THE EFFECT OF CARBON ON PHOSPHORUS AVAILABILITY TO CORN (*ZEA MAYS* L.)

by

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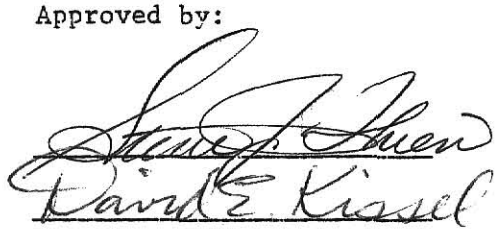

Co: Major Professors

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

LIST OF FIGURES

LIST OF FIGURES (Cont.)

LIST OF TABLES

LIST OF TABLES (Cont.)

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INTRODUCTION

Phosphorus (P) is one of the three primary nutrients required for plant growth. Unlike nitrogen and potassium, P forms compounds of low solubility when applied as inorganic fertilizer. These P compounds generally have reduced availability for plant nutrition (Tisdale and Nelson, 1975).

As a result of the reduced solubility of P compounds in the soil, a sufficient level of available P may not occur throughout the growing season. Even under ideal fertile soil conditions and intensive fertilizer P applications the level of available P may be insufficient for optimum plant growth. Therefore it is important to understand how complex P compounds may be made more available by increasing their solubility.

Soil solution P is normally very low in concentration when compared to the available P and total P levels, as a result of reduced solubility of the P compounds. Soon and Miller (1977) observed that when soil solution P increased, a significant increase in P uptake occurred. Higher P concentrations have been observed in the rhizosphere's soil solution compared to the bulk soil's (Bhat et al., 1976). By increasing the volume of soil, referred to as the rhizosphere, a higher P concentration may occur in the soil solution.

The rhizosphere is the only site of appreciable and continuous microbial activity in the soil (Barber and Lynch, 1977). This microbial activity is the result of a high energy source being

present in the rhizosphere due to carbon exudation. Extra carbon addition to the soil has been shown to stimulate microbial growth and the level of phosphatase activity (Speirs and McGill, 1979). By increasing this microbial activity zone to coincide with the fertilizer P zone, an increase in soil solution P may occur as an end result of a higher solubility of P compounds.

Hannapel et al. (1964a+b) observed significant increases in soil solution P due to carbon addition. Although, the observed increases resulted from microbially-synthesized soluble organic P and not soluble, available orthophosphate ions. It may be possible for this mobile organic P to be transformed by phosphatase enzymes into available orthophosphate ions more easily. This mineralization of organic P and the initial immobilization of fertilizer P may play an important role in increasing the solubility of P compounds.

The present research was established to determine if carbon addition will increase P solubility and P availability. More specifically, the objectives of this research were:

1) To determine if carbon addition increases mineralization of soil organic P by increasing the microbial population of the soil.

2) To determine whether carbon addition would increase the utilization of fertilizer P or if carbon addition might stimulate the release of inorganic P complexes of low solubility.

3) To determine if carbon addition increases the movement of P away from the fertilizer band, by possibly increasing soil solution P.

LITERATURE REVIEW

Introduction

The importance of phosphorus in plant nutrition has been recognized for as long as man has been trying to improve crop growth and achieve high yields. Phosphorus (P) is classified as one of the three primary plant nutrients, along with nitrogen (N) and potassium (K), which are essential for crop growth (Tisdale and Nelson, 1975).

Phosphorus has some unique characteristics pertaining to plant availability. The total P content present in the soil is considerably less than that of N and K. A large portion of this total soil P is unavailable for plant uptake. The small percentage of the total soil P that is available, is susceptible, with the passage of time, to formation of less soluble P soil components, further complicating plant availability (Brady, 1974).

Problems associated with P availability make it essential to fully understand the complex P situation so efficient fertilizer P utilization can be realized. Maintaining P availability from the many P forms present in the soil is an interesting problem facing the soil scientist of today.

Soil P

Soil P can be divided into two general forms: inorganic and organic. Inorganic P is considered the primary form most important to plant nutrition since plant roots absorb the majority of their P as orthophosphate ions. A soil test for "available-P" will ignore

the organic P form and consider the inorganic P form the dominant source of available P. The organic P fraction has been reported to make up 40 to 50 percent of the total P content present in some soils (Black, 1968). Generally overlooked, this organic P fraction is great enough to be considered as an important source of P when considering P availability.

The identification of the organic P fraction is important for determining the availability of organic P for mineralization. Bower (1949) recognized that organic P exists primarily in three principal forms: inositol phosphates, nucleic acids, and phospholipids. These three forms, which are relatively low-molecular-weight compounds, represent only approximately 50 percent of the total organic P fraction (Barrow, 1961). Fares et al. (1974) found approximate values of 7, 50, and 2 percent in the nucleic acid, inositol phosphate, and phospholipid forms, respectively. This leaves approximately one-half of the total organic P unidentified. Thomas and Bowman (1966) reported this unidentified fraction as high-molecular-weight, organic compounds, which are present in very stable and complex forms in the soil and less likely to undergo mineralization. By fractioning the organic P in terms of complexity it would be possible to determine which fraction are capable of mineralization, therefore, achieving a better understanding of organic P availability.

Bowman and Cole (1978b) used different extraction methods to fractionate the total organic P into four fractions with regard to availability for mineralization. The recovery of organic P

averaged 7, 34, 47, and 12 percent in the labile, moderately labile, moderately resistant, and highly resistant fractions, respectively. Labile P is considered the organic P fraction which is available for mineralization by certain enzymes, i.e. phosphatase. The two labile fractions mentioned, consisted of organic P complexed with simple chemical compounds. The two resistant fractions consisted of P fixed, or absorbed through complex cationic bonds, with organic matter and may be considered partly mineral in nature much like insoluble inorganic P. Forty percent of the total organic P was in the labile fractions, therefore, must be considered as a significant factor in replenishing the soil solution P.

The concentration of available P in the soil is generally small compared to the total amount of inorganic P present in the soil due to the formation of less soluble compounds. The reduction in solubility may be referred to as P retention. Generally, researchers consider P retention as being involved with precipitation and adsorption mechanisms. Precipitation refers to P compounds such as aluminum (Al), calcium (Ca), and iron (Fe) phosphates and adsorption refers to inorganic P ions which are adsorbed by cations by chemical bonds at the surfaces of soil minerals. A distinction between adsorption and precipitation is hard to resolve (Wild, 1950).

Since P adsorption occurs on the solid phase surfaces in the soil, the specific surface area of the solid phase determines the quantity and type of phosphates which are formed (Chang and Chu, 1961). Chang and Jackson (1957) classified the different types of P compounds formed during P retention into four main fraction: Al,

Ca, Fe, and reductant-soluble phosphates. The reductant-soluble phosphates were formed by adsorption and would be less soluble than the Al, Ca, and Fe phosphates.

Dunbar and Baker (1965) carried this fractionation further with the use of isotopic dilution. They classified inorganic P into six main fractions: soil solution P, Al phosphate, Fe phosphate, Ca phosphate, "insoluble" Fe phosphate, and occluded P. Aluminum phosphate is regarded as the primary source of available P replenishing the soil solution, especially immediately following a fertilizer P application. Iron phosphate may become an important source supplying soluble P as time after the fertilizer P application increases. Calcium phosphate is the primary source in calcareous soils due to the high levels of calcium present in the soil. The insoluble Fe phosphate and the occluded phosphate fractions are classified as the mineral fractions with low solubility which increase in concentration after a long period of time under cultivation, due to a decrease in organic matter and organic P.

The most important P fraction in regard to plant nutrition will be the soil solution P. Plants absorb P mainly as the soluble orthophosphate ions, $H_2PO_4^-$ and $HPO_4^{=}$ (Tisdale and Nelson, 1975). The concentration of these ions in the soil solution at any given time is very small compared to the total available P present in the soil and is constantly being depleted by plant absorption and soil retention. Adequate P nutrition requires both the labile organic P and the slightly insoluble inorganic P fractions to replenish the soil solution concentration at levels required by optimum crop production demands.

Role of P in Plant Physiology

Phosphorus plays a primary function in the physiology of the plant. Phosphorus is present in every living cell and is essential for active cell metabolism and the utilization and transfer of energy in active plant cells (Seatz and Stanberry, 1963). In the form of ATP, adenosene triphosphate, P will store and transfer energy (Salisbury and Ross, 1978). Adenosene triphosphate is also required for the production of proteins and nucleic acids essential to cell growth and maintenance. The metabolic synthesis of fats and polysaccharides is yet another important function of ATP. For these reasons, ATP is referred to as an activated form of phosphoric acid capable of many reactions that phosphoric acid is not (Noggle and Fritz, 1976). The importance of ATP implies that the enhancement of P nutrition to the corn plant would increase the overall growth and production potentials of the corn plant.

The ATP synthesis from inorganic phosphates and ADP occurs by two processes: transphosphorylation and oxidative phosphorylation. Transphosphorylation reactions occur when ACP accepts a "loosely" held phosphate group from another already phosphorylated compound found in the glycolytic pathway. Only a small fraction of the total ATP which is generated in living plant cells is produced by transphosphorylation (Noggle and Fritz, 1976). Oxidative phosphorylation is the main method of ATP synthesis. It occurs in the respiratory chain of mitochondria in conjunction with electron transfer and is very similar in nature to photosynthetic phosphorylation, a light reaction completed in the chloroplasts (Salisbury and Ross, 1978). Both

transphosphorylation and oxidative phosphorylation use glucose as an energy source and together account for the synthesis of more than 30 molecules of ATP from each molecule of glucose (Noggle and Fritz, 1976).

Phosphorus, as the central element in ATP, possesses high mobility within the plant. Moving as ATP, P is readily translocated throughout the plant from older tissues into active meristematic tissue. As physiological maturity is reached the high concentration of P found in the meristematic regions will be transferred to the grain portion of the crop (Tisdale and Nelson, 1975). Hanway (1962) found at least 50 percent of the total P in the grain at physiological maturity represented P that was translocated from above ground plant parts. This translocation of P indicates that a high P content in the shoot tissue is very critical toward increasing crop yields.

Carbon Exudation

Martin (1977) defined root exudation as substances released into the rhisosphere by actively growing plant roots. Hale and Moore (1979) described root exudates as slime material, or mucigel, which contained polysaccharides. This mucigel was excreted from cell bodies of living cells in the root cap region called the Golgi apparatus. Root exudates are usually considered materials leaked from active roots and not sloughed off material from dead or older roots. No one has yet been able to show whether the root exudates are harmful toward plant metabolism or if this carbon leakage is

simply a method of disposal for excess metabolites. It is known that soil microorganisms play an important role in root exudation. Martin (1975) found that the water soluble exudates were from microbial origin and not directly from the plant roots. In a later paper, Martin (1977) concluded that the soil microbes will enhance carbon exudation by absorbing the carbon material for use and then releasing it into the rhizosphere. It is apparent that there is a strong interaction between soil microorganisms and carbon exudation since carbon exudation occurs in the rhizosphere which is the only location in the soil where appreciable and continuous microbial activity occurs (Barber and Lynch, 1977). The increase in microbial activity in the rhizosphere due to the accessable energy from the exudates play an important, but as of yet undescribed, role in the availability of labile organic P to the plant roots.

Barber and Martin (1976) were able to partially quantify the question of root exudation. Under sterile soil conditions they showed that 5 to 10 percent of the carbon fixed during the photosynthesis process by a barley plant was released by root exudation. In the presence of soil microorganisms, 12 to 18 percent of the photosynthetically-fixed carbon was released due to root exudation. This was an equivalent to 18 to 25 percent of the total dry matter produced by the plant. For a plant to lose one fourth of it's carbohydrate energy which is available for plant metabolism would seem to put an unnecessary stress upon the plant. Therefore by decreasing carbon exudation, a plant would have more energy available for growth and production purposes.

Plant growth and soil factors, affecting plant growth, will affect carbonaceous material exuded by the roots. Vancurra et al. (1977) increased carbon exudation by increasing shoot growth. As the supply of nutrients in the shoots increased so did the amount of carbon compounds released by the plant roots. This occurred up to the time of flowering or period of greatest vegetative growth. Hale and Moore (1979) observed that a decrease in soil water content will cause a decrease in carbon exudation. They also reported a decrease in the amount of carbonaceous exudates as the pH rose above 6.4. Carbon exudation is closely associated with plant growth, since under optimium growth conditions the amount of carbonaceous exudates increased.

Carbon exudation must be considered a normal plant function associated with plant growth and determined to some extent by factors affecting plant growth. A problem could arise when carbon exudation occurs to such a great extent that it induces a metabolic stress upon the plant, therefore limiting crop yields. Carbon exudation appears to benefit P availability. Plant roots influence the soil rhizosphere by their exudates resulting in higher microbial activity. The role this higher microbial activity plays in enhancing P availability in the rhizosphere, and in turn affecting P nutrition, has only recently begun to be studied.

The Rhizosphere Effect

The soil rhizosphere is described as a nonuniform, poorly defined zone of soil surrounding each plant root. The heterogenous nature of the soil makes it impossible to define a specific volume

precisely, but an average zone of several millimeters away from the root is usually considered (Rovira and Davey, 1974).

The factors affecting P availability and phosphorous nutrition of plants are most dominant in the rhizosphere. A corn plant will take up most of it's P from within a five millimeter zone of soil around the root surface (Olsen et al., 1962). Thus an increase in the soil solution P in the rhizosphere compared to the non-rhizosphere soil would enhance P availability and consequently uptake by plant roots (Bhat et al., 1976).

Several factors may be involved in this enhancement of soil solution P. The pH of the rhizosphere is an important one. The ratio of orthophosphate ions $H_2PO_4^-$ to $HPO_4^{=}$, present in the soil solution will depend upon the pH of the rhizosphere. $H_2PO_4^-$ dominates at acidic pH levels while $HPO_4^{=}$ dominates at basic pH values. Plants absorb most of their P as the $H_2PO_4^-$ ion because they have approximately ten times more absorption sites for the $H_2PO_4^-$ ion than for the $HPO_4^{=}$ ion (Hagen and Thompson, 1955). A lower pH value should tend to increase absorption by plant roots, by favoring a large $H_2PO_4^-$: $HPO_4^{=}$ ratio.

Riley and Barber (1971) suggested that the ammonium form of nitrogen fertilizer would decrease the pH of the rhizosphere soil, thus increasing the availability of P to soybeans. The change in the pH of the rhizosphere was largely attributed to the differential absorption of anions and cations. Plant roots secrete H^+ ions into the soil following NH_4^+ absorption and OH^- ions with NO_3^- absorption in order to maintain electrical charge balance in the cell.

Soon and Miller (1977) found similar results for corn. The pH of the rhizosphere was lowered when ammonium was used as the

nitrogen source. This reduced pH was associated with an increase in soil solution P and P uptake by corn seedlings.

Carbon exudation could possibly have an effect on the pH of the rhizosphere similar to NH_4^+ nitrogen. A decrease in the pH was found when carbon exudation was increased (Hale and Moore, 1979). Carbon products leaked from roots could possibly have a positive charge thus decreasing the pH of the rhizosphere and increasing the soil solution P.

Ammonia as the source of nitrogen will initally increase the pH of the soil causing a dispersion of the organic matter present in the soil. This dispersed organic P may also play a role in transforming organic P into an available form, by allowing some of the resistant organic P fraction to be available for transformation.

Organic P Transformation

The labile organic P fraction in the rhizosphere undergoes transformation into an available inorganic form when soil conditions are right. This transformation process, commonly called mineralization, may occur throughout the growing season in substantial amounts and may help the inorganic fraction replenish the soil solution P, and the P requirements of a plant to be met.

A seasonal pattern involving the labile organic P fraction has been found in perennial range grass soils. Dormarr (1971) showed that the amount of the labile P fraction decreased when the grasses were rapidly growing and in the greatest need of P. A rapid decline of labile organic P occurred in April and May, after an overwinter buildup of organic P had occurred.

Saunders and Metson (1971) conducted similar work and suggested a possible interpretation to Dormarr's results. Soil is a dynamic system and the level of soil solution P at any certain time results from two opposing processes: first, the uptake of P by plant roots and secondly by the release of P from soil sources including the labile organic P fraction. During the spring when soil conditions are suitable for high biological activity a steady mineralization of labile organic P occurred causing the decline in organic P.

To show that this transformation of labile organic P will actually occur, Bowman and Cole (1978a) added commercial forms of organic substrates that would normally be found in the soil. They reported that the ribonucleic acid and the glycerophosphate substrates had mineralization patterns consistent with those expected for the labile organic P fraction. Some losses due to microbial immobilization did occur at the beginning but were not significant. The release of labile P that the commercial forms of organic substrates simulated, was shown to be positively correlated with the phosphatase activity and the microbial population during the growing season (Stewart et al., 1973). Therefore, the phosphatase activity and microbial population may be adequate indicators of organic P mineralization.

Phosphatase is a soil enzyme that can hydrolyze organic P into readily available inorganic P forms. Soil phosphatase activity will be the greatest in the rhizosphere and results from live microorganisms, release by actively growing roots, and the labile pool (Ramirez Martinez, 1968).

Geller and Dobsolvors'ka (1960) showed that the level of phosphatase activity in the rhizosphere was closely related to the level of microbial activity. Chang and Bandurski (1964) however reported that phosphatase was found on the root surfaces of corn and was capable of hydrolyzing labile organic P in the absence of soil microorganisms. It has been concluded that both sources of phosphatase are equally important and will not be distinguished in subsequent discussion on phosphatase activity.

The enzyme kinetics of phosphatase involves mobility of the substrate and the enzyme. The enzyme is readily adsorbed by clays once released into the soil from the roots and the microbes, rendering it immobile. Most of the organic P is relatively immobile, too, being complexed by organic matter and soil components (Skujins, 1967). This low mobility will be one reason why low amounts of organic P are transformed into inorganic P. By increasing the organic P mobility, transformation of organic P by phosphatase may be expected to increase as a result of a higher quantity of substrate being available.

In the rhizosphere phosphatase activity is great enough to react with the amount of substrate present, therefore the substrate, organic P, will be the limiting factor in the enzyme reaction. In the native soil, levels of phosphatase appear adequate but under certain soil conditions phosphatase synthesis may be inhibited resulting in a reduction of phosphatase activity. This reduction in activity may allow the enzyme to become a limiting factor, too.

