# THE UNIVERSITY OF MANITOBA

ORGANIC AND INORGANIC PHOSPHORUS CONTENT, MOVEMENT AND MINERALIZATION OF PHOSPHORUS IN SOIL BENEATH A FEEDLOT.

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LYALL B. CAMPBELL

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# ORGANIC AND INORGANIC PHOSPHORUS CONTENT, MOVEMENT AND

# MINERALIZATION OF PHOSPHORUS IN SOIL

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## LYALL B. CAMPBELL

A dissertation submitted to the Faculty of Graduate Studie; of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

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#### ABSTRACT

Studies were conducted to determine the amounts, forms and movement of P in soil beneath a feedlot and to determine the factors affecting mineralization of organic P in the soil. The above studies compared adjacent manured (feedlot) and non-manured (field) sites.

Greater amounts of 0.5 M NaHCO<sub>3</sub> extractable P and water soluble P were found in the surface feedlot soil than in the surface field soil. Phosphorus moved to a depth of about 150 cm in the soil under the feedlot. Concentration of total P in the feedlot soil was usually greater than in the corresponding field soil. The field soil contained more organic P than the feedlot soil, particularly at a depth of 0 to 90 cm. Organic P concentrations at 0 to 15 cm were 268 and 56 ppm for the field and feedlot sites, respectively.

Mineralization of organic P in soil was mainly influenced by the moisture level and was greater under flooded (anaerobic) than field capacity (aerobic) conditions. Application of manure was also necessary for mineralization to occur but its effect was not as pronounced as that of the anaerobic environment. Hence, both a reducing or anaerobic environment and application of manure were essential for significant mineralization of organic P.

Organic and inorganic P moved at about equal rates in soil treated with manure extract. Rates of movement of both decreased with increasing depth in the feedlot soil. The feedlot soil below 30 cm and all of the field soil samples exhibited a high potential for both inorganic and organic P fixation. Organic and inorganic P applied as manure extract moved faster than an equivalent concentration of  $$^{\rm KH}_2$^{\rm PO}_4$ in two field samples studied.$ 

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## INTRODUCTION

The use of land for disposal of manures and the establishment of large feedlots has resulted in a need for studies on the effects of manures on soil and water quality.

Phosphorus content of liquid manure is about 0.31 and 0.49 kg P per 100 1 for beef and dairy cattle, respectively.<sup>1.</sup> If P is not removed from the soil by erosion or crop uptake, it can accumulate to very high amounts in the soil. Very little research has been conducted concerning the effect of manure additions and accumulations on forms and amounts of P or movement of P in soil.

The objective of this study was to investigate the behaviour of P in soils beneath a feedlot. Specific studies conducted were as follows:

determination of the amounts and forms of P in the soils;
 investigation of the effects of moisture level and manure on mineralization of organic P;

(3) investigation of convective transport of organic and inorganicP in soils treated with manure extract.

<sup>1.</sup> Progress Report 1966, Research and Advisory Service, Dept. of Soil Sci., Univ. of Guelph.

## REVIEW OF LITERATURE

## Forms of Phosphorus in Soil

The three principal fractions of soil P are organic P, inorganic P, and P in the soil solution. Organic P accumulates from residues of plants, animals, bacteria, and fungi. Mineral soils generally contain less organic P than organic soils or pasture land (Mattingly and Talibudeen, 1967). Organic P is mainly associated with the clay and silt fractions of the soil and varies from 20 to 90% of total soil P. (Lawton, 1961; Mattingly and Talibudeen, 1967; Spratt and McCurdy, 1966). Fuller and McGeorge (1951a and 1951b) reported that organic P concentrations in a variety of soils were approximately one third of the total soil P concentrations. However, Kurtz (1953) found that most soil P in several soils was in the organic form. Thomas and Lynch (1960) found that organic P concentrations in the A and B horizons of some Alberta soils varied from 109 to 710 ppm and 70 to 333 ppm, respectively.

The five principal groups of organic P compounds in soil are phospholipids, nucleic acids, inositol phosphates, "metabolic" phosphates, and phosphoproteins (Black and Goring, 1953). Amounts of phospholipid P are seldom in excess of three ppm although they can be as high as 34 ppm (Black and Goring, 1953). Nucleic acids constitute 17 to 58% and inositol phosphates 41 to 83% (30 to 149 ppm P) of the total organic P (Black and Goring, 1953). According to Mattingly and Talibudeen (1967), 25 to 33% of soil organic P cannot be positively identified.

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Hannapel <u>et al</u>. (1964a) found that organic P and organic C concentrations in calcareous soils were positively correlated and that the ratio of C:P was approximately 110:1. Other researchers reported that C:N:P ratios (amounts of organic C, organic N, and organic P in soil organic matter) varied from 110:9:1. (Black and Goring, 1953) to 135:10:1 (Dormaar and Webster, 1963). Fuller and McGeorge (1951a and 1951b) found C:P ratios of 13:1 to 76:1 for a variety of soils.

Inorganic P concentrations in some Alberta soils have been found to vary from 300 to 1300 ppm (Dormaar and Webster, 1963). Soil inorganic P can be classified into four fractions: water soluble (usually less than one ppm), acid-soluble (usually less that 40% of the inorganic P for acid soils and usually the majority of inorganic P in alkaline soils) adsorbed or alkaline soluble (usually a low percentage of inorganic P in alkaline soils and usually a high percentage for acid soils) and residual or lattice P (Kurtz, 1953; Olsen, 1953).

Native soil P derived from primary apatites and other P-containing minerals exists in various forms in the soil depending on soil pH and relative activities of Fe, Al, Ca, and Mg ions (Lawton, 1961). In acid soils, Fe and Al ions combine with P to form compounds such as taranakite, strengite, variscite, and wavellite. In neutral and alkaline soils, Ca and Mg ions combine with applied P to form compounds such as  $CaHPO_4 \cdot 2H_2O$ ,  $MgHPO_4 \cdot 3H_2O$ ,  $Mg_3(PO_4)_2 \cdot 22 H_2O$ , and  $Ca_4H(PO_4)_3 \cdot 3H_2O$  (Racz and Soper, 1967; Strong and Racz, 1970). Iron and Al phosphate concentration of soils varies from a trace to about 280 ppm. Most of the inorganic P in neutral and alkaline soils is present as Ca and Mg phosphates (Weir and Soper, 1962 and

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1963). Inorganic P added to base saturated soils reacts with soil constituents with a series of reactions occurring over a considerable period. Initially DCPD forms which then changes to OCP; OCP changes to HA when the time of final equilibrium is reached (Nagelschmidt and Nixon, 1944).

Phosphorus concentration in the soil solution is very low, rarely greater than one ppm, but is significant in terms of availability of P to plants. Phosphorus in solution exists is  $H_3PO_4$ ,  $H_2PO_4^-$ ,  $HPO_4^-$ , or  $PO_4^-$  depending on the pH of the soil solution. Phosphorus concentration of the soil solution depends on the amount of P held on soil particles, solubility and relative abundance of the various inorganic P compounds, and the amount of P mineralized from organic sources. Extraction of soil P with 0.5M NaHCO<sub>3</sub> extracts P in the soil solution as well as part of the readily exchangeable and water soluble inorganic P. Sodium bicarbonate extractable P contents of Manitoba soils vary from 1 to 30 ppm and average approximately 11 ppm.<sup>1</sup>.

Various factors affect the amounts and forms of inorganic, organic, and solution P in the soil. Amounts and forms of organic and inorganic P in soil are influenced by type of parent material, climate, vegetation, microbial population, soil texture, soil depth, temperature, moisture, and soil age (Bowman <u>et al</u>., 1968; Lawton, 1961). Liming or acidulation causes changes in the forms of inorganic P (Lawton, 1961). Liming increases pH and amounts of Ca and Mg

1. unpublished data, Dept. of Soil Sci., Univ. of Man.

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phosphates in a soil. Mattingly and Talibudeen (1967) found that the pH of the soil at time of manuring governed the distribution of added P into various insoluble phosphates. Ridley and Hedlin (1962) found that additions of manure to a clay soil over a long period (38 years) increased total P, inorganic P, and NaHCO<sub>3</sub> extractable P at a depth of 15 to 30 cm.

