till	Lacustro Till
Till	Till
Fl	Fluvial
Aeo	Aeolian
Resid	Residual
SL	Sandy Loam
S	Sand
Sorted Till	Sorted Till

Soil Classification

abbreviations follow Canadian System of Soil Classifcaton (1978)

Table B-1. Barley Sites

Site	Soil Zone	Agro-climatic Area	Parent Material	Soil Classification
B01	D.G.	2H	Lac Till	SZ.DG
B02	D.G.	2H	Fl/Till	D.GL
B03	G.	3Ha	Fl/Aeo	O.GL
B04	G.	3Ha	Lac	SZ.GL
B05	D.G.	2H	Lac Till	SZ.DG
B06	D.G	2H	Till,Lac Till	D.GL
B07	G.	2H	Lac	SZ.GL
B08	G.	3H	Fl	O.GL
B09	G.	3H	Lac Till	SZ.GL
B10	G.	3H	Fl	O.GL
B11	D.G.	2H	Lac Till	SZ.DG
B12	G.	3H	Lac Till	SZ.GL
B13	G.	3H	Lac Till	SZ.GL
B14	G.	3Ha	Fl/Aeo	O.GL
B15	D.G.	3Ha	Fl/Aeo	D.GL
B16	D.G.	2H	Lac Till	SZ.DG
B17	G.	3H	Lac Till	SZ.GL
B18	G.	3H	Fl	O.GL
B19	G.	3Ha	Lac	SZ.GL
B20	D.G.	3Ha	Fl/Aeo	D.GL
B21	D.G.	2H	Lac Till	SZ.DG
B22	D.G.	2H	Fl	D.GL
B23	G.	3Ha	Fl/Aeo	O.GL
B24	D.G.	3Ha	Fl/Aeo	D.GL
B25	D.G.	3Ha	Fl/Aeo	D.GL
B26	BL.	3Ha	Fl	O.BL
B27	D.G.	2H	Lac	DG.SO
B28	D.G.	2H	Lac Till	SZ.DG
B29	G.	3Ha	Fl/Aeo	O.GL
B30	G.	3Ha	Lac	SZ.GL
B31	G.	3Ha	Fl/Aeo	O.GL
B32	G.	3Ha	Fl	O.GL
B33	D.G.	3Ha	Fl/Aeo	D.GL
B34	D.G.	3Ha	Fl	GL.DG
B35	G.	3Ha	Fl/Aeo	O.GL
B36	G.	3Ha	Fl/Aeo	O.GL
B37	G.	3Ha	Fl/Aeo	O.GL
B38	D.G.	3Ha	Fl/Aeo	D.GL
B39	D.G.	3Ha	Fl/Aeo	D.GL
B40	G.	3Ha	Lac	SZ.GL

Table B-1. Barley Sites (cont.)

Site	Soil Zone	Agro-climatic Area	Parent Material	Soil Classification
E01	BL.	1	Lac	E.BL
E02	D.G.	2H	Fl	O.DG
E03	BL.	1	Lac	E.BL
E04	BL.	2H	Fl	GLE.BL
E06	D.G.	3H	Till	O.DG
E07	BL.	1	Fl/Till	O.BL
E08	BL.	1	Fl/Till	E.BL
E09	BL.	2H	Till	O.BL
E10	G.	2H	Fl	O.GL
E11	BL.	1	Fl	E.BL
E13	D.G.	1	Till	O.DG
E14	BL.	1	Fl/Till	E.BL
E15	BL.	1	Resid	BL.SS
E17	BL.	1	Till	BLA.SZ
E20	BL.	2H	Till	O.BL
E21	BL.	1	Till	O.BL
E22	BL.	1	Till	O.BL
E23	D.G.	1	Till	D.GL
E24	D.G.	2H	Till	O.DG
E25	BL.	1	Lac	E.BL
E26	G.	1	Till	O.GL
E27	BL.	1	Till	E.BL
E29	D.G.	1	Till	D.GL
[illegible]0	G.	2H	Till	O.GL
E32	D.G.	1	Till	HU.LG
E33	D.G.	1	Till	O.DG
E34	D.G.	2H	Fl	GL.DG

Table B-1. Barley Sites (cont.)

Site	Soil Zone	Agro-climatic Area	Parent Material	Soil Classification
L01	BL.	2H	Fl	O.BL
L03	D.G.	2H	Fl/Till	O.DG
L04	BL.	2H	Lac/Till,Lac	O.BL
L05	BL.	2H	Fl/Till	O.BL
L06	D.G.	2H	Till	O.DG
L08	D.G.	2H	Till	O.DG
L10	BL.	2H	Fl/Till	O.BL
L11	G.	2H	Till	O.GL
L12	BL.	2H	Fl,Fl/Till	O.BL
L13	G.	2H	Till	O.GL
L14	BL.	1	Fl/S,Fl/Till	O.BL
L15	BL.	2H	Fl/Till	O.BL

Table B-1. Barley Sites (cont.)

Site	Soil Zone	Agro-climatic Area	Parent Material	Soil Classification
W01	D.B.	2A	Lac	O.DB
W02	D.B.	2A	Lac	O.DB
W03	TBL.	1	Fl/Till,Till	O.TBL
W04	D.B.	2A	Till,Till/Resid	O.DB
W05	D.B.	1	Lac	O.DB
W06	D.B.	2A	Fl	R.DB
W07	TBL.	1	Fl/Till	O.TBL
W08	BL.	1	Fl/Till	O.TBL
W09	BL.	1	Till	O.BL
W10	TBL.	1	Fl/SL	E.TBL
W12	D.B.	2A	Lac/S	R.DB
W13	D.B.	2A	Fl	O.DB
W14	TBL.	1	Till/Resid,Till	O.TBL
W15	D.B.	2A	Lac	R.DB.
W16	D.B.	2A	Fl,Fl/Till	O.DB.
W17	BL.	1	Till	O.BL
W18	BL.	3H	Till	O.BL
W19	BL.	2H	Lac	O.BL
W20	TBL.	2H	Till	O.TBL
W22	TBL.	1	Till,Fl/Till	O.TBL
W23	D.B.	2A	Fl	O.DB
W24	TBL.	1	Lac	O.TBL
W25	TBL.	1	Till	O.TBL
W26	TBL.	1	Fl/Till	O.TBL
W27	D.B.	2A	Lac	O.DB
W28	D.B.	2A	Lac	SZ.DB
W29	TBL.	1	Till	O.TBL
W31	D.B.	1	Fl	O.DB
W34	D.B.	2A	Fl	R.DB
W36	TBL.	1	Fl	O.TBL
W37	BL.	1	Till	O.BL
W38	D.B.	1	Fl	O.DB
W41	TBL.	1	Lac	R.TBL
W42	TBL.	1	Lac,Lac/Till	O.TBL
W43	BL.	1	Till	O.BL
W44	BL.	1	Fl	R.HG
W46	BL.	2H	Lac/Resid	E.BL
W47	D.G.	2H	Lac,Lac/Till	D.GL

Table B-1. Barley Sites (cont.)

Site	Soil Zone	Agro-climatic Area	Parent Material	Soil Classification
T01	D.B.	2A	Fl	O.DB
T02	TBL.	1	Fl,Fl/Till	O.TBL
T03	TBL.	1	Fl,Fl/Till,Till	O.TBL
T07	D.B.	2A	Fl	O.DB
T08	TBL.	1	Fl,Fl/Till	O.TBL
T09	TBL.	1	Fl/Till,Fl	O.TBL
T10	D.B.	2A	Fl	O.DB
T12	TBL.	1	Fl/Till,Fl,Till	O.TBL

Table B-2. Rapeseed Sites

Site	Soil Zone	Agro-climatic Area	Parent Material	Soil Classification
B41	G.	3H	Fl	O.GL
B42	G.	3Ha	Fl/Aeo	O.GL
B43	G.	3Ha	Lac	SZ.GL
B44	D.G.	2H	Lac Till	SZ.DG
B45	D.G.	2H	Till,Lac Till	D.GL
B46	G.	2H	Lac	SZ.GL
B47	D.G.	2H	Lac Till	SZ.DG
B48	G.	3H	Fl	O.GL
B49	D.G.	2H	Fl/Till	D.GL
B50	D.G.	3Ha	Lac	SZ.GL
B51	D.G.	3Ha	Fl/Aeo	D.GL
B52	D.G.	2H	Lac Till	SZ.DG
B53	D.G.	3Ha	Fl/Aeo	D.GL
B54	G.	3H	Lac Till	SZ.GL
B55	D.G.	2H	Lac Till	SZ.DG
B56	D.G.	2H	Lac Till	SZ.DG
B57	G.	3H	Lac Till	SZ.GL
B58	G.	3H	Lac Till	SZ.GL
B59	D.G.	2H	Lac Till	SZ.DG
B60	D.G.	2H	Fl	D.GL
B61	G.	3Ha	Fl/Aeo	O.GL
B62	D.G.	3Ha	Fl/Aeo	D.GL
B63	D.G.	3Ha	Fl/Aeo	D.GL
B64	BL.	3Ha	Fl	O.BL
B65	D.G.	2H	Lac	DG.SO
B66	D.G.	2H	Lac Till	SZ.DG
B67	D.G.	3Ha	Fl/Aeo	D.GL
B68	G.	3Ha	Lac	SZ.GL
B69	G.	3Ha	Fl/Aeo	O.GL
B70	G.	3Ha	Fl	O.GL
B71	D.G.	3Ha	Fl/Aeo	D.GL
B72	D.G.	3Ha	Fl	GL.DG
B73	G.	3Ha	Fl/Aeo	O.GL
B74	G.	3Ha	Fl/Aeo	O.GL
B75	G.	3Ha	Fl/Aeo	O.GL
B76	D.G.	3Ha	Fl/Aeo	D.GL
B77	D.G.	3Ha	Fl/Aeo	D.GL
B78	G.	3Ha	Lac	SZ.GL

Table B-2. Rapeseed Sites (cont.)

Site	Soil Zone	Agro-climatic Area	Parent Material	Soil Classification
E37	D.G.	1	Lac	O.DG
E38	BL.	1	Fl/Till	E.BL
E39	BL.	2H	Till	O.BL
E40	BL.	1	Fl/Till	O.BL
E41	BL.	1	Fl/Till	E.BL
E42	D.G.	3H	Till	O.DG
E44	BL.	1	Lac	E.BL
E45	BL.	1	Lac	E.BL
E46	D.G.	1	Till	O.DG
E47	BL.	1	Fl/Till	E.BL
E48	BL.	1	Resid	BL.SS
E49	BL.	1	Till	BLA.SZ
E53	BL.	2H	Till	O.BL
E54	BL.	1	Till	O.BL
E55	BL.	1	Till	O.BL
E57	D.G.	1	Till	D.GL
E58	BL.	1	Lac	E.BL
E60	D.G.	2H	Till	O.DG
E61	D.G.	1	Till	O.DG
E62	BL.	1	Till	E.BL
E63	D.G.	2H	Fl	GL.DG
E64	G.	2H	Till	O.GL
E65	D.G.	1	Till	D.GL
E66	D.G.	1	Till	HU.LG

Table B-2. Rapeseed Sites (cont.)

Site	Soil Zone	Agro-climatic Area	Parent Material	Soil Classification
L48	BL.	2H	Lac/Till,Lac	O.BL
L49	BL.	2H	Fl	O.BL
L50	BL.	2H	Fl/Till	O.BL
L51	BL.	2H	Fl/Till	O.BL
L52	BL.	2H	Fl/Till	O.BL
L53	BL.	2H	Fl,Fl/Till	O.BL
L54	BL.	1	Fl/S,Fl/Till	O.BL

Table B-2. Rapeseed Sites (cont.)

Site	Soil Zone	Agro-climatic Area	Parent Material	Soil Classification
W49	D.B.	2A	Fl	O.DB
W50	TBL.	1	Till	O.TBL
W52	TBL.	1	Fl	O.TBL
W53	D.B.	1	Fl	O.DB
W54	BL.	1	Till	O.BL

Table B-2. Rapeseed Sites (cont.)

Site	Soil Zone	Agro-climatic Area	Parent Material	Soil Classification
T19	D.B.	2A	Fl/Till	O.DB
T20	TBL.	1	Fl/Till	O.TBL
T21	TBL.	2H	Lac,Lac/Till	R.TBL
T22	BL.	2A	Fl/Till	O.B
T17	BL.	2A	Fl/Till	O.B
T18	TBL.	2H	Lac,Lac/Till	R.TBL
T13	TBL.	1	Fl,Fl/Till	O.TBL
T14	BL.	2H	Lac	R.BL
T15	TBL.	2H	Lac,Lac/Till	R.TBL
T16	TBL.	1	Fl,Fl/Till,Till	O.TBL
T26	D.B.	2A	Fl	O.DB
T27	BL.	2A	Fl/Till	O.B
T28	TBL.	2H	Lac,Lac/Till	R.TBL
T29	TBL.	1	Fl,Fl/Till	O.TBL
T30	TBL.	1	Fl/Till	O.TBL
T31	TBL.	1	Fl/Till,Fl,Till	O.TBL
T32	D.B.	2A	Fl	O.DB

Table B-3. Wheat Sites

Site	Soil Zone	Agro-climatic Area	Parent Material	Soil Classification
J01	TBL.	1	Till,Fl/Till	TBL.SS
J02	D.B.	2A	Fl	O.DB
J03	D.B.	2A	Till	DB.SS
J04	TBL.	1	Till	O.TBL
J06	TBL.	1	Lac	TBL.SS
J07	TBL.	1	Fl/Till,Fl	SZ.TBL
J08	D.B.	2A	Fl/Till	O.DB
J09	D.B.	2A	Till	DB.SZ
J10	TBL.	1	Fl/Till	O.TBL
J11	D.B.	2A	Lac,Lac/Till	O.DB
J12	TBL.	1	Fl/S	O.TBL
J13	D.B.	2A	Fl	O.DB
J14	D.B.	2A	Till	DB.SZ
J15	D.B.	2A	Till	SZ.DB
J16	TBL.	1	Lac,Lac/Till,Till	TBL.SS
J17	TBL.	1	Till,Lac/Till	SZ.TBL
J18	BL.	1	Till	E.BL
J19	BL.	1	Sorted Till	GLE.BL
J20	BL.	1	Till	O.BL
J22	TBL.	1	Till	SZ.TBL
J23	TBL.	1	Till,Lac/Till	TBL.SS
J24	D.B.	2A	Till	DB.SZ
J25	BL.	1	Till,Till/Resid	BL.SO
J26	BL.	1	Fl/Till,Till	BL.SO
J27	BL.	1	Till	BL.SZ
J28	BL.	1	Till, Fl/Till	BL.SZ
J29	BL.	1	Fl/Till,Till	E.BL
J30	BL.	1	Fl/Till,Till	E.BL
J31	BL.	1	Till	E.BL
J32	BL.	1	Sorted Till	E.BL
J33	TBL.	1	Till,Lac/Till	TBL.SS
J34	TBL.	1	Till	TBL.SS
J35	D.B.	2A	Till	DB.SZ
J36	TBL.	1	Till	TBL.SZ
J37	BL.	1	Till,Fl/Till	BL.SZ
J38	BL.	1	Fl/Till	BL.SZ
J39	BL.	1	Till	BL.SS
J40	BL.	1	Till,Fl/Till	BL.SS

