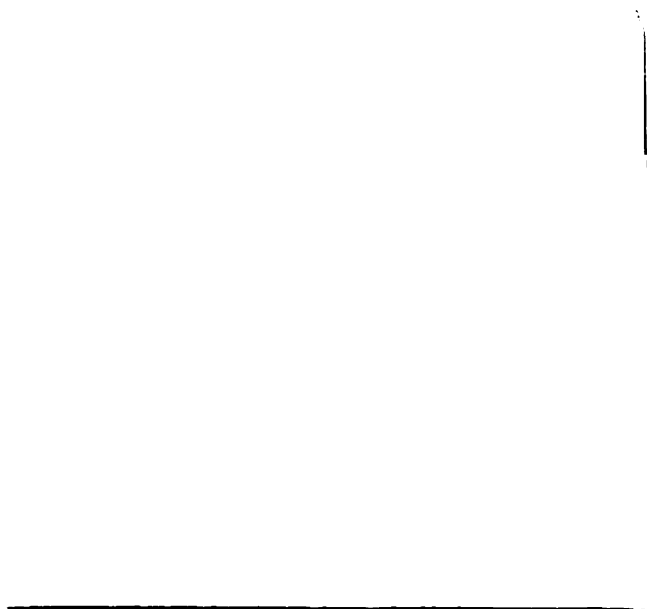


TRANSFORMATION OF
SOILS AFTER FLOODING
BY CHEMICAL EXTENSION
UPTAKE BY

Thesis for the Doctor of Philosophy
MICHIGAN STATE UNIVERSITY
Manoowetay
1971

THESIS



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ABSTRACT

TRANSFORMATION OF PHOSPHORUS IN SOILS AFTER FLOODING AS MEASURED BY CHEMICAL EXTRACTION AND UPTAKE BY RICE

By

Manoowetaya Srisen

Eight Michigan soils, including sandy loam, loam, clay loam and clay textures with poorly and well-drained soils of each texture, were selected to study in the greenhouse. Both A and B horizons of each soil were placed in one-gallon cans with plastic liners. Rice seedlings were planted in NK and NPK treatments (100 ppm of each element). Also, a control pot (NK, 100 ppm of each) with no rice was maintained. Micronutrients were added after the soils were submerged. Soil samples before flooding were analyzed to determine pH, Eh, saturated CaSO_4 extractable Mn, 0.1 NH_4OAc extractable Fe, organic matter and Bray's P-1, Olsen's sodium bicarbonate P, and Truog's dilute sulfuric acid P. Soil and water samples after flooding were taken at 3-week intervals and analyzed for pH, Eh, extractable Mn and Fe, Bray's P-1, Olsen's P and Truog's P. Yield of rice was determined at the end of the study.

The following conclusions were drawn:

- 1) The yield of rice responded remarkably to P application in B horizons whereas little response to P fertilization was found in A horizons.

2) Relative yield of rice was related to either Bray's P-1 or Olsen's sodium bicarbonate extractable P where soils containing less than 10 ppm P before flooding responded to P fertilization. P extracted by Truog's weak sulfuric acid was not related to relative yield of rice.

3) After flooding there was a large chemical change:

a) pH of the soil increased about 1 pH unit, except in soil in which initial pH was lower than 5.30. In the latter, pH changed slightly due to flooding.

b) Eh decreased considerably due to submergence of the soils, except soils with high acidity (pH about 4.6-5.3).

c) Extractable Fe and Mn increased greatly after flooding, reached the maxima at 3-6 weeks, after which they declined slightly with time. Fe remained more constant after reaching the maxima.

d) The amount of extractable P by Bray 1, Olsen's and Truog's increased remarkably due to flooding. The quantity of Truog's P increase was much more than Bray's P-1 and Olsen's P. Olsen's P and Truog's P showed good relationship between initial P and P after flooding.

TRANSFORMATION OF PHOSPHORUS IN SOILS AFTER
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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Crop and Soil Sciences

1971

This work is dedicated to the
Thai farmers who have devoted
themselves to my country for
centuries, and to my parents
to which my debt is beyond thanks.

ACKNOWLEDGEMENTS

The author wishes to express his sincere gratitude to his major professor, Dr. B. G. Ellis, for his patient guidance and helpful suggestions throughout the course of this study and preparation in the manuscript. Sincere thanks is also expressed to the members of the Department of Crop and Soil Sciences for the many opportunities for intellectual growth.

I am indebted and grateful to the Thai Government for financial support which has enabled me to complete the study.

Special thanks is expressed to my friend, Usana Navanugraka, for her encouragement and support in this undertaking.

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INTRODUCTION

Rice (Oryza sativa L.) is one of the most important grain crops in the world. It is the staple food of the populous Far East and has also become an important crop in some countries of America, Europe, Africa and West Asia (Guidry, 1964). The total world production of rice in 1968 was 181 million metric tons and the area devoted to rice production was 238 million acres (U.S.D.A., 1969).

Rice is usually grown under paddy or flooded conditions. Where soils are submerged, the flow of oxygen from the atmosphere to the soil is curtailed and the oxygen entrapped between soil particles is readily consumed by aerobic soil microorganisms for their respiration. Consequently, a flooded soil will be devoid of oxygen, for all practical purposes, within a day of flooding causing the aerobic soil microorganisms to become inactive or die. The facultative and obligate anaerobic organisms then take over decomposition of plant residue and soil organic matter using oxidized soil components (e.g., ferric and inorganic compounds). This will produce a deficiency of oxygen in flooded soils except in a very thin soil surface layer (a few millimeters thick).

The environmental conditions prevailing in submerged soils are entirely different from those of well-drained soils. It has been shown by many experiments (Ponnamperuma, Tianco and Loy, 1967) that dramatic chemical changes occur after a soil is flooded.

Many workers (Mandel and Das, 1970) have reported no response of paddy rice to P fertilization even though upland rice does respond. This has been chiefly due to the increase in availability of native P in submerged soils. Most workers in this field (Mandel and Das, 1970) have the opinion that the increase is largely due to the reduction of FePO_4 to more soluble P compounds under anaerobic conditions.

Considerable work has been done on the transformation of water soluble P applied to upland soils. But similar studies in submerged or lowland soil are very limited and the effect of flooding on P transformation in Michigan soils has received no prior attention. The objectives of this study were: 1) to determine the nature, magnitude, and dynamics of both native and applied P after flooding soils; 2) to study the response of rice to P fertilization; and 3) to study the relationship between the solubility of P and Fe, Mn, pH, and Eh changes due to flooding.

LITERATURE REVIEW

Rice

Rice is grown over a very wide range of climatic, soil and water conditions, ranging from moist tropical to semi-arid regions in warm temperature climates; in heavy clay or infertile sandy soils; on dry land or in swamp land with water that may be 20 feet deep, and in fresh or brackish water. Innumerable varieties of rice that exist account for this cosmopolitan nature, for a variety may be found to suit almost any condition, provided that the plant is subjected to abundant sunshine, sufficient for the requirements of the particular variety (Grist, 1965).

The highest yields of rice are obtained in countries in a subtropical or warm temperature climate especially between 30 to 45° north of the equator. These are not, however, the extreme limits at which successful cultivation is possible. For instance, in Europe cultivation has moved northward to 49° north latitude in Czechoslovakia, and in the Soviet Union it extends to 47° north latitude and may be extended to 50-53° north latitude.

Paddy rice production is adapted to regions of high temperature and prolonged sunshine. The average temperature required throughout the life of the plant ranges from 68 to 100 F. The total temperature required (sum of daily mean temperatures during the growing period) is between 3,000 and 4,000 F. This is probably the lower range of requirement for in many countries this figure is greatly exceeded. In Hungary, one of the most northerly situated rice-producing countries, a total

temperature of 5,500 F and 1,200 hours of sunshine are considered the lowest limits for successful production in paddies.

The altitude at which paddy rice may be grown depends on latitude. It has been grown at 10,000 feet in the Himalayas, 6,000 feet in the Philippines, and over 4,000 feet in South America, while in many countries it is grown at altitudes exceeding 2,000 feet. But the area cultivated at considerable elevations is small compared to flat land because in such regions it is difficult to supply and control water.

The length of day is one factor affecting rice production. Paddy rice varieties can be grouped, based on photoperiodism, as sensitive and nonsensitive varieties. Sensitive varieties flower when the day length decreases and reaches a critical value for induction of the flowering phase. Such varieties are frequently of medium to long maturation periods. The inducement of flowering by shortening the day length influences their ripening period so that they are "date fixed" with regard to maturation date though their growing period can be extended by earlier planting. Nonsensitive varieties do not respond to the differences in photoperiod; their length of life is independent of day length so they can be grown at any season. They are "period fixed" with regard to length of maturation and the date of planting has little influence on the length of life. They may be influenced by factors other than photoperiod such as temperature. Among sensitive varieties there are variations in the degree of response to photoperiod.

The types of soil suitable for paddy cultivation depend more on the condition under which the plant is grown than on the nature of the soil. Chemical analyses of a soil do not appear to provide a very sure guide as to its suitability for paddy cultivation. The fact that a

soil can produce satisfactory paddy crops annually for centuries has no parallel in agriculture. Thus, paddy soils which are dissimilar in chemical composition will yield equally good crops. The apparent paradox may be partially explained by the nutrient-carrying role of irrigation water.

Flooding Soils

Flooding produces drastic changes in a soil. Ponnamperuma (1964) stated that water-logging caused a decrease in redox potential, an increase in pH in acid soils, an increase in specific conductance, the disappearance of nitrate accompanied by accumulation of ammonia, the generation of a variety of organic substances, an increase in solubility of Fe, Mn, P and Si, and the displacement of cations into the soil solution.

Oxidation-Reduction Potential and Soil Acidity

Reduction of the soil is the most important chemical change brought about by flooding. Oxidation-reduction potential or redox potential (Eh) is a quantitative measure of the intensity of this change. Because of their diagnostic and interpretative value in the study of water-logged and submerged soils, marsh soils, lake muds, and marine sediments, redox potentials have been extensively measured and their ecological significance indicated. Ponnamperuma and Castro (1964) stated that the single electrical property that served to differentiate a submerged soil from an upland soil was its redox potential. The high promise this property has for diagnostic and interpretative purposes in rice production cannot be fully exploited without a clear understanding of the redox system in submerged soils.

Application of the concept of oxidation-reduction potentials to a soil system has been tried by numerous researchers, but they have, at best, had only limited success. As will be seen later, different conclusions have been reached by various workers as to the usefulness of redox potential measurements as a valid analytical tool.

Yamane and Sato (1968) conducted a series of experiments to determine the best way to obtain reproducible redox potentials of submerged soils. They found that the area of the electrode was related to the measured Eh values. The smaller the area of the electrode, the slower the soil Eh value was reached. Therefore, they felt that platinum electrodes should be at least 100 mm^2 in area. Even with such large electrodes, it was necessary for the electrode to be in contact with the soil for longer than 6 hours and, in most cases, at least 24 hours to obtain reproducible results.

Ponnamperuma, Tianco and Loy (1967) in a 17-week study found that the quantitative treatment of redox equilibria in such a complex system as a flooded soil was difficult because: 1) the highly dynamic nature of the flooded soil prevents the attainment of a stable, true equilibria; 2) of uncertainty about which of a large number of possible redox systems is operating at a given time; 3) the lack of thermodynamic data on the transition elements present in the soils that undergo reversible oxidation reduction; 4) complex formations which may alter redox equilibria between inorganic ions; and 5) the uncertainty about the true potential of a reduced soil--the soil potential or the potential of the soil solution. However, they were able to determine that the equation

$$Eh = 1.058 - 0.059 \log Fe^{+2} - 0.177 \text{ pH} \quad (1)$$

where Fe^{++} = activity of ferrous ion of soil solution

holds for most of the 17 weeks of submergence. They proposed that the precipitation of the metastable compounds $\text{Fe}(\text{OH})_3$ and $\text{Fe}_3(\text{OH})_8$ in the equilibria was confirmed by their findings, indicating that the soil solution was the thermodynamically meaningful phase.

In another paper, Ponnamperna, Loy and Tianco (1969) also attempted to study the quantitative change of redox potential, pH and activity of Mn^{++} in solutions of flooded soils. They found that the data supported the hypothesis that the manganese dioxides involved in redox equilibria in soils that undergo seasonal oxidation-reduction are complex, non-stoichiometric oxides of variable composition where apparent standard-free energies of formation are considerably less than those of their theoretical counterpart.

Jeffery (1961) found that he could differentiate between oxidized and reduced soils with Eh measurements, but the error was too great to yield precise information about the state of reduction of the water-logged soils. He also felt that the large experiment error made it of little value to correct for pH change. He suggested that a more accurate estimation of the state of reduction of a soil could be obtained by determining the concentrations of the two oxidation states of Fe in the soil. He developed the equation

$$\text{Eh} = 1.033 - 0.0601 C_{\text{Fe}^{+2}} - 0.180 \text{ pH (at 30 C)} \quad (2)$$

where $C_{\text{Fe}^{+2}}$ = ferrous iron concentration (me/l) in soil solution

as being applicable to water-logged soils.

In another paper, Jeffery (1961) expanded this equation and made experiments in an effort to define oxidizing conditions, healthy reducing conditions, and extreme reducing conditions in quantitative terms. Using the above equation, he developed the term $r_h =$

Eh + 0.180 pH and calculated the value $r_h > 1.34$ volts for oxidizing conditions, r_h equal to 1.12-1.27 volts for healthy reducing conditions and $r_h < 1.15$ volts for extreme reducing conditions.

Mukhopadhyaya, Fisher and Smith (1967) studied the effect of submergence and lime treatment on changes in Eh, pH, plant uptake of Mn, yield of rice grain and straw. They found that the Eh values in all treatments declined sharply during the first two to three weeks of submergence, after which relative stability was attained. The pH of both limed and unlimed soils stabilized near 7.0 after 64 days of flooding.

Ponnamperuma and Castro (1964) studied 31 soils of known chemical compositions by submerging them in pots. The redox potentials in the soils and the leachates were measured at regular intervals with black platinum electrodes. Parallel chemical and physico-chemical determinations were made on the soil and the soil solution.

Eh, dE/dpH and chemical analyses were the criteria used for identification of the redox systems. The Eh of soil immediately after moistening ranged from +350 to +620 m.v. The potentials were highly correlated with pH and defined by the equation

$$Eh = 851.2 - 56.47 \text{ pH.}$$

This suggested that the potential of aerobic soils was governed by the irreversible oxygen system.

During the first three days after flooding, Eh of all soils dropped a few hundred m.v. The subsequent changes of Eh varied from soil to soil but five patterns were noted. Soils low in organic matter showed a small decrease in potential and maintained positive potential even after 180 days of submergence. Soils rich in NO_3^- maintained an

Eh of about +200 m.v. for two weeks and then showed a drop in potential. In soils with a high content of MnO_2 , Eh decreased gradually to 0 m.v. after 180 days of flooding. Soils rich in active iron decreased the Eh to approximately 50-200 m.v. and appeared to be strongly buffered. The greatest decrease in Eh and the lowest Eh were shown by soils low in NO_3^- , MnO_2 and Fe_2O_3 but high in organic matter. The result showed that the poisoning systems operate in flooded soils in the sequence predicted by thermodynamics.