## Phosphorus Solubility, Availability, and Fixation

Solubility of soil P is generally low under native soil conditions (Lawton, 1961). Factors favouring increased solubility of P compounds are a good supply of organic matter, neutral pH, high amounts of soil P, substantial soil moisture, and a high silicate: sesquioxide ratio (Lawton, 1961). Availability of P to plants is affected by the form of inorganic P present which in turn is affected by liming or acidulation (Lawton, 1961). Phosphorus fixation depends on pH, concentration of P, and time of contact (Hibbard, 1935; Sakdinan, 1971). Phosphorus fixation involves primarily chemical precipitation and physiochemical sorption (Lawton, 1961). Orthophosphate ions added to the soil are retained by anion exchange adsorption on soil constituents and precipitation of simple and complex phosphates of Mg, Ca, Al, Fe, and Mn when their solubility products are exceeded in the soil solution (Mattingly and Talibudeen, 1967). Phosphorus adsorbing constituents are clay minerals, hydrated and anhydrous oxides of A1, Fe, Mn, and alkaline earth carbonates and sulfates (Mattingly and Talibudeen, 1967). Adsorbed P is believed to be present

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as a mono-molecular layer on the surface of the soil colloids (Rennie and McKercher, 1959). The strength with which some organic P compounds are adsorbed is as follows: nucleoproteins > nucleic acids > nucleotides (Mattingly and Talibudeen, 1967).

Phosphorus is retained by clays and precipitated as Fe and Al phosphates at pH values of 2 to 5. At pH values 6 to 10, P is fixed by divalent cations primarily Ca and Mg (Lawton, 1961). Saini and MacLean (1965) found that P retention was related to Al and organic matter levels and not to the amount of clay or Fe in some New Brunswick soils. Solubility and availability of P decrease in both directions from neutrality (Heck, 1934; Lawton, 1961). An exception to this is at pH values 8.5 to 10.0 where Na ions are released forming relatively soluble phosphates.

Phosphorus is rapidly converted to water-insoluble forms and becomes extremely immobile when added to an aerated soil (Holt <u>et al.</u>, 1970). Increases in the availability of native and applied P have been noted in soils submerged continuously (Holt <u>et al.</u>, 1970). This may be an important factor when considering amounts of P supplied to water from soil. If soils containing relatively large amounts of insoluble P are transported to an anaerobic environment, lake or stream sediment, P may be converted to soluble or available forms.

Initial removal of applied organic P from solution is rapid suggesting its direct combination with colloidal matter in soil (Hilbert <u>et al.</u>, 1938). However, increases in fixation of organic P with time is primarily due to the action of microorganisms on the organic P. Macura and Kunc (1965) defined biological immobilization

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of P as the difference between the amount of P fixed in soils with glucose added and P fixed with no glucose added. In soil columns to which glucose had been added, the amount of biological immobilization was directly related to microbial population distribution. Organisms involved in biological fixation are of both faunal and floral origin, including protozoa, nematodes, earthworms, insects, algae, fungi, and bacteria (Macura and Kunc, 1965). Immobilization by organisms causes a release of  $CO_2$  which faculitates release of P from relatively insoluble soil minerals (Lawton, 1961).

#### Phosphorus Movement

Phosphorus (soil and fertilizer P) flux through the soil is by soil organism transport, mass flow transfer by water, or thermal movement along a concentration gradient (diffusion) (Larsen, 1967; Lewis, 1968; Mattingly and Talibudeen, 1967). Factors affecting P movement are the soil: water ratio, morphology and growth pattern of plants, soil type and texture, and soil organisms such as earthworms (Hibbard, 1935; Stephenson and Chapman, 1931). Neller (1946) studied the mobility of P and found that P did not move down the soil profile to any appreciable extent and moved less than all other major nutrients. Henderson and Jones (1941) found that P did not move very far from the point of application. Phosphorus applied at a rate of 109 kg P/ha as  $Ca(H_2PO_4)_2$  moved 3.2 cm from the point of application

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in clay as compared to 10 cm in silt-loam. Sakdinan (1971) found that orthophosphate movement through a soil was affected by chemical reactions in the soil such as adsorption, exchange, precipitation, and other transformations. Dehghan and Williams (1967), and Ridley and Hedlin (1962) found very little movement of P in soil with a high clay content. Movement of P was greater in coarser textured soils (Dehghan and Williams, 1967). Lewis (1968) found that the amount and rate of P movement in calcareous soils was less than in non-calcareous soils. He studied the movement of applied fertilizer P and found that P movement decreased with increasing amounts of Ca and/or Mg in the soil solution. Stephenson and Chapman (1931) found that P accumulated in the soil horizon with which it had been incorporated and that movement from the zone of application was slow. The more soluble the P source the greater the penetration. Neller (1936) found that water-soluble P content in sands was higher than in sandy loams or loams. More movement would thus be expected in the coarser soils. Dehghan and Williams (1967) found that when the original moisture content of a sandy loam was increased, leaching losses of P from the soil decreased. These findings are contradictory to those obtained by Stephenson and Chapman (1931) who found that P diffusion increased with an increase in soil water content. They also found that P diffusion in acid soils was greater than in calcareous soils. Stechel (1970) found that P movement was associated with high rainfall. The site was heavily manured with poultry manure and movement of P occurred to a depth of about 130 cm. Levesque and Hanna (1966) found that movement of P in a podzol soil was associated with movement of Fe.

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Organic P compounds have a greater penetrability than inorganic P compounds (Hannapel et al., 1964a). In calcareous soils, considerable P is transported in organic form by saturated flow of water (Hannapel et al., 1964a; Hibbard, 1935). Degree of P movement was related to the organic P content of the soil solution. Large applications of manure or inorganic fertilizer can increase downward movement of P (Stephenson and Chapman, 1931). Early tests on some Rothamsted fertility plots showed that P penetration was especially marked in manured plots as compared with plots receiving inorganic P. Penetration, however, was less than 100 cm. Hannapel et al. (1964a) found that addition of organic residues increased the amount of total P movement and that increases in P movement resulted from increases in organic P in the soil solution. Hannapel et al. (1964a and 1964b) found that organic P movement was related to the microbial population and hence to factors affecting their metabolic activity. Addition of a microbial energy source increased P movement thirty-eight fold with 95% of the mobile P being organic (Hannapel et al., 1964a and 1964b; Macura and Kunc, 1965). Using column leaching studies, Bowman et al. (1968) found that phytic acid moved very slowly because it was rapidly bound by the soil. Inorganic P accumulated at the base of the column and organic P at the surface. Bowman et al. (1968) concluded that P movement might be significant in soil genesis but insignificant regarding movement into ground water. Larsen et al. (1958) applied labelled P to organic soils and found that P moved completely through 30-cm organic soil columns but moved only 3.8 cm in mineral soil columns.

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## Phosphorus Mineralization

Most organic P compounds must be acted upon by microorganisms before P is released to the soil solution and/or water environment (Black, 1970). Organic P is converted to soluble inorganic P by phytases and nucleases. Plants and animals convert the soluble inorganic P to organic forms (Mattingly and Talibudeen, 1967). Thompson <u>et al</u>. (1954) found that organic P mineralization increased with soil pH. However, no soil pH values greater than 8.0 were used in the study. In a review of data on mineralization, Black and Goring (1953) reported that the amounts of organic P mineralized depended on previous heating, drying, freezing, temperature, pH, aeration, and type of organic material. They also reported that the loss of organic P was accounted for by an increase in inorganic P.

## METHODS AND MATERIALS

## Description of Soils

Soil samples were obtained from and near a confined cattle unit located close to Haywood, Man. (legal description SW 26-8-6W), on an Almasippi sandy loam soil. Samples were taken at two locations: (1) within the confined cattle feeding area (feedlot) and (2) in a field approximately 150 m east of the feedlot site. In the feedlot, soil samples were taken at depths of 0 to 15 cm and 15 to 30 cm, and at intervals of 30 cm to a depth of 300 cm. Similar depths were sampled in the field but only to a depth of 240 cm. Approximately 4.5 kg of soil were collected from each depth at both locations. The feedlot had been in existence for about 13 years resulting in manure accumulations of 30 cm or greater. If movement of P was to occur, it should have been most easily detected in the Almasippi sandy loam because of its coarse texture (Dehghan and Williams, 1969; Neller, 1946). The varying moisture conditions caused by the relatively high and fluctuating water table facilitated study of the influence of a range of oxidation-reduction environments on amounts and forms of P in the soil.

#### Soil Analyses

## 1. Characterization of Soils

The soil samples were air dried and soil texture determined by hand. Calcium carbonate content (Skinner <u>et al.</u>, 1959), pH, total N (Kjeldahl) (Jackson, 1958a), and organic matter content (Walkley

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and Black, 1934) of the soils were determined. Soil pH was determined on a 1:1 soil-water paste using glass and calomel electrodes and a Coleman Metrion 3 pH meter.