APPENDIX C

Growing Season Precipitation, and Soil Chemical Analyses of Experimental Sites

Analysis	Units
E.C.	mmhos/cm^2
NO_3-N	kg/ha
K	kg/ha

*	indicates estimated value
NA	indicates that data were Not Available

Table C-1. Barley Sites

Site	Pptn. (cm)	pH 0-15	pH 15-30	E.C. 0-15	E.C. 15-30	%CaCO$_3$ 0-15	%O.M. 0-15	NO$_3$-N 0-15	K 0-15
B01	31.7	5.5	4.6	0.3	0.2	0.0	3.9	27	405
B02	25.7	5.6	5.1	0.4	0.3	0.0	7.3	39	325
B03	16.5	6.5	5.6	0.3	0.3	0.0	2.3	8	249
B04	19.0	5.4	5.0	0.3	0.3	0.0	3.8	10	365
B05	32.3	5.3	4.6	0.3	0.2	0.0	7.0	4	306
B06	33.5	6.2	5.5	0.3	0.2	0.0	7.1	10	703
B07	30.0	5.6	4.5	0.3	0.3	0.0	3.3	15	407
B08	25.7	7.4	7.9	0.4	0.3	0.3	5.4	43	149
B09	36.3	6.1	4.6	0.3	0.1	0.0	2.8	20	330
B10	22.1	6.7	4.9	0.3	0.3	0.0	2.7	29	277
B11	12.7	5.2	6.0	0.3	0.6	0.0	5.9	32	358
B12	15.5	6.0	5.3	0.2	0.1	0.0	2.9	19	448
B13	17.0	6.4	5.6	0.2	0.1	0.0	4.4	27	370
B14	16.0	7.4	7.4	0.3	0.3	0.2	3.4	27	459
B15	16.5	6.3	6.5	0.3	0.3	0.0	5.4	20	336
B16	19.6	5.4	6.8	0.3	0.7	0.0	5.1	37	403
B17	16.3	6.2	5.9	0.3	0.2	0.0	4.0	4	543
B18	25.4	7.1	8.0	0.2	0.4	0.1	5.8	8	146
B19	11.9	6.2	5.6	0.4	0.3	0.0	8.1	50	739
B20	16.5	6.3	6.6	0.3	0.5	0.0	4.8	18	151
B21	7.4	5.6	6.3	0.3	0.7	0.0	7.3	49	448
B22	27.7	7.2	6.2	0.2	0.2	0.1	3.3	9	403
B23	24.1	7.7	7.8	0.4	0.3	0.2	3.7	7	370
B24	31.2	7.4	7.9	0.3	0.4	0.1	4.3	31	336
B25	38.1	7.3	7.5	0.3	0.2	0.1	3.4	19	230
B26	37.3*	6.7	6.8	0.8	1.5	0.0	4.0	90	1378
B27	24.1	6.8	6.4	0.2	0.2	0.0	2.3	1	907
B28	18.3	6.0	5.3	0.2	0.1	0.0	5.0	3	543
B29	38.1	7.1	7.7	0.3	0.3	0.1	4.3	9	325
B30	32.5	7.2	6.9	0.6	0.5	0.2	6.2	56	851
B31	24.1	7.5	7.3	0.3	0.3	0.1	1.4	2	515
B32	36[illegible]	7.6	7.9	0.6	1.3	0.2	14.7	18	409
B33	22.6	7.2	7.3	0.4	0.3	0.0	3.0	22	347
B34	20.8*	6.4	6.2	0.4	0.3	0.0	4.4	20	969
B35	19.0*	7.3	6.9	0.4	0.2	0.0	1.2	13	398
B36	22.6	6.6	6.7	0.2	0.2	0.0	4.5	19	252
B37	19.0*	6.6	6.7	0.2	0.2	0.0	1.8	10	515
B38	22.6	6.9	7.1	0.3	0.2	0.0	3.3	12	347
B39	20.8*	7.5	7.2	0.5	0.3	0.0	3.3	37	319
B40	20.8*	7.1	6.9	0.6	0.4	0.0	7.4	27	840

Table C-1. Barley Sites (cont.)

Site	Pptn. (cm)	pH 0-15	pH 15-30	E.C. 0-15	E.C. 15-30	%$CaCO_3$ 0-15	%O.M. 0-15	NO_3-N 0-15	K 0-15
E01	23.6	6.0	6.5	0.3	0.4	0.0	11.7	31	613
E02	25.4	6.8	6.3	0.2	0.2	0.0	4.0	10	566
E03	22.6	5.8	5.9	0.2	0.3	0.0	8.2	52	577
E04	41.9	7.6	8.0	0.4	0.3	0.0	4.9	27	305
E06	27.9	6.1	6.3	0.2	0.2	0.0	9.4	1	392
E07	28.2	6.8	7.4	0.3	0.3	0.0	10.7	20	159
E08	27.7	5.9	6.0	0.2	0.2	0.0	8.6	16	223
E09	19.8	6.7	7.0	0.3	0.3	0.0	6.4	13	272
E10	32.5	6.4	5.4	0.1	0.2	0.0	2.5	16	339
E11	24.9	6.0	6.1	0.4	0.2	0.0	6.2	85	184
E13	28.2	6.5	6.6	0.2	0.2	0.0	6.5	11	246
E14	23.6	6.0	6.0	0.5	0.3	0.0	7.9	90	498
E15	21.1	6.5	6.7	0.5	0.6	0.0	6.0	2	370
E17	21.3	6.3	7.1	0.9	4.5	0.0	9.2	25	465
E20	35.8	7.6	8.4	0.5	0.4	0.0	8.9	20	510
E21	27.4	7.8	8.1	0.6	0.5	0.0	8.6	12	280
E22	26.7	6.1	7.4	0.2	0.7	0.0	8.8	8	543
E23	23.1	8.0	8.2	0.4	0.3	0.0	3.4	6	437
E24	29.5	6.5	6.8	0.2	0.2	0.0	4.0	7	342
E25	24.9	6.0	6.5	0.4	0.3	0.0	10.4	31	560
E26	33.0	6.8	6.8	0.2	0.2	0.0	3.6	3	392
E27	22.6	6.9	6.3	0.2	0.2	0.0	6.2	7	622
E29	23.9	6.8	7.0	0.3	0.3	0.0	4.8	44	426
E30	28.4	6.7	6.5	0.2	0.2	0.0	3.0	4	342
E32	24.9	8.0	8.1	0.5	0.5	0.1	7.2	4	291
E33	29.0	6.6	7.2	0.2	0.5	0.0	6.7	12	291
E34	26.7	7.7	8.0	0.5	0.4	0.3	6.4	7	325

Table C-1. Barley Sites (cont.)

Site	Pptn. (cm)	pH 0-15	pH 15-30	E.C. 0-15	E.C. 15-30	%CaCO$_3$ 0-15	%O.M. 0-15	NO$_3$-N 0-15	K 0-15
L01	35.6	6.9	7.0	0.3	0.3	0.0	4.4	2	272
L03	24.9	6.7	6.8	0.2	0.[illegible]	0.0	3.8	7	377
L04	23.1	6.8	6.7	0.3	0.[illegible]	0.0	11.4	18	431
L05	24.6	6.6	6.7	0.2	0.2	0.0	7.0	15	1142
L06	24.9	6.6	6.8	0.3	0.2	0.0	3.9	29	236
L08	29.7	6.5	6.5	0.2	0.2	0.0	7.1	22	310
L10	15.0*	6.5	6.8	0.2	0.2	0.0	3.7	8	224
L11	20.6	6.4	6.6	0.3	0.3	0.0	2.9	24	325
L12	21.1*	6.7	6.8	0.3	0.3	0.0	5.5	8	683
L13	15.0	6.8	6.7	0.3	0.3	0.0	4.1	28	403
L14	14.7	6.2	6.4	0.3	0.2	0.0	5.1	30	370
L15	15.0*	6.3	6.6	0.3	0.3	0.0	3.7	22	302

Table C-1. Barley Sites

Site	Pptn. (cm)	pH 0-15	pH 15-30	E.C. 0-15	E.C. 15-30	%CaCO$_3$ 0-15	%O.M. 0-15	NO$_3$-N 0-15	K 0-15
W01	13.5	6.4	7.1	0.4	0.8	0.0	5.2	48	1434
W02	12.7	6.6	6.9	0.4	0.4	0.0	5.6	75	1109
W03	8.9	[illegible].4	7.3	0.3	0.4	0.0	5.3	19	831
W04	11.9	6.2	7.1	0.3	0.4	0.0	3.2	21	506
W05	16.3	7.1	7.2	0.3	0.2	0.1	5.6	36	1413
W06	14.0	7.7	7.8	0.4	0.4	16.9	2.8	65	517
W07	21.3	6.6	7.4	0.5	0.4	0.0	3.4	78	1014
W08	25.1*	7.0	7.3	0.8	0.5	0.1	6.2	78	1831
W09	32.0*	7.2	7.1	0.6	0.2	0.1	7.3	29	986
W10	28.4*	6.6	7.6	0.3	0.5	0.0	6.6	43	504
W12	17.3	8.0	8.2	0.6	0.6	3.6	2.3	25	1378
W13	18.3	7.6	8.0	0.5	0.4	0.0	2.9	25	1159
W14	21.6	7.5	8.1	0.8	0.4	0.4	9.4	94	246
W15	18.0*	7.6	8.0	0.8	0.6	0.0	4.9	54	1394
W16	22.1*	6.4	7.2	0.4	0.4	0.0	7.5	34	728
W17	25.1*	7.7	7.4	0.4	0.3	0.0	7.2	18	325
W18	18.0*	7.4	7.1	0.4	0.2	0.0	7.4	20	801
W19	28.4*	8.0	8.4	0.4	0.4	0.0	8.0	11	364
W20	23.4*	7.4	7.9	0.3	0.4	0.0	4.8	9	560
W22	20.1	6.7	7.2	0.4	0.4	0.0	5.0	43	963
W23	13.0	7.7	7.8	0.5	0.4	0.1	8.4	46	1042
W24	10.9	7.5	7.6	0.5	0.5	2.1	3.5	29	806
W25	23.9*	7.1	7.1	0.4	0.3	0.1	7.1	35	801
W26	20.3	6.4	6.8	2.3	2.3	0.0	5.5	213	638
W27	31.2*	7.5	7.5	0.6	0.4	0.0	5.5	20	1635
W28	23.6	8.0	8.0	0.6	0.7	0.0	4.1	10	1406
W29	12.4	7.1	7.1	0.3	0.2	0.0	6.4	7	896
W31	10.9	7.0	7.3	0.2	0.2	0.2	2.6	3	722
W34	13.0	7.4	7.5	0.5	0.4	0.1	8.4	6	1165
W36	9.1	7.5	7.5	0.3	0.4	0.0	5.2	10	905
W37	18.0	6.6	6.6	0.4	0.2	0.0	8.9	18	946
W38	24.6	7.1	7.0	0.5	0.4	0.0	7.0	15	560
W41	14.2	6.6	7.6	0.3	0.3	0.0	8.0	67	1170
W42	14.5	6.2	6.9	0.2	0.2	0.0	3.3	45	605
W43	9.9	7.2	7.4	0.6	0.4	0.1	9.2	112	907
W44	18.3	8.0	8.2	0.5	0.5	0.4	9.0	134	246
W46	15.2	8.3	8.4	0.4	0.4	0.2	7.7	45	291
W47	16.0	6.9	6.9	0.2	0.2	0.0	5.2	34	482

Table C-1. Barley Sites

Site	Pptn. (cm)	pH 0-15	pH 15-30	E.C. 0-15	E.C. 15-30	%$CaCO_3$ 0-15	%O.M. 0-15	NO_3-N 0-15	K 0-15
T01	15.7	7.9	8.0	0.5	0.4	1.5	3.2	37	853
T02	17.8	7.0	7.4	0.2	0.7	0.1	5.0	69	1086
T03	23.9	7.4	7.7	0.7	0.8	0.1	4.0	36	746
T07	10.7	8.0	8.1	0.4	0.4	1.6	3.0	36	1385
T08	3.3	6.7	7.5	0.6	0.6	0.0	5.8	45	1000
T09	6.9	6.6	7.5	0.5	0.8	0.0	5.0	60	1280
T10	9.9	8.2	8.4	0.3	0.4	3.8	2.9	25	716
T12	9.7	7.2	7.9	0.4	0.5	0.6	4.2	56	715

Table C-2. Rapeseed Sites

Site	Pptn. (cm)	pH 0-15	pH 15-30	E.C. 0-15	E.C. 15-30	%CaCO$_3$ 0-15	%O.M. 0-15	NO$_3$-N 0-15	K 0-15
B41	22.1	6.7	4.9	0.3	0.3	0.0	2.7	29	277
B42	16.5	6.5	5.6	0.3	0.3	0.0	2.3	8	249
B43	19.0	5.4	5.0	0.3	0.3	0.0	3.8	10	365
B44	32.3	5.3	4.6	0.3	0.2	0.0	7.0	4	306
B45	33.5	6.2	5.5	0.3	0.2	0.0	7.1	10	703
B46	30.0	5.6	4.5	0.3	0.3	0.0	3.3	15	407
B47	32.3	5.5	4.6	0.3	0.2	0.0	3.9	27	405
B48	25.7	7.4	7.9	0.4	0.3	0.3	5.4	43	149
B49	25.7	5.6	5.1	0.4	0.3	0.0	7.3	39	325
B50	11.9	6.2	5.9	0.4	0.3	0.0	4.0	34	672
B51	16.5	6.3	6.6	0.3	0.5	0.0	4.8	19	174
B52	12.7	5.2	6.0	0.3	0.6	0.0	5.9	32	358
B53	16.5	6.3	6.5	0.3	0.3	0.0	5.4	22	347
B54	17.0	6.4	5.6	0.2	0.1	0.0	4.4	27	370
B55	25.4	7.1	8.0	0.2	0.4	0.1	5.8	8	146
B56	19.6	5.4	6.8	0.3	0.7	0.0	5.1	37	403
B57	15.5	6.0	5.3	0.2	0.1	0.0	2.9	19	448
B58	16.3	6.2	5.9	0.3	0.2	0.0	4.0	4	543
B59	7.4	5.6	6.3	0.3	0.4	0.0	7.3	49	448
B60	27.7	7.2	6.2	0.2	0.2	0.1	3.3	9	403
B61	24.1	7.7	7.8	0.4	0.3	0.2	3.7	7	370
B62	31.2	7.4	7.9	0.3	0.4	0.1	4.3	31	336
B63	38.1	7.3	7.5	0.3	0.2	0.1	3.4	19	230
B64	37.3*	6.7	6.8	0.8	1.5	0.0	4.0	90	1378
B65	24.1	6.8	6.4	0.2	0.2	0.0	2.3	1	907
B66	18.3	6.0	5.3	0.2	0.1	0.0	5.0	3	543
B67	38.1	7.1	7.7	0.3	0.3	0.1	4.3	9	325
B68	32.5	7.2	6.9	0.6	0.5	0.2	6.2	56	851
B69	24.1	7.5	7.3	0.3	0.3	0.1	1.4	2	515
B70	36.8	7.6	7.9	0.6	1.3	0.2	14.7	18	409
B71	22.6	7.2	7.3	0.4	0.3	0.0	3.0	22	347
B72	20.8*	6.4	6.2	0.4	0.3	0.0	4.4	20	969
B73	19.0*	7.3	6.9	0.4	0.2	0.0	1.2	13	398
B74	22.6	6.6	6.7	0.2	0.2	0.0	4.5	19	252
B75	19.0*	6.6	6.7	0.2	0.2	0.0	1.8	10	515
B76	22.6	6.9	7.1	0.3	0.2	0.0	3.3	12	347
B77	20.8*	7.5	7.2	0.5	0.3	0.0	3.3	37	319
B78	20.8*	7.1	6.9	0.6	0.4	0.0	7.4	27	840

Table C-2. Rapeseed Sites (cont.)

Site	Pptn. (cm)	pH 0-15	pH 15-30	E.C. 0-15	E.C. 15-30	%$CaCO_3$ 0-15	%O.M. 0-15	NO_3-N 0-15	K 0-15
E37	21.1	6.2	6.7	0.3	0.2	0.0	7.2	3	343
E38	27.7	5.9	6.0	0.2	0.2	0.0	8.6	16	223
E39	19.8	6.7	7.0	0.3	0.3	0.0	6.4	13	272
E40	28.2	6.8	7.4	0.3	0.3	0.0	10.7	20	159
E41	23.9	6.4	6.5	0.6	0.3	0.0	8.6	83	252
E42	27.9	6.1	6.3	0.2	0.2	0.0	9.4	1	392
E44	22.6	5.8	5.9	0.2	0.3	0.0	8.2	52	577
E45	23.6	6.0	6.5	0.3	0.4	0.0	11.7	31	613
E46	29.5	6.5	6.6	0.2	0.2	0.0	6.5	11	246
E47	23.6	6.0	6.0	0.5	0.3	0.0	7.9	90	498
E48	21.8	6.5	6.7	0.5	0.6	0.0	6.0	2	370
E49	23.9	6.3	7.1	0.9	4.5	0.0	9.2	25	465
E53	35.8	7.6	8.4	0.5	0.4	0.0	8.9	20	510
E54	27.4	7.8	8.1	0.6	0.5	0.0	8.6	12	280
E55	26.7	6.1	7.4	0.2	0.7	0.0	8.8	8	543
E57	23.9	6.8	7.0	0.3	0.3	0.0	4.8	44	426
E58	24.1	6.0	6.5	0.4	0.3	0.0	10.4	31	560
E60	28.2	6.5	6.8	0.2	0.2	0.0	4.0	7	342
E61	29.0	6.6	7.2	0.2	0.5	0.0	6.7	12	291
E62	21.8	6.9	6.3	0.2	0.2	0.0	6.2	7	622
E63	26.7	7.7	8.0	0.5	0.4	0.3	6.4	7	325
E64	28.4	6.7	6.5	0.2	0.2	0.0	3.0	4	342
E65	22.4	8.0	8.2	0.4	0.3	0.0	3.4	6	437
E66	24.9	8.0	8.1	0.5	0.5	0.1	7.2	4	291

Table C-2. Rapeseed Sites (cont.)

