A STUDY OF THE APPLICATION OF PHOSPHORUS TO POTENTIAL PADDY SOILS OF THE ACCRA PLAINS AND ITS INTERACTION WITH OTHER PLANT NUTRIENTS

THESIS

PRESENTED BY

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DECLARATION

I hereby declare that the work presented in this thesis

"A Study of the application of phosphorus to potential paddy soils of the Accra Plains and its interaction with other plant nutrients"

in the Soils Division, Department of Crop Science, Faculty of Agriculture of the University of Ghana, has been done entirely by me between 1978 and 1979 and has never until now been presented to this University nor to any other for a degree.

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ABSTRACT

A greenhouse pot experiment was set up to find the effect of added phosphorus on the availability and uptake of P, Mn and Fe by rice plant under flooded conditions. Two soil series Akuse and Amo (Vertisol and Inceptisol, respectively) were used. The experiment was of a simple factorial design comprising of four levels of P with and without rice plant on both soils under continuous submergence. Samples of growing rice plants, supernatant soil solution, and the wet soils were taken for laboratory analysis at one, two, three, five, six and eight weeks of age during an eight week period. The soluble P, Mn and Fe in the supernatant liquids, the uptake of these ions by the plant and the extractable Mn and Fe from the wet soil were determined.

In most of the treatments, P, Mn and Fe followed similar trends in both cropped and uncropped soils. In the majority of the treatments, the highest values of nutrients were obtained in the first week with marked decrease in the second or third week after trans-

planting/submergence. In the case of iron in the plant material, the marked decrease was in the fifth week. The concentration of the nutrients in the treatments generally decreased to about the lowest level in the eighth week except Mn and Fe in the wet soil treatments and Fe in the plant material which increased then.

Changes in availability may have been due to reduction or oxidation of phosphate compounds of Mn and Fe, solubility or precipitation of Ca phosphate, hydrolysis, or complex forming tendencies of Fe and Mn, resulting in availability or precipitation of P, Mn and or Fe which in turn sometimes affected the uptake by the plant.

The two soils studied were found to be significantly different in release of the nutrients under study as affected by the addition of triple superphosphate fertilizer. These differences were reflected in the yield of the rice crop in which Amo series did much better than Akuse series.

INTRODUCTION

Rice is the world's most important and widely grown cereal for human consumption (IITA, 1978) and it contributes 26 per cent of the world's cereal production (FAO, 1966). It also provides 22 percent and 17 per cent of the world's supply of calories and protein respectively (FAO, 1965).

Although cultivation of rice is primarily in tropical and sub-tropical areas, nevertheless it is universal except in the arctic and antarctic regions.

Because of the tolerance and adaptability of rice, its cultivation is increasingly used to reclaim saline areas as well as to bring large expanses of fresh water swamps into production thereby increasing the total size of arable areas under rice (IRRI, 1964).

Yields of rice under paddy have been found to be far greater than that grown under upland conditions. However, the increased production of rice still cannot meet the demand, to the extent that most West African countries import almost 30 per cent of their total requirement (IITA, 1978).

Where continuous cropping is practised production is increased by the use of fertilizers, improved irrigation systems and effective management practices. Although it is well known that yields of paddy rice can be substantially increased by application of fertilizers, more research is needed to enhance their efficiency. Knowledge in this field is still limited, more especially in the distribution and role of plant nutrients within the soil-water-plant-interphases.

In West Africa, the alternating wet and dry seasons result in changes in the form and availability of plant nutrients. Not much however is known of the extent to which these alterations influence the growth and yield of rice. With more research, vast areas of poorly drained land could be efficiently used for growing rice and their production could also be further increased by using short duration, disease and lodging resistant rice varieties, making it possible to obtain two or three crops annually.

Several research workers have highlighted the role of nitrogen, potassium, phosphorus, manganese, iron and other micro nutrients in both upland and paddy fields

(Yamasaki, 1965; Ponnamperuma, 1965; De Geus, 1973).

Phosphorus, manganese and iron in the soil have been found to become more available under paddy (Rodrigo, 1962; Ponnamperuma, 1965; Meek, Mackenzie and Grass, 1968; Gorantiwar, Jaggi and Khanna, 1973); but not much is known of what happens when phosphorus fertilizers are applied to paddy fields more especially in West African soils.

The present investigation attempts to study the role of applied phosphorus and its effect on yield of paddy rice, taking into account its distribution and uptake within the soil-water plant interphases, and its possible effect on soil phosphorus, manganese and iron.

CHAPTER ONE

LITERATURE REVIEW

1.1.0. Introduction

Most countries produce rice under waterlogged conditions for part or all of the growing season (FAO, 1966).

Submergence or waterlogging creates conditions however, that are very different from those in well drained soils in relation to the preparation of the land, nursing and transplanting of seedlings, application of fertilizer, weed control, cultivation and harvesting (Patrick Jr. and Mahapatra, 1968). In addition the presence of excess water *per se* causes physical, chemical and biological changes in paddy that affect plant nutrition.

1.2.0. Changes that take place during waterlogging

1.2.1. Physical

The structure of the soil is destroyed. Because of the physical reactions between soil and water, the bonds holding the soil particles together are broken by the slightest manupulation (Patrick Jr. and Mahapatra, 1968).

The waterlogged soil is differentiated into distinct zones consisting of the layer of water at the top, and two zones based on oxygen penetration that were first described by Pearsall and Mortimer (1939). The part of the soil closest to the water forms a thin yellowish horizon of oxidized zone, below this is the reduced zone which is dark grey in colour. It is in the reduced zone that most of the rice roots are found. The thin yellowish oxidized layer is due to the presence of oxidized iron (Mitsui, 1954; Alberda, 1953). This surface of the soil in contact with the water containing dissolved gases may have a high concentration of oxygen (Mortimer, 1941, 1942; de Gee, 1950). This is believed to be due to diffusion of air through the water and oxygen from algae growing on the surface. The root zone of the rice roots is devoid of oxygen and reduced. But the immediate vicinity is oxidative with reddish brown streaks (Ponnamperuma, 1955). These features, together with the secretion of oxygen by roots of rice plants (Mitsui, 1955) lead to certain characteristics peculiar to paddy soils.

1.2.2. Biological

Soon after the soil is submerged its oxygen supply is drastically reduced and the rate of diffusion of the oxygen becomes infinitesmally slow (Grote, 1934). Within a few hours the aerobic organisms use up the trapped oxygen and become quiescent or die (Ponnamperuma, 1972). The need for electron acceptors by facultative anaerobic and true anaerobic organisms results in sequential reduction of several oxidized components. As a result energy sources including nitrates, higher oxides of manganese hydrated iron III oxide and sulphates will be reduced by microorganisms. Takai and Kamura (1966) and Turner and Patrick (1968) have presented evidences for the sequential reduction of oxygen, nitrates, higher oxides of manganese and iron III oxide and products of organic matter decomposition. Usually one component is not completely reduced before the next most easily reduced compound begins to be reduced.

The root zone of the rice plant is converted from aerobic to anaerobic or near anaerobic environment where oxygen is absent or limiting. It has however been suggested that rice roots receive oxygen from aerial parts by gaseous diffusion (Barber, Ebert and Evans, (1962).

1.2.3. Chemical

Waterlogging results in incomplete metabolism of compounds under strongly reducing conditions in which substances such as NH_3, Nitrogen gas, H_2S, CH_4, manganese II, iron II, phosphate ions, and low molecular weight organic acids are formed (Ponnamperuma, 1972; de Geus, 1973). The degree of reduction depends on the amount of organic matter present, the temperature, the nature and content of electron acceptors and pH. Also air drying a wet soil results in oxidation, and on re-submergence reduction is intensified and acidity increased. (Ponnamperuma, 1972).

The reduced forms of Fe, Si, Mn and phosphate ions become more soluble under submergence, diffuse to the surface and by diffusion and mass flow reach the roots and subsoil. On reaching the oxygenated surface or oxidized zone they become oxidized and are precipated (Ponnamperuma, 1972). Plowing and puddling redistribute the precipitated Fe, Mn and phosphate compounds. They are therefore lost from the top soil and leached down with irrigation water to below the plow layer. Hence reduction eluviation and oxidation illuviation are the soil forming processes of paddy soil (Ponnamperuma, 1972).

According to Takai, Koyama and Kamura (1956), oxygen is the first gas to disappear from soil when submerged, to be followed by the evolution of hydrogen. Then there is a rapid increase of CO_2, a slow increase of nitrogen, a final decrease of CO_2 and nitrogen and an increase in CH_4. The gases escape as bubbles through the water.

Ponnamperuma (1965) found that the usual concentration of CO_2 in paddy soils is below toxic limit. But suggested that to avoid CO_2 toxicity, rice seedlings should not be transplanted till at least two weeks after waterlogging the soil. This is because excess soil CO_2 even in the presence of oxygen does not only retard growth of shoots and roots sometimes causing death of plants (Vlamis and Davis, 1944) but retards water absorption and nutrient uptake including uptake of P (Chang and

Loomis, 1945).

Ponnamperuma (1965, 1972) advocated that reduction of flooded soil components is favoured by the presence of easily decomposable organic matter and proceeds in a certain thermodynamic sequence viz: nitrate, MnO_2, Fe III hydroxide, intermediate dissimilation products of organic matter, sulphate, CO_2 and perhaps phosphate. He suggested that nitrate and MnO_2 if present retard reduction. In the reduction of organic matter the end products include NH_3, fatty acids, amines, diamines, mercaptans and H_2S from carbohydrate and protein metabolism and fatty acids, alcohols and methane from carbohydrate metabolism.

The end product of the mineralization of organic nitrogen in the soil is ammonia due to the absence of oxygen which would normally convert it to nitrate.

Sulphur containing compounds are converted to sulphates and thence to sulphides by strict anaerobes (Starkey and Wright, 1946). This results in theprecipitation of iron sulphide compounds which when oxidized give sulphate and sulphuric acid thus increasing acidity (Ponnamperuma, 1972).

Presence of organic matter provides available phosphates to plants (Bradley and Sieling, 1953; Mandal, 1964). Likewise organic matter makes Mn and Fe available to plants (Meek, Mackenzie and Grass, 1968; Mandal and Chatterjee, 1972; Singh and Ram, 1977).

1.2.4. Electrochemical

Electrochemical changes including alterations in pH, redox potential, and specific conductivity accompany reduction of soils.

pH

Studies at IRRI revealed that on flooding the pH values of acid soils increased whereas those of calcareous soils decreased (IRRI, 1963). The pH of practically all soils when further studied, showed pH values of 6.9 to 7.3 after 16 weeks of submergence regardless of the initial pH and soil property. It was also found that the majority of soils had pH values of 6.7 to 7.2 seven weeks after flooding (IRRI, 1964). Decrease in pH of alkaline soils may be due to high CO_2 concentration (Ponnamperuma, 1965, 1972) and increase in pH of acid soils may be due to presence of ammonia (Karunkar and Daniel, 1950).