#### 2. Sodium Bicarbonate Extractable Phosphorus

The 0.5 M NaHCO $_3$  extractable P content of the soils was determined as outlined by Olsen et al. (1954).

## 3. Water Soluble Phosphorus

Water soluble P was extracted from soil by shaking 20 g of soil in 100 ml of distilled water for 24 hr. The suspension was filtered and the inorganic P concentration of the extract determined as outlined by Mozersky et al. (1966). The procedure was as follows: 10 ml of 1.5% (NH<sub>4</sub>)  $_6$  Mo $_7$  O $_{24}$  · 4H $_2$ O in 0.5 N H $_2$ SO $_4$  were added to an aliquot of 10 ml of the extract. Twenty ml of an isobutanol-benzene mixture (1:1) were then added, the mixture shaken for 30 sec and allowed to settle for one min. The organic phase was decanted and the color intensity measured at 370 mu on a Coleman Universal Model 14 Spectrophotometer in order to determine inorganic P concentration. The total (organic and inorganic) water soluble P concentration of the extract was determined by evaporating an aliquot of 10 ml to dryness in a porcelain crucible followed by ignition at 500 C for 4 hr in a muffle furnace. After cooling, 10 ml of  $\rm H_{2}O$  and 10 ml of 0.5 N  $H_2$  SO<sub>4</sub> were added to the crucible and the solution hydrolyzed at approximately 90 C for 4 hr. The P concentration of the solution was determined as previously described (Mozersky et al., 1966) except for the substitution of 1.5% (NH<sub>4</sub>)<sub>6</sub>  $Mo_7 O_{24} \cdot 4H_2 O$  in 0.25 N  $H_2SO_4$ 

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for 1.5% (NH<sub>4</sub>)<sub>6</sub> Mo<sub>7</sub> O<sub>24</sub> · 4 H<sub>2</sub>O in 0.50 N H<sub>2</sub>SO<sub>4</sub>. The organic P concentration was determined by the difference between the total and inorganic P concentrations.

4. Total Phosphorus Determinations

Total P content of soil was determined as outlined by Jackson (1958b). One gram of air-dried soil was digested with 10 ml of  $HNO_3$  and 15 ml of  $HCIO_4$  until colorless. Phosphorus concentration in the extract was determined by the vanadomolybdophosphoric yellow color method in a nitric acid system (Method V, Jackson, 1958b).

## 5. Organic Phosphorus Determinations

Organic P content of soil was determined by two methods. The first method was as outlined by Olsen and Dean (1965). Ignited (240 C for one hr) and non-ignited one gram samples were extracted with 20 ml of HCl for one hr, filtered, and diluted to 250 ml. The molybdenum-blue colorimetric method was employed to determine P concentration in the solutions (Legg and Black, 1955). The difference in P concentrations between ignited and non-ignited samples was the organic P concentration.

The second method was as outlined by Mehta <u>et al</u>. (1954). Successive extractions with 10 ml of concentrated HCl, 30 ml of 0.5 N NaOH, and 60 ml of 0.5 N NaOH were conducted on one gram of soil. The extracts were combined and diluted to 250 ml. The inorganic P concentration was determined on an aliquot of 5 ml using the molybdenum-blue colorimetric method of Legg and Black (1955). A second aliquot of 5 ml was treated with one ml of concentrated HClO<sub>4</sub> and

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digested by heating. The concentration of P in the digested samples was determined by the method of Legg and Black (1955). The difference in P concentration between digested and non-digested samples represented the organic P concentration.

## Water Analyses

Water samples were obtained from a well beneath the feedlot and from five wells located at various distances from the feedlot. The sixth well was located near the field soil sampling site. Depths to water table were recorded at all wells. Concentration of water soluble P in the water obtained from the wells was determined. Inorganic P concentrations were determined as previously described (Mozersky <u>et al.</u>, 1966). Total P (organic and inorganic) was determined as previously described (Mozersky <u>et al.</u>, 1966) following hydrolysis of the water samples. Hydrolysis was conducted by heating 10 ml of 0.5 N  $H_2SO_4$  and 10 ml aliquots of water at about 90 C for 24 hr. Organic P concentration was calculated by the difference between the total and inorganic P concentrations.

## Mineralization of Organic Phosphorus in Soils with and without Manure

Soil from depths of 0 to 15, 120 to 150 and 210 to 240 cm in the feedlot and from depths of 0 to 15 and 210 to 240 cm in the field was incubated with and without manure at two moisture levels for varying periods up to 28 weeks. Manure used for the study was collected from a confined beef cattle feeding area, air dried, mixed, and finely ground. Organic P content of the manure was determined

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as described by Mehta <u>et al</u>. (1954). Total P was determined by digesting 0.2 g of manure in 3 ml of  $HClO_4$  and measuring P concentration in the extract (Jackson, 1958b). Inorganic P was determined by calculating the difference between total and organic P. The manure contained 3050 ppm of total P, 1070 ppm of organic P, and 1980 ppm of inorganic P.

Fifteen-gram samples of each soil without and with manure (1.5 g of manure to increase the total P concentration of the samples by about 300 ppm), were placed into glass vials about 5 cm in height. In addition to the soil and soil-manure samples, 4 g samples of manure were placed in vials. The moisture levels were (1) flooded, for the feedlot samples from depths of 0 to 15, 120 to 150, and 210 to 240 cm and for the field samples from depths of 0 to 15 and 210 to 240 cm and (2) field capacity, for feedlot samples from depths of 0 to 15 and 120 to 150 cm and field samples from a depth of 0 to 15 cm. Flooded soils were saturated with water with a head of one cm throughout incubation. Samples from the depth of 210 to 240 cm were incubated under flooded conditions only as this would represent actual field conditions. The vials were placed into a closed glass container maintained at a high relative humidity, and incubated at 10 C for 0, 1, 2, 4, 9, 17, and 28 weeks.

At the conclusion of each incubation interval, the Eh of each sample was measured using an Orion model 801 Ionalyzer with platinum and calomel electrodes. The electrodes were inserted 1 to 2 cm into the sample and the reading taken after 30 sec. The samples were removed from the vials, air dried, and concentrations of soil

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organic and inorganic P determined. Inorganic P was extracted by shaking one gram of soil with 20 ml of concentrated HCl for one hr. The P content of the filtrate was determined by the molybdenum-blue colorimetric method of Legg and Black (1955). A second set of onegram samples was ignited at 550 C for one hr. Twenty ml of concentrated HCl were added to each ashed sample, the mixture shaken for 5 min, and then heated at 70 C for 4 hr. The samples were then shaken for 10 min, filtered, and diluted to volume. Phosphorus concentration in the filtrates was determined by the molybdenum-blue colorimetric method of Legg and Black (1955). The difference in P content between the ignited and non-ignited samples was considered as organic P.

## Movement of Phosphorus in Soil Treated with Manure Extract

The soils selected for study were from depths of 0 to 15, 15 to 30, 30 to 60, 120 to 150 and 210 to 240 cm in the feedlot and depths of 0 to 15 and 210 to 240 cm at the field location. The manure extract was prepared by mixing 400 g of manure with 2400 ml of water. The mixture was allowed to stand for 24 hr and then filtered. About 1150 ml of extract were obtained. The extract was diluted with distilled water (4 volumes of distilled  $H_20$  to one volume of extract) and concentrations of organic and inorganic P determined (01sen and Dean, 1965). Inorganic P was determined as follows: 5 ml of (NH<sub>4</sub>)<sub>6</sub> Mo<sub>7</sub>0<sub>24</sub> - HCl solution was added to one ml of extract and the solution diluted to about 40 ml. The solution was filtered, treated with 5 ml of dilute Sn Cl<sub>2</sub> and diluted to 50 ml. Color intensity was measured at 660 mu on a Spectronic 20 colorimeter. Blank determinations were

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conducted using extract and the above reagents except Sn  $\text{Cl}_2$ . A second one-ml sample of extract was digested with one ml of concentrated HClO<sub>4</sub> and transfered to a 50 ml volumetric flask. The pH was adjusted using 6N NH<sub>4</sub>OH and 0.5 N HCl. Five ml of  $(\text{NH}_4)_6 \text{ Mo}_7 \text{ O}_{24}$  - HCl solution were added and the mixture diluted to about 40 ml. Five ml of dilute Sn Cl<sub>2</sub> were added and the solution diluted to volume. The blank consisted of all reagents and no extract. Phosphorus concentration in the digested samples was determined as described for the non-digested samples. The difference in P concentration between the digested and non-digested samples represented the organic P and 28 ppm organic P.