The potential of the soil could not be interpreted quantitatively in terms of the concentration of Fe^{++} or Mn^{++} . Also dE/dpH for the soils diverged markedly from dE/dpH for the inorganic systems likely to be operating in reducing soils; dE/dpH varied with the soils, stage of reduction and the kind and amount of organic matter. Further, Eh of the soil was considerably lower than Eh of the leachate which could be due to filtering out or adsorption of bacteria and enzymes by the soil as the soil solution was removed.

This observation and the fact that a high proportion of the reduced products in the soil solution were organic substances suggest that the redox systems in reduced soils are organic systems mediated by enzymes. In other words, the potential of reduced soils is probably bacterial potential.

Mn and Fe

Robinson (1930) found that submerged soil solutions were different from aerated soil solutions in that they contained high concentrations of Fe and Mn. The Fe and Mn were present as protobicarbonates. Submerged soil solutions were also high in Ca and Mg and contained H_2S and other sulfides.

He stated that the high concentration of Fe, Mn, Ca and Mg was caused indirectly by the microbiological action on the organic matter which produced CO₂ along with other gases. It was the CO₂ that was mainly responsible for holding the Fe, Mn, Ca and Mg in the solution. In the absence of organic matter the solubility of Fe, Mn, Ca and Mg was not increased under submerged soil conditions. He also found that toxic concentrations of Fe⁺⁺ and sulfides developed in a few days after submergence. Toxic concentrations of Mg developed somewhat more slowly.

The International Rice Research Institute (1963) reported that flooding the soil caused a reduction of Fe and increased its solubility. Only a small amount of the reduced Fe in a flooded soil is in the soil solution. The bulk of it is in the solid phase as the hydroxide, carbonate, sulfide or exchangeable Fe⁺⁺.

The reddish brown latosolic soils (pH values of 4.6-6.2, active Fe content of 2.8-7.6%, and organic matter content of 2.3-4.3%) showed steep increases in the concentration of reduced Fe during the first 30 days of submergence. The concentration reached a maximum value of about 10,000-15,000 ppm and remained more or less constant. Soils with lower organic matter or active Fe content, regardless of pH and texture, attained lower maxima (6,000-9,000 ppm) and at a slower rate than the first group. Soils low in active Fe, irrespective of pH and organic matter content, attained still lower maxima (500-4,000 ppm) at an even slower rate. This result suggests that the maximum amount of reduced Fe in a soil is determined by the active Fe content and availability of organic matter with pH being relatively unimportant. They also reported that Mn compounds, such as ferric iron, function as electron acceptors in biological oxidations in flooded soils and undergo reduction, forming

the more soluble manganous compounds. Mn was more easily reduced than Fe, but the kinetics of Mn reduction was similar to that of Fe.

There were marked differences among the soils in the pattern of Mn reduction. Soils with a high content of active Mn, regardless of pH and organic matter content, showed steep increases in Mn^{++} during the first 30 days of submergence and declined slowly thereafter. Soils low in active Mn increased slowly in Mn^{++} concentration and reached maximum values which were very much lower than in the higher manganese soils. The overriding factor that determined the kinetics of Mn reduction was the active Mn content of the soil.

Takkar (1969) conducted a laboratory experiment to observe the effects of different levels of organic matter and different incubation times on extractable Fe and active Mn. Acidic, neutral, calcareous and saline-alkali soils were studied at 60% water-holding capacity (WHC) and under water-logged conditions. He found that the availability of Fe and Mn was influenced by the temperature in these soils. On incubations at 60% WHC, a marked increase in Fe was observed after 85 days and a decrease in Mn was observed after 7 days with increased organic matter content and with the time lag in most soils. An exception was the acidic soils where increases in Mn were found after 69 days.

Similarly, under water-logged conditions, marked increases in Fe and decreases in Mn were noticed after 7 days. The lowest amount of Fe and the time lag in its release in calcareous soils were due to the presence of iron oxides in highly crystalline forms in these soils. High content of free Fe and low pH resulted in higher amounts of extractable Fe in acidic soils. Under water-logged and high organic

matter content conditions, a decrease in Eh and a high concentration of ferrous iron were observed. This was accompanied by a decrease in pH except in acidic soils where pH increased.

P and Reducing Conditions

Considerable work has been done showing that submergence of a soil causes the availability of P to increase. Gasser (1965) noted that flooding soils caused an increase in acid-soluble P. This increase could be attributed to the reduction of ferric phosphate to ferrous phosphate. He proposed that in assessing the P status of rice soils the ferric phosphate should be considered as an "available" form.

Hayes and Phillips (1958) reported that the redox potential had little or no effect upon the level of P in soil solution. They felt that the biological system was the controlling factor and that the inorganic chemical system was secondary in importance. After water-logging a series of soil samples and administering antibiotics to quench the biological system, 10 out of 12 of the soil samples showed an increase in P under reducing conditions; but in 4 out of 10 the difference was less than 5%. They concluded that these results indicated the minor influence of the inorganic reducing system upon P levels in solution.

Shapiro (1958) showed that flooding caused an increase in P availability. He noted that applied P was utilized more efficiently under flooded conditions. These results held for soils high, moderate and low in native P. His data show that the increased P availability came from both the Fe-P and Al-P fractions but that the Fe-P fraction was affected to a much greater degree. He proposed that the small

increase in Al-P availability was probably due to a chelation reaction. The large increase in Fe-P availability was due to the reducing conditions brought on by the addition of organic matter and flooding the soil.

Mandal (1964) tested the effects of starch and lime on the availability of P in water-logged soil and found that water-logging a soil only slightly increased acetic-acid soluble P with a slight decrease in Fe-P and no change in the Al-P or Ca-P. When starch was added, however, a considerable increase in acetic-acid soluble P and a decrease in the Ca-P fraction occurred. He stated that the release of large quantities of CO₂ formed during starch decomposition may have caused tricalcium phosphate to convert to more soluble di- and mono-calcium phosphates. The addition of lime caused a decrease in Fe- and Al-P, especially Fe-P. Ca-P was increased appreciably, the effect seeming to be a conversion from Fe-P to Ca-P upon flooding. He suggested that in acid soils having most of their inorganic P in the ferric form liming followed by the addition of organic matter in a few days will result in an increase in P under water-logged conditions.

Mandal further found that after 105 days of water-logging the Al-P fraction remained unchanged. The Ca-P fraction showed results similar to the Al, except in very high organic matter soils where CO₂ evolution was sufficiently high to be important. His data did not support the view that the increased availability of soil P upon water-logging is largely due to the reduction of ferric phosphate. The data on P availability suggested that the reduction of ferric phosphates did not occur to any great extent or that, if it did proceed, a reversion reaction with Fe⁺³ in the soil occurred at almost an equal rate.

Patrick (1964) found that extractable ferric and ferrous forms of Fe were very sensitive to changes in redox potential of the soil. Ferric iron predominated at potentials above +200 m.v. and extractable Fe was mostly ferrous below +200 m.v. At the same time, he found that extractable P increased over threefold between redox potentials +200 and -200 m.v. The sharp break in the phosphate release curve at +200 m.v., the same point at which ferric Fe began to be reduced, indicated that the conversion of P to an extractable form is dependent upon the reduction of ferric compounds in the soil.

Broeshart, Haunold and Fried (1965) noted that flooding significantly increased the availability of soil P in rice soils in which free CaCO_3 is absent. The reduced availability of phosphates under upland conditions was not enough to account for the reduced growth of rice under upland conditions in their opinion. They also found that the availability of fertilizer P was similar under reduced or oxidized conditions but that the efficiency of use was greater under flooded conditions.

Williams and Simpson (1965), in conducting experiments on cultivation and water-logging, found that flooding for 1-2 days produced anaerobic conditions that caused a decrease in P availability and an increase in sorption capacity. This reduced P availability applied both to soil P and applied P. They concluded that the decrease in P availability upon water-logging was due to the effects of certain reactions during the water-logging treatment. Reducible metals such as Mn could have interfered; the nature of the sorption sites may have been altered due to Fe reduction causing P to be more tightly bound; or some of the P sorbed could have been occluded by reprecipitation of Fe upon restoration of aerobic conditions. They felt that the increase in soil

P availability upon water-logging must be due to the presence of easily reducible ferric phosphates. Soils low in ferric phosphates would not be expected to increase in P availability upon water-logging.

Ehiang (1968) noted that soils rich in organic matter showed rapid lowering of Eh and increased formation of organic acids and gases upon water-logging. Disintegration of soil aggregates and lowered Eh values caused an increase in P solubility. These effects were more significant in Fe-rich soils. H_2 , H_2S and the organic acids, especially HOAc, increased P solubility in Fe- and Al-rich soils whereas CO_2 increased Ca-P solubility.

Patrick and Mahapatra (1968) and Mahapatra and Patrick (1969) showed that the greatest change in a P fraction between a soil under flooded conditions and under aerobic conditions occurs in the reductant-soluble fraction. When placed under water-logged conditions, the reductant-soluble fraction was greatly decreased indicating that the ferric oxide coating on the P had been reduced to a soluble ferrous oxide and the P released to the solution. The mechanism of P release in a flooded soil may be explained by 1) reduction of ferric phosphate to soluble ferrous phosphate; 2) release of occluded P by reduction of ferric oxide coating; 3) displacement of P from Fe- and Al-P by organic anions; 4) hydrolysis of Fe- and Al-P; and 5) anion (phosphate) exchange between clay and organic anions. They warn, however, that resorption processes can occur and water-logging will not always increase available P.

Furukawa and Kawaguchi (1969) submerged paddy soil samples for 2 weeks at 40 C and obtained up to a 21% decrease in organic P. This decrease correlated well with the increase of Bray No. 2 extractable P and was attributed to the mineralization of organic P. This increased

mineralization was thought to be due to the enhanced solubility of Fe or Al salts of inositol hexaphosphoric acid, the prominent organic P constituent, by reducing conditions or pH increase and rapid hydrolysis accompanying submergence.

Chakravarti and Ghoshal (1968) mixed two acid soils with 50% dried grass and each of the following treatments: 1) Fe-P; 2) Al-P; or 3) Fe and Al-P. Then they water-logged and incubated the samples at room temperature for 53 days. The amount of P released was found to be greatest in the Fe phosphate treatment followed by Fe and Al phosphate treatment, Al phosphate and the control in decreasing order.

Terman, Allen and Engelstad (1970) conducted a greenhouse pot experiment with flooded rice on a soil which was low in available P for upland crops. Marked yield responses by rice to applied P were obtained, but maximum yields were obtained at much lower rates of applied P than was true for most upland crops. Response to applied P decreased with liming of the soil and with increasing levels of acid-soluble soil P. Granular, water-soluble sources of P were most effective. The P in Fe-P was more available than that in Al-P in the flooded soil. Both forms were more available in fine particles than as granules and in colloidal form rather than fine crystals.

Mandal and Das (1970) studied the transformation of applied water-soluble phosphate in three acidic lowland rice soils and stated that the amount of added P remaining in solution in equilibrium with the soil declined sharply in all three soils but the rate at which it declined was found to be influenced more by the Fe_2O_3 and active iron content of the soils than by the pH of the soils. The solid-bound P fraction in the treated soils showed practically no increase over the

untreated ones. The aluminum phosphate fraction in the treated soil, however, showed a marked increase over the untreated one in all three soils. The magnitude of increase appeared to be influenced by Fe_2O_3 and active iron content, rather than by the pH of the soils. The calcium phosphate fraction showed little increase in all the soils with application of phosphate. Reductant-soluble iron phosphate showed significant increase only on one soil which was comparatively rich in Fe_2O_3 and active iron.

MATERIALS AND METHODS

This study was conducted in a greenhouse by growing rice on eight Michigan soil series.

I. Materials

a. Rice: Oryza Sativa Linn. Japonica type, Nato variety.

b. Fertilizer:

- 1) N as $(\text{NH}_4)_2\text{SO}_4$ (1.414 gm (100 ppm N) per pot)
- 2) K as KCl (0.5727 gm (100 ppm K) per pot)
- 3) P as Ca $(\text{H}_2\text{PO}_4)_2$ (1.052 gm (100 ppm P) per pot)
- 4) Micronutrients:

$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ 0.0240 gm/l (6.4 ppm Cu)

$\text{Zn SO}_4 \cdot 7\text{H}_2\text{O}$ 0.0296 gm/l (6.5 ppm Zn)

H_3BO_3 0.1860 gm/l (37.0 ppm B)

$(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}$ 0.0035 gm/l (1.9 ppm Mo)

CoCl_2 0.0028 gm/l (0.6 ppm Co)

The micronutrients were made up to a 1000 ml solution with distilled water and 6 ml of this solution added to each pot after flooding.

c. Type and location of soil samples

Michigan soils (Table 1) were selected to give a variation in chemical properties such as pH, organic matter content, amount of Fe and Mn and physical characteristics including drainage and texture which ranges from sandy loam to clay soil.

Table 1. Soil series and location of soils studied.

Soil series	Drainage	Texture	Location
1. St. Clair	well drained	clay	T2S, RTE SE $\frac{1}{4}$ of SE $\frac{1}{4}$ of NE $\frac{1}{4}$ of S2
2. Hoytville	poorly drained	clay	T9N, R1W NE $\frac{1}{4}$ of NE $\frac{1}{4}$ of NE $\frac{1}{4}$ of S18
3. Morley	well drained	clay loam	T1S, R5E SW $\frac{1}{4}$ of SW $\frac{1}{4}$ of NW $\frac{1}{4}$ of S23
4. Sims	poorly drained	clay loam	T9N, R3E NE $\frac{1}{4}$ of NW $\frac{1}{4}$ of NE $\frac{1}{4}$ of S33
5. Miami	well drained	loam	T4N, R1W SE $\frac{1}{4}$ of SE $\frac{1}{4}$ of S $\frac{1}{4}$ of S30
6. Conover	poorly drained	loam	T4N, R1W SE $\frac{1}{4}$ of SE $\frac{1}{4}$ of SE $\frac{1}{4}$ of S19
7. Hillsdale	well drained	sandy loam	T4N, R1W NE $\frac{1}{4}$ of NE $\frac{1}{4}$ of SE $\frac{1}{4}$ of S19
8. Locke	poorly drained	sandy loam	T4N, R1W NE $\frac{1}{4}$ of SE $\frac{1}{4}$ of SE $\frac{1}{4}$ of S19

Both surface soil (Horizon A) and subsoil (Horizon B) were collected from eight soil series. The detailed soil characteristics are given in the soil profile description in Table 1a of the Appendix.

II. Methods

1. Greenhouse work

a. Soil preparation:

Soil samples were air dried in the greenhouse for 1-3 days until their moisture content became satisfactory for screening. Each sample was passed through a 2 mm sieve and air dried. Three thousand grams of each prepared soil sample was weighed out and placed in a 1-gallon can with a plastic liner.

The treatments were as follows:

Can No. 1 mixed with NK and did not grow rice.

Cans No. 2, 3, 4 mixed with NK and rice grown.

Cans No. 5, 6, 7 mixed with NPK and rice grown.

There was a total of 112 cans for the 16 soil samples.

2. Flooding the soil

After the fertilizer treatments were added to each soil, each pot was flooded with distilled water. Six ml of micronutrient solution was added to each pot about 2 weeks before transplanting rice seedlings. The level of water was maintained at about 6 cm above the soil surface.

3. Preparation of rice seedlings

Rice seeds were germinated in a flat of water-saturated sand and kept in a greenhouse for 2 weeks until they became 10-15 cm high. Then 3 rice seedlings were transplanted to the previously flooded soil in each can.