Site	Pptn. (cm)	pH 0-15	pH 15-30	E.C. 0-15	E.C. 15-30	%$CaCO_3$ 0-15	%O.M. 0-15	NO_3-N 0-15	K 0-15
L48	23.1	6.8	6.7	0.3	0.3	0.0	11.4	18	431
L49	35.6	6.7	6.8	0.3	0.3	0.0	4.4	2	249
L50	24.6	6.6	6.7	0.3	0.3	0.0	7.0	18	1018
L51	15.0*	6.3	6.6	0.3	0.3	0.0	3.7	22	302
L52	15.0*	6.5	6.8	0.2	0.2	0.0	3.7	8	224
L53	21.1*	6.7	6.8	0.3	0.3	0.0	5.5	8	683
L54	14.7*	6.2	6.4	0.3	0.2	0.0	5.1	30	370

Table C-2. Rapeseed Sites (cont.)

Site	Pptn. (cm)	pH 0-15	pH 15-30	E.C. 0-15	E.C. 15-30	%$CaCO_3$ 0-15	%O.M. 0-15	NO_3-N 0-15	K 0-15
W49	22.1*	6.8	7.6	0.4	0.3	0.0	3.9	4	
W50	12.4	7.4	7.6	0.4	0.3	0.0	6.4		
W52	9.1	7.5	7.5	0.4	0.4	0.0	5.2		
W53	24.6	7.1	7.2	0.3	0.3	0.0	7.0		
W54	20.1	7.9	7.9	0.4	0.4	0.0	7.8		

Table C-2. Rapeseed Sites (cont.)

Site	Pptn. (cm)	pH 0-15	pH 15-30	E.C. 0-15	E.C. 15-30	%$CaCO_3$ 0-15	%O.M. 0-15	NO_3-N 0-15	K 0-15
T19	10.9	6.1	6.6	0.2	0.2	0.0	3.6	36	575
T20	10.9	7.1	7.3	0.7	0.5	0.0	4.9	63	1161
T21	11.2	6.8	7.2	0.2	0.7	0.0	4.5	20	1262
T22	12.7	8.2	8.3	0.7	0.5	0.0	2.2	40	987
T17	13.2	7.7	7.7	0.4	0.4	0.9	1.9	24	889
T18	5.1	7.3	7.5	0.5	0.5	0.0	3.8	11	1243
T13	17.8	7.0	7.4	0.2	0.7	0.1	5.0	69	1086
T14	5.8	8.1	8.2	0.7	0.6	8.1	2.6	53	1281
T15	8.6	7.0	7.1	0.4	0.6	0.0	3.9	22	1437
T16	23.9	7.4	7.7	0.7	0.8	0.1	4.0	36	746
T26	10.7	8.0	8.1	0.4	0.4	1.6	3.0	36	1385
T27	13.0	8.1	8.3	0.4	0.4	2.6	2.0	18	753
T28	11.7	7.2	7.6	0.5	0.6	0.0	4.1	22	1518
T29	3.3	6.7	7.5	0.6	0.6	0.0	5.8	45	1000
T30	6.9	6.6	7.5	0.5	0.8	0.0	5.0	60	1280
T31	9.7	7.2	7.9	0.4	0.5	0.6	4.2	56	715
T32	9.9	8.3	8.4	0.3	0.4	3.8	2.9	25	716

Table C-3. Wheat Sites

Site	Pptn. (cm)	pH 0-15	pH' 15-30	E.C. 0-15	E.C. 15-30	%CaCO$_3$ 0-15	%O.M. 0-15	NO$_3$-N 0-15	K 0-15
J01	14.5	5.7	6.1	0.4	NA	0.0	7.5	29	426
J02	14.5*	5.5	5.7	0.3	NA	0.0	3.4	9	482
J03	25.4	5.0	5.5	0.3	NA	0.0	5.6	40	368
J04	44.7	5.1	5.2	0.5	NA	0.0	10.1	46	504
J06	36.8*	6.3	NA	0.4	NA	0.0	9.7	56	1098
J07	27.4*	5.9	NA	0.4	NA	0.0	7.4	48	737
J08	23.1*	5.6	NA	0.2	NA	0.0	3.4	16	722
J09	20.3*	5.8	NA	0.3	NA	0.0	5.2	29	502
J10	36.8*	6.2	NA	0.3	NA	0.0	5.1	21	1611
J11	18.8*	5.2	NA	0.3	NA	0.0	3.7	18	533
J12	18.3*	5.6	NA	0.4	NA	0.0	6.5	48	538
J13	18.8*	5.7	NA	0.3	NA	0.0	2.2	27	629
J14	19.8*	5.6	NA	0.5	NA	0.0	5.8	41	414
J15	18.8*	5.4	NA	0.3	NA	0.0	2.9	16	563
J16	18.3*	5.5	NA	0.4	NA	0.0	5.9	36	482
J17	20.8*	6.0	NA	0.7	NA	0.0	5.0	41	346
J18	22.9*	5.9	NA	0.3	NA	0.0	6.8	48	409
J19	22.9*	5.8	NA	0.3	NA	0.0	7.2	46	265
J20	22.9*	6.0	NA	0.2	NA	0.0	7.1	8	316
J22	34.3*	5.4	NA	0.3	NA	0.0	5.6	18	815
J23	32.5	5.3	NA	0.5	NA	0.0	6.0	26	603
J24	25.1*	5.4	NA	0.5	NA	0.0	4.5	49	513
J25	17.3	5.5	NA	0.5	NA	0.0	5.3	17	233
J26	22.9*	5.8	NA	0.4	NA	0.0	6.1	15	321
J27	22.9	5.7	NA	0.5	NA	0.0	6.9	22	181
J28	22.9*	5.4	NA	0.7	NA	0.0	6.0	72	329
J29	40.4*	6.3	NA	0.2	NA	0.0	7.8	10	329
J30	14.7	5.7	NA	0.4	NA	0.0	7.5	67	327
J31	14.7*	6.0	NA	0.4	NA	0.0	7.1	41	491
J32	35.8	5.7	NA	0.5	NA	0.0	8.0	74	448
J33	40.6	5.4	NA	0.6	NA	0.0	7.1	91	702
J34	39.1	5.8	NA	0.3	NA	0.0	6.3	13	764
J35	36.8*	5.3	NA	0.5	NA	0.0	5.4	56	804
J36	34.5	5.7	NA	0.4	NA	0.0	5.2	20	673
J37	33.0	5.7	NA	0.6	NA	0.0	6.5	77	427
J38	33.0*	5.6	NA	0.5	NA	0.0	5.4	12	[illegible]
J39	14.7	5.8	NA	0.7	NA	0.0	6.2	83	[illegible]
J40	40.4	5.6	NA	0.4	NA	0.0	5.8	57	[illegible]

APPENDIX D

Soil Physical Analysis and Textural Classification for the 0-15 cm Depth of the Experimental Sites

<u>List of Textural Class Abbreviations</u>

HC	High Clay
C	Clay
SiC	Silty Clay
SC	Sandy Clay
SiCL	Silty Clay Loam
CL	Clay Loam
SCL	Sandy Clay Loam
L	Loam
SL	Sandy Loam
LS	Loamy Sand
S	Sand
Si	Silt

Table D-1. Barley Sites

Site	% Sand	% Silt	% Clay	Textural Class
B01	27.2	38.6	34.2	CL
B02	24.2	52.1	23.7	L
B03	27.7	56.0	16.3	SiL
B04	13.0	51.8	35.2	SiCL
B05	26.8	38.5	34.7	CL
B06	19.5	42.2	38.3	SiCL
B07	16.0	45.9	38.1	SiCL
B08	15.2	53.8	31.0	SiCL
B09	20.3	38.4	40.8	C
B10	29.7	42.3	28.0	CL
B11	21.4	41.3	37.3	CL
B12	20.9	39.9	39.2	CL
B13	27.1	39.2	33.7	CL
B14	26.0	58.0	16.0	SiL
B15	45.1	40.4	14.5	L
B16	18.3	38.5	43.2	C
B17	23.1	40.8	36.1	CL
B18	16.6	54.9	28.5	SiCL
B19	15.9	59.2	24.9	SiL
B20	29.0	53.5	17.5	SiL
B21	18.2	46.9	34.9	SiCL
B22	25.0	47.4	27.6	SiL
B23	39.5	45.8	14.7	L
B24	68.6	21.2	10.2	SL
B25	69.7	20.1	10.2	SL
B26	16.9	54.7	28.4	SiCL
B27	11.8	43.4	44.8	SiC
B28	24.2	40.9	34.9	CL
B29	47.7	37.5	14.8	L
B30	16.1	52.8	31.1	SiCL
B31	55.5	32.2	12.3	SL
B32	12.5	35.4	52.1	C
B33	57.2	32.5	10.3	SL
B34	3.7	24.6	71.6	HC
B35	67.7	24.1	8.2	SL
B36	51.0	36.6	12.4	L
B37	69.7	4.0	26.3	SCL
B38	66.5	24.1	9.4	SCL
B39	61.4	22.2	16.4	SL
B40	16.3	55.0	28.7	SiCL

Table D-1. Barley Sites (cont.)

Site	% Sand	% Silt	% Clay	Textural Class
E01	14.6	43.4	42.0	SiC
E02	25.5	50.1	24.1	SiL
E03	10.6	51.7	37.7	SiCL
E04	43.6	31.1	25.3	L
E06	22.3	54.4	23.3	SiL
E07	50.3	30.1	19.6	L
E08	25.7	42.1	32.2	CL
E09	31.9	39.4	28.7	CL
E10	25.7	51.6	22.7	SiL
E11	74.9	14.8	10.3	SL
E13	33.5	39.5	27.0	L
E14	40.9	34.1	25.0	L
E15	39.1	33.5	27.4	L
E17	25.2	43.2	31.6	CL
E20	18.0	43.9	38.1	SiCL
E21	27.5	43.8	28.7	CL
E22	28.6	49.5	21.9	L
E23	36.1	36.9	27.0	L
E24	42.7	32.4	24.9	L
E25	16.6	40.6	42.8	SiC
E26	53.7	31.9	14.4	SL
E27	25.9	43.3	30.8	CL
E29	32.9	39.5	27.6	L
E30	59.7	27.2	13.1	SL
E32	62.9	20.8	16.3	SL
E33	32.0	39.4	28.6	CL
E34	38.2	34.0	27.8	CL

Table D-1. Barley Sites (cont.)

Site	% Sand	% Silt	% Clay	Textural Class
L01	78.6	12.2	9.2	LS
L03	57.3	29.8	12.9	SL
L04	19.0	51.1	29.9	SiCL
L05	70.3	18.3	11.4	SL
L06	65.2	23.4	11.3	SL
L08	41.3	33.8	24.9	L
L10	74.4	14.1	11.5	SL
L11	43.3	38.5	18.2	L
L12	40.4	29.8	29.8	CL
L13	54.8	28.7	16.5	SL
L14	44.6	27.9	27.5	L
L15	74.4	14.1	11.5	SL

Table D-1. Barley Sites (cont.)

Site	% Sand	% Silt	% Clay	Textural Class
W01	8.1	29.4	62.5	HC
W02	9.9	31.7	58.4	C
W03	23.6	44.3	32.1	CL
W04	33.3	42.0	24.7	L
W05	3.3	15.0	81.7	HC
W06	50.0	35.5	14.5	L
W07	31.0	36.2	32.8	CL
W08	20.4	47.5	32.1	CL
W09	32.9	45.4	21.7	L
W10	42.1	38.2	19.7	L
W12	10.6	17.9	71.5	HC
W13	56.2	25.2	18.6	SL
W14	31.9	45.1	23.0	L
W15	12.6	27.4	60.0	HC
W16	20.1	48.8	31.1	CL
W17	33.3	42.1	24.6	L
W18	21.3	33.7	45.0	C
W19	13.9	48.3	37.8	SiCL
W20	36.7	33.7	29.6	CL
W22	24.2	44.0	31.8	CL
W23	59.7	23.1	17.2	SL
W24	29.1	40.1	30.8	CL
W25	17.2	35.7	47.1	C
W26	32.6	35.6	31.8	CL
W27	3.9	24.6	71.5	HC
W28	5.4	21.2	73.4	HC
W29	22.0	46.1	31.4	CL
W31	56.6	16.9	26.5	SCL
W34	59.7	23.1	17.2	SL
W36	55.0	28.5	16.5	SL
W37	28.7	46.6	24.7	L
W38	23.3	43.5	33.2	CL
W41	29.4	33.5	36.9	CL
W42	41.6	21.5	36.9	CL
W43	21.7	47.4	30.9	CL
W44	28.7	50.5	20.6	SiL
W46	34.2	32.7	33.1	CL
W47	26.7	45.0	28.3	CL

Table D-1. Barley Sites (cont.)

Site	% Sand	% Silt	% Clay	Textural Class
T01	31.7	47.1	21.2	L
T02	23.1	45.6	31.3	CL
T03	28.4	42.8	28.8	CL
T07	32.2	47.7	20.1	L
T08	22.3	47.0	30.7	CL
T09	28.4	43.3	28.3	CL
T10	31.1	48.2	20.7	L
T12	28.9	41.1	30.0	CL

Table D-2. Rapeseed Sites

Site	% Sand	% Silt	% Clay	Textural Class
B41	29.7	42.3	28.0	CL
B42	27.7	56.0	16.3	SiL
B43	13.0	51.8	35.2	SiCL
B44	26.0	38.5	34.7	CL
B45	19.5	42.2	38.3	SiCL
B46	16.0	45.9	38.1	SiCL
B47	27.2	38.6	34.2	CL
B48	15.2	53.8	31.0	SiCL
B49	24.2	52.1	23.7	L
B50	15.9	59.2	24.9	SiL
B51	29.0	53.5	17.5	SiL
B52	21.4	41.3	37.3	CL
B53	45.1	40.4	14.5	L
B54	27.1	39.2	33.7	CL
B55	16.6	54.9	28.5	SiCL
B56	18.3	38.5	43.2	C
B57	20.9	39.9	39.2	CL
B58	23.1	40.8	36.1	CL
B59	18.2	46.9	34.9	SiCL
B60	25.0	47.4	27.6	SiL
B61	39.5	45.8	14.7	L
B62	68.6	21.2	10.2	SL
B63	69.7	20.1	10.2	SL
B64	16.9	54.7	28.4	SiCL
B65	11.8	43.4	44.8	SiC
B66	24.2	40.9	34.9	CL
B67	47.7	37.5	14.8	L
B68	16.1	52.8	31.1	SiCL
B69	55.5	32.2	12.3	SL
B70	12.5	35.4	52.1	C
B71	57.2	32.5	10.3	SL
B72	3.7	24.6	71.6	HC
B73	67.7	24.1	8.2	SL
B74	51.0	36.6	12.4	L
B75	69.7	4.0	26.3	SCL
B76	66.5	24.1	9.4	SL
B77	61.4	22.2	16.4	SL
B78	16.3	55.0	28.7	SiCL

Table D-2. Rapeseed Sites (cont.)

