Phosphorus fertilization of newly cleared soils in interior Alaska
by Barbara Jean Pierson

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Soils
Montana State University

Abstract:

Agriculture in Interior Alaska has become more extensive since the mid 70'S when land was released for development by the State of Alaska to stimulate the industry. Agricultural research in Interior Alaska has relied primarily on current technology and methodology of Canada, Scandinavia, and the "lower 48" of the United States.

Ongoing research of the University of Alaska evaluates conservation tillage systems in barley production. Newly cleared soils of Interior Alaska are highly susceptible to wind and water erosion and conservation tillage systems must be adapted for Alaskan agriculture.

Within the scope of conservation tillage research, fertilizer application is of major concern. A two year study was initiated to evaluate phosphorus fertilizer application on a newly cleared soil. Two methods of application and five rates of application were evaluated. Residual effects of the fertilizer application were examined during the second year of the study.

Based on two growing seasons, a minimal application of 10 kg P/ha is necessary to provide adequate phosphorus for normal crop production following land clearing operations. Application of fertilizer phosphorus in excess of 10 kg P/ha may be beneficial for higher yields. Application of phosphorus by using Broadcast or Banded methods provided adequate placement of fertilizer at the time of seeding. Soil phosphorus levels after the first growing season were significantly higher in soils that received higher rates of phosphorus fertilizer, however, these higher levels did not contribute to higher yields in the second growing season.

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APPROVAL

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Barbara Jean Pierson

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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Date June 21, 1985

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ABSTRACT

Agriculture in Interior Alaska has become more extensive since the mid 70's when land was released for development by the State of Alaska to stimulate the industry. Agricultural research in Interior Alaska has relied primarily on current technology and methodology of Canada, Scandinavia, and the "lower 48" of the United States.

Ongoing research of the University of Alaska evaluates conservation tillage systems in barley production. Newly cleared soils of Interior Alaska are highly susceptible to wind and water erosion and conservation tillage systems must be adapted for Alaskan agriculture.

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INTRODUCTION

Agricultural production has historically contributed little to Alaska's economic base and was not really a factor in statewide development. The 70's marked the beginning of the age of the Trans-Alaska pipeline. Oil revenues have provided financial means to encourage development in various sectors of the state's economy. In 1978, legislative mandate released 23,000 hectares (58,000 acres) of state land for purchase by qualified lottery applicants for agricultural development. This large scale "Agriculture Project" was the beginning of a state sponsored venture to establish a successful agricultural economy. Since this initial project was started, 10,000 additional hectares (24,000 acres) of state land have been released for agriculture purposes.

Small-scale agricultural operations existed before this recent push toward a stable Alaskan agricultural economy. These small farms became the stepping stones toward larger, more intensive methods of production. Cereal grain production on large farms (1000-1200 ha) involves assessment of 1)crop nutrition requirements, 2)availability of cost effective fertilizers, 3)proper application rates, and 4)timeliness of fertilizer application. Prior knowledge of grain production from the Midwestern and Great Plain states and Canadian provinces has proven to be helpful for Alaskan conditions, but Alaskan agriculture has unique conditions deserving additional attention and research.

Growing seasons in Interior Alaska are typically shorter and cooler than areas of small grain production in the "lower 48". Soils identified as those of agricultural potential are relatively colder and wetter than most soils of dryland agriculture. Field research with Alaskan soils is gradually beginning to provide fertilizer response data which may provide a basis for fertilizer recommendations for Alaskan soils.

A critical problem of high erodibility exists with the majority of Alaskan soils cleared for agriculture production. Newly cleared soils are silty, poorly aggregated and lack surface roughness. Plant residues remaining after clearing operations are not sufficient to reduce erosion damage during seasonal high prevailing winds. Conservation tillage systems are encouraged by state and federal agricultural agencies to reduce erosion losses. Research priority is given to fertilizer management appropriate for conservation tillage and the unique conditions of Interior Alaska.

The objectives of this study were to address phosphorus fertilization in barley production on soils which have been recently cleared of native vegetation and are destined for small grain production. The affect of phosphorus fertilizer in barley production was evaluated with two different methods of application and five rates of application. The second year of the study examined the possible residual effect of the fertilizer application from the previous year.