Redox potential

The most striking electrochemical change that takes place and is measurable in waterlogged soils is the decrease in redox potential. In 1955, Ponnamperuma discovered that the reduction oxidation potential of flooded soil (Eh) falls sharply on flooding, reaches a minimum within a few days, rises to a maximum and then decreases with time. Aerated soils have redox potentials in the range of +400 to 700 mv. Reduced soils have low Eh with values as low as -250 to -300 mv. Ponnamperuma (1965) also found that the courses of Eh changes are determined by the initial aerobic potential, the temperature, the nature and content of electron acceptors present in the soil. The Eh therefore measures the state of oxidation or reduction of the soil.

The thermodynamics of flooded soils have been extensively studied (IRRI, 1963, 1964, 1965; Ponnamperuma, Loy and Tianco, 1967, 1969). It was shown in these studies that the clear solution drawn out by gravity from the flooded soils may be considered the equilibrium soil solution and the thermodynamic medium. Ponnamperuma et al (1967, 1969) correlated Eh values obtained in redox system of flooded soils with theoretic Eh values, and concluded the presence of iron redox systems. Earlier Ponnamperuma (1955) studied the effect of addition of (a) organic matter, (b) nitrate on two submerged soils over a period of time on Eh and compared the iron and manganese contents of the soils. From his investigations he concluded that organic matter accentuates the decline of Eh under submergence and nitrate supresses it. He however felt that redox systems have not been clearly defined as such, that low Eh values indicate the presence of highly reduced substances but says little about their concentration, and that the iron redox system has been over emphasized by some workers (Jeffery 1960; Motomura, 1962a).

It was considered (Ponnamperuma, 1965) that the chief contribution a study of redox potential of submerged soils can make to improve nutrition and higher rice yields would be (a) to define a measurable oxidation-reduction zone in which rice plants will not suffer from deficiency of essential nutrients and excess of reduction products and (b) to device practical methods of achieving this optimum oxidation-reduction status. However, there are limitations that create difficulties. But they have not prevented the qualitative way of differentiating between a good and bad soil (Ponnamperuma, 1965) and the boundary between oxidizing and reducing soil surfaces (Pearsall, 1950).

Specific conductance

Specific conductance of a soil generally increases in the early stages of submergence to a maximum (Ponnamperuma, 1965) coinciding with peak reduction to be followed by decrease. Ponnamperuma (1965) found that soils vary widely in the change of their specific conductance during submergence and concluded that specific conductance helps to elucidate chemical changes occurring in flooded soils and can be used to study the concentration of ionic reduction products of certain soils.

1.3.0. Phosphorus

1.3.1 Role of phosphorus in nutrition of the rice plant

Phosphorus is one of the major nutrients required by plants including rice. Its role is quite extensive and includes direct or indirect action on cell division, flowering, fruiting and grain formation, crop maturation, counteracting the effect of excess nitrogen application, lateral and fibrous root development, promotion of early growth and increase in the strength of rice straw preventing lodging. It affects photosynthesis, synthesis of protein, break down of carbohydrates and transfer of energy within the plant. In short it promotes healthy growth of the rice plant.

1.3.2. Distribution of phosphorus in flooded soils

Phosphorus content for most mineral soils is low, with values between 0.2 and 0.4 per cent of P_2O_5 (Patrick Jr. and Mahapatra, 1968). Nye and Bertheux (1957) attributed the low phosphorus in Ghanaian soils to the low content of apatite in the parent rocks and the great age and intensive weathering to which the rocks have been subjected.

Soil P consists of both organic and inorganic forms of which the latter is more important in waterlogged soils (Patrick Jr. and Mahapatra, 1968).

The inorganic compounds of P in soils have been classified into four main groups by Chang and Jackson (1957a). They are calcium phosphate, aluminium phosphate, iron phosphate and reductant soluble phosphate extractable after the removal of the first three forms. Calcium phosphate exists mainly in the form of apatite of which flouroapatite is the most insoluble and unavailable. Other forms of calcium phosphate are mono, di- and tri-calcium phosphate (Brady, 1974) in small amounts as transitional forms.

Little is known of the forms of iron and aluminium phosphate present in soils (Brady, 1974). But Chang and Jackson (1957b) have suggested that they could be in the form of hydroxy-phosphates which are stable in acid and extremely insoluble. The insoluble P fraction has been termed "non extractable" phosphorus by Bauwin and Tyner (1957) and is equivalent to reductant soluble Fe phosphate plus occluded Al and Fe phosphate fractions of Chang and Jackson (1957b). This fraction is thought to be important in waterlogged soils as part of it is released (Mahapatra and Patrick Jr., 1969) when the hydrated iron oxide present is reduced.

Gley horizon of many poorly drained mineral soils contain a minimum of total P in the form of reduced Fe and Mn compounds. Glenworth (1947) stated that a maximum concentration of Fe and Mn compounds of P in poorly drained profiles is found in the A horizon whilst it is found in the C horizon in well drained profiles. As rocks weather, the soluble calcium forms of the inorganic P are converted to the less soluble Fe and Al forms. In the presence of soil organic matter, this conversion does not take place. Instead many alkali and acid soluble complexes of P are formed (Godfrey and Riecken, 1957).

Information on the distribution of soil P in flooded soils is rather limited (Patrick Jr. and Mahapatra, 1968). Hesse (1962) however reported that 87 per cent of total P in swamp mud in Sierra Leone was in organic combination and the rest was in association with Fe and Ca. Tseng (1960) found only Fe and Al phosphates in acid red earth or yellow earth and mudstone alluvial paddy soils of Taiwan. In sandstone and shale alluvial soils, Ca, Fe and Al phosphates were present in about equal quantities. The minimum solubility of phosphate in soils of differnnt soil groups was in the range of pH 6 to 8 (Patrick Jr. and Mahapatra, 1968).

1.3.3. Factors that control the availability of Inorganic Soil P under submergence include

(a) Soil pH. (b) Soluble iron, aluminium, manganese and their minerals (c) Amount and decomposition of organic matter (d) Type and amount of clay (e) activities of micro-organisms.

There are three general types of reactions namely adsorption, double decomposition and isomorphous replacement by which P can be fixed in soils. Kardos (1955) suggested that one or more of the ionic forms of orthophosphoric acids can be involved in these reactions.

Soil pH

The availability of P is determined by the kind of phosphate ion present and this varies with the pH of the soil solution. For normal soils pH4 to 7.5, HPO_4^{2-} and $H_2PO_4^-$ ions prevail. Above pH 6, $H_2PO_4^-$ ions increase to 98.4 per cent at pH 9. Where there are insoluble phosphate compounds, the soil reaction produces a mixture of $H\ PO_4^{2-}$ and $H_2PO_4^-$ ions and in very alkaline soil reaction pH9 or above PO_4^{3-} is dominant.

Flooding was reported by Ponnamperuma (1965) to cause a decrease in soil pH during the first one or two days, followed by an increase to a maximum of 6.5 to 7.5 pH in 2 to 3 weeks, and that there is strong correlation between soil reaction and P availability.

Solubility of P increased under flooded conditions (Kawaguchi, 1944; Islam and Elahi, 1954; Patrick and Mahapatra, 1968) and de Geus (1973) noted that the increase in availability of P was greater under prolonged flooding. However, Basak and Bhattacharya (1962), IRRI (1963), Hossner, Freeouf and Folsom (1973), Singh and Ram (1977) suggested that both soluble and extractable phosphorus increase to a maximum, days after flooding and then decrease.

With increase in pH between 6.5 and 7.5 there is a decrease in available P (Aoki, 1941; USDA, 1957; Tseng, 1960). Brady (1974) suggested that above pH 7 the complex insoluble phosphate and below pH 5 insoluble Fe, Al and Mn compounds fix phosphate ion while between pH6 and 7 P fixation is at a minimum thus P availability is at a maximum.

Effect of soluble iron, aluminium, manganese and their minerals on the availability of P under submergence

Ponnamperuma (1965) discovered that soils between pH 6.2 to 6.6 have low Fe but high active manganese. Patrick Jr. and Mahapatra (1968) mentioned the possibility of substantial quantity of Fe and Al ions in active form in acid soils. They also suggested that these ions will react with soluble phosphates to form both crystalline and amorphous precipitates, thus making P unavailable. Chang and Jackson (1957b) demonstrated the precipitation and accumulation of Fe and Al phosphate in neutral soils. Wild (1950) reviewed soil P fixation and drew attention to the correlation between phosphorus fixation and the amount of Fe and Al in the soils. He pointed out that the fixation was reduced when Fe and Al oxides were removed and increased when they were added to colloids. This reaction between Fe and Al with phosphate ions could be represented thus:-

$$Fe^{3+} + \underset{\text{soluble}}{H_2PO_4^-} + 2H_2O \rightleftharpoons 2H^+ + \underset{\text{insoluble (strengite)}}{Fe(OH)_2H_2PO_4}$$

$$Al^{3+} + \underset{\text{soluble}}{H_2PO_4^-} + 2H_2O \rightleftharpoons 2H^+ + \underset{\text{insoluble (variscite)}}{Al(OH)_2\ H_2PO_4}$$

forming hydroxy-phosphate. As the concentration of Fe, Al and Mn ions are usually greater than that of phosphate ions the reaction above will move to the right. So only a small amount of phosphate ion will be available (Brady, 1974).

Hesse (1962) observed that when excess soluble phosphate was not continuously present in the soil, there occurred a loss of Al phosphate and a gain in Fe phosphate with time. The absence of Al bound phosphate was due to its transfer of the phosphate to iron phosphate resulting in fixation.

The increase in availability of native and added phosphate in flooded soils as compared to well drained soils (Aoki, 1941; Shapiro, 1958a,b; Davide, 1960) was attributed to the increase in reduction of Fe III phosphate to more soluble Fe II form. Phosphate reactions in flooded soils have been associated with Fe II rather than with Fe III which is usually found in well drained soils (Mitsui, 1954). This finding was confirmed by Fujiwara (1950) when he discovered that lowland rice responded much better to Fe or Al phosphate than barley or upland rice.

Islam and Elahi (1954) noticed that there was a progressive reduction of Fe III to Fe II and an increase in readily soluble phosphate in lateritic soils incubated under waterlogged conditions in the laboratory. William, Bromfield and William (1958) stated that soils containing appreciable amounts of Fe III phosphate increased the phosphate supply to plants under anaerobic conditions, but soils without Fe III phosphate showed a decrease in available phosphate.

The coatings of hydrated Fe III, MnIV, Al and Ca oxides present on silt and clay particles have occluded in them several forms of phosphate, some of which are available to crops but separated from the soil solution (Chang and Jackson, 1958; Mahapatra, 1966) by hydrated Fe III oxide which when reduced as a result of waterlogging to the more soluble Fe $(OH)_2$ releases the occluded phosphate.

