PHOSPHORUS NUTRITION OF CORN (*ZEA MAYS* L.) AS AFFECTED BY HIGH NUTRIENT FERTILIZATION INCLUDING CARBON

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by

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INTRODUCTION

It is widely known that phosphorus is associated with increased root growth and greater strength of cereal straw. It hastens plant maturity, increases disease resistance, and improves the quality of certain fruit, forage, vegetable and grain crops (26, 34, 35, 45, 55, 65, 68, 73, 81, 93, 108, 113). It is therefore of interest to determine if the phosphorus content of crop plants can be increased by amending a plant's nutrient environment.

The effects of four fertilization treatments were observed in a high yield corn (Zea mays L.) study conducted at the North Agronomy Farm, Manhattan, Kansas in 1979. Three treatments received a daily application of nutrient solution by drip irrigation throughout the growing season. Nutrient levels were sufficient to provide amounts required for a high yield (49, 86). The nutrients were supplied to match the utilization rate depicted by Hanway's growth curve (45). The four treatments used were: 1) nutrient solution minus phosphorus, 2) nutrient solution, 3) nutrient solution plus carbon (added as sucrose), and 4) no nutrient solution - control. All treatments received identical soil fertilization prior to planting. Observations made throughout the growing season were: organic and inorganic soil phosphorus concentrations in the rhizosphere, phosphorus concentrations in roots, leaves, and grain, and grain yield.

LITERATURE REVIEW

GENERAL

Phosphorus uptake and translocation in corn (Zea mays L.) are two major factors that determine grain quality and quantity. Phosphorus is the central element involved in plant cell energy utilization (29, 47, 96, 113) and is responsible for maintaining active plant metabolism. The mechanism employed to obtain energy for plant cells uses carbohydrates as the initial source of fuel. The effects of soil microorganisms on the loss of carbohydrates by growing plant roots has been the subject of study in three experiments. Initially, Martin supplied radio active carbon to wheat plant tops, successively leached the soil, and found the labeled C in the leachates had been released from the soil microflora rather than directly from the plant cells (70). Then Barber and Martin showed 5 to 10 percent of the photosynthetically fixed carbon in a growing plant may be released by the roots under sterile conditions while in unsterilized soil 12 to 18 percent of the carbon was released by the roots (6). This is an equivalent of 18 to 25 percent of the total dry matter of the plants which had been lost through the roots under conditions where soil microorganisms are present. In a succeeding paper Martin concludes carbon leakage from the roots is greatly accelerated by soil microflora (71). This microbial mediated carbon release from the roots occurs with a resulting loss of carbohydrate energy available for plant metabolism.

It was of interest to see if carbohydrates added to the soil would result in differences in plant phosphorus nutrition, possibly by preventing the drain of plant carbon caused by soil microorganisms. If a source

of carbohydrates was added to the soil supplying the amount of plant carbon depleted by the microbes, the carbon drain through the roots might be avoided. Since glucose and fructose are the primary forms of carbohydrate present in plants, a combination of these was used as a carbohydrate source in the present experiment. Sucrose (glucose + fructose) was added to the nutrient solution of one of the treatments as the carbohydrate source. This carbohydrate is a source of fuel for energy utilization in plants and is also a source of energy for soil microorganisms (2, 7, 19, 20, 39, 41, 44, 57, 78, 83, 85, 99, 102).

Due to the concentration of phosphorus-mineralizing microorganisms surrounding the roots of corn plants (2, 5, 6, 10, 12, 17, 18, 20, 27, 38, 39, 42, 60, 70, 71, 77, 84, 91, 100, 101, 102, 118), unavailable organic phosphorus may be mineralized to the readily available inorganic form (2, 7, 12, 18, 20, 27, 36, 39, 41, 42, 44, 57, 66, 74, 77, 78, 83, 84, 100, 102, 113, 116, 117, 118). Increasing the availability of phosphorus has been shown to increase P uptake (72, 89).

Since organic phosphorus has been reported to comprise 10 to 85 percent of the total phosphorus present in the soil (1, 2, 15, 18, 36, 82, 84), any increase in organic P mineralization may increase crop growth. The existence of a large reservoir of organic phosphorus in soil that can't be readily utilized by plants emphasizes the role of microorganisms in converting organic P to inorganic forms (2). While it is true that only a very small percent of the total soil organic phosphorus may be mineralized within a growing season, it must be recognized that the release of only a few kilograms of P per hectare would supply a large proportion of the phosphorus needed for crop production (18).

PHOSPHORUS UPTAKE AND TRANSLOCATION IN RESPONSE TO PLANT PHYSIOLOGY

Nutrients in the soil are supplied to plant roots by root interception, mass-flow, and diffusion. Less than 3 percent of the available soil phosphorus is obtained through root interception (8, 119). Mass-flow supplies approximately 1 to 5 percent of the phosphorus taken up by corn plants (8, 119). That leaves the majority of phosphorus supply to occur through diffusion (119).

Since most of the phosphorus taken up by plants is supplied by diffusion it is usually the most important means by which a plant may obtain phosphorus. Diffusion is affected by the amount of P present and its proximity to the root. It is necessary to supply phosphorus to a large proportion of the root system to adequately supply the plant (55). A greater root surface area will allow for a greater P uptake potential. Jungk and Barber found the uptake of phosphorus to be proportional to the length of root exposed to the P solution (68). When a greater root length is exposed, root surface area is likewise increased. McClure found phosphorus content of shoots to be proportional to the amount of root surface in contact with the ambient P (73). The shoot-to-root ratio was also found to increase with a high supply of P (34, 35). Other studies have shown that non-uniform distribution of phosphorus in the root zone may result in a 20 percent reduction in shoot growth (103, 104).

Not only is the amount of phosphorus present and its proximity to the root important, but also the form in which it occurs. Plants will only take up certain forms of nutrients. Phosphorus is generally absorbed by corn in the form of inorganic phosphates (65) as $H_2PO_4^-$ or $HPO_4,^{2-}$ depending on the soil pH (96, 113).

Phosphorus is an important nutrient which should never become limit-

ing for corn to yield to its fullest potential. Phosphorus is present in all living cells and is utilized to form nucleic acids and in storage and transfer of energy (96). It is the central element in ATP which traps and stores energy (29).

Phosphorus can be assimilated in the plant in two ways: oxidative phosphorylation, the main method of ATP generation, and transphosphorylation, which contributes considerably less to total respiratory metabolism. Oxidative phosphorylation is that pathway where inorganic phosphorus is metabolized into ATP by mitochondria (115).

ATP is an essential constituent in many metabolic reactions in living cells. It is required in biosynthetic pathways for the production of materials essential to cellular maintenance and growth, active transport processes, and protoplasmic streaming, among others (29, 47).

The generation of ATP by oxidative phosphorylation occurs when phosphorus is incorporated into ADP in conjunction with electron transfer in the respiratory chain of the mitrochondria. Phosphorus is also incorporated into ATP through photophosphorylation which is a similar process occurring in the light reactions in chloroplasts. Since oxidative phosphorylation and photophosphorylation accompany the tricarboxylic acid cycle (TCA cycle or Kreb's citric acid cycle), carbon is yielded as one of the products. The processes of transphosphorylation and oxidative phosphorylation together account for the generation of more than 60 molecules of ATP from ADP during the oxidation of one molecule of sucrose.

Since phosphorus is the central element in ATP, active P flux is vital to the plant's energy metabolism. The greatest P flux rate occurs during the first 24 days of growth after which it decreases rapidly and then levels off when the corn plant is about 75 days old, or about two weeks after tasseling (56, 75). Two separate transport systems are in-

volved in P uptake and translocation (52, 110). Following phosphorus assimilation into the plant, the P content of the leaves remains farily constant throughout the grain filling period (45) as the P is used in the manufacture of photosynthates needed to make grain. Phosphorus presence (as ATP) in the culm is also expected, as it is the source of energy utilized for active transport of nutrient ions up and down conductive tissues. This active transport also occurs for most metabolites such as amino acids, sucrose, and organic acids all of which are actively and selectively transported through energy derived from ATP. Translocation of phosphorus from the cobs, husks, and culm to the grain is evident as physiological maturity nears. One half or more of the P in the grain at maturity appeared to represent phosphorus lost by translocation from other above ground plant parts (45, 46). Approximately 75 percent of the total P in the corn plant at maturity is found in the grain (65).

If the majority of phosphorus in the above ground plant parts of the corn plant is translocated to the grain at maturity, it is important that the leaves contain a high P content so as to promote a high P content in the grain. Heavy amounts of phosphorus added to soil were found to significantly increase the P content of corn leaves (93) and grain, and increase yields (81).