Soil columns were prepared by placing soil in a plastic tube with a filter plate funnel as a base. A layer of glass wool was placed on top of the filter plate to prevent soil from passing through. Glass wool was also placed on the soil surface to spread the extract drop over the entire surface of the soil column. Height and weight of the soil columns varied from 3.5 to 4.0 cm and 20.5 to 21.0 g, respectively. Column diameter was 2.5 cm. The manure extract was applied dropwise to the surface of the soil columns. Flow rate of the extract through the soil columns varied from 6.7 to 8.5 ml per hr. The extract passing through the soil column was collected at intervals of 20 min in test-tubes in a fraction collector for periods up to 12 hr. Inorganic and organic P concentrations in the soil leachates were determined as described for the manure extract (Olsen and Dean, 1965). Leaching of the soils was continued until the concentration

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of both inorganic and organic P in the soil leachate (C) equalled the concentration of both inorganic and organic P in the manure extract  $(C_{o})$ .

The movement of P in soil treated with KH2PO4 was also studied. Only soils from the depths of 0 to 15 and 210 to 240 cm at the field location were used in this study. A P solution of 35 ppm was prepared using KH<sub>2</sub>PO<sub>4</sub>. Soil columns were prepared as previously described and the P solution was added dropwise to the surface of the soil columns. Flow rate of the P solution varied from 7.0 to 8.0 ml per hr for both soil columns. Samples were collected at intervals of 20 min in a fraction collector for periods up to 12 hr. Inorganic P concentration in the soil leachates was then determined (Olsen and Dean, 1965). One ml of the solution was placed in a 50 ml volumetric flask and the pH adjusted with 6N  $\mathrm{NH}_4\mathrm{OH}$  and 0.5 N HCl. Five ml of  $(NH_4)_6 Mo_7 O_{24}$  - HCl solution were added and the new solution diluted to about 40 ml. Five ml of dilute Sn Cl<sub>2</sub> were added and the color intensity measured at 660 mu on a Spectronic 20 colorimeter in order to determine inorganic P concentration.

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#### RESULTS AND DISCUSSION

## Soil Samples

Texture of the feedlot soil samples was loamy fine sand (LFS) except for the 150-to 210-cm depth which was loamy very fine sand (LVFS) (Table 1). Texture of the field soil samples was fine sandy loam (FSL) from 0 to 30 cm and loamy fine sand (LFS) below 30 cm.

Soil samples from the 120- to 300-cm depth at the feedlot site and all samples from the adjacent field site contained more than four percent CaCO<sub>3</sub>. No CaCO<sub>3</sub> was detected in the 0-to 90-cm samples from the feedlot (Table 1). At both locations, CaCO<sub>3</sub> content of soil above the water table increased with depth. The water table was at 185 and 165 cm for the feedlot and field locations, respectively. Calcium carbonate content of soil below the water table decreased with depth. All soils from both sites were alkaline (Table 1). The pH of feedlot soil above the water table varied from 8.3 to 8.5. The pH of feedlot soil below the water table was slightly lower than for soil above the water table and varied from 8.0 to 8.4. This trend was not as evident for the field samples although samples from 120 to 240 cm had lower pH values than samples from 30 to 120 cm.

Total N (Kjeldahl) and organic matter contents of both feedlot and field samples decreased with depth. It is interesting to note that both total N and organic matter contents were higher for the field site than for the feedlot site at the O-to 15-cm depth. The lower total N content of feedlot could be due to a rapid mineralization of N during periods of dry weather and aerobic conditions followed

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SITE	DEPTH (cm)	TEXTURE	CaCO <sub>3</sub> CONTENT (%)	pН	TOTAL N CONTENT (%)	ORGANIC MATTER CONTENT (%)
Feedlot	0-15	LFS	*	8.4	0.101	2,06
	15-30	LFS	*	8.5	0.139	3.37
	30-60	LFS	*	8.5	0.069	1.61
	60-90	LFS	*	8.5	0.035	0.33
	90-120	LFS	0.28	8.3	0.047	0.70
	120-150	LFS	8.57	8.5	0.045	0.46
	150-180	LVFS	19.77	8.5	0.057	0.33
	180-210	LVFS	18.56	8.4	0.039	0.40
	210-240	LFS	14.12	8.2	0.023	0.36
	240-270	LFS	12.85	8.1	0.017	0.16
	270-300	LFS	10.85	8.0	0.011	0.13
Field	0-15	FSL	4.24	7.9	0.232	6.09
	15-30	FSL	5.07	8.2	0.091	2.51
	30-60	LFS	12.99	8.5	0.035	0.76
	60-90	LFS	13.99	8.7	0.014	0.68
	90-120	LFS	17.65	8.6	0.012	0.38
	120-150	LFS	17.14	8.3	0.012	0.30
	150-180	LFS	11.58	8.3	0.013	0.40
	180-210	LFS	13.14	8.2	0.008	0.31
	210-240	LFS	10.59	8.4	0.011	0.12

Table 1. Texture, calcium carbonate content, pH, total nitrogen content and organic matter content of the feedlot and field sampling sites.

\*not detectable

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by volatilization of  $NH_3$  and/or leaching and dentrification of  $NO_3$  during periods of anaerobic conditions. Below 15 cm, total N and organic matter contents were higher for the feedlot site than for the field site at almost every sampling depth.

The 0.5 M NaHCO<sub>3</sub> extractable P concentration of the feedlot soil above the water table was very high (Table 2), and varied from 9.4 to 76.0 ppm P. Below the water table, P was only slightly higher in the feedlot than in the field soil and both were very low. Sodium bicarbonate extractable P concentration below the water table in the field was higher than just above the water table (60-to 120-cm depth). This was probably caused by an increase in solubility of P under an anaerobic environment (Holt <u>et al.</u>, 1970). The increase in NaHCO<sub>3</sub> extractable P in soil receiving manure agrees with results of other workers. Ridley and Hedlin (1962) also found increases in NaHCO<sub>3</sub> extractable P due to manure application. The NaHCO<sub>3</sub> extractable P values show that under the feedlot P moved to a depth of at least 150 cm.

Accumulation of manure in the feedlot had a considerable effect on the concentration of water soluble P. Organic and inorganic water soluble P concentrations at 0 to 60 cm in the feedlot were very high. Most of the water soluble P in the 0-to 60-cm feedlot samples was inorganic P. Most of the water soluble P in the feedlot samples below the water table was organic P. It is interesting to note that a high percentage of total organic P was extracted by water. Water soluble P concentrations in the field samples were very low and in several samples no water soluble P was detected (Table 2). Inorganic water soluble P concentration below the water table was

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SITE	DEPTH (cm)	0.5 M NaHCO <sub>3</sub> DEPTH EXT. P CONC. (cm) (ppm)		SOLUBLE ONC. pm)  INORGANIC	TOTAL P CONC. (ppm)	ORG. P <sup>1.</sup> CONC. (ppm)	ORG P <sup>2</sup> . CONC. (ppm)
Feedlot	0-15	76.0	10.4	39.7	882	56	15
	15-30	56.0	21.0	25.0	619	70	14
	30-60	62.0	12.9	6.0	535	13	*
	60-90	17.0	1.3	0.3	458	6	*
	90-120	19.0	0.2	5.3	478	4	43
	120-150	9.4	0.2	0.4	615	20	*
	150-180	2.0	*	0.5	699	*	*
	→ 180-210	1.8	0.3	*	684	51	*
	210-240	1.6	0.4	*	661	9	*
	240-270	1.0	0.8	*	613	*	*
	270-300	1.2	*	0.3	733	*	*
Field	0-15	1.8	0.3	0.8	661	268	234
	15-30	1.0	0.6	0.1	523	159	137
	30-60	0.8	*	*	451	106	104
	60-90	0.2	0.1	*	509	54	111
	90-120	0.2	*	*	481	47	54
	120-150	0.6	1.0	0.1	504	33	10
	<sub>→</sub> 150–180	1.0	*	*	527	27	11
	180-210	1.0	*	1.0	535	29	*
	210-240	1.0	0.7	1.4	584	41	75

Table 2. Sodium bicarbonate extractable, water soluble, total and organic phosphorus concentrations in soils from the feedlot and field sites.

\* not detectable

1. method of Olsen and Dean (1965)

2. method of Mehta et al. (1954)

→ indicates water table level

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greater than just above the water table. This was probably due to an increase in solubility of P under anaerobic conditions. Water soluble P concentration in samples from the feedlot indicated that P from the manure moved to a depth of at least 120 cm.