Valencia (1962) studied the availability of native and applied P to rice grown on five waterlogged soils. He found that phosphate became more available on flooding and concluded that this was due to the hydrolysis of

Al phosphate and reduction of Fe III phosphate. He argued that the subsequent decrease in availability was probably due to fixation of phosphate, a view supported by Rodrigo (1962), IRRI (1963), Hossner et al. (1973). Singh and Ram (1977) related this decrease in available phosphorus to reformation of insoluble Fe and Ca phosphate in one soil and Al and Ca phosphate in another. But Ponnamperuma (1965) pointed out that the vicinity of the rhizosphere of rice is oxidative hence the precipitation of Fe PO_4 around rice roots which will lead to decrease in available phosphorus. On the other hand Bromfield (1960) contends that the subsequent decrease may have been caused by resorption of phosphate on clay or Al hydroxide with destruction by further microbial action of the organic anions or complexing agents. Patrick Jr. and Mahapatra (1968) tried to emphasize the fact that though submergence increases phosphate solubility and availability, this need not necessarily be so as several factors affect release and refixation of phosphate in flooded soils.

Fujiwara (1950), Ponnamperuma (1958), Shapiro

(1958b) and Mandal (1964) expressed that the effect of flooding which increases the availability of P may not only be due to hydrolysis of Al phosphate but that hydrolysis of Fe phosphate may also be involved.

Brady (1974) has stressed that $H_2PO_4^-$ ion reacts not only with soluble Fe, Al and Mn ions but also insoluble hydrous oxides of these elements such as limonite and goethite. Consequently phosphoric acid becomes available under submergence and P could be fixed in the form of hydroxy phosphate (Kittrick and Jackson, 1956) resulting in decrease in availability of P.

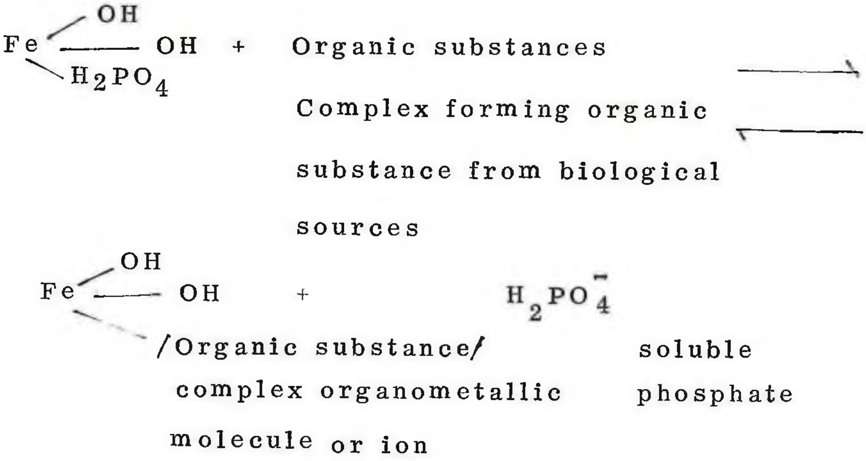
Production of hydrogen sulphide gas under highly reduced conditions may contribute towards the increase in availability of P as explained by Sperber (1958) and Kawaguchi (1965).

$Fe_3(PO_4)_2 + 3H_2S \longleftrightarrow 3FeS + 2H_3PO_4$. This process is thought to prevail in soils poor in free Fe.

Large amounts of Al enhances the refixation of phosphate that becomes soluble during the reduction of Fe phosphate. If there are large quantities of compounds of Fe under flooded conditions and reduction of the iron is incomplete, refixation of phosphate takes place. After the wet soil is dried oxidation and dehydration result in precipitation of phosphate (Patrick Jr. and Mahapatra 1968).

Effect of amount, type and decomposition of organic matter on the availability of phosphorus

Bradley and Sieling (1953), USDA (1957), Olomu, Racz and Cho (1973) reported that certain organic substances that are products of organic decay (Brady, 1974) are effective in preventing precipitation of phosphate by Fe and Al because of their ability to form stable complex molecules with these metals, thus making P available. The equation below has been suggested by Bradley and Sieling (1953) for the type of reaction that could go on in a wide range of pH values.



Shapiro (1958b) proposed that organic matter does not only form straight complexes with cations but reduces and chelates metallic cations thereby increasing P solubility and its concentration in solution under submergence. This idea has been supported by Mandal and Mandal (1973), Hossner et al. (1973), Singh and Ram (1977). The role played by organic matter in reducing the intensity of P fixation by sesquioxides on fifteen Indian soils was studied by Datta and Srivastava (1963). The statistical data indicated a strong interaction of organic matter and pH with the sesquioxide content. When corrections were made for these factors the sesquioxide level and phosphate bonding were highly correlated in waterlogged soils.

Basak and Bhattacharya (1962), Pathak, Krishna and Tiwari (1972) discovered that waterlogged soils show a unique capacity for regenerating an increasing quantity of available phosphoric acid during the active period of crop life. They suggested that the source of its supply and the cause of its regeneration resulted from the release of phosphoric acid from mineralization of organic phosphorus and the transformation of Fe and

A1 phosphates to reduced forms under anaerobic metabolism developed during waterlogging. On the contrary Patrick Jr. and Mahapatra (1968) advocated that there is little mineralization under anaerobic conditions. Hence organic phosphate appears to be of little practical value in flooded soils as it has to be converted to the inorganic form before being utilized by plant. However, rate of mineralization of organic P increases as liming raises the pH which increases the activity of micro-organisms whilst Fe and A1 oxides become less active in absorbing organic P (USDA, 1957).

Islam and Elahi (1954) found out that the addition of organic matter in the form of green manure was particularly useful in effecting the reduction of Fe III to Fe II and greatly increased the availability of P in submerged soils. But Tanaka and Navasero (1967) and Jaggi and Russell (1973) stated that the application of green manure under similar conditions produced an accumulation of organic acids which retarded plant growth.

Bartholomew (1931) and Paul and Delong (1949) noted that transformation of inorganic to organic phosphate in flooded soils resulted in decrease in phosphate availability. Gasser (1956) suggested that organic complexes in soils under submergence do not necessarily make P available and demonstrated that P was fixed when insoluble Al organic complexes of P were produced during anaerobic fermentation of rice straw.

Very little is known of the factors that affect the availability of organic P to higher plants (Brady 1974). Rogers et al. (1941) established that both phytin and nucleic acids can be utilized as sources of P. Phytin is said to be absorbed directly by plants whilst nucleic acid is decomposed by enzymes at the root surfaces and P absorbed either in the organic or inorganic form (Brady, 1974). Bower (1949) studied availability of soil phosphorus and found that phytin forms Fe, Al and Ca phytates, also that in acid soils the phytin is insoluble and thus unavailable. But under alkaline conditions, Ca phytate is precipitated hence P is unavailable.

Nucleic acids are strongly adsorbed by clays especially by montmorillonite under acid conditions, resulting in decreased rate of decomposition of the acid and availability of P respectively and also resulting in fixation (Brady, 1974).

Effect of type and amount of clay mineral on the availability of P under submergence

Clay minerals participate in the fixation or availability of phosphate ions.

Under moderately acidic condition, silicate clay minerals such as kaolinite, montmorillonite and illite fix P ion by adsorption especially around the exposed crystal edges. Phosphate has been shown to be fixed by clay minerals by reacting with soluble Al originating from the exchange sites and from lattice dissociation of clay minerals to form very soluble Al phosphate compounds (Hemwall, 1957).

Toth (1937) showed that phosphate fixation takes place through a mechanism of silicate ion replacement. Low and Black (1950) studied the reaction between phosphate and kaolinite clay and postulated a two stage reaction - adsorption followed by isomorphous replacement in which phosphate penetrates the crystal structure to replace a proportionate amount of silicate. Part of the phosphate which reacts with Fe and Al compounds and with silicate clays is subject to replacement by other anions such as hydroxyl ion (Brady, 1974). In the extreme case this fixation of phosphate ion is double decomposition, 15 per cent displacement of silicate anion by phosphate occurs resulting in the formation of new solid phase as precipitates of Fe and Al (Haseman, Brown and Whitt, 1950). The extent of the fixation can be determined by concentration of the phosphate ions, the temperature, and the length of time the reaction takes to go on.

Concentration of Al in clay is usually much higher than that of Fe or Ca. Hence phosphates are fixed initially as Al phosphate. With time phosphates bound to Al combine with Fe to form less soluble Fe phosphate.

Bromfield (1960) noted that decrease in phosphate availability under submergence may be caused by resorption of phosphate by clay or by Al hydroxide. However, when phosphate anion exchange occurs between clay and organic anion, phosphate ion is more available

(Russel, 1962).

Effect of Micro-organism on phosphate release

Tsubota (1959) investigated the process of biological phosphate reduction in volcanic soils and humus rich alluvial soils of Japan and found that after one week of incubation of reducing medium containing orthophosphate and small amount of soil, a large amount of phosphite and hypophosphite ions were detected. He reported that *Clostridium butyricum* and *Escherichia coli* were capable of phosphate reduction.

Organic substances produced as a result of action of micro-organisms under submergence were responsible for some of the organometallic complexes and chelated molecules formed (Bradley and Sieling, 1953; Shapiro, 1958b; Olomu *et al.*, 1973), production of which enhanced the availability of P. Basak and Bhattacharya (1962) reported the release of phosphoric acid from mineralization of organic P and in addition microbial population temporarily tie up inorganic phosphate (Brady, 1974).

Effect of phosphate availability by calcium and calcium minerals

The mechanism of phosphate fixation in alkaline and calcareous soils is caused mostly by Ca ions and in most cases $CaCo_3$ (Patrick Jr. and Mahapatra, 1968 and Brady, 1974) and it was suggested that the products of reaction between phosphate and Ca ions were complex orthophosphate compounds of varying solubilities. The formation of insoluble tricalcium phosphate takes place at high pH - apatites are said to be the most important of the phosphate minerals. Hydroxy apatite is considered to be the stable solid phase in weakly acid, neutral or alkaline solutions and Moreno, Lindsay and Osborne (1960) believed that octacalcium phosphate is a very stable form.

Brady (1974) stated that available phosphate reacts with both Ca ions and carbonate ions in soils resulting in fixation of P. In alkaline soils that contain free $CaCO_3$, phosphate ions are precipitated, and according to Patrick Jr. and Mahapatra (1968) the quantity of precipitate is dependent on the amount of exposed surface of $CaCO_3$.

In some soils, Ca phosphate crystals begin to form around pH 6 and their solubility decreases as the pH increases to about 7.5. But in the presence of excess Ca CO_3, the solubility of the Ca phosphate increases between pH 7.5 and 9, and the availability of P is at a maximum at pH 6.5 to 7. As the soil pH increases from 7 to 8.5, phosphorus is fixed due in part to changes in the rate and capacity of the roots to adsorb P or to a decrease in concentration of $H_2PO_4^-$ (USDA, 1957).

During submergence the availability of P increases due to dissolution of Ca phosphate by carbonic acid produced in the soil (Ponnamperuma 1965), also the equilibrium of acid soils rich in iron is regulated by Fe $(OH)_2$-CO_2 - H_2O equilibrium. Hence where there is an increase in the concentration of Ca ions, it will be reflected in the pH. There will be a simultaneous decrease in the concentration of iron ions, which will in turn affect the solubility of phosphate ions.