Nannipieri et al. (1978) observed an increase in phosphatase activity when an extra energy source, glucose, was added to the soil.

This increase coincided with an increase in the microbial population. When an inorganic phosphate was added with the glucose, phosphatase synthesis was completely inhibited causing a gradual decline in phosphatase activity.

Spiers and McGill (1979) reported a six-fold increase in phosphatase activity when they added glucose and NH_4NO_3. With the addition of an inorganic phosphate to produce an added C:added P ratio of 20:1 the synthesis of phosphatase was completely inhibited.

These results help to explain earlier work by Wier and Black (1968) concerning organic P mineralization. They reported that addition of inorganic P inhibited mineralization of organic P and caused an increase in organic P. The inorganic P could have acted as a competitive inhibitor of phosphatase, but this is doubtful since the P ions affects phosphatase synthesis and not the activity of the existing phosphatase.

It appears that when the inorganic P level is high, such as would occur in a fertilizer band, the demand for the transformation of the labile organic P is reduced and phosphatase synthesis is inhibited. But when the inorganic P level is limiting, plant roots and rhizosphere microbes need another source of P. This is when phosphatase synthesis and activity increases, enabling the transformation of labile organic forms to possibly supply some of the needed P.

The role of organic P in plant nutrition could be likened to organic N, with regard to the C:organic P ratio and mineralization of organic P. Black and Goring (1953) theorized that during

the decomposition of plant residue, mineralization of organic P occurs if the C:organic P ratio is less than 200:1 and that immobilization occurs if the ratio is greater than 300:1. This theory of the C:organic P ratio for determining organic P mineralization had similar aspects to the C:N ratio of plant residues used to determine the mineralization of organic nitrogen.

Thompson et al. (1954) demonstrated considerable similarity in the behavior of organic P, N, and C. They reported the amount of organic P mineralized during incubation was substantial in relation to crop requirements for P under certain situations.

Enwezor (1967) studied the extent to which the C:organic P ratio influences the mineralization of stable soil organic P as compared to fresh plant residue. He failed to show a significant correlation between the C:organic P ratio and mineralization of the labile organic P fraction. He concluded that use of the ratio for predicting the mineralization of stable organic P would be unreliable and the mineralization of organic P appears to be more complex than the mineralization of organic N.

One complication with using the C:P ratio in organic matter would be the complexity of the organic P after its release from plant residue. At least half of the organic P is capable of being fixed by soil components into very stable compounds. Another problem would be the higher concentration of carbon that is present in the rhizosphere due to root exudation. This exudated carbon could cause a reduction in the mineralization of labile organic P by increasing the immobilization of the inorganic P by soil microbes.

Cole et al. (1978) determined the rates of P immobilization and mineralization following addition of C in forms similar to root exudates. The addition of glucose increased immobilization of inorganic P. This immobilized P is released when the microbial growth ceases and microbial cells are decomposed by grazers called amoebae. Approximately 50 percent of the immobilized P was released as available inorganic P. But no net mineralization of labile organic P was shown to occur.

Chauhan et al. (1979) added grass residue and cellulose and followed the change in the following P forms: labile organic, inorganic, and "immobilized" P. A sharp increase in immobilized P was seen after addition of carbon materials but decreased below steady state conditions after four weeks. Inorganic P decreased during initial build-up of the immobilized P, then increased to a constant value. Labile organic P also decreased during the microbial P build-up, but did not return to the previous level showing that some net mineralization did occur. The increase in the immobilization of inorganic P and labile organic P was the result of the carbon's effect on the microbial population. This rapid increase in immobilized P would be closely correlated with the rapid rise in microbial population. Therefore, a measurement of microbial activity should present a criteria for estimating the immobilization and mineralization of soil P.

P Movement

Phosphorus must be present at root surfaces to be absorbed. Supply to the surface is by two main processes: mass-flow and

diffusion. Both processes will involve soluble P forms. Mass-flow movement involves P ions carried by soil solution as it is being absorbed by plant roots. Diffusion movement involves a gradient, which occurs when concentration soil solution P is lower than P concentration at the root surface. Diffusion will be the dominant process (Barber, 1962).

The amount of P supplied by mass-flow will depend upon the concentration of P ions in the soil solution and the amount of water uptake per unit of root surface (Barber, 1962). Shapiro et al. (1960) concluded that by increasing the soil moisture content by frequent irrigations, a larger soil volume will be contributing to the replenishment of the soil solution P. Under field conditions, a soil solution P concentration of 0.2 to 0.3 ppm is common, mass-flow can only supply two to four percent of the total P required by a corn plant (Olsen et al., 1962). But under frequent irrigations, a three-fold increase was observed in the amount of P supplied by mass-flow.

Olsen et al. (1961) suggested the following explanation for the relationship between P movement and soil water content. When the soil moisture decreased, moisture films between roots and soil particles got thinner and the distance that the P ions had to travel increased. But under near saturated soil conditions, P ions had shorter distances to travel. This shorter distance, besides reducing the time involved, may also reduce the number of fixation sites that the P ions come in contact with and increase the P concentration in the soil solution. If the soil moisture is

adequate and the soil solution P concentration can be increased significantly, mass-flow may play a more visible role in P movement.

Fried et al. (1957) have shown that concentration of P in soil solution is governed by the solid phase since the rate of replenishment of soil solution P is much faster than the capacity of roots to absorb P. But they concluded that since P removal is just from rhizosphere soil, P uptake may be limited by the rate of movement due to the small volume of soil involved. With the addition of carbon the rhizosphere may be expanded allowing a greater volume of soil to be utilized for soil solution P replenishment and may induce a higher P availability.

When concentration of soil solution P is lower than the P concentration at the root surface, which is possible in the rhizosphere, diffusion movement will be the major movement process. The rate of P movement by diffusion depends on: concentration gradient, diffusion coefficient for the root-soil system, and area of active roots involved (Barber, 1974). The concentration gradient directly affects diffusion and is dependent upon the following factors: initial concentration of P in the soil solution, rate of P uptake per unit of root surface, rate of P movement to the root's surface by mass-flow, and capacity of the soil to replenish the soil solution P (Barber, 1962).

Regardless of which process supplies the most P to root surfaces, an important factor concerning P movement is the concentration of soil solution P. If soil moisture is adequate, a high

concentration of P in the soil solution would enhance P supplied by both processes.

Work on P movement by water transport in soil is centered around the inorganic ions to the exclusion of organic P. Hannapel et al. (1964a) examined the possibility of organic P movement, finding sucrose and plant residues, added as an extra energy source to enhance microbial activity, increased movement of organic P in columns of calcareous soil. No movement of inorganic P was observed. The organic P that moved is largely of microbially-synthesized origin. In the plant residue treatments, 75 percent of the total organic P that moved was microbially mobilized native soil P.

In a later study, Hannapel et al. (1964b) observed a 38-fold increase in organic P movement with the addition of sucrose. Again no movement of inorganic P occurred. They concluded that a large portion of the organic P that moved was associated with microbial cells and cellular debris and would not be truly in the soil solution. This organic P could not be utilized by the plant roots. But, mass-flow could possibly move this organic P debris into the rhizosphere, where phosphatase could then transform it into plant available forms (Tinker and Sanders, 1975).

It has been shown that carbon addition stimulates microbial activity and phosphatase activity. A better understanding of carbon addition's benefits to the rhizosphere is needed. One possible benefit would be the enlargement of the rhizosphere enabling a larger volume of soil to supply more available P to the soil

solution and more organic P for transformation by the phosphatase enzymes. Both occurrences would enhance P availability and improve P nutrition of the plant.

MATERIALS AND METHODS

Field Study 1980

A field experiment was conducted at the North Agronomy Research Farm, Kansas State University, Manhattan, Kansas in 1980 on corn (Zea mays L.). This research was a continuation of similar research conducted at the same location the previous year (Sorden, 1980).

The purpose of the field study was to investigate the possible effect a readily available energy source, sucrose, would have on P nutrition of corn under a very fertile soil condition. A daily application of a nutrient solution was accomplished through a drip irrigation system onto a sand trench. The purpose of the sand trench was to provide a uniform distribution area for the nutrient solution, enabling a larger volume of roots to be exposed to the nutrient solution. The four treatments utilized in this study as shown on the plot map (Fig. 1) are:

Trt. 1: Field, no nutrient solution,

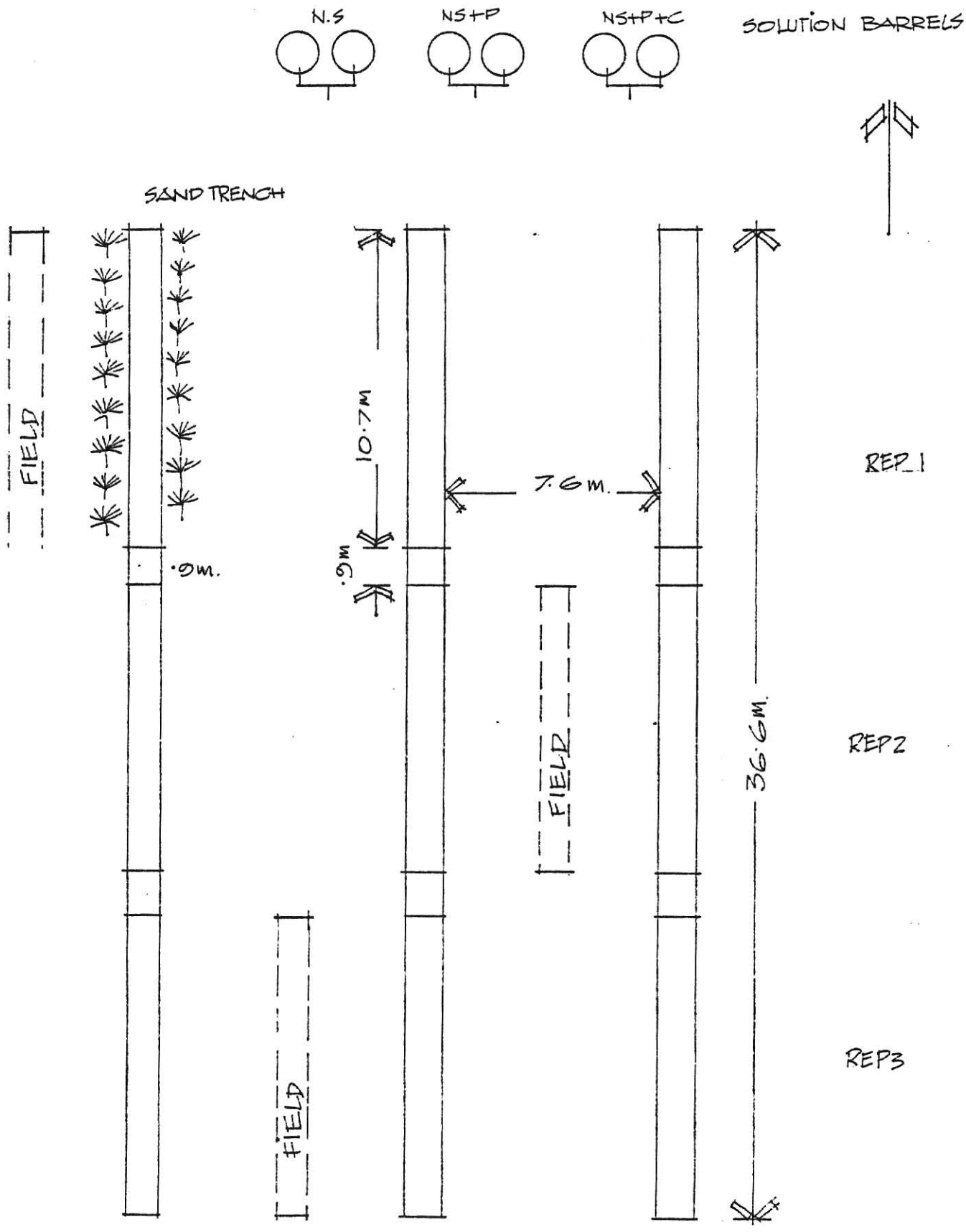
Trt. 2: Nutrient solution minus P,

Trt. 3: Nutrient solution plus P,

Trt. 4: Nutrient solution plus P and sucrose.

This study was designed using a randomized, complete block design with three replications. The individual plots were the two rows adjacent to a sand trench approximately 30 cm deep by 15 cm wide which was backfilled with a coarse river sand. Each plot was 10.7 m

Figure 1. Plot diagram of the field study (North Agronomy Farm, Kansas State University, Manhattan, KS, 1980)


N.S
NS+P
NS+P+C
SOLUTION BARRELS
SAND TRENCH
FIELD
.9m.
10.7m
.6m
7.6m.
FIELD
FIELD
36.6m.
REP 1
REP 2
REP 3

in length with a 0.9 m alley between the replication blocks. There was 7.6 m between each sand trench. A field treatment was also included (without a sand trench) allowing the comparison between nutrient solution fertilization and the general field fertilization programs.

The plot location was moldboard plowed in early spring to remove the heavy crop residue left from the previous study. The overall fertilization program was adjusted to the initial soil test (Table 1). A modified dual N-P knife applicator was used to apply 207 kg N/ha as anhydrous ammonia and 17 kg N and 56 kg P_2O_5 per hectare as ammonium polyphosphate (APP, 10-34-0). A broadcast application of ammonium sulfate supplied 49 kg N and 56 kg SO_4-S per hectare. The fertilization was conducted one week before planting.

The entire plot was then disked twice and planted with a two row Buffalo planter on 22 April 1980. A corn hybrid with a high yielding potential, Pioneer 3183, was planted in 0.76 m rows at a plant population of 84,000 plants per hectare. The purpose of the high population was to provide the capability for a high yield. The actual plot rows were planted by hand to obtain accurate populations.

Plant emergence was on 3 May and the nutrient solution application was started on 8 May. The nutrient solution was applied daily with the irrigation water required by the two plot rows. The irrigation water required was estimated by considering the water needed by a corn plant, at full canopy and evapotranspiration conditions, to be approximately six mm per day. The drip

Table 1. Initial soil analyses[a] and general information

Soil Type	Location	Studies	Soil Depth (cm)	pH	N[b]	P[c]	K[d]	Zn[e]
					(ppm)			
Kennebec silt loam Cummulic Halpludoll	Riley Co.	Field, Greenhouse Incubation	0-15	6.8	27.6	45	250+	1.12
			15-60	6.2	28.2	13	250+	0.38
Pawnee clay loam Aquic Agriudoll	Jackson Co.	Greenhouse	0-15	6.4	10.5	4	236	1.43
Pawnee clay loam Aquic Agriudoll	Jackson Co.	Incubation	0-15	5.5	9.9	6	162	---

[a]Conducted by Soil Testing Lab at Kansas State University
[b]NH_4^+ and NO_3^-
[c]Bray-1
[d]NH_4OAc Extractable
[e]DTPA Extractable

irrigation system used a 12 mil drip-hose manufactured by Chapin Watermatics Inc. Two 208 liter barrels were used to hold the nutrient solution and irrigation water for each treatment. These barrels together, allowed a head of pressure for equal flow to all three replications.

The nutrient solution was a modified Hoagland's solution that consisted of the following macronutrient containing compounds: ammonium nitrate, calcium nitrate, potassium nitrate, potassium phosphate (KH_2PO_4), and magnesium sulfate (Hoagland and Arnon, 1950). Zinc was the only micronutrient that was added in the solution. Treatment two which did not have P added used potassium chloride (KCl) to replace the equivalent amount of K normally supplied by KH_2PO_4.

The nutrients were supplied at concentrations to meet requirements for corn suggested by Hanway's growth curve (Hanway, 1962) assuming a maximum dry matter accumulation of 44,800 kg/ha. The sucrose source added, common table sugar, was equivalent to the 15 percent carbon that may be lost by the root due to carbon exudation. The concentration of each nutrient added during various time periods are presented in Table 2.

Five sampling times were schedules to correspond to early vegetative growth, tasseling, silking, dough, and harvest stages of growth. Due to abnormal moisture and temperature conditions in the corn growing season of 1980 only four sample dates were used: vegetative growth--4 June, tasseling--25 July, post-pollination--16 July, and silage harvest--12 August.

Table 2. Nutrients supplied through irrigation system during five growth periods (Field Study--1980)

Date	NH_4NO_3	$Ca(NO_3)_2$	KNO_3	KH_2PO_4	$MgSO_4$	Sucrose	N	P	K	S	C
	mg/plant/day										
9 May - 24 May	140	155	170	65	95	260	99.4	14.8	85.5	25.8	108.8
25 May - 9 June	235	255	285	95	155	340	165.2	21.6	137.6	41.3	142.8
9 June - 23 June	270	305	340	200	185	745	193.6	45.6	189.0	49.4	312.9
24 June - 2 Aug	270	305	340	228	185	1445	193.6	52.0	197.0	49.4	606.9
3 Aug - 17 Aug[a]	125	135	150	155	80	1445	87.6	35.3	102.5	21.4	606.9

[a]was not completed because of the weather conditions

Zinc was applied in the form of $ZnSO_4$ at the rate of .02 mg/plant/day

At the first three sampling dates two plants were randomly taken from each plot and composited. Plant height, leaf area, and dry weight were measured at each sampling date. Plant height was measured from the soil surface to the tip of the last leaf that had emerged from the whorl. Leaf area was measured on a Licor leaf area meter Model 3100. Leaf area was measured on all leaves that had merged from the whorl. Plant samples were placed in paper bags and dried in a forced air dryer at 60° C for five days. Dry weights of the entire plant sample were then taken.

The lack of pollination due to hot, dry weather conditions made it impossible to obtain a grain yield, so the corn was harvested as silage. The silage was harvested mechanically with a one row silage harvester modified for plot studies. The entire plot row was harvested and blown into a collection barrel attached to the machine. A load cell weighed the entire harvested row and a digital readout meter gave the total wet weight. Wet weights of subsamples, approximately 2.25 kg, were taken with a set of milk scales in the field. These subsamples were then dried at 60° C for seven days in a forced air dryer. Dry weights of the subsamples were taken and used to calculate the total dry matter yields of each silage sample.