LITERATURE REVIEW

Soil Phosphorus Essentiality and Availability

Phosphorus is a nutrient indispensable for all forms of life and often becomes a life-limiting factor in natural systems due to low availability (Ozanne, 1980). Phosphorus functions as a key element in energy transfers via adenosinetriphosphate (ATP) and in genetic transformations associated with ribonucleic acid (RNA). The majority of phosphorus in the natural system is present in the soil. Soil phosphorus (P) can be described by the following equilibria:

$$\text{Soil solution P} \rightleftharpoons \text{Labile soil P} \rightleftharpoons \text{Nonlabile soil P}$$

True equilibrium rarely is established between nonlabile P and labile soil P, yet equilibrium is rapidly established between soil solution P and labile soil P (Olsen and Khasawneh, 1980). Soil solution P is the medium from which the plant obtains phosphorus. Researchers have described the relationship between plant uptake and soil solution phosphorus as an intensity factor. (Tisdale et al.,1985; Kamprath and Watson, 1980; Olsen and Khasawneh, 1980). The intensity factor describes the amount of phosphorus in soil solution available for plant uptake. Labile soil P, from which the soil solution is replenished, is described as the quantity factor. The quantity factor can be used as an indication of how much phosphorus is available to move from the labile phase to soil solution.

Besides attempting to measure quantity and intensity of soil phosphorus, it is important to understand the movement of phosphorus to the root surface. Plant phosphorus uptake by roots removes phosphorus from soil solution immediately surrounding the root. Phosphorus concentrations are greater away from this zone of depletion and a concentration gradient is established at the root surface. Diffusion becomes the primary mechanism moving phosphorus to the root. (Barber, 1980). The replenishment of phosphorus in solution is regulated by the equilibria between labile soil P and solution phosphorus (Holford, 1980).

The equilibria of soil phosphorus are affected by depletion of soil solution phosphorus by 1) uptake of the growing plant, 2) adsorption of phosphorus in solid phase, and 3) factors changing or maintaining diffusion mechanisms.

Plant uptake of phosphorus is primarily in the form of primary ($H_2PO_4^-$) or secondary ($HPO_4^=$) orthophosphate ions present in soil solution (Olsen and Khasawneh, 1980). Bieleski (1973) has shown primary orthophosphate is taken up faster than secondary orthophosphate. This work proves a large concentration gradient exists between root xylem tissue and soil solution and phosphorus is accumulated in plant tissue. Inorganic phosphorus is 20-100 times more concentrated in xylem tissue than in soil solution.

Research with hydroponically grown barley (Green et al., 1973) proved that transpirational uptake and accumulation occurs across the concentration gradient between the root tissue and soil solution. Unless there is active movement across this concentration gradient, plant uptake is explained by nutrient transport in water associated with the transpirational demands of the plant.

Barber (1980) outlined conditions affecting phosphorus uptake by plant roots as follows: 1) change of phosphorus absorption with the age of plant, 2) age and morphology of lateral and seminal roots, and 3) soil depth, i.e. anything affecting root penetration such as soil structure, soil, soil temperature, fertility and water relations.

Adsorption of phosphorus in the solid or labile phases of soils has often been referred to as "fixation". The definition of fixation includes precipitation reactions of phosphorus as well as adsorption reactions (Tisdale et al., 1985). In slightly acid soils, adsorption reactions involve primarily iron and aluminum hydrous oxides. These reactions affect the overall equilibrium of soil phosphorus in varying degrees depending on: 1) length of time for reaction to take place, 2) temperature, 3) pH, and 4) concentration of phosphorus in solution. These reactions with iron and aluminum are relatively fast when taking place on the surface of hydrous oxides (Ibrahim and Pratt, 1982). Adsorption of phosphorus on other soil surfaces is relatively slower and subject to other cation and anion competition.

Fixation and retention are frequently used synonymously in regard to soil phosphorus reactions. Fixation collectively includes retention reactions at soil surfaces (adsorption) and chemical precipitation of phosphorus from soil solution. Phosphorus retention has been explained by many researchers by using an either/or approach toward adsorption reactions or precipitation reactions (Sample et al., 1980). Regardless of precise mechanism, retention will affect phosphorus availability.

Soil organic matter plays a significant part in phosphorus equilibria reactions. Bloom (1981) has shown that organic matter has a high affinity for phosphorus in low pH environments. Work by Black and Reitz (1972) has proven wheat straw incorporated in the soil immobilizes phosphorus. Mineralization of organic phosphorus may benefit subsequent crop production. Organic matter and the association with calcium, iron, and aluminum ions will definitely have an impact in equilibria reactions (Sample et al., 1980).