Mandal (1964) studying transformation of inorganic phosphate in waterlogged soils in India, found a slight increase in 0.5 N ethanoic acid extractable P and a slight decrease in Fe PO_4, although Al and Ca phosphates were unchanged. With the addition of starch, ethanoic - extractable phosphate increased and Ca phosphate decreased.

He argued that the profuse production of CO_2 as a result of the decomposition of starch may have converted some insoluble tricalcium phosphate to more soluble mono and di calcium phosphates. In the presence of lime, he found that Fe III phosphate decreased considerably and Al phosphate decreased slightly, but that Ca phosphate increased appreciably. He concluded that some of the Fe III phosphate must have been transformed to Ca phosphate, something he thought would not take place under well drained conditions.

1.4.0. Availability of Manganese and Ironin Submerged soil

The presence of nitrate in submerged soil represses the reduction of other components. The reduction of the higher oxides of Mn (Mn_2O_3, Mn_3O_4) follow in the wake of denitrification. The reduction may result from the compounds functioning as electron acceptors in the respiration of micro-organisms (Ponnamperuma, 1965) and as chemical oxidant of reduction products (Mann and Quastel, 1946). Manganese is more readily reduced, rendered soluble and released quicker into solution than Fe (Mandal, 1961; Ponnamperuma 1965). The increase in availability of manganese under waterlogged condition has been reported by Pearsall (1950), Mandal (1961, 1962), Rodrigo (1962), Pathak et al. (1972) and Olomu et al. (1973).

Changes in reduced Mn vary from one soil to another. Ponnamperuma (1965) has shown that soils with high Mn content, irrespective of pH value and organic matter content show steep increase in Mn II ion during the first few weeks of submergence followed by a gradual fall. Whilst the Mn concentration in soils with low active Mn increases slowly to a peak value far less than for soils of high manganese concentration. He stipulated that the pattern of change in concentration also varies from soil to soil. Clark, Nearpass and Specht (1957), Mandal (1961), Olomu et al. (1973) discovered that Mn entered the exchange complex within a week after waterlogging and that the amount of soluble Mn showed a gradual increase followed by a decrease. Mandal (1961) observed a simultaneous increase in reducible Mn. Rodrigo (1961) discovered that Mn in the wet soil and water percolates (he collected from a hole at the lower side of the pots) increased with time of submergence to a peak and then fell. He did not detect any manganese in the supernatant liquids.

According to Ponnamperuma (1965) the most important chemical change that takes place when a soil is flooded is reduction of Fe and its accompanying increase in solubility. The amount of Fe reduced depends on the iron content, pH, the amount of reducible organic matter, and the absence of substances at a higher oxidizing state. Changes in the state of oxidation could be caused by micro-organisms that obtain their energy under submergence through the conversion of iron III to iron II or vice versa. In other cases organic compounds formed by microbes may be responsible for the oxidation-reduction reactions. At the same time high pH favours oxidation, and acid conditions are conducive to reduction.

Soils with initial pH of 4.6 to 5.7 tend to have high active Fe content and those with pH 6.2 to 6.6 a low active iron content (Ponnamperuma, 1965). The constant value of soils at pH 6.5 to 7.2 decreased the concentration of iron (Ponnamperuma, 1965), caused iron deficiency in alkaline soils (Ingebretson, Martin, Vlamis and Jeter, 1959) and iron toxicity in Latosolic soils (Ponnamperuma, 1958, 1960).

The amount of iron brought into solution under waterlogged conditions depends on the pH (Rodrigo, 1962; Ponnamperuma, 1965) organic matter content, cation exchange capacity of the soil and the duration of submergence (Ponnamperuma, 1965). The lower the pH of the soil, the greater the solubility of iron, and the amount in solution is proportional to the increase in pH (Rodrigo, 1962).

Jeffery (1961a) stated that as the soil changed from oxidizing to reducing conditions Fe III decreases and Fe II increases. Ponnamperuma (1972) reported that compounds of iron that undergo reduction under submergence include Fe_3O_4 nH_2O (hydrated magnetite) or $Fe_3 (OH)_8$ established by Singh and Pasricha (1978) and iron sulphate. Some of the Fe III compounds are thought to have been reduced to Fe II sulphide, hydroxide, silicate, carbonate or phosphate, some of which may be in the solid phase. Mandal (1961) was of the opinion that insoluble Fe II compounds originally in the dry soil were initially converted to insoluble iron II compounds then later transformed to soluble Fe II compound. This is because insoluble Fe II increased in the soil, and no soluble Fe II was found in the soil solution for at least during the first three weeks. As a result of the increased production of CO_2, some of the insoluble Fe II must have been converted to bicarbonate, part of which remained in the soil solution and the rest precipitated as sulphide.

When a soil is waterlogged, Fe becomes increasingly soluble because of reduction of Fe III compounds (Islam and Elahi, 1954; Mandal, 1964; Ponnamperuma, 1965, 1972; Olomu et al. 1973; Jaggi and Russel, 1973; Singh and Pasricha, 1978) and mineralization of iron complex organic matter (Olomu et al., 1973). The increase in soluble Fe under submergence rose to a peak and gradually decreased (Rodrigo, 1962; Ponnamperuma, 1965; Pathak _et al._, 1972; Jaggi and Russel, 1973). Rodrigo (1962), Pathak _et al_ (1972), Jaggi and Russel (1973) gave no explanation for the subsequent decrease in Fe days after submergence. Ponnamperuma (1965) suggested that the decrease in concentration could be due to precipitation of iron III phosphate on or around rice roots at pH values of more than 7 and the presence and interferance of other ions such as Mn, Cu, P, and silicon.

Meek, Mackenzie and Grass (1968) showed how factors other than redox changes could cause precipitation of Fe and Mn or make them unavailable. They suggested that some of the soluble Fe and Mn may be present under flooded conditions in the form of organic complexes. These complexes they thought were adsorbed by clay or utilised by soil micro-organisms, thus becoming unavailable to plants.

Organometallic ringed and straight chained complexes protect their cationic component such as Fe and Mn from precipitation by phosphates (Bradley and Sieling, 1953; USDA, 1957; Olomu *et al*., 1973). Shapiro (1958b) was amongst the first to suggest that organic matter reduces and chelates metallic cations. Therefore the cation-chelate combination is less likely to take part in soil reactions that would make them unavailable. This property is useful in that it improves translocation of the metal in the plant (Brady, 1974). However, Fe being more strongly attracted to chelates than other metals displaces other cations in the soil in cation-chelate combinations (Brady, 1974).

An increase in pH in the soil solution in the presence of organic matter results in precipitation of Fe and Mn (Ponnamperuma, Martiney and Loy, 1966) although Hem (1960 , 1963) suggested that a higher concentration of Mn is more stable at a given redox potential and pH than Fe.

Manganese and Fe interact with silicate clays in cation exchange reactions, and may also be fixed to the structure of some of the clays especially the 2 : 1 type and depending on the soil condition they may be released (Brady, 1974).

1.5.0. Effect of added phosphate fertilizer on Submergence

Experimentation shows that paddy or lowland rice shows considerably less response to phosphate than do upland crops grown on the same type of soils (Bartholomew, 1931; Aoki, 1941; Mitsui, 1955, 1960; Patrick Jr. and Mahapatra, 1968). Davide (1965) explained this difference in response as a reason why phosphate fertilization has not been given as much attention as nitrogen fertilization. But Iso (1954) emphasized that the study of P as a fertilizer is neglected because its effect is not as clearly observed as that of nitrogen.

Nye and Bertheux (1957) reported that quartzose rocks of Ghana were not particularly deficient in phosphorus, but attributed the low P in Ghanaian soils to the low content mineral apatite in the parent rocks as well as their age and intense weathering. Response of phosphate fertilizer on tropical soils has not always been obtained and has been attributed to high fixation capacity of these soils (Nye, 1952), a view contended by Tempany and Grist (1958), Ignatieff and Lemos, (1963). Vice (1966) found that tropical soils contain minimal extractable phosphorus but that the response to applied P was poor. Nye (1963) was of the opinion that possible explanation other than fixation, includes the empirical nature of the chemical methods used, and the more heterogenous nature of the tropical soils (Burridge and Cunningham, 1960; Jenny, Bingham and Padilla-Seravia, 1948).

Dumont (1966) indicated that due to the high rates of P efficiency under irrigated conditions in Upper Volta, optimum results were obtained with moderate amount of P on soils poor in P. The greatest and most widespread deficiency in soils in Ivory Coast is P and loss in yield may reach 50% (Le Buanec, 1973), and P responses were very marked in the valley swamp soils in Liberia (Carpenter, 1973). In Senegal, the major mineral deficient in all paddy soils is P, but grain response to phosphate fertilizer regardless of the form (soluble or not) used was quite apparant (Gora Beye, 1973) and many tropical soils show a response even under wet rice growing (de Geus, 1973).

Although the availability of phosphate in flooded soils has been attributed to reduction of insoluble Fe III phosphate to soluble Fe II phosphate (Islam and Elahi, 1954; Ponnamperuma, 1955; Mitsui, 1960), Shapiro (1958a) concluded from a series of studies, that rice plants not only utilized the applied P better in flooded soils than in well drained soils, but also more efficiently at higher applications of P in flooded conditions. This he attributed to the increased solubility of native P at equal fertilizer application. Basak and Bhattacharya (1962) reported 60 per cent increase in availability of phosphate in unmanured paddy soil in West Bengal from planting till tillering.

The phosphate solubility pH curves for flooded and non flooded soils were found by Aoki (1941) to resemble those of precipitated Fe II and Fe III phosphate. As a result of this work, Mitsui (1954) conjectured that phosphate availability under submerged condition was governed mainly by the solubility of Fe phosphate. The high solubility of phosphate in alkaline pH range was presumed to be due to the hydrolysis of this compound. Fujiwara (1950), Shapiro (1958a), and Mitsui (1960) also attributed the increase in available phosphorus under flooded condition to hydrolysis of soil phosphates and increased solubility of iron phosphate.

Davide (1960), Chang and Chu (1961), Tyner and Davide (1962) and Mahapatra (1966) studied the fractionation of inorganic P in paddy soils and proposed that Fe phosphate was predominant. But in systems where Ca phosphate was predominant, Shapiro (1958b) noticed little or no increase in availability of P. On the other hand, Patrick Jr. and Mahapatra (1958) observed that the manural value of the phosphate compound added as fertilizer is to a great extent determined by the strength in which the Ca^{2+} are bound to the phosphate. This they thought determined the solubility of the phosphate ions in the paddy soil solution. In the study of phosphate distribution in a soil that had received application of super-phosphate for 31 years, Chang and Chu (1961) found that the phosphate was retained mostly as Fe phosphate, Al phosphate next and Ca phosphate the least. They postulated that the first stage of fixation of P in the soil occurred on the surface of the solid phases with which P came in contact and the relative amounts and kinds of phosphate formed depended on the specific area of the solid phases associated with Al, Fe, Mn and Ca. It was found that subsequently, Al and Ca phosphates gradually changed to less soluble Fe phosphate, The rate of transformation increased with moisture content of the soil (Patrick Jr. and Mahapatra (1968) and that all soluble phosphate fertilizers added to the soil went through similar reaction in which they were converted to Al and Fe phosphates (Valencia, 1962). Hence unless a soil is deficient in phosphate, the yield response to applications of phosphate fertilizer in field experiments cannot easily be detected (Davide, 1965).