The entire dried plant and silage samples were ground in a macro-Wiley rotary mill with a one mm screen. A large subsample was then passed through a Udy rotary abrasion mill and a 10 g subsample was stored in a sealed, plastic vial for chemical analysis for N and P.

The samples were redried at 60° C for twenty four hours prior to chemical analysis to insure dryness. A 0.25 g sample was weighed out on a Mettler analytical balance and placed into a digestion tube. A two ml aliquot of concentrated sulfuric acid and a one ml aliquot of 30% hydrogen peroxide (H_2O_2) were added to the tube (Linder and Harley, 1942). The samples were placed in digestion blocks and heated at a temperature of 375° C for forty-five minutes. The samples were then removed, allowed to cool, and an additional one ml aliquot of 30% H_2O_2 was added. The samples were reheated at the same temperature for thirty minutes. This procedure was repeated until the solution was clear. The samples were diluted to fifty ml with distilled, deionized water; mixed uniformly and stored in polyethylene bottles for future N and P analyses.

The N and P concentrations of these digestion solutions were determined by using a Technicon Auto Analyzer. The nitrogen determinations were based on a colorimetric reaction of ammonia, sodium salicylate, sodium nitroprusside, and sodium hypochlorite in a buffered medium with a pH of 12.8 to 13.0. The ammonia-salicylate complex that was produced had an emerald-green color and can be read on a spectrophotometer at 660 nm (Technicon Industrial Systems, 1977).

The phosphorus determinations were based on a colorimetric method using ammonium molybdate, ascorbic acid, and antimony potassium tartrate to react with the orthophosphate ions and produce a blue color which was read on a spectrophotometer at 660 nm (Technicon Industrial Systems, 1977).

A dilution factor of 200 was used to convert the concentration in the digestion solution to the concentration of N and P in the plant tissue.

Greenhouse Study 1980

A greenhouse study was conducted in the fall of 1980 at the Research Greenhouses, Kansas State University, Manhattan, Kansas. This experiment was developed to examine more closely the effect of sucrose on P availability and P uptake by corn under controlled greenhouse conditions. A radioactive isotope of P was utilized to determine the fate of the fertilizer P after application. Two important questions considered were if the fertilizer P solubility and the percent of the fertilizer P taken up by the plant could be increased by the addition of sucrose.

The two soils (Table 1) used were a high P soil, Kennebec silt loam, and a low P soil, Pawnee clay loam, with P soil test levels of 45 and 4 ppm respectively. The top 15 cm of the soil profiles were collected from the respective locations, then spread out and allowed to air dry at room temperature. The soils were then passed through a five mm mesh screen to remove all crop residue and large soil particles.

Approximately 33.5 kg (25.8 liter volume) of soil was packed uniformly in PVC pipe columns that were 25.4 cm in diameter and 50.8 cm in height. The bottom of the pipe columns were covered with burlap to retain the soil. The soil was fertilized by uniformly mixing 305 kg N/ha as ammonium nitrate and 3.4 kg SO_4-S/ha as zinc

Table 3. Nutrients supplied through solution application for three growth periods (Greenhouse Study--1980)

Date	NH_4NO_3	$Ca(NO_3)_2$	KNO_3	KH_2PO_4	$MgSO_4$	Sucrose	Total Nutrients Received				
							N	P	K	S	C
	mg/plant/day										
17 Oct - 28 Oct	140	150	170	30	90	260	99.4	6.8	85.5	24.0	108.8
29 Oct - 12 Nov	240	260	290	50	160	340	168.5	11.4	126.6	42.7	142.8
13 Nov - 27 Nov	280	310	340	100	190	750	198.0	22.8	160.3	50.7	315.0

Zinc was applied in the form of $ZnSO_4$ at the rate of .02 mg/plant/day

sulfate in the top 15 cm of the soil columns. A sand column with a diameter of 3.8 cm ran the entire height of the soil column. To insure a uniform distribution of the nutrient solution a fine, white, silica sand was used to fill the sand column.

The study was designed as a randomized, complete block design with eight treatments and three replications. The eight treatments were:

Trt. 1: Low P soil; nutrient solution minus P,

Trt. 2: Low P soil; nutrient solution plus P,

Trt. 3: Low P soil; nutrient solution plus P and sucrose,

Trt. 4: Low P soil; nutrient solution plus sucrose minus P,

Trt. 5: High P soil; nutrient solution minus P,

Trt. 6: High P soil; nutrient solution plus P,

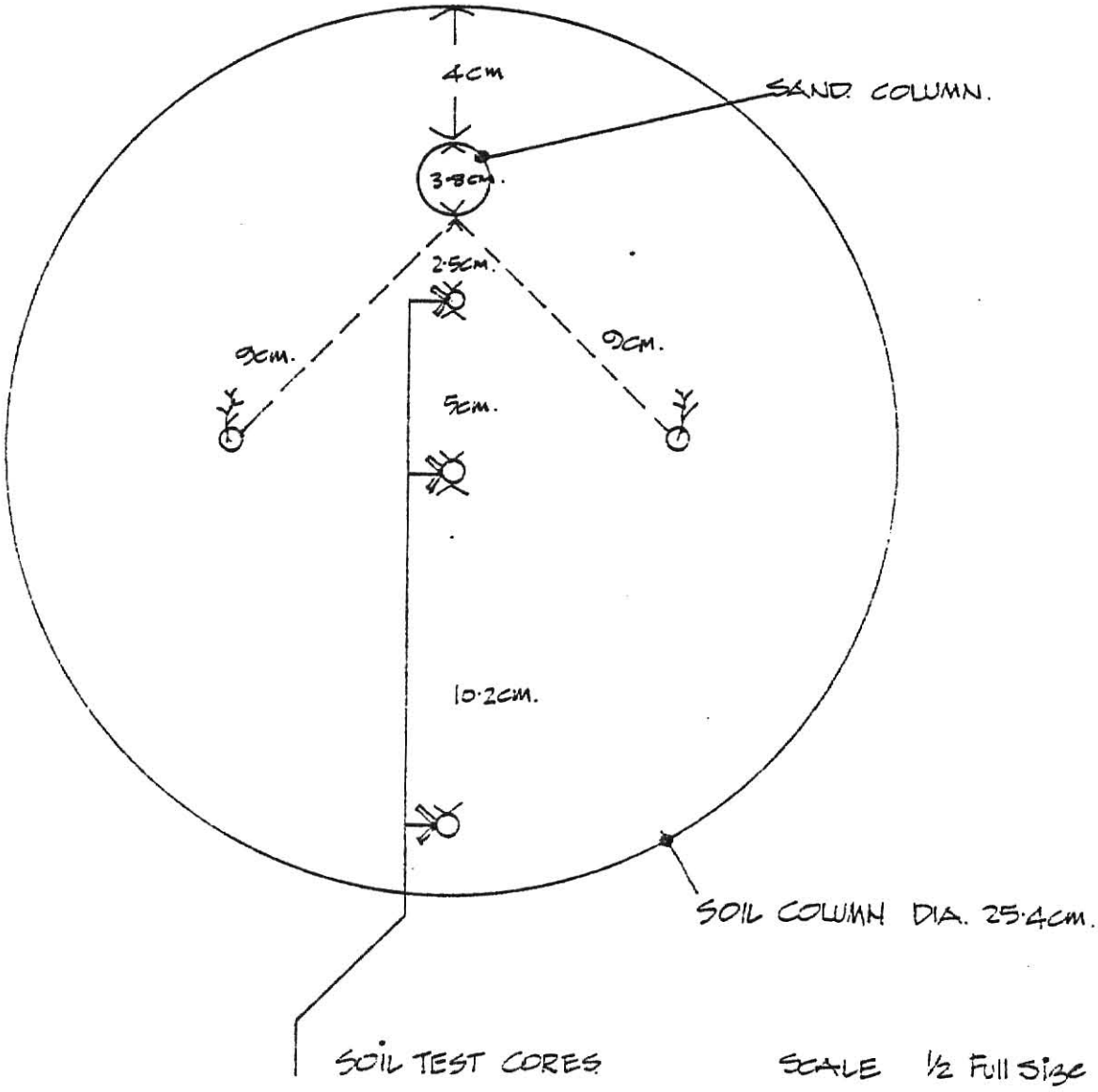
Trt. 7: High P soil; nutrient solution plus P and sucrose,

Trt. 8: High P soil; nutrient solution plus sucrose minus P.

A nutrient solution similar to the one used previously in the field study was applied daily according to Hanway's growth curve (Table 3). Potassium chloride was added to the treatments without P to replace the K normally supplied with the KH_2PO_4. The previous P concentration used in the field study had to be reduced by a factor of one half to keep the radioactivity at a safe, acceptable level.

The soil columns were watered sufficiently to keep the soil near field capacity two weeks before planting. Two seeds of the corn hybrid Pioneer 3183 were planted in each soil column. A schematic diagram (Fig. 2) shows the locations of the sand column and seed placement. Planting date was 9 October 1980 and emergence occurred six days later. Daily applications of the nutrient solutions

Figure 2. Schematic diagram showing the topview of the soil column, indicating the location of the sand column, corn plants, and soil sampling sites (^{32}P Greenhouse Study--1980).



were started on 17 October. The plants were grown forty-two days until 28 November.

The radioactive isotope used to label the P fertilizer was ^{32}P. Ten mCi of ^{32}P were obtained from New England Nuclear in the form of orthophosphoric acid in one ml of 0.02 M HCl solution. The ^{32}P isotope is a beta (β) emitter with a β_{max} of 1.71 million electron volts (MeV) and a half-life of 14.3 days.

The one ml of ^{32}P was diluted to a 100 ml volume with distilled, deionized water. Aliquots of 12, 20, and 40 ml from this solution were added respectively to the three P solutions used for the three application periods. These three ^{32}P solutions were diluted to a final volume of one liter. An initial specific activity of 400 µCi ^{32}P/g P was needed to have a final specific activity of 52 µCi ^{32}P/g P. The three ^{32}P solutions in order of application period had total activities of 393.8, 820.4, and 1680.9 µCi. Five ml aliquots were mixed with the remaining nutrient solution and irrigation water and added to each respective treatment per day. The same quantity of water was applied to each soil column per day to keep the soil moisture slightly below field capacity.

To reduce the human handling of the ^{32}P solutions a special metering device was developed. A five ml automatic pipet was used to reduce the human error involved in hand pipeting an aliquot. The closed tubing system reduced the possibility of spillage, adding a safety aspect in the everyday handling of the radioactive isotope.

The survey meter with an end window Geiger-Mueller tube was used to make qualitative measurements on the activity found in the

leaves and the whorl of the plant. The purpose of these measurements was to determine a relative time at which the corn plant would take up the fertilizer P and if sucrose would enhance the fertilizer P uptake. Measurements with the Geiger-Mueller tube were taken on four dates 31 October, 7 November, 14 November, and 21 November. A piece of lead material was placed around the window to hold the background interference at a minimum.

At harvest the two plants per pot were measured seperately and then averaged as one sample. Plant height, leaf area, and dry weight were measured as growth components. Plant height was measured from the surface of the soil to the tip of the last leaf which had emerged from the whorl. The plants were cut off at the soil surface and all the leaves stripped from the stalk. A Licor leaf area meter, Model 3100, was used to measure the leaf area. The entire plant sample was then placed in paper sacks and dried in a forced air dryer at 60° C for five days. Total dry weights were taken on a Mettler top-loading balance.

Soil samples were taken from the ^{32}P treatments to examine the movement of the fertilizer away from the sand column. On a line midway between the two plants, soil samples were taken 2.5, 5, and 10 cm away from the sand column (Fig. 2). A metal tube with a diameter of 1.5 cm was used for sampling the entire depth of the soil column. The profile sample was divided into four depths: 0-7.5, 7.5-15, 15-30, and 30-45 cm. The soil samples were placed into soil sample bags and dried in an oven at 40° C for 24 hours.

The soil columns were cut open vertically using a power saw, to visually examine the root distribution throughout the column. The entire soil column was sieved with a two mm screen to remove the majority of the roots. The entire root sample was placed in paper bags and dried in a forced air dryer at 60° C for five days and weighed on a Mettler top-loading balance for total dry weight.

The root and plant samples were prepared for chemical analysis as described in the preceding section. The chemical analyses of N and P were conducted as previously described, with an exception of a smaller dilution volume of 25 ml being used. The smaller dilution was used to insure safety in handling the radioactive digestion solutions.

The assay of the radioactivity of the tissue samples was conducted on a five ml aliquot of the original sulfuric digestion solution. A 15 ml aliquot of Aquasol, a scintillation solvent, was pipetted into a glass, liquid scintillation vial and mixed well with the five ml sample. A blank was prepared by adding a five ml aliquot of 2.9 N sulfuric acid and a fifteen ml aliquot of Aquasol. Three standards were prepared using a 0.2 ml aliquot of each of the three ^{32}P reference solutions, a 4.8 ml aliquot of 2.9 N sulfuric acid, and a 15 ml aliquot of Aquasol.

On 5 December, a Beckman LS-100 Liquid Scintillation System (ambient temperature soft-beta spectrometer) was used to count the radioactivity of the samples. Each sample was counted for 10 minutes to minimize the counting error to less than 0.05 percent. This reading was then converted to counts per minute (CPM). The

sample reading was corrected for background radiation by subtracting the blank's reading from the sample reading. Because the half-life of ^{32}P is relatively short, 14.3 days, the specific activity of the ^{32}P in the final plant sample was calculated using the specific activities of the three ^{32}P solutions as follows:

Mass of P found in 0.2 ml of three standards

1) 4.8×10^{-4} g P for growth period 1,

2) 8.0×10^{-4} g P for growth period 2,

3) 1.6×10^{-3} g P for growth period 3.

Specific activity for three standards

$$SA = \frac{\text{Net CPM for standard}}{\text{g of P in standard}}$$

1) 1.35×10^{8} CPM/g P

2) 1.37×10^{8} CPM/g P

3) 1.33×10^{8} CPM/g P

Mean specific activity for final ^{32}P content

1.35×10^{8} CPM/g P

Calculations used for converting CPM to percent P from fertilizer P in the plant tissue are described by the following equations.

$$\text{g of fertilizer P in sample} = \frac{\text{Net CPM of sample}}{1.35 \times 10^{8} \text{ CPM/g P}}$$

%P from fertilizer found in tissue =

$$\frac{\text{g of fertilizer P in sample}}{\text{g of P in chemical analysis}} \times 100$$

The assay, radioactivity of the soil samples, was conducted in a manner similar to the previous tissue procedure. The dried

soil samples were ground by hand with mortar and pestle, then redried in an oven at 40° C for 24 hours to insure dryness. A one g sample of soil was weighed out on a Mettler analytical balance and placed into a digestion tube. A seven ml aliquot of concentrated sulfuric acid was added and the previously mentioned digestion procedure was followed. The digestion solutions were counted for activity on 13 December using the previously mentioned assay preparation and counting procedures described above. The readings were left in the form of CPM for statistical analysis.

Incubation Study 1981

An incubation experiment was initiated in June 1981 to determine if addition of a carbon source (sucrose) to the soil might increase P availability by enhancing the mineralization of organic P. Also studied was the level of available soil P and the rate of inorganic P application effects on organic P mineralization.

The experimental design was a randomized, complete block with three replications. A 3 X 3 X 2 fractorial was used in order to investigate the three factors involved with organic P mineralization. Three C rates used were 0, 1, and 2 mg C/g soil (equivalent to 0, 2240, and 4480 kg C/ha). Three P rates used were 0, 20, and 40 µg P/g soil, (equivalent to 0, 45, and 90 kg P/ha). The two soils used were a Kennebec silt loam and a Pawnee clay loam with available P soil test levels of 45 and 6 ppm, respectively (Table 1).

Soil preparation for the experiment was carried out by collecting the top 15 cm of the soil profiles and air drying at

room temperature. The soils were passed through a five mm mesh screen to remove plant debris and then sieved through a two mm sieve to insure uniform soil particle size. The soils were placed in a Freas 815 incubator set at a temperature of 27° C. The soil water content was maintained at approximately 18 percent by weight. A three week incubation period was utilized to allow the microbial activity to equilibrate to near normal field conditions, which had been disrupted during the drying and sieving processes.

After the incubation period, 50 g of soil were weighed out into 125 ml bottles. Two g of vermiculite were added to improve the physical condition of the soil. Then a total of five ml of solution were slowly added with pipettes to each bottle, enabling a good uniform mixing of the soil and solution. A one ml aliquot containing 75 g N/g of soil as ammonium nitrate was applied to each bottle. The remaining four ml consisted of a two ml aliquot of the required sucrose and two ml aliquot of the required P, which were added separately. Treatments with zero rates used distilled, deionized water to make up the five ml.

The experiment was started on 9 June. In order to investigate the rate of mineralization of organic P, samples were analyzed at different times after starting the experiment. Three sampling times used were one, two, and four weeks from the start of the experiment. To reduce error in sampling three times from the same bottle, the entire study was replicated three times allowing an entire bottle to be sacrificed for analysis at each sampling time. At each sampling time the CO_2 evolved, soil solution P, inorganic P, and total P were

measured. Organic P was then estimated by subtracting the inorganic P value from the total P.

Microbial activity determination: To measure the microbial activity in the soil, the carbon dioxide (CO_2) evolved was trapped in a sodium hydroxide (NaOH) solution. A five ml aliquot of 2.9 N NaOH was transferred into a glass vial using a buret. The vial was placed inside the bottle of soil and an air tight lid was attached. The bottles were placed into a Freas 815 incubator at a temperature setting of 27° C.