Soil texture is a major factor affecting water holding capacity of soils. At a specfic water content, the thickness of water films and total amount of water for solution is generally controlled by soil texture. Phosphorus diffusion in soils of differing texture depend on 1) concentration gradients between soil solution and root surfaces, 2) equilibria reactions between solution phosphorus and solid phase phosphorus and, 3) diffusion coefficients. (Olsen and Watanabe, 1970). Subsequent work by Mahtab et al., (1972) confirmed the influence that soil water content of different soil textures affects diffusion of phosphorus. Their work also recognizes the movement of phosphorus from the labile solid phase to replenish soil solution. This work further indicates the importance of proper fertilization on dry or droughty soils. Clayey soils have less tendency towards phosphorus deficiency in dry conditions than sandy soils.

Additional work has been done relating phosphorus nutrition and plant water requirements (Follett and Reichman, 1972; Matar, 1977; Sharpley and Reed, 1982). Their work indicates low soil water content becomes a very important factor influencing plant growth and subsequently phosphorus uptake. Movement of phosphorus through soil solution under these conditions may not be due to diffusion, but rather plant transpirational demands. Boatwright and Viets (1966) linked adequate phosphorus nutrition and soil water during the early stages of growth as a critical period in order to realize optimal yield. Phosphorus availabiltiy early in the season may be sufficient for plant growth and adequate development. Phosphorus fertilizer recommendations for phosphorus deficient soils in areas of inadequate soil moisture may require adjustment.

Phosphorus available to the root via diffusion is not only affected by soil moisture, but also tortuosity, and temperature. The tortuosity of the diffusion path depends on the thickness of the water films and the fineness of the soil particles (Barber, 1980). The supply of phosphorus to the root by diffusion will be affected by temperature related factors of solution viscosity and solubilization. Power et al., (1970) have provided evidence of reduced growth rate of barley at lower temperatures with phosphorus solubility unaffected. This is not directly affecting diffusion, but reflecting changes in the concentration gradient created by the growing plant responding to temperature. Their work suggests that increased levels of phosphorus fertilizer provides greater flexibility in cool temperature regimes of the Northern Great Plains. This implies adequate phosphorus nutrition allows the plant greater tolerance in regions of cool soils. Research by Michaelson et al., (1984) supports the conclusion that low soil temperatures of Interior Alaska may reduce phosphorus availability.

Another factor affecting phosphorus availability is the transformations of organic soil phosphorus to available inorganic ions. Characterization of soil phosphorus is a difficult process primarily due to the readsorption reactions taking place during extraction procedures for organic and inorganic phosphorus (Tiessen et al., 1984).

Their research involved soils of differing pedogenesis. One soil order they studied was an Ultisol, which is highly developed, with low organic matter, and delivers available phosphorus mostly from the labile inorganic phase. Their study indicates moderately developed soils, such as Mollisols, have stable reservoirs of organic matter from which organic phosphorus may be mineralized. The study of soils with little or no development and various levels of organic matter may introduce unique questions of phosphorus availability.

A summary of phosphorus use in the soil-plant system is found in a model projected by Scaife and Smith (1973). (Figure 1). Although their work was on phosphorus requirements of lettuce, it provides an excellent illustration of the path of phosphorus utilization in plants.

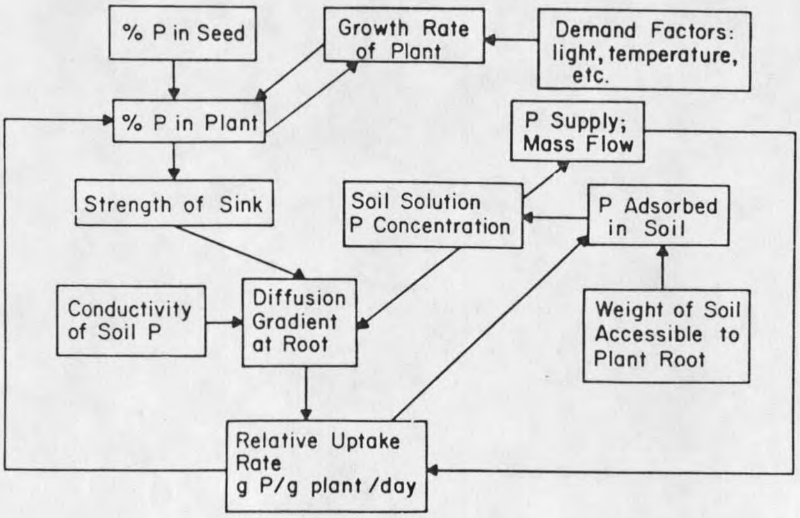

Figure 1. Diagram of a model indicating relationships of the different processes involved in plant growth and phosphorus utilization. (Scaife and Smith, 1973)

In using this model for other plant species, it is important to realize differences come from seed size, root morphology, growth rate, tolerance to low phosphorus concentrations, yield potentials and crop requirements.