4. Sampling

At 3-week intervals, both soil and water samples were collected for laboratory analysis. The soil samples were taken with a 1 in diameter tube and kept in covered polyethylene cups. Water samples were taken by pipet and kept in sealed glass bottles.

b. Analytical Methods

The moisture content of the soil samples of each can was determined for calculation of the oven-dried soil used in each chemical analysis.

Before flooding the soil pH, redox potential and content of organic matter, Mn, Fe, and P were determined.

Redox potential, pH, Mn, Fe and P content were determined for all samples (both soil and water) collected after flooding.

1. Exchangeable Fe⁺² analysis

Exchangeable Fe⁺² is not completely extracted from a soil by neutral NH₄OAc in the usual procedure for exchangeable cations

because Fe^{+2} is oxidized to Fe^{+3} during the extraction and much of it then precipitated.

From a freshly collected soil sample, field moisture conditions unchanged, an equivalent to 5 gm of oven-dried soil sample was quickly weighed out, placed in a 150 ml Erlenmeyer flask and 50 ml neutral 1N NH_4OAc solution added. The suspension was shaken vigorously for 30 seconds and quickly filtered through a previously prepared Buchner funnel fitted with filter paper. Three successive 10 ml portions of neutral 1N NH_4OAc solution were employed for further extraction of the soil. The entire extraction was completed in 5 minutes or less. The quantity of Fe in the filtrate was determined by use of a Perkin-Elmer Model 303 atomic absorption spectrophotometer.

2. Extractable Mn

Saturated CaSO_4 solution was used to extract Mn from the soil. An equivalent of 5 gm of oven-dried soil sample was shaken in 25 ml of saturated CaSO_4 for 15 minutes. The solution was filtered and Mn content of the clear filtrate determined on a Perkin-Elmer Model 303 atomic absorption spectrophotometer.

3. Redox potential and pH analysis

The redox potential and pH of the samples were measured by using a Sargent Model DR pH meter. A glass electrode and a saturated calomel electrode were used to obtain pH measurements. A 1 cm^2 bright Pt electrode was used along with a saturated calomel electrode to measure redox potential. The ratio of soil and distilled water was 1:1 (10 gm of oven-dried sample to 10 ml of distilled water) and pH was measured after stirring for 30 minutes.

4. Available P analysis

Three extracting solutions were utilized in this study for soil samples both before and after flooding.

(a) Dilute acid-soluble P of soils (Truog's solution)

An equivalent of 1 gm of oven-dried soil was weighed and placed in 100 ml of the buffered 0.002N H_2SO_4 extracting solution. The suspension was shaken for 30 minutes and immediately filtered through a retentive P-free filter paper. Then the clear filtrate was analyzed for P content by the molybdenum blue color reduction method.

(b) Dilute fluoride--Dilute acid-soluble P (Bray's extraction solution)

An equivalent to 2.85 gm oven-dried soil sample was weighed out into a 125 ml Erlenmeyer flask. Then 10 ml of 0.03N NH_4F in 0.25N HCl extracting solution was added and the suspension was shaken for 60 seconds. The suspension was immediately filtered and the clear filtrate retained for P determination.

(c) Hydroxyl and carbonate extractable phosphorous of soils (Olsen's extracting solution)

An equivalent to 2.5 gm of oven-dried soil sample and 1 teaspoon of P-free carbon black (Davco activated carbon G-60, washed with .1N HCl) was suspended in 50 ml of 0.5M NaHCO_3 extracting solution with pH 8.5. The suspension was shaken for 30 minutes, filtered and the clear filtrate retained for P analysis.

d. Color Development2.1 Chlorostannous Reductant in a Sulfuric System Method

Chlorostannous-reduced phosphomolybdic blue in a sulfuric system and 1,2,4-amino naphthal sulfonic-reduced phosphomolybdic blue color method, in a perchloric acid system were utilized in this study (Jackson, 1965). The heteropoly complexes are thought to be formed by coordination of molybdate ions with P as the central

coordinating atom. These heteropoly complexes are slightly yellow but appear colorless in lower concentration. The addition of a reducing agent will bring about a reduction in the phosphomolybdic complex yielding a blue color that can be measured colormetrically at 660 m μ . The concentration of P, molybdate ion, pH and reductant must be carefully controlled to take advantage of a narrow region where only the heteropoly complex is reduced and not the excess or an appreciable amount of interfering ions such as arsenic.

The chlorostannous-reductant molybdophosphoric blue color method in a sulfuric acid system has the highest sensitivity per unit of P present, providing a working range from 0.02 to 0.6 ppm of P. It provides for noninterference of Si in solution up to 200 ppm, Fe⁺⁺ up to 100 ppm, Fe⁺⁺⁺ up to 2 ppm, Ti up to 20 ppm, Ca and Mg up to 500 or more ppm, NO₃⁻ up to 100 ppm, F up to 5 ppm, Cl up to 250 ppm, SO₄⁻ up to 1000 ppm--but it includes arsenate in chemical equivalence to P. This method was used to determine P in water samples and in the filtrate of soil before flooding.

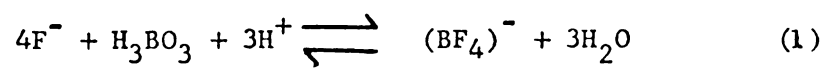
Twenty-five ml of centrifuged water sample or the filtrate of soil sample is placed in a 50 ml volumetric flask and 2-4 drops of 2,4-dinitrophenol indicator added and pH adjusted with 2N H₂SO₄ or 2N Na₂CO₃ until 1 drop of 2N Na₂CO₃ produces a yellow color (pH about 3). Two ml of 2.5% sulfomolybdic acid solution is added and the sample diluted nearly to volume with distilled water and thoroughly mixed. Then 0.2 ml of 0.1N SnCl₂ is added to develop the color. The sample is diluted to 50 ml with distilled water. After 5 minutes, but not later than 10 minutes, the color is read photometrically on an Evelyn photoelectric colorimeter at 660 m μ (filter).

2.2 1,2,4-Aminonaphtholsulfonic Acid Reductant in Perchloric System Method

The 1,2,4-aminonaphtholsulfonic acid-reduced molybdo-phosphoric blue color method in perchloric acid system is about one-sixth as sensitive as the above method with the standard curve ranging from 0.4 to 2.4 ppm of P. The chief advantage of this method is that 200 ppm of ferric iron will not interfere with the development of the blue color. Thus, it is well suited to the determination of total P of soils following perchloric acid digestion of the sample. The iron gives the solution a greenish cast, but that effect is eliminated by the light filter. Ti and V do not interfere nor does Mg from the magnesium nitrate ashing procedure. Silica and nitrate are eliminated by HClO_4 predigestion. This method was utilized for P determination on flooded soils.

An aliquot of 5-25 ml of filtrate is pipeted into a 50-volumetric flask. The pH is adjusted to 3 with 2N HClO_4 or 2N Na_2CO_3 , 2,4 dinitrophenol being used as an indicator. Then 5 ml of 60% HClO_4 is added and the solution volume is adjusted approximately to 40 ml. The solution is thoroughly mixed after each successive reagent is added. (The temperature is maintained at $25\text{ C} \pm 4\text{ C}$ throughout the color development.) Next 1.6 ml of 1,2,4-aminonaphtholsulfonic acid reagent is added. (Reductant reagent is recrystallized 1,2,4-aminonaphtholsulfonic acid, Eastman Kodak Co.). Exactly 15 minutes before the colorimetry reading 4.0 ml of the ammonium molybdate solution is added. The volume is quickly adjusted to 50 ml with distilled water. At the end of 15 minutes, optical density is read with a 660-m μ light maximum on an Evelyn photoelectric colorimeter. For F extractable P of soil, H_3BO_3

is added in the ammonium molybdate solution to remove F interference in the molybdenum blue color reaction.



RESULTS AND DISCUSSION

Yield of Rice

Soil type had relatively little influence upon the oven-dry weight of rice plants except that the A horizon of the Sims and the B horizon of the Locke were exceptionally high yielding (Table 2). Both soils are poorly drained with high quantities of available P.

In general, the yield of rice per pot from A horizons was greater than that of B horizons. But the Locke soil was an exception.

There was no response to P application on rice yield for A horizons except in the Locke soil. Without P application the A horizons yielded much more than the B horizons except for the Locke soil. A significant response to P fertilization of B horizons was obtained. Indeed, this response was often dramatic; for example, in the St. Clair B, NK yield was 1.33 g as compared to 18.67 for NPK.

There was little difference between yield of rice from A and B horizons after P fertilization. The greater P response with B horizons is associated with lower native contents of available P (Table 1a, Appendix).

The relationship between the amount of extractable P of the soil samples before flooding determined by Bray's No. 1, Olsen's and Truog's methods and the yield of rice was examined by plotting the relative yield against the amount of extractable P (Figures 1, 2 and 3).

The relative rice yield was defined as:

$$\frac{\text{yield of rice of NK treatment}}{\text{yield of rice of NPK treatment}}.$$

The relationship between P extracted by Truog's method and rice yield (Figure 3) is very poor. But the Bray No. 1-P and Olsen P were related to the yield of rice. The soils with Bray No. 1-P and Olsen P at the level of 10 ppm or lower responded to P fertilization (Figures 1 and 2).

Table 2. Yield of greenhouse rice as influenced by soil type, horizon and P level.

Soil Type	Horizon	Yield of rice (gm/pot)				
		NK ¹	NPK ¹	Averages		
				A	B	(A and B)
St. Clair	A	20.67	18.67	19.7		14.8
	B	1.33	18.67		10.0	
Hoytville	A	18.17	19.50	18.8		14.5
	B	2.00	18.33		10.2	
Morley	A	15.50	16.17	14.2		13.8
	B	8.67	17.83		13.2	
Sims	A	23.17	24.00	23.6		19.0
	B	10.33	18.50		14.4	
Miami	A	16.00	16.17	16.1		14.5
	B	9.50	16.17		12.8	
Conover	A	16.33	19.33	17.8		14.4
	B	4.33	17.66		11.0	
Hillsdale	A	14.66	14.50	14.6		13.6
	B	9.33	16.17		12.8	
Locke	A	11.83	19.50	15.7		17.4
	B	19.00	19.33		19.2	
Average	A	17.00	18.48	17.56		15.25
	B	8.06	17.83		12.95	
Average	A & B	12.53	18.16			15.25
		Treatment (NK, NPK)	Average (A, B)		Soil Type (A&B)	
L.S.D. 0.05		3.330 gm	2.945 gm		3.363 gm	
0.01		4.474 gm	4.058 gm		4.391 gm	

¹Each value is an average of 3 replications.

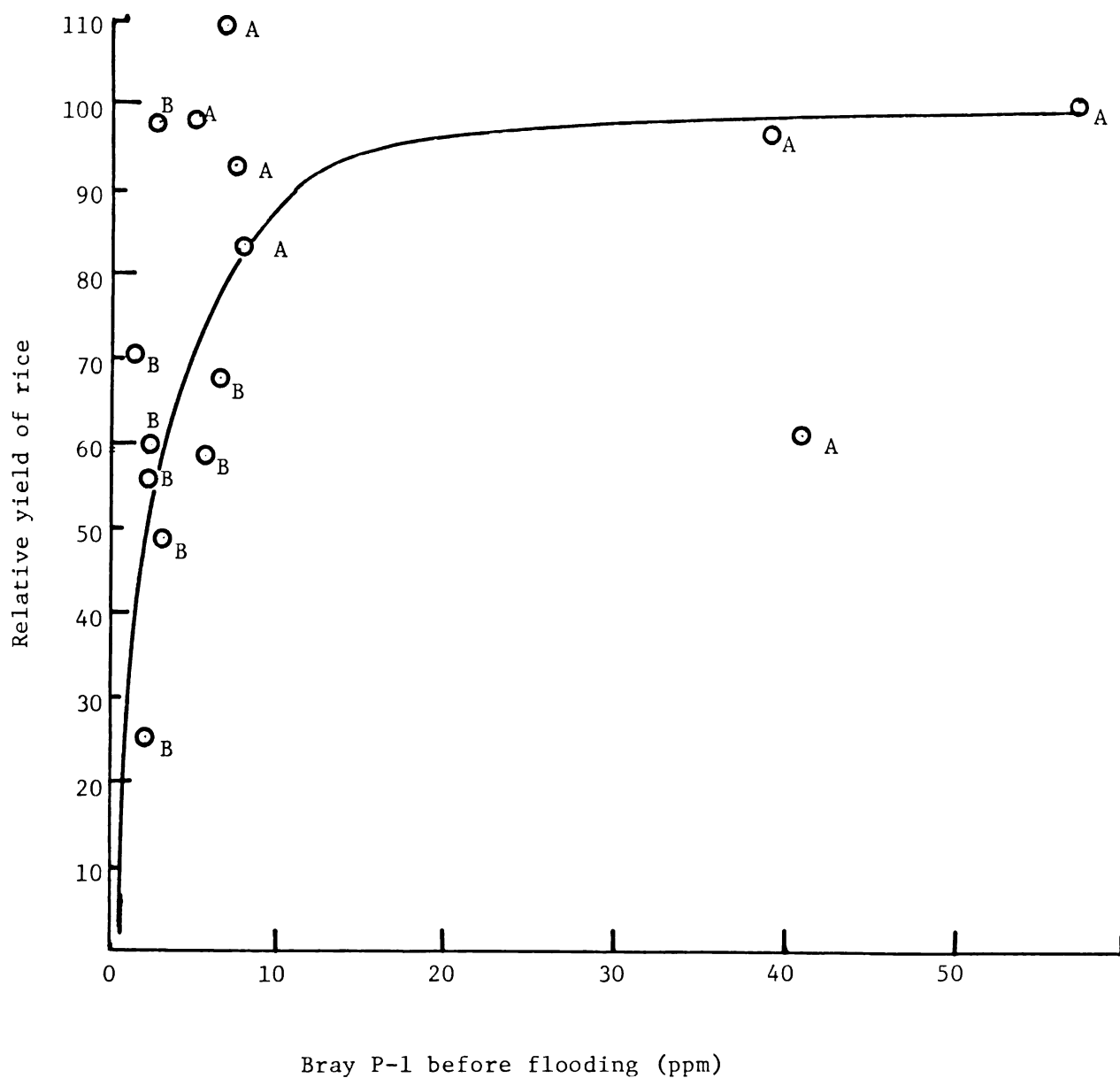
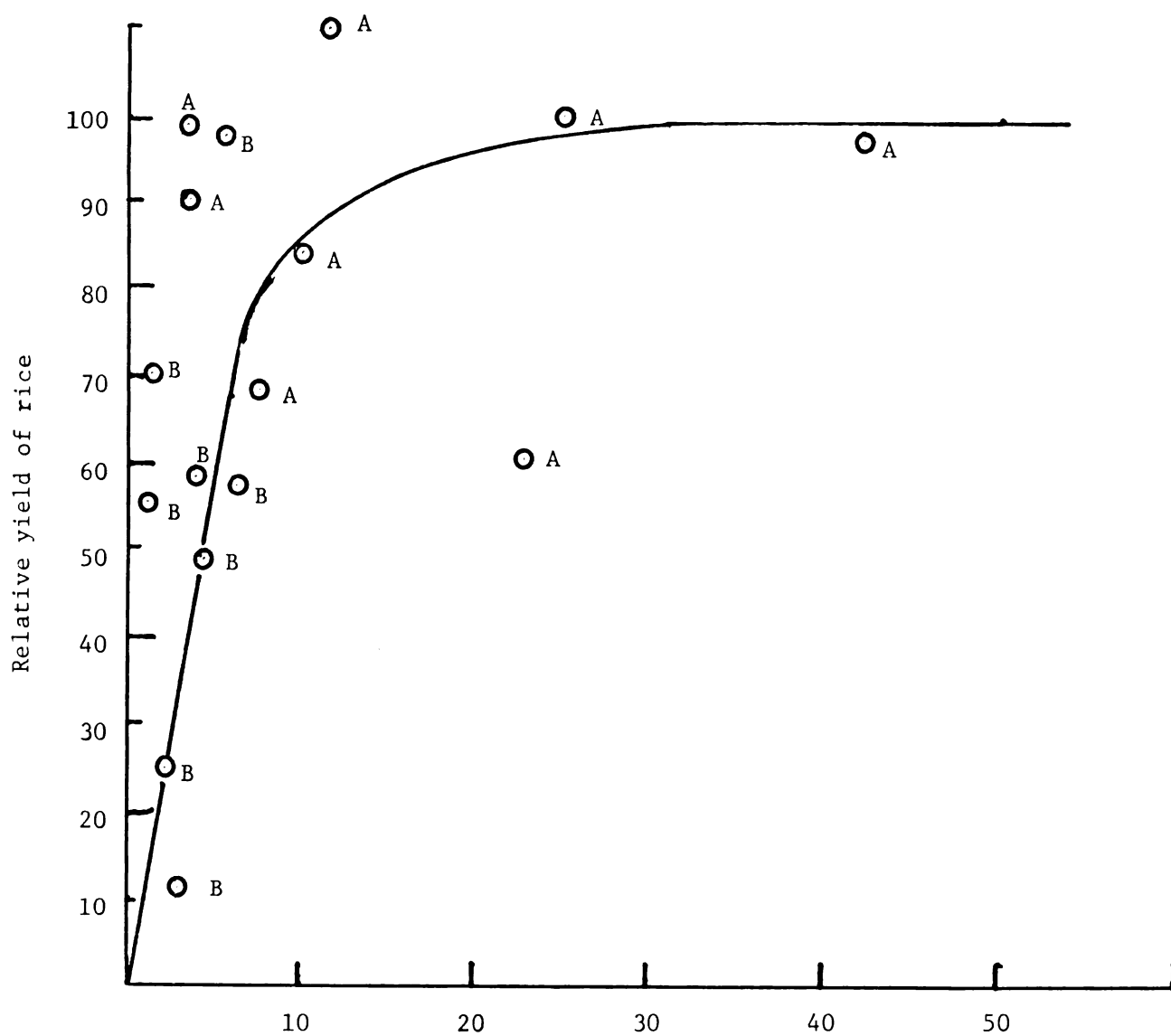