Site	% Sand	% Silt	% Clay	Textural Class
E37	11.8	48.5	39.7	SiCL
E38	25.7	42.1	32.2	CL
E39	31.9	39.4	28.7	CL
E40	50.3	30.1	19.6	L
E41	35.5	37.9	26.6	L
E42	22.3	54.4	23.3	SiL
E44	10.6	51.7	37.7	SiCL
E45	14.6	43.4	42.0	SiC
E46	33.5	39.5	27.0	L
E47	40.9	34.1	25.0	L
E48	39.1	33.5	27.4	L
E49	25.2	43.2	31.6	CL
E53	18.0	43.9	38.1	SiCL
E54	27.5	43.8	28.7	CL
E55	28.6	49.5	21.9	L
E57	32.9	39.5	27.6	L
E58	16.6	40.6	42.8	[illegible]C
E60	42.7	32.4	24.9	L
E61	32.0	39.4	28.6	CL
E62	25.9	43.3	30.8	CL
E63	38.2	34.0	27.8	CL
E64	59.7	27.2	13.1	SL
E65	36.1	36.9	27.0	L
E66	62.9	20.8	16.3	SL

Table D-2. Rapeseed Sites (cont.)

Site	% Sand	% Silt	% Clay	Textural Class
L48	19.0	51.1	29.9	SiCL
L49	78.6	12.2	9.2	LS
L50	70.3	18.3	11.4	SL
L51	74.4	14.1	11.5	SL
L52	74.4	14.1	11.5	SL
L53	40.4	29.8	29.8	CL
L54	44.6	27.9	27.5	L

Table D-2. Rapeseed Sites (cont.)

Site	% Sand	% Silt	% Clay	Textural Class
W49	54.6	17.5	27.9	SCL
W50	22.0	46.1	31.9	CL
W52	55.0	28.5	16.5	SL
W53	23.3	43.5	33.2	CL
W54	31.2	39.9	28.9	CL

Table D-2. Rapeseed Sites (cont.)

Site	% Sand	% Silt	% Clay	Textural Class
T19	30.4	38.5	31.1	CL
T20	34.1	39.0	26.9	L
T21	10.4	26.9	62.9	HC
T22	37.7	37.7	24.6	L
T17	31.9	41.4	26.7	L
T18	9.3	46.3	44.4	SiC
T13	23.1	45.6	31.3	CL
T14	2.9	27.9	69.2	HC
T15	12.4	26.6	61.0	HC
T16	28.4	42.8	28.8	CL
T26	32.2	47.7	20.1	L
T27	3.1	72.8	24.1	SiL
T28	11.8	25.1	63.1	HC
T29	22.3	47.0	30.7	CL
T30	28.4	43.3	28.3	CL
T31	28.9	41.1	30.0	CL
T32	31.1	48.2	20.7	L

Table D-3. Wheat Sites

Site	% Sand	% Silt	% Clay	Textural Class
J01	38.3	39.1	22.6	L
J02	69.5	16.2	14.2	SL
J03	38.7	40.9	20.4	L
J04	29.6	47.6	22.8	CL
J06	20.8	40.6	38.6	CL
J07	39.6	40.6	19.8	L
J08	58.9	24.7	16.5	SL
J09	42.9	34.7	22.4	L
J10	30.2	41.5	28.7	CL
J11	36.4	34.9	28.7	CL
J12	48.7	30.8	20.5	L
J13	36.7	32.7	30.7	CL
J14	44.8	31.7	23.5	L
J15	55.3	22.4	22.4	SCL
J16	25.9	39.1	35.0	CL
J17	40.6	38.9	20.5	L
J18	31.7	34.1	34.1	CL
J19	37.8	31.1	31.1	CL
J20	27.3	35.3	37.4	CL
J22	38.3	35.0	26.8	L
J23	21.5	42.3	36.1	CL
J24	40.7	35.8	23.5	L
J25	46.8	32.8	20.5	L
J26	40.6	34.8	24.6	L
J27	36.3	39.1	24.7	L
J28	30.1	41.1	28.8	CL
J29	35.9	37.2	26.9	L
J30	44.5	37.0	18.5	L
J31	28.7	42.4	28.9	CL
J32	26.3	40.5	33.2	CL
J33	24.8	46.4	28.9	CL
J34	37.2	37.1	25.7	L
J35	36.4	39.0	24.7	L
J36	32.1	37.0	30.9	CL
J37	44.6	34.9	20.5	L
J38	40.7	36.8	22.5	L
J39	31.1	43.2	25.7	L
J40	39.4	38.0	22.6	L

APPENDIX E

Available Phosphorus (kg/ha) Analyses of Experimental Sites

NA indicates data were Not Available

Table E-1. Barley Sites

Site	ASFTL-P (0-15)	ASFTL-P (15-30)	M & A-P (0-15)	M & A-P (15-30)	Olsen-P (0-15)	Olsen-P (15-30)
B01	37.0	0.0	31.4	4.5	23.5	20.2
B02	26.9	0.0	31.4	4.5	24.6	20.2
B03	49.3	23.5	51.5	29.1	29.1	20.2
B04	34.7	6.7	37.0	14.6	22.4	11.2
B05	13.4	0.0	14.6	0.0	9.0	4.5
B06	62.7	0.0	68.3	2.2	40.3	6.7
B07	37.0	0.0	32.5	2.2	25.8	11.2
B08	0.0	0.0	6.7	1.1	12.3	9.0
B09	12.3	0.0	16.8	2.2	16.8	23.5
B10	19.0	0.0	21.3	5.6	21.3	39.2
B11	29.1	2.2	28.0	5.6	34.7	14.6
B12	7.8	2.2	7.8	2.2	9.0	12.3
B13	13.4	1.1	12.3	3.4	11.2	12.3
B14	151.2	66.1	153.4	70.6	122.1	65.0
B15	9.0	2.2	11.2	6.7	12.3	12.3
B16	31.4	3.4	32.5	9.0	32.5	17.9
B17	24.6	3.4	28.0	4.5	35.8	15.7
B18	9.0	1.1	6.7	0.0	20.2	10.1
B19	15.7	6.7	16.8	5.6	17.9	11.2
B20	5.6	13.4	7.8	2.2	15.7	10.1
B21	49.3	9.0	54.9	14.6	25.8	17.9
B22	68.3	7.8	67.2	12.3	50.4	13.4
B23	115.4	71.7	112.0	67.2	59.4	40.3
B24	26.9	12.3	25.8	14.6	19.0	9.0
B25	14.6	15.7	10.1	16.8	11.2	9.0
B26	30.2	11.2	32.5	13.4	38.1	31.4
B27	45.9	3.4	44.8	7.8	56.0	22.4
B28	9.0	1.1	12.3	2.2	12.3	9.0
B29	12.3	5.6	9.0	4.5	9.0	4.5
B30	19.0	14.6	16.8	10.1	16.8	9.0
B31	108.6	201.6	101.9	200.5	51.5	89.6
B32	32.5	5.6	29.1	4.5	25.8	13.4
B33	157.9	117.6	157.9	119.8	76.2	58.2
B34	9.0	0.0	14.6	7.8	26.9	13.4
B35	134.4	125.4	131.0	144.5	62.7	58.2
B36	12.3	3.4	20.2	7.8	17.9	4.5
B37	218.4	213.9	221.8	207.2	76.2	71.7
B38	31.4	32.5	53.8	31.4	22.4	17.9
B39	127.7	3.4	134.4	7.8	76.2	9.0
B40	19.0	2.2	25.8	7.8	26.9	9.0

Table E-1. Barley Sites (cont.)

Site	ASFTL-P		M & A-P		Olsen-P	
	(0-15)	(15-30)	(0-15)	(15-30)	(0-15)	(15-30)
E01	58.2	5.6	78.4	7.8	58.2	7.8
E02	78.4	12.3	72.8	3.4	40.3	15.7
E03	40.3	4.5	43.7	7.8	31.4	12.3
E04	34.7	15.7	23.5	7.8	24.6	30.2
E06	40.3	15.7	38.1	13.4	30.2	21.3
E07	26.9	14.6	24.6	9.0	30.2	12.3
E08	26.9	9.0	14.6	5.6	11.2	6.7
E09	28.0	3.4	22.4	14.6	23.5	16.8
E10	26.9	12.3	20.2	3.4	19.0	14.6
E11	21.3	7.8	17.9	10.1	15.7	13.4
E13	38.1	4.5	40.3	5.6	33.6	11.2
E14	58.2	1.1	65.0	7.8	40.3	9.0
E15	40.3	2.2	30.2	5.6	21.3	13.4
E17	48.2	1.1	49.3	3.4	33.6	11.2
E20	12.3	0.0	14.6	0.0	23.5	11.2
E21	6.7	0.0	7.8	1.1	19.0	14.6
E22	26.9	5.6	22.4	5.6	21.3	15.7
E23	3.4	1.1	4.5	1.1	7.8	4.5
E24	15.7	2.2	19.0	5.6	16.8	9.0
E25	19.0	7.8	19.0	7.8	15.7	9.0
E26	40.3	21.3	49.3	26.9	29.1	26.9
E27	34.7	24.6	35.8	25.8	25.8	17.9
E29	35.8	22.4	45.9	34.7	31.4	42.6
E30	58.2	23.5	54.9	26.9	23.5	22.4
E32	5.6	0.0	12.3	7.8	14.6	9.0
E33	7.8	2.2	14.6	6.7	11.2	9.0
E34	9.0	2.2	9.0	4.5	11.2	9.0

Table E-1. Barley Sites (cont.)

Site	ASFTL-P		M & A-P		Olsen-P	
	(0-15)	(15-30)	(0-15)	(15-30)	(0-15)	(15-30)
L01	73.9	82.9	66.1	68.3	38.1	31.4
L03	58.2	52.6	61.6	38.1	30.2	22.4
L04	38.1	17.9	31.4	14.6	38.1	23.5
L05	44.8	22.4	40.3	16.8	29.1	14.6
L06	38.1	17.9	34.7	17.9	17.9	14.6
L08	26.9	28.0	31.4	24.6	29.1	19.0
L10	14.6	7.8	NA	NA	14.6	NA
L11	19.0	9.0	NA	NA	16.8	NA
L12	39.2	15.7	NA	NA	29.1	NA
L13	40.3	6.7	NA	NA	35.8	NA
L14	13.4	13.4	NA	NA	14.6	NA
L15	12.3	21.3	NA	NA	13.4	NA

Table E-1. Barley Sites (cont.)

Site	ASFTL-P		M & A-P		Olsen-P	
	(0-15)	(15-30)	(0-15)	(15-30)	(0-15)	(15-30)
W01	34.7	6.7	40.3	10.1	44.8	23.5
W02	23.5	2.2	31.4	4.5	33.6	14.6
W03	21.3	0.0	28.0	5.6	26.9	24.6
W04	20.2	6.7	26.9	12.3	23.5	14.6
W05	14.6	3.4	13.4	7.8	33.6	NA
W06	4.5	0.0	5.6	0.0	13.4	13.4
W07	29.1	2.2	33.6	9.0	39.2	17.9
W08	69.4	30.2	71.7	33.6	87.4	43.7
W09	40.3	6.7	44.8	17.9	48.2	29.1
W10	31.4	0.0	33.6	6.7	35.8	14.6
W12	4.5	0.0	5.6	6.7	24.6	21.3
W13	21.3	1.1	23.5	3.4	24.6	15.7
W14	15.7	4.5	16.8	7.8	29.1	35.8
W15	15.7	0.0	28.0	3.4	34.7	13.4
W16	44.8	2.2	26.9	15.7	33.6	12.3
W17	13.4	2.2	15.7	9.0	24.6	20.2
W18	12.3	0.0	11.2	5.6	20.2	13.4
W19	14.6	0.0	12.3	0.0	22.4	19.0
W20	10.1	0.0	13.4	0.0	22.4	11.2
W22	22.4	2.2	26.9	12.3	30.2	15.7
W23	29.1	0.0	28.0	3.4	22.4	9.0
W24	30.2	2.2	35.8	9.0	33.6	13.4
W25	31.4	4.5	32.5	13.4	16.8	13.4
W26	35.8	4.5	59.4	20.2	33.6	17.9
W27	43.7	6.7	37.0	14.6	41.4	26.9
W28	19.0	1.1	22.4	1.1	35.8	13.4
W29	41.4	2.2	48.2	9.0	29.1	13.4
W31	47.0	10.1	51.5	15.7	32.5	17.9
W34	20.2	7.8	19.0	17.9	15.7	22.4
W36	69.4	15.7	57.1	21.3	35.8	22.4
W37	45.9	6.7	67.2	21.3	42.6	22.4
W38	65.0	24.6	75.0	33.6	69.4	44.8
W41	61.6	15.7	NA	NA	NA	NA
W42	57.1	11.2	NA	NA	NA	NA
W43	67.2	16.8	NA	NA	NA	NA
W44	14.6	5.6	NA	NA	NA	NA
W46	7.8	3.4	NA	NA	NA	NA
W47	43.7	19.0	NA	NA	NA	NA

Table E-1. Barley Sites (cont.)

Site	ASFTL-P		M & A-P		Olsen-P	
	(0-15)	(15-30)	(0-15)	(15-30)	(0-15)	(15-30)
T01	22.4	6.7	24.6	16.8	31.4	17.9
T02	63.8	5.6	86.2	7.8	67.2	9.0
T03	25.8	5.6	35.8	10.1	35.8	17.9
T07	56.0	11.2	33.6	4.5	35.8	9.0
T08	63.8	14.6	71.7	12.3	62.7	13.4
T09	57.1	3.4	70.6	5.6	58.2	9.0
T10	40.3	4.5	40.3	14.6	49.3	13.4
T12	26.9	3.4	33.6	17.9	35.8	13.4

Table E-2. Rapeseed Sites

Site	ASFTL-P		M & A-P		Olsen-P	
	(0-15)	(15-30)	(0-15)	(15-30)	(0-15)	(15-30)
B41	19.0	0.0	21.3	5.6	21.3	39.2
B42	49.3	23.5	51.5	29.1	29.1	20.2
B43	34.7	6.7	37.0	14.6	22.4	11.2
B44	13.4	0.0	14.6	0.0	9.0	4.5
B45	62.7	0.0	68.3	2.2	40.3	6.7
B46	37.0	0.0	32.5	2.2	25.8	11.2
B47	37.0	0.0	31.4	4.5	23.5	20.2
B48	0.0	0.0	6.7	1.1	12.3	9.0
B49	26.9	0.0	31.4	4.5	24.6	20.2
B50	13.4	3.4	16.8	5.6	24.6	11.2
B51	5.6	0.0	6.7	3.4	13.4	9.0
B52	29.1	2.2	28.0	~~5.6~~	34.7	14.6
B53	9.0	2.2	11.2	6.7	12.3	12.3
B54	13.4	1.1	12.3	3.4	11.2	12.3
B55	9.0	1.1	6.7	0.0	20.2	10.1
B56	31.4	3.4	32.5	9.0	32.5	17.9
B57	7.8	2.2	7.8	2.2	9.0	12.3
B58	24.6	3.4	28.0	4.5	35.8	15.7
B59	49.3	9.0	54.9	14.6	25.8	17.9
B60	68.3	7.8	67.2	12.3	50.4	13.4
B61	115.4	71.7	112.0	67.2	59.4	40.3
B62	26.9	12.3	25.8	14.6	19.0	9.0
B63	14.6	15.7	10.1	16.8	11.2	9.0
B64	30.2	11.2	32.5	13.4	38.1	31.4
B65	45.9	3.4	44.8	7.8	56.0	22.4
B66	9.0	1.1	12.3	2.2	12.3	9.0
B67	12.3	5.6	9.0	4.5	9.0	4.5
B68	19.0	14.6	16.8	10.1	16.8	9.0
B69	108.6	201.6	101.9	200.5	51.5	89.6
B70	32.5	5.6	29.1	4.5	25.8	13.4
B71	157.9	117.6	157.9	119.8	76.2	[illegible].2
B72	9.0	0.0	14.6	7.8	26.9	13.4
B73	134.4	125.4	131.0	144.5	62.7	58.2
B74	12.3	3.4	20.2	7.8	17.9	4.5
B75	218.4	213.9	221.8	207.2	76.2	71.7
B76	31.4	32.5	53.8	31.4	22.4	17.9
B77	127.7	3.4	134.4	7.8	76.2	9.0
B78	19.0	2.2	25.8	7.8	26.9	9.0

Table E-2. Rapeseed Sites (cont.)