Both solubility and deficiency of added P are affected to some extent by the kind or sources of fertilizer, soil reaction, the level of the native P, the rate, method and time of application (Davide, 1965).

1.6.0 Effect of native phosphorus, manganese, iron and fertilizer on growth of rice under submergence

It is advantageous to grow rice under submerged conditions because the water layer protects the plant from cold damage or excess heat, hence it is possible to grow rice in both temperate and tropical climatic conditions.

The growth of weeds in greatly reduced, and the natural supply of nutrients is far more favourable. The blue green algae and other microorganisms enhance the fixation of nitrogen and increase the supply of oxygen (de Geus, 1973). Gralley and Adair (1943) showed that rice grown on continuously submerged soil was larger, tillered more profusely, produced higher yields and had higher grain straw ratio than those grown on moist soil. Beneficial effects of submergence especially on tillering were reported by Vlamis and Davis (1944).

Okajima (1965) reported that rice can absorb an adequate amount of phosphorus from a soil solution of lowland rice with low phosphate concentration, and that waterlogging releases phosphate from fixed forms to the soil solution as a result of reduction reactions. This ensures an adequate supply of phosphorus throughout most of the season in soils that would otherwise be dificient in phosphate but contain appreciable amounts of Fe phosphate and reductant soluble phosphate. It is not surprising then that rice has usually been found to show little or no response to phosphate fertilizer on soils where marked response to phosphate is made by small grain crops in rotation with rice (Mitsui, 1954).

Adequate phosphorus in the soil is essential to nitrogen uptake and, if limiting, plants do not grow normally and yields are depressed (Sircar and Sen, 1941; Aiyer, 1946). Mitsui (1954) reported that the application of P during the initial growth stages was most effective for good yield. This conclusion was corroborated by Fried and Broeshart (1963) who used ^{32}P in their studies. Gama and De (1960) studied the uptake during the growth of the rice plant, and recommended split phosphate fertilizer. Large concentration of phosphate in the soil solution produced chlorosis (Patrick Jr. and

Mahapatra, 1968). The mechanism of the utilization of P by lowland rice is weak compared to that of barley and other plants; and high concentration of phosphate inhibit the intake and translocation of iron in the plant (Kimura, 1932; Kimura and Okajima, 1950).

Extensive studies of microelements for upland crops have been conducted although there is very limited information on the effects of application of micro-elements except for Mn to degraded paddy fields (Yamasaki, 1965).

Iron and Mn play an important role in nutrition of rice plant (Mandal, 1961). Gericke (1930) studied nutrient requirements of rice in culture solution and found that iron was more frequently required by young rice seedlings than by other cereals grown under the same conditions. He also, discovered that rice required available Fe in culture solution longer than any other element except nitrogen and potassium. Ishizuka, Tanaka and Fujita (1961) in culture studies on rice noted that 0.1 ppm Fe in the solution increased yield, but 10ppm had no further influence and 100 ppm reduced yield but showed no toxic effects (Hosoda, 1942).

The increase in solubility of Fe in paddy soil may be beneficial to rice because rice has a higher apparent Fe requirement than other plants (Gericke, 1930; Lin, 1946; Kimura and Okajima, 1950; Ponnamperuma, 1955) and Fe $(HCO_3)_2$ promotes the growth of rice roots (Takijima, 1963). An excess of Fe however may be toxic (Ponnamperuma, Bradfield and Peech, 1955; Yamanda 1959; Yakahashi, 1960) or cause potassium and P deficiencies (Yamanda, 1959). The factors however that influence Fe II uptake by rice plants are not clearly understood (Ponnamperuma, 1965).

Aiyer (1946) observed that along with Fe, rice required Mn in much larger quantities than other minor elements. Japanese workers (Ministry of Agriculture, 1954) have claimed that rice yields increased ten per cent by Fe and Mn supply. But a marked yield response of rice to Mn was observed by Clark et al. (1957) who concluded that rice has a high requirement for and an exceptionally high tolerance to Mn. Ishizuka _et al_. (1961) reported that in culture studies on rice a concentration of less than 0.1 ppm of Mn increased yield, up to 10 ppm increased yield only a little, above 10 ppm reduced yield. The interaction between Mn and Fe is reiterated by Mc Hargue (1945) that when a plant is deficient in Mn, there is toxic level of Fe and if Mn concentration is high Fe becomes deficient and suggested that Mn oxides oxidized Fe II to Fe III in rice soils.

CHAPTER TWO

MATERIALS AND METHODS

2.1.0. Description of the soils

Two soil series from the Accra Plains were used in this study (a) Akuse (b) Amo. Sampling of the soils was done at 0-15 cm in uncultivated land Both soil series have been used to some extent for the growing of rice.

2.1.1. Akuse series

Akuse series is the major soil of the Tropical Black clays (Vertisols). The origin is sedementary It is associated with basic rocks developed from locally transported weathered products of garnetiferous hornblende gneisses found at depths greater than 76 cm. It contains varying amounts of calcium carbonate concretions between 45 to 70 cm depth in the profile. There could be iron-stone or MnO_2 concretions throughout the profile (Brammer, 1967).

The vegetation is medium grassland with Panicum maximum Dur. and Sch. and Sporobulus pyramidalis

Beauv in the area.

Akuse soil series is dark grey to black in colour. It is heavy and plastic when moist, and on drying it becomes compact, nutty and cloddy in structure cracking widely from the surface. It is well drained externally but poorly drained internally.

The Amo soil series

The Amo soil series is the Savanna acid gleisols (Inceptisols) of the Accra Plains.

This soil series is well developed in fine textured alluvial deposits of the river Volta. It is believed to have been transported and redeposited on the flood plain savanna under silk cotton and palm tree.

The Amo soil series is yellowish in colour and rather silty progressing downwards to yellow brown mottled grey, red porous light clay. It becomes waterlogged and often flooded during the wet season but it dries out thoroughly during the dry season and becomes very loose but compact with depth (Brammer, 1967).

2.1.2 Preparation and storage of soil samples

Akuse and Amo series samples were collected from uncultivated sites. The soils were spread out on plastic sheets on work benches in the green house. Undecomposed plant material was removed. The Amo soil series was left to dry at room temperature for one week and the Akuse for three to four weeks as it was moist when received.

The air-dried soils were pounded lightly in a mortar with a pestle and passed through a 2 mm sieve to get the fine earth fraction for growing rice and for analytical work. The fine earth fraction from each soil was thoroughly mixed to facilitate homogeniety.

2.2.0 Chemical characterization of the soils

Each property was tested in three replications of each soil.

pH

The pH of the soils was measured in

(a) Water

Twenty gram of soil sample were put into 50 ml beakers. Twenty millilitres of distilled water were added to this and stirred several times during a period of 30 minutes. The soil suspension was then allowed to stand for about an hour for most of the suspended clay to settle. The pH was read with a Fisher Accument Model 320 pH meter.

(b) Calcium chloride

The pH of the soils were measured in the ratio of 1 soil : 2, 0.01 M $CaCl_2$ solution using a Fisher Accument Model 320 pH meter.

Cation Exchange Capacity

The method by Bascomb (1964) was used for the determination of cation exchange capacity of the soils. Five gram of fine earth fraction were weighed into polythene extraction bottles. The weight of the bottle plus soil was noted (W_1g). Buffered barium chloride solution at pH 8.1 was prepared by mixing equal volumes of triethanolamine and 2 $\underline{N}$ $BaCl_2$ solution. The pH of the triethanolamine was adjusted with 2$\underline{N}$ Hydrochloric acid.

Two hundred millilitres of the buffered solution were added to each soil and allowed to stand overnight. They were centrifuged at 1500 r.p.m. for 15 mins and the supernatant liquid discarded. They were shaken with 200 ml of distilled water for a few minutes to break up the soil cake, centrifuged and the supernatant liquid again discarded. The weight of the bottles and contents were noted (W_2g). A 100 ml of 0.05 N magnesium sulphate solution was pipetted into each bottle stoppered and shaken occasionally for a period of two hours. After centrifuguing the clear liquid was transferred into reagent bottles.

To 5 ml aliquot of the solution, 6 drops of 2N ammonia and 2 drops of catechol violet indicator were added and the mixture titrated with standard EDTA solution (titre A_1 ml).

In order to correct the titre (A_1) for the effect of the volume of liquid retained by the centrifuged soil after the washing, the following relationship was used. The corrected titre (A_2) = A_1 $(100 + W_2 - W_1)/100$ ml.

Organic Carbon and Organic Matter

The organic carbon in the soils was determined by the modification of the wet oxidation method of Walkley and Black (1934) and Walkley (1946).

Two gram of soil were put into a 500 ml Erlenmeyer flask with 10ml portion of N potassium dichromate, and 20 ml of concentrated $H_2 SO_4$ were added to the soil. The flasks were swirled to make sure that the solution was in contact with all the particles of soil and allowed to stand on asbestos sheet for 30 minutes. A volume of 200 ml of water and 10 ml of H_3PO_4 were put into each flask and the mixture titrated against 0.2N iron II ammonium sulphate. From the result the per cent of carbon and organic matter were calculated.

Total Nitrogen

This determination was done by the method of Bremner (1960) being modification of Kjeldahls method.

Ten gram of the fine earth fraction of each air dry soil sample were put into 300 ml Kjeldahl flasks. The following were added: a few millilitres of water to moisten the soils, 20 ml of concentrated H_2SO_4 and a scoop of digestion acceleration mixture. The mixture was digested for at least two hours or until the digest was clarified. The digest was cooled and transfered with distilled water into a 250 ml volumetric flask and the liquid made up to volume. A 5 ml aliquot was distilled in a Markham apparatus with 20 ml of 40 per cent NaOH and the distillate collected in 5 ml of 2 per cent boric acid. Three drops of a mixture of indicators were added and the distillate titrated with 0.001 N hydrochloric acid. From the result, the percentage of nitrogen per gram of soil was calculated.

Free Iron Oxide

The amount of free iron oxide present in soils was estimated by the method of Jackson (1956).

Five gram of soil were put into 100 ml centrifuge tube for each replicate. Forty millilitres of 0.3 M sodium citrate solution and 5 ml of 1 M sodium hydrogen carbonate solution were added to the soil. The tubes were put in a hot water bath till a thermometer inserted into each registered 70 - 80 °C. One gram sodium dithionite was put into each tube and the mixture stirred constantly for 1 minute and then occasionally for 15 minutes. Ten millilitres of saturated solution of sodium chloride were added to flocculate the mixture. It was then cooled and centrifuged for 10 - 15 minutes at 1600 rpm. The clear supernatant liquid was decanted into a 500 ml volumetric flask. The steps from the addition of the citrate to the centrifuging were repeated once to ensure that all the iron oxide was removed, and the supernatant once more added to the original volumetric flask. The sediment was washed twice with a mixture of sodium citrate and sodium chloride. The combined washings of each soil were brought to 500 ml volume with distilled water separately and then they were analysed for iron by the colorimetric orthophenanthroline method and hence for the percentage Fe_2O_3 in the soil.