Phosphorus Fertilization

Phosphorus requirements for small grain cereal production vary slightly depending on local conditions. Crop requirements for average yields from the Northern Great Plains, Northern Scandinavia, and England range from 11 kg P/ha (27 kg P_2O_5/ha) to 15 kg P/ha (34 kg P_2O_5/ha)(Greenwood et al., 1980; Anon., 1981; Russell, 1973; Lyngstand and Stabbetorp, 1981). These requirements are based on the amount removed by the plant during the period of growth. Recommendations for phosphorus fertilization should consider these basic requirements in addition to local factors affecting availability.

Fertilizer recommendations must be made with consideration of cropping systems. In conservation tillage systems, as well as conventional systems, nutrient cycling has been of specific importance in development of fertilizer recommendations (Ritchie and Follett, 1983). Plant residue accumulation in conservation tillage systems may have significant impact on nutrient cycling (Black and Reitz, 1983; Holt, 1979; and Larson, 1979). Several researchers have identified nutrient cycling of essential nutrients, including phosphorus, as foremost in assessing fertilizer management recommendations in reduced tillage and conservation tillage systems (Carter and Rennie, 1982; Parr et al., 1983; and Ritchie and Follett, 1983).

Conventional fertilization methods in small grain production have generally included phosphorus fertilization in the same operation as seeding. This process places fertilizer in close proximity to the seed during seeding operations. Localized placement of phosphorus may have advantages for early growth following germination. Phosphorus placed in a restricted band at the time of seeding will reduce soil-fertilizer contact and retention reactions (Tisdale et al., 1985). In greenhouse studies, phosphorus was placed in a band and contrasted with a broadcasted treatment (Sleight et al., 1984). These researchers contend placement of phosphorus near the growing plant root has advantages due to improved root-fertilizer contact and not due to improved availability obtained from decreased soil-fertilizer contact and reduced retention. In contrast to these observations, it has been noted that root growth and root proliferation might be suppressed by the restricted placement of nitrogen and phosphorus placement (Drew, 1975; Barrow, 1980). Plants growing in this restricted zone may not be required to explore beyond the zone of fertilizer placement.

Placement of phosphorus fertilizer is especially important in conservation tillage systems. Plant access to fertilizer amendments may vary due to changes in moisture and temperature regimes due to crop residue accumulation (Klepper et al., 1983; Murphy, 1983). Current research strongly suggests placement of fertilizers with or below the seed or incorporation of fertilizer with limited tillage (Fenster, 1977). New developments in fertilizer placement are forthcoming as conservation tillage systems become common.

Evaluation of Residual Soil Phosphorus

The previous discussion of equilibria affecting phosphorus availability introduced the nonlabile, labile, and solution phases of soil phosphorus. Reactions affecting these solid and solution phases are of key importance in assessing the amount of residual phosphorus remaining from previous fertilization. Fractionation of all soil phosphorus is essential to begin to estimate the effect of residual soil phosphorus (Hedley et al., 1982). The buffer capacity of individual soils is also necessary to evaluate labile soil phosphorus (Probett and Willett, 1983; McIntosh, 1968; Holford, 1979, 1980b). These researchers studied the sensitivity of extractants in measuring labile soil phosphorus. Extractants of the Bray-I (NH_4F and HCl) test used in slightly acid soils do not accurately remove phosphorus from the labile pool. Measurement of labile soil phosphorus reflects the "sink" for residual phosphorus and accurate measurement of this labile pool would indicate soil phosphorus equilibria changes.

In addition to accurate measurement of the labile phosphorus, it is necessary to estimate the buffer capacity of the soil to completely evaluate residual phosphorus. Soil buffer capacity characterizes the dynamic relationship between soil phosphorus in solution and the labile solid phase (Holford, 1979; Holford, 1980b). Buffer capacity refers to the ability of the phosphorus concentration or intensity of soil solution to resist change when phosphorus is added or removed from solution. The equilibria reactions of soil solution phosphorus and labile phosphorus proceed according to the degree of buffering. Holford has shown a measure of labile soil phosphorus and buffer capacity provides explanation for the wide variance in plant uptake in various soils. Changes in phosphorus uptake by plants was attributed to buffer capacity and diffusion characteristics (Olsen, et al., 1983).