Figure 1. Relationship between Bray P-1 phosphorus and relative yield of rice.



Olsen's sodium bicarbonate P before flooding (ppm)

Figure 2. The relationship between Olsen's sodium bicarbonate extractable phosphorus and relative yield of rice.

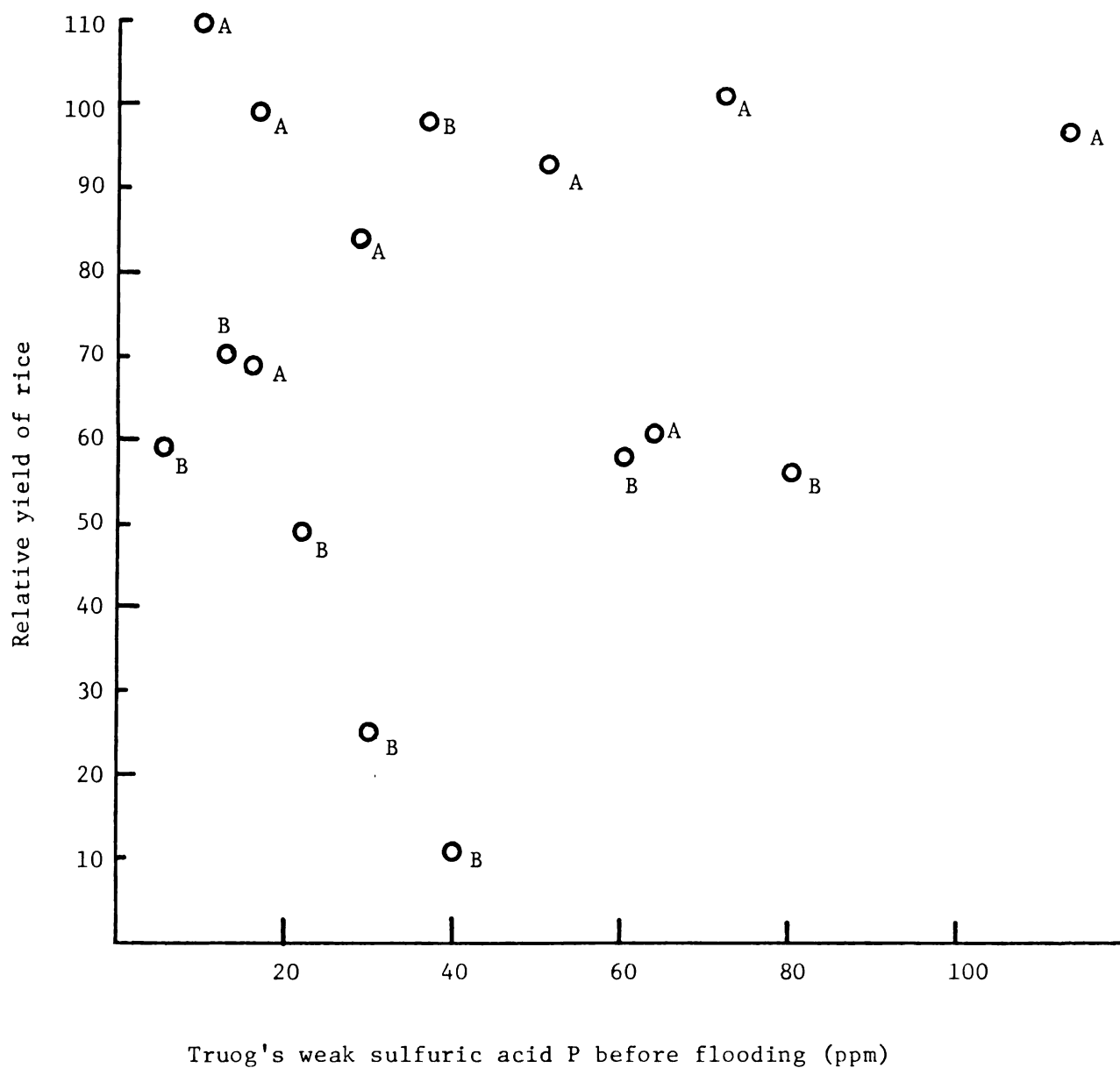


Figure 3. The relationship between Truog's weak sulfuric acid extractable phosphorus and relative yield of rice.

Chemical Changes in Soil Water After Flooding

The pH of soil samples before flooding ranged from 4.60-6.76. After flooding, the pH of the soil water generally increased during the first 3 weeks and then stabilized (Table 2a, Appendix). The increase in pH was of the order of 1 pH unit or a 10-fold decrease in hydrogen ion concentration. The control pots without plants were not greatly different from those containing rice plants with or without P fertilization indicating that the growing plant had relatively little influence upon the soil water pH.

Soils with lower initial pH values showed much more buffering capacity than soils with higher initial pH values. For example, in the B horizon of the Morley soil (pH 4.6), the pH value was rather constant throughout the experiment. This may be due to the fact that in acid soil an equilibrium exists between H and Al. In soils with low pH's, as in Sims B with soil (pH 4.6), much of the Al may be present as hexahydrated Al^{+3} ions (Seatz and Peterson, 1967). This complex ion would act as strong buffering components in the acid soils.

The Eh of the soil samples before flooding ranged from 525-696 m.v. Generally the Eh of the soil water samples dropped markedly from the original Eh values after 3 weeks of flooding (Table 3a, Appendix). After that the redox potentials of the soil water decreased slightly with time. The Eh of soil water from the A horizons was lower than that of the B horizons. This may be due to the greater activity of microorganisms associated with the higher organic matter content in the A horizons than that in the B horizons. In some soils the redox potential showed some fluctuation. This may be due to many factors. It has been suggested that the redox system in flooded soils would be

generated by the bacterial metabolism and/or activated by enzymes giving rise to the name "bacterial potentials" (The International Rice Research Institute, Annual Report, 1965). This bacterial potential may fluctuate due to the condition of the system. The P application did not appear to affect Eh when compared to the control (Table 3a, Appendix).

The amount of P in water samples was very small when compared to the amount of P in the soil samples before flooding (Table 4a, Appendix). Even in the soils with high P contents such as Sims A, Hillsdale A and Locke A and in P application treatments, the amount of P in the water samples was less than 1 ppm. This shows that the rate of P fixation or precipitation with active cations in the soils is much greater than the rate of P liberation from the soil into the water sample. This occurs because the available forms of P (HPO_4^{-2} , $\text{H}_2\text{PO}_4^{-1}$) are easily fixed in the soil with active cations of Fe, Al, Mn and Ca. In acid soils, there is an enhancement in the activity of Fe, Al and Mn. Under such conditions soluble P is markedly fixed as very complex and insoluble compounds of these elements. At pH's above seven, the complex and insoluble calcium phosphates are formed. It was noted that the amount of P in water samples decreased with time after flooding. This may be due to plant uptake and recrystallization of P in the soil.

Only a small fraction of the exchangeable Mn was found to be water soluble (Table 5a, Appendix). Generally the amount of water-soluble Mn in soil water samples decreased with time after flooding. But in Morley A and Miami A soils the amount of water-soluble Mn was increased after 3 weeks of flooding and maintained a high level until 6 weeks, after which the amount of water-soluble Mn in water samples decreased with time. P application showed little effect on the amount of Mn in the water samples.

The amount of water-soluble Fe in the soil water of all soils was very small (Table 6a, Appendix). In some soils the amount of water-soluble Fe increased after 3 weeks of submergence, for example, Morley A, Sims A, Miami A and Locke A. But after that it decreased with time. In Hoytville B, Morley A and Sims B, the amount of water-soluble Fe could not be detected after 15 weeks of flooding. This shows that the rate of Fe released into the soils is very slow. The decrease of water-soluble Fe with time may be due to reprecipitation of Fe and/or plant uptake.

Chemical Change in the Soil After Flooding

The pH of most soils increased about 1 pH unit after 3 weeks of flooding and reached a maximum value about 6 weeks of submergence, after which it stabilized throughout the experiment. Soils with lower initial pH values, for example in Morley B (pH 4.60), St. Clair B (pH 5.30) and Hillsdale B (pH 5.20), had higher buffering capacities and pH values were relatively stable after flooding. The reason for this was given in the prior section.

Generally the amount of hydrogen ion concentration decrease in the A horizons after flooding was greater than that of B horizons, for example, the Locke A soil increased from pH 6.00 to about pH 6.80 when compared to Locke B soil which increased from pH 6.29 to about pH 6.53 after 3 weeks of flooding (Table 7a, Appendix).

The P application showed no effects on pH change when compared to control (no rice plants) and no P application treatment.

The redox potential of A horizons of the soils before flooding was slightly lower than that of B horizon.

After flooding, the Eh of all soils decreased remarkably. The redox potential of A horizons of all soils decreased more than that of

B horizons, for example, in the Hoytville A the Eh dropped approximately 400 m.v. whereas the Eh of the B horizon dropped only about 150 m.v. In general Eh of A horizons decreased about 200-500 m.v., and the Eh of B horizons dropped approximately 150-300 m.v. This may be due to more reduction reactions in A horizons associated with higher organic matter content. This is called bacterial potential of the soil system. In some soils the Eh decreased until the redox potential reached the maximum about 36 weeks after submergence, and then they increased slightly afterwards, e.g., Miami A and Morley A soils. But in most soils the Eh decreased rapidly within 3 weeks and remained rather constant afterwards. P fertilization has no effect on Eh changes after flooding when compared to the controls. It was noted that the Eh of soils with lower pH values and higher buffering capacity, such as St. Clair B, Morley B and Hillsdale B, did not decrease much after flooding.

Generally, the amount of Mn increased more in the A horizons than in the B horizons, e.g., in St. Clair A the amount of extractable Mn increased about 30-fold, whereas in St. Clair B the amount of extractable Mn increased only about 4-fold from the original extractable Mn. Even in Morley soil the original extractable Mn of the B horizon was greater than that of A horizon (16 ppm compared to 1.6 ppm), but the amount of extractable Mn increased only 6-fold whereas in A horizon the amount of extractable Mn increased approximately 80-fold. The result showed that there were stronger reducing conditions in the A horizons than in the B horizons associated with higher inorganic matter content and also higher microbial activities in A horizon.

The amount of extractable Mn increases generally reached their maxima within 3 weeks and after that they decreased slightly with time

or held constant in some soils, e.g., in Hoytville A the amount of extractable Mn in the soil stabilized at 3.5-5.5 ppm throughout the experiment. P fertilization showed no effect on the increases in the amount of Mn due to flooding.

The amount of 1N NH_4OAc extractable Fe in the soils before flooding was very small and ranged from less than 1 ppm to about 1.5 ppm. The amount of extractable Fe in B horizons was slightly greater than that of A horizon (Table 1a, Appendix).

The amount of extractable Fe in some soils increased greatly after flooding, e.g., in Hoytville A the amount of extractable Fe before flooding was 0.29 ppm and at 6 weeks of submergence the amount of extractable Fe was about 60 ppm. The amount of extractable Fe increase reached the maxima about 6 weeks of flooding and held rather constant afterwards. In general the amount of extractable Fe in A horizons increased more than that of B horizons, e.g., in St. Clair A the amount of extractable Fe increased from the original of 0.29 ppm to about 12-14 ppm, whereas in the B horizon it increased from the original of 1.48 ppm to about 4-9 ppm after 6 weeks of flooding. This may be due to more anaerobic metabolism in A horizons than in B horizons associated with higher inorganic matter content. It was noted that in the Sims A and Hillsdale A the amount of extractable Fe in control pots without rice plants was greater than that in no P and P application treatments. This showed that growing rice plants were able to reduce the quantity of available Fe in the soils.

Transformations of Soil P After Flooding

During submergence the soil studies all increased in available P as measured by plant growth and 3 chemical extractants. The soils before

flooding can be divided into 2 groups based on the amount of P extracted by Bray P-1: those containing 1.3-7.9 ppm P and those containing 37-58 ppm P. The amount of native P extracted by Bray P-1 from A horizons was generally greater than that extracted from B horizons except for the Locke soils.

After flooding the amount of Bray P-1 in the soils increased considerably due to the reducing conditions, e.g., the Morley A increased from 6.5 ppm to about 90 ppm and the Morley B increased from 3 ppm to about 77 ppm. The amount of Bray 1 extractable P of A horizons increased more than that of B horizons, for example, in Miami A the amount of extractable P increased from 4.8 ppm to 95.6 ppm in the control (no rice plants). This may be due to the higher amount of native P and organic matter in A horizons. The amount of extractable P increased due to flooding, reached a maxima in 3-6 weeks, after which it decreased orderly and dropped to about one half of the maximum value at 15 weeks of submergence. This may be due to recrystallization of P, assimilation by microorganisms and/or plant uptake. P application increased the amount of P extracted by Bray P-1 in the soils. For example, in Hillsdale A with a high level of native P initially (57.9 ppm) the amount of Bray P-1 increased to a maximum of 109, 99 and 135 after flooding in control (no P and no rice plants), NK and NPK treatments, respectively. In the Hillsdale B with lower native P (5.2 ppm), the amount of Bray P-1 increased due to flooding to 56 ppm in control, 55 ppm in NK treatment and 203 in the application treatment at the maxima.