Total P concentration in most feedlot samples was greater than in the field samples (Table 2). Similar findings were noted by Ridley and Hedlin (1962) for soils manured over a period of 38 years. Total P concentration decreased with depth to 90 and 60 cm for the feedlot and field sites, respectively. Total P concentration below these depths was greater but did not increase with depth. It was not known if the water table at the sampling locations had an effect on this phenomenon.

Organic P was determined as described by Olsen and Dean (1965) and by Mehta <u>et al</u>. (1954). Both methods showed that the surface feedlot samples contained very low amounts of organic P. Most P in the soil beneath the feedlot was in the inorganic form. The O-to 15-cm field sample contained about 250 ppm organic P which was about 40% of the total P content of the soil. The low levels of organic P in the feedlot samples might have been caused by a greater mineralization of organic P under manured than under non-manured conditions. Also anaerobic soil conditions would generally prevail under the feedlot whereas aerobic conditions would generally prevail in the field. This might have also affected mineralization of organic P.

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The C:N and C:N:P ratios were calculated for depths of 0 to 15 and 15 to 30 cm for each location (Table 3). The C:N ratios were similar for both sites and varied from 12:1 to 16:1. The C:N:P ratios of the feedlot site indicated a much lower organic P content in relation to C and N contents than that for the field site. Ratios of C:N:P of 110:9:1 are common for soils (Black and Goring, 1953). Values of C:N:P for the field samples were similar to those reported by Black and Goring (1953). However, values of C:N:P for the feedlot samples differed greatly from those for the non-manured soils. The high C:N:P ratios in the feedlot soil were due to low organic P levels since the C:N ratios for the field and feedlot sites were similar.

## Water Samples

Depths to water table in the feedlot and field wells were 185 cm and 165 cm, respectively. Samples of water from the feedlot well and from wells located at increasing distances from the feedlot contained non-detectable amounts of P (Results not shown). The method used was the same as that for detecting water soluble P in the soil samples in which P concentrations as low as 0.1 ppm were detected. Thus, the levels of P in the well water samples must have been less than 0.1 ppm.

## Mineralization of Organic Phosphorus in Soils with and without Manure

The previous studies showed that the organic P content of soil beneath a feedlot was very low. It was thought that mineralization of organic P would be increased when manure was mixed with soil,

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Table 3.	Organic carbon, total nitrogen and organic phosphorus concentrations,
	and C:N and C:N:P ratios of the O-to 15- and 15-to 30-cm feedlot and field samples.

SITE	DEPTH (cm)	ORG. C <sup>1.</sup> CONTENT (%)	TOTAL N CONTENT (%)	ORG. P <sup>2</sup> . CONTENT (%)	C:N	C:N:P
Feedlot	0-15	1.20	0.101	.0056	12:1	214:18:1
	15-30	1.95	0.139	.0700	14:1	279:20:1
Field	0-15	3.54	0.232	.0268	15:1	132:8.7:1
	15-30	1.46	0.091	.0159	16:1	92:5.7:1

1. Walkley and Black (1934)

2. method of Olsen and Dean (1965)

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particularly under anaerobic conditions such as those in the feedlot. Thus, an experiment was designed to study the mineralization of organic P in soils with and without manure added and under aerobic and anaerobic conditions. Manure used in the mineralization experiment contained 3050 ppm total P, 1070 ppm organic P and 1980 ppm inorganic P. Thus, about one third of the P was organic. A total P concentration of 3050 ppm is equivalent to about 0.32% P or 3.2 kg P per ton of dry matter which is considerably higher than the 1.0 kg of P per ton of dry matter reported by researchers at the University of Guelph.<sup>1.</sup> Since the total P concentration of soils was increased by 300 ppm P, the organic P concentration was increased by 100 ppm P.

The Eh readings (Table 4) were obtained as an indication of the oxidation-reduction environment of the samples. The flooded treatment was designed to create an anaerobic environment while the field capacity moisture treatment created an aerobic environment with adequate moisture for microbial activity. The 0-to 15-cm feedlot samples were in a more reduced state than the field samples for corresponding treatments and sampling times. This may have been due to the higher amounts of available P in the feedlot samples resulting in greater microbial activity and depletion of oxygen supplies. The flooded samples all exhibited lower Eh values than samples at field capacity for corresponding soil treatments and sampling times. This was expected as saturation of soils with water usually lowers the oxygen content of the soil. Samples treated with manure were more reduced

<sup>1.</sup> Progress Report 1966, Research and Advisory Service, Dept. of Soil Sci., Univ. of Guelph.

SAMPLE		AMOUNT OF	NT OF MOISTURE Eh (mv)								
SITE	DEPTH (cm)	MANURE ADDED (g)	LEVEL	t=0 wk	t=1 wk	t=2 wk	t=4 wk	t=9 wk	t=17 wk	t=28 wk	Mean t=1 to 28 wk
Manure	N.A. N.A.	N.A. <sup>1.</sup> N.A.	F. 2. F.C. <sup>3</sup> .	+224 233	+ 71 157	+ 84 228	+ 89 90	+ 96 152	+ 20 324	+144 235	+ 84 198
Feedlot	0-15 0-15 0-15 120-150 120-150 120-150 120-150 210-240 210-240	$     \begin{array}{r}       1.5 \\       0 \\       0 \\       1.5 \\       1.5 \\       0 \\       0 \\       1.5 \\       0 \\       1.5 \\       0 \\       0 \\       1.5 \\       0 \\       0 \\       1.5 \\       1.5 \\      1.5 \\      1.5 \\      1.5$	F. F.C. F. F.C. F. F.C. F. F.	243 247 264 269 242 261 273 268 283 316	28 12 119 103 26 261 240 196 81 297	13 95 55 101 0 221 160 270 34 137	55 78 61 162 43 53 167 270 -9 +230	113 262 83 187 109 138 239 289 104 178	34 223 28 349 67 37 180 328 58 250	146 386 132 339 134 390 407 420 123 388	65 176 80 207 63 183 232 295 65 247
Field	0-15 0-15 0-15 0-15 210-240 210-240	1.5 1.5 0 1.5 0	F. F.C. F. F. F.	298 317 316 341 272 336	143 208 338 384 79 404	59 123 140 384 8 412	90 245 138 284 14 309	142 319 244 446 83 229	141 358 178 456 63 341	161 401 177 430 77 433	123 276 202 397 54 355

Table 4. Eh values (mv) of samples incubated for varying periods with and without manure, under field capacity and flooded conditions.

1. N.A. = not applicable
2. F. = flooded

3. F.C. = approximately field capacity

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than non-manured samples except for the 0-to 15-cm feedlot sample which showed no definite trend. It is possible that the addition of manure to the samples increased microbial activity and the utilization of oxygen.

The Eh values of the flooded samples generally decreased for about the first two weeks then remained relatively constant or increased for the duration of the study (28 weeks). A similar trend occurred for samples maintained at field capacity except that the decrease in Eh was generally less than for the flooded samples. The decrease in Eh with time for manured samples followed a pattern similar to that of non-manured samples. The decrease in Eh for manured samples was greater than for non-manured samples.

Percent recovery of applied P (300 ppm increase) was calculated for the manured samples (Table 5). Percent recovery varied from 65.5% to 128% for the various treatments. Percent recovery of applied P for the 0-to 15-cm samples was greater for the feedlot than for the field samples. However, percent recovery of P applied to samples obtained at the 210-to 240-cm depth was greater for the field than for the feedlot samples. Slightly greater amounts of applied P were recovered from the flooded samples of the 0-to 15-cm depth at both sites than from the field capacity samples. The converse was true for the 120-to 150-cm feedlot samples. Percent recovery varied considerably with time, but there was no apparent trend in change of percent recovery with time. Due to the large variations in percent recovery of applied P with time for any one soil sample, it is unlikely if the differences in recovery were significant.

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SAMPLE		AMOUNT OF MANURE ADDED (g)	MOISTURE LEVEL	VT OF MOISTURE % RECOVERY 1.								
	(cm)			t=0 wk	. t=1 wk	t=2 wk	t=4 wk	t=9 wk	t=17 wk	t=28 wk	Mean t=0 to 28 wk	
Feedlot	0-15	1.5	F.	111	97	113	114	81	114	81	101	
	0-15	1.5	F.C.	86	78	75.5	108	97	90	128	95	
	120-150	1.5	F.	86	109	96	85	88	88	85	01	
	120-150	1.5	F.C.	91	103	94.5	116	98.5	99.5	92	99	
	210-240	1.5	F.	76	79.5	80	73	65.5	74.5	80	75.5	
Field	0-15	1.5	F.	101	93.5	83.5	77	108	82.5	78.5	80	
	0-15	1.5	F.C.	73	90.5	95.5	78.5	94.5	73.5	90	85	
	210-240	1.5	F.	85	82.5	106	106	98	85.5	86.5	93	

Table 5.	Percent recovery of applied phosphorus (inorganic and organic for samples
	incubated for varying periods, under field capacity and flooded conditions.