PHOSPHORUS IN THE SOIL

Phosphorus in soils occurs in two principle forms: 1) inorganic phosphorus, which is made available to plants through weathering release, and 2) organic phosphorus, generally considered to be unavilable until mineralized.

Inorganic soil phosphates can be classified into four main groups:

calcium phosphate, aluminum phosphate, iron phosphate, and reductant-soluble phosphate (22, 23, 40). These forms of phosphates will eventually result following the addition of phosphate fertilizers to the soil (24).

Once available, soil phosphate may become unavailable if either fixation or immobilization occurs. Phosphate fixation may occur when available phosphate is in contact with the soil and is made unavailable to plants, even though the phosphate is positionally available to the roots (21, 122). Under conditions where phosphate reacts with organic soil complexes, only a portion remains available for plant use (63, 120). This is because phosphorus can be held very tightly by the solid portion of the soil (20). Allen et al. found that phosphate availability decreased with time following fertilizer application due to fixation (4). Although exchangable phosphate is in the solution, it is balanced by opposite charges on, or attached to the solid phase surface. In order to be taken up, the phosphate ion must be disassociated from the complex. Immobilization of phosphate occurs when it is used as an energy source for microorganisms. The phosphorus is incorporated into their cells making it unavailable for plant use until the microbe itself decomposes. Phosphorus defficiencies due to immobilization have been reported following P fertilization of corn (107).

When making comparisons between available soil phosphorus and the amounts of P taken up by plant roots, the soil pH (whether artifically, root, or microbially altered) must be taken into account. Soil pH affects the concentration of available phosphate (76). The range of maximum availability of phosphorus is between pH 5.5 and 7.0 (19, 76, 96, 113). At low pH values roots absorb $H_2PO_4^-$ ions whereas at higher values HPO_4^{2-} is absorbed (19, 113). A reduction in the rhizosphere pH increased rhizosphere solution phosphorus concentration which in turn increased P uptake in corn (87, 97, 98).

The presence of organic phosphorus in soils was first suggested by Mulder in 1844 (37). Today it is known that organic soil phosphorus occurs in three principle forms: phospholipids, nucleic acids, and inositol phosphates (84, 113). Phosphate in the soil solution must be constantly renewed if the P requirements of growing plants are to be matched (62). Organic forms of phosphorus in the soil have been described as a storehouse of the mineral nutrient (84). Experiments have shown organic phosphorus content of the soil to decrease through the growing season (33, 111).

Portions of the organic phosphorus may be made available for plant uptake through the mineralization of organic phosphorus to the inorganic form. This conversion has been reported to take place by means of enzymatic hydrolysis by plant root exudates and by microbial decomposition (105). These two processes occur primarily in the rhizosphere.

THE RHIZOSPHERE EFFECT

The "rhizosphere" was defined by Hiltner in 1904 as the region of the soil altered by the root. This zone extends several millimeters beyond the root in the case of fungal mycelia.

Conditions in the rhizosphere commonly differ from those present in the non-rhizosphere soil. A study by Bhat et al. suggested an enhanced release of soil phosphorus into solution in the rhizosphere (11). Several factors thought to be responsible include the increased enzyme activity of the rhizosphere, greater abundance of microorganisms present around the roots, and reduced rhizosphere pH.

Soils normally have a low level of enzyme activity (13). It has been reported that when the supply of phosphorus was abundant, the phosphatase activity was low (74). But when maize plants became defficient in phosphorus, an increase in phosphatase activity was observed (85). High

concentrations of active plant cell phosphatases were found in the root cap, protoderm and cortex of corn roots (92). These same areas of the root slough cells and the organic materials in them accumulate in this region. Soil phosphatase and saccharase activities, and soil respiration were reported to have increased with increasing soil organic matter in areas of greatest microbial populations (117).

Some researchers propose that roots are responsible for solubilizing organic nutrient sources alone rather than in combination with soil microorganisms. Szember reported that lecithin and phytin can serve as phosphorus sources for higher plants even under sterile conditions (106). Enzymes found on the root surface of corn by Chang and Bandurski were found to hydrolyze sucrose, cellobiose, ATP, pyrophosphate, RNA and DNA. It was therefore thought to be possible for corn roots to enzymically solubilize organic soil macromolecules independently of soil microbial activity (25). Martin concluded soil microflora probably did not increase the dephosphorylation of soil inositol hexaphosphates at root surfaces above the activity due to plant enzymes (69).

Estermann and McLaren, however, concluded non-sterile roots had greater phosphatase activity than the sterile roots (38). Compared to sterile conditions, in the presence of microorganisms plant growth was greater and more phosphate was absorbed from the various P compounds present (14, 42). Dense rhizosphere microorganism populations result from the diversity of organic materials present, such as amino acids, vitamins, sugars, phosphatides, etc. (102). This abundant energy supply is the main reason why microbes are found in greater abundance near plant roots than at further distances from the roots (100, 101). The increased number of organic phosphorus solubilizing organisms at the root surface, when compared to the observed increase in metabolic activity of the root surface organisms, could

be considered significant in relation to the organic P degradation for the plant (42).

Scientists in the Soviet Union and several European countries have experimented with increasing the mineralization of organic phosphorus by extensive soil inoculation programs. Russian researchers reported effective use of soil microorganisms by commercial preparation of phosphobacterins which they distributed to farmers. Yield increases of 0 to 70 percent with an average yield increase of 10 percent were reported (113). However, the USDA showed their cultures readily decompose glycerophosphates but that no influence on phosphorus concentration or total phosphorus uptake was seen. These differences may be linked to the limited use of chemical fertilizer in Russia.

Clark and Brown realized that plant absorption of phosphorus was affected by both the pH of the root environment and the phosphatase activity of the roots (28). The pH of the rhizosphere differed from that of non-rhizosphere soil by up to 1.2 units (94). When a population of soil microorganisms expands, the CO_2 pressure rises and results in a decreased pH (66). Microbial decomposition of organic residues is accompanied by the evolution of CO_2 which, when dissolved in water, forms carbonic acid. The presence of soil microorganisms significantly increased CO_2 release from the rhizosphere, but had no effect on the carbon content of the soil (71). Use of C-14 tracer showed C in soil leachates to be released from the soil microflora rather than directly from plant cells (70). The greater amounts of CO_2 produced from soil regions of intense root development is linked to higher microbe populations in those areas (101).

Zagallo and Katznelson found roots to selectively stimulate the Gram-negative species of bacteria which are characterized by their fast growth rates, growth response to glucose, and production of acid from glu-

cose (20). These researchers also found the oxygen uptake of the rhizosphere to be greater than that of the bulk soil when both were supplied with sucrose and concluded rhizosphere soil samples to be richer in bacteria capable of responding to nutrients such as sucrose.

CARBON AS A SOURCE OF ENERGY

A major objective of the degradation of carbon substrates by a living organism is the production of energy for the development and growth of that organism (29). Plant organic matter usually consists of approximately 5 percent fats, waxes and tannins, 10 percent protein, 25 percent lignins, and 60 percent carbohydrates (19). The carbohydrate fraction includes sugars, which are decomposed the most rapidly and which are examples of readily available energy sources for soil organisms.

Following the addition of organic matter to the soil, the microbial population increases. Microbial phosphorus assimilation occurs casuing non-utilizable forms of the element to accumulate. A microbe-plant competition for phosphate forms. If the carbonaceous residue is deficient in P, the microbial assimilation of available phosphate may be complete enough to depress crop yields. As the decomposition of P-deficient substrates progresses, the percent phosphorus in the remaining residue increases. Addition of carbohydrates to the soil was found to artifically induce a phosphorus deficiency (2).

Gerretsen reports that Stoklasa studied the effects of carbohydrate addition to soils (39). The microbiological solubilization of organic phosphorus by adding glucose to the soil was studied to check the P uptake, but Stoklasa's studies were inconclusive.

Hannapel et al. conducted an experiment in which sucrose was added to columns of soil (44). The organic phosphorus in the soil solution was

found to increase. Using P-32 tracer it was determined that a large portion of the organic phosphorus came from the native soil phosphorus fraction and was mobilized by the microbial population.

Ghonsikar and Miller added orthophosphate to soils previously incubated with glucose and found inorganic polyphosphorus formation resulting from microbial activity (41). The glucose incubated soils contained 2 to 4 times the amount of inorganic phosphorus as the soils not amended with glucose.

In another experiment, Pepper et al. incubated glucose amended soils to determine the effect on naturally occurring inorganic polyphosphorus (83). After 4 days of incubation all poly-P had disappeared. After incubation for 7 days poly-P was present again and the poly-P concentration was a little more than 2 times the original concentration in the soil. Differing quantities of carbonaceous substrate for microbial activity were also compared using 0, 1, and 2 percent glucose. The quantity of inorganic polyphosphate accumulation in the soil was found to be directly related to increasing ratios of glucose amendment up to 2 percent.