The measurement of the CO_2 evolved was conducted by a titration procedure (Willard and Furman, 1940). The contents of the glass vial were transferred into a 125 ml beaker and the glass vial was rinsed several times with distilled, deionized water. A 15 ml aliquot of 2 N barium chloride ($BaCl_2$) was added to precipitate the carbonates out of the solution. This left only the sodium hydroxide not neutralized during incubation in the solution. Five drops of phenolphthalein indicator were added changing the solution to a pink color. The solution was then titrated with 0.5 N hydrochloric acid (HCl) to a colorless end point. The amount of HCl used in the titration procedure was then used in calculating the mg of CO_2 evolved. The following calculations were used:

$$meq_{NaOH} = 2.9 \text{ meq/ml} \times 5 \text{ ml} = 14.5 \text{ meq}$$

$$meq_{HCl} = .5 \text{ meq/ml} \times \text{ml used}$$

$$meq_{CO_2} = 14.5 - meq_{HCl}$$

$$\text{mg } CO_2 = meq_{CO_2} \times 22 \text{ mg/meq}$$

Soil solution P determination: A water extraction procedure was utilized to obtain the soil solution. Twenty g of soil were weighed from each bottle and then saturated with 20 ml of distilled, deionized water. The soil solution was then extracted by vacuum filtration for 30 minutes using a Buchner funnel. The filtrate was then filtered twice through Whatman No. 2 filter paper to remove all cloudiness in the solutions. A four ml aliquot of a working solution, used for P determination, was added to the filtrate, which was then diluted to a final volume of 50 ml with distilled, deionized water.

The concentration of P in the filtrate was determined by the method of Murphy and Riley (1962) in which the formation and reduction of phosphomolybdic acid is brought about by an acidic molybdate solution (working solution). This working solution was made up from two stock solutions, an acid molybdate solution and an ascorbic acid solution.

To prepare the acid molybdate solution 60 g of ammonium molybdate, $(NH_4)_6Mo_7O_{24}\cdot 4H_2O$, were dissolved in 200 ml of distilled water by heating to 60° C. After allowing the solution to cool at room temperature, 1.455 g of antimony potassium tartrate was added. Then 700 ml of concentrated sulfuric acid, H_2SO_4, were slowly added to the molybdate solution. The solution was then diluted to a final volume of one liter and stored in a dark glass bottle at 4° C.

In preparing the ascorbic acid stock solution 132 g of ascorbic acid were dissolved in distilled, deionized water. The solution was then diluted to one liter and stored in a dark glass bottle at 4° C.

A working solution consisting of 50 ml of acid molybdate stock solution and 20 ml of ascorbic acid stock solution was prepared every day. The working solution was then diluted to 250 ml with distilled, deionized water (Knudsen, 1980).

After the addition of the working solution, the samples were allowed to stand for ten minutes to allow blue color development. A reading of absorbance was then taken on a Bausch and Lomb Model 88 spectrophotometer at 882 nm. A standard curve was used to convert the absorbance readings to ppm of P found in the solution.

Organic P determination: An ignition method was utilized for determining soil organic P. This method, similar to the one described by Legg and Black (1955), involves extracting comparable soil samples of ignited and non-ignited soil with an acid and determining the inorganic P in the extracts. The increase in extracted inorganic P resulting from the ignition procedure provides an estimate of the organic P content of the soil.

Two one g soil samples were weighed from each bottle, one into a 50 ml beaker and the other into a 50 ml digestion tube. The sample in the 50 ml beaker was ignited in a muffle furnace at 550° C for one hour and then also transferred into a 50 ml disgestion tube. The purpose of the high temperature was to mineralize the organic P into inorganic P. Then both samples were extracted with concentrated HCl.

A ten ml aliquot of concentrated HCl was pipetted into the digestion tubes and the samples mixed for 30 seconds with a Vortex

mixer. The digestion tubes were then placed in digestion blocks and heated at 70° C for ten minutes. Another ten ml aliquot of concentrated HCl was then added and the samples mixed again for 30 seconds on a Vortex mixer. The samples were allowed to stand for one hour at room temperature. The extracts were filtered through Whatman No. 2 filter paper into a 50 ml volumetric flask and diluted to volume.

A ten ml aliquot of the filtrate was pipetted into a 100 ml beaker to readjust the pH of the filtrate. The samples were adjusted to a pH of 2.5 with 5 N ammonium hydroxide (NH_4OH). Solution pH was then measured on each individual sample with an Orion pH meter, Model 601A. The adjusted solutions were then filtered through Whatman No. 2 filter paper into 100 ml volumetric flasks. An eight ml aliquot of the working solution, previously mentioned, was added and the solution diluted to volume. Reference standards were prepared in a similar manner. The samples and standards were read according to the previous procedure.

Statistical Analysis Procedure

The data collected from the three experiments were analyzed statistical by Statistical Analysis System (SAS) developed at North Carolina State University and available at the computer center at Kansas State University. A 5 percent level of significance was used to express any differences. Figure used for the results and discussion section were obtained from a Calcomp plotter and plotting program developed by Kemp et al. (1976).

RESULTS AND DISCUSSION

Field Study--1980

At the first sampling date, 4 June, no significant responses to addition of either C or fertilizer P were observed (Table 4). The lack of response to C addition and fertilizer P at this first sampling date was probably a result of the high fertility status of the plot soil. The amount of available P, soil test P of 45 ppm, present in the soil was probably sufficient to satisfy the plant requirements for the early part of the growing season.

Growth response to C addition became apparent at the second sampling date, 25 June. Corn plants receiving C addition with fertilizer P showed slight, but insignificant, increases in the plant height, leaf area, and dry weight (Table 4). Plants receiving fertilizer P, but no added C, had lower values indicating the differences observed visually resulted from the C addition. It appeared these trends became apparent as: (1) time after P application increased and, (2) as plant demand for P increased. The combination of these two factors probably reduced the available P present in the soil, and allowed a response to C addition. Although this response was statistically insignificant at the second sampling date, we believed the differences would tend to become greater later in the growing season as the two factors became more involved.

As the demand for P increases later in the growing season, a response to added C would be expected to become significant. But, by the third sampling date, 16 July, extremely hot and dry weather

Table 4. Effect of C addition and fertilizer P on growth components of corn (Field Study-1980-North Agronomy Farm, Manhattan, KS)

Treatment	Plant Height (cm/plant)	Leaf Area (cm^2/plant)	Dry Weight (g/plant[a])
	----------6/4/80----------		
Field	51.8	1631.9	30.0
Nutrient - P	50.0	1608.3	27.1
Nutrient + P	47.8	1674.8	29.5
Nutrient + P + C	48.5	1659.1	27.4
LSD (.05)	ns	ns	ns
	----------6/25/80----------		
Field	170.2	7136.2	92.3
Nutrient - P	174.0	6888.0	89.8
Nutrient + P	171.5	6780.7	77.3
Nutrient + P + C	180.8	7363.6	97.7
LSD (.05)	ns	ns	ns
	----------7/13/80----------		
Field	225.7	7255.5	224.6
Nutrient - P	234.0	7525.3	220.2
Nutrient + P	236.3	7625.2	208.4
Nutrient + P + C	242.3	7071.1	204.5
LSD (.05)	ns	ns	ns

[a]shoots only

conditions created an undue stress upon the corn plants erasing the differences previously observed. Instead, variability developed in the study due to the moisture and temperature stresses, disguising the C addition response.

Precipitation for the three month growing season considered in the study is shown in Table 5, as measured by the Physics Department at Kansas State University, Manhattan, Kansas. The deficit, exceeding 22 cm, was well over half the normal rainfall level expected for this three month period. The high plant population and early excessive vegetative growth required more water under these extreme drought and evapotranspiration conditions than could be supplied by the irrigation system used.

Table 5. Rainfall for 1980 growing season

(Manhattan, KS)

Month	Rainfall (cm)	Deficit (cm)
May	4.57	-6.48
June	7.14	-7.70
July	3.05	-8.08
Total	14.76	-22.26

In the last week of June and the first three weeks of July, a very critical period for the reproduction process of the corn plant, no measureable precipitation was recorded. Included in this period of

no measureable precipitation was a seventeen day period when temperatures exceeded 38° C. This extremely hot period was very detrimental to the grain yield of the corn crop. With tasseling and silking occurring within this period, pollination was reduced significantly.

Pollination was estimated at less than ten percent of normal, making a grain yield measurement useless. A decision was made to harvest the study as corn silage and calculate total dry matter yields. The yield data, shown in Table 6, was very inconsistent and the differences present probably resulted from variation due to uneven moisture and temperature stresses instead of a C addition response. A slight response to C addition did occur in the P content of the silage tissue, as percent P increased to .239 with the C addition with fertilizer P compared to .222 with fertilizer P without C, however, due to the variation in the data the difference was not significant at the .05 probability level.

Table 6. Effect of C addition and fertilizer P on total dry matter yield and P content (Field Study-North Agronomy Farm-1980)

Treatment	Total Dry Weight (kg/ha)	%P
Field	11,853	.205
Nutrient solution - P	14,537	.220
Nutrient solution + P	15,372	.222
Nutrient solution + P + C	14,236	.239
LSD (.05)	ns	ns

Harvest date--12 August 1980

The increase in precent P found in the silage tissue and the growth responses observed visually at the second sampling date, represented sufficient evidence for us to believe that the C addition with fertilizer P may increase P availability in the soil. More research, however, is needed to investigate what effects C additions have on P availability.

Geenhouse Study--1980

The results of the previous described field study suggested that C addition to the fertilizer zone may have a positive effect on corn growth by possibly enhancing P availability and uptake. A greenhouse study was initiated to investigate the C addition effect more thoroughly. By exercising careful control over environmental conditions it should be possible to reduce variables that might obscure responses in the field.

Two soils with different available P soil test levels, 4 and 45 ppm, were used in this experiment to investigate the effect C has on P availability. As was expected, significant differences in plant growth due to available P levels were observed. Mean values of plant height, leaf area, and dry weight, shown in Table 7, were significantly higher for the high P soil.

As a result of the soil P levels, the corn plants grown on the low P soil were very responsive to fertilizer P. A visual response to fertilizer P was clearly evident as a result of P deficiency in the low P soil. Plant height and leaf area measurements were significantly higher due to adding fertilizer P. Dry

Table 7. Effect of C addition and fertilizer P on growth components and P content of corn (^{32}P Greenhouse Study--1980)

Soil P Level (ppm)	Nutrient Additions[a]	Plant Height (cm)	Leaf Area (cm^2)	Dry Weights		%P	
				Shoots (g)	Roots (g)	Shoot	Root
4	None	53.3	524.2	1.9	0.51	.119	.088
4	+P	82.5	2036.4	10.2	1.57	.321	.166
4	+P+C	90.5	2101.9	12.3	1.83	.327	.162
4	+C	59.7	517.3	2.0	0.44	.111	.101
45	None	85.0	1647.7	8.5	1.49	.181	.117
45	+P	78.2	1996.9	10.3	1.52	.326	.172
45	+P+C	82.5	1925.5	10.6	1.37	.329	.177
45	+C	86.0	1514.0	6.9	1.37	.145	.099
LSD (.05)		16.9	292.5	2.6	.53	.060	.021
Mean Values:							
Soil P Level:							
4		71.5	1295.0	6.6	1.09	.219	.129
45		82.9	1771.0	9.1	1.44	.245	.141
LSD (.05)		8.4	146.2	1.3	.26	ns	.011
Nutrient Addition:							
None		69.2	1086.0	5.2	1.00	.150	.102
+P		80.3	2016.6	10.3	1.54	.324	.169
+P+C		86.5	2013.7	11.4	1.60	.328	.169
+C		72.8	1015.7	4.5	0.90	.128	.100
LSD (.05)		11.9	206.8	1.8	0.37	.043	.015

[a]Nutrient solution was added to each treatment

weight of the roots and shoots were increased three and five times, respectively, by the addition of fertilizer P. These responses to fertilizer P were also observed in the P content of the plant, as significantly higher levels were observed in the roots and shoots.

A slight growth response could be observed visually when C was added with fertilizer P. This response was also evident in the plant height, leaf area, and dry weights of the roots and shoots, however, the response was not significant at the .05 probability level. Total P content of the roots and shoots did not show a significant difference with C addition. The reason for the lack of response to C addition might have been a result of the length of time the corn plants were grown. In the field study, a response to C addition did not occur until midway through the growing season, when the soil possibly could not meet the plant's requirements. The greenhouse study was conducted for only six weeks due to limitations in the greenhouse and may not have offered sufficient time for a significant response to develop.

Adding C in the absence of fertilizer P did not cause plant growth to differ from the control treatments. The P level in the low P soil may have been simply too low to allow C addition to affect P availability. Only when C was added in conjunction with fertilizer P did a response occur in the low P soil.

The growth responses to fertilizer P additions were more pronounced on the low P soil than on the high P soil. The available P soil test level of 45 ppm appeared sufficient to eliminate any significant difference due to fertilizer P, however, leaf area and

dry weight measurements did indicate a slight increase to fertilizer P additions. A significant response to fertilizer P was also indicated in the P concentration of the roots and shoots. Even though 45 ppm is considered a high available soil P level and capable of supplying the required amount of P (Thomas and Peaslee, 1973), according to their P content, the corn plants still required fertilizer P to obtain optimum plant growth.

The addition of C without fertilizer P to the high P soil reduced plant growth (Table 7). A visual deficiency, purpling of leaves, was observed early in the experiment. Leaf area and dry weight measurements indicated a significant response to fertilizer P, as did the total P content of the roots and shoots. The reason for this increase in fertilizer P response may have been a result of an increase in the microbial population. The C addition may have stimulated the microbial population, therefore increasing the microbial's demand for P. This increased demand for P would decrease the available P level and initiate a significant response to fertilizer P to become more visual (Chauhan et al., 1979).

The addition of C with fertilizer P indicated some visual but no measured growth components differences. However, a slight response to C addition was evident in the P content of the root and shoot tissue. Although this response was insignificant at the .05 level, it appeared that a trend similar to the one occurring in the previous field study may have developed if the experiment would have been conducted longer than six weeks.

These insignificant results would only allow us to theorize that the level of available P in the soil with fertilizer P added

appeared to be sufficient enough to supply the plant's P demands during the early stages of growth. However, as time progressed in the growing season, P demands could not be met allowing for slight differences due to C addition to develop. We believed that significant growth differences may have occurred later in the growing season. More research is required to develop this theory further.

Utilization of fertilizer P: Fertilizer P was tagged with the radioactive isotope, ^{32}P, to assist in calculating the corn plant's utilization of fertilizer P and to determine if C addition affected fertilizer P utilization. The data presented in Table 8, describe the effect of C addition on fertilizer P utilization.

Mean values for the percent P of the roots and shoots from the fertilizer indicated a significant difference due to the available soil P level. Plants in the low P soil utilized more fertilizer P than those in the high P soil, as was evident by the significant responses to fertilizer P observed in the low P soil.

The percent of total plant P obtained from the fertilizer indicated a slight increase due to C addition for the low P soil. This response is defined more clearly by observing total fertilizer P uptake, expressed as mg P per plant. Plants receiving fertilizer P with a C addition utilized 34.6 mg fertilizer P per plant compared to 27.7 mg fertilizer P utilized per plant when C was omitted. Although this difference was not significant at the .05 probability level, it supported the slight growth components increases that were observed with the addition of C. Carbon addition did not significantly affect the plant's utilization of fertilizer P, however, if the

Table 8. Effect of C addition and soil P level on fertilizer P utilization by corn (^{32}P Greenhouse Study--1980)

Soil P Level	Nutrient Additions	%P From Fertilizer P		Fertilizer P Uptake (mg P/plant[a])
		Shoot	Root	
4	+P	78.8	76.5	27.7
4	+P+C	80.4	77.2	34.6
45	+P	59.6	52.7	21.5
45	+P+C	64.6	59.6	23.8
LSD (.05)		3.2	4.1	10.4
Mean Values:				
Soil P Level:				
4		79.6	76.9	31.2
45		62.1	56.1	22.6
LSD (.05)		2.3	2.9	7.4
Nutrient Additions:				
+P		69.2	64.6	24.6
+P+C		72.5	68.4	29.6
LSD (.05)		2.3	2.9	ns

[a]Both shoots and roots

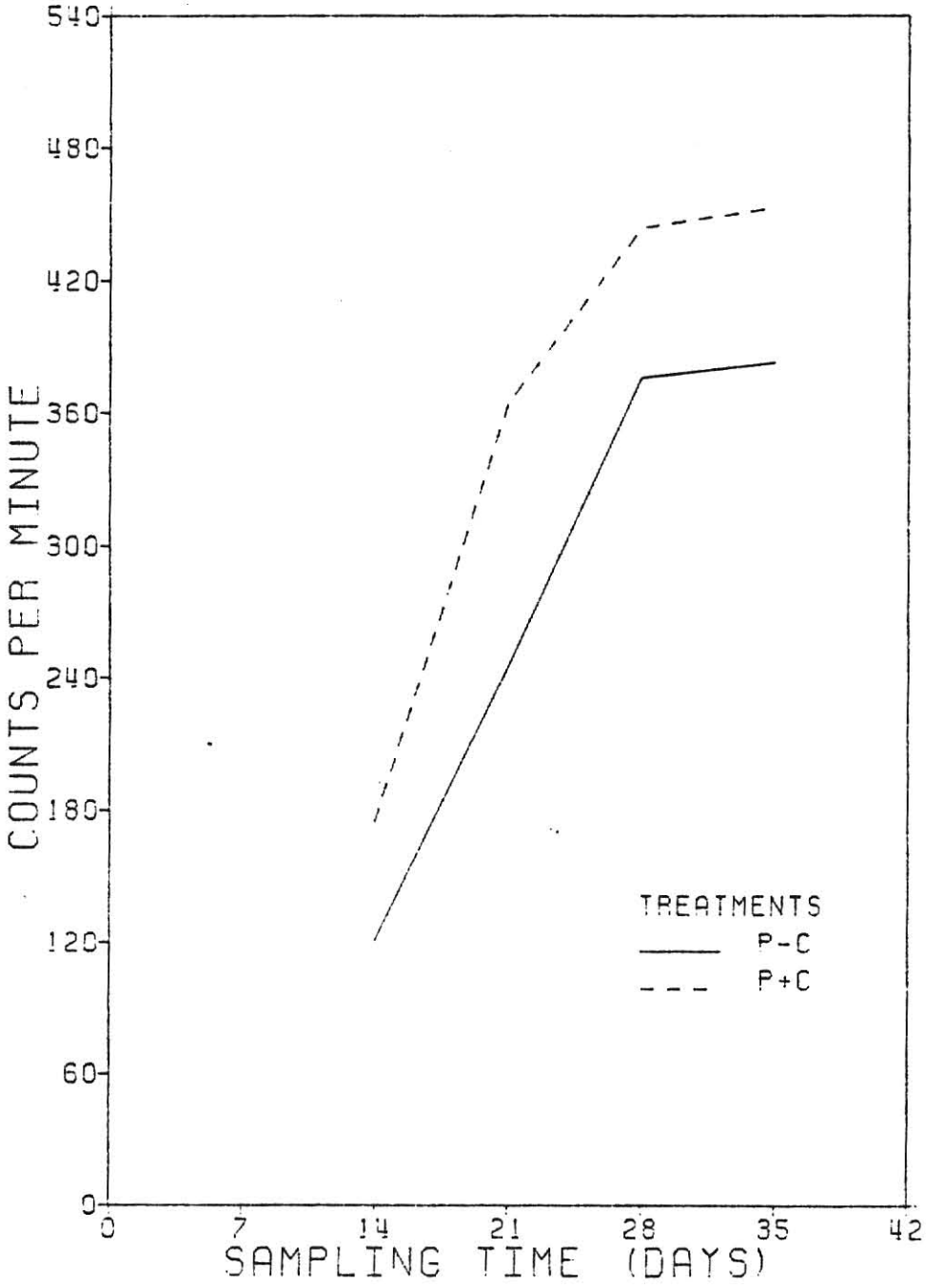
experiment had been conducted to physiological maturity significant differences may have appeared.