Site	ASFTL-P (0-15)	ASFTL-P (15-30)	M & A-P (0-15)	M & A-P (15-30)	Olsen-P (0-15)	Olsen-P (15-30)
E37	17.9	0.0	23.5	3.4	29.1	16.8
E38	26.9	9.0	14.6	5.6	11.2	6.7
E39	28.0	3.4	22.4	14.6	23.5	16.8
E40	26.9	14.6	24.6	9.0	30.2	12.3
E41	33.6	9.0	37.0	12.3	25.8	16.8
E42	40.3	15.7	38.1	13.4	30.2	21.3
E44	40.3	4.5	43.7	7.8	31.4	12.3
E45	58.2	5.6	78.4	7.8	58.2	7.8
E46	38.1	4.5	40.3	5.6	33.6	11.2
E47	58.2	1.1	65.0	7.8	40.3	9.0
E48	40.3	2.2	30.2	5.6	21.3	13.4
E49	48.2	1.1	49.3	3.4	33.6	11.2
E53	12.3	0.0	14.6	0.0	23.5	11.2
E54	6.7	0.0	7.8	1.1	19.0	14.6
E55	26.9	5.6	22.4	5.6	21.3	15.7
E57	[illegible]	22.4	45.9	34.7	31.4	42.6
E58	19.0	7.8	19.0	7.8	15.7	9.0
E60	15.7	2.2	19.0	5.6	16.8	9.0
E61	7.8	2.2	14.6	6.7	11.2	9.0
E62	34.7	24.6	35.8	25.8	25.8	17.9
E63	9.0	2.2	9.0	4.5	11.2	9.0
E64	58.2	23.5	54.9	26.9	23.5	22.4
E65	3.4	1.1	4.5	1.1	7.8	4.5
E66	5.6	0.0	12.3	7.8	14.6	9.0

Table E-2. Rapeseed Sites (cont.)

Site	ASFTL-P		M & A-P		Olsen-P	
	(0-15)	(15-30)	(0-15)	(15-30)	(0-15)	(15-30)
L48	38.1	17.9	31.4	14.6	38.1	23.5
L49	49.3	38.1	42.6	24.6	25.8	21.3
L50	45.9	14.6	34.7	12.3	32.5	9.0
L51	12.3	21.3	NA	NA	13.4	NA
L52	14.6	7.8	NA	NA	14.6	NA
L53	39.2	15.7	NA	NA	29.1	NA
L54	13.4	13.4	NA	NA	14.6	NA

Table E-2. Rapeseed Sites (cont.)

Site	ASFTL-P		M & A-P		Olsen-P	
	(0-15)	(15-30)	(0-15)	(15-30)	(0-15)	(15-30)
W49	26.9	2.2	NA	NA	NA	NA
W50	40.3	5.6	45.9	13.4	33.6	13.4
W52	69.4	21.3	71.7	26.9	47.0	22.4
W53	75.0	28.0	80.6	37.0	73.9	40.3
W54	10.1	10.1	13.4	11.2	22.4	22.4

Table E-2. Rapeseed Sites (cont.)

Site	ASFTL-[redacted]		M & A-P		Olsen-P	
	(0-15)	[redacted]	(0-15)	(15-30)	(0-15)	(15-30)
T19	17.9	7.8	28.0	10.1	17.9	4.5
T20	42.6	7.8	59.4	24.6	44.8	17.9
T21	42.6	4.5	47.0	4.5	44.8	9.0
T22	25.8	6.7	31.4	10.1	22.4	9.0
T17	22.4	4.5	25.8	5.6	22.4	9.0
T18	24.6	3.4	24.6	9.0	35.8	13.4
T13	63.8	5.6	86.2	7.8	67.2	9.0
T14	5.6	1.1	4.5	0.0	40.3	4.5
T15	29.1	5.6	38.1	14.6	40.3	17.9
T16	25.8	5.6	35.8	10.1	35.8	17.9
T26	56.0	11.2	33.6	4.5	35.8	9.0
T27	13.4	2.2	15.7	1.1	9.0	4.5
T28	43.7	2.2	42.6	3.4	49.3	4.5
T29	63.8	14.6	71.7	12.3	62.7	13.4
T30	57.1	3.4	70.6	5.6	58.2	9.0
T31	26.9	3.4	33.6	17.9	35.8	13.4
T32	40.3	4.5	40.3	14.6	49.3	13.4

Table E-3. Wheat Sites

Site	ASFTL-P		M & A-P		Olsen-P	
	(0-15)	(15-30)	(0-15)	(15-30)	(0-15)	(15-30)
J01	11.2	2.2	34.7	NA	26.9	NA
J02	15.7	4.5	37.0	NA	22.4	NA
J03	52.6	32.5	84.0	NA	49.3	NA
J04	28.0	10.1	51.5	NA	35.8	NA
J06	38.1	NA	47.0	NA	44.8	NA
J07	37.0	NA	39.2	NA	22.4	NA
J08	35.8	NA	34.7	NA	17.9	NA
J09	43.7	NA	47.0	NA	26.9	NA
J10	116.5	NA	128.8	NA	62.7	NA
J11	43.7	NA	42.6	NA	22.4	NA
J12	31.4	NA	33.6	NA	22.4	NA
J13	32.5	NA	33.6	NA	22.4	NA
J14	38.1	NA	56.0	NA	31.4	NA
J15	51.5	NA	50.4	NA	26.9	NA
J16	56.0	NA	56.0	NA	40.3	NA
J17	52.6	NA	58.2	NA	40.3	NA
J18	11.2	NA	16.8	NA	13.4	NA
J19	14.6	NA	20.2	NA	17.9	NA
J20	7.8	NA	13.4	NA	13.4	NA
J22	62.7	NA	63.8	NA	35.8	NA
J23	107.5	NA	121.0	NA	71.7	NA
J24	43.7	NA	50.4	NA	31.4	NA
J25	34.7	NA	41.4	NA	26.9	NA
J26	69.4	NA	73.9	NA	40.3	NA
J27	38.1	NA	42.6	NA	31.4	NA
J28	37.0	NA	38.1	NA	26.9	NA
J29	28.0	NA	42.6	NA	26.9	NA
J30	24.6	NA	57.1	NA	26.9	NA
J31	22.4	NA	43.7	NA	22.4	NA
J32	26.9	NA	49.3	NA	31.4	NA
J33	104.2	NA	98.6	NA	67.2	NA
J34	54.9	NA	72.8	NA	40.3	NA
J35	70.6	NA	63.8	NA	44.8	NA
J36	112.0	NA	107.5	NA	53.8	NA
J37	49.3	NA	35.8	NA	35.8	NA
J38	44.8	NA	25.8	NA	31.4	NA
J39	66.1	NA	28.0	NA	40.3	NA
J40	41.4	NA	33.6	NA	31.4	NA

APPENDIX F

Mean Yields (100 kg/ha) of the Phosphate Treatments for Experimental Sites

check	indicates site yield for nil fertilizer treatment

Table F-1. Barley Sites

P_2O_5 Rate kg/ha	Site									
	B01	B02	B03	B04	B05	B06	B07	B08	B09	B10
check	23.4	23.9	15.9	14.2	20.3	5.5	22.5	21.6	22.0	17.7
0	26.2	21.5	16.1	19.3	32.0	12.1	32.3	18.5	24.1	22.6
11										
17	31.5	27.2	15.5	24.0	32.7	9.7	36.8	33.7	30.1	32.3
22										
28										
34	34.7	27.0	13.2	17.4	37.7	13.4	39.5	47.9	36.5	33.5
45										
50	33.3	29.6	16.4	20.0	37.2	13.9	35.4	52.4	30.6	33.0
56										
67	36.3	27.3	17.1	20.4	39.1	14.8	45.9	53.8	36.7	37.3
84										
90										
101	40.7	29.3	16.0	22.3	40.3	12.1	39.2	56.6	37.7	34.6
134										
Reps.	3	3	3	3	3	3	3	3	3	3

P_2O_5 Rate kg/ha	Site									
	B11	B12	B13	B14	B15	B16	B17	B18	B19	B20
check	30.6	13.3	26.8	29.7	35.6	27.6	15.9	10.9	25.1	15.5
0	34.5	16.8	32.4	27.0	32.8	33.4	37.1	21.7	19.3	14.8
11										
17	34.6	27.4	39.2	32.8	44.0	35.2	39.4	32.3	25.6	22.5
22										
28										
34	43.1	28.3	43.5	30.9	49.3	42.8	38.5	35.1	28.6	29.3
45										
50	46.9	33.7	44.1	29.3	49.8	41.7	32.6	38.3	42.4	31.4
56										
67	45.5	35.8	48.6	31.4	55.1	40.7	37.1	36.7	29.9	41.0
84										
90										
101	47.2	34.0	49.5	37.7	51.4	41.9	42.7	39.4	37.6	42.7
134										
Reps.	3	3	3	3	3	3	3	3	3	3

Table F-1. Barley Sites (cont.)

P_2O_5 Rate kg/ha	Site									
	B21	B22	B23	B24	B25	B26	B27	B28	B29	B30
check	17.8	29.7	24.2	28.2	20.9	6.9	7.7	19.0	13.3	26.0
0	20.4	41.7	21.1	24.9	24.0	7.1	33.9	18.1	19.4	29.7
11										
17	20.9	39.6	26.7	35.1	31.0	10.3	36.0	23.6	30.0	30.7
22										
28										
34	19.5	38.1	21.2	40.0	32.9	8.3	33.6	29.9	28.6	39.1
45										
50	22.7	39.6	18.5	31.0	30.2	7.8	31.0	30.5	29.5	34.9
56										
67	22.8	40.3	22.7	36.2	30.7	6.3	33.5	33.4	36.3	29.3
84										
90										
101	20.5	37.9	26.9	32.4	26.5	6.5	36.5	30.6	28.7	41.3
134										
Reps.	3	3	3	3	3	3	3	3	3	3

P_2O_5 Rate kg/ha	Site									
	B31	B32	B33	B34	B35	B36	B37	B38	B39	B40
check	11.3	4.7	42.7	39.5	44.4	27.6	14.6	12.9	43.8	21.1
0	27.2	19.5	52.8	47.7	53.4	31.9	18.5	40.9	36.8	36.8
11										
17	23.3	27.6	51.2	51.6	48.6	37.1	20.9	37.0	45.4	37.6
22										
28										
34	22.0	19.6	49.3	52.4	51.1	53.0	13.9	39.9	42.9	38.1
45										
50	21.3	23.9	53.9	51.2	55.6	53.4	23.0	43.5	47.2	38.5
56										
67	16.5	17.6	52.2	48.2	53.0	50.5	23.3	41.1	46.7	43.3
84										
90										
101	22.5	24.9	54.0	49.2	50.2	58.9	21.8	40.2	50.0	40.0
134										
Reps.	3	3	3	3	3	3	3	3	3	3

Table F-1. Barley Sites (cont.)

P_2O_5 Rate kg/ha	Site E01	E02	E03	E04	E06	E07	E08	E09	E10	E11
check	28.0	16.2	31.8	34.2	19.9	18.5	19.4	25.8	11.1	18.9
0	27.2	38.8	35.5	33.6	32.1	23.7	22.8	35.2	20.8	20.4
11										
17	28.8	39.5	38.4	36.4	37.3	27.0	30.5	36.4	35.2	26.4
22										
28										
34	32.0	38.1	35.5	37.9	35.1	28.8	32.7	38.5	35.7	28.4
45										
50	33.7	39.5	32.9	37.2	37.7	26.2	35.5	41.3	36.3	30.5
56										
67	37.4	39.2	32.8	37.4	38.3	27.6	39.8	41.9	37.7	29.6
84										
90										
101	33.6	36.2	30.8	37.5	41.1	29.1	41.8	43.7	38.3	28.3
134										
Reps.	3	3	3	3	3	3	3	3	3	3

P_2O_5 Rate kg/ha	Site E13	E14	E15	E17	E20	E21	E22	E23	E24	E25
check	34.6	41.7	8.5	18.8	21.4	15.7	21.5	10.4	7.6	30.1
0	36.1	41.4	25.1	29.8	29.6	31.8	27.7	23.0	18.7	33.2
11	41.2	41.4	28.8	31.2	30.2	32.0	31.8	27.2	23.1	42.6
17	35.8	39.3	27.6	32.5	28.4	30.1	37.4	28.3	30.4	44.0
22	38.0	41.4	28.2	25.3	29.2	32.4	34.7	28.2	24.4	38.0
28										
34	43.5	38.4	29.7	33.0	29.7	33.6	39.0	30.2	25.0	39.8
45										
50	41.3	41.0	28.3	29.5	29.1	36.3	38.6	34.2	25.0	47.4
56										
67	36.6	38.1	29.8	31.6	32.0	36.7	41.2	32.7	26.8	44.0
84										
90										
101	36.3	38.5	27.2	34.7	28.9	31.5	42.4	32.3	35.8	44.7
134										
Reps.	3	3	3	3	3	3	3	3	3	3

Table F-1. Barley Sites (cont.)

P_2O_5 Rate	Site						
kg/ha	E26	E27	E29	E30	E32	E35	E34
check	9.1	11.4	43.9	12.4	5.3	19.9	17.9
0	28.2	25.8	40.5	32.1	23.3	23.0	28.4
11	27.3	30.0	50.5	30.9	30.4	23.9	28.9
17	29.9	30.1	50.8	33.0	33.0	27.1	29.0
22	28.7	32.6	47.2	29.5	30.8	26.9	31.1
28							
34	30.0	30.9	47.7	30.0	32.1	30.4	29.5
45							
50	31.1	32.6	47.4	30.9	34.5	31.1	29.0
56							
67	32.0	33.6	48.3	31.4	37.0	32.4	29.1
84							
90							
101	30.5	29.8	50.0	30.4	32.9	38.0	27.6
134							
Reps.	3	3	3	3	3	3	3

Table F-1. Barley Sites (cont.)

P_2O_5 Rate kg/ha	L01	L03	L04	L05	L06	L08	L10	L11	L12	L13
check	4.7	13.0	24.6	25.9	30.6	23.1	8.7	21.4	16.6	20.5
0	26.2	33.5	24.9	35.1	35.1	34.2	23.4	24.3	28.9	40.3
11										
17	23.6	35.4	33.9	33.2	45.6	32.8	31.1	36.6	31.5	42.8
22										
28										
34	26.2	31.6	28.9	31.4	43.5	33.4	32.7	42.1	33.7	49.6
45										
50	25.1	35.7	34.0	33.8	43.8	36.8	34.5	43.0	33.6	47.5
56										
67										
84										
90										
101										
134										
Reps.	4	4	4	4	4	4	4	4	4	4

P_2O_5 Rate kg/ha	L14	L15
check	17.0	22.6
0	16.4	22.2
11		
17	33.9	32.6
22		
28		
34	34.7	39.8
45		
50	36.3	38.9
56		
67		
84		
90		
101		
134		
Reps.	4	4

Table F-1. Barley Sites (cont.)

P_2O_5 Rate kg/ha	Site W01	W02	W03	W04	W05	W06	W07	W08	W09	W10
check	36.3	38.2	28.1	28.2	31.6	19.8	35.3	30.0	14.9	19.4
0	35.4	41.9	30.9	31.6	36.8	19.3	40.0	29.7	32.6	26.5
11							37.5	30.6	36.2	27.6
17	39.0	44.7	29.9	34.7	39.2	24.8	39.8	30.7	33.9	31.0
22	40.5	45.6	28.6	36.1	40.1	29.0	40.2	32.9	35.3	28.3
28	40.9	41.1	33.2	35.6	38.0	28.4	39.3	35.5	36.0	31.5
34	38.1	41.1	28.9	36.0	38.2	28.9	37.0	34.2	36.5	30.2
45										
50	46.5	41.3	29.6	38.8	40.3	32.0	39.3	33.8	34.4	29.6
56										
67	45.1	39.9	28.8	39.5	39.0	32.4	37.7	30.9	37.4	28.8
84										
90										
101							42.8	36.1	38.5	30.7
134										
Reps.	6	6	6	6	6	5	6	6	6	6

P_2O_5 Rate kg/ha	Site W12	W13	W14	W15	W16	W17	W18	W19	W20	W22
check	32.4	39.1	45.9	30.8	22.5	14.0	26.5	21.3	20.0	27.1
0	42.6	46.3	47.4	34.7	32.9	29.3	30.8	40.0	28.3	29.5
11	40.1	46.6	46.7	39.2	34.5	29.0	37.5	44.0	33.7	29.1
17	41.7	46.6	43.2	38.9	36.1	28.9	36.4	39.6	33.5	30.6
22	42.6	46.3	45.4	38.8	36.1	28.8	39.3	37.9	32.4	31.4
28	41.9	50.7	45.8	41.2	38.2	31.7	41.4	42.4	36.3	33.4
34	38.3	48.6	44.0	38.8	35.4	30.5	39.5	40.1	32.8	29.5
45										
50	42.9	47.6	45.6	45.6	34.3	33.3	41.3	38.4	35.7	31.1
56										
67	43.3	49.7	43.5	45.1	37.0	31.5	37.1	39.8	34.6	31.6
84										
90										
101	40.4	49.8	43.7	46.4	33.2	30.9	40.7	37.0	34.6	31.0
134										
Reps.	6	6	6	6	6	6	6	6	6	6

Table F-1. Barley Sites (cont.)