Spiers and McGill found phosphatase activity was increased up to sixfold by incubation of soil with glucose (99). The increase was thought to occur as a result of an increased demand for phosphorus. When phosphorus was added to produce an added C : added P ratio of 20:1, the proliferating microorganisms ceased producing phosphatase.

A number of studies have shown that when the C:P ratio is less than 200:1 mineralization takes place. But when the C:P ratio is greater than 300:1, immobilization occurs during the initial stages of decomposition (2, 36, 113). With time, the C:P ratio is narrowed due to CO_2 volatilization, and phosphate is formed from the residue originally low in phosphorus. On the other hand, Wier and Black found addition of inorganic

phosphorus did not influence the soil organic P mineralization rate, and concluded that their findings were strikingly different than many other scientists' results (121).

Acquaye found no correlation between available P and organic C or organic P but did find the amount of organic P mineralized to be significantly related to the organic C (1). Thompson et al. reported a positive correlation between soil organic C and soil organic P (112). On the other hand, Pearson and Simonson reported organic C : organic P ratios to vary considerably (82), whereas Bornemisza and Igue found the organic C : organic P ratio to decrease with depth (16).

SUMMARY

Phosphorus uptake and translocation in corn is actively involved with the mechanism employed to obtain carbohydrates for plant metabolism. Microbial mediated carbon release from the roots occurs with a resulting loss of carbohydrate energy available for plant metabolism. Barber and Martin found 12 to 18 percent of the plant carbon was released by the roots in the presence of microbes.

The present study employs the use of a carbon source which supplies 15 percent of the plant carbon in one of the fertility treatments applied to a plot of corn. It is proposed the addition of a carbon source may prevent the drain of plant carbon by soil microorganisms, and in turn, alter the plant phosphorus nutrition. Dense rhizosphere microorganism populations result from organic materials present, such as the root released carbohydrates. Since phosphorus-mineralizing microorganisms are concentrated around plant roots, unavailable organic P may be mineralized to the readily available inorganic form. Availability of phosphorus has been shown to increase P uptake. The author feels the increased P uptake would

improve the plant phosphorus nutrition.

MATERIALS AND METHODS

Research to determine the phosphorus nutrition of corn as affected by fertilizer treatments including carbon was conducted at the North Agronomy Farm, Manhattan, Kansas, during the 1979 growing season.

The experiment was designed as shown by the plot diagram, Figure 1. Since the plot area used was known to have uniform soil characteristics and to facilitate experimental design, replications were made within each treatment row. Corn hybrid DeKalb XL72AA was selected due to its high yield potential and was planted on May 16, 1979 in rows 0.76 meters (30 inches) apart and 30.48 meters (100 feet) long. This gave a final plant population of 69,187 plants per hectare (28,000 plants per acre). Each row was divided into three replications, each 10.16 meters (33.3 feet) long. Three subsamples were taken from each replication for analysis. Furidan was applied at time of planting to provide control of corn root worm and corn borer (66).

The plot was located on a Kennebec silt loam, a Cumulic Hapludoll. Results from soil tests indicated the soil to have high available phosphorus and potassium, and a pH of 6.5.

The soil fertility program included methods of fertilizer application by conventional means and by the addition of a nutrient solution applied by drip irrigation. The fertilizer applied by conventional means consisted of 224 kg N as anhydrous ammonia, 90 kg P_2O_5 and 2 kg Zn (as Zn-Chemin) per hectare. An application of 168 kg of N per hectare as ammonium nitrate and 56 kg of SO_4-S per hectare as gypsum was broadcast and disked into the soil prior to planting. This brought the total fertilizer application by conventional means to 392 kg of N, 90 kg P_2O_5, 56 kg S and 2 kg Zn per hectare.

Figure 1. Plot design diagram.

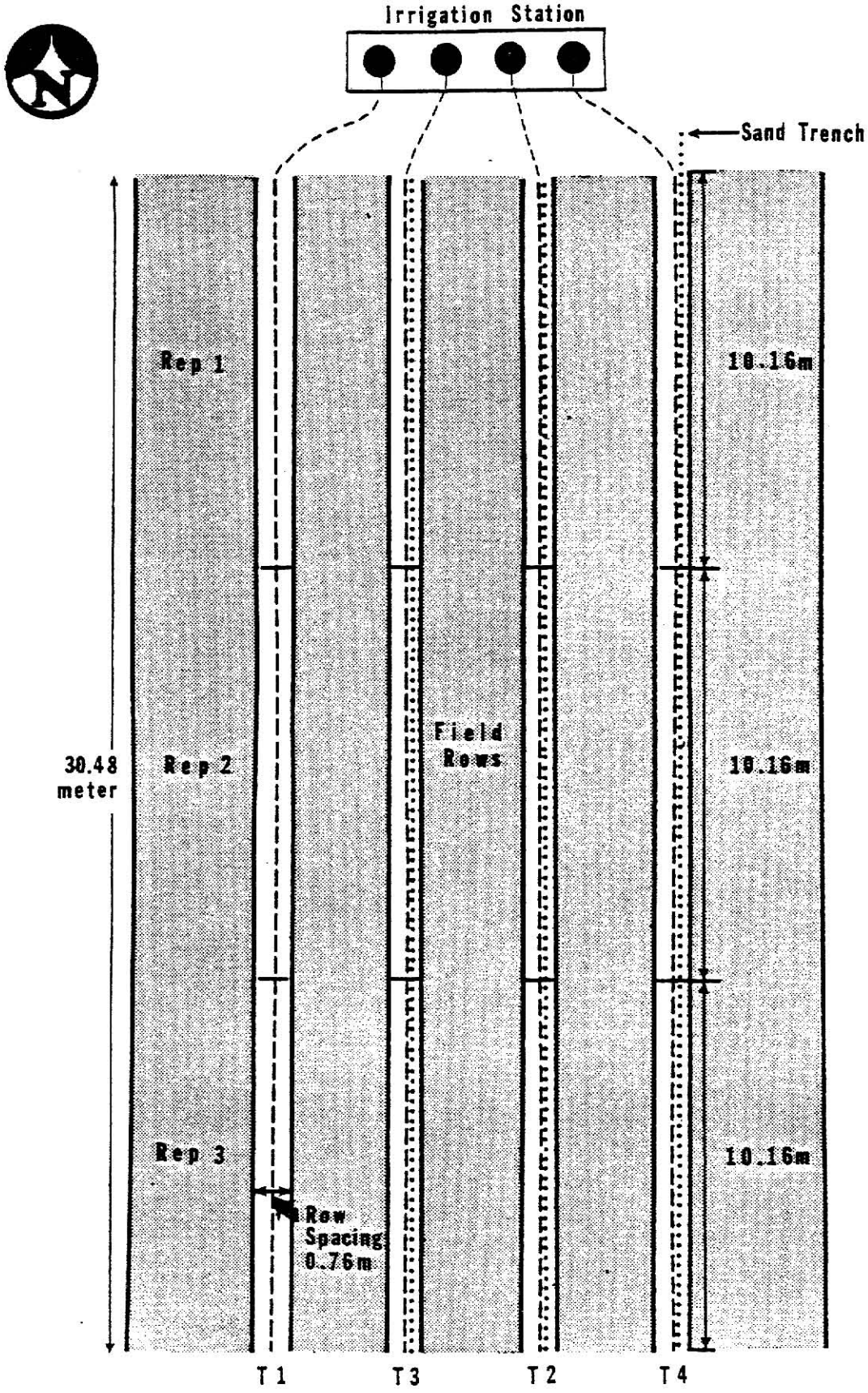


Table 1. Treatment code.