Soils high in extractable Fe showed relatively little increase in P due to flooding compared to the soils lower in extractable Fe. For

example, in Hoytville A where extractable Fe at the maxima was about 50-55 ppm, the amount of P extracted by Bray P-1 increased from 7.47-17 ppm in control, 59 ppm in NK and 61 ppm in NPK treatments; in the Hoytville B, with 6 ppm of extractable Fe at maxima after flooding, the amount of P extractable by Bray P-1 increased from 2.94 ppm to 89 ppm, 77 ppm and 86 ppm in control, NK and NPK treatments, respectively.

There appeared to be little relationship between extractable Mn, pH or Eh and extractable P.

There was no relationship between the amount of native P by Bray's method before flooding and the amount of Bray P-1 after flooding (Figure 4), even though a large increase in extractable P occurred upon flooding.

Extractable P by both Olsen's and Truog's methods showed a good relationship between initial P and P after 3 weeks of flooding. In Olsen's the increase was about 40%, whereas Truog's P increased more than 100% after flooding.

The pattern of P release by flooding as measured by Truog's extraction was similar to that measured by Bray's P-1 in that it increased sharply, reached a maximum in 3-6 weeks and then steadily declined at 15 weeks. The quantity of P released, however, was much larger than in the case of Bray's P-1. It was large enough to suggest release of organic P. P extracted by sodium bicarbonate (Olsen's) increased to a maxima in about 3 weeks and remained constant throughout the study.

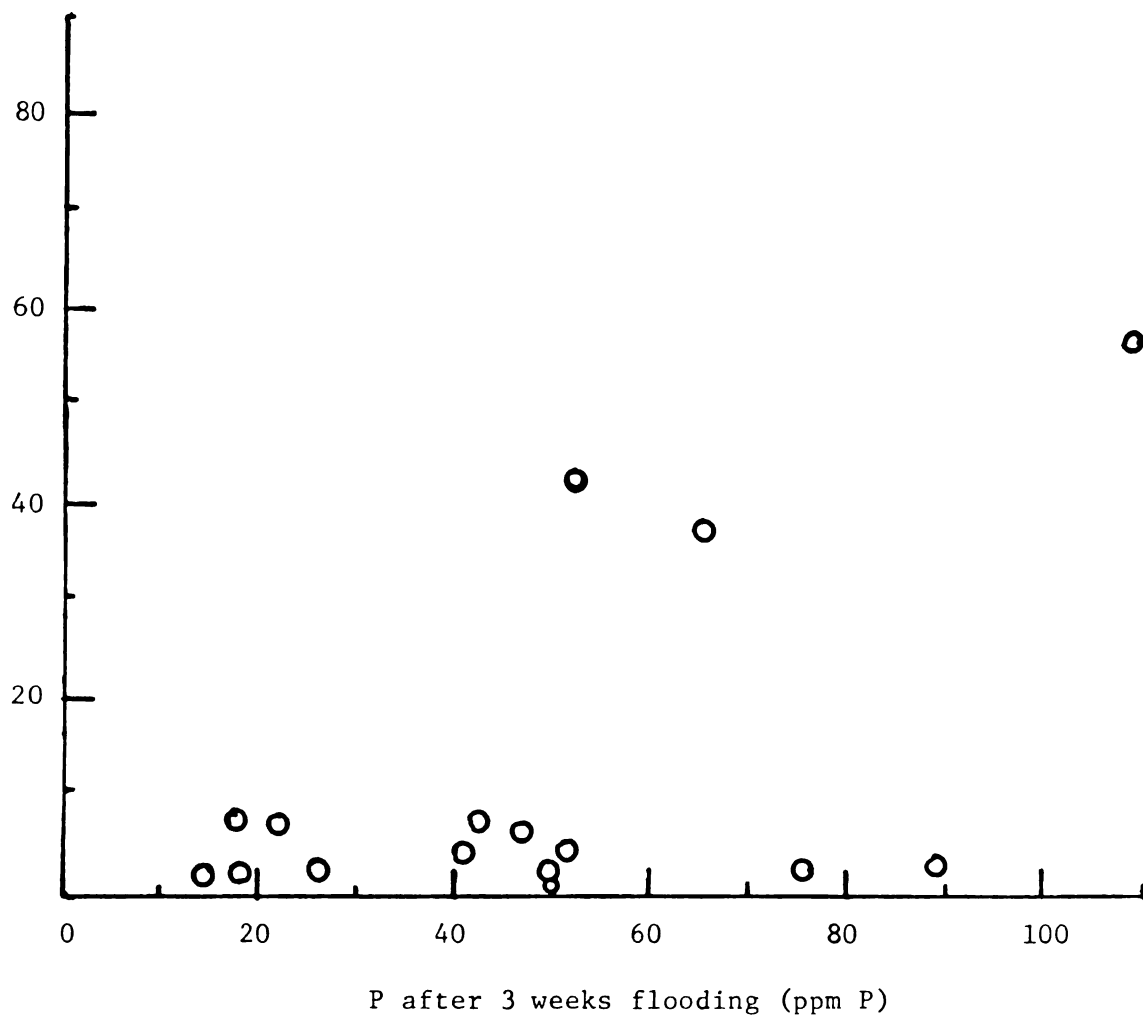


Figure 4. Bray P-1 extractable phosphorus initially and after three weeks' flooding.

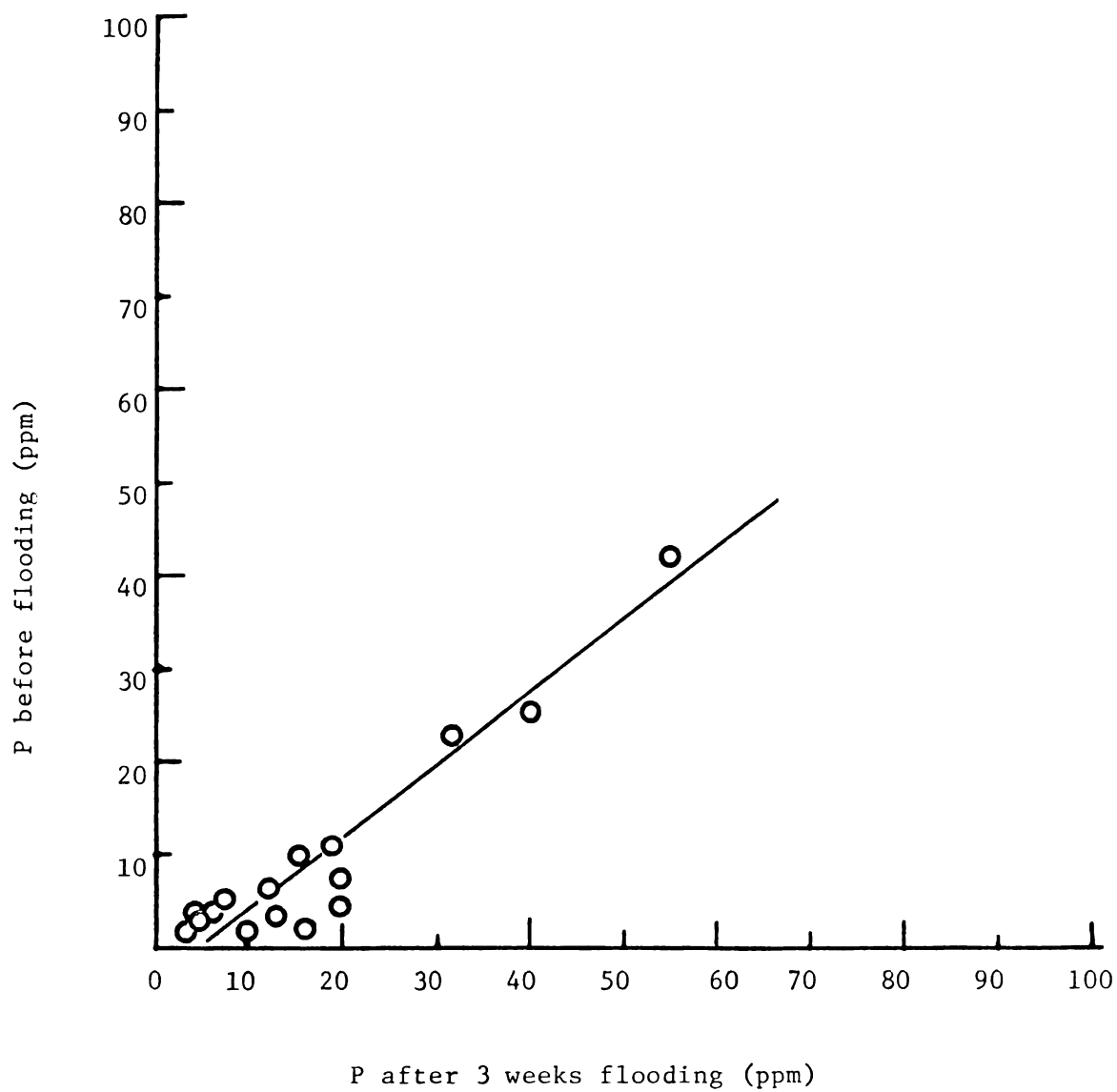


Figure 5. Olsen's sodium bicarbonate extractable phosphorus initially and after three weeks' flooding.

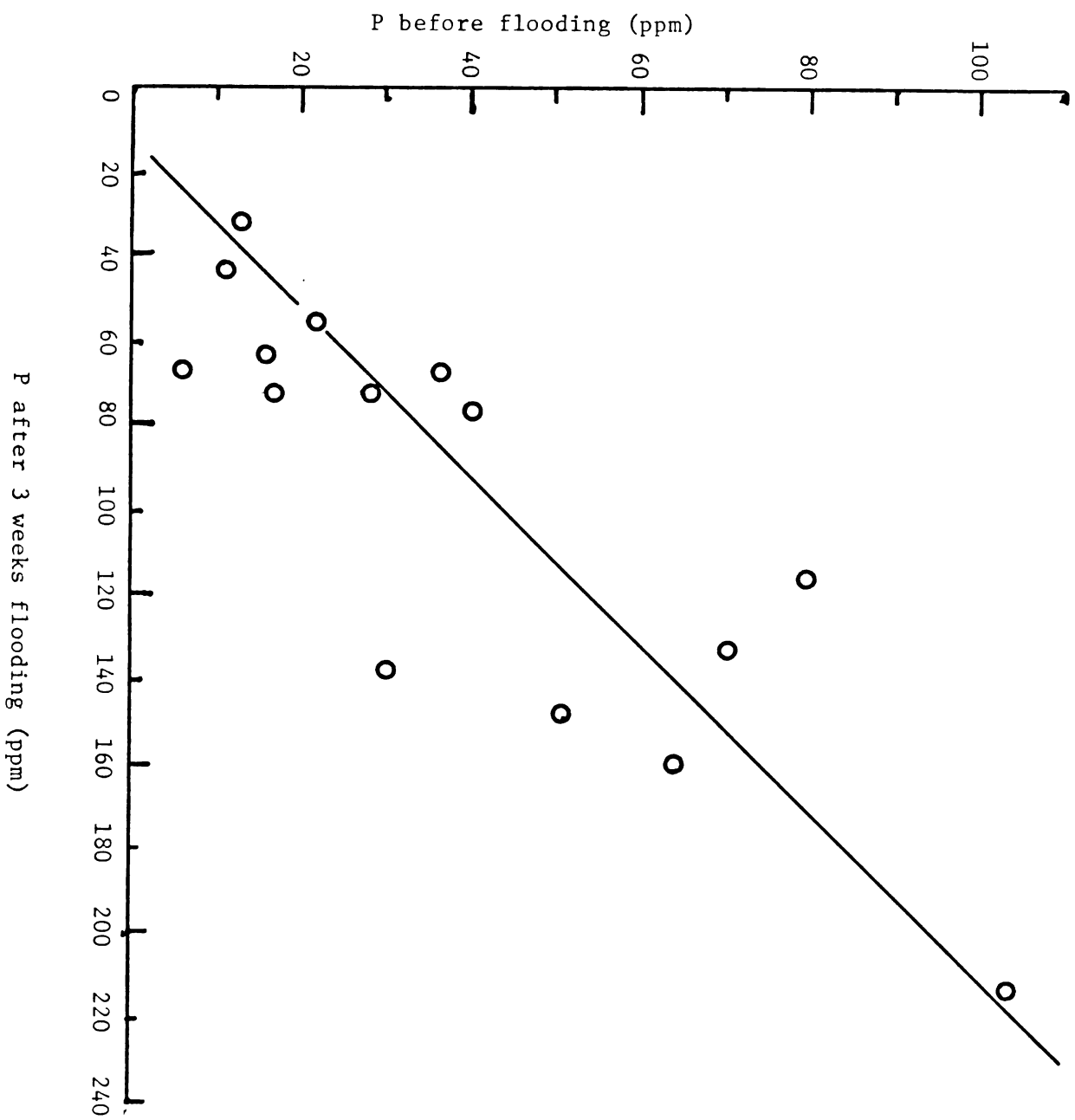


Figure 6. Truog's weak sulfuric acid extractable phosphorus initially and after three weeks' flooding.

SUMMARY AND CONCLUSIONS

Eight Michigan soils ranging from loamy sand to clay with both poorly and well-drained soils of each texture and with high and low nature P were selected to study in the greenhouse. Rice seedlings were planted in NK and NPK pots of 3 replications. Also, a control pot (NK) with no rice was maintained. Soil samples before flooding and soil and water samples after flooding were taken at 3-week intervals and analyzed in the laboratory. Yield of rice was determined at the end of the study.

The following conclusions were drawn:

1. Rice did not respond to P application in A horizons.
2. There was a marked response of yield of rice to P fertilization in B horizons.
3. Relative yield of rice was related to either Bray's P-1 or Olsen's sodium bicarbonate extractable P where soils containing less than 10 ppm P before flooding responded to P fertilization. P extracted by Truog's weak sulfuric acid was not related to relative yield of rice.
4. There were large chemical changes due to flooding.
 - a. pH of the soil increased about 1 pH unit except in soils whose initial pH was lower than 5.30. In the latter, pH changed slightly due to flooding.
 - b. Eh decreased remarkably due to flooding except in soils with high acidity (pH about 4.2-5.3).
 - c. The amount of exchangeable Fe and Mn increased considerably after flooding, reached the maxima at 3-6 weeks, after which they

decreased slightly with time. Fe remained more constant after reaching the maxima than Mn.

d. The amount of extractable P by Bray 1, Olsen's and Truog's methods increased considerably due to flooding. The quantity of Truog's increase was much more than Bray's P and Olsen's P. Olsen's P and Truog's P showed good relationship between initial P and P after flooding.