Exchangeable bases

Ten gram sample of the fine earth fraction were shaken in an extraction bottle with 100 ml of N NH_4OAC solution for one hour. The mixture was centrifuged for 20 minutes and the supernatant filtered through Whatman No. 42 filter paper. Aliquots of the extract were used for the determination of Ca, Mg, and potassium. Calcium and magnesium were determined by titration with EDTA according to Moss (1961) and potassium and sodium using the Evans Electro-selenium flame photometer.

Exchangeable iron

The method of Olson (cited by Black *et al.*, 1965) and Jackson (1956) were adopted for the determination of exchangeable iron in the soils.

Twenty five gram of the fine earth fraction were put in a 300 ml extraction bottle and 250 ml of neutral 1N NH_4 OAC were added. The flask was stoppered and shaken (on a mechanical shaker) for 30 minutes. It was centrifuged, filtered with Whatman No.42 filter paper and aliquots used in the colorimetric determination of exchangeable iron in ppm of soil.

Exchangeable and water soluble manganese

Exchangeable and water soluble Mn were determined according to the methods of Sherman *et al.* (1942) and the colorimetric determination according to Willard and Greathouse (1917).

Thirty five millilitres aliquot of the extractant prepared for iron above were used for the colorimetric determination of exchangeable Mn in ppm of soil.

Particle size analysis

The modification of Bouyoucos Hydrometer method by Day (1950) was used in the mechanical analysis of the soils.

Forty gram of each soil sample was dispersed with a mixture of water and calgon and a corresponding amount of soil used to find the oven dry weight. Each soil calgon mixture was brought up to a volume of 1000 ml in a sedimation cylinder and moved to a constant temperature room together with a similar cylinder with distilled water and calgon only till the temperature was constant. The mixture was agitated with a plunger and hydrometer readings taken at 5 minutes, 2 hours, 5 hours, and 10 hours. The suspension was then passed through a 47/45 micron sieve, the residue washed thoroughly oven dried and weighed. From the results, the percentage of sand, silt and clay fractions were found.

Extraction of Phosphorus

The method of Olsen *et al.* (1954) was used for most of the work.

To 5g of the fine earth fraction 100 ml of 0.5M sodium hydrogen carbonate at pH 8.5 were added and the mixture shaken for 30 mins, centrifuged and filtered. Aliquots of the filtrate were used to determine the available phosphorus colorimetically in ppm of soil using ammonium molybdate solution and $SnCl_2$.

All colorimetric readings were taken with Bausch and Lomb Spectronic 20.

The chemical properties of the soil series used in this investigation are presented in table 1. The pH of the soil series in 1:2 soil and 0.01M Calcium chloride ratio were 6.8 for Akuse series and 5.5 for Amo series. The pH of 6.8 for Akuse series may be described as slightly acid to neutral whilst that of 5.5 for Amo series as moderately acidic.

The textural classification for each of the soil series is clay loam. The percentage clay content determined by mechanical analysis hydrometer method was 46.4 per cent and 21.2 per cent for Akuse and Amo soil series respectively. This reaffirms the conjecture that Amo soil series is highly weathered. The cation exchange capacity (CEC) of any soil is related to its clay content. The CEC of Amo series was 8.1 me/100g and that of Akuse soil series was 37.36 me/100g soil.

The absorption complex of Akuse series contained 22.34 me of Ca and 6.6 me of Mg/100g soil. This soil sample has

TABLE 1 CHEMICAL CHARACTERISTICS OF OF THE SOILS (OVEN DRY BASIS)

	AMO Series	AKUSE Series
pH in $CaCl_2$	5.5	6.8
pH in Water	6.5	7.5
% Clay	21.2	46.4
% Nitrogen	0.114	0.097
% Carbon	0.72	0.92
% Organic Matter	1.25	1.59
Ca me/100g	4.06	22.34
Mg me/100g	1.64	6.60
K me/100g	0.043	0.031
Na me/100g	0.0099	0.038
Fe ppm	11.74	3.84
Fe ppm	106.5×10^2	56.93×10^2
% Fe_2O_3	1.52	0.813
P ppm	15.04	3.23
Mn ppm.	527.6	384.6
CEC me/100g	8.1	37.36

not been saturated with Ca as could be expected (Brammer, 1967), In Amo soil series the amount of Ca was 4.06 me and 1.64 me of Mg. Potassium and Na values were low. However, K was slightly greater in Amo than Akuse soil series whereas Na was less in the former. The annual rainfall in the savannah area is between 45 and 55 inches. Such rainfall moderately leach soils. Consequently soil series such as Amo with alluvial origin lose a great amount of the more soluble compounds including the bases, hence lower calcium and magnesium values and lower CEC than Akuse soil series. As a result in such soils there are higher values of more resistant compounds such as iron and manganese oxides.

When the more basic rich rocks weather, particularly under moderate rainfall, montmorillonite is likely to be formed in Akuse series. But where the rainfall is a little heavier and the rocks not so basic, the dorminant clay mineral is usually kaolinite as in Amo series with some high charge montmorillonite (Oteng, 1976). Thus 1.52 per cent of free iron oxide was found in Amo series compared to 0.813 in Akuse series and 527.6ppm of exchangeable manganese in the former compared to 384.6 ppm in the latter.

Experimental results of organic matter are in the order of 1.25 and 1.59 per cent for Amo and Akuse soil series respectively, though Brammer (1967) stated that Amo soil series is moderately well provided with organic matter, whilst Akuse soil series is not. The nitrogen content in each soil series is low, 0.114 per cent in Amo series and 0.097 per cent in Akuse series.

The available P values determined by Olsen _et al_ (1954) were 15.04 ppm and 3.23 ppm for Amo and Akuse soil series respectively. Akuse soil series is derived from basic rocks such as igneous rocks which frequently contain apatite. But Amo soil series are well provided with nutrient because of the admixture of Black clay alluvium from Okwe colluvium wash and bases rich drainage water coming down from the Black clays on the adjoining slopes (Brammer, 1967).

From these results obtained above it appears that with the exception of potassium, phosphorus, iron and manganese, Akuse soil series has more nutrient and organic matter than Amo soil series. And, together with higher CEC and clay content of the former, a possibility arises that Akuse soil series has as much potential if not better for the production of rice than Amo soil series.

2.3.0 Greenhouse Pot Culture Experiments

2.3.1. Preparation of the seedlings, treatments and transplanting

The rice seeds grown were 112 day IR 30 variety, used in field tests at the WARDA station in Liberia. This was chosen because it is a dwarf variety resistant to lodging, disease, pests and convenient to grow in pots in a greenhouse. The growth too was just long enough to complete sampling just before the plants were mature.

Rice seeds were sewn in six plastic containers of sand in the green house. They were treated with Hoagland and Arnon (1950) complete nutrient solution by daily additions of this mixture till the end of the second week of growth.

One kilogram soil sample from the fine earth fraction of Akuse soil series was put into each of 144 pots and repeated for Amo soil series. The total of 288 pots were arranged in rows of eighteen on the benches in the green house with the two soils separated.

There were four treatments of triple superphosphate (45 per cent P_2O_5) with zero kg/ha (P_0), 22kg/ha (P_1), 44 kg/ha (P_2) and 66kg/ha (P_3) of phosphorus (P). At the same time the fertilizer was applied, 89.75 kg urea/ha and 22.44 kg/ha muriate of potash were used as dressing in all the pots. There were 36 replicates at each phosphorus level for each of Amo and Akuse soil series arranged in rows of eighteen according to treatment.

The two weeks old seedlings were well washed in distilled water and four were transplanted into each pot. Starting with the row of eighteen pots with Amo soil series at zero level of P alternate rows were planted with rice seedlings to which 850 ml of distilled water were immediately added. The same amount of water was put in the rest of the pots with no rice. This arrangement was such that 18 replicates of soil with one level of P treatment had rice and a corresponding eighteen had no rice. All 288 pots were waterlogged to the same height of $2\frac{1}{2}$ cm throughout the experiment by daily additions of distilled water. All pots had adequate amount of light and air in the green house.

2.3.2. Harvesting of the Plants

This was done at the following times, first, second, third, fifth, sixth and eighth weeks after transplanting/submergence of rice seedlings. Shoots were cut above soil level in 24 pots. Three replicates of each treatment from each soil series were washed in distilled water and put into separate labelled envelopes. They were oven dried at 80°C for 24 hours and kept in dessicators. They were weighed, ground and kept once more in dessicators. The dry matter yield are recorded in appendix 11a and b.

2.3.3. Sampling

At the same time as the plants were harvested, the supernatant liquid from the pots as well as that from the corresponding three pots without rice all chosen at random, were filtered using Whatman No.42 filter paper into labelled polythene bottles and stored in a refrigerator, a total of forty eight bottles each week of sampling.

2.3.4. The wet soil

The corresponding wet soil from the above were well drained of supernatant as much as possible, then thoroughly mixed, some put into labelled plastic bags and some air dried in plastic plates. The ends of the bags were tied to prevent them spilling and the bags kept in a cold room or refrigerator.

2.4.0 Laboratory Analysis of the Samples

2.4.1 Analysis of the supernatant liquid

pH.

The pH of the supernatant liquid was taken within five hours of sampling. The data are recorded in appendix 13a and b.

Determination of nutrient in the Supernatant

Phosphorus

The concentration of phosphorus was determined by Watanabe and Olsen method (1965).

Forty millilitres aliquot of liquid was measured from each supernatant of each of the twenty samples from each soil series into separate labelled 50 ml volumetric flask arranged according to treatment. Distilled water was added to each up to a volume of about 40 ml. One drop of para nitrophenol indicator was added, the pH adjusted with 4 N NH_4OH and the blue colour seen when 5 ml of 0.05M solution of ascobic acid, 5 ml of ammonium molybdate and antimony tartarate mixture in Sulphuric acid were added.

The percentage transmission of the solutions were read at a wavelength of 882mu in the Bausch and Lomb Spectronic 20 after adjusting the galvanometer to read 100 per cent transmission with a blank solution containing all the reagents. The calibration curve was prepared by using 0, 5, 10, 15, 20, 25, 30, 35, and 40 ml. aliquots of a solution that contained 1 ug of P per ml. The soluble P was then calculated in ppm of soil. The data are recorded in appendix 1a and b then transformed for statistical analysis as shown on page 79.

Manganese

Water soluble manganese was determined according to the method of Sherman *et al.* (1942), and Willard and Greathouse (1917).