(P extracted from manured soil) - (P extracted from corresponding non-manured soil) × 100 300 1. % recovery =

2. F. = flooded

3. F. C. = field capacity

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1

Organic P concentrations in the feedlot samples were very low in comparison to organic P concentrations of corresponding field samples (Table 2). These results suggested that the methods employed did not extract all of the organic P in the manured soils. However, percent recovery of inorganic and organic P, applied as a manure, indicated that the method used did recover most of the P. Thus, the low amounts of organic P found in the surface feedlot soils were probably not due to incomplete recovery of organic P but due to the very rapid mineralization of organic P.

Inorganic P concentrations in the samples were determined for each sampling time (Table 6). For a particular site, moisture treatment and sampling time, manured samples had higher concentrations of inorganic P than non-manured samples. Flooded samples usually had lower inorganic P concentrations than samples maintained at field capacity during the first few weeks of incubation. However, flooded samples contained more inorganic P than samples at field capacity when incubated for more than 17 wk. This suggested that microbial immobilization or chemical fixation of inorganic P in flooded soils was greater than in soils at field capacity during the first few weeks of incubation, but that the reverse was true during the later stages of incubation. Inorganic P concentration of manure alone decreased during the first few weeks of incubation. Inorganic P concentration of flooded samples was greater than for samples at field capacity after 17 to 28 wk of incubation. This was similar to results for the soil samples.

Organic P concentrations of manured samples were greater

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SAMPLE SITE	חדסתת	AMOUNT OF DEPTH MANURE	MOISTURE LEVEL	MOISTURE INORGANIC P (ppm) 4.							
	(cm)	ADDED (g)		t=0 wk	t=1 wk	t=2 wk	t=4 wk	t=9 wk	t=17 wk	t=28 wk	
Manure	N.A. N.A.	N.A. <sup>1</sup> . N.A.	F. 2. F.C. <sup>3</sup> .	1720 2196	1858 2059	1368 1692	1332 2009	1519 2326	2088 2498	2621 2570	
Feedlot	$\begin{array}{c} 0-15\\ 0-15\\ 0-15\\ 120-150\\ 120-150\\ 120-150\\ 120-150\\ 120-150\\ 210-240\\ 210-240\end{array}$	$     \begin{array}{r}       1.5 \\       1.5 \\       0 \\       1.5 \\       1.5 \\       0 \\       0 \\       1.5 \\       0 \\       0 \\       1.5 \\       0 \\       0 \\       1.5 \\       0 \\       0 \\       1.5 \\       0 \\       0 \\       1.5 \\       1.5 $	F. F.C. F.C. F.C. F.C. F. F.C. F.	648 686 506 523 586 624 432 449 634 466	605 653 463 480 610 586 408 418 638 456	658 614 485 478 600 564 401 394 662 478	653 658 550 545 638 614 461 456 638 466	643 706 485 494 624 595 427 418 629 502	710 624 494 533 619 566 437 432 638 466	718 758 530 533 643 634 461 451 701 538	
Field	0-15 0-15 0-15 0-15 210-240 210-240	1.5 1.5 0 1.5 0	F. F.C. F. F.C. F.	444 442 283 302 610 463	420 367 262 283 619 442	410 403 276 278 605 490	454 494 307 295 662 494	444 451 276 295 600 456	439 425 278 293 629 482	511 456 286 293 691 490	

Table 6. Inorganic phosphorus concentration (ppm) of samples incubated for varying periods with and without manure, under field capacity and flooded conditions.

- 1. N.A. = not applicable
- 2. F. = flooded
- 3. F.C. = field capacity

4. soils extracted with 20 ml concentrated HCl without ignition

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than for non-manured samples (Table 7). Organic P concentrations of flooded samples were similar or slightly higher than for samples at field capacity during the first 2 to 17 wk of incubation. After 28 wk of incubation, organic P concentrations of flooded samples tended to be less than those of samples at field capacity. Generally organic P concentrations of samples increased for the first few weeks of incubation then decreased during the remainder of the incubation period. These findings showed the same immobilization and mineralization trends as for inorganic P. Increases in organic P during the first few weeks of incubation corresponded to the decreases in inorganic P over the same time period.

Ratio of inorganic to organic P was calculated (Table 8) and statistical analyses conducted to determine if significant changes in the ratio occurred with time of incubation. A significant increase in the inorganic : organic P ratio would have indicated that net mineralization of organic P occurred. The ratios of the 0-to 15-cm feedlot samples were higher than the ratios of the 0-to 15-cm field samples due to the differences in organic P concentrations of the feedlot and field soils. The manured feedlot samples have considerably lower inorganic : organic P ratios than the non-manured feedlot samples due to the P concentration of the added manure. A similar trend existed for the 210-to 240-cm field sample but not for the 0-to 15-cm field sample because the native P concentration of the latter was very high. Inorganic : organic P ratios of flooded and field capacity samples decreased the first few weeks then increased with time.

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Table 7. Organic phosphorus concentration (ppm) of samples incubated for varying periods (wk) with and without manure, under field capacity and flooded conditions.

SAMPLE	וויייסס	AMOUNT OF	MOISTURE			ORGAN	IC P (ppm)	<sup>4</sup> .		
SILE	(cm)	ADDED (g)	LEVEL -	t=0 wk	t=1 wk	t=2 wk	t=4 wk	t=9 wk	t=17 wk	t=28 wk
Manure	N.A. N.A.	N.A. <sup>1.</sup> N.A.	F. 2. F.C. <sup>3</sup> .	1347 1570	1706 1505	2448 2124	2182 1533	2146 1684	1109 1714	1173 1469
Feedlot	$\begin{array}{c} 0-15\\ 0-15\\ 0-15\\ 120-15\\ 120-150\\ 120-150\\ 120-150\\ 120-150\\ 210-260\end{array}$	$     \begin{array}{r}       1.5 \\       1.5 \\       0 \\       1.5 \\       1.5 \\       0 \\       0 \\       1.5 \\       1.5 \\       0 \\       0 \\       1.5 \\       1.5 \\       0 \\       0 \\       1.5 \\       1.5 \\       0 \\       1.5 \\       1.5 \\       0 \\       1.5 \\       1.5 \\       0 \\       1.5 \\       1.5 \\       0 \\       1.5 \\       1.5 \\       0 \\       1.5 \\       1.5 \\       0 \\       1.5 \\       1.5 \\       0 \\       1.5 \\       1.5 \\       1.5 \\       0 \\       1.5 \\       1.5 \\       0 \\       1.5 \\       1.5 \\       1.5 \\       0 \\       1.5 \\       1.5 \\       1.5 \\       0 \\       1.5 \\      1$	F. F.C. F.C. F.C. F.C. F.C.	319 176 128 82 189 202 86 105	300 233 223 173 240 247 115 105	316 279 149 189 221 269 132 156	384 357 146 146 149 303 72 113	267 204 182 125 190 250 123 132	305 317 183 139 168 291 86 127	163 264 108 105 149 187 77 94
Field	210-240 210-240 0-15 0-15 0-15 210-240 210-240	$     1.5 \\     0 \\     1.5 \\     1.5 \\     0 \\     0 \\     1.5 \\     0 \\     1.5 \\     0 \\     1.5 \\     0 \\     1.5 \\     0 \\     1.5 \\     0 \\     1.5 \\     0 \\     1.5 \\     0 \\     1.5 \\     0 \\     1.5 \\     0 \\     1.5 \\     0 \\     1.5 \\    $	F. F. F.C. F.C. F.C. F.	175 115 425 345 281 267 177 70	176 120 430 490 307 303 173 103	154 98 416 454 300 293 228 26	195 148 372 327 288 291 188 39	163 93 401 370 245 243 209 60	171 120 394 367 308 278 168 58	98 21 293 377 283 271 101 43

1. N.A. = not applicable

2. F. = flooded

3. F.C. = field capacity

4. difference between ignited (550 C) and non-ignited

Table 8. Ratio of inorganic to organic phosphorus of samples incubated for various periods (wk) with and without manure, under field capacity and flooded conditions.