BIBLIOGRAPHY

BIBLIOGRAPHY

- Broeshart, H., Haunold, E. and M. Fried. 1965. The effect of water conditions and oxidation-reduction status of rice soils on the availability of soil and fertilizer phosphate. *Plant and Soil* 23:305-313.
- Chakravarti, S. and T. K. Ghoshal. 1968. Anaerobic reduction phosphate solubility. *J. Indian Soc. Soil Sci.* 16:409-413.
- Chiang, Ching-Tsun. 1968. Availability and forms of phosphorus in paddy soils: V. factors affecting the solubility of soil phosphorus. *Taiwan Fertilizer Co., Ltd., Res. Bull. No. 30.* pp. 11-37.
- Furukawa, H. and K. Kawaguchi. 1969. Contribution of organic phosphorus to the increase of easily soluble phosphorus in water-logged soils, especially related to phytic phosphorus (inositol hexaphosphate). *Nippon Dojo-Hiryogaku Zasshi* 40:141-148.
- Gasser, J. X. R. 1956. The effects of anaerobically fermenting rice straw on the mobilization of aluminum, calcium and iron phosphate. 6th International Cong. of Soil Sci., Vol. C, pp. 479-491.
- Grist, D. H. 1965. *Rice*. Longmans, Green and Co., Ltd. London.
- Guidry, N. P. 1964. A graphic summary of world agriculture. Misc. Pub. No. 705, U.S.D.A., U.S. Govt. Printing Office, Washington, D.C. pp. 21-25.
- Hayes, F. R. and J. E. Phillips. 1958. Lake water and sediment: IV. radiophosphorous equilibrium with mud, plants and bacteria under oxidized and reduced conditions. *Limnology and Oceanography* 3: 459-475.
- Jackson, M. L. 1965. *Soil chemical analysis*. Prentice-Hall, Inc., Englewood Cliffs, N.J. U.S.A.
- Jeffery, J. W. O. 1961. Defining the state of reduction of a paddy soil. *J. of Soil Sci.* 12:172-179.
- _____. 1961. Measuring the state of reduction of a paddy soil. *J. of Soil Sci.* 12:317-325.
- Mahapatra, J. C. and W. H. Patrick, Jr. 1969. Inorganic phosphate transformation in water-logged soils. *Soil Sci.* 107:281-288.

- Mandel, L. N. 1964. Effect of time, starch and lime on the transformation of inorganic P in a water-logged rice soil. *Soil Sci.* 97:127-132
- Mandal, L. N. and R. K. Das. 1970. Transformation of applied water soluble phosphate in acidic lowland rice soils. *Soil Sci.* 10: 263-267.
- Mukhopadhyay, A., Fisher, T. R. and G. E. Smith. 1967. Submergence and liming effects on soil: I. changes in pH, Eh and manganese uptake by rice plants. *Soil Sci.* 104:107-112.
- Patrick, W. H., Jr. 1964. Extractable iron and phosphorus in a submerged soil at controlled redox potentials. 8th International Cong. of Soil Sci. Bucharest, Rumania. pp. 605-609.
- Patrick, W. H., Jr. and I. C. Mahapatra. 1968. Transformation and availability to rice of nitrogen and phosphorus in water-logged soils. *Advances in Agron.* 20:323-359.
- Ponnamperuma, F. N. 1964. Dynamic aspects of flooded soils. The mineral nutrition of rice plants. The International Rice Res. Institute. The John Hopkins Press, Baltimore, Maryland. U.S.A. pp. 295-328.
- Ponnamperuma, F. N. and R. U. Castro. 1964. Redox systems in submerged soils. 8th International Cong. of Soil Sci. Bucharest, Rumania. pp. 107-109.
- Ponnamperuma, F. N., Tianco, E. M. and T. Loy. 1967. Redox equilibria in flooded soils: I. The iron hydroxide systems. *Soil Sci.* 103: 374-382.
- _____. 1969. Redox equilibria in flooded soils: II. The manganese oxide system. *Soil Sci.* 108:48-57.
- Robinson, O. W. 1930. Chemical phase of submerged soils. *Soil Sci.* 30:197-217.
- Seatz, L. F. and H. B. Peterson. 1970. Acid, alkaline, saline and sodic soils. *Soil Chemistry*. Amer. Chem. Soc. Monograph Series, New York. pp. 293-295.
- Shapiro, R. E. 1958. Effect of flooding on availability of phosphorus and nitrogen. *Soil Sci.* 85:190-197.
- Takkar, P. N. 1969. Effect of organic matter on soil and manganese. *Soil Sci.* 108:108-112.
- Terman, G. L., Allen, S. E., and O. P. Engelstad. 1970. Response by paddy rice to rate and sources of applied phosphorus. *Agron. J.* 62:390-394.

The International Rice Research Institute. 1963. Soil Chemistry. IRRI Annual Report. Los Baños, Laguna, The Philippines. pp. 61-86.

U.S.D.A. 1969. Agricultural Statistics. 1969. U. S. Govt. Printing Office. Washington, D.C. U.S.A. pp. 21-35.

Williams, C. H. and J. R. Simpson. 1965. Cultivation and water-logging on soil phosphorus availability. Aust. J. of Agric. Res. 16:413-427.

Yamane, I. and K. Sato. 1968. Measurement of redox potentials of submerged soils. Nippon Dejo-Hiryogaku Zasshi 39:535-542.

APPENDIX

Table 1a. Soil type, chemical and physical properties of the 8 Michigan soils used in the greenhouse study.

Soil Type	Drainage	Texture	Horizon	pH	Eh m.v.	Organic		Fe	P		
						Matter %	14n		Bray's ppm	Olsen's	Truog's
St. Clair	well drained	clay	A	5.95	545	3.16	3.09	0.29	7.06	11.52	11.2
			B	5.30	690	.56	2.43	1.48	2.09	1.01	13.2
Hoytville	poorly drained	clay	A	6.50	599	4.66	0.50	0.29	7.47	4.48	51.6
			B	6.76	525	.28	0.76	0.44	1.30	3.21	40.3
Morley	well drained	clay loam	A	6.38	569	3.09	1.59	0.44	6.49	7.58	16.0
			B	4.60	689	.68	16.8	1.17	2.94	4.47	22.1
Sims	poorly drained	clay loam	A	6.23	599	6.77	0.50	0.29	39.5	42.7	113.1
			B	6.54	575	.93	0.82	0.59	2.69	1.70	80.8
Miami	well drained	loam	A	6.48	544	2.84	1.45	0.59	4.78	3.52	17.5
			B	6.52	561	.48	1.20	0.59	2.57	4.15	5.62
Conover	poorly drained	loam	A	6.50	550	3.15	2.50	0.59	7.90	10.28	29.1
			B	6.64	535	.69	1.40	0.44	2.21	2.00	30.0
Hillsdale	well drained	sandy loam	A	5.82	595	1.66	7.24	0.74	57.9	25.9	71.9
			B	5.20	660	.41	6.05	0.44	5.26	6.51	60.8
Locke	poorly drained	sandy loam	A	6.00	536	2.72	1.59	0.15	41.7	23.7	64.3
			B	6.29	587	.40	0.82	0.29	3.47	5.47	37.0

Table 2a. Soil-water pH with time after flooding.

Soil Type	Treatment ¹	Initial Soil pH	Time after flooding (weeks)				
			3	6	9	12	15
			pH ²				
St. Clair A	C	5.95	6.92	7.69	7.35	8.26	8.01
	NK		6.84	7.74	7.10	8.12	7.73
	NPK		6.88	7.83	7.36	7.56	8.10
St. Clair B	C	5.30	6.00	4.37	4.48	4.84	4.77
	NK		5.71	4.36	4.52	4.91	5.22
	NPK		5.68	4.19	5.14	6.43	6.34
Hoytville A	C	6.50	6.95	8.38	7.50	8.11	8.08
	NK		7.24	8.39	7.69	8.30	8.23
	NPK		7.42	8.57	7.77	8.39	8.55
Hoytville B	C	6.76	7.04	8.17	7.94	8.14	8.08
	NK		6.96	8.11	8.00	8.06	8.23
	NPK		7.11	7.60	7.67	7.99	8.06
Morley A	C	6.38	7.16	7.99	7.58	7.84	8.15
	NK		6.83	7.33	7.69	7.98	7.60
	NPK		7.03	8.14	7.36	7.64	7.65
Morley B	C	4.60	4.70	4.90	4.18	4.18	4.75
	NK		4.78	4.92	4.04	4.74	5.05
	NPK		5.63	5.38	5.33	6.11	6.45
Sims A	C	6.23	7.10	8.41	7.05	8.15	8.30
	NK		7.05	8.31	7.18	7.68	7.83
	NPK		7.58	8.19	7.14	7.43	7.83
Sims B	C	6.54	6.60	7.97	8.17	8.12	8.11
	NK		6.80	8.30	7.91	8.01	7.95
	NPK		6.64	8.13	7.68	8.15	8.09
Miami A	C	6.48	7.65	7.73	8.08	8.26	7.31
	NK		7.49	7.81	7.81	8.10	7.64
	NPK		7.89	8.37	7.81	8.05	7.65
Miami B	C	6.52	6.85	7.33	6.68	7.15	6.65
	NK		7.56	7.16	7.16	7.63	7.53
	NPK		7.84	7.62	7.31	7.73	7.74
Conover A	C	6.50	7.60	7.40	8.08	8.31	8.42
	NK		7.36	8.20	7.81	8.10	7.90
	NPK		7.16	8.17	7.54	7.95	8.18
Conover B	C	6.64	6.20	7.41	8.23	8.09	8.42
	NK		6.38	7.82	8.06	8.41	7.76
	NPK		6.59	7.53	7.73	7.81	8.02
Hillsdale A	C	5.82	5.65	7.35	8.24	7.86	7.86
	NK		5.59	7.49	7.15	7.43	7.52
	NPK		6.19	7.44	7.10	7.18	7.11
Hillsdale B	C	5.20	6.77	6.67	4.61	4.07	3.97
	NK		6.25	5.63	4.99	5.89	5.30
	NPK		5.26	4.82	6.24	6.45	6.23
Locke A	C	6.00	7.20	7.73	8.07	7.53	6.86
	NK		7.02	7.93	7.21	7.30	7.57
	NPK		7.20	7.79	7.18	7.31	7.33
Locke B	C	6.29	7.30	7.91	5.59	6.09	5.91
	NK		7.39	7.62	6.98	7.17	7.36
	NPK		7.20	7.56	7.32	7.07	7.77

¹C = Control (NK) with no plants, NK = 100 ppm N, 100 ppm K, NPK = 107 ppm N, 100 ppm P, 100 ppm K.

²Values reported for NK and NPK are averages of 3 replications; the value for Control (C) is a single determination.

Table 3a. Soil-water Eh with time after flooding.

Soil Type	Treatment ¹	Initial Soil Eh	Time after flooding (weeks)				
			3	6	9	12	15
-----m.v. ² -----							
St. Clair	C	545	491	443	440	427	418
A	NK		497	443.3	460.3	433.6	405.3
	NPK		422.7	438.6	455.7	429	401.3
St. Clair	C	695	555	586	555	497	468
B	NK		601.3	583	558.3	473.3	487.3
	NPK		576	565	531.3	456.7	449
Hoytville	C	559	500	376	435	382	378
A	NK		473	386.3	444.7	394.7	393
	NPK		480	376.7	440.7	406.7	406.7
Hoytville	C	525	515	452	432	401	431
B	NK		501.3	440	437	402	411.3
	NPK		545	449	454.3	409.7	403.7
Morley	C	569	535	379	449	377	414
A	NK		450	416.3	457	401	410.7
	NPK		395	378	471	417	417
Morley	C	685	650	534	586	477	468
B	NK		647.3	549	606.7	499	495.7
	NPK		663	555.7	551.3	468	469
Sims	C	599	491	363	478	368	402
A	NK		485.7	385.7	488.3	410.3	426.7
	NPK		432.7	394.7	483.3	427	420
Sims	C	570	439	360	442	413	392
B	NK		481	391.7	459.3	416.7	421.3
	NPK		497	401.3	470	410	417.3
Miami	C	544	445	394	387	417	403
A	NK		430.7	405	416.3	436.3	469.7
	NPK		426.3	380.7	423.3	425.7	452
Miami	C	561	515	450	472	442	466
B	NK		530.3	477	446	434.8	451
	NPK		531.3	482	444.3	434.7	441.3
Conover	C	555	395	392	383	383	379
A	NK		417.3	427	418.3	406.7	426.7
	NPK		454	389	432	417.3	426
Conover	C	535	495	521	392	409	419
B	NK		474	465	404.7	397	418
	NPK		503	456	424.3	403	423
Hillsdale	C	595	561	437	403	397	412
A	NK		527	499	493	428	442.3
	NPK		542	465	484	440	435.3
Hillsdale	C	660	641	468	597	525	550
B	NK		642	510	552	478	493
	NPK		660	535.7	505.7	470	461
Locke	C	536	519	439	421	419	454
A	NK		496.7	447	462	433	430
	NPK		510	449.7	464	436	432.7
Locke	C	587	545	499	494	459	460
B	NK		546	473	476.7	436	434
	NPK		567	507.7	487.3	447.7	435

¹C = Control (NK) with no plants, NK = 100 ppm N, 100 ppm K, NPK = 107 ppm N, 100 ppm P, 100 ppm K.

²Values reported for NK and NPK are averages of 3 replications; the value for Control (C) is a single determination.

Table 4a. Soil-water P content with time after flooding.

		Initial P	Time after flooding (weeks)				
Soil Type	Treatment ¹	Soil Content ²	3	6	9	12	15
			----- ppm ³ -----				
St. Clair A	C	7.06	.24	.20	.06	.09	.01
	NK		.14	.13	.04	.12	.02
	NPK		.25	.14	.09	1.44	.04
St. Clair B	C	2.09	.08	.13	.05	.04	.01
	NK		.16	.10	.07	.09	.01
	NPK		.19	.15	.07	.13	.10
Hoytville A	C	7.47	.18	.14	.13	.11	.02
	NK		.19	.11	.08	.09	.02
	NPK		.22	.17	.12	.10	.05
Hoytville B	C	1.30	.14	.11	.10	.09	.01
	NK		.06	.12	.09	.09	.04
	NPK		.12	.22	.09	.10	.05
Morley A	C	6.49	.19	.15	.08	.06	.08
	NK		.17	.15	.09	.08	.08
	NPK		.42	.22	.10	.09	.09
Morley B	C	2.94	.12	.18	.08	.03	.02
	NK		.14	.19	.08	.08	.06
	NPK		.16	.22	.10	.08	.10
Sims A	C	39.48	.73	.53	.13	.21	.13
	NK		.38	.33	.16	.26	.07
	NPK		.68	.57	.20	.10	.16
Sims B	C	2.69	.10	.10	.08	.03	.01
	NK		.14	.11	.10	.03	.03
	NPK		.16	.15	.10	.06	.05
Miami A	C	4.78	.22	.15	.10	.04	.12
	NK		.29	.08	.07	.04	.07
	NPK		.36	.16	.10	.05	.12
Miami B	C	2.57	.16	.11	.09	.06	.07
	NK		.11	.13	.07	.04	.11
	NPK		.29	.20	.10	.03	.05
Conover A	C	7.90	.46	.15	.13	.10	.11
	NK		.30	.08	.12	.08	.05
	NPK		.35	.21	.19	.08	.03
Conover B	C	2.21	.18	.11	.08	.05	.12
	NK		.09	.06	.12	.06	.06
	NPK		.30	.16	.12	.08	.07
Hillsdale A	C	57.91	.32	.14	.15	.08	.07
	NK		.32	.19	.10	.07	.07
	NPK		.37	.29	.22	.07	.10
Hillsdale B	C	5.26	.15	.09	.06	.07	.07
	NK		.21	.09	.06	.06	.10
	NPK		.21	.10	.09	.07	.11
Locke A	C	41.71	.41	.12	.12	.13	.14
	NK		.38	.11	.20	.07	.11
	NPK		.81	.14	.13	.08	.14
Locke B	C	3.47	.15	.08	.12	.02	.02
	NK		.21	.09	.10	.04	.04
	NPK		.25	.22	.12	.06	.07

¹C = Control (NK) with no plants, NK = 100 ppm N, 100 ppm K, NPK = 107 ppm N, 100 ppm P, 100 ppm K.