Code	Explanation of treatment
T1	Control (No sand trench)
T2	Nutrient solution - P (Sand trench)
T3	Nutrient solution (Sand trench)
T4	Nutrient solution + C (Sand trench)

The soil fertility program was supplemented with a drip irrigation tube run down three 30.48 meter rows of corn. The treatment code for the plot design is presented in Table 1. These three rows were planted alongside trenches backfilled with coarse sand onto which a nutrient solution was applied with the drip irrigation system. The sand trenches were utilized to obtain a more uniform application of nutrient solution. The trenches were 15 cm wide and 30 cm deep. The location and spacing between the sand trenches in the plot are shown in Figure 1. The nutrient solution consisted of a modified Hoagland's solution (47, 48, 49, 50, 54, 124) containing macro- and micronutrients. The macronutrients added in the solution are listed in Table 2. The micronutrients added in the solution, per row per day, were 0.0186 mg KCl, 0.007 mg H_3BO_3, 4.225 mg $MnSO_4$, 2.875 mg $ZnSO_4$, 0.625 mg $CuSO_4$, and 0.092 mg $(NH_4)_6Mo_7O_{24}$. The treatments included in the study are indicated in Figure 1 and the amount of total nutrients applied for each treatment are listed in Table 1. Treatment one (T1) was comprised of no trench or nutrient solution with only irrigation water added by trickle tube. Treatments two (T2), three (T3), and four (T4) employed a sand trench and received a daily application of nutrient solution throughout the growing season with the amount of major and secondary nutrients supplied in sufficient amounts to produce high yields. The nutrients were supplied to meet the requirements suggested by Hanway's growth curve assuming a maximum dry matter accumulation of 47436 kg/ha (45, 46). The amounts and times of application are presented in Table 2. Treatment two was comprised of the supplemental nutrient solution minus phosphorus (where the KH_2PO_4 was replaced with an equivalent amount of K as KCl). Treatment three consisted of the nutrient solution containing phosphorus and added sucrose as a carbon source. The application times, amounts, and values used to obtain amounts of sucrose added are presented

Table 2. Nutrient solution composition of macronutrients.

Date	NH_4NO_3*	$Ca(NO_3)_2$	KNO_3	KH_2PO_4	$MgSO_4$
	g/row/d				
June 4 - June 17	10.3	11.3	12.6	4.6	6.8
June 18 - July 1	18.5	20.3	22.7	7.6	12.2
July 2 - July 15	22.0	24.2	27.0	15.9	14.6
July 16 - Aug. 23	22.0	24.2	27.0	17.9	14.6
Aug. 24 - Sept. 7	9.7	10.7	11.9	12.2	6.4
Sept. 8 - Sept. 27	2.3	2.6	2.9	3.4	1.6

Addition of nutrients is based on Hanway's growth curve.

*½ of N is from NH_4NO_3 and the other ½ from $Ca(NO_3)_2$ and KNO_3 according to the proportions of Ca to Mg in regular Hoagland's nutrient solution.

in Table 3.

Plant and soil samples were collected on June 13, June 27, July 13, July 31, and September 28. Analyses included: N, P, K, and Zn in above ground plant tissue and root tissue (above ground plant tissue composition data of N, K, and Zn are presented in Tables 11, 12, and 13. Root composition data of N, K, and Zn are presented in Tables 14, 15, and 16.); organic and inorganic phosphorus content of rhizosphere soil; and organic and inorganic phosphorus content of the bulk (non-rhizosphere) soil. The corn was harvested on September 28, 1979 and the phosphorus content of the grain was determined as well as grain yield. (Values for N, K, and Zn content of the grain are presented in Table 17.) Root length measurements were determined according to Rowse and Phillip's modification of Newman's line intercept method (79, 88).

Above ground plant tissue samples were taken at the first three sampling dates by collecting the total above ground plant tissue. Above ground plant tissue samples taken at the last two sampling dates were taken by collecting the middle five leaves of the plant. All above ground plant tissue samples were dried at 70 degrees centigrade, and the dry matter was ground to pass through a 1 mm screen. Samples used to determine N, P, and K underwent a sulfuric acid digest procedure (51). Nitrogen and phosphorus concentrations were measured colorimetrically on a dual channel Technicon Auto-analyzer using industrial method 334-74 W/B (109). Potassium concentrations were determined on the sulfuric acid digest using flame emission analysis (58). Identifical samples were digested in a 1:1 mixture of nitric and perchloric acids and the Zn concentrations were measured by atomic absorption analysis (58).

Root samples were collected by digging up a root ball of approximately 8 cubic centimeters in circumference and shaking until only a small

Table 3. Nutrient solution composition of sucrose (carbon).

Date	Dry matter (shoot)† kg/ha	Shoot/ root†† ratio	Dry matter (root) kg/ha	Dry matter (total) kg/ha	Change in dry matter kg/ha	Carbon* accumulation g/row/d	Carbon* exuded g/row/d	Sucrose*** amendment g/row/d
June 4-July 3	3228	2.5	1291	4519	4519	140	21	53
July 4-July 18	11972	3.7	3235	15207	10688	664	100	250
July 19-Aug 2	20133	7.0	2875	23008	7801	485	73	182
Aug 3-Aug 17	24931	8.0	3116	28047	5039	313	47	118
Aug 18-Sept 1	34078	9.0	3787	37865	9818	608	91	228
Sept 2-Sept 16	43483	11.0	3953	47436	9571	595	89	222

† Dry matter accumulation based on Hanway's growth curve

†† Carson, (20) p. 50

* Dry matter is 40% carbon, (19) p. 139; 1 row=.00233 ha

** 15% of total carbon present is exuded

*** Sucrose ($C_6H_{12}O_6$) is 40% C

amount of soil remained on the roots. This soil left clinging to the roots was removed and saved as the rhizosphere soil samples (59). The roots were then rinsed in deionized water and oven dried at 75 degrees centigrade for 48 hours. Dried roots were then ground to pass through a 1 mm screen and were tested for N, P, K, and Zn as were the above ground plant tissue samples.

The rhizosphere soil collected from the roots was dried, ground, and sieved through an 0.84 mm (No. 20 mesh) sieve (53). Organic and inorganic phosphorus content was then determined. A 1 gram sample of the prepared soil was placed in a 30-ml beaker and put into a muffle furnace at 525 degrees centigrade for one hours (90). (It took approximately 25 minutes for the furnace to reach a temperature of 525 degrees centigrade.) The high temperature of 525 degrees centigrade was necessary to mineralize the organic P and at the same time was not high enough to volatilize the phosphorus (31, 32). The ignited sample was then transferred to a 50-ml Erlenmeyer flask with the aid of a brush to remove any adhering particles. The ignited soil sample was used to determine the amount of total phosphorus whereas a comparable sample of unignited soil was used to determine the amount of inorganic phosphorus present. Ten mls of 0.5 N HCl was then added to the flask and was placed on a shaker for ten minutes to allow for extraction (123). At the end of ten minutes the sample was immediately filtered through Whatman No. 2 paper. A ten-fold dilution was then made by pipetting a 5 ml aliquot of the filtrate into a 50-ml volumeteric flask and diluting to volume with 0.5 N HCl. After thoroughly mixing the solution a 5 ml aliquot of the diluted solution was pipetted into a cuvette to which 0.35 ml of the acid molybdate solution (P-B solution) and 0.35 ml of the dilute reducing agent (P-C solution) were added and immediately mixed (61). The molybdenum blue color was allowed to develop for 15 min-

utes after adding the P-C solution, after which the transmittance was measured photometrically at 660 nm. A blank was carried out using 5 mls of 0.5 N HCl and adding the same amounts of reagents as described for the unknown sample. This blank was used to adjust the photometer to read 100% transmittance or 0 ppm P (14). The unknown sample was then read. The ignition procedure allowed the soil organic phosphorus to be mineralized so that the amount of organic phosphorus is equal to the difference of the amount of total 0.5 N HCl-extracted phosphorus (measured in the ignited sample) and the amount of inorganic 0.5 N HCl-extracted phosphorus (measured in the unignited sample) (3, 43, 53, 64, 80).

The bulk soil samples taken at time of harvest were collected from the soil shaken loose from the root ball. The bulk soil was dried, ground, and sieved through an 0.84 mm sieve and was tested for organic and inorganic phosphorus content as described for the rhizosphere soil samples.

Insect problems (mainly chinch bugs) were encountered during the study which may have slightly retarded growth early in the season.

Statistical analyses of the data were accomplished by utilizing the Kansas State University Computing Center SAS (Statistical Analysis System) program. Basic plot data were converted to % above ground plant tissue N, P, K, and ppm Zn; % root N, P, K, and ppm Zn; ppm rhizosphere soil organic P; ppm rhizosphere soil inorganic P. Analyses were also run on kg/ha grain yield; percent grain N, P, K, and ppm Zn; kg/ha yield of P, cm/cm^3 root density, and ppm bulk soil organic and inorganic P data. Three replications were used to compute all mean values. An analysis of variance was run on each of the data by treatment, by date, and by treatment X date. Duncan's multiple range test was then applied to the data to determine significance among means (95).

RESULTS AND DISCUSSION

The effects of fertilizer treatments one, two, three, and four (herein referred to as control, NS-P, NS, and NS+C, respectively) will be examined. Data collected on plant and soil parameters will be discussed in relation to the phosphorus nutrition of corn.