Aliquots of 40 ml of supernatant liquid were pipetted into separate Kjeldahl flasks from the set of weekly samples and heated to dryness. To the residue 5 ml of concentrated HNO_3 and 2 ml of 30 per cent hydrogen peroxide were added. Each flask was swirled to mix the liquids and heated for 30 minutes to destroy organic matter. It was then heated to dryness. After cooling the flask 20 ml of water, 2ml of concentrated HNO_3, 5ml of 85 per cent orthophosphoric acid and 0.3 g of KIO_4 were put into the flask to develop the colour. After heating for 5 minutes longer, the solution was transferred into 50 ml volumetric flask and brought up to the mark with distilled water.

The calibration curve was prepared using 0, 5, 10, 15, 20, 25 and 30 ml aliquots of a standard stock solution which contained 0.01 mg of manganese per ml. The transmittances were read in a Bausch and Lomb 'Spectronic 20' colorimeter after standardizing the instrument to read 100 per cent transmission with a blank solution at 540 mu wavelength. The Mn was calculated in ppm of soil. The data are recorded in Appendix 2a and b, then transformed for statistical analysis as shown on page 79.

Iron

The method by Jackson (1958) for exchangeable iron and the unpublished method by Olson (published by Black *et al.*, 1965) were used in the determination of iron in the supernatant liquids.

Forty cubic centimetre aliquot of supernatant samples were put into Kjeldahl flasks and heated to dryness. Ten millilitres of aqua regia were added to each residue and the solution again evaporated slowly to dryness. The residue was then heated with 3.5 ml of N HCl and the sides of the flasks washed with water to complete the dissolution of the residue.

The solution was then transferred into 50 ml volumetric flask using water to rinse the flask, and 2 ml of 5N NH_4OAc, 1 ml of 10 per cent hydroxylamine hydrochloride, and 1ml orthophenanthroline reagent were added. The solution was diluted to volume and the pH checked and ensured to be between 3 and 5. A blank was run simultaneously beginning with the same amount of neutral N NH_4O AC. The ppm of the iron in the test solution and the blank were determined and hence the exchangeable iron in the soil (Jackson, 1958).

A 5 ppm standard solution was used to determine the calibration curve, by measuring 0, 5, 10, 15, 25, 35, and 45 ml portions into separate 100 ml volumetric. To each, 2 ml of 10 per cent hydroxylamine hydrochloride, and 2 ml of orthophenanthroline reagent were added, followed by 1 N NaOAc solution dropwise until a permanent orange red colour developed. Three more ml of the Na ethanoate solution were further added and the liquids brought up to the mark with distilled water (Black *et al*, 1965).

The percentage transmittance was read in a Bausch and Lomb 'Spectronic 20' colorimeter at 510 mu wavelength after setting the galvanometer to read 100 per cent light transmission with distilled water. The Fe was calculated in ppm of soil. The data are recorded in Appendix 3a and b and then transformed for statistical analysis as shown on page 79.

2.4.2. Analysis of the Plant Material

Digestion of the Plant Material

The procedure used was that developed by Black (1957).

Accurately weighed samples of the plant of two gram or less of the ground material were put into 300 ml dry Kjeldahl flasks. To each 15 ml of concentrated acid were added and the mixtures heated gently. Two blanks were prepared with just 15 ml of concentrated nitric acid and carried through the same processes as the samples. The heating was continued until the reaction ceased. The flasks were then heated until, the contents were almost dry without charring. On cooling 10 ml of 8 N nitric acid and 10 ml of 70 per cent perchloric acid were added and the heating continued until there was no visible sign of organic matter in the flasks. After cooling, the insides of the flasks were washed with a stream of water to get all the contents to the bottom of the flask and the solution once more slowly heated to dryness. Fifteen millilitres of 2N HCl were added to the residue and the contents heated for 10 minutes to dissolve the salts. They were then well shaken and filtered through Whatman No.541 filter paper into 100 ml volumetric flasks. The flasks were rinsed several times and the filter paper at least 6 times with distilled water and the washings added to the solution in the volumetric flasks. The flasks were allowed to cool to room temperature before bringing the volumes up to the mark.

Determination of nutrient in the plant Material

Phosphorus

The method of Black (1957) was used to determine the amount of P in the plant material.

An aliquot of 20 ml of diluted digest of plant material and blanks were pipetted into separate Kjeldahl flasks. Five millilitres of 2N HNO_3 were added to each solution and the contents evaporated to dryness. Five milliliters of 0.1N HNO_3 were pipetted onto the residue in each flask after cooling. The flasks were swirled several times in 10 minutes and the liquids transferred into 25 ml volumetric flasks. The Kjeldahl flasks were rinsed a few times and the liquids added to that in the volumetric flask and brought up to the mark with distilled water. The solutions were transferred into 50 ml volumetric flasks. The 25 ml flasks were rinsed once with 5 ml of water to make a total of 25 ml of water used. This was then added to that in the 50 ml flasks.

Five millilitres aliquot of diluted solution from each flask were then pipetted into separate second set of 50 ml volumetric flasks. To each 20 ml of water and 10 ml of molybdate vanadate solution were added from a pipette and the resulting solution mixed thoroughly and brought up to volume (Juo, 1978) to develop the colour.

To calibrate the colorimeter 5 ml laliquot of 3, 5, 8, 10, 15, 20, 30 and 50 ug of standard phosphorus solutions per ml were pipetted into separate 50 ml volumetric flasks (Black, 1957) the colour developed as in the samples above, and the solutions brought up to the mark with distilled water. After one hour, the transmittancy of the samples and standards were read in the Bausch and Lomb 'Spectronic 20' colorimeter at a wavelength of 400 mu after setting the galvanometer to read 100 per cent transmission with the blank prepared (Juo, 1978). The P was then calculated as percentage of plant material.

Manganese

Manganese in the plant material was determined according to Black (1957).

Twenty millilitres aliquot of diluted digest and blank were pipetted into separated 300 ml Kjeldahl flasks. Ten millilitres of concentrated HNO_3 acid were added to each of the solutions boiled for a few minutes and then evaporated to dryness. The following were added to the residue, 25ml of water, 2.5 ml of concentrated H_2SO_4, 0.1 g of KIO_4 and the mixture boiled for five minutes to develop the perman-ganate colour. After cooling the coloured solutions were transfered into 50 ml volumetric flasks and diluted to volume with distilled water that contained 0.5g of KIO_4 per litre. The transmittancy was immediately measured at wave-length 520 mu after setting the galvanometer to read 100 per cent transmittancy with the solution containing no Mn in a Bausch and Lomb 'Spectronic 20'.

The calibration curve was prepared using the same colorimetric method described in section 2, 4, 1 for Mn with 0, 2, 4, 6, 8, 10, 12 ml of a 10 ppm Mn standard stock solution. The Mn content in ppm per gram of plant was then calculated for each pot of plant harvested.

Iron

Iron in the plant material was determined according to Black (1957).

A pipetted volume of 20 ml aliquot of diluted digest of plant material and the blank were put into separate 50 ml volumetric flasks. Fifteen millilitres of NaOAc ethanoic acid mixture were pipetted into each flask. One millilitre each of 10 per cent hydroxylamine hydrochloride and 0.3 per cent orthophenanthroline solution was added to the resulting solution in the flask and swirled. The solutions were brought up to the mark with distilled water.

The colorimeter was calibrated by pipetting aliquots of 1, 2, 3, 5, 7, 10, 15, 20 ml of 5 ppm standard stock Fe solution into separate 50 ml volumetric flasks to which 0.75 ml of 2 N HCl was added. The reddish brown colour of the standard solution was developed using the same procedure as the samples and blanks. The percentage transmission of all the solutions was read at wavelength 520 mu after adjusting the galvanometer to indicate 100 per cent transmission with distilled water. The iron in the plant material was then calculated in ppm of plant material. The data for P, Mn and Fe are recorded in appendix 8, 9 and 10 respectively.

2.4.3. Analysis of the Wet Soil

Determination of the mass of the wet soil

The wet soil from each bag was thoroughly mixed and small amounts put into separate crucibles that had been labelled and weighed. The mass of the wet soil plus crucible was found. Ten gram of the fine earth fraction of the corresponding wet soil sample that had been left to air dry and kept in tightly fitted screwtop bottles were also put into weighed crucibles. Both sets of wet and air dry soils in crucibles were left to dry in an oven for 24 hours at a temperature of 105°C and afterwards cooled in a dessicator and weighed again. Thus the amount of wet soil samples equivalent to 10 g of air dry soil was determined for each individual sample.

Manganese and Iron in Wet Soil

Wet soil samples equivalent to 25 g of air dry soil were weighed into separate 250 ml extraction bottles. Two hundred and fifty millilitres of neutral N NH_4O Ac solution were added to each weighed sample, shaken for 30 minutes, centrifuged and filtered with Whatman No.42 filter paper.

Twenty five millilitres aliquot of this extractant were used in the determination of extractable Mn and Fe as was done in section 2, 4, 1. The data are recorded in appendix 5 and 6, then transformed for statistical analysis as shown on page 79.

pH of Wet Soil

Wet soil samples equivalent to 20 g of air dry soil were weighed into separate plastic bottles. Forty millilitres of 0.01 M $CaCl_2$ solution were added to each bottle. The mixture was swirled intermittently during a period of 30 mins, poured into 100 ml labelled beakers and then allowed to stand for an hour. The pH was read in a Fisher 'Accument Model 320' pH meter. The data are recorded in Appendix 12a and b.

Redox potential and Specific Conductance

No redox potential or specific conductance measurement was made because the facilities were not available.

2.5.0. Transformation of data

Because the control values for each replicate data relating to P, Mn Fe respectively in the wet soil and supernatant were different, each datum was transformed to obtain a more workable scale data and maintain independence of experimental error (S). The transformation was performed as follows :- For zero level of P treatment (P_o) in week 1 for Amo soil series supernatant P the replicate data are 1.51, 4.62 and 4.62. The corresponding control values are 3.05, 2.27 and 2.67.

Mean = 2.66.

Transformed value of 1st data i.e. 1.51 is 2.66 - 1.51 = 1.15
" " " 2nd " 4.62 is 2.66 - 4.62 = 1.96
" " " 3rd " 4.62 is 2.66 - 4.62 = 1.96

The Transformed values are recorded in Appendix 4 and 7 for supernatant and wet soil respectively.

Statistical Analysis

The appropriate values were subjected to three way analysis of variance (ANOVA) performed by a Wang Computer using the WARDA program. Data were considered significant at 5 and 1 per cent levels.

CHAPTER THREE

RESULTS AND DISCUSSION

3.1.0. Changes in pH values in Flooded Soils

3.1.1. Changes in pH with time in the supernatant liquids

The initial pH of Amo series was 6.5 in 1:1 soil/ water ratio. The average pH of the supernatant from the submerged Amo soil series of all the treatments increased on waterlogging to between 7.5 and 8.3 pH units in the first week (Fig.1a). Those cropped with rice had slightly higher values in the first week than those with no rice. The former decreased in value after the first week, but the values were still higher than the initial pH. The pH of pots without rice continued to rise till about the fifth week and then decreased.

The initial pH of the Akuse series was 7.5 in 1:1 soil/water ratio. On flooding the soil, the average pH of the supernatant liquids in all the treatments, (Fig. 1b) except that of the P_3 level rose to a maximum in the third week and then decreased. Those of the P_3 level with and without rice rose to a maximum in the fifth week before there was a decline.