Measurements of the radioactivity in the corn leaves were conducted on the live plant throughout the duration of the experiment. The level of radioactivity was used as an estimation of the fertilizer P utilized during the growth of the corn plant. These measurements could not be converted into quantitative values, but indicated a similar trend as observed in the final fertilizer P uptake values. Figure 3 represents the differences in ^{32}P uptake by corn leaves as a result of C addition to a low P soil.

A leveling off in activity was present in both treatments after four weeks. This leveling off may indicate that the majority of the P was being accumulated during the first four weeks of growth; or, it may be a result of P being translocated from older leaves to the actively growing plant parts as the same leaf was sampled throughout the experiment. A dilution effect on the radioactivity, due to the increase in leaf size with time, may have also been a reason for the leveling off. The measurements did not consider the half-life decay process of the radioactive isotope.

The percent of total plant P obtained from the fertilizer was significantly higher as the result of C addition with the fertilizer P to the high P soil (Table 8). This significant increase in the utilization of fertilizer P as a result of C addition was not observed in the growth components measured and the total P content of the roots and shoots. I believe that as a result of C addition the more efficient utilization of fertilizer P may have appeared in

Figure 3. Effect of C addition observed on the measurements of radioactivity found in corn leaves grown on a low P soil, 4 ppm P (^{32}P Greenhouse Study--1980)



the growth and P content of the plants later in the growing season.

The measurements, presented in Figure 4, describes the time factor in more detail. The first four weeks of the experiment no response to C addition occurred, possibly due to the high level of available P, but as time went on a slight difference appeared to develop. The difference due to C addition was disguised due to the leveling off in activity that occurred in both treatments possibly a result of P translocation and a dilution effect. The measurements did not consider the half-life decay process and could not be converted into quantitative values.

The mean values of the percent of total plant P obtained from the fertilizer (Table 8) indicated a significantly higher level of fertilizer P due to C addition for both soils. This difference possibly suggests that the addition of C may enhance fertilizer P utilization, regardless of the soil P level.

P Movement: The effect of C addition on P availability was investigated further by examining the possibility of fertilizer P mobilization. The soil sampling procedure, described previously, was initiated to determine the effect of C addition on P movement away from the band or in this experiment, the sand column. Qualitative measurements were conducted on the radioactivity of the soil and expressed as counts per minute (CPM) to estimate fertilizer P movement. These qualitative measurements shown in Table 9, will be discussed in relative terms and not quantitative values.

Phosphorus movement in the low P soil did not increase significantly due to the C addition. The low level of available

Figure 4. Effect of C addition observed on the measurements of radioactivity found in corn leaves grown on a high P soil, 45 ppm P (^{32}P Greenhouse Study--1980)

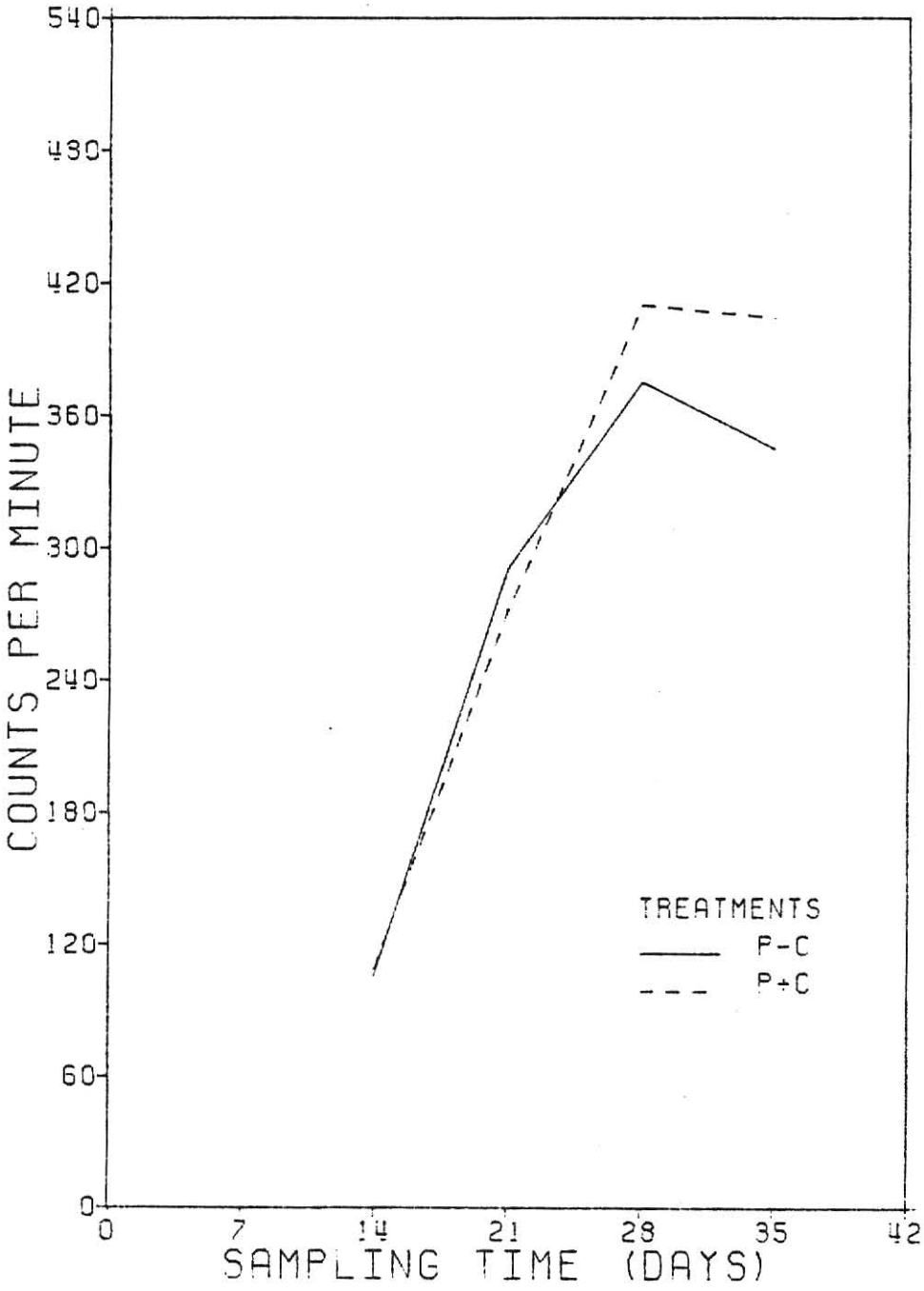


Table 9. Effect of C addition on fertilizer P movement at 2.5 cm from the band (^{32}P Greenhouse Study--1980)

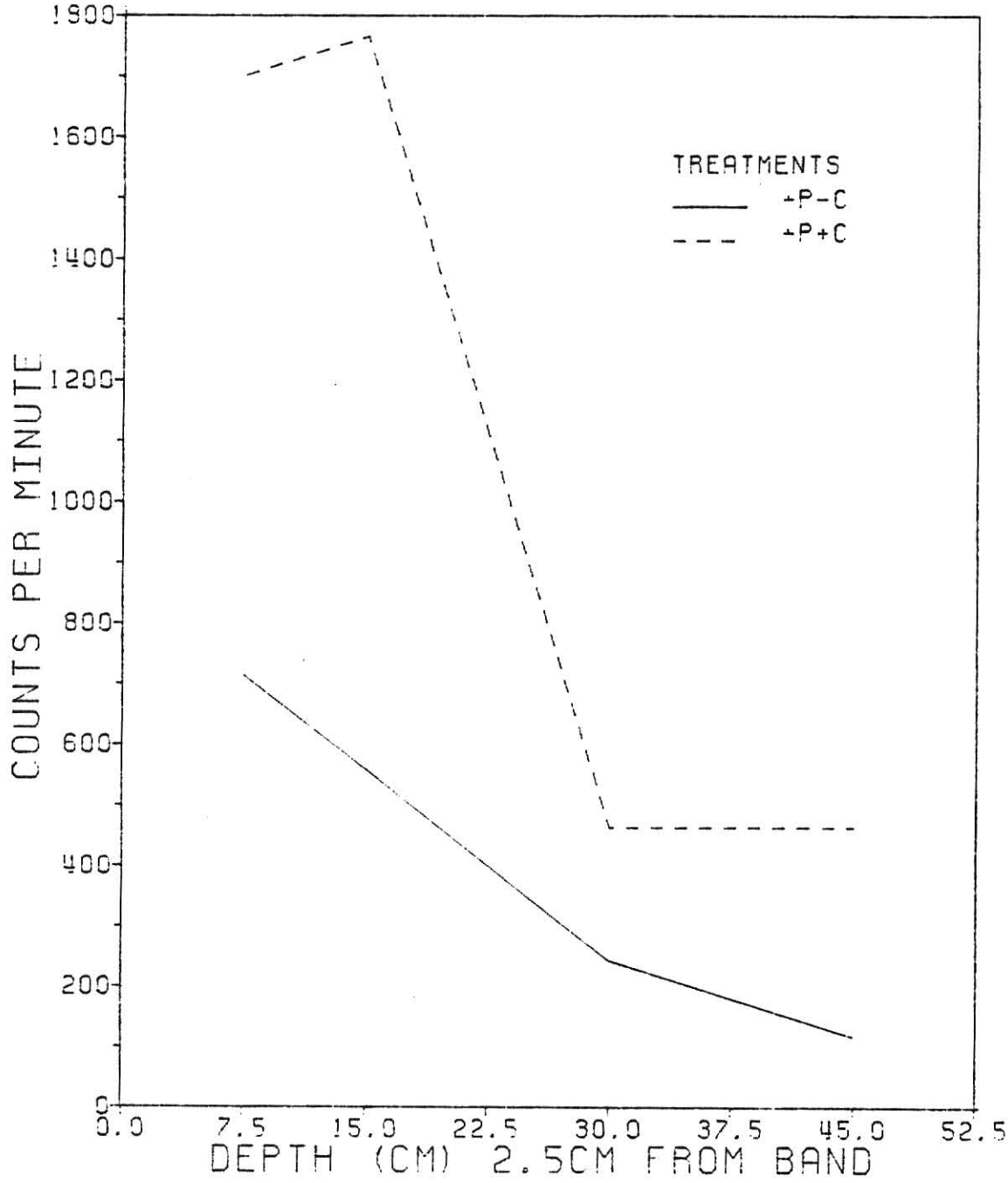
Treatment	Soil P Level (ppm)	Depth (cm) 0-7.5	7.5-15.0	15.0-30.0	30.-45.0
		counts/min.			
+P	4	628	129	72	77
+P+C	4	443	162	114	89
+P	45	713	559	243	243
+P+C	45	1702	1766	818	463
LSD (.05)		429	553	639	100
Mean Values:					
Soil P Level:					
	4	536	145	93	83
	45	1206	1146	531	290
	LSD (.05)	303	391	435	71
Carbon Additions:					
	-C	671	344	158	97
	+C	1072	964	466	276
	LSD (.05)	303	391	ns	71

P present in this soil may have indicated that a large number of sites, capable of P fixation and retention, were present (Chang and Chu, 1961). Therefore, when the fertilizer P was applied to the soil, a large number of fixation sites may increase the number of highly insoluble complexes. These complexes are largely unavailable to be utilized by the plant (Dunbar and Baker, 1965), therefore, the additional C may have less opportunity to increase soil solution P and enhance fertilizer P mobilization.

For the high P soil, the treatments receiving the C addition with fertilizer P indicated a significantly higher level of radioactivity, 2.5 cm from the sand column (Fig. 5). This increase in activity occurred throughout the height of the soil column. No significant differences due to C addition were observed at the two further distances, 5 and 10 cm, from the sand column (Appendix 2). The significant increase in activity suggested an increase in movement of fertilizer P away from the sand column as a result of C addition.

The effect of C addition on increasing fertilizer P movement may be linked to two possible explanations. A biological explanation suggests that the C addition will initially increase the microbial population, therefore increasing the immobilization of inorganic P (Chauhan et al., 1979). This microbially, immobilized P will be released into the soil solution as the soil microbes are decomposed. The microbially-synthesized organic P may be readily transferred in the soil solution (Hannapel et al., 1964a), where it may be subjected to mineralization by phosphatase enzymes and transformed into available P.

Figure 5. Effect of C addition on the movement of fertilizer P at 2.5 cm from the band in a high P soil, 45 ppm P (^{32}P Greenhouse Study--1980)



The quantity of P transferred by this process may not be sufficient enough to account for the significantly higher movement that occurred as a result of C addition.

Another possibility involves a chemical reaction resulting in the enhancement of fertilizer P movement by C addition. The significantly higher activity levels may be a result of an increase of inorganic P observed in the soil solution. Carbon addition to the bulk soil, similar to carbon exudates in the rhizosphere, may possibly increase microbial populations and the attending phosphatase activity. As a result of these higher microbial phosphatase levels, increases in organic P mineralization may occur, possibly resulting in a higher P concentration in the soil solution. By supplying additional C, the volume of soil classified as the rhizosphere may be enlarged. This larger rhizosphere would enable a larger volume of soil to be capable of supplying P to the soil solution, therefore possibly increasing P mobility and availability. The increase in soil solution P concentration means more P available to be moved by the mass-flow process (Barber 1962), which may in turn result in P being moved greater distances.

Available P levels (Bray-1 method) for the top three depths of the high P soil, shown in Table 10, were highly correlated at the .01 probability level (R^2 = .95) with the ^{32}P activity measurements. This correlation provided creditability to the theory that the higher activity levels may possibly represent fertilizer P movement, resulting from a higher concentration of P present in the soil solution. Additional research is required to address the

question of the increase in soil solution P and how C addition affects the increase.

Table 10. Effect of C addition on available P[a] levels at 2.5 cm from the band (^{32}P Greenhouse Study--1980)

Treatment	Soil P Level (ppm)	0-7.5	7.5-15	15-30	30-45
		cm			
		ppm			
P	45	171	124	66	43
P+C	45	271	284	143	62
	LSD (.05)	73	95	69	ns

[a]Bray-1 method

Incubation Study--1981

Results from the two previous experiments have indicated some plant growth responses to C addition with fertilizer P. The greenhouse study indicated that C addition may have increased fertilizer P movement away from the band. A significant higher level of fertilizer P utilized by the plant may have been due to an increase in fertilizer P mobilized. An incubation study was initiated to investigate in more detail why C addition may affect P movement. We believed that C addition may possibly increase soil solution P by extending the high microbial activity zone to coincide with the fertilizer zone, thereby possibly allowing a greater volume of soil to supply P to the soil solution.

Microbial Activity: Carbon additions to soil have been shown to increase the levels of carbon dioxide (CO_2) evolved (Nannipieri et al., 1978). The level of CO_2 evolved is a good indicator of the levels of microbial activity present in the soil. The CO_2 levels, shown in Table 11, are presented in accumulative amounts as measured over the four week period that the experiment was conducted. A significant increase was observed with each additional increment of C added. Treatments receiving 2 mg C/g soil had an accumulative increase of 2.18 mg CO_2/g soil over treatments receiving 1 mg C/g soil and 4.32 mg CO_2/g soil over treatments receiving no C. The significant differences due to C addition were not affected by the rate of P fertilization. This indicated that fertilizer P had no inhibitory effect on microbial activity such as had been discovered in phosphatase synthesis (Spiers and McGill, 1979). The soil's initial, available P level also had no effect on the CO_2 evolved.