Several years of experimentation are essential to make recommendations for phosphorus fertilization based on residual phosphorus. Several researchers have found response to phosphorus fertilization based on residual effects (Alessi and Power, 1980; Ridley and Tayakepisuthe, 1974; and Spratt et al., 1980; Nosko, 1983). Research of several years of production indicates reduced phosphorus recovery by the plant as soil phosphorus levels increased. Phosphorus recovery was calculated from phosphorus content of grain from fertilized plots of known fertilizer input. The levels of soil phosphorus increased with applied fertilizer, but apparently plant availability did not. It may be important to apply a critical phosphorus level each year for greatest efficiency. Luxurious consumption by wheat, in excess of a critical level may have been observed on soils studied by Alessi and Power (1980). A critical level is reached when no response is obtained from additional application of fertilizer. McLean et al., (1982) support fertilizer recommendations based on a critical level indicated by the appropriate soil test method for independant locations.

Soil test values for extractable phosphorus and labile phosphorus are dependant upon local environments. Recent innovations have improved correlations between plant available soil phosphorus and soil test values. Flow injection analysis is a technique developed in Europe which avoids a mechanical disturbance which affects duration of adsorption reactions. Electroultrafiltration (EUF) may also prove important in assessing conventional soil phosphorus tests (Nemeth and Recke, 1982). Anion exchange resins (AER) have been used successfully in correlating phosphorus uptake on previous highly fertilized soils (Adepoju et al., 1982).

Models have been developed to evaluate residual soil placed in each facet of a mathematical model to understand synergistic effects. Reactions of residual soil phosphorus take place over several years and sophisticated models must include this essential time factor.

Soil Phosphorus Availability as Affected by Vesicular Arbuscular Mycorrhiza

Nutrient availabilitiy has been enhanced in natural and agricultural systems by the presence of mycorrhizal populations (Molina et al., 1978). Several species of endotrophic and ectotrophic mycorrhizal fungi exist symbiotically within several host species. Endotrophic mycorrhiza are distinguished from ectotrophic by the location of threadlike hyphae. Endotrophic hyphae penetrate epidermal and cortex cells of the living root (Alexander, 1977). Endotrophic mycorrhiza are frequently referred as vesicular arbuscular mycorrhiza (VAM) because of the presence of vesicles and arbuscles in the hyphal structure.

Most research with VAM and nutrient uptake enhancement has specifically dealt with phosphorus. Hyphae extending from the root is capable of exploring a greater volume of soil. Phosphorus in the soil may be reached by VAM which was unavailable to the root without VAM association. Phosphorus fertililization studies have evaluated the effectiveness of VAM in aiding phosphorus uptake (Gray and Gerdeman, 1969; Daft and Nicolson, 1969). These studies have shown existing mycorrhizal populations promoted plant growth when less soluble forms of phosphorus are applied, e.g. rock phosphate and tricalcium phosphate. More soluble forms of phosphorus seem to reduce hyphae penetration in the root.

Research by Black and Tinker (1977) suggest VAM infections in soil are affected in various degrees in continuous barley production. Maintenance of existing mycorrhizal population may provide greater uptake efficiency of soil phosphorus (Hall et al., 1977). Maintenance or inoculation of those plants with a confirmed VAM association may be considered important when assessing soils of high phosphorus retention capacities (Jackson et al., 1972).

The ultimate productivity of any ecosystem involves a dynamic relationship of all factors affecting biological functions. Within the soil ecosystem, microorganism populations are present in recognizable quantities. Attempting to understand a segment of this population, vesicular arbuscular mycorrhiza, may prove fruitful in soil phosphorus availability.

MATERIALS AND METHODS

Soils of the study area are classified in the Beales series. They are mixed, Typic Cryochrepts (SCS, 1973). They are located on stabilized deposits of loess on large glacial outwash plains. Surface horizons of cleared areas are silt loam ranging in thickness from 8 cm to 25 cm (3 - 10 in). Subsurface horizons vary from loamy fine sand to fine sand and are underlain by stratified coarse sand and gravel at a depth of 90 cm to 120 cm. All horizons are micaceous and the pH ranges from moderately acid (pH 5) in surface horizons to less acid (pH 6) in subsurface horizons. Mottling is present in lower horizons. Other series associated with Beales soils are Nenana, Chena, and Volkmar. These differ in depth of silt loam and fine sand horizons, depth to gravel, and degree of mottling. They are all highly susceptible to wind erosion when cleared of native vegetation.