Increase in pH under submergence has been reported by Jeffery (1960), Rodrigo (1962), Ponnamperuma (1965), Kar, Hussain and Dhua (1977). Of these workers only Rodrigo (1962) specifically mentioned the pH of the supernatant. He found that the pH increased and reached a constant value after 24 weeks of submergence of uncropped soils. Ponnamperuma (1965) also illustrated graphically changes in pH of soils kept under submergence but not cropped with rice. His results showed that the pH was constant after about 22 weeks of submergence. Whilst Kar, Hussain and Dhua (1977) had increase in pH after flooding with values becoming constant after sixty days of submergence. The measured average pH values in this investigation for the supernatant liquids plotted against weeks of submergence (Fig. 1a) for uncropped Amo series and (Fig. 1b) for cropped and uncropped Akuse series show increase in pH to a maximum of between 8.2 and 8.3 pH units after 3 weeks in Akuse soil and 5 weeks in Amo soil series. These graphs do not approach a constant value as reported by Shapiro (1958a), Rodrigo (1962) and Ponnamperuma (1965). This may be because

Table -2 MEANS OF pH OF SUPERNATANT LIQUIDS

(a) AMO Series

Treatment	Week 1	2	3	5	6	8
P_o R	7.9	7.3	7.0	6.9	6.8	6.9
P_oNR	7.7	7.7	8.1	8.2	7.6	6.9
P_1 R	8.0	7.3	7.0	7.0	6.8	7.1
P_1NR	7.8	7.6	8.1	8.2	7.3	6.9
P_2 R	8.0	7.2	6.8	6.8	6.5	7.0
P_2NR	7.9	7.6	8.1	8.3	7.5	6.9
P_3R	7.9	7.4	6.8	7.6	6.9	7.0
P_3NR	7.7	7.8	8.1	8.4	7.4	7.0

(b) AKUSE Series

P_o R	7.7	8.2	8.3	8.2	7.5	6.9
P_oNR	7.9	8.3	8.3	8.3	7.7	7.1
P_1 R	7.6	8.2	8.4	8.2	7.8	7.0
P_1NR	7.8	8.1	8.5	8.4	7.9	7.3
P_2 R	7.7	8.1	8.3	8.0	7.5	6.9
P_2NR	7.5	8.0	8.4	8.3	7.8	7.2
P_3 R	7.5	8.1	8.2	8.2	7.1	7.0
P_3NR	7.6	8.1	8.3	8.4	7.7	7.2

R - pots with rice NR - pots with no rice the experiments did not go on as long as those of these workers. The increase could be associated with reduction of the soil, and its course may have been determined by the initial pH of the soil, the nature and content of oxidized soil components, and the kind and content of organic matter (Ponnamperuma, 1965).

In (Fig. 1a) Amo soil series cropped with rice, the average pH values of the supernatant liquids for all four levels of P application attained a maximum within the first week of flooding and decreased approaching more or less the same value by the eighth week. The lowest average value was still higher than the initial pH value of Amo soil in 1:1 soil/water ratio . These are in line with results obtained by Olomu _et al_. (1973) for uncropped soils. The initial pH of Amo was a whole pH unit lower than that of Akuse series, but they attained almost the same maximum pH. The lower the pH of the soil before flooding, the greater the observed increase in pH (Tomlinson, 1957; Moorman, 1961; Ponnamperuma, 1965). The decrease in pH of the supernatant liquids of Amo series cropped with rice after the first week of submergence was due to either an increase in acidity or a decrease in alkalinity of the medium. The increase in acidity could have been due to increase in production of carbon dioxide or organic acids, from mineralization of organic matter. But Amo series is low in organic matter. The decrease in alkalinity could have been caused by removal of calcium ions by precipitation (Bradfield, 1941; Ponnamperuma, 1965). Analysis of the wet soil extract however did not reflect any increase in Ca content after waterlogging. It may well be, that the pH of this Amo soil was regulated by the Fe $(OH)_2 - CO_2 - H_2O$ equilibrium because of its high active iron content. (Ponnamperuma, 1965). The Amo series has neither high CEC nor high organic matter content. Hence the buffer capacity of the soil must influence the relative change in pH when the soil is reduced (Olomu <u>et al.</u>, 1973).

There were no marked differences during any week (table 2b), in the pH between the different treatments in the supernatant liquids from Akuse soil series, throughout the period of experimentation. pH values of the supernatant liquids of Amo soil series with rice were higher in the first week of submergence than those without rice. The former reduced whilst the latter increased to a maximum before decreasing to approximately the same values as those with rice. It does appear (table 2a) that the only difference shown in the pH values of the supernatant was due to the fact that some of the pots of soil were cropped with rice and the others were not. Hence the difference in pH between the cropped and uncropped soil may have been due to the uptake of plant nutrient, exudates and CO_2 released by the roots.

pH values for the different treatments of the supernatant from Amo soil and Akuse soil series at 8 weeks after waterlogging were between 6.7 and 7.3 (table 2a & b). In experiments conducted at IRRI (1964) pH values of 6.7 to 7.2, 7 weeks after flooding were obtained for the majority of the treatments. pH of 6.5 to 7.5 has an important bearing on the nutrition of the rice plant (Ponnamperuma, 1965). A pH of 6.5 to 7.5 has been found to (a)

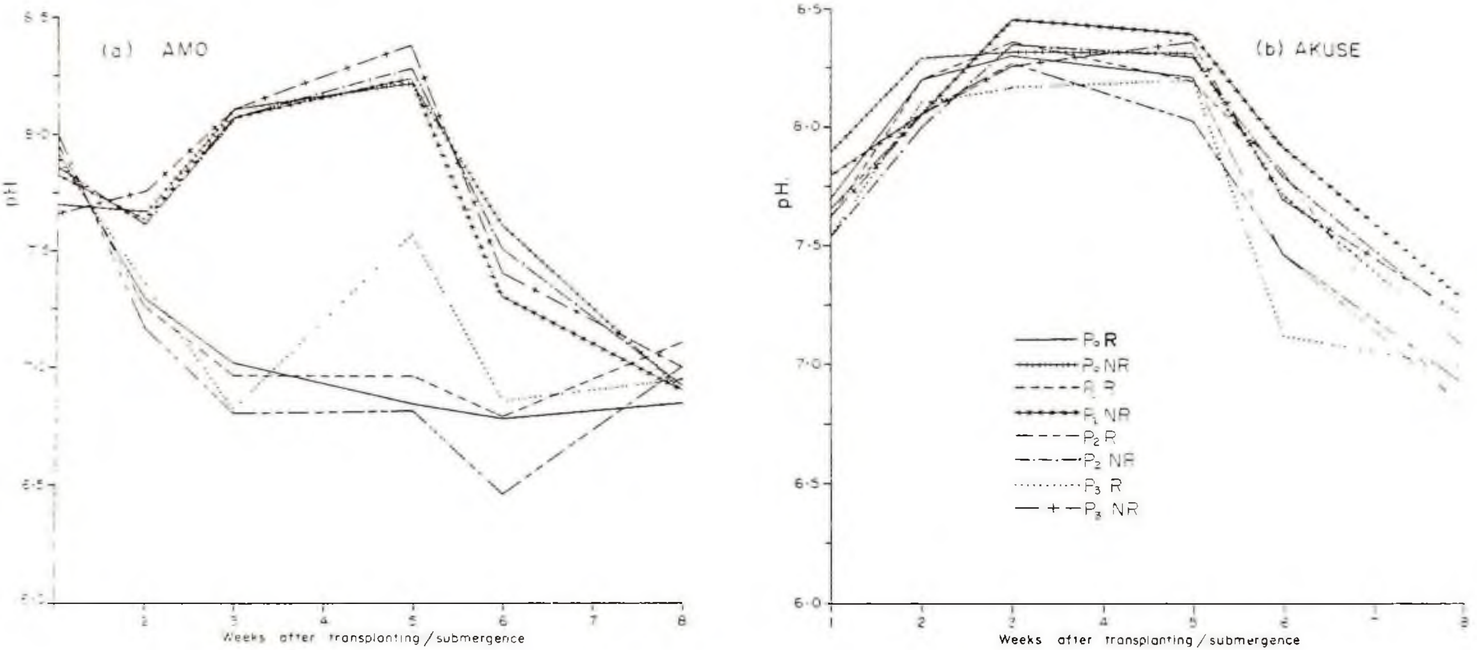


Fig 1 PH of Supernatant from flooded soils vs weeks after transplanting / submergence during Paddy growth in pot experiments carried out in the Green House

decrease the availability of P (Aoki, 1941; Tseng, 1960) (b) increase the rate of mineralization of organic matter (Mitsui, 1955) and the destruction of organic acids (Acharya, 1935), (c) decrease the concentration of CO_2, (d) decrease the concentration of Fe (Ponnamperuma, 1955) and Al (Raupach, 1963) and (e) favour denitrification (De and Sarkor, 1936; Delwiche, 1956) and perhaps sulphite reduction (Osugui and Kawaguchi, 1939).

3.1.2 Changes in pH of the Wet Soils

The initial pH of the soils in 1:2 soil/0.01 M $CaCl_2$ solution ratio were 5.5 and 6.8 for Amo and Akuse soil series respectively. There was an initial decrease in pH (Fig. 2a, table 3a) in the first week in the wet Amo series. Decrease was observed in all the P_0 and P_1 level of P treatments in the wet Akuse series (table 3b). The initial decrease was no doubt the result of accummulation of CO_2 produced by respiration of aerobic bacteria. (Ponnamperuma, 1965, 1972) and the production of organic acids (Motomura, 1962a). The subsequent increase to a maximum three weeks

TABLE -3 MEANS OF pH OF WET SOIL

(a) AMO series

Treatment	Week 1	2	3	5	6	8
P_o R	5.2	5.5	5.7	5.6	5.5	5.7
P_oNR	5.3	5.6	5.6	5.7	5.7	5.7
P_1 R	5.2	5.6	5.6	5.7	5.7	5.8
P_1NR	5.1	5.8	5.9	5.7	5.9	5.8
P_2 R	5.5	5.7	5.8	5.5	5.8	5.8
P_2NR	5.2	5.9	5.8	5.7	5.8	5.8
P_3 R	5.2	5.8	5.9	5.5	5.7	5.8
P_3NR	5.4	5.8	5.9	5.6	5.7	5.8

(b) AKUSE series

P_oR	6.6	6.7	7.1	6.5	6.7	6.7
P_oNR	6.7	6.8	7.0	6.7	6.9	7.0
P_1 R	6.7	6.7	7.3	6.7	6.7	6.7
P_1NR	6.9	6.8	7.2	6.6	6.7	6.8
P_2 R	6.8	6.7	7.2	6.6	6.7	6.7
P_2NR	6.9	6.8	7.2	6.6	6.7	7.0
P_3 R	6.8	6.8	7.1	6.7	6.7	6.7
P_3 NR	6.8	6.8	7.2	6.8	6.7	7.0

R - pots with Rice NR - pots with no rice