²Determined by Bray's P1 method.

³Values reported for NK and NPK are averages of 3 replications; the value for Control (C) is a single determination.

Table 5a. Soil-water Mn content with time after flooding.

Table 3a. Soil water Mn content with time after flooding.							
Soil Type	Treatment ¹	Initial Extractable Mn	Time after flooding (weeks)				
			3	6	9	12	15
			----- ppm ² -----				
St. Clair A	C	3.09	.40	.21	.02	.02	.07
	NK		.18	.28	.02	.01	.13
	NPK		1.09	.09	.01	.01	.16
St. Clair B	C	2.43	.22	.48	1.10	1.00	.83
	NK		.31	.46	.69	.59	.41
	NPK		.30	.65	.02	.02	.06
Hoytville A	C	0.50	.17	.03	.16	.02	.02
	NK		.15	.06	.01	.02	.004
	NPK		.15	.08	.01	.02	.05
Hoytville B	C	0.76	.17	.07	.02	--	.01
	NK		.14	.25	.01	--	.02
	NPK		.12	.11	.01	--	.03
Morley A	C	1.59	5.40	4.92	.01	.01	.12
	NK		5.11	4.93	.18	.07	.10
	NPK		7.69	6.82	.02	.01	.60
Morley B	C	16.8	1.57	7.81	15.4	11.2	.80
	NK		1.99	9.53	8.50	2.88	1.42
	NPK		3.57	11.1	.25	.04	.45
Sims A	C	.50	.08	.74	.11	.008	.10
	NK		.06	.13	.04	.003	.05
	NPK		.20	.48	.02	--	.02
Sims B	C	.82	.06	.08	.01	--	.02
	NK		.07	.06	.02	--	.03
	NPK		.07	.05	.01	--	--
Miami A	C	1.45	2.81	6.07	3.95	.32	3.10
	NK		3.32	4.50	.04	--	.27
	NPK		3.31	.75	.02	--	.06
Miami B	C	1.20	.17	.18	.01	--	.06
	NK		.11	.08	.04	--	.06
	NPK		.09	.14	.01	--	.05
Conover A	C	2.50	.37	3.96	.46	.10	.77
	NK		.68	2.25	.02	--	.05
	NPK		.46	1.18	.03	--	.03
Conover B	C	1.40	.15	.05	.02	--	.07
	NK		.15	.05	.03	--	.01
	NPK		.12	.04	.03	--	.11
Hillsdale A	C	7.24	.08	3.42	.19	.01	.52
	NK		.18	3.95	.06	--	.40
	NPK		.45	3.08	.05	--	.15
Hillsdale B	C	6.05	.41	1.66	6.17	5.34	5.11
	NK		.42	1.29	.92	.40	.51
	NPK		.49	2.81	.06	--	.08
Locke A	C	1.59	.05	.07	.05	--	.03
	NK		.09	.08	.03	.02	.004
	NPK		.11	.07	.03	--	--
Locke B	C	0.82	.04	.01	.18	.08	.01
	NK		.04	.06	.04	--	--
	NPK		.14	.11	.05	--	.01

¹C = Control (NK) with no plants, NK = 100 ppm N, 100 ppm K,
NPK = 107 ppm N, 100 ppm P, 100 ppm K.

²Values reported for NK and NPK are averages of 3 replications; the value for Control (C) is a single determination.

Table 6a. Soil-water Fe content with time after flooding.

Soil Type	Treatment ¹	Initial Extractable Fe	Time after flooding (weeks)				
			3	6	9	12	15
			----- ppm ² -----				
St. Clair A	C	.29	.18	.07	.36	.24	--
	NK		.30	.07	.01	.18	.10
	NPK		.70	.05	.01	.15	.04
St. Clair B	C	1.47	.33	.09	.20	.21	.04
	NK		.49	.20	.24	.18	.04
	NPK		.38	.29	.16	.22	.72
Hoytville A	C	.29	.19	1.15	.05	1.09	.96
	NK		.22	.63	.01	.15	.11
	NPK		.27	.50	.01	.19	.01
Hoytville B	C	.44	.22	.04	--	.16	--
	NK		.34	.04	--	.17	--
	NPK		.90	.17	.01	.22	--
Morley A	C	.44	.97	1.46	.04	.19	--
	NK		.72	.50	.03	.14	--
	NPK		1.06	1.55	.01	.04	--
Morley B	C	1.17	.28	.09	--	.19	.22
	NK		.61	.08	--	.13	--
	NPK		.17	.13	.01	.13	.03
Sims A	C	.29	.43	7.09	.09	2.28	2.51
	NK		.34	2.00	.04	.22	.13
	NPK		2.27	6.08	--	.22	.08
Sims B	C	.59	.46	.02	.09	.14	--
	NK		.81	.08	.01	.12	--
	NPK		.25	.12	.06	.09	--
Miami A	C	.59	.69	3.28	4.75	.69	.32
	NK		1.22	4.28	.05	.14	.01
	NPK		1.69	.55	.02	.11	.05
Miami B	C	.59	.10	.07	--	.12	--
	NK		.41	.05	.04	.15	.07
	NPK		.66	.86	.02	.17	.01
Conover A	C	.5884	.45	3.03	.13	.21	.32
	NK		.43	.39	.01	.10	.04
	NPK		.31	1.00	.01	.12	.07
Conover B	C	.4411	.55	.05	.02	.17	--
	NK		.41	.06	.01	.08	.12
	NPK		.37	.04	.01	.10	.26
Hillsdale A	C	.7359	.18	.60	.07	.12	.54
	NK		.35	.54	.01	.06	.07
	NPK		.33	1.14	--	.08	.01
Hillsdale B	C	.4411	.27	.09	.05	.16	--
	NK		.34	.06	.02	.14	--
	NPK		.50	.10	.03	.11	.07
Locke A	C	.1468	.97	.19	.05	.07	.02
	NK		1.18	.28	.01	.08	.23
	NPK		1.12	.72	--	.11	.28
Locke B	C	.2939	.25	.05	.04	.09	.13
	NK		.35	.14	--	.10	.22
	NPK		.27	.18	.03	.14	.24

¹C = Control (NK) with no plants, NK = 100 ppm N, 100 ppm K, NPK = 107 ppm N, 100 ppm P, 100 ppm K.

²Values reported for NK and NPK are averages of 3 replications; the value for Control (C) is a single determination.

Table 7a. Soil pH with time after flooding.

Soil Type	Treatment ¹	Initial Soil pH	Time after flooding (weeks)				
			3	6	9	12	15
			----- pH ² -----				
St. Clair A	C	5.95	6.76	7.35	7.40	7.46	7.33
	NK		6.98	7.32	7.35	7.19	7.20
	NPK		7.10	7.37	7.42	7.30	7.28
St. Clair B	C	5.30	5.43	5.16	5.21	5.24	4.73
	NK		5.08	5.04	5.08	5.27	4.93
	NPK		4.98	4.92	5.39	5.80	5.73
Hoytville A	C	6.50	7.20	7.40	7.39	7.36	7.42
	NK		7.32	7.42	7.40	7.33	7.43
	NPK		7.42	7.48	7.44	7.35	7.59
Hoytville B	C	6.76	7.29	7.43	7.44	7.42	7.48
	NK		7.39	7.32	7.33	7.34	7.43
	NPK		7.40	7.25	7.30	7.25	7.34
Morley A	C	6.38	7.55	7.47	7.40	7.28	7.46
	NK		7.38	7.45	7.38	7.09	7.03
	NPK		7.38	7.44	7.40	7.19	7.10
Morley B	C	4.60	5.46	4.81	4.96	5.02	5.09
	NK		5.13	4.78	4.89	4.96	5.09
	NPK		5.20	4.70	4.26	5.52	6.11
Sims A	C	6.23	6.76	7.41	7.57	7.38	7.34
	NK		7.02	7.39	7.30	7.04	7.05
	NPK		7.13	7.37	7.31	7.01	7.18
Sims B	C	6.54	7.05	7.32	7.36	7.52	7.46
	NK		7.02	7.08	7.20	7.31	7.22
	NPK		7.03	7.09	7.24	7.40	7.38
Miami A	C	6.48	6.85	7.02	7.38	7.51	7.37
	NK		7.11	7.20	7.19	7.01	7.05
	NPK		7.11	7.38	7.27	7.17	7.14
Miami B	C	6.52	6.80	6.40	6.71	6.92	6.66
	NK		6.66	6.49	6.77	6.91	6.85
	NPK		6.59	6.54	6.77	6.80	7.14
Conover A	C	6.50	6.94	7.67	7.61	7.56	7.43
	NK		6.99	7.55	7.40	7.32	7.20
	NPK		7.00	7.62	7.50	7.26	7.24
Conover B	C	6.64	6.74	7.31	7.42	7.64	7.32
	NK		6.66	7.21	7.29	7.38	7.21
	NPK		6.84	7.21	7.24	7.27	7.15
Hillsdale A	C	5.82	6.80	6.73	7.06	7.32	7.30
	NK		6.93	6.92	6.94	6.88	6.98
	NPK		6.88	6.83	6.90	6.76	6.96
Hillsdale B	C	5.20	5.50	5.07	5.03	4.87	4.95
	NK		5.40	4.99	5.06	5.21	5.91
	NPK		5.25	4.99	5.60	6.00	5.96
Locke A	C	6.00	6.70	6.96	7.11	7.27	6.94
	NK		6.94	6.76	6.92	6.98	6.80
	NPK		6.89	6.85	6.97	7.02	6.76
Locke B	C	6.29	6.50	5.84	6.45	6.65	6.42
	NK		6.52	5.91	6.37	6.94	6.87
	NPK		6.66	6.22	6.68	7.02	6.80

¹C = Control (NK) with no plants, KN = 100 ppm N, 100 ppm K,
NPK = 107 ppm N, 100 ppm P, 100 ppm K.

²Values reported for NK and NPK are averages of 3 replications; the
value for Control (C) is a single determination.

Table 8a. Soil Eh with time after flooding.

Soil Type	Treatment ¹	Initial Soil Eh	Time after flooding (weeks)				
			3	6	9	12	15
			----- m.v. ² -----				
St. Clair A	C	545	214	158	167	201	150
	NK		259	164	166	171	136
	NPK		213	136	128	125	121
St. Clair B	C	690	419	495	447	429	408
	NK		516	511	486	442	438
	NPK		537	528	488	310	363
Hoytville A	C	599	74	59	61	71	73
	NK		78	81	83	113	87
	NPK		79	67	66	83	60
Hoytville B	C	525	345	428	345	311	262
	NK		380	430	378	347	250
	NPK		386	433	263	176	98
Morley A	C	569	251	117	101	168	160
	NK		82	85	163	274	118
	NPK		58	106	146	273	106
Morley B	C	689	500	514	483	461	429
	NK		529	537	507	485	376
	NPK		541	561	487	410	240
Sims A	C	599	83	55	58	60	47
	NK		70	76	90	91	106
	NPK		60	68	75	82	52
Sims B	C	575	224	188	186	168	81
	NK		236	228	211	208	120
	NPK		194	225	190	150	88
Miami A	C	544	95	288	117	127	159
	NK		119	272	216	216	178
	NPK		82	218	184	169	123
Miami B	C	561	385	371	335	368	271
	NK		405	408	365	348	234
	NPK		407	422	369	304	139
Conover A	C	550	135	175	109	119	130
	NK		76	174	154	154	160
	NPK		81	120	125	132	166
Conover B	C	535	385	335	322	343	218
	NK		386	360	357	356	211
	NPK		393	384	299	221	127
Hillsdale A	C	595	240	314	161	150	182
	NK		164	282	226	206	127
	NPK		174	259	200	182	116
Hillsdale B	C	660	450	462	447	473	408
	NK		476	496	460	463	290
	NPK		504	451	432	352	283
Locke A	C	536	181	261	280	156	184
	NK		122	286	233	204	182
	NPK		111	235	190	172	173
Locke B	C	587	376	460	406	321	196
	NK		395	482	419	240	212
	NPK		399	475	395	186	99

¹C = Control (NK) with no plants, NK = 100 ppm N, 100 ppm K, NPK = 107 ppm N, 100 ppm P, 100 ppm K.

²Values reported for NK and NPK are averages of 3 replications; the value for Control (C) is a single determination.

Table 9a. Soil P extractable by Bray P₁ as influenced by time after flooding.

Flooded.		Initial P Soil Content	Time after flooding (weeks)				
Soil Type	Treatment ¹		3	6	9	12	15
			----- ppm ² -----				
St. Clair A	C	7.06	22.2	30.3	19.7	12.8	9.35
	NK		25.9	35.0	25.7	22.8	8.8
	NPK		34.4	34.0	33.2	23.1	12.73
St. Clair B	C	2.08	14.3	45.9	43.4	26.6	24.8
	NK		19.2	34.7	38.7	27.4	16.5
	NPK		36.5	49.5	47.0	29.5	28.0
Hoytville A	C	7.47	17.3	13.5	12.1	10.0	8.01
	NK		14.8	59.4	20.4	11.4	3.16
	NPK		20.0	61.8	30.8	12.1	5.22
Hoytville B	C	1.30	49.9	89.8	39.9	39.9	20.5
	NK		22.1	77.3	31.7	24.3	6.93
	NPK		22.5	86.9	45.1	31.6	10.10
Morley A	C	6.48	47.2	87.1	45.9	48.5	28.4
	NK		57.1	94.2	48.2	44.8	31.6
	NPK		77.4	100.5	61.7	61.7	34.6
Morley B	C	2.94	75.3	62.1	55.7	51.3	41.0
	NK		73.3	70.1	61.4	35.9	45.5
	NPK		80.6	101.2	79.4	47.5	44.8
Sims A	C	37.4	65.6	42.2	39.9	23.0	25.7
	NK		67.2	46.1	27.7	26.6	21.7
	NPK		81.8	50.6	33.0	20.6	23.7
Sims B	C	2.69	49.9	49.9	39.9	35.4	13.5
	NK		43.3	46.6	39.6	35.7	16.9
	NPK		46.4	48.8	42.7	45.1	19.0
Miami A	C	4.78	51.3	95.6	54.2	44.7	14.3
	NK		57.0	96.6	63.3	38.0	18.7
	NPK		59.4	102.0	73.3	52.0	23.1
Miami B	C	2.56	26.6	19.7	23.0	23.9	21.3
	NK		57.3	22.9	22.2	24.2	18.6
	NPK		84.9	25.5	27.9	28.6	18.6
Conover A	C	7.8964	42.2	30.3	21.3	19.7	19.7
	NK		33.3	36.6	20.2	15.3	15.9
	NPK		68.7	44.7	29.2	28.7	22.5
Conover B	C	2.2055	18.1	26.6	29.4	21.3	12.1
	NK		51.1	31.4	26.6	21.1	12.9
	NPK		29.4	32.0	30.1	28.4	13.8
Hillsdale A	C	57.9099	109.2	92.6	77.5	71.2	49.9
	NK		63.6	99.9	74.7	65.1	50.9
	NPK		111.1	135.5	92.7	76.5	65.8
Hillsdale B	C	5.2593	41.0	56.9	35.4	41.0	39.9
	NK		39.9	55.8	34.0	30.5	36.1
	NPK		203.0	99.3	44.2	41.6	52.1
Locke A	C	3.4718	89.7	114.4	52.7	48.6	54.2
	NK		196.4	100.1	41.8	37.3	43.1
	NPK		240.7	125.3	51.5	59.2	50.5
Locke B	C	41.7105	52.7	89.4	32.3	34.4	29.4
	NK		74.0	79.4	29.1	27.8	18.4
	NPK		94.4	84.2	31.0	28.8	32.1

¹ C = Control (NK) with no plants, NK = 100 ppm N, 100 ppm K, NPK = 107 ppm N, 100 ppm P, 100 ppm K.