SAMPLE SITE	DEPTH (cm)	AMOUNT OF MANURE ADDED (g)	MOISTURE LEVEL	RATIOS OF INORGANIC P : ORGANIC P						
				t=0 wk	t=1 wk	t=2 wk	t=4 wk	t=9 wk	t=17 wk	t=28 wk
Manure	N.A. N.A.	N.A. <sup>1.</sup> N.A.	F. F.C.	1.28 1.40	1.09 1.37	0.56 0.80	0.61 1.33	0.71 1.38	1.88 1.46	2.15 1.75
Feedlot	0-15 0-15 0-15 120-150 120-150 120-150 120-150 210-240 210-240	$     \begin{array}{r}       1.5 \\       1.5 \\       0 \\       1.5 \\       1.5 \\       0 \\       0 \\       1.5 \\       0 \\       1.5 \\       0 \\       1.5 \\       0 \\       1.5 \\       0 \\       1.5 \\       0 \\       1.5 \\       0 \\       1.5 \\       0 \\       1.5 \\       0 \\       1.5 \\       0 \\       1.5 \\       0 \\       1.5 \\       0 \\       1.5 \\       1.5 \\       0 \\       1.5 \\       0 \\       1.5 \\       1.5 \\       0 \\       1.5 \\       1.5 \\       1.5 \\       0 \\       1.5 \\      1$	F. F.C. F.C. F. F.C. F. F.C. F.	2.03 3.90 3.96 6.38 3.10 3.10 5.02 4.27 3.63 4.05	2.02 2.80 2.08 2.78 2.54 2.38 3.55 3.98 3.63 3.80	2.08 2.20 3.25 2.53 2.72 2.10 3.04 2.52 4.30 4.88	$1.70 \\ 1.85 \\ 3.77 \\ 3.74 \\ 4.30 \\ 2.03 \\ 6.40 \\ 4.04 \\ 3.28 \\ 3.15 $	2.41 3.46 2.67 3.96 3.29 2.38 3.47 3.17 3.86 5.40	2.33 1.97 2.70 3.84 3.69 1.95 5.08 3.40 3.74 3.88	4.40 2.88 4.90 5.08 4.32 3.4- 6.00 4.80 7.15 25.60 4.
Field	0-15 0-15 0-15 0-15 210-240 210-240	$     1.5 \\     1.5 \\     0 \\     0 \\     1.5 \\     0     $	F. F.C. F. F. F.	1.04 1.28 1.01 1.13 3.45 6.61	0.98 0.75 0.85 0.93 3.58 4.30	0.99 0.89 0.92 0.95 2.66 18.85	1.22 1.51 1.06 1.05 3.52 12.68	1.11 1.22 1.13 1.21 2.88 7.60	1.11 1.16 0.90 1.05 3.75 8.32	$1.75 \\ 1.21 \\ 1.23 \\ 1.08 \\ 6.85 \\ 11.40$

4. values not included in test of significance

1. N.A. = not applicable

2. F. = flooded

3. F.C. = field capacity

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It was difficult to assess the significance of net mineralization of organic P from the trends in the ratio of inorganic : organic P shown in table 8. Therefore, linear regression analysis was conducted and  $r^2$  values calculated (Table 9). Significant mineralization occurred in both manure samples but the greater rate of mineralization occurred in the flooded sample. Significant mineralization also occurred in all manured soil samples from both sites but only under flooded conditions. No significant change in ratio was obtained for all other treatments. However, although not significant in the time period of the experiment, rate of mineralization appeared greater under flooded than under field capacity conditions for non-manured soils.

This study showed that rates of organic P mineralization were greatest in soil samples treated with manure and incubated under flooded conditions. Since the soils under feedlots tend to be anaerobic, the low organic P concentrations of the feedlot soils were probably due to rapid mineralization of native and applied organic P and a depletion of organic P in the soil after the establishment of the feedlot.

## Movement of Phosphorus in Soil Treated with Manure Extract

The manure extract used in the study contained 7 ppm organic P and 28 ppm inorganic P. The  $\text{KH}_2\text{PO}_4$  solution contained 35 ppm inorganic P which corresponded to the total P concentration of the manure extract. Breakthrough curves were calculated for the seven soil samples used in the convective transport studies (Figures 1 to 7). The ratio

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SAMPLE SITE	DEPTH (cm)	AMOUNT OF MANURE ADDED (g)	MOISTURE LEVEL	LINEAR EQUATION $y = a + bx^{4} \cdot$	r <sup>2</sup>	LEVEL OF SIGNIFICANCE
Manure	N.A. N.A.	N.A. <sup>1.</sup> N.A.	F. 2. F.C. 3.	= .762 + .048x = 1.195 + .018x	.514 .453	.05 .10
Feedlot	0-15 0-15 0-15 120-150 120-150 120-150 120-150 210-240 210-240	$     \begin{array}{c}       1.5 \\       1.5 \\       0 \\       0 \\       1.5 \\       1.5 \\       0 \\       0 \\       1.5 \\       0 \\       0 \\       1.5 \\       0 \\       0 \\       1.5 \\       0 \\       0 \\   \end{array} $	F. F.C. F.C. F.C. F.C. F.C. F.C. F.	= 1.75 + .077x = 2.81010x = 2.96 + .043x = 3.78 + .030x = 3.02 + .046x = 2.30 + .021x = 4.15 + .058x = 3.50 + .028x = 3.33 + .103x = 4.13 + .011x	.784 .017 .217 .054 .449 .150 .207 .143 .646 .008	.01   .10  .05
Field	0-15 0-15 0-15 0-15 210-240 210-240	$     1.5 \\     1.5 \\     0 \\     0 \\     1.5 \\     0 \\     0     $	F. F.C. F. F.C. F.	= 0.98 + .022x = 1.10 + .005x = 0.95 + .008x = 1.04 + .002x = 2.84 + .112x = 7.10 + .141x	.729 .043 .352 .064 .689 .245	.01  .05 

Table 9. Linear regression analysis of samples incubated with and without manure, under field capacity and flooded conditions.

- 1. N.A. = not applicable
- 2. F. = flooded
- 3. F.C. = field capacity
- 4. y = Ratio of inorganic : organic P
  - x = Time (wk)

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of the concentration of P in the leachate to the concentration of P in the extract  $(C/C_{\rm o})$  was plotted versus pore volume.

Leaching the 0-to 15-cm feedlot sample with manure extract resulted in removal of both inorganic and organic P from the soil (Figure 1). A value of  $C/C_0 = 1$  was obtained at about a pore volume of 1.5. Thus the soil was in equilibrium, with concentrations of P in the soil solution much higher than those of the prepared manure extract. The highest concentration of organic and inorganic P in the leachate was obtained in the first sample collected and was 51 ppm and 26 ppm, respectively. The  $C/C_0$  value of 1.5 for organic and inorganic P was obtained at pore volumes of 0.75 and 1.25, respectively. Thus it would appear that organic P was leached from the soil at a faster rate than inorganic P. However, this difference may have been due to experimental error. The determination of organic P was obtained by the difference between total and inorganic P. Errors in estimating either total or inorganic P would result in a relatively large error for organic P. A C/C<sub>o</sub> value of about 1.15 was obtained for inorganic P, whereas a value of about 0.9 was obtained for organic P. A  $C/C_{o}$ value of 1.0 should have been obtained for both organic and inorganic This would tend to verify that the difference in rate of movement Ρ. shown in figure 1 was probably due to experimental error.

The 15-to 30-cm feedlot sample (Figure 2) adsorbed P from the manure extract. A  $C/C_0$  value of 0.8 was obtained when one pore volume of extract was eluted. This indicated that P was moving at a rate nearly equal to that of water. Thus, this sample had very little capacity to fix P from the manure extract. The organic and

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Figure 1. Breakthrough curves of inorganic and organic phosphorus for manure extract--O-to 15-cm feedlot sample.

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Figure 2. Breakthrough curves of inorganic and organic phosphorus for manure extract--15-to 30-cm feedlot sample.

inorganic P moved at about the same rate since  $C/C_0 = 0.5$  was obtained at 0.7 pore volumes for both organic and inorganic P.

Appreciable quantities of P were fixed by the 30-to 60-cm feedlot sample (Figure 3). At  $C/C_0 = 0.5$ , pore volumes of 2.0 and 2.4 were found for organic and inorganic P, respectively. Therefore, there was very little or no difference in their rate of movement. Values of  $C/C_0 = 1$  were not obtained even at pore volumes of 15 to 17 suggesting that this sample was capable of fixing P even when leached with large amounts of manure extract. This sample exhibited a much greater P adsorptive capacity than the 15-to 30-cm depth.