In this study, two methods of fertilizer application were implemented by use of grain seeding equipment specifically designed for conservation tillage applications. Two growing seasons were evaluated. During the 1983 growing season, barley growth was the indicator of the effects of different phosphorus fertilizer rates and method of application. During the 1984 growing season, the effects of the prior year's fertilization were evaluated to determine if residual soil phosphorus is effective for subsequent crop growth. This study placed emphasis upon evaluation of "no-till" seeding equipment in barley production.

The study area for this project is approximately 170 km southeast of Fairbanks, Alaska (Figure 2.) and lies adjacent to the Delta Agricultural Project. The area was initially cleared in December, 1978. Native vegetation consisted primarily of black spruce [*Picea mariana* (Mill.) Britt., Sterns and Pogg], aspen [*Alnus crispa* (Ait.) Pursh.], and understory species of crowberry (*Empetrum nigrun L.*), sedges (*Carex spp.*), grasses [*Agrostis spp.* and *Calamagrostis canadensis* (Michx.) Nutt.] and mosses (*Sphagnum spp.*). The overstory vegetation was "chained" by means of a heavy length of chain connecting heavy track equipment moving parallel. The debris which had been chained was pushed into debris piles. This entire chaining operation was usually accomplished during the winter months and before spring thaw of subsurface soil horizons. While the mineral horizons are frozen, the organic horizons and understory vegetation was easily pushed into the large piles of debris. In 1980 , the site was root raked twice. Loose debris was raked together and placed in debris piles to allow normal cultivation practices on cleared areas. Prior to the first season of this study, the entire area was lightly tilled with a disc to prepare an adequate seedbed. Spring 1983 marked the beginning of the first cropping season for this area.

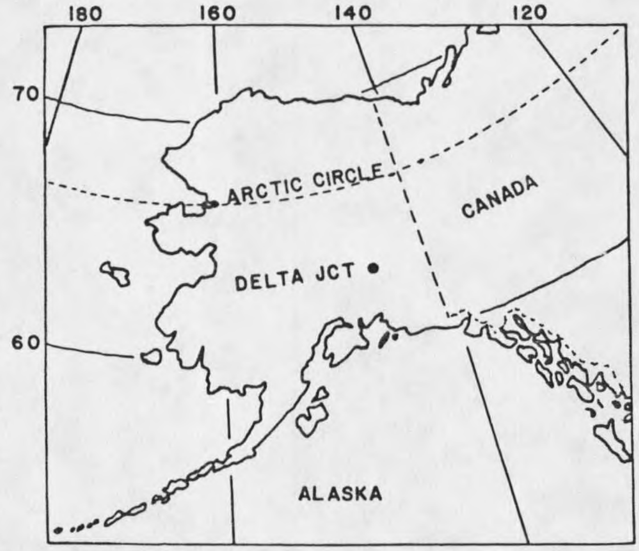

Figure 2. Location of the Delta Agricultural project near Delta Junction, Alaska.

1983 Growing Season

Before fertilization, soil samples were taken randomly across the study area. A Oakfield soil probe was used to sample to a depth of 0-15cm (0-6in). Eight cores per sample were composited and analyzed for NO_3-N, NH_4-N, P, K, Ca, Mg, Fe, CEC, % clay, % organic matter, and soil pH. Nitrogen (nitrate-N and ammonium) was extracted by 2N KCl (Bremner, J.M., 1979); phosphorus determined by Bray P-I(Olsen and Dean, 1979); potassium, calcium and magnesium by 1N NH_4OAc extraction (Pratt, P.F., 1979); iron by EDTA extraction (Olsen, 1979); CEC by NaOAc (Chapman, 1979); texture by Bouyoucous hydrometer (Day, 1979); % organic matter by Walkley-Black (Allison et al., 1979) and; pH of 1:1 soil-water.

On 5 May, a fertilizer blend of urea, muriate of potash, and ammonium sulfate was uniformly broadcast over the study area. The blend was applied to deliver 34 kg N/ha, 0 kg P/ha, 23 kg K/ha and 11 kg S/ha (75 lbs N/ac, 0 lbs P_2O_5/ac, 60 lbs K_2O/ac, and 24 lbs S/ac). Following this application, the entire study area was lightly disced.