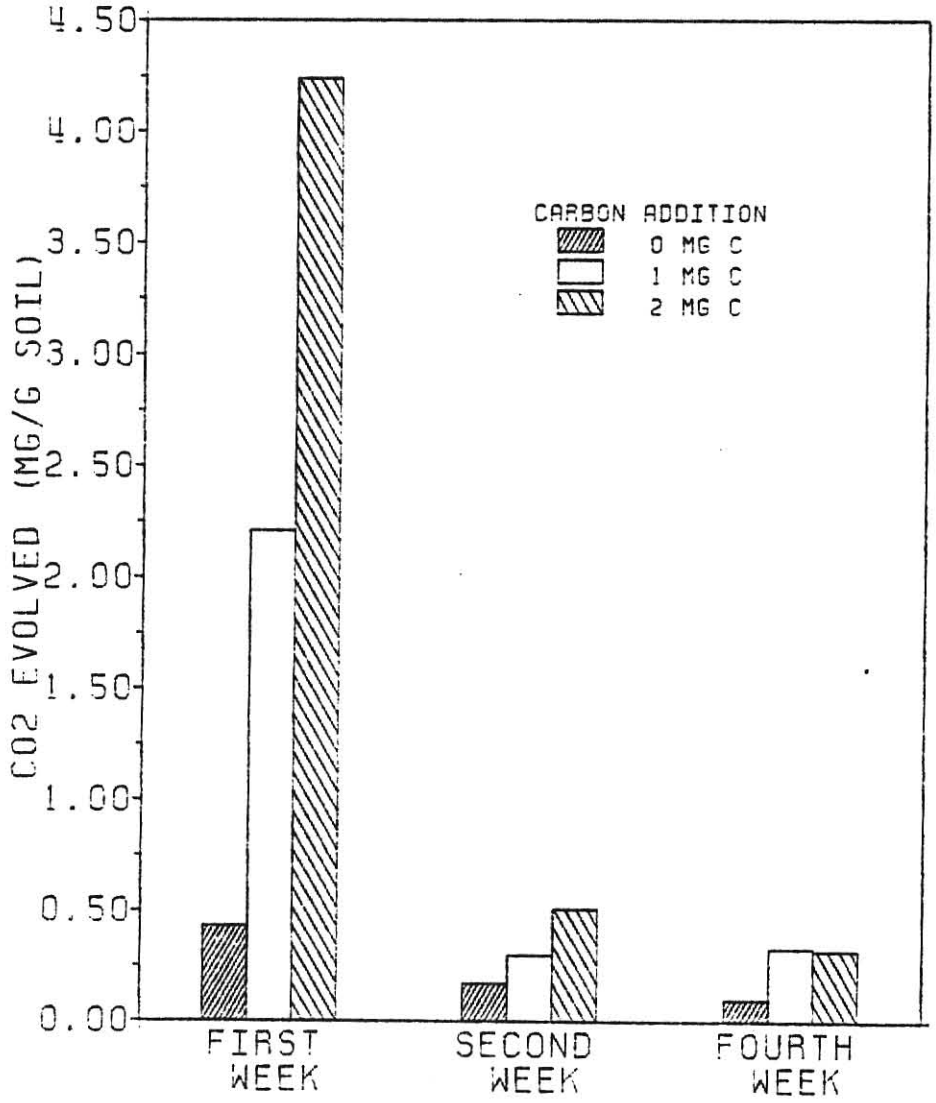
Three sampling dates were used to determine the dynamics of the microbial populations. Figure 6 clearly shows that the majority of the total CO_2 evolved was produced by the first sampling time. The C source used, sucrose, was a readily, available energy source that could be utilized rapidly by soil microbes, therefore accounting for the microbial bloom occurring in the first week's sampling. A more stable C source, i.e. plant residue, might have delayed this microbial bloom. By the second week's sampling the microbial activity had returned to near steady state conditions and was at steady state conditions by the fourth week's sampling.

Organic P Mineralization: Soil levels of organic P, as measured at the three sampling times, are shown in Table 12. Over

Table 11. Effect of C addition, fertilizer P, and soil P level on the accumulative evolvement of CO_2 (Incubation Study--1981)

Soil P Level (ppm)	P rate (µg/g soil)	C Addition (mg/g soil)	Weeks		
			1st	2nd	4th
			---mg CO_2/g soil----		
6	0	0	0.40	0.70	0.60
6	0	1	2.03	2.48	2.97
6	0	2	4.19	4.88	5.10
6	20	0	0.48	0.57	0.86
6	20	1	2.19	2.53	2.89
6	20	2	4.05	4.50	5.18
6	40	0	0.48	0.54	0.78
6	40	1	2.20	2.39	2.89
6	40	2	4.33	4.85	5.21
45	0	0	0.48	0.68	0.74
45	0	1	2.24	2.52	2.82
45	0	2	4.22	4.74	4.99
45	20	0	0.59	0.66	0.70
45	20	1	2.34	2.53	2.89
45	20	2	4.25	4.79	4.94
45	40	0	0.45	0.75	0.81
45	40	1	2.25	2.59	2.87
45	40	2	4.37	4.77	5.01
		LSD (.05)	0.26	0.22	0.35
Mean Values:					
	Soil P Level:				
	6 ppm		2.26	2.61	2.94
	45 ppm		2.36	2.67	2.86
		LSD (.05)	0.09	ns	ns
	P Rate: (µg P/g soil)				
	0		2.26	2.67	2.87
	20		2.32	2.60	2.91
	40		2.35	2.65	2.93
		LSD (.05)	ns	ns	ns
	C Addition: (mg/g soil)				
	0		0.48	0.65	0.75
	1		2.21	2.51	2.84
	2		4.24	4.75	5.07
		LSD (.05)	0.11	0.09	0.14

Figure 6. Effect of C addition on the mean level of CO_2 evolved per week for both soils (Incubation Study--1981).



the entire experiment, mineralization, as shown by the reduction in the organic P level, occurred regardless of the treatment. The quantity of organic P mineralized appeared large, ranging between 21 to 60 ppm P, for the relatively short time span the experiment was conducted. However, work conducted by Thompson et al. (1954) indicated a mineralization rate ranging between -4 and 45 ppm P for 25 different soils over a 25 day time period. The soil, moisture and temperature, conditions must have been at optimum levels for this amount of mineralization to occur in such a short period of time. Figure 7 presents the mean values of organic P for the high and low P soils. Both soils showed an increase in organic P levels after the first week. This increase probably coincides with a microbial population bloom. These higher organic P levels possibly represent the immobilization of fertilizer P, resulting from an increase in P required by the higher microbial population (Chauhan et al., 1979). However, the CO_2 evolved was not correlated with the organic P levels. An explanation for this lack of correlation is unclear at this time.

Figure 8 shows the effect of fertilizer P on mean organic P levels. Organic P increased significantly with the addition of fertilizer P at the first week's sampling. The addition of fertilizer P may provide more available P for microbial immobilization. A significantly higher level of organic P was observed at the 20 µg P rate than the 40 µg P rate, indicating that the higher P rate might have inhibited microbial activity and reduced the immobilization rate. But, P rate had no effect on the CO_2 evolved, therefore

Table 12. Effect of C addition, fertilizer P, and soil P level on soil's organic P level (Incubation Study--1981)

Soil P Level (ppm)	P Rate (µg P/g soil)	C Addition (mg C/g soil)	Initial Organic P (ppm)	Organic P (ppm) ------Weeks------- 1st	2nd	4th
6	0	0	102	102.0	77.7	79.3
6	0	1	102	100.1	78.7	78.7
6	0	2	102	96.7	74.0	78.3
6	20	0	102	124.0	94.7	91.3
6	20	1	102	124.3	90.3	93.0
6	20	2	102	115.3	89.7	94.0
6	40	0	102	112.7	94.0	102.3
6	40	1	102	117.3	94.0	111.0
6	40	2	102	116.0	96.7	105.3
45	0	0	150	154.0	112.0	90.0
45	0	1	150	158.0	107.7	96.7
45	0	2	150	159.7	108.0	94.3
45	20	0	150	174.3	108.3	114.0
45	20	1	150	183.3	112.0	114.7
45	20	2	150	167.7	109.3	102.7
45	40	0	150	165.7	131.7	132.0
45	40	1	150	160.7	135.7	125.0
45	40	2	150	174.0	132.0	123.3
		LSD (.05)		10.2	11.3	9.4
Mean Values:						
Soil P Levels: (ppm)						
6			102	112.1	87.7	92.6
45			150	166.4	117.4	110.3
		LSD (.05)		3.4	3.8	3.1
P Rate: (µg P/g soil)						
0			126	128.5	93.0	86.2
20			126	148.2	100.7	101.6
40			126	141.1	114.0	116.5
		LSD (.05)		4.2	4.6	3.8
C Addition: (mg C/g soil)						
0			126	138.8	103.1	101.5
1			126	140.7	103.1	103.2
2			126	138.2	101.6	99.7
		LSD (.05)		ns	ns	ns

Figure 7. Effect of original available P levels on organic P level (Incubation Study--1981).

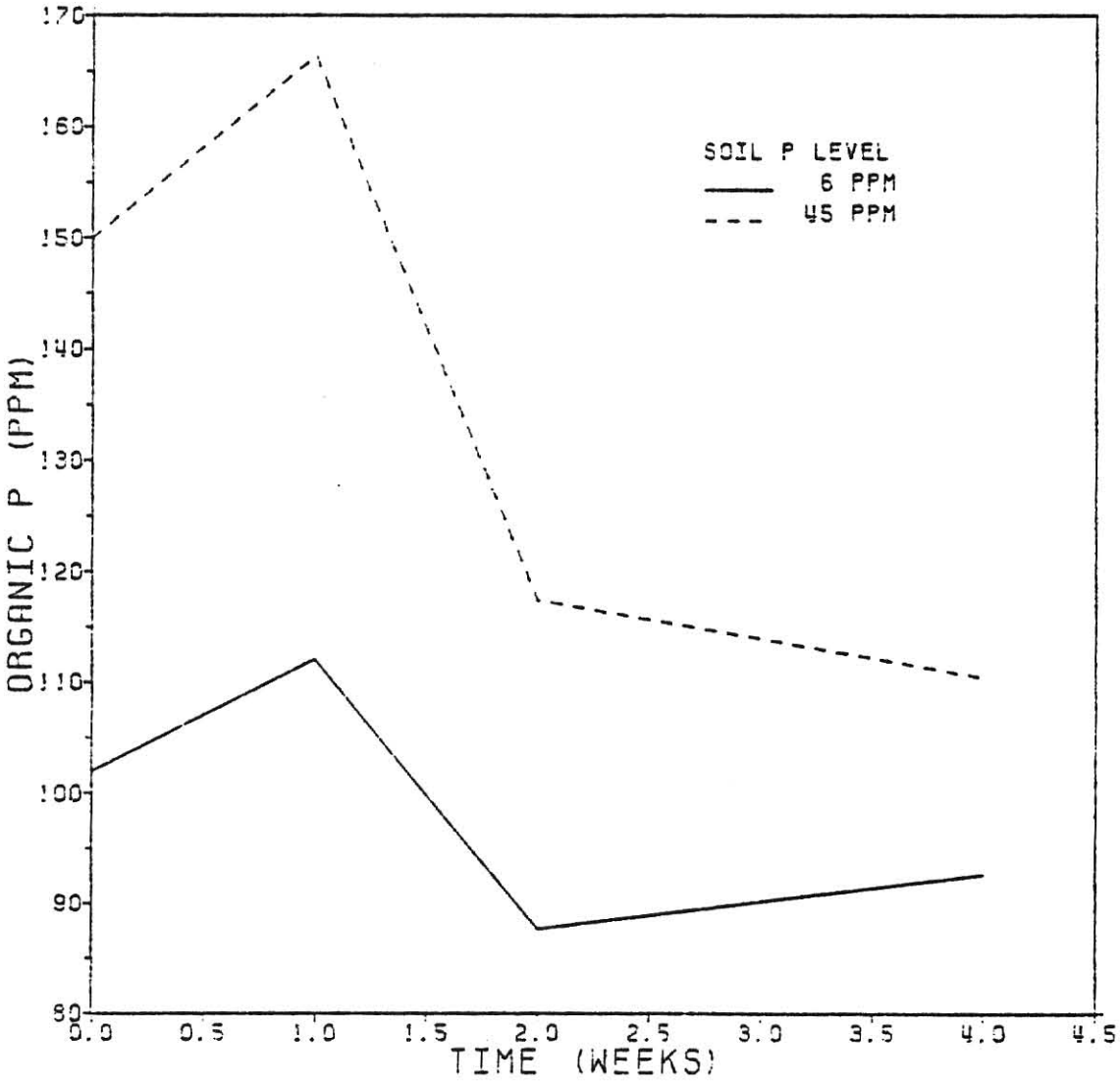
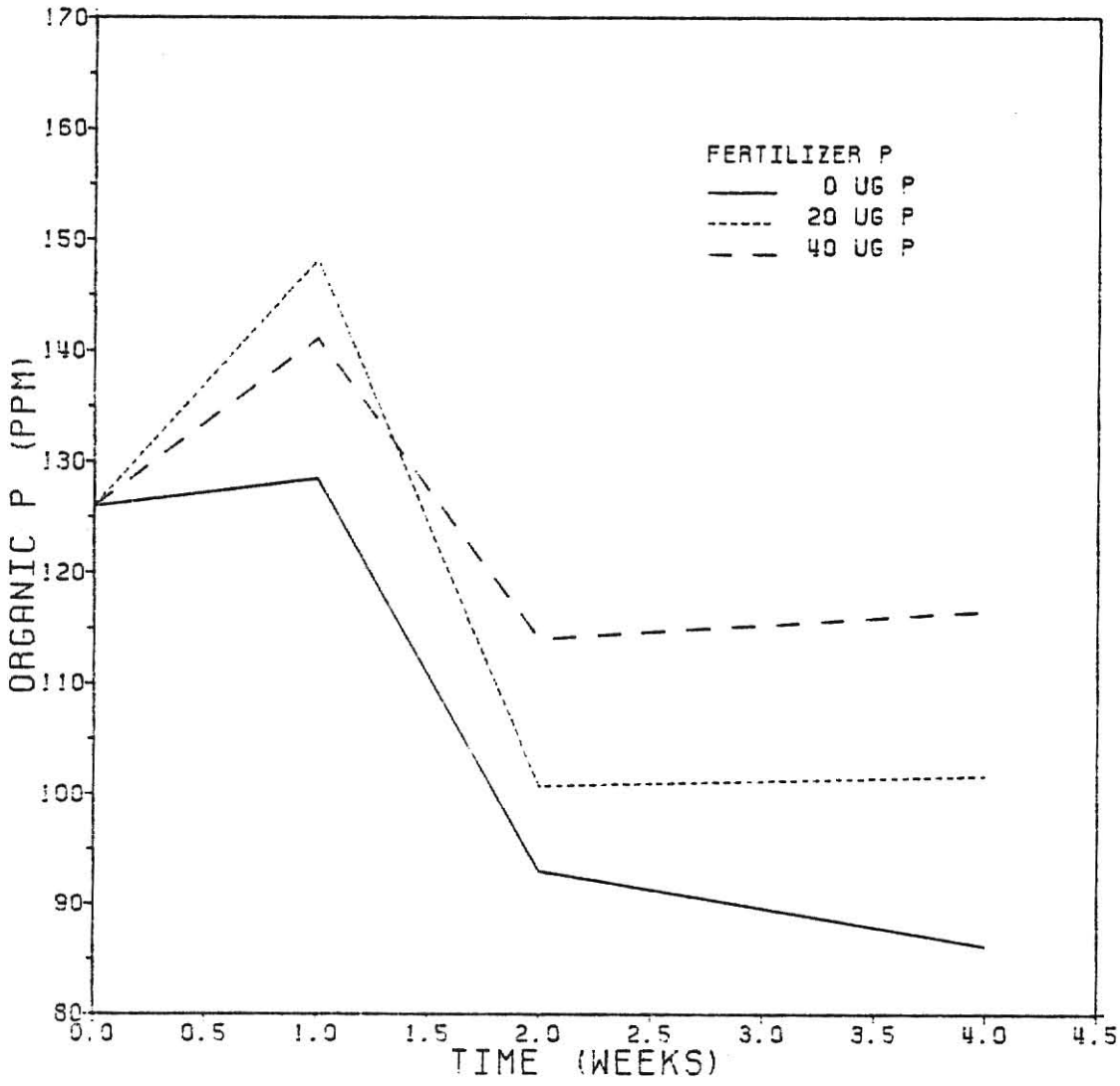


Figure 8. Effect of P fertilization on mean organic P level of both soils (Incubation Study--1981).



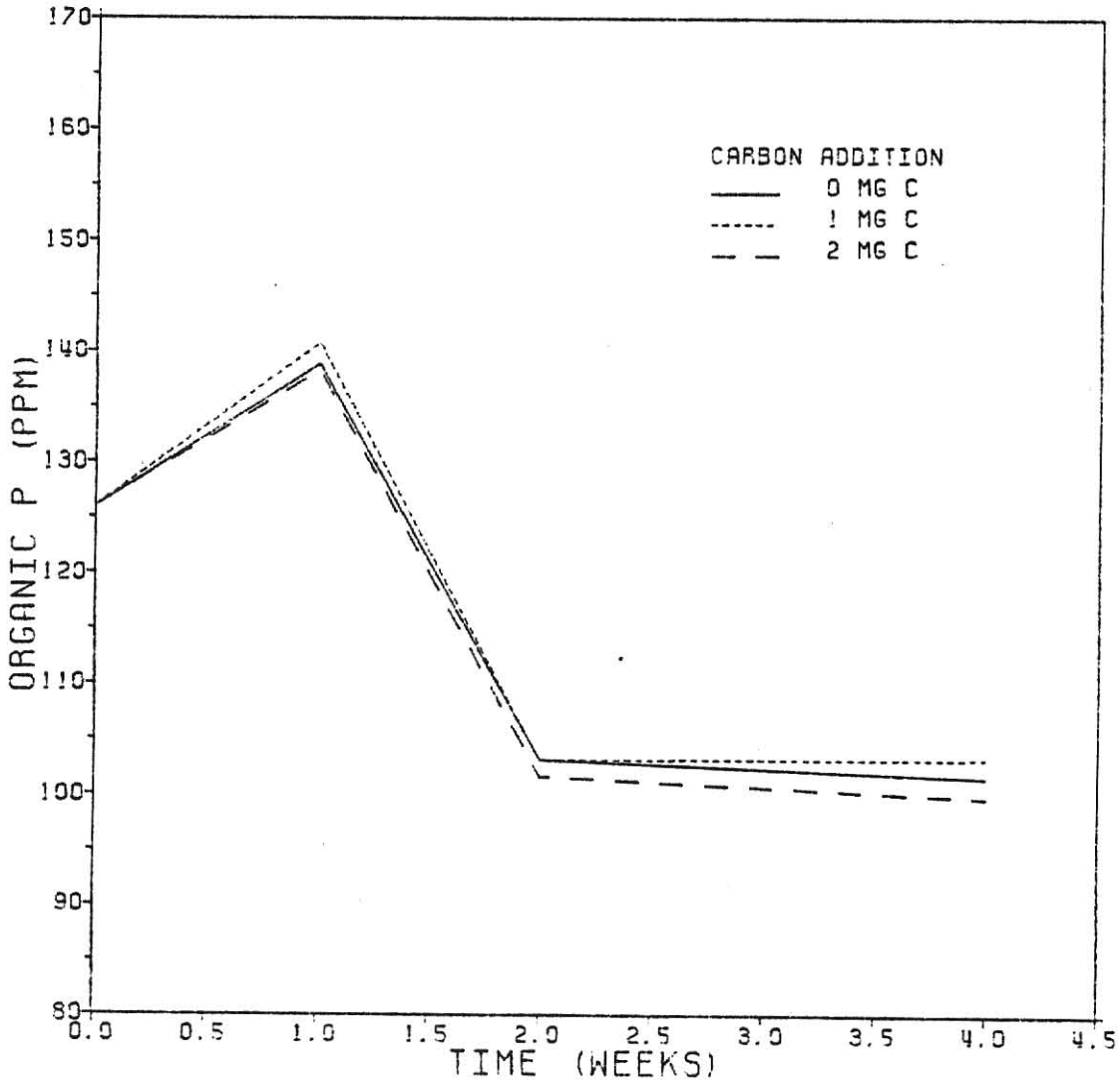
the explanation is unclear at this point. At the second week's sampling a reduction in organic P occurred, indicating mineralization of organic P coincided with a decrease in microbial activity, although no correlation was observed. By the fourth week's sampling mineralization had leveled off similar to the level of CO_2 evolved. There is no clear explanation for the lack of correlation between the organic P level and level of CO_2 evolved. They appear to increase and decrease at similar times but no correlation was observed throughout the experiment.