Breakthrough curves of organic and inorganic P for the 120-to 150-cm depth were different (Figure 4). A value of  $C/C_0 = 0.5$  was obtained at pore volumes of 3.8 and 6.5 for organic and inorganic P, respectively. Thus, organic P moved at a greater rate than inorganic P. Saturation ( $C/C_0 = 1$ ) was attained at pore volumes of 9.0 and 11.0 for organic and inorganic P, respectively. This indicated a high potential for P adsorption by the soil.

Breakthrough curves of organic and inorganic P for the 210to 240-cm feedlot sample using manure extract (Figure 5) showed that the soil was not saturated with P even at a pore volume of 12. At  $C/C_0 = 0.5$ , pore volumes for inorganic and organic P were 4.8 and 5.6, respectively. This suggested that inorganic P moved at a slightly faster rate than organic P. This may have been due to errors in measurement of inorganic and total P.

Organic, inorganic and total (organic plus inorganic) P breakthrough curves for the manure extract and the breakthrough curves

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Figure 4. Breakthrough curves of inorganic and organic phosphorus for manure extract--120-to 150-cm feedlot sample.



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Figure 5. Breakthrough curves of inorganic and organic phosphorus for manure extract--210-to 240-cm feedlot sample.

for a 35 ppm  $\rm KH_2PO_4$  solution are shown in figures 6 and 7 for the 0-to 15-and 210-to 24-cm field samples, respectively. Total P concentration of the manure extract was about equal to the total P concentration of the  $\rm KH_2PO_4$  solution (35 ppm). At  $\rm C/C_0$  = 0.5, pore volumes for organic and inorganic P using manure extract were 4.5 and 5.0, respectively for the 0-to 15-cm field samples (Figure 6). This indicated the organic and inorganic P in the manure extract moved at about equal rates. Saturation ( $\rm C/C_0$  = 1) was attained at about 7 to 8 pore volumes for the organic P and 9.5 pore volumes for the inorganic P, indicating an appreciable capacity for fixation of P.

A comparison of the breakthrough curves of total P for the manure extract and  $\text{KH}_2\text{PO}_4$  solution shows the effect of the organic P fraction on the movement of P. Pore volumes of 4.6 and 6.8 were obtained at  $C/C_o = 0.5$  for the manure extract and  $\text{KH}_2\text{PO}_4$  solution, respectively. Thus, P in the manure extract was not retained as readily as  $\text{KH}_2\text{PO}_4$  by the soil and movement of P in the soil was greater with the manure extract than with the  $\text{KH}_2\text{PO}_4$  solution. The greater P movement obtained with the manure extract could be due to the coating of soil particles with organic matter and a decrease in number of P fixing sites. Also, inorganic P in the manure extract may be associated or complexed by organic matter which would result in less fixation as well. The soil became saturated with P  $(C/C_o = 1)$  at pore volumes of 8.0 and 14.0 for the manure extract and  $\text{KH}_2\text{PO}_4$  solution, respectively. This indicates that the soil was capable of fixing more P from the KH<sub>2</sub>PO<sub>4</sub> solution than from the manure extract.

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Figure 6. Breakthrough curves of inorganic, organic and total phosphorus (organic and inorganic) for manure extract and KH<sub>2</sub>PO<sub>4</sub> solution--0-to 15-cm field sample.

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Pore volumes for organic and inorganic P at  $C/C_0 = 0.5$ using manure extract were 3.8 and 4.2, respectively, for the 210-to 240-cm field sample (Figure 7). This indicated that organic and inorganic P in the manure extract moved at about equal rates. Saturation  $(C/C_{O} = 1)$  was attained at a pore volume of about 11 for inorganic P while the organic P did not reach saturation even at a pore volume of 14 with the manure extract. This may have been due to errors in the measurement of inorganic and total P concentrations in the leach-The curves indicate that the soil (210-to 240-cm field sample) ates. was capable of fixing considerable amounts of organic and inorganic P from the manure extract. Pore volumes of 3.8 and 5.0 were obtained at  $C/C_0 = 0.5$  for the manure extract and  $KH_2PO_4$  solution, respectively. Thus, the soil retained P from the  $\text{KH}_2\text{PO}_4$  solution more readily than P from the manure extract and movement of P in the soil was greater with the manure extract than with the  $\text{KH}_2\text{PO}_4$  solution. Differences in movement and fixation of P between the manure extract and KH2PO1 solution were also noted for the O-to 15-cm depth. The soil became saturated with P (C/C = 1) at a pore volume of 12 for the  $KH_2PO_4$ solution but the manure extract did not reach saturation even at a pore volume of 14. This was probably due to error in measurement of total P in soils leached with manure extract. The breakthrough curves indicate the 210-to 240-cm field sample was capable of fixing large amounts of P from both the manure extract and the KH2PO4 solution.

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Figure 7. Breakthrough curves of inorganic, organic and total phosphorus (organic and inorganic) for manure extract and KH<sub>2</sub>PO<sub>4</sub> solution--210-to 240-cm field sample.

## SUMMARY AND CONCLUSIONS

Beef and milk production and confined cattle feeding units are part of many Manitoba farm enterprises. This has resulted in problems associated with accumulations of manure on farmsteads. Effects of large accumulations of manure on the soil environment, particularly with respect to P, has received little attention by researchers. A confined cattle feeding area was selected and studies initiated to determine the forms and amounts of P in the soil beneath the feedlot. Laboratory studies were also conducted to determine the mineralization rate of organic P applied as manure to flooded and non-flooded soils. Movement of both inorganic and organic P from a manure extract was studied using several soil samples from the feedlot site. The above studies were also conducted on soil samples from an adjacent non-manured field and comparisons made between feedlot and field samples.

Accumulations of manure in the feedlot affected the amounts and forms of P in the soil. Amounts of 0.5 M NaHCO<sub>3</sub> extractable P in the surface feedlot samples were very high and showed that P had moved to a depth of about 150 cm. The NaHCO<sub>3</sub> extractable P concentrations in the feedlot samples were much greater than those for samples from the adjacent non-manured field. Inorganic and organic water soluble P concentrations in the feedlot soils were also high compared to the water soluble P concentrations of samples from the adjacent field. Concentration of total P in the feedlot soil was greater than for the field soil at depths of 0 to 60 and 120 to 300 cm. Greater amounts of organic P were found in the field samples, particularly the 0-to 60-cm

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depths, than in the feedlot samples in spite of the latter having more than one-ft accumulations of manure. The C:N:P ratios of the O-to 15and 15-to 30-cm feedlot samples were 214:18:1 and 279:20:1, respectively. The C:N:P ratios of the corresponding field samples were 132: 8.7:1 and 92:5.7:1, respectively. C:N ratios for the two sites were similar.

The laboratory studies indicated that mineralization of organic P was significantly greater under flooded conditions (anaerobic) than under conditions at field capacity (aerobic) in soils treated with manure. Thus, a reducing or anaerobic environment and applications of manure were essential to obtain significant mineralization of organic P. Since anaerobic conditions usually prevail in soil under a feedlot, the low organic P concentrations in the feedlot soil were most likely due to rapid mineralization of organic P.

Rate of movement of organic, inorganic, and total P in soil was studied using a manure extract and a  $\rm KH_2PO_4$  solution. Organic and inorganic P moved at about the same rate in most soils. Organic P moved at a greater rate than inorganic P in one of seven soils investigated. Rate of movement of organic and inorganic P decreased with increasing depth for the feedlot samples. The O-to 15-cm feedlot samples appeared to be saturated with P and the 15-to 30-cm feedlot sample had only a small potential for P fixation. All other feedlot samples and the field samples exhibited a high potential for both organic and inorganic P fixation.  $\rm KH_2PO_4$  moved at a slower rate and was fixed more readily than an equivalent concentration of organic and inorganic P applied as manure extract to two field samples. The organic fraction

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of the manure extract probably retarded fixation by coating soil particles thus decreasing fixation sites and resulting in a greater P movement.

The studies reported herein indicated that movement of P occurred in soil beneath a feedlot having large accumulations of manure. Movement of P probably occurred as both organic and inorganic P as these two forms moved at about equal rates when applied as a manure extract to soil from the feedlot. The anaerobic condition existing in the soil beneath the feedlot was likely conducive to rapid mineralization and depletion of organic P in the soil. This finding suggests that release of P from organic matter of soils entering lakes or streams is greater than under field conditions.

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