² Values reported for NK and NPK are averages of 3 replications; the value for Control (C) is a single determination.

Table 10a. Soil P extractable by Olsen's sodium bicarbonate method as influenced by time after flooding.

Influenced by time after flooding.							
Soil Type	Treatment ¹	Initial P Soil Content	Time after flooding (weeks)				
			3	6	9	12	15
			-----ppm ² -----				
St. Clair A	C	11.52	19.6	20.6	20.6	19.6	17.8
	NK		20.0	21.6	19.3	20.5	16.0
	NPK		32.4	32.7	29.1	28.5	25.6
St. Clair B	C	1.01	2.92	10.8	9.98	9.16	3.67
	NK		6.55	12.2	11.9	10.8	6.24
	NPK		33.9	31.2	23.5	18.4	11.3
Hoytville A	C	4.47	20.6	16.9	12.5	17.8	15.1
	NK		18.5	18.1	17.5	16.6	15.1
	NPK		19.3	29.7	25.6	22.2	19.0
Hoytville B	C	3.20	13.3	14.2	12.5	11.6	6.76
	NK		13.4	13.6	13.2	11.3	6.50
	NPK		19.7	18.7	16.3	13.3	7.03
Morley A	C	7.58	20.6	14.2	13.3	13.3	14.2
	NK		17.0	18.1	14.8	11.9	9.98
	NPK		38.3	28.0	26.2	22.9	16.0
Morley B	C	4.47	6.78	9.16	7.55	5.20	7.55
	NK		16.4	9.98	8.36	4.95	6.76
	NPK		39.8	31.1	22.9	16.7	19.0
Sims A	C	42.6	55.6	49.7	41.5	46.8	46.8
	NK		55.1	42.4	44.6	51.0	46.9
	NPK		62.8	55.1	55.7	60.0	47.3
Sims B	C	1.70	16.0	9.98	11.6	12.5	12.5
	NK		10.5	11.9	10.5	7.60	11.3
	NPK		30.2	19.4	16.0	15.7	13.9
Miami A	C	3.51	5.97	12.5	13.3	12.5	11.6
	NK		13.6	13.6	11.1	9.22	9.46
	NPK		27.6	21.2	19.0	15.7	12.3
Miami B	C	4.15	4.43	9.16	7.55	5.97	6.46
	NK		9.10	9.33	8.89	6.01	8.44
	NPK		30.6	15.4	14.2	9.71	8.99
Conover A	C	10.2	16.9	15.1	13.3	11.6	12.5
	NK		21.0	13.9	11.9	11.1	11.1
	NPK		35.6	30.8	23.7	19.7	16.9
Conover B	C	2.00	9.98	7.55	6.76	7.55	5.97
	NK		6.78	10.7	7.30	5.53	5.48
	NPK		22.5	16.0	17.8	9.18	9.18
Hillsdale A	C	25.8	41.57	31.8	29.7	32.0	30.8
	NK		41.5	27.6	33.5	32.8	30.7
	NPK		47.3	33.1	45.1	39.9	38.6
Hillsdale B	C	6.50	12.5	12.5	10.8	9.16	9.98
	NK		12.8	6.50	9.19	8.92	7.58
	NPK		49.8	25.5	25.3	26.6	20.3
Locke A	C	23.7	32.0	27.6	29.7	29.7	24.5
	NK		39.4	22.2	20.6	19.4	19.3
	NPK		51.6	38.8	32.4	29.6	27.1
Locke B	C	5.47	7.55	6.76	3.65	4.43	5.97
	NK		11.1	3.43	4.67	3.96	5.72
	NPK		25.5	16.9	11.8	11.6	14.9

¹C = Control (NK) with no plants, NK = 100 ppm N, 100 ppm K,
NPK = 107 ppm N, 100 ppm P, 100 ppm K.

²Values reported for NK and NPK are averages of 3 replications; the value for Control (C) is a single determination.

Table 11a. Soil P extractable by Truog's weak H_2SO_4 method as influenced by time after flooding.

Soil Salinity Flooding.							
Soil Type	Treatment ¹	Initial P Soil Content	Time after flooding (weeks)				
			3	6	9	12	15
-----ppm ² -----							
St. Clair	C	11.2	114.	86.3	60.5	28.9	10.7
A	NK		71.8	75.0	53.7	28.0	11.7
	NPK		116.	102.	66.1	42.8	21.5
St. Clair	C	13.2	32.7	21.4	28.9	10.5	17.8
B	NK		47.2	17.9	26.6	11.8	14.1
	NPK		67.6	52.4	43.1	25.3	31.6
Hoytville	C	51.6	149.	177.	133.	118	73.2
A	NK		65.0	157.	120.	70.3	64.8
	NPK		118.	174.	129.	87.0	70.1
Hoytville	C	40.3	77.5	90.8	64.7	48.3	36.6
B	NK		55.1	76.1	69.0	27.7	31.6
	NPK		75.0	92.4	82.0	69.4	45.8
Morley	C	16.0	64.7	81.8	48.3	44.4	25.2
A	NK		60.8	103.	48.4	25.2	32.7
	NPK		95.4	125.	49.7	47.1	49.7
Morley	C	22.1	56.4	48.3	36.6	25.2	21.4
B	NK		41.8	47.0	32.9	24.0	21.1
	NPK		57.8	49.2	43.2	39.0	22.8
Sims	C	113.1	214.	255.	195.	144.	123.
A	NK		193.	289.	189.	121.	101.
	NPK		232.	339.	291.	143.	117.
Sims	C	80.8	118.	149.	123.	109.	44.4
B	NK		158.	160.	103.	96.8	69.4
	NPK		180.	206.	170.	116.	77.7
Miami	C	17.5	73.2	77.5	48.3	36.6	28.6
A	NK		96.3	40.5	45.8	36.7	26.4
	NPK		128.	87.8	74.7	69.0	52.7
Miami	C	5.62	68.9	56.4	32.7	36.6	32.7
B	NK		70.4	60.0	34.1	40.6	25.2
	NPK		106.	67.7	45.9	23.8	48.5
Conover	C	29.0797	73.2	86.3	77.5	64.7	64.7
A	NK		71.7	65.5	67.6	64.8	69.0
	NPK		136.	134.	102.	85.0	71.8
Conover	C	30.0082	139.	90.8	114.	109.	95.3
B	NK		124.	107.	101.	96.8	92.3
	NPK		141.	135.	146.	118.	115.
Hillsdale	C	71.9123	133.	109.	109.	86.2	104.
A	NK		146.	111.	110.	85.1	92.4
	NPK		199.	115.	133.	111.	108.
Hillsdale	C	60.8	40.4	44.4	36.6	32.7	36.6
B	NK		37.9	45.9	34.0	31.5	22.8
	NPK		63.3	48.5	47.5	51.2	39.2
Locke	C	64.2730	160.	149.	139.	118.	104.
A	NK		127.	139.	132.	120.	103.
	NPK		153.	162.	164.	139.	104.
Locke	C	37.0073	68.9	86.3	77.5	64.7	56.4
B	NK		43.1	79.0	77.5	63.3	36.6
	NPK		72.0	83.7	79.0	71.9	59.2

¹C = Control (NK) with no plants, NK = 100 ppm N, 100 ppm K, NPK = 107 ppm N, 100 ppm P, 100 ppm K.

²Values reported for NK and NPK are averages of 3 replications; the value for Control (C) is a single determination.

Table 12a. Soil Mn⁺⁺ content with time after flooding.

		Initial	Time after flooding (weeks)				
Soil Type	Treatment ¹	Mn Content	3	6	9	12	15
			----- ppm ² -----				
St. Clair A	C	3.08	98.1	107.	75.0	42.1	41.2
	NK		96.3	86.2	70.3	61.8	51.3
	NPK		96.0	79.8	72.7	60.4	68.4
St. Clair B	C	2.43	9.03	11.7	13.3	14.7	14.8
	NK		9.94	11.3	13.8	13.5	12.9
	NPK		10.5	12.2	19.6	19.3	21.2
Hoytville A	C	.50	4.05	4.04	5.06	5.06	3.86
	NK		3.66	3.31	4.43	3.78	5.57
	NPK		3.49	3.41	4.85	5.17	4.98
Hoytville B	C	.75	1.61	1.46	2.08	2.71	2.76
	NK		1.76	1.10	3.32	2.87	6.39
	NPK		2.18	2.15	5.27	7.50	12.5
Morley A	C	1.58	142.	128.	83.3	69.8	51.2
	NK		126.	107.	77.7	76.2	44.7
	NPK		130.	118.	88.1	83.0	64.2
Morley B	C	16.8	92.7	131.	75.0	67.4	49.6
	NK		90.8	99.9	71.0	61.4	43.8
	NPK		102.	106.	73.9	72.9	56.1
Sims A	C	5.03	7.35	5.24	6.85	7.33	5.28
	NK		6.30	4.02	4.08	3.05	1.32
	NPK		6.07	4.97	5.29	4.70	3.49
Sims B	C	.82	9.74	3.82	6.59	6.56	11.5
	NK		7.46	8.50	8.10	6.77	11.1
	NPK		9.41	5.91	10.2	13.6	13.9
Miami A	C	1.45	81.7	77.3	64.7	44.4	49.5
	NK		78.4	74.4	49.6	41.6	52.5
	NPK		76.7	76.8	68.5	47.7	53.2
Miami B	C	1.20	12.6	6.47	12.7	15.4	16.5
	NK		17.0	11.7	14.3	18.7	29.8
	NPK		17.3	10.9	15.5	24.1	33.8
Conover A	C	2.4952	82.5	80.0	66.5	44.6	56.9
	NK		78.6	68.9	48.4	45.0	51.5
	NPK		79.4	73.5	69.4	56.5	54.9
Conover B	C	1.3953	26.2	9.80	22.8	25.5	28.2
	NK		25.4	15.9	17.4	18.6	34.6
	NPK		33.3	16.4	31.8	49.3	52.5
Hillsdale A	C	7.2392	123.	107.	75.0	60.0	61.4
	NK		126.	121.	77.9	61.6	60.4
	NPK		122.	112.	78.0	59.2	65.4
Hillsdale B	C	6.0537	8.96	17.6	22.7	20.9	23.8
	NK		10.3	13.7	22.8	31.4	38.5
	NPK		11.9	20.8	30.5	54.7	47.1
Locke A	C	1.5880	8.75	4.53	6.20	5.31	3.19
	NK		7.76	4.84	5.95	5.50	4.38
	NPK		7.93	4.93	6.83	6.28	4.43
Locke B	C	.8207	3.40	.95	.87	.73	.67
	NK		3.42	.88	.81	1.35	1.27
	NPK		3.57	.93	1.38	1.60	1.47

¹C = Control (NK) with no plants, NK = 100 ppm N, 100 ppm K, NPK = 107 ppm N, 100 ppm P, 100 ppm K.

²Values reported for NK and NPK are averages of 3 replications; the value for Control (C) is a single determination.

Table 13a. Soil Fe⁺⁺ content with time after flooding.

Table 13a. Soil Fe content with time after flooding.							
Soil Type	Treatment ¹	Initial Fe Content	Time after flooding (weeks)				
			3	6	9	12	15
			ppm ²				
St. Clair A	C	.29	1.04	15.7	18.2	16.2	17.4
	NK		1.61	17.4	18.3	12.0	14.2
	NPK		1.89	17.5	20.5	14.2	14.7
St. Clair B	C	1.48	1.25	9.40	10.2	7.29	8.97
	NK		1.61	5.61	6.34	5.46	6.38
	NPK		3.03	4.53	9.94	6.66	8.54
Hoytville A	C	.29	2.73	55.8	49.1	52.2	60.1
	NK		4.68	77.0	41.7	56.4	73.5
	NPK		3.74	49.0	48.9	53.0	64.6
Hoytville B	C	.44	1.68	5.85	10.8	5.91	6.58
	NK		1.46	7.88	5.68	4.03	5.15
	NPK		1.32	4.06	5.75	5.34	6.23
Morley A	C	.44	2.73	22.0	22.3	18.6	23.6
	NK		2.88	26.7	22.8	22.2	23.8
	NPK		4.95	28.5	27.0	25.3	26.9
Morley B	C	1.17	1.68	0.87	1.33	.99	1.04
	NK		1.11	1.10	.38	.41	1.11
	NPK		1.11	1.45	1.05	.94	1.46
Sims A	C	.29	38.7	45.1	65.2	54.7	62.1
	NK		9.45	48.0	34.7	44.5	55.1
	NPK		7.16	50.3	41.0	42.2	53.7
Sims B	C	.59	4.43	7.47	5.91	4.88	6.37
	NK		.48	5.02	2.73	3.24	3.94
	NPK		.69	3.64	3.52	3.92	4.48
Miami A	C	.59	12.0	9.86	8.51	8.34	10.0
	NK		10.7	15.6	10.3	10.2	12.9
	NPK		8.09	11.1	9.60	8.67	11.6
Miami B	C	.59	.20	5.13	2.50	3.35	4.01
	NK		1.82	1.10	2.28	1.61	1.68
	NPK		2.56	7.97	3.29	2.34	2.73
Conover A	C	.59	1.68	9.68	9.56	7.64	7.88
	NK		1.39	16.3	5.63	12.74	10.6
	NPK		1.74	16.3	14.6	12.3	11.3
Conover B	C	.44	1.25	3.16	2.00	1.66	1.89
	NK		1.32	2.10	.83	1.61	1.11
	NPK		2.02	4.14	.49	1.56	1.04
Hillsdale A	C	.74	19.7	15.3	10.9	9.56	11.8
	NK		7.76	13.1	8.18	9.64	10.8
	NPK		9.93	11.4	7.61	11.0	13.3
Hillsdale B	C	.44	1.04	2.45	2.67	1.83	2.73
	NK		1.60	1.45	0.72	1.44	1.53
	NPK		2.16	2.25	1.61	2.39	2.38
Locke A	C	.15	1.04	13.7	6.91	10.8	10.0
	NK		1.04	11.9	5.40	6.61	8.18
	NPK		.83	10.4	6.32	9.11	11.1
Locke B	C	.29	.20	1.22	.66	.83	.83
	NK		.76	2.10	1.01	.99	.90
	NPK		1.11	1.81	1.55	1.52	1.61

¹C = Control (NK) with no plants, NK = 100 ppm N, 100 ppm K,
NPK = 107 ppm N, 100 ppm P, 100 ppm K.

²Values reported for NK and NPK are averages of 3 replications; the value for Control (C) is a single determination.