The results of this experiment indicate that application of fertilizer P significantly increases the level of organic P, indicating a reduction in the mineralization rate. Wier and Black (1968) observed similar results and concluded that inorganic P fertilization may appear to inhibit organic P mineralization by increasing the immobilization of inorganic P.

After the first week's microbial bloom and increased immobilization of fertilizer P, a net mineralization did occur even at the highest P rate. The data indicates that organic P mineralization rate was not inhibited, but instead was delayed due to the increase in immobilization of fertilizer P.

Adding C with fertilizer P did not result in any significant effect on the organic P levels (Fig. 9). An increase in immobilized P was observed at the first week's sampling possibly due to the microbial bloom, but no differences due to C addition were observed. Likewise, mineralization did occur at the second and fourth week's

Figure 9. Effect of C addition on mean organic P level of both soils (Incubation Study--1981).



samplings but, again no significant differences were observed.

From these results it may be concluded that C addition did not affect the mineralization of organic P. Instead fertilizer P had a significant effect on the level of organic P and the mineralization rate. The increase in fertilizer P movement observed in the greenhouse experiment may be a result of some other occurrence besides mineralization.

Soil Solution P: The previous greenhouse experiment indicated that adding C enhanced P movement. It was theorized that the increase in movement of fertilizer P away from the band resulted from an increase in soil solution P. The measurement of the soil solution, described previously, was initiated to investigate whether an increase in soil solution resulted from the addition of C.

The same three sampling periods were used as in the CO_2 and organic P measurements. Experimental error caused the first week's sampling data to be discarded from the results shown in Table 13.

Figures 10 and 11 represent the soil solution P observed for all nine treatments for the low and high P soil, respectively. An increase in soil solution P was observed at the second week's sampling for all treatments. This increase corresponded with the decrease observed in the organic P levels at the same sampling time. A significant correlation at the .01 probability level (R^2 = .80) was indicated between soil solution P and organic P levels, however, it was coupled to the level of fertilizer P applied. Both organic P and soil solution P increased significantly as P

Table 13. Effect of C addition, fertilizer P, and soil P level on the soil solution P (Incubation Study--1981)

Soil P level (ppm)	P rate (µg P/g soil)	C addition (mg C/g soil)	Soil Solution P (ppm) 2nd week	4th week
6	0	0	0.14	0.19
6	0	1	0.22	0.35
6	0	2	0.37	0.38
6	20	0	0.15	0.31
6	20	1	0.27	0.33
6	20	2	0.39	0.50
6	40	0	0.21	0.33
6	40	1	0.27	0.42
6	40	2	0.50	0.57
45	0	0	0.39	0.45
45	0	1	0.47	0.53
45	0	2	0.75	0.73
45	20	0	0.65	0.76
45	20	1	0.75	0.77
45	20	2	0.98	1.03
45	40	0	1.13	1.10
45	40	1	1.14	1.16
45	40	2	1.32	1.22
		LSD (.05)	0.19	0.15
Mean Values:				
	Soil P Levels:			
	6 ppm		0.28	0.38
	45 ppm		0.84	0.86
		LSD (.05)	0.06	0.05
	P Rate: (µg P/g soil)			
	0		0.39	0.44
	20		0.53	0.62
	40		0.76	0.80
		LSD (.05)	0.08	0.06
	C Addition: (mg C/g soil)			
	0		0.46	0.54
	1		0.50	0.62
	2		0.72	0.73
		LSD (.05)	0.08	0.06

Figure 10. Effect of C addition and fertilizer P on the soil solution P concentration for a low P soil test soil, 6 ppm P (Incubation Study--1981)

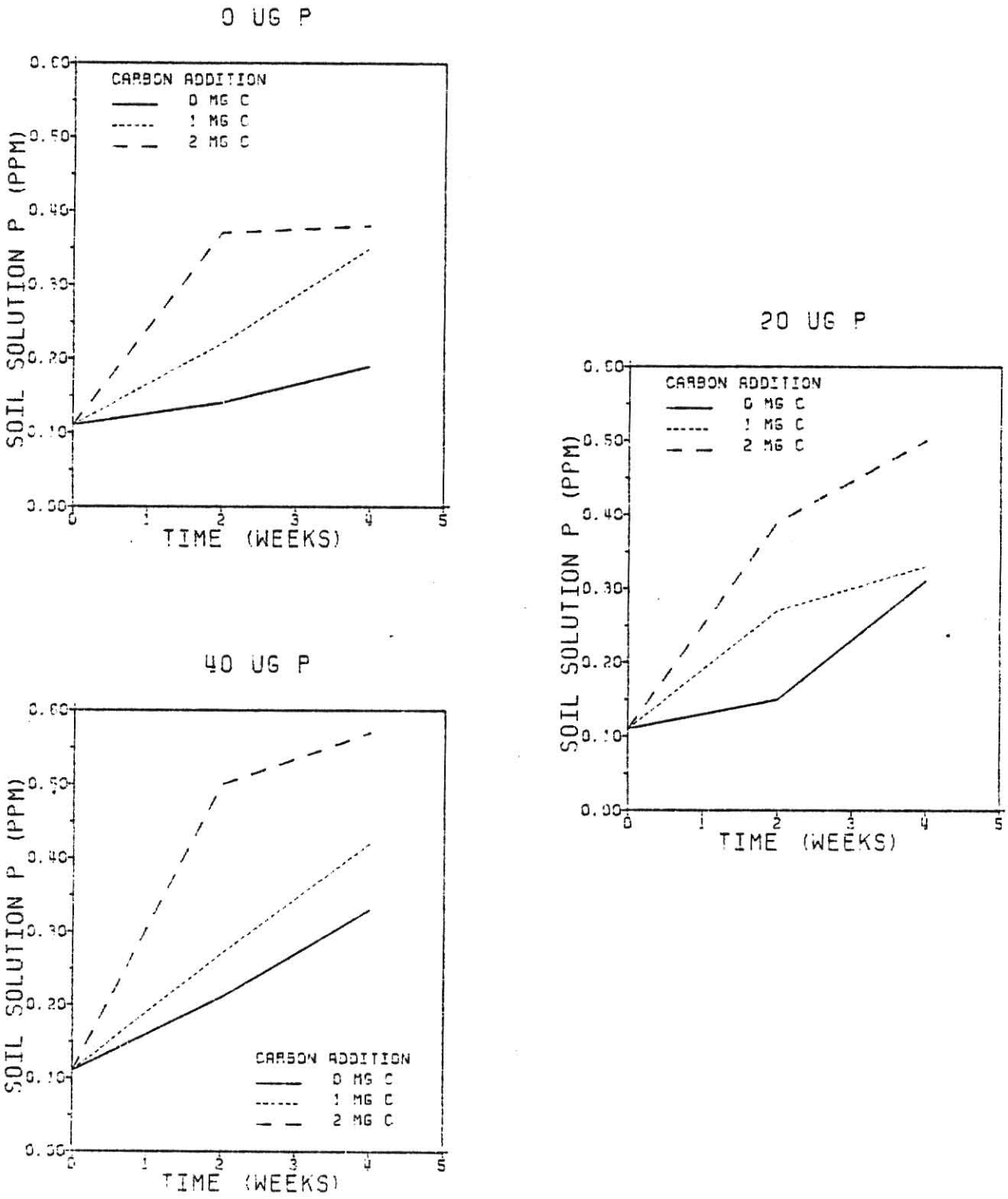
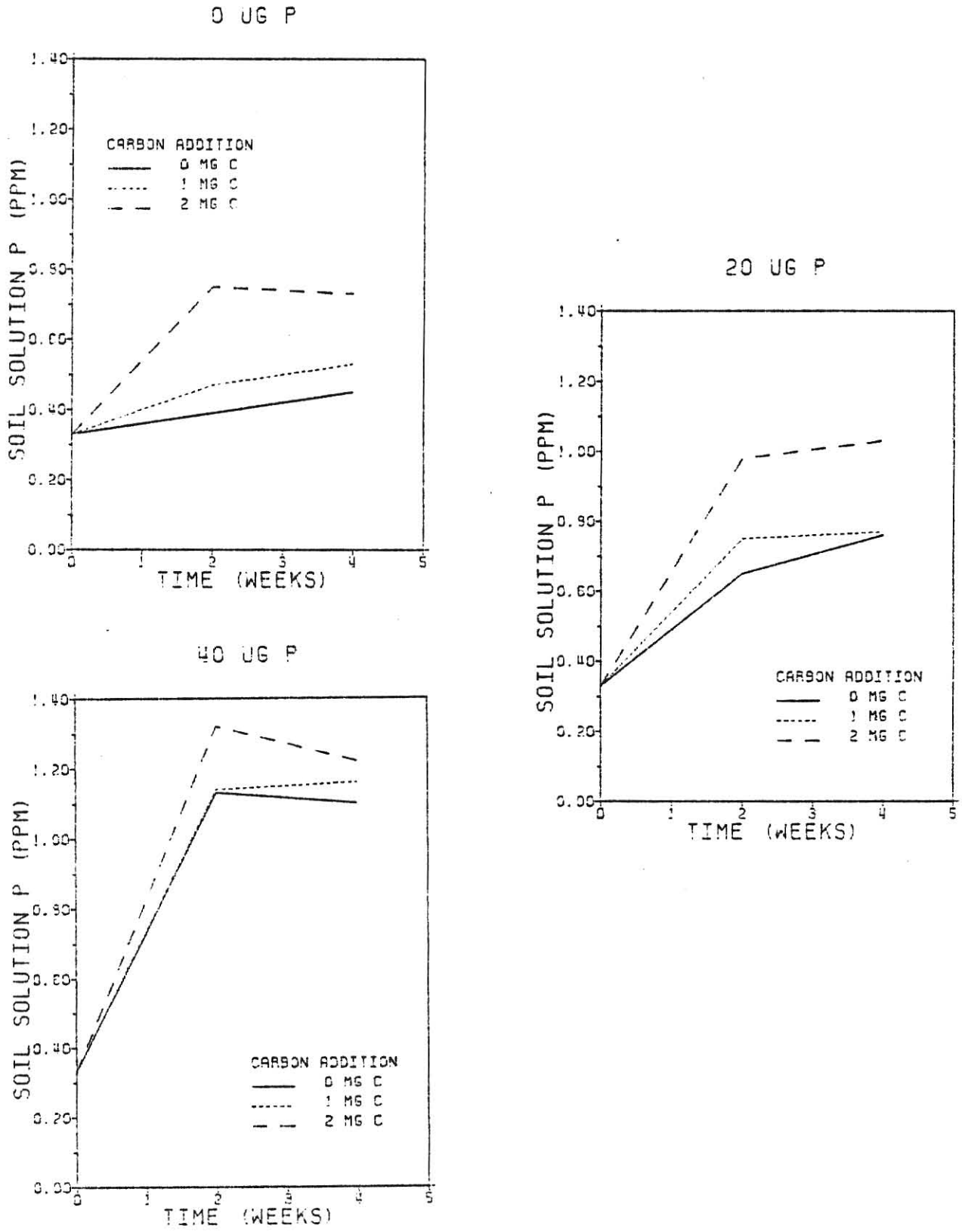


Figure 11. Effect of C addition and fertilizer P on the soil solution P concentration for a high P soil test soil, 45 ppm P (Incubation Study--1981)



fertilization increased. It may be speculated that a decrease in soil solution P levels had occurred at the first week in relationship to the increase in microbial activity and P immobilization, since microbes would take up the readily available P first causing a decrease in soil solution P (Chauhan et al., 1979).

Figure 12 represents the effect of the rate of P fertilization on the soil solution P. As was expected, a significant increase in soil solution P was observed after adding 20 and 40 µg P/g soil. The 40 µg P treatments had a final soil solution P concentration of 0.80 ppm P compared to 0.62 ppm P for the 20 µg P treatments and 0.44 ppm P for the 0 µg P treatments.

Figure 13 represents the effect of the available P level upon the soil solution P. As would be expected the high P soil had a significantly higher level of soil solution P compared to the low P soil throughout the experiment. At the second week's sampling the rate of increase was greater for the high P soil than the low P soil. By the fourth week the high P soil's solution P had leveled off while the low P soil's solution P was still increasing.

The leveling off of the high P soil's solution P may be possibly explained by a significant interaction, at the .01 level, that was indicated between soil P level and rate of P fertilization (Fig. 14). As the rate of fertilizer P increased, soil solution P increased at a faster rate in the high P soil than the low P soil, represented by the steeper slope for the high P soil. The low P soil possibly had a greater number of retention sites vacant compared to the high P soil, allowing a larger amount of fertilizer P to become absorbed

Figure 12. Effect of P fertilization on mean soil solution P concentration of both soils (Incubation Study--1981)

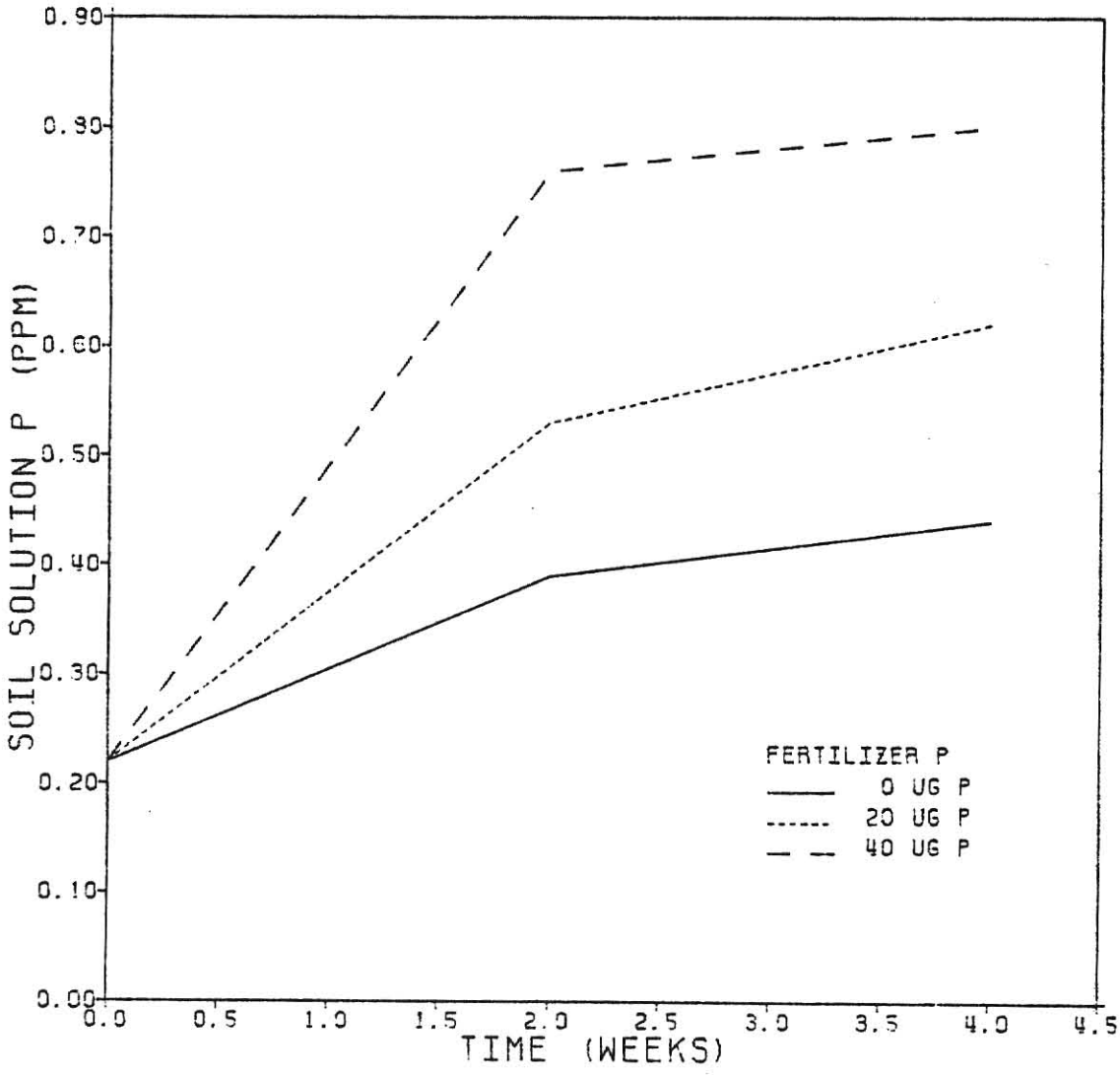


Figure 13. Effect of the original available P level on soil solution P concentration (Incubation Study--1981)