Above ground plant tissue content of P (Table 4) in the control treatment was significantly higher than in tissues from either the NS-P or NS+C treatments for the June 13 sampling date. The NS treatment was not significantly different from any of the treatments. Above ground plant tissues samples on June 27 show the control, NS and NS+C treatments to be significantly higher in above ground plant tissue content of P than the NS-P treatment. By July 13 no significant differences occurred among treatments. Above ground plant tissue samples taken on July 31 show the NS+C treatment to have a significantly higher concentration in above ground plant tissue content of P than the other treatments. Also, the control and NS treatments were lower than the NS+C treatment but significantly higher in above ground plant tissue content of P than the control treatment. The last date of sampling, September 28, again indicates no significant differences among treatments. In general, the above ground plant tissue content of P started out high and dropped continuously throughout the growing season for all treatments, with the most rapid decline in above ground plant tissue content of phosphorus occurring at the last three sampling dates. And so it appears that the plants were accumulating P in their above ground plant tissues until approximately the third sampling date at which time it began to decline. This decline corresponds to the beginning of the

Table 4. Above ground plant tissue content of phosphorus at five sampling dates.

Dates	Treatments			
	T1	T2	T3	T4
	%			
June 13	.40[a]	.34[b]	.38[ab]	.33[b]
June 27	.38[a]	.31[b]	.35[a]	.37[a]
July 13	.38[a]	.35[a]	.34[a]	.37[a]
July 31	.24[b]	.22[c]	.24[b]	.26[a]
Sept. 28	.12[a]	.16[a]	.13[a]	.13[a]

Means within a date for each fertilizer treatment followed by the same letter are not significantly different (Duncan 10%).

reproductive stage when the plant nutrients start to translocate into the grain, a feature demonstrated by Hanway (45). Plants in the NS+C treatment plot appeared to be larger than plants in the other treatments throughout the growing season. When comparing plant tissue samples of different sized corn plants varying in nutrient content, nutrient determination on total plant basis might prove to be a valuable measurement for this study in the future.

P content (Table 5) of root tissue from the control treatment was significantly higher in P than the root tissue from either the NS or the NS+C treatments, but is not significantly different than the NS-P treatment for the June 13 sampling date. June 27 samples indicate no significant differences among treatments. Root tissues sampled on July 13 show the control treatment to have a significantly higher P concentration in the root than the other treatments. Roots from the NS treatment were significantly lower in P content than roots in the NS+C treatment but significantly higher in P than roots from the NS-P and NS+C treatments. Root tissues sampled on July 31 indicate no significant differences among treatments. On the last date of sampling, September 28, roots from the control treatment contained significantly higher levels of P than those from the NS+C treatment. P levels in roots from either the control or NS+C treatment were not significantly different from roots of the NS-P or NS treatments. In general, the root P levels started out at a relatively moderate level, increasing at the second sampling date, then decreasing at the third sampling date followed by a final leveling trend or slight increase in root P. This final increase which occurred at the last sampling date for some of the treatments, often appears as a plant nears maturity (20).

When comparing the changes in P concentrations in the above ground plant tissue to those in the root, a pattern becomes evident. When above

Table 5. Root phosphorus content at five sampling dates.

Dates	Treatments			
	T1	T2	T3	T4
	%			
June 13	.16[a]	.15[ab]	.12[b]	.14[b]
June 27	.18[a]	.16[a]	.16[a]	.15[a]
July 13	.15[a]	.12[c]	.13[b]	.11[c]
July 31	.14[a]	.11[a]	.12[a]	.12[a]
Sept. 28	.15[a]	.12[ab]	.12[ab]	.08[b]

Means within a date for each fertilizer treatment followed by the same letter are not significantly different (Duncan 10%).

ground plant tissue levels of P are high, root P levels are low and vice versa. This illustrates the source-sink relationships which occur in plant nutrition. Early in the season the above ground plant tissue acts as a P sink with the roots obtaining nutrients from the soil, assimilating and translocating them to the above ground plant tissue acting as the source. At silking the above-ground tissue contains half of the total plant P taken up during the growing season (45). At this time the above ground plant tissue becomes the P source and the developing grain becomes the P sink, ultimately claiming approximately 75 percent of the total above-ground plant P (45). At maturity, root systems decrease their activities and reduce in size, so any slight increases observed may actually be a concentrating effect. These findings are concurrent with findings by Carson, Hanway, and Leonard and Martin (20, 45, 46, 65).

None of the treatments were found to differ significantly in P content of the grain (Table 6). By also looking at the N, K, and Zn concentrations in the grain (Table 17) we see that none of those values differ significantly among treatments either. When varying nutrient supply to corn, the reproductive tissue incorporates only a certain amount of nutrients. This is concurrent with findings by Cook and Turk (30, 114), substantiating that differences in soil fertility and plant tissue nutrient content do not affect the concentration of nutrient in the grain, providing that the plant is not deficient in nutrients.

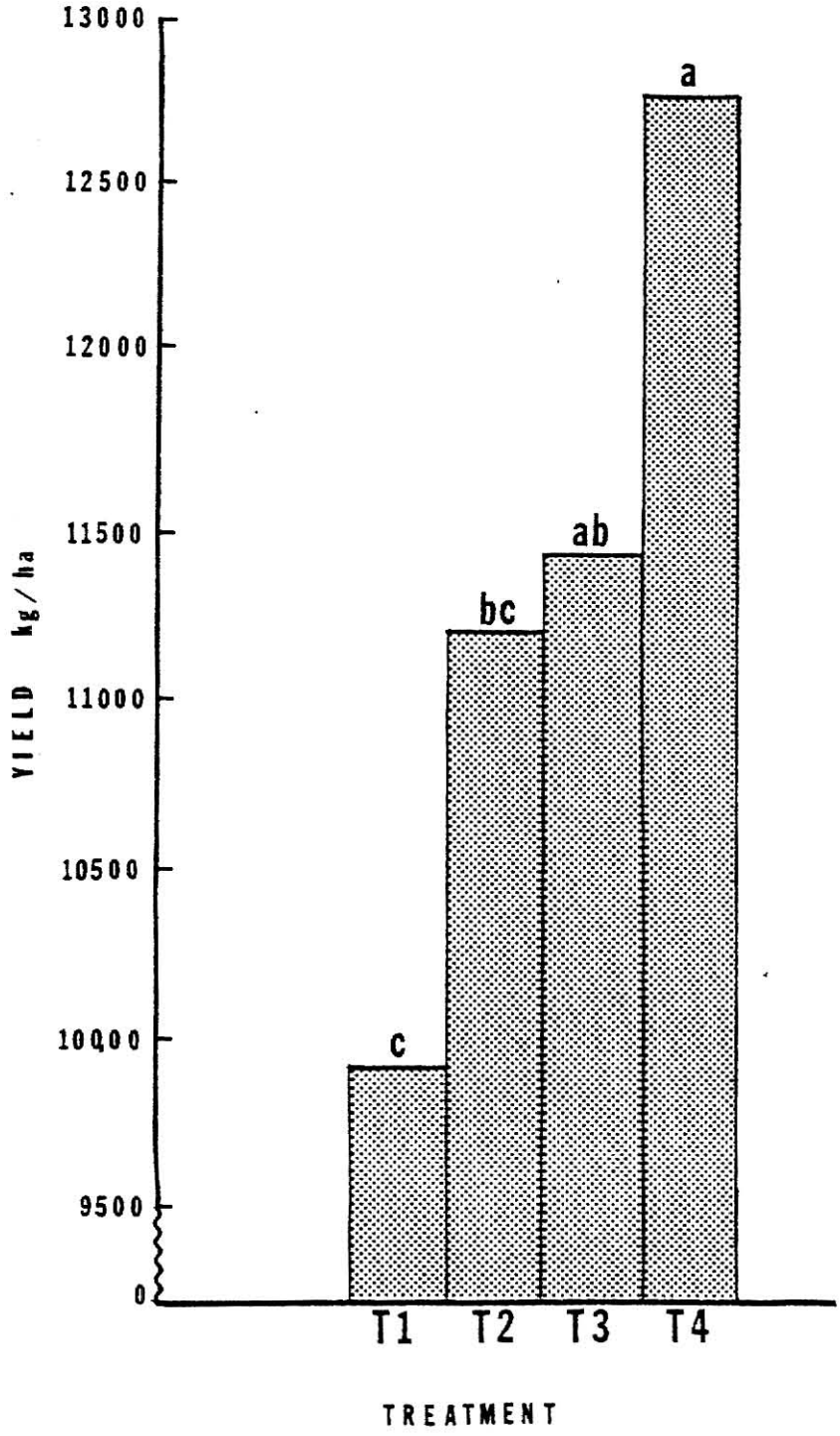
Grain P concentration, however, does not seem to correlate to grain yield (Figure 2). The NS+C treatment produced a significantly higher yield than the control or NS-P treatments, averaging 12723 kg/ha. This was followed by the NS treatment, yileding 11446 kg/ha, which was significantly higher than the control treatment but not significantly different than yields from the NS-P and NS+C treatments. The NS-P treatment produced 11153 kg/ha which

Table 6. Grain yield, phosphorus content, and yield of phosphorus.