Two grain seeding implements were calibrated to deliver 90 kg/ha (80 lbs/ac) of pure live seed. The variety of barley was "Lidal", a variety developed from the barley breeding program in Alaska. The grain seeding implements were calibrated to deliver five different levels of fertilizer at the time of seeding. Five fertilizer treatments included ammonium nitrate and triple superphosphate which delivered the following levels of nitrogen and phosphorus:

kg N/ha	(lbs N/ac)	kg P/ha	(lbs P_2O_5/ac)
10	(8.9)	0	(0)
10	(8.9)	10	(20)
10	(8.9)	20	(41)
10	(8.9)	40	(82)
10	(8.9)	80	(164)

One seeding implement placed the fertilizer directly with the seed (Banded treatment) via double-disc openers immediately followed by heavy press wheels. The other seeding implement broadcasted the seed and the fertilizer after a gang of one-way discs turned the soil (Broadcast treatment). This treatment resulted in random distribution of seed and fertilizer instead of distinct rows. The operation was followed by a "Brillion" packer which firmed the seedbed. Seeding the plot area was complete 18 May. Each plot measured 3.6m X 22.2m (12' X 72'). Four replications were seeded in a randomized block design.

On 15 June, a plant count was taken of each plot to compare plant establishment. It was noted during this measurement that the Broadcast treatments tended to have seed placed deeper than the desired 4 cm depth.

On 21 June, access tubes for neutron probe moisture measurements were placed in four plots of one replication. Earlier installation of these access tubes was prohibited by shallow depth of frost. The frost depth averaged 90 cm (3 ft) during the last week of June.

Broadleaf weeds were sprayed on 22 June with 24 ml/ha of bromoxynil. Good control of annual weed species was obtained. Perennial species were slightly affected.

Plant tissue samples were taken at late tillering (Stage 5 - Feekes scale) on 28 June. Samples were cut at ground level from a 625 cm^2 area. A frame measuring 25cm X 25cm was placed over two drill rows in random locations in the Banded treatments. The frame was placed randomly in the Broadcasted treatments. Three samples were cut from each plot on every replication. The samples were oven dried at 60°C, weighed and analyzed for total phosphorus content by using an acid digest method (Steckel and Flannery, 1971).

At the same growth stage, an additional sampling of plots was made to determine plants per plot and tillers per plant. An assessment of root development and vigor was also made at this time. On one replication, five samples were taken. Each sample area measureda 625 cm^2. Plants and tillers were counted. Assesment of roots was made by giving each root sample a rating based on a scale of 1 to 5. A rating of 1 was given to few roots easily separated from soil. A rating of 5 was given to a sample with many fibrous roots difficultly separated from soil. Intermediate ratings were given based on their appearance relative to a 1 or 5 rating.

Soil samples were taken at this growth stage over all plots. Eight cores were randomly taken from each Broadcast treatment application to a depth of 15 cm. These eight samples were composited. Core samples were taken within the barley row and also between the row on the Banded treatment plots. Samples were analyzed for available phosphorus using the Bray-I method.

Plots on one replication were sampled for dry matter production on 20 July. Five samples were cut from each plot. The sample area measured 625 cm^2. Samples were oven dried at 60° C and weighed.

Barley inflorescences were cut on 5 Aug and percent moisture was determined. Awns were removed before samples were weighed and dried. Identical samples were taken on 11 August, 19 August, 3 September, and 14 September. This procedure was used to measure percent moisture as an indication of degree of maturity.

Plots were harvested on 1 September by clipping three one square meter samples per plot. Samples were clipped at the soil surface, bagged and transported to Fairbanks where each sample was weighed and threshed. Grain and straw subsamples were taken from harvest samples and analyzed for percent total phosphorus and percent total nitrogen.

1984 Growing Season

Soil samples were taken on 9 May from each of the plots established in 1983. Eight cores per plot were composited. Soil at 0-7 cm (0-3 in) and 7-15 cm (3-6 in) depths were sampled and analyzed for available phosphorous.

A uniform broadcast fertilizer application of 27 kg N/ha, 29 kg P/ha, and 56 kg K/ha (80 lbs N/ac, 60 lbs P_2O_5/ac, and 60 lbs K_2O/ac) was inadvertently applied over the entire plot area prior to seeding.

The seeding design for the second year of this study included direct no-till seeding into the stubble remaining over winter after the 1983 crop. The plots were seeded by the double disc no-till drill with two different fertilizer blends. Both blends included 10 kg N/ha (8.9 lbs N/ac). In one blend, 10 kg P/ha (8.9 lbs P/ac) was included. No phosphorus was included in the second blend. One half of each plot from the 1983 design received fertilizer without P and the remainder received fertilizer with P at the time of seeding. Seeding rates and barley variety remained identical to 1983 season. Seeding operations were complete 10 May and barley emerged 12 days later.

On 30 May, isolated grassy areas within plots were sprayed with glysophate at a rate of 40 ml/ha. Care was taken to avoid healthy barley plants by using a hand held sprayer and walking across the entire plot area.