P_2O_5 Rate kg/ha	W23	W24	W25	W26	W27	W28	W29	W31	W34	W36
check	39.8	27.1	35.3	37.0	31.4	25.1	13.7	25.6	14.9	17.6
0	44.8	32.6	42.6	41.7	34.8	31.5	21.2	30.6	23.7	32.4
11	46.6	35.6	41.0	45.5	40.8	33.2	25.3	28.7	23.9	31.6
17										
22	48.8	36.6	41.1	44.2	41.7	35.4	24.9	29.0	26.2	32.8
28										
34	50.8	31.7	42.1	49.8	39.0	31.6	24.0	28.8	27.7	33.6
45										
50	48.8	33.6	40.5	47.0	38.3	33.9	24.8	28.4	29.0	36.0
56										
67	50.7	35.3	41.7	47.0	40.4	30.1	23.6	29.2	28.3	35.3
84										
90										
101	52.3	36.2	42.4	45.5	38.4	31.5	25.4	28.8	27.4	33.0
134										
Reps.	6	6	6	6	6	6	6	6	6	6

P_2O_5 Rate kg/ha	W37	W38	W41	W42	W43	W44	W46	W47
check	22.0	23.6	21.5	14.8	30.8	28.1	12.7	14.9
0	30.1	40.5	28.8	28.2	43.5	31.7	17.8	24.6
11	36.0	40.9	29.5	25.2	43.7	37.2	20.0	28.1
17								
22	30.9	43.2	30.6	27.6	41.2	40.8	22.1	27.7
28								
34	33.6	40.4	29.0	26.1	49.2	40.2	20.6	30.5
45								
50	32.0	42.8	30.4	27.0	43.7	41.2	24.5	29.8
56								
67	36.3	43.6	29.6	27.2	48.5	44.4	23.6	27.2
84								
90								
101	36.8	43.0	22.2	25.5	49.2	39.8	22.4	29.7
134								
Reps.	6	6	6	6	6	6	6	6

Table F-1. Barley Sites (cont.)

P_2O_5 Rate kg/ha	Site							
	T01	T02	T03	T07	T08	T09	T10	T12
check	25.2	34.8	20.9	31.5	26.3	49.3	52.1	52.8
0	21.2	35.8	31.1	40.2	29.0	50.0	44.7	53.4
11								
17								
22	31.6	37.0	36.4	41.2	32.3	53.6	50.0	54.4
28								
34								
45	30.9	34.2	34.0	43.6	34.0	57.0	50.3	54.0
50								
56								
67								
84								
90	29.1	39.6	40.2	42.8	36.7	54.1	52.8	55.9
101								
134								
Reps.	6	6	6	6	6	6	6	6

Table F-2. Rapeseed Sites

P_2O_5 Rate kg/ha	Site									
	B41	B42	B43	B44	B45	B46	B47	B48	B49	B50
check	4.8	5.0	2.6	5.2	3.7	5.7	13.4	5.7	10.4	7.5
0	5.9	5.2	3.7	7.8	7.7	11.6	17.7	7.5	10.3	6.3
11										
17	9.7	6.4	4.5	14.1	6.6	13.3	24.6	15.5	8.3	9.0
22										
28										
34	8.8	6.5	3.4	17.1	8.4	12.7	22.0	16.6	10.4	10.2
45										
50	9.5	8.1	2.2	15.5	7.3	10.6	26.1	16.2	9.1	9.1
56										
67	9.7	5.2	4.6	13.0	8.7	13.6	23.6	15.9	10.0	9.7
84										
90										
101	9.7	8.2	4.9	15.7	6.9	14.1	21.6	16.9	13.4	9.9
134										
Reps.	3	3	3	3	3	3	3	3	3	3

P_2O_5 Rate kg/ha	Site									
	B51	B52	B53	B54	B55	B56	B57	B58	B59	B60
check	2.9	12.3	[illegible]0.9	9.4	3.8	3.4	8.5	2.7	6.3	3.4
0	3.5	16.1	11.9	14.1	10.1	5.6	12.8	10.4	5.9	10.1
11										
17	10.1	15.5	16.5	16.9	15.7	10.4	17.6	15.0	6.5	10.2
22										
28										
34	8.3	19.4	15.9	21.4	17.5	14.4	20.6	12.8	8.1	8.7
45										
50	9.3	17.7	15.9	20.6	16.8	13.4	20.8	18.0	9.0	8.0
56										
67	11.6	18.7	15.3	17.4	15.9	15.6	21.6	15.1	8.5	9.7
84										
90										
101	12.9	21.6	13.9	19.7	15.9	18.5	23.4	15.9	8.0	9.1
134										
Reps.	3	3	3	3	3	3	3	3	3	3

Table F-2. Rapeseed Sites (cont.)

P_2O_5 Rate kg/ha	Site B61	B62	B63	B64	B65	B66	B67	B68	B69	B70
check	2.7	4.3	5.5	5.4	0.1	4.7	0.7	5.9	1.9	1.3
0	3.2	7.8	10.1	5.9	8.1	6.5	1.6	6.0	7.6	7.6
11										
17	3.7	8.8	15.8	6.8	8.1	11.6	7.1	9.2	6.9	9.0
22										
28										
34	3.8	12.3	14.4	7.7	8.7	12.7	9.4	13.6	9.9	10.3
45										
50	3.8	13.4	17.8	6.8	8.3	11.3	11.0	13.3	8.3	8.5
56										
67	4.3	11.8	15.2	7.2	8.7	14.6	8.0	13.1	9.2	8.7
84										
90										
101	3.5	15.2	18.0	6.9	7.6	9.4	8.8	15.7	9.0	9.4
134										
Reps.	3	3	3	3	3	3	3	3	3	3

P_2O_5 Rate kg/ha	Site B71	B72	B73	B74	B75	B76	B77	B78
check	13.9	12.9	15.0	12.1	5.8	6.4	12.9	6.9
0	15.3	15.6	21.5	16.7	12.7	16.4	18.1	7.7
11								
17	14.3	17.1	25.1	22.5	13.7	20.0	20.9	14.6
22								
28								
34	16.2	17.6	21.3	25.3	12.0	22.7	18.8	18.3
45								
50	15.8	19.8	25.0	22.2	11.3	21.2	14.0	16.4
56								
67	13.2	18.8	26.7	23.5	12.8	22.3	17.6	18.9
84								
90								
101	14.7	19.2	23.7	25.5	14.3	21.5	18.5	16.5
134								
Reps.	3	3	3	3	3	3	3	3

Table F-2. Rapeseed Sites (cont.)

P_2O_5 Rate kg/ha	Site									
	E37	E38	E39	E40	E41	E42	E44	E45	E46	E47
check	1.6	5.0	8.5	9.5	15.3	10.9	12.4	7.1	12.2	20.8
0	10.6	10.9	15.7	9.5	21.1	14.2	14.7	17.2	18.0	19.4
11									20.8	20.7
17	14.2	14.3	15.2	15.7	23.5	11.5	16.6	13.8	19.0	19.7
22									20.5	18.0
28										
34	14.9	15.0	16.5	16.8	23.6	13.4	14.2	14.3	19.5	18.0
45										
50	15.2	17.1	15.2	15.0	23.5	19.7	17.0	16.0	19.4	20.3
56										
67	14.4	14.3	18.8	16.7	22.4	17.4	14.8	12.5	22.5	19.6
84										
90										
101	13.4	16.0	17.2	11.3	24.6	13.4	14.0	13.8	21.5	19.8
134										
Reps.	3	3	3	3	3	3	3	3	3	3

P_2O_5 Rate kg/ha	Site									
	E48	E49	E53	E54	E55	E57	E58	E60	E61	E62
check	3.2	10.5	3.9	4.8	6.0	15.3	14.0	9.7	5.7	5.8
0	10.4	14.9	5.5	11.0	13.3	15.2	17.9	13.1	5.6	11.3
11	13.4	14.3	9.3	11.3	16.9	15.1	19.7	15.6	10.4	13.2
17	13.1	16.2	8.1	12.0	14.9	14.3	19.3	14.0	10.8	12.9
22	14.0	18.4	7.1	12.0	15.5	14.8	17.8	13.8	11.9	13.1
28										
34	13.7	15.8	6.6	11.2	15.9	15.2	19.4	15.9	11.9	12.7
45										
50	13.3	13.4	7.1	13.0	15.1	17.2	19.9	16.5	12.3	12.3
56										
67	12.7	15.8	7.4	10.3	15.7	16.5	20.3	16.2	14.3	14.3
84										
90										
101	13.0	18.8	6.4	10.6	14.6	16.6	20.9	16.1	14.4	12.2
134										
Reps.	3	3	3	3	3	3	3	3	3	3

Table F-2. Rapeseed Sites (cont.)

P_2O_5 Rate kg/ha	Site			
	E63	E64	E65	E66
check	4.5	6.5	5.3	1.3
0	6.3	15.8	8.3	4.0
11	8.3	17.5	14.1	8.4
17	8.7	15.3	13.6	9.4
22	9.1	17.1	14.0	8.3
28				
34	9.5	17.0	14.6	7.7
45				
50	9.7	17.7	15.2	8.6
56				
67	12.4	18.4	14.4	9.7
84				
90				
101	12.4	19.6	15.2	10.3
134				
Reps.	3	3	3	3

P_2O_5 Rate kg/ha	Site						
	L48	L49	L50	L51	L52	L53	L54
check	7.1	4.9	10.6	9.4	3.1	5.0	5.8
0	9.7	11.0	17.5	22.6	14.3	11.6	6.9
11							
17	10.9	10.6	15.5	17.0	15.0	10.9	12.4
22							
28							
34	12.2	14.9	14.4	19.3	16.6	11.0	11.9
45							
50	11.6	12.7	17.7	19.4	14.8	10.5	16.5
56							
67							
84							
90							
101							
134							
Reps.	4	4	4	4	4	4	4

Table F-2. Rapeseed Sites (cont.)

P_2O_5 Rate kg/ha	Site W49	W50	W52	W53	W54
check	6.7	2.1	3.8	6.2	5.2
0	9.2	3.4	11.1	13.1	8.6
11	8.4	4.3	11.2	14.2	11.1
17	10.6				
22	9.7	3.9	9.2	14.9	12.2
28	10.8				
34	8.6	3.2	8.5	13.9	11.6
45					
50	9.7	4.1	9.1	14.8	13.7
56					
67	9.6	2.7	9.4	14.1	12.5
84					
90					
101	6.5	2.4	9.9	14.1	11.3
134					
Reps.	5	4	3	6	6

Table F-2. Rapeseed Sites

P_2O_5 Rate kg/ha	Site									
	T19	T20	T21	T22	T17	T18	T13	T14	T15	T16
check	13.6	12.8	8.5	8.5	~~4.6~~	17.6	9.6	1.5	4.1	6.5
0	14.4	13.7	12.1	9.7	6.6	17.8	8.6	0.9	3.4	8.8
11										
17										
22	15.7	14.7	13.3	10.6	6.3	19.9	8.1	1.3	5.6	10.5
28										
34										
45	15.3	13.6	12.2	7.6	4.7	17.1	6.7	2.5	5.9	8.6
50										
56										
67										
84										
90	10.9	11.8	10.9	5.6	1.8	12.0	6.8	2.5	6.4	8.2
101										
134										
Reps.	6	6	6	6	6	6	6	6	6	6

P_2O_5 Rate kg/ha	Site						
	T26	T27	T28	T29	T30	T31	T32
check	10.8	3.8	1.5	8.6	9.9	11.6	11.1
0	14.0	4.7	4.0	9.0	12.3	12.2	14.0
11							
17							
22	13.7	4.0	3.2	8.7	11.8	12.1	14.7
28							
34							
45	13.0	4.9	3.9	9.2	11.5	12.4	12.2
50							
56							
67							
84							
90	13.3	4.5	3.9	9.1	7.7	13.0	14.2
101							
134							
Reps.	6	6	6	6	6	6	6

Table F-3. Wheat Sites

	Site									
P_2O_5 Rate kg/ha	J01	J02	J03	J04	J06	J07	J08	J09	J10	J11
check					37.4	25.8	12.9	23.3	26.2	10.9
0	16.7	17.5	11.2	24.3	36.4	23.5	16.6	28.7	34.0	14.0
11										
17										17.2
22										
28					36.2	32.7	19.9	27.3	34.2	
34										18.9
45	19.7	21.7	13.1	21.2						
50										20.9
56					38.1	30.0	21.3	31.7	32.8	
67	19.5	21.8	14.0	25.8						20.4
84					34.2	27.3	23.9	29.1	35.4	
90										
101										
134	20.6	22.0	18.1	24.5						
Reps.	3	3	3	3	3	3	3	3	3	4

	Site									
P_2O_5 Rate kg/ha	J12	J13	J14	J15	J16	J17	J18	J19	J20	J22
check	21.4	20.4	20.3	15.8	23.0	17.9	18.6	22.1	12.7	13.9
0	22.3	26.7	16.2	16.4	24.8	19.5	20.3	21.7	17.5	28.4
11										
17	24.0	26.3	24.0	17.0	25.8	25.6	29.9	24.1	20.8	29.3
22										
28										
34	25.4	31.2	25.8	17.9	26.8	26.3	35.4	24.6	22.0	28.8
45										
50	25.3	31.5	26.1	22.7	28.8	26.9	37.1	26.0	20.4	29.7
56										
67	25.3	30.2	22.6	21.2	31.0	24.4	36.7	25.9	23.4	31.1
84										
90										
101										
134										
Reps.	4	4	4	4	4	4	4	4	4	4

Table F-3. Wheat Sites (cont.)

P_2O_5 Rate kg/ha	Site									
	J23	J24	J25	J26	J27	J28	J29	J30	J31	J32
check	19.9	22.1	11.4	16.6	14.8	15.2	12.9	38.5	27.9	29.5
0	28.0	18.6	12.5	17.6	16.7	12.0	29.9	38.5	32.8	28.3
11										
17	26.8	21.6	14.2	21.1	17.7	18.0	31.1	40.1	36.3	32.7
22										
28										
34	25.6	25.6	15.7	21.2	18.6	20.9	31.4	40.5	35.1	31.7
45										
50	27.7	29.3	16.5	22.7	18.5	20.6	35.2	38.9	35.6	31.7
56										
67	26.5	32.0	15.2	24.3	19.6	22.1	30.8	40.1	35.5	33.8
84										
90										
101										
134										
Reps.	4	4	4	4	4	4	4	4	4	4

P_2O_5 Rate kg/ha	Site							
	J33	J34	J35	J36	J37	J38	J39	J40
check	31.5	11.0	24.3	20.3	33.5	10.0	34.6	25.1
0	29.8	20.0	24.6	23.7	25.9	14.4	34.5	30.9
11								
17	27.0	23.2	27.0	21.2	31.8	15.0	34.5	33.2
22								
28								
34	28.8	22.6	35.4	29.2	35.8	13.2	35.2	33.3
45								
50	27.8	22.0	32.8	17.9	29.8	15.9	37.3	40.1
56								
67	29.0	22.4	34.6	18.6	30.8	14.2	32.4	36.2
84								
90								
101								
134								
Reps.	4	4	4	4	4	4	4	4.

APPENDIX G

Second Order Polynomial Coefficients for Experimental Sites

Note Coefficients calculated on the basis of mean treatment yields.

R^2 indicates goodness of fit.

* significant at $p \leq 0.05$.