Treatments	Yield	P concentration	Yield of P
	- kg/ha -	%	kg/ha
T1	9898[c]	0.28[a]	27.71[ab]
T2	11153[bc]	0.27[a]	30.11[ab]
T3	11446[ab]	0.23[a]	26.33[b]
T4	12723[a]	0.28[a]	35.62[a]

Means within a column followed by the same letter are not significantly different (Duncan 10%).

Figure 2. Grain yield.



Yield mean levels designated by the same letter are not significantly different (Duncan 10%).

was significantly lower than the NS+C treatment yield but not significantly different than the control or NS treatment yields. The lowest yield, 9898 kg/ha, occurred in the control treatment and was significantly lower than the other treatment yields, except when P was omitted from the nutrient solution. These results show that treatments with supplemental P in daily irrigation significantly increased yields over those treatments with no added P. Patel and Wallace also found an increase in yields to result from increasing P additions to the soil above the optimum level (81). The treatment with daily carbon fertilization resulted in the highest grain yield. When an amount of carbon matching that which is normally exuded from the roots is supplied externally, by fertilization, the plants seem able to direct this conserved energy into growth. The mean yield from the NS+C treatment showed 11%, 14%, and 22% increases over the mean yields of the NS, NS-P, and control treatments, respectively. Although the mean yield from the NS+C treatment is not statistically significantly different than the mean yield from the NS treatment, the large difference indicates that carbon fertilization is worthy of further investigations.

Another method of comparing plant nutritional status is to express yield of P (grain yield X grain P concentration). Yield of P values (Table 6) show that the NS+C treatment has the highest yield of P and it is significantly higher than that of the NS treatment. Yield of P for the control and NS-P treatments are intermediate to those of the NS and NS+C treatments and not statistically different from either of them. The mean yield of P from the NS+C treatment showed 35%, 18% and 29% increases over the mean yields of P of the NS, NS-P, and control treatments, respectively. Similar P concentrations present in corn plant reproductive tissue, regardless of the fertility treatment, means the yield of grain is the distinguishing component. So, in order to determine the amount of P obtained from a

hectare of corn grain, the yield of P must be studied also.

At both sampling dates the NS-P treatment produced the highest root density in the soil (Table 7). This might be expected when compared with the NS and NS+C treatments. In the treatment where phosphorus was omitted from the nutrient solution, a higher root density could occur due to an increase in phosphorus use efficiency. This view is supported by work of McLachlan (74) who found greater root weights and root volumes to occur as the P availability was decreased. Another situation may also occur when root growth is stimulated by added P in addition to the already high soil P amounts present (34). In this case, however, the control treatment had neither highest nor lowest root density values and the other treatments in the soil were not consistent between dates. Root density data taken in the sand trenches did not differ significantly among treatments, but did become noticeably lower at the second sampling date. Perhaps since sand does not have the exchange properties of soil and because nutrient solution was added daily, the nutrients were readily available for root uptake. This would obviate the necessity for a large mass of roots in this area. The roots that are present in the sand trench would have a very favorable environment and would not need to produce a strongly branched root system to obtain more nutrients. When root density samples were taken it was observed that although roots were fewer in the sand trenches, the ones present were much larger in diameter than those found in the soil. This may explain the decrease of root density in the sand as compared to that in the soil since root density only measures length of root per volume of soil. Roots for all treatments in the soil had higher densities at the August 17 sampling date as compared to those at the July 13 sampling date. Conversely, root densities in the sand trenches decreased for the treatments at the August 17 sampling date as compared to those at the July 13 sampling date. This

Table 7. Root density in soil and sand trenches.

Treatments	Dates	
	July 13	August 17
	cm/cm^3	
	Soil	
T1	$.09^{ab}$	$.13^{b}$
T2	$.14^{a}$	$.22^{a}$
T3	$.05^{b}$	$.15^{ab}$
T4	$.09^{ab}$	$.13^{b}$
	Sand	
T1	___*	___*
T2	$.11^{a}$	$.09^{a}$
T3	$.13^{a}$	$.09^{a}$
T4	$.17^{a}$	$.09^{a}$

Means within a column for either soil or sand followed by the same letter are not significantly different (Duncan 10%).

*Treatment 1 did not employ a sand trench.

occurrence was not explained by the data at hand nor were any previous works found which encountered this situation.

Organic P content of the rhizosphere soil (Table 8) from the control treatment is significantly higher than from soil in the NS-P and NS+C treatments but is not significantly different than the NS treatment for the June 13 sampling date. Organic P content of the rhizosphere soil sampled on June 27 indicates none of the treatments to have values with significant differences although the control treatment contains the highest amount of organic P. Samples taken July 13 show the soil organic P in the rhizosphere of the control treatment to be significantly higher than in soil of the NS+C treatment but not significantly different than soil in the NS-P and NS treatments. Rhizosphere soil sampled on July 31 was again found to be significantly higher in organic P for the control treatment than any of the other treatments. September 28 samples indicate no significant differences to occur among treatments, although soil from the control treatment again contained the highest amount of organic P. In general, the control treatment was consistently higher in organic P content of the rhizosphere soil than any of the other treatments. These results might be explained if future research shows this area to contain fewer microorganisms, less phosphatase enzyme activity, or both. A greater enhancement of the microbial population of the rhizosphere was expected in the NS-P, NS, and NS+C treatments as a result of the added nutrients (2, 7, 19, 20, 39, 41, 44, 57, 78, 83, 99, 102). The addition of nutrients, particularly the carbon amendment, could cause an increase in the microbe population, which in turn increases phosphorus mineralization as shown by a corresponding decrease in the soil organic P level (2, 19, 20, 39, 41, 44, 57, 83, 85, 99, 102). The extracting agent (0.5 N HCl) removes only part of the total soil organic P pool. A more accurate monitoring of organic P changes will be dependent on a more

Table 8. Organic* phosphorus content of rhizosphere soil.

Dates	Treatments			
	T1	T2	T3	T4
	ppm			
June 13	192[a]	108[b]	133[ab]	117[b]
June 27	140[a]	123[a]	102[a]	127[a]
July 13	141[a]	137[ab]	129[ab]	119[b]
July 31	167[a]	126[b]	120[b]	109[b]
Sept. 28	131[a]	123[a]	124[a]	126[a]

Means within a date for each fertilizer treatment followed by the same letter are not significantly different (Duncan 10%).

*0.5 N HCl-extractable; determined as Total P - Inorganic P.

exacting extraction procedure, perhaps a stronger acid (64) or a second extraction (3).

Levels of inorganic P in the rhizosphere soil (Table 9) for three sampling dates (June 13, June 27, and September 28) were found not to be significantly different due to treatments, although the control treatment had the highest value at each date. For two sampling dates, July 13 and July 31, the control treatment had significantly higher inorganic P content in the rhizosphere soil than the other treatments. In general, the inorganic P content of the rhizosphere soil, for all treatments, starts out high at the beginning of the season and drops to its lowest point at the end of the growing season. This pattern is unlike the organic fraction, probably because of its depletion by plant uptake. So, the inorganic P content of the rhizosphere soil should, and was observed to, decrease continuously throughout the growing season.

Carbon fertilization was hypothesized to not only reduce the carbon leakage from the roots, but to also stimulate the microbial population of the rhizosphere. Increasing the microbial population near the roots increases the likelihood of two benefits. First, microbial mineralization of soil organic phosphorus could be enhanced with the extra available P, buffering the inorganic pool decrease, observed through the growing season. Secondly, by encouraging that part of the soil P cycle designated by the double arrows (Figure 3). P is maintained within a dynamic immobilization/ mineralization cycle at the soil-root interface, exactly the place affording maximum plant uptake opportunity. This balance between soil microorganisms that promote mineralization and plant uptake will aid in reducing the fixation pathway in the cycle which limits growth by reducing available soil phosphate.