Plant samples were collected at tillering (Stage 5-Feekes scale, 20 June) by cutting 1m of row at the soil surface. These were oven-dried at 60^{o} C, weighed and analyzed for percent phosphorous. Soil samples were taken adjacent to the plant sample at depths of 0-7 cm and 7-15 cm (0-3 in and 3-6 in). Soil samples were analyzed for available phosphorous.

On 13 July, a sample was made of each plot similar to the sample taken during tillering on 20 June. The barley was at Stage 10.2-Feekes scale, flowering. Percent total phosphorus was determined from these plant samples.

On 11 August, barley roots were collected on three treatments on one replication. These treatments represented high, medium, and low phosphorus application levels. Soil samples were collected from the same treatments. Soil was collected from a 225 cm^2 area of soil to a depth of 7 cm.

The root samples were examined for vesicular-arbuscular mycorrhizal infection.

All plots were harvested on 30 August by cutting one square meter per plot. These harvest samples were cut at the soil surface, bagged and transported to Fairbanks. The samples were air-dried, weighed, and sub-sampled for straw and grain. Percent total phosphorus and total nitrogen were determined by the acid digest method.

Soil samples were taken from each plot immediately after harvest. Each plot was sampled to depths of 0-7 cm and 7-15 cm (0-3 in and 3-6 in). Eight cores were taken at each depth and composited on each plot. In addition, on one replication, soil samples were taken at 2.5 cm (1 in) increments to a depth of 7.5 cm (3 in). All samples were analyzed for available soil phosphorus.

RESULTS AND DISCUSSION

Table 1 shows general chemical and physical characteristics of the plot area before fertilization. The phosphorus level extracted by the Bray-I procedure indicates a phosphorus deficient soil.

Table 1. Initial soil status

pH	O.M. %	Total N	P	K	Ca	Mg	Al	Fe	clay %	sand %
		ug/g	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g		
5.5	4.8	22.6	5.8	91	832	127	1.2	201	10.8	31.7

1983 Growing Season

Stand establishment counts on 15 June showed differences between treatment at emergence. Plots of the Broadcasted treatments had been observed to have been seeded to a depth of approximately 6.4 cm (2.5 in) and the Banded treatments approximately 3.8 cm (1.5 in) deep. The deep-seeded plants of the Broadcasted treatments were slightly delayed in emerging due to depth of seeding, but there were no significant differences in emergence between phosphorus treatments and method of phosphorus application.

Plots of two phosphorus levels and both methods of application contained access tubes for moisture measurements. Neutron probe measurements beginning in early July indicated no differences in soil moisture content across treatments. During the time of access tube installation, texture variation between horizons at each access tube installation site was observed. Soil textural differences may be so great that soil moisture use by the crop may be difficult to measure.

The first soil samples after fertilization were taken on 6 July (late tillering) and showed that the treated plots contained more phosphorus than the untreated plots(Table 2).

Table 2. Soil phosphorus levels at tillering, 6 July 1983.

Phosphorus Treatment	Banded	Broadcasted
kg P/ha	ug/g P	
0	7.4	7.2
10	8.1	8.9
20	9.1	8.9
40	11.8	9.2
80	17.2	9.3

Phosphorus Treatment $LSD_{.05} = 2.9$

Method of Application $LSD_{.05} = 1.3$

These samples also indicated that the Banded plots contained significantly more phosphorus than the Broadcast plots, especially at the higher rates of application. This occured inspite of identical application rates in the two methods of application. Two explanations are possible: 1) soil phosphorus levels from the Banded treatment plots were averaged between samples taken between the row and within the row and may have been skewed toward higher values or 2) the dilution and mixing of fertilizer phosphorus in the Broadcast treatments resulted in lower values. A greater difference between phosphorus rates was certainly expected in the Broadcast treatments as was seen in the Banded treatments.

On the one replication sampled, root rating and tiller count provides evidence of phosphorus levels effecting differences in plant growth. Table 3 illustrates these differences. The most notable change across phosphorus levels is the average number of tillers per plant. With Banded treatments, the first increment of applied phosphorus (10 kg P/ha) resulted in the largest difference in tiller development. The Broadcast treatments showed this reponse at 20 kg P/ha and as levels of applied phosphorus increased, tiller count generally increased. This count was made before fertile and nonfertile tillers could be distinguished. Even though high phosphorus treatments may influence tiller production, yield increases at harvest due to tiller numbers were not evident in this study. Differences in root ratings are obvious at the 10 kg P/ha phosphorus application rate in the Banded treatments and both 10 kg P/ha and 20 kg P/ha application rates of the