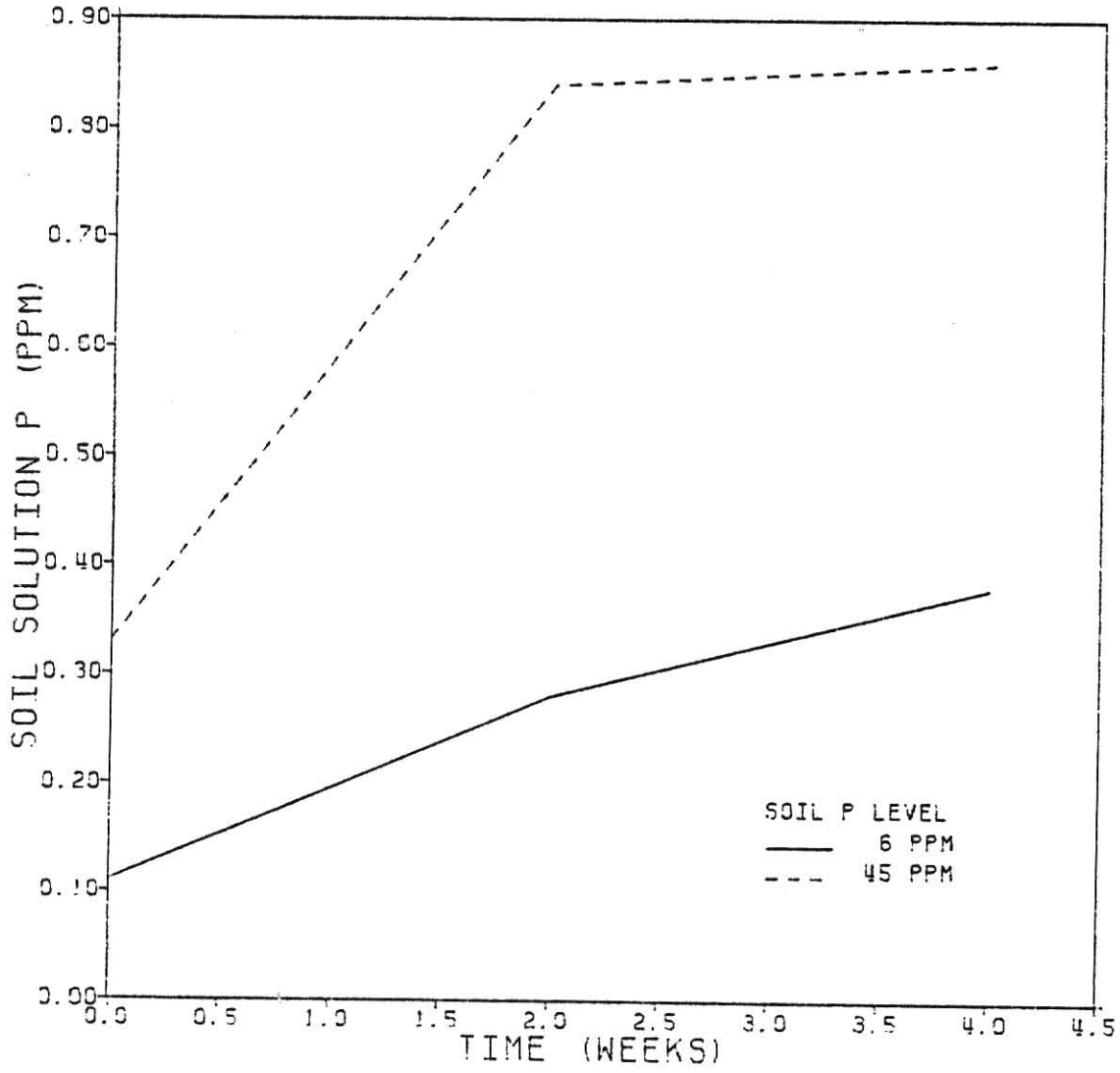
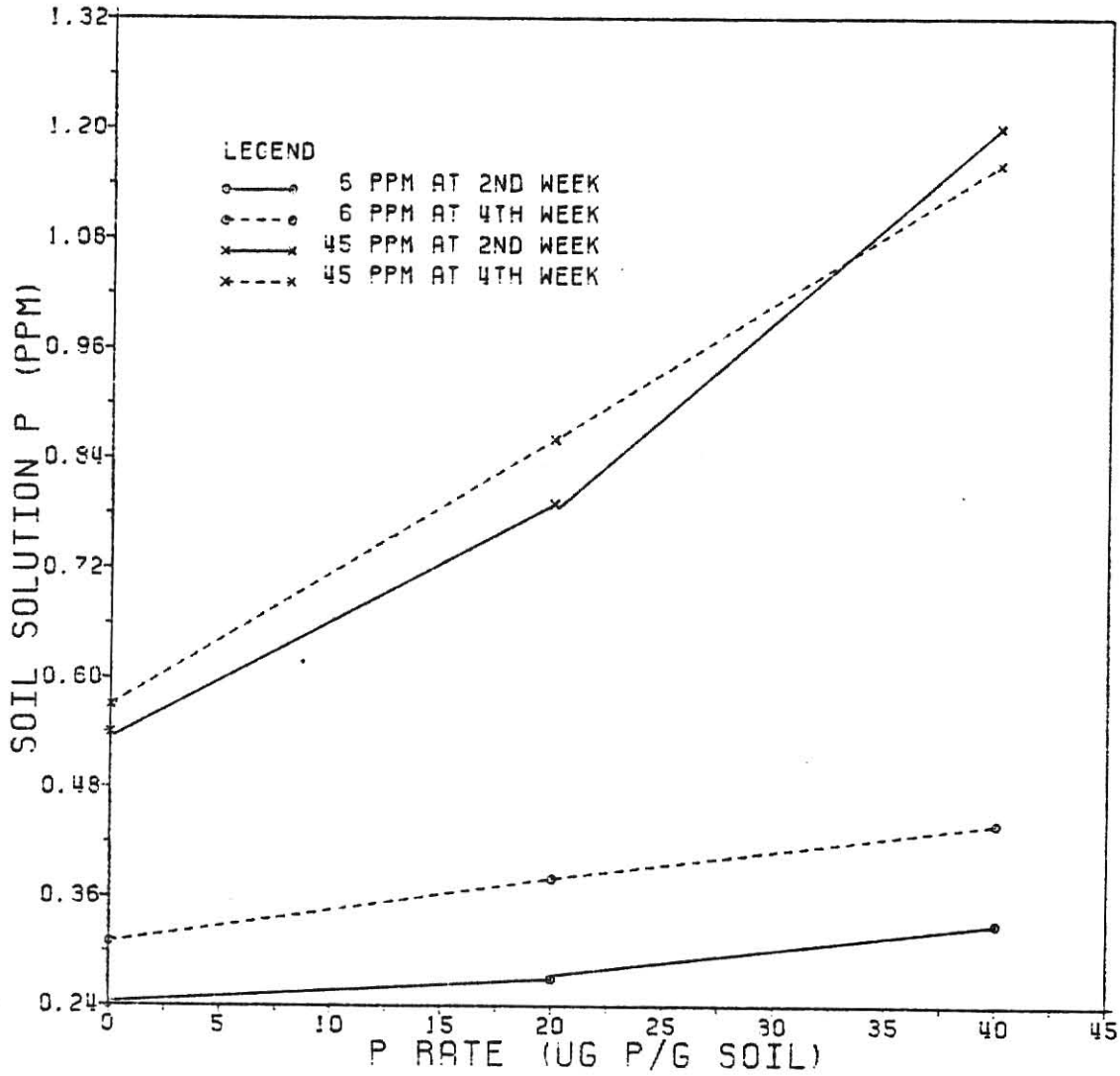


Figure 14. Represents the interaction between rate of fertilizer P and soil solution P for the two soils, 6 and 45 ppm available P, at the second and fourth weeks (Incubation Study--1981)



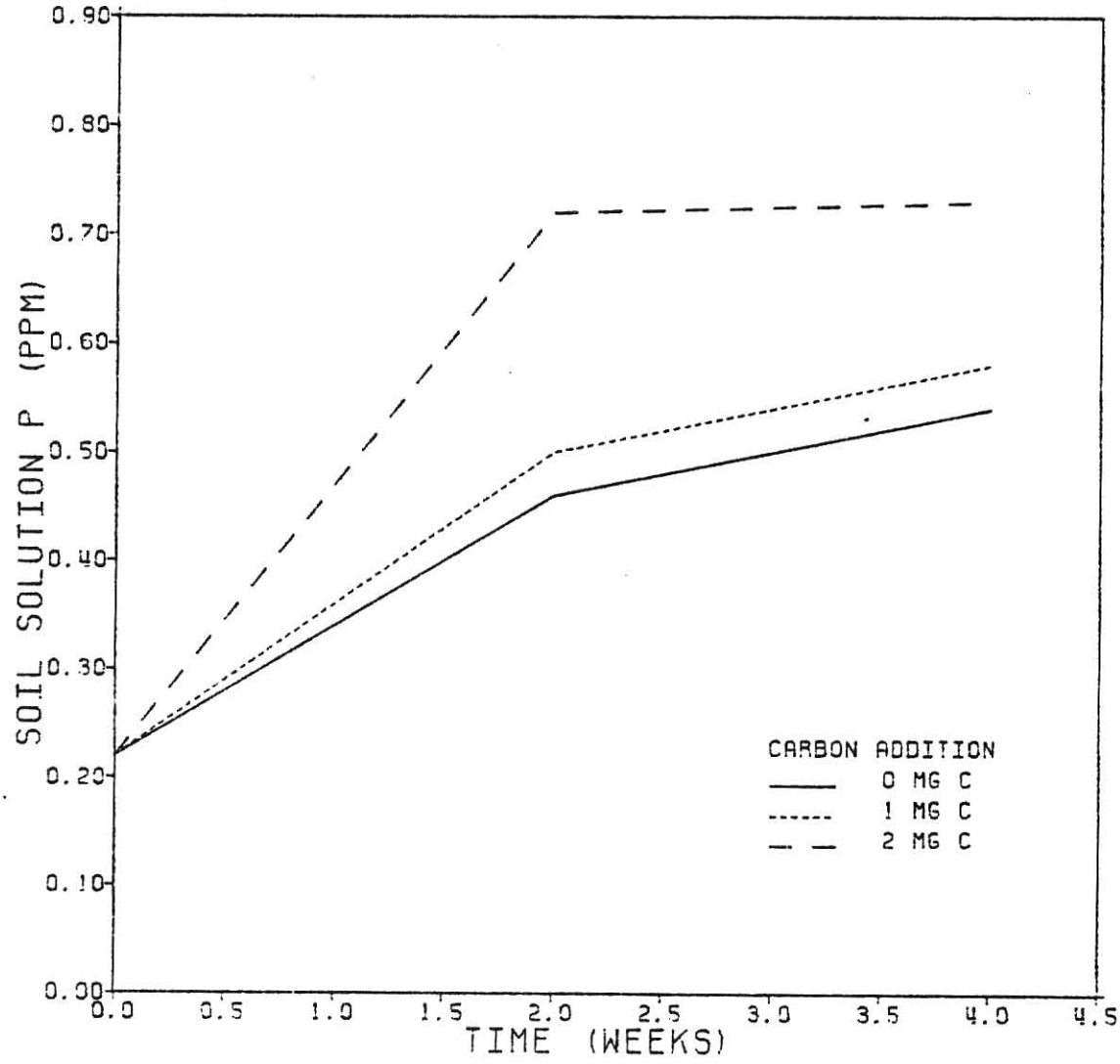
or precipitated as P compounds with low solubility, resulting in the lower solution P concentration.

The concentration of P in the soil solution of the high P soil did not change with time of sampling, indicating that the soil had arrived at a steady state condition and would not increase without the addition of more fertilizer P. The low P soil's solution P concentration increased significantly from the second week to the fourth week. This indicates that some of the insoluble phosphates may have been solubilized possibly resulting in the increase observed in soil solution P.

The effect C addition had on soil solution P is shown in Figure 15. A significantly higher P concentration was observed in the soil solution as a result of the highest C addition, 2 mg C/g soil. No significant increase was indicated at the 1 mg C/g soil rate. We believe that the significant increase in soil solution P as a result of C addition indicated that the increase in P movement, observed in the greenhouse experiment, was a result due to an increase in soil solution P.

The question of how the C addition increased the soil solution P remains unanswered. Carbon addition did not appear to affect mineralization of organic P, which we had theorized as being a possible explanation for the increase of soil solution P. But, another possible explanation for the increase in soil solution P might be that the C could have reacted with some of the retention sites, causing less soluble phosphates to be increase in solubility, resulting in an increase in soil solution P. Moreno et al. (1960)

Figure 15. Effect of C addition on mean soil solution P concentration of both soils (Incubation Study--1981)



showed that organic matter may complex Ca ions, thereby increasing soil solution P concentration. Nagaragah et al. (1970) suggested that organic acid were capable of competing with P for adsorption sites on the mineral surfaces of the soil, thus reducing P adsorption. The mobilization of these phosphates could occur without affecting the organic P measurements. Soil pH might be an important factor affecting the solubility of these phosphates, but it is doubtful that the amount of C used in these experiments could have changed the soil pH to any great extent. Additional research is needed to investigate precisely why the C addition increased soil solution P.

SUMMARY AND CONCLUSIONS

The main objective of the field study was to obtain supporting evidence for Sorden's data (1980). The results from the field study were inconclusive due to severe weather conditions which occurred during the 1980 growing season. However, a slight growth difference at the second sampling date and an increase in the P content of the silage tissue may have indicated a positive response to C addition. It was concluded that more research was needed to investigate the possible effect of C addition upon P availability.

A greenhouse study, using ^{32}P labeled fertilizer P, investigated the effect of C on fertilizer P uptake and P movement in the soil. The results from this experiment indicated a significant increase in the growth measurements due to fertilizer P, but no differences were observed with C additions. Data for the high P soil, 45 ppm P soil test, indicated a significantly higher amount of fertilizer P was utilized by the plants receiving C addition with fertilizer P. A slight increase was also observed for the low P soil, 4 ppm P soil test, but was not significant at the .05 probability level. This increase in the utilization of fertilizer P suggests an increase in fertilizer P availability. Measurements of radioactivity, in the high P soil, indicated a significantly higher level of fertilizer P had moved away from the band due to C addition. These results seem to suggest that C addition may be increasing the movement of fertilizer P by increasing the solubility, thereby increasing P availability.

Results from the greenhouse experiment suggests that only when C was added in conjunction with fertilizer P did a positive response occur. The addition of C probably did not affect the P compounds already present in the soil, but may have increased the availability of fertilizer P by affecting the solubility of fertilizer P.

An incubation experiment investigated the possibility of C enhancing organic P mineralization and increasing the soil solution P. Results showed that treatments receiving C with fertilizer P had a significant increase in soil solution P, but no direct effect on the mineralization of organic P was observed. The increase in P movement and soil solution P was possibly due to the effect of C on the solubility of the fertilizer P and not to an increase in the mineralization of organic P.

In conclusion, these studies indicated no real significant increase in plant growth as a result of C addition. However, a significant increase in the movement of fertilizer P from the band and a higher concentration of P in the soil solution were observed with the addition of C with fertilizer P. Additional research is needed on C additions, to investigate how and why these increases in P solubility may occur.

APPENDIX I

Appendix I. Effect of P and C fertilization on N and P content of corn tissue field study (North Farm--1980)

Treatment	Percent N	Percent P
	----------6/4/80----------	
Field	3.75	.351
Nutrient solution	3.69	.393
Nutrient solution + P	3.72	.355
Nutrient solution + P + C	3.99	.372
LSD (.05)	ns	ns
	----------6/25/80---------	
Field	2.47	.278
Nutrient solution	2.58	.289
Nutrient solution + P	2.61	.306
Nutrient solution + P + C	2.48	.279
LSD (.05)	ns	ns
	----------7/13/80---------	
Field	1.67	.192
Nutrient solution	1.59	.173
Nutrient solution + P	1.65	.207
Nutrient solution + P + C	1.61	.203
LSD (.05)	ns	ns

APPENDIX II

Appendix II. Effect of C addition on fertilizer P movement (32P Greenhouse Study--1980)

Treatment	Soil P Level (ppm)	Depth (cm) 0-7.5	7.5-15	15-30	30-45
		counts/min.			
		At 5cm From Band			
+P	4	84	83	77	82
+P+C	4	94	95	79	73
+P	45	90	84	66	80
+P+C	45	163	107	81	73
	LSD (.05)	64	ns	ns	ns
Mean Values:					
	Soil P Level				
	4	89	89	78	77
	25	126	96	73	77
	LSD (.05)	ns	ns	ns	ns
	C Addition				
	-C	87	83	72	81
	+C	129	101	80	73
	LSD (.05)	ns	ns	ns	ns
		At 10cm From Band			
+P	4	92	83	87	90
+P+C	4	74	80	76	80
+P	45	81	90	79	86
+P+C	45	80	74	79	80
	LSD (.05)	ns	ns	ns	ns
Mean Values:					
	Soil P Level				
	4	83	81	82	85
	25	80	82	79	83
	LSD (.05)	ns	ns	ns	ns
	C Addition				
	-C	86	86	83	88
	+C	77	77	78	80
	LSD (.05)	ns	ns	ns	ns

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THE EFFECT OF CARBON ON PHOSPHORUS AVAILABILITY TO CORN (ZEA MAYS L.)

by

DONALD EUGENE HARRIS

B.S., Kansas State University, 1979

AN ABSTRACT OF A MASTER'S THESIS

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requirements for the degree

MASTER OF SCIENCE

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Manhattan, Kansas

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Phosphorus (P) is one of the three primary nutrients required for plant growth. Phosphorus may form P compounds of low solubility when applied as inorganic fertilizer. As a result of this lower solubility, a sufficient level of available P may not occur throughout the growing season. Even under ideal fertile soil conditions and intensive fertilizer P applications the level of available P may be insufficient for optimum plant growth.

The present research was established to determine if soluble carbon (C), added to the soil as sucrose, may possibly increase P solubility, thereby increasing P availability. A field study indicated slight increases in vegetative growth at the second sampling rate, 25 June 1980, and final P content at silage harvest, 12 August 1980, may have been a result of C addition with fertilizer P.

In additional work conducted in the greenhouse, a significant increase in the utilization of fertilizer P was observed when C was added. A significantly higher level of fertilizer P was also observed further from the band when C was added with fertilizer P. These results suggested that C addition may possibly increase the solubility of fertilizer P.

Data from an incubation study supported the greenhouse results. The P concentration in the soil solution was increased significantly when C was added with fertilizer P. The results indicated that even though C addition was significantly increasing microbial activity, no increase in the mineralization rate of organic P was observed. It was concluded that C addition was

affecting the solubility of fertilizer P and not the organic P compounds already present in the soil.