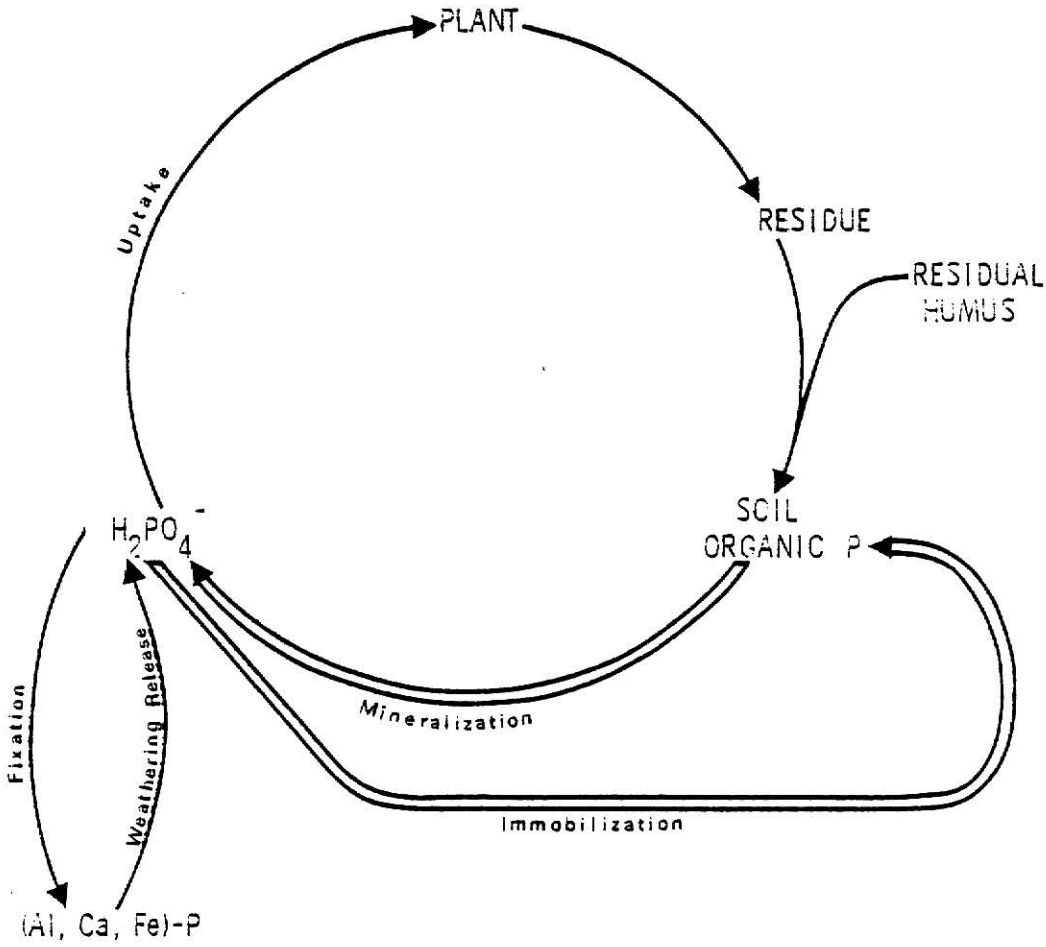
Table 9. Inorganic* phosphorus content of rhizsophere soil.

Dates	Treatments			
	T1	T2	T3	T4
	ppm			
June 13	138[a]	105[a]	98[a]	108[a]
June 27	138[a]	126[a]	100[a]	96[a]
July 13	119[a]	92[b]	93[b]	96[b]
July 31	111[a]	87[b]	88[b]	88[b]
Sept. 28	86[a]	81[a]	83[a]	72[a]

Means within a date for each fertilizer treatment followed by the same letter are not significantly different (Duncan 10%).

*0.5 N HCl-extractable.

Figure 3. Interaction of soil organic P in the rhizosphere with inorganic P cycling.



Comparisons between soil organic P and soil inorganic P in the rhizosphere within a treatment are presented in Figure 4. It is apparent that the organic fraction nearly always remains larger than the inorganic fraction. While the organic soil P content exhibits some variability, it still exhibits less fluctuation than the inorganic soil phosphorus which displays a downward trend throughout the growing season for all treatments.

Bulk (non-rhizosphere) soil P content data is available for only the September 28 sampling date (Table 10). No significant differences among organic P levels of the soil were found. The control treatment was significantly higher in inorganic P in the bulk soil than the other treatments. In general, the organic fraction was larger than that of the inorganic fraction of the bulk soil. High soil inorganic phosphorus levels in the control treatment for both rhizosphere and bulk soil is probably linked to the low grain yield. Conversely, the NS+C treatment showed lower levels of soil inorganic phosphorus which was reflected in its high yield and high yield of P. These data show that plants receiving the carbon fertilization, utilized the phosphorus most efficiently. Or, in other words, the NS+C treatment produced higher grain yields with the same amount of P present in the grain as the NS treatment.

In conclusion, it has been found that while grain quality remained basically the same for all treatments, grain quantity increased when phosphorus was added above optimum soil levels and continued to increase with carbon fertilization. The addition of carbon to the nutrient solution, in amounts determined to offset a portion of the C exuded from the roots, resulted in an 11% increase of yield above plants grown without the additional carbon. The treatment in which plants were fertilized with carbon resulted in less soil inorganic P present at the end of the season. These results show that C fertilization somehow aids in the efficiency of phosphorus re-

Figure 4. Soil organic P and soil inorganic P in the rhizosphere.

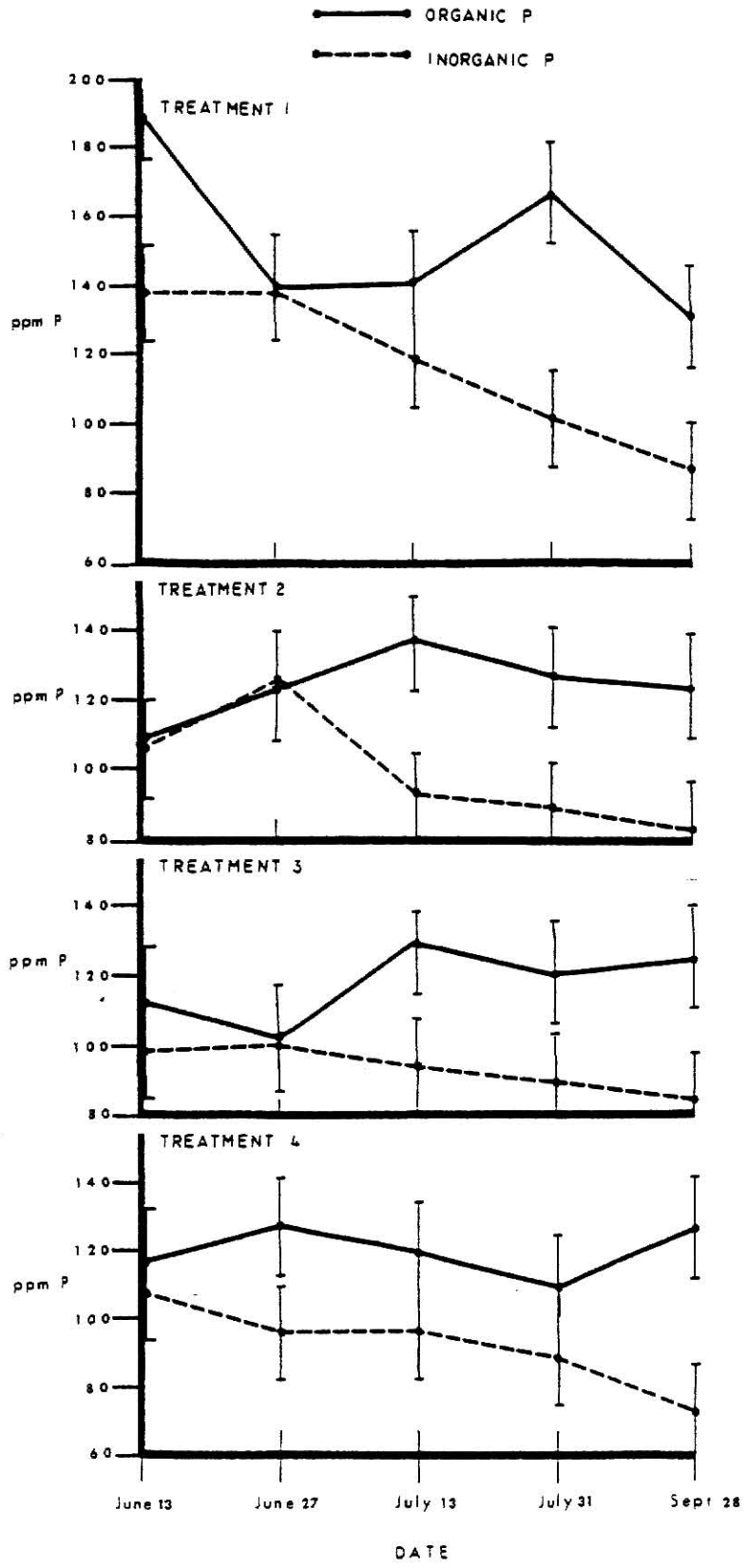


Table 10. Organic and inorganic phosphorus content of the bulk soil.