** significant at $p \leq 0.01$.

Lack of significance is due to the number of treatments at the site.

Units for b_0 are 100 kg/ha.

Table G-1. Barley Sites

Site	b_0	b_1	b_2	R^2
B01	26.92	0.176	-0.00055	0.95*
B02	22.31	0.174	-0.00128	0.76
B03	15.18	-0.008	0.00020	0.10
B04	20.46	-0.048	0.00068	0.14
B05	31.05	0.151	-0.00083	0.91*
B06	10.52	0.100	-0.00091	0.42
B07	31.78	0.249	-0.00192	0.54
B08	19.31	0.951**	-0.00659**	0.98**
B09	24.94	0.258	-0.00156	0.74
B10	23.62	0.349	-0.00276	0.86
B11	32.40	0.333	-0.00214	0.88*
B12	17.48	0.472**	-0.00346*	0.95**
B13	32.41	0.347**	-0.00205*	0.97**
B14	28.72	-0.006	0.00092	0.66
B15	33.30	0.561**	-0.00432*	0.96**
B16	32.64	0.253	-0.00192	0.80
B17	38.27	-0.145	0.00196	0.49
B18	23.12	0.415*	-0.00297	0.91*
B19	19.04	0.427	-0.00287	0.67
B20	14.42	0.492*	-0.00232	0.97**
B21	19.51	0.068	-0.00064	0.32
B22	40.46	-0.040	0.00018	0.39
B23	23.13	-0.116	0.00161	0.35
B24	27.07	0.321	-0.99314	0.47
B25	25.04	0.257	-0.00280	0.76
B26	8.14	0.008	-0.00034	0.36
B27	34.62	-0.104	0.00127	0.48
B28	17.72	0.414**	-0.00322**	0.98**
B29	20.30	0.391	-0.00341	0.74
B30	30.54	0.040	-0.00047	0.34
B31	27.02	-0.261**	0.00228	0.80
B32	22.25	-0.054	0.00070	0.04
B33	51.11	-0.036	0.00065	0.34
B34	48.20	0.086	-0.00104	0.32
B35	50.22	0.067	-0.00077	0.10
B36	31.38	0.551	-0.00331	0.87*
B37	18.07	0.054	-0.00008	0.22
B38	38.35	0.064	-0.00053	0.14
B39	37.93	0.207	-0.00111	0.80
B40	35.57	0.105	-0.00067	0.57

Table G-1. Barley Sites (cont.)

Site	b_0	b_1	b_2	R^2
E01	25.76	0.246*	-0.00185	0.88*
E02	37.93	0.043	-0.00072	0.72
E03	36.21	-0.042	-0.00024	0.75
E04	33.57	0.111*	-0.00089	0.83
E06	32.70	0.096	-0.00023	0.80
E07	24.34	0.079	-0.00045	0.56
E08	23.19	0.334**	-0.00171*	0.98**
E09	34.03	0.142*	-0.00058	0.98**
E10	23.46	0.430	-0.00330	0.81
E11	20.74	0.290**	-0.00247**	0.95**
E13	36.20	0.148	-0.00179	0.31
E14	40.67	-0.054	0.00028	0.45
E15	25.53	0.130*	-0.00132*	0.68
E17	29.93	-0.036	0.00086	0.30
E20	28.52	0.036	-0.00036	0.10
E21	29.36	0.186	-0.00181	0.60
E22	28.67	0.317**	-0.00212*	0.88**
E23	23.08	0.287**	-0.00224**	0.95**
E24	22.26	0.046	0.00080	0.61
E25	35.46	0.262	-0.00200	0.53
E26	26.92	0.110*	-0.00035	0.76*
E27	26.32	0.228**	-0.00221*	0.83*
E29	44.48	0.117	-0.00089	0.20
E30	31.23	-0.036	0.00028	0.15
E32	24.84	0.335**	-0.00288*	0.83*
E33	22.68	0.184**	-0.00046	0.96**
E34	28.22	0.047	-0.00067	0.52

Table G-1. Barley Sites (cont.)

Site	b_0	b_1	b_2	R^2
L01	25.30	-0.070	0.00144	0.13
L03	33.56	-0.083	0.00222	0.15
L04	25.62	0.309	-0.00389	0.50
L05	34.63	-0.228	0.00433	0.88
L06	35.17	0.598	-0.01011	0.83
L08	33.61	-0.164	-0.00478	0.99
L10	23.30	0.472	-0.00589	0.97
L11	23.98	0.877*	-0.01133	1.00*
L12	28.28	0.217	-0.00267	0.99
L13	38.95	0.374	-0.00456	0.84
L14	16.93	1.076	-0.01589	0.94
L15	21.54	0.846	-0.01122	0.99

Table G-1. Barley Sites (cont.)

Site	b_0	b_1	b_2	R^2
W01	34.80	0.201	-0.00075	0.78*
W02	42.11	0.038	-0.00148	0.41
W03	30.09	-0.011	-0.00025	0.14
W04	31.20	0.177**	-0.00102	0.96**
W05	36.50	0.098	-0.00115	0.41
W06	19.01	0.428**	-0.00393*	0.96**
W07	39.36	-0.089	0.00123	0.53
W08	29.90	0.088	0.00049	0.39
W09	33.22	0.057	-0.00014	0.60
W10	27.16	0.819	-0.00066	0.30
W12	40.50	0.021	-0.00025	0.02
W13	45.23	0.079	-0.00047	0.49
W14	45.86	-0.071	0.00047	0.44
W15	34.55	0.225**	-0.00125	0.88**
W16	33.06	0.120	-0.00139*	0.47
W17	27.74	0.107*	-0.00088	0.56
W18	32.89	0.240*	-0.00204	0.55
W19	40.29	-0.017	-0.00025	0.32
W20	29.58	0.175*	-0.00150	0.59
W22	28.93	0.069	-0.00061	0.27
W23	44.62	0.132	-0.00075	0.83*
W24	33.57	-0.013	0.00036	0.16
W25	41.36	-0.042	0.00051	0.43
W26	41.66	0.194	-0.00186	0.64
W27	36.60	0.113	-0.00117	0.27
W28	32.12	0.019	-0.00041	0.18
W29	22.53	0.051	-0.00035	0.27
W31	29.36	-0.042	0.00038	0.45
W34	22.73	0.168**	-0.00139**	0.92**
W36	30.70	0.122*	-0.00113	0.71
W37	31.31	0.031	0.00022	0.43
W38	39.83	0.058	-0.00036	0.50
W41	27.89	0.124*	-0.00202**	0.92**
W42	26.52	-0.001	-0.00012	0.14
W43	42.12	0.067	-0.00003	0.47
W44	32.24	0.333**	-0.00293**	0.89*
W46	17.67	0.173*	-0.00144*	0.84*
W47	25.45	0.109	-0.00088	0.46

Table G-1. Barley Sites (cont.)

Site	b_0	b_1	b_2	R^2
T01	21.67	0.400	-0.00405	0.86
T02	35.82	-0.080	0.00142	0.70
T03	31.48	0.083	0.00005	0.77
T07	39.24	0.106	-0.00091	0.88
T08	28.58	0.144	-0.00074	1.00
T09	48.83	0.255	-0.00256	0.97
T12	52.66	0.009	0.00019	0.86

Table G-2. Rapeseed Sites

Site	b_0	b_1	b_2	R^2
B41	6.67	0.093	-0.00073	0.68
B42	5.51	0.023	-0.00003	0.32
B43	4.00	-0.034	0.00049	0.38
B44	9.48	0.195	-0.00163	0.55
B45	7.06	0.030	-0.00034	0.18
B46	12.10	-0.015	0.00036	0.33
B47	18.55	0.213	-0.00211	0.64
B48	9.21	0.238	-0.00190	0.75
B49	9.87	-0.058	0.00101	0.81
B50	6.79	0.092	-0.00073	0.74
B51	4.85	0.141	-0.00072	0.77
B52	15.68	0.038	0.00017	0.77
B53	12.69	0.127	0.00135	0.67
B54	14.54	0.166	-0.00140	0.56
B55	11.14	0.198	-0.00177	0.76
B56	6.35	0.214*	-0.00111	0.93
B57	13.30	0.217*	-0.00138	0.95*
B58	10.86	0.148	-0.00114	0.59
B59	5.59	0.091*	-0.00076*	0.92*
B60	10.05	-0.046	0.0004	0.39
B61	3.18	0.028*	-0.00028*	0.79
B62	7.71	0.114	-0.0005	0.84
B63	11.17	0.144	-0.00093	0.68
B64	6.04	0.039	-0.00036	0.58
B65	7.79	0.028	-0.00034	0.69
B66	6.99	0.225*	-0.00224*	0.79
B67	2.52	0.242*	-0.00207	0.81
B68	6.38	0.191*	-0.00116	0.90*
B69	7.17	0.048	-0.00035	0.42
B70	7.99	0.035	-0.00029	0.25
B71	15.02	-0.0036	-0.00007	0.11
B72	15.28	0.098*	-0.0007	0.88*
B73	21.34	0.099	-0.00083	0.34
B74	18.01	0.166	-0.00114	0.65
B75	13.00	-0.055	-0.00073	0.59
B76	16.71	0.171*	-0.00144	0.83
B77	19.40	-0.092	-0.00085	0.21
B78	8.64	0.311*	-0.00265*	0.88

Table G-2. **Rapeseed Sites (cont.)**

Site	b_0	b_1	b_2	R^2
E37	11.10	0.140*	-0.00135*	0.85
E38	11.34	0.133	-0.00105	0.70
E39	14.96	0.033	-0.0001	0.40
E40	10.37	0.245*	-0.00266*	0.83
E41	21.52	0.038	-0.00017	0.45
E42	11.81	0.161	-0.00156	0.35
E44	14.73	0.039	-0.00056	0.30
E45	16.15	-0.071	0.00049	0.41
E46	18.46	0.048	-0.00021	0.47
E47	19.27	-0.019	0.00026	0.07
E48	11.58	0.071	-0.00071	0.38
E49	15.63	-0.038	0.00069	0.29
E55	14.22	0.055	-0.00062	0.28
E57	14.28	0.398	-0.0002	0.57
E58	18.01	0.032	-0.00007	0.65
E60	13.11	0.082	-0.0006	0.68
E61	7.14	0.184**	-0.00128*	0.86**
E62	11.66	0.055	-0.00056	0.36
E63	6.62	0.104**	-0.00052	0.92**
E64	15.74	0.031	-0.00005	0.77*
E65	10.29	0.160*	-0.00133	0.66
E66	5.91	0.098	-0.00065	0.56

Table G-2. Rapeseed Sites (cont.)

Site	b_0	b_1	b_2	R^2
L48	9.47	0.117	-0.00167	0.93
L49	10.23	0.14	-0.00189	0.46
L50	17.33	-0.237	0.00522	0.93
L51	21.74	-0.300	0.00567	0.69
L52	13.87	0.127	-0.00244	0.68
L53	11.37	-0.034	-0.00033	0.84
L54	7.37	0.207	-0.00089	0.86

Table G-2. Rapeseed Sites (cont.)

Site	b_0	b_1	b_2	R^2
W49	8.42	0.053	-0.00079	0.70
W50	3.64	0.008	-0.00025	0.60
W52	11.00	-0.082*	0.00078*	0.70
W53	13.31	0.036	-0.00035	0.39
W54	8.99	0.137**	-0.0013*	0.85*

Table G-2. Rapeseed Sites (cont.)

Site	b_0	b_1	b_2	R^2
T19	16.57	-0.055	-0.0004	0.97
T20	12.84	0.047	-0.00056	0.42
T21	12.09	0.032	-0.00061	0.81
T22	8.47	0.109**	-0.0019**	1.00**
T17	6.59	-0.025	-0.00038	0.99
T18	17.50	0.110	-0.00174	0.62
T19	9.55	-0.130	0.00123	0.91
T14	0.77	0.046	-0.00033	0.91
T15	3.44	0.090	-0.00073	0.95
T16	9.06	0.020	-0.00042	0.43
T26	12.73	0.062	-0.00076	0.95
T27	3.59	0.066	-0.00068	0.98
T28	3.81	-0.013	0.00018	0.23
T29	7.90	0.074	-0.00068	0.77
T30	11.59	-0.014	-0.0003	0.70
T31	12.78	0.004	-0.00015	0.98
T32	14.19	-0.056	0.00065	0.31

Table G-3. Wheat Sites

Site	b_0	b_1	b_2	R^2
J01	16.50	0.066	-0.00032	0.94
J02	17.26	0.107	-0.00063	0.97
J03	12.34	0.038	0.00016	1.00*
J04	23.35	-0.011	0.00016	0.09
J06	35.36	0.082	-0.00132	0.59
J07	23.68	0.349	-0.00424	0.85
J08	16.44	0.104	-0.00028	0.98
J09	27.53	0.053	-0.00044	0.20
J10	33.70	-0.156	0.00088	0.57
J11	13.72	0.222*	-0.00206	0.99*
J12	21.88	0.128*	-0.00140*	0.98*
J13	25.33	0.184	-0.00184	0.72
J14	16.26	0.494**	-0.00676*	0.98*
J15	15.61	0.101	-0.00016	0.77
J16	24.35	0.034	0.00098*	1.00**
J17	19.50	0.361*	-0.00492*	0.96*
J18	20.10	0.642**	-0.00673**	1.00**
J19	21.44	0.131*	-0.00117	0.97*
J20	17.72	0.125	-0.00095	0.72
J22	28.19	-0.010	0.00073	0.86
J23	27.31	-0.069	0.00095	0.35
J24	18.05	0.223*	-0.00029	1.00**
J25	12.16	0.156*	-0.00184	0.96*
J26	17.69	0.130	-0.00067	0.93
J27	16.48	0.053	-0.00022	0.93
J28	12.18	0.347*	-0.00352	0.96*
J29	28.90	0.164	-0.00216	0.46
J30	38.15	0.059	-0.00079	0.30
J31	32.75	0.119	-0.00152	0.61
J32	28.64	0.118	-0.00098	0.64
J33	28.85	-0.094	0.00149	0.42
J34	20.20	0.004	-0.00156	0.58
J35	23.58	0.359	-0.00343	0.83
J36	22.59	0.138	-0.00365	0.36
J37	25.94	0.386	-0.00565	0.67
J38	14.21	0.003	0.00000	0.01
J39	33.25	0.134	-0.00238	0.42
J40	29.89	0.199	-0.00159	0.65

APPENDIX H

Crop Response Calculations for Experimental Sites

List of Abbreviations

Y-max	Calculated Maximum Site Yield (100 kg/ha)
X-max	Phosphate Rate for Y-max (kg P_2O_5/ha)
Y-90%max	90% of Y-max (100 kg/ha)
X-90%max	Phosphate Rate for Y-90%max (kg P_2O_5/ha)

Yield Increase (100 kg/ha)

Table H-1. Barley Sites

Site	Y-max	X-max	X-90%max	Y-90%max	Yield Increase	%Yield Increase
B01	40.2	101	62	36.2	8.7	24.2
B02	29.3	76	26	26.4	3.7	13.9
B03	15.5	0	0	15.5	0.0	0.0
B04	20.8	0	0	20.8	0.0	0.0
B05	40.3	101	35	36.3	4.7	13.0
B06	10.8	0	0	10.8	0.0	0.0
B07	41.4	73	24	37.3	4.9	13.2
B08	57.8	81	48	52.0	32.5	62.5
B09	37.3	93	40	33.6	8.1	24.3
B10	36.6	71	32	33.0	8.8	26.6
B11	47.5	87	37	42.7	9.7	22.7
B12	35.8	76	43	32.3	14.4	44.8
B13	49.4	95	45	44.5	11.4	25.7
B14	29.2	0	0	29.2	0.0	0.0
B15	54.3	73	36	48.9	15.0	30.6
B16	42.6	74	24	38.3	5.0	13.2
B17	39.0	0	0	39.0	0.0	0.0
B18	39.8	78	38	35.8	12.3	34.3
B19	37.0	83	32	33.3	13.9	41.8
B20	43.2	101	71	38.9	24.2	62.3
B21	21.8	59	0	19.8	0.0	0.0
B22	40.9	0	0	40.9	0.0	0.0
B23	23.5	0	0	23.5	0.0	0.0
B24	36.7	57	21	33.1	5.5	16.7
B25	32.1	52	16	28.9	3.4	11.7
B26	8.3	13	0	8.3	0.0	0.0
B27	35.3	0	0	35.3	0.0	0.0
B28	33.0	73	38	29.7	11.7	39.4
B29	33.0	64	30	29.7	9.0	30.3
B30	32.0	48	0	31.1	0.0	0.0
B31	27.6	0	0	27.6	0.0	0.0
B32	22.6	0	0	22.6	0.0	0.0
B33	52.1	0	0	52.1	0.0	0.0
B34	51.1	46	0	49.1	0.0	0.0
B35	51.1	0	0	51.1	0.0	0.0
B36	57.5	93	49	51.7	19.8	38.3
B37	18.1	0	0	18.1	0.0	0.0
B38	41.2	67	0	39.1	0.0	0.0
B39	49.4	101	34	44.5	5.8	13.1
B40	40.8	87	6	36.7	0.5	1.4

Table H-1. Barley Sites (cont.)

Site	Y-max	X-max	X-90%max	Y-90%max	Yield Increase	%Yield Increase
E01	35.3	74	28	31.8	5.5	17.5
E02	39.3	34	0	38.6	0.0	0.0
E03	36.8	0	0	36.8	0.0	0.0
E04	38.0	69	0	34.2	0.0	0.0
E06	40.9	101	39	36.8	3.5	9.6
E07	28.7	99	0	24.8	0.0	0.0
E08	41.8	101	57	37.6	14.0	37.1
E09	43.8	101	38	39.4	4.7	11.9
E10	39.5	73	36	35.6	11.7	33.0
E11	30.7	66	29	27.6	6.5	23.4
E13	40.2	46	0	36.8	0.0	0.0
E14	44.4	101	0	41.4	0.0	0.0
E15	29.6	55	6	26.6	0.6	2.4
E17	30.5	0	0	30.5	0.0	0.0
E20	30.0	56	0	29.0	0.0	0.0
E21	35.2	57	11	31.7	1.7	5.5
E22	42.4	84	37	38.2	9.0	23.5
E23	33.8	72	31	30.4	6.9	22.7
E24	23.4	32	0	22.6	0.0	0.0
E25	45.7	74	22	41.1	5.1	12.3
E26	31.5	73	8	28.3	0.9	3.1
E27	33.5	58	17	30.1	3.4	11.2
E29	49.6	74	0	45.2	0.0	0.0
E30	31.8	0	0	31.8	0.0	0.0
E32	36.2	65	27	32.6	7.2	22.3
E33	37.5	101	68	33.8	10.7	31.7
E34	29.7	39	0	28.7	0.0	0.0

Table H-1. Barley Sites (cont.)

Site	Y-max	X-max	X-90%max	Y-90%max	Yield Increase	%Yield Increase
L01	25.8	0	0	25.8	0.0	0.0
L03	34.2	0	0	34.2	0.0	0.0
L04	33.0	45	15	29.7	3.6	12.2
L05	35.3	0	0	35.3	0.0	0.0
L06	46.0	34	11	41.4	5.6	13.5
L08	34.2	0	0	34.2	0.0	0.0
L10	34.3	45	20	30.8	7.1	23.0
L11	43.5	44	22	39.1	14.7	37.6
L12	33.8	46	9	30.4	1.7	5.4
L13	48.3	46	12	43.4	3.8	8.7
L14	37.9	38	22	34.1	16.8	49.4
L15	40.1	43	24	36.1	14.1	39.2

Table H-1. Barley Sites (cont.)

Site	Y-max	X-max	X-90%max	Y-90%max	Yield Increase	%Yield Increase
W01	45.9	67	34	41.3	5.9	14.4
W02	43.1	15	0	42.9	0.0	0.0
W03	30.7	0	0	30.7	0.0	0.0
W04	39.5	67	25	35.6	3.8	10.6
W05	39.5	48	0	37.2	0.0	0.0
W06	32.1	60	30	28.9	9.6	33.0
W07	40.1	0	0	40.1	0.0	0.0
W08	34.8	101	11	31.3	0.9	2.8
W09	38.3	101	12	34.5	0.6	1.9
W10	30.5	69	0	27.7	0.0	0.0
W12	41.8	47	0	41.2	0.0	0.0
W13	49.7	94	0	46.0	0.0	0.0
W14	46.7	0	0	46.7	0.0	0.0
W15	46.5	101	36	41.8	6.7	15.9
W16	36.5	48	0	33.7	0.0	0.0
W17	31.9	68	4	28.7	0.5	1.8
W18	41.4	66	19	37.3	3.8	10.2
W19	41.0	0	0	41.0	0.0	0.0
W20	35.7	65	13	32.2	2.0	6.3
W22	31.7	64	0	29.5	0.0	0.0
W23	52.0	99	10	46.8	1.3	2.8
W24	34.2	0	0	34.2	0.0	0.0
W25	42.1	0	0	42.1	0.0	0.0
W26	48.0	58	4	42.4	0.0	0.0
W27	39.4	38	0	37.3	0.0	0.0
W28	32.9	26	0	32.7	0.0	0.0
W29	25.0	82	0	23.0	0.0	0.0
W31	29.9	0	0	29.9	0.0	0.0
W34	28.8	67	19	25.9	2.7	10.5
W36	34.9	60	2	31.2	0.0	0.0
W37	33.0	78	0	31.9	0.0	0.0
W38	43.2	91	0	40.5	0.0	0.0
W41	30.6	35	0	28.4	0.0	0.0
W42	27.0	0	0	27.0	0.0	0.0
W43	49.4	101	25	44.5	1.6	3.5
W44	43.5	64	24	39.1	6.3	16.1
W46	23.7	67	24	21.4	3.3	15.6
W47	29.7	69	8	26.7	0.8	3.1

Table H-1. Barley Sites (cont.)

Site	Y-max	X-max	X-90%max	Y-90%max	Yield Increase	%Yield Increase
T01	32.9	55	25	29.6	7.6	25.5
T02	36.5	0	0	36.5	0.0	0.0
T03	39.9	90	45	35.9	3.9	10.7
T07	43.3	65	0	40.0	0.0	0.0
T08	36.7	90	31	33.1	3.9	11.9
T09	56.9	56	7	51.2	1.5	2.9
T10	52.6	81	13	47.4	2.2	4.7
T12	55.8	90	0	53.6	0.0	0.0

Table H-2. Rapeseed Sites

Site	X-max	Y-max	X-90%max	Y-90%max	Yield Increase	%Yield Increase
B41	72	10.2	32	9.2	2.4	25.6
B42	101	7.6	60	6.9	1.3	19.4
B43	0	4.0	0	4.0	0.0	0.0
B44	67	16.2	35	14.7	5.0	34.4
B45	50	8.0	0	7.2	0.0	0.0
B46	0	12.3	0	12.3	0.0	0.0
B47	56	24.8	19	22.3	3.5	15.6
B48	71	17.8	39	16.0	6.6	41.3
B49	0	10.1	0	10.1	0.0	0.0
B50	71	10.2	31	9.2	2.2	24.4
B51	101	12.7	65	11.3	6.4	56.4
B52	101	21.4	67	19.2	3.1	16.4
B53	53	16.2	16	14.7	1.8	12.2
B54	66	20.3	26	18.3	3.5	19.0
B55	63	17.6	29	15.8	4.5	28.4
B56	101	17.9	65	16.1	9.6	59.7
B57	88	22.5	46	20.8	7.3	34.9
B58	73	16.5	32	14.8	3.7	25.0
B59	67	8.7	31	7.8	2.1	27.1
B60	0	10.2	0	10.2	0.0	0.0
B61	56	4.0	16	3.6	0.3	9.4
B62	101	14.8	64	13.3	5.5	41.2
B63	86	17.6	41	15.9	4.5	28.2
B64	60	7.4	12	6.6	0.4	6.8
B65	46	8.6	0	8.0	0.0	0.0
B66	56	13.4	30	12.1	4.9	40.7
B67	65	10.5	41	9.4	6.8	72.6
B68	92	15.3	54	13.8	7.3	52.8
B69	77	9.2	22	8.3	1.0	12.2
B70	67	9.3	8	8.4	0.2	2.7
B71	0	15.3	0	15.3	0.0	0.0
B72	78	19.4	22	17.5	1.9	10.9
B73	67	25.1	9	22.5	0.8	3.5
B74	82	25.1	32	22.6	4.3	18.8
B75	0	13.2	0	13.2	0.0	0.0
B76	66	22.7	25	20.4	3.4	16.5
B77	0	19.7	0	19.7	0.0	0.0
B78	66	19.0	37	17.1	8.3	48.4

Table H-2. Rapeseed Sites (cont.)

Site	X-max	Y-max	X-90%max	Y-90%max	Yield Increase	%Yield Increase
E37	58	15.3	22	13.9	2.6	18.5
E38	71	16.2	29	14.7	3.1	21.4
E39	101	17.7	21	15.9	0.7	4.2
E40	52	16.9	25	15.2	4.7	30.7
E41	101	24.2	0	22.0	0.0	0.0
E42	58	16.7	24	15.0	3.0	20.1
E44	39	15.8	0	15.0	0.0	0.0
E45	0	16.5	0	16.5	0.0	0.0
E46	101	21.7	17	19.6	0.8	4.0
E47	0	19.6	0	19.6	0.0	0.0
E48	56	13.8	9	12.4	0.7	5.4
E49	0	15.9	0	15.9	0.0	0.0
E53	40	7.5	0	6.9	0.0	0.0
E54	39	11.8	0	11.2	0.0	0.0
E55	49	15.9	0	14.4	0.0	0.0
E57	101	16.8	15	15.1	0.6	3.7
E58	101	20.9	17	18.8	0.1	0.6
E60	76	16.5	21	14.9	1.6	10.5
E61	81	14.7	45	13.2	5.9	44.9
E62	55	13.4	3	12.1	0.2	1.9
E63	101	12.5	59	11.3	4.6	40.6
E64	101	18.7	25	16.8	0.8	4.7
E65	67	15.9	31	14.3	3.8	26.6
E66	84	10.2	43	9.2	3.1	34.1

Table H-2. Rapeseed Sites (cont.)

Site	X-max	Y-max	X-90%max	Y-90%max	Yield Increase	%Yield Increase
L48	39	12.0	11	10.8	1.1	10.4
L49	41	13.3	13	12.0	1.6	13.1
L50	0	17.7	0	17.7	0.0	0.0
L51	0	22.2	0	22.2	0.0	0.0
L52	29	16.0	2	14.3	0.2	1.6
L53	0	11.5	0	11.5	0.0	0.0
L54	50	15.9	38	14.3	6.8	47.7

Table H-2. Rapeseed Sites (cont.)

Site	X-max	Y-max	X-90%max	Y-90%max	Yield Increase	%Yield Increase
W49	38	9.5	0	8.6	0.0	0.0
W50	18	3.8	0	3.7	0.0	0.0
W52	0	11.2	0	11.2	0.0	0.0
W53	57	14.6	0	13.6	0.0	0.0
W54	59	13.2	26	11.9	2.7	22.6

Table H-2. Rapeseed Sites (cont.)

Site	X-max	Y-max	X-90%max	Y-90%max	Yield Increase	%Yield Increase
T19	30	15.7	0	14.4	0.0	0.0
T20	24	14.2	0	13.9	0.0	0.0
T21	29	12.8	0	12.3	0.0	0.0
T22	0	10.2	0	10.2	0.0	0.0
T17	0	6.7	0	6.7	0.0	0.0
T18	20	18.8	0	18.3	0.0	0.0
T13	0	8.7	0	8.7	0.0	0.0
T14	78	2.6	48	2.4	1.6	66.7
T15	69	6.6	37	5.9	2.5	41.5
T16	27	9.5	0	9.2	0.0	0.0
T26	0	14.1	0	14.1	0.0	0.0
T27	56	4.6	0	4.5	0.0	0.0
T28	0	3.9	0	3.9	0.0	0.0
T29	90	9.1	0	8.8	0.0	0.0
T30	7	12.2	0	12.2	0.0	0.0
T31	0	12.2	0	12.2	0.0	0.0
T32	0	14.4	0	14.4	0.0	0.0

Table H-3. Wheat Sites

Site	Y-max	X-max	X-90%max	Y-90%max	Yield Increase	%Yield Increase
J01	20.6	115	30	18.6	1.8	9.6
J02	22.7	95	31	20.4	2.8	13.7
J03	20.3	134	106	18.3	5.7	31.3
J04	23.7	0	0	23.7	0.0	0.0
J06	37.4	35	0	36.1	0.0	0.0
J07	32.1	46	17	29.0	4.9	17.0
J08	23.7	84	50	21.3	4.5	21.1
J09	29.9	68	0	28.0	0.0	0.0
J10	34.3	0	0	34.3	0.0	0.0
J11	20.6	60	27	18.6	4.6	24.7
J12	25.5	52	6	23.0	0.7	2.9
J13	30.9	56	12	27.9	2.1	7.6
J14	26.7	41	20	24.0	7.4	30.8
J15	22.1	67	41	19.8	3.9	19.8
J16	31.0	67	44	27.9	3.1	11.2
J17	27.3	41	17	24.5	4.7	19.2
J18	37.6	54	28	33.8	13.3	39.4
J19	26.0	63	13	23.4	1.6	6.7
J20	22.6	67	21	20.4	2.4	11.5
J22	28.7	0	0	28.7	0.0	0.0
J23	27.8	0	0	27.8	0.0	0.0
J24	32.3	67	50	29.0	10.6	36.7
J25	16.1	47	16	14.4	2.0	14.0
J26	24.1	67	34	21.6	3.6	16.6
J27	19.5	67	15	17.5	0.7	3.8
J28	22.0	55	29	19.8	7.4	37.3
J29	32.9	43	1	29.7	0.2	0.8
J30	40.1	41	0	38.9	0.0	0.0
J31	36.0	44	0	33.4	0.0	0.0
J32	33.2	67	7	29.9	0.8	2.6
J33	29.3	0	0	29.3	0.0	0.0
J34	22.8	41	0	20.6	0.0	0.0
J35	34.5	58	26	31.1	7.2	23.0
J36	24.5	21	0	23.0	0.0	0.0
J37	33.8	38	12	30.5	4.0	13.2
J38	14.7	67	0	14.4	0.0	0.0
J39	36.0	31	0	33.8	0.0	0.0
J40	37.4	67	19	33.7	3.2	9.6

APPENDIX I

Effect Coding of Site Classification Systems

Table I-1. Barley Sites

Agro-climatic Area

	D1	D2	D3	D4
1	1	0	0	0
2A	0	1	0	0
2H	0	0	1	0
3H	0	0	0	1
3Ha	-1	-1	-1	-1

Soil Zone

	D1	D2	D3	D4
Gray	1	0	0	0
Black	0	1	0	0
Dark Gray	0	0	1	0
Dark Brown	0	0	0	1
Thin Black	-1	-1	-1	-1

Soil Order

	D1	D2	D3
Chernozemic	1	0	0
Luvisolic	0	1	0
Solonetzic	0	0	1
Gleysolic	-1	-1	-1

Table I-2. Rapeseed Sites

Agro-climatic Area

	D1	D2	D3	D4
1	1	0	0	0
2A	0	1	0	0
2H	0	0	1	0
3H	0	0	0	1
3Ha	-1	-1	-1	-1

Soil Zone

	D1	D2	D3	D4	D5
Gray	1	0	0	0	0
Black	0	1	0	0	0
Dark Gray	0	0	1	0	0
Dark Brown	0	0	0	1	0
Brown	0	0	0	0	1
Thin Black	-1	-1	-1	-1	-1

Soil Order

	D1	D2	D3
Gleysolic	1	0	0
Luvisolic	0	1	0
Solonetzic	0	0	1
Chernozemic	-1	-1	-1

Table I-3. Wheat Sites

Agro-climatic Area

	D1
1	1
2A	-1

Soil Zone

	D1	D2
Black	1	0
Dark Brown	0	1
Thin Black	-1	-1

Soil Order

	D1
Chernozemic	1
Solonetzic	-1

APPENDIX J

Calculation of Total Discriminatory Power

Total Discriminatory Power[1]

$$TDP = 1 - (N / (N - K) (1 + \lambda) + 1)$$

N = Total Sample Size

K = Number of Groups

λ = Eigenvalue

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[1] Reference: Tatsuoka, 1970