Treatments	Date
	Sept. 28
	ppm
	Organic*
T1	136[a]
T2	129[a]
T3	142[a]
T4	132[a]
	Inorganic*
T1	93[a]
T2	82[b]
T3	81[b]
T4	80[b]

Means within a column for either organic or inorganic followed by the same letter are not significantly different (Duncan 10%).

*0.5 N HCl-extractable; organic P determinations determined at Total P - Inorganic P.

moval from soils. Increased efficiency of phosphorus removal from soils is again reflected by the yield of P which was also greatest in the treatment receiving carbon fertilization and was 35% higher than that of the treatment without additional carbon. So, results of this study found carbon fertilization to increase the efficiency of P removal by plants from soil high in P, resulting in a trend towards higher yields.

Carbon fertilization is an area which needs more evaluation before its utility in affecting plant nutrition and yield is known. Work done using different levels of carbon addition to the soil would benefit our understanding of plant energy needs, especially at the soil-root interface. It would be helpful to know what level of carbon addition produces the greatest yields and/or root nutritional activities. Although many aspects of carbon addition to the soil remain unknown, it has been determined that carbon fertilization does play an important role in the phosphorus nutrition of corn.

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APPENDIX

Table 11. Above ground plant tissue content of nitrogen at five sampling dates.

Dates	Treatments			
	T1	T2	T3	T4
	%			
June 13	4.49[a]	4.16[b]	4.48[a]	4.27[ab]
June 27	3.72[a]	3.40[b]	3.67[a]	3.69[a]
July 13	3.78[a]	3.51[ab]	3.08[b]	3.46[ab]
July 31	1.48[c]	1.55[bc]	1.61[b]	1.79[a]
Sept. 28	1.16[a]	1.27[a]	1.20[a]	1.26[a]

Means within a date for each fertilizer treatment followed by the same letter are not significantly different (Duncan 10%).

Table 12. Above ground plant tissue content of potassium at five sampling dates.

Dates	Treatments			
	T1	T2	T3	T4
	%			
June 13	4.00[b]	4.49[a]	4.51[a]	4.27[a]
June 27	4.62[a]	4.70[a]	4.54[a]	4.29[a]
July 13	2.79[a]	2.76[a]	2.98[a]	2.60[a]
July 31	2.33[c]	2.36[c]	2.46[b]	2.56[a]
Sept. 28	1.89[a]	1.98[a]	2.16[a]	1.94[a]

Means within a date for each fertilizer treatment followed by the same letter are not significantly different (Duncan 10%).

Table 13. Above ground plant tissue content of zinc at five sampling dates.

Dates	Treatments			
	T1	T2	T3	T4
	ppm			
June 13	39.7[a]	45.3[a]	44.3[a]	41.0[a]
June 27	32.7[a]	38.7[a]	33.3[a]	31.7[a]
July 13	32.0[a]	34.7[a]	36.0[a]	40.7[a]
July 31	24.7[b]	30.0[a]	26.7[b]	31.0[a]
Sept. 28	12.7[c]	18.0[b]	20.7[a]	18.0[b]

Means within a date for each fertilizer treatment followed by the same letter are not significantly different (Duncan 10%).

Table 14. Root nitrogen content at five sampling dates.

Dates	Treatments			
	T1	T2	T3	T4
	%			
June 13	1.66^{ab}	1.77^{a}	1.52^{b}	1.63^{ab}
June 27	1.49^{a}	1.38^{a}	1.46^{a}	1.47^{a}
July 13	1.40^{a}	1.30^{ab}	1.31^{ab}	1.24^{b}
July 31	1.21^{a}	1.47^{a}	1.35^{a}	1.44^{a}
Sept. 28	1.03^{a}	1.32^{a}	1.27^{a}	1.17^{a}

Means within a date for each fertilizer treatment followed by the same letter are not significantly different (Duncan 10%).

Table 15. Root potassium content at five sampling dates.

Dates	Treatments			
	T1	T2	T3	T4
	%			
June 13	2.04[a]	2.00[a]	2.03[a]	2.12[a]
June 27	2.16[a]	2.00[ab]	1.35[c]	1.66[bc]
July 13	1.78[a]	2.11[a]	1.78[a]	1.86[a]
July 31	2.34[b]	2.58[ab]	2.73[ab]	2.97[a]
Sept. 28	3.51[a]	3.58[a]	2.87[a]	3.13[a]

Means within a date for each fertilizer treatment followed by the same letter are not significantly different (Duncan 10%).

Table 16. Root zinc content at five sampling dates.

Dates	Treatments			
	T1	T2	T3	T4
	ppm			
June 13	39.0[a]	21.7[c]	32.3[b]	27.0[bc]
June 27	33.0[a]	26.3[b]	25.3[b]	24.3[b]
July 13	31.7[a]	24.0[c]	30.3[ab]	26.3[bc]
July 31	26.3[a]	23.7[a]	24.3[a]	25.0[a]
Sept. 28	16.7[a]	22.7[a]	20.3[a]	15.7[a]

Means within a date for each fertilizer treatment followed by the same letter are not significantly different (Duncan 10%).

Table 17. Grain N, K, and Zn content.

Plant Nutrient	Treatments			
	T1	T2	T3	T4
N (%)	1.46[a]	1.44[a]	1.25[a]	1.42[a]
K (%)	0.36[a]	0.37[a]	0.32[a]	0.36[a]
Zn (ppm)	23.0[a]	21.0[a]	19.0[a]	22.0[a]

Means within a line for each plant nutrient followed by the same letter are not significantly different (Duncan 10%).

PHOSPHORUS NUTRITION OF CORN (ZEA MAYS L.) AS AFFECTED BY HIGH NUTRIENT FERTILIZATION INCLUDING CARBON

by

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Phosphorus is associated with increased root growth, greater strength of cereal straw, hastened plant maturity, increased disease resistance, and other favorable conditions. It was therefore of interest, and the purpose of this study, to determine if amending the plant's nutrient environment, especially in regard to P, could increase yield, phosphorus uptake efficiency, or both. The effects of four fertilization treatments were observed in a high yield corn (Zea mays L.) study conducted at the North Agronomy Farm, Manhattan, Kansas in 1979. Three treatments received a daily application of nutrient solution by drip irrigation throughout the growing season. Nutrient levels were sufficient to provide amounts required for a high yield. The macronutrients were supplied to match the utilization rate depicted by Hanway's growth curve (1962). The three treatments receiving the added nutrients were: treatment two (T2) consisting of a modified Hoagland's nutrient solution without phosphorus; treatment three (T3) consisting of the nutrient solution; and treatment four (T4) consisting of the nutrient solution plus a source of carbon (sucrose). Since Barber and Martin (1976) found 12 to 18 percent of the carbon in plant dry matter is lost through the roots where soil microorganisms are present, carbon was added at a rate equal to 15 percent of the total plant accumulation of carbon projected by Hanway's growth curve assuming a maximum accumulation of 47,436 kg/ha. Each of these treatments was applied by trickle tube over a sand trench which ran the length of the treatment row. Treatment one (T1) was a control treatment where no sand trench was employed and no nutrient solution was added, only irrigation water.

Data collected at five sampling dates and analyzed include: above ground plant tissue N, P, K, and Zn; root N, P, K, and Zn; and soil organic and inorganic P in the rhizosphere. Other data collected and analyzed were: grain N, P, K, and Zn; grain yield; root density; and soil organic and in-

organic P in the bulk soil.

While grain quality remained the same for all treatments, grain qauntity increased when phosphorus was added in amounts above optimum soil levels and continued to increase with carbon fertilization. The mean yields for T1, T2, T3, and T4 were 9898 kg/ha, 11153 kg/ha, 11446 kg/ha, and 12723 kg/ha, respectively. The addition of carbon to the nutrient solution, in amounts to offset a portion of the C exuded from the roots, resulted in an 11% increase of yield above plants grown without the additional carbon, even though this increase was not statistically significant. The treatment in which plants were fertilized with carbon resulted in less soil inorganic P present at the end of the growing season and showed a 35% increase in yield of P above plants grown without the additional carbon. This shows that C fertilization aids in the efficiency of phosphorus removal from soils. Results of this study found carbon fertilization to increase the efficiency of P removal by plants from soil high in P, resulting in a trend towards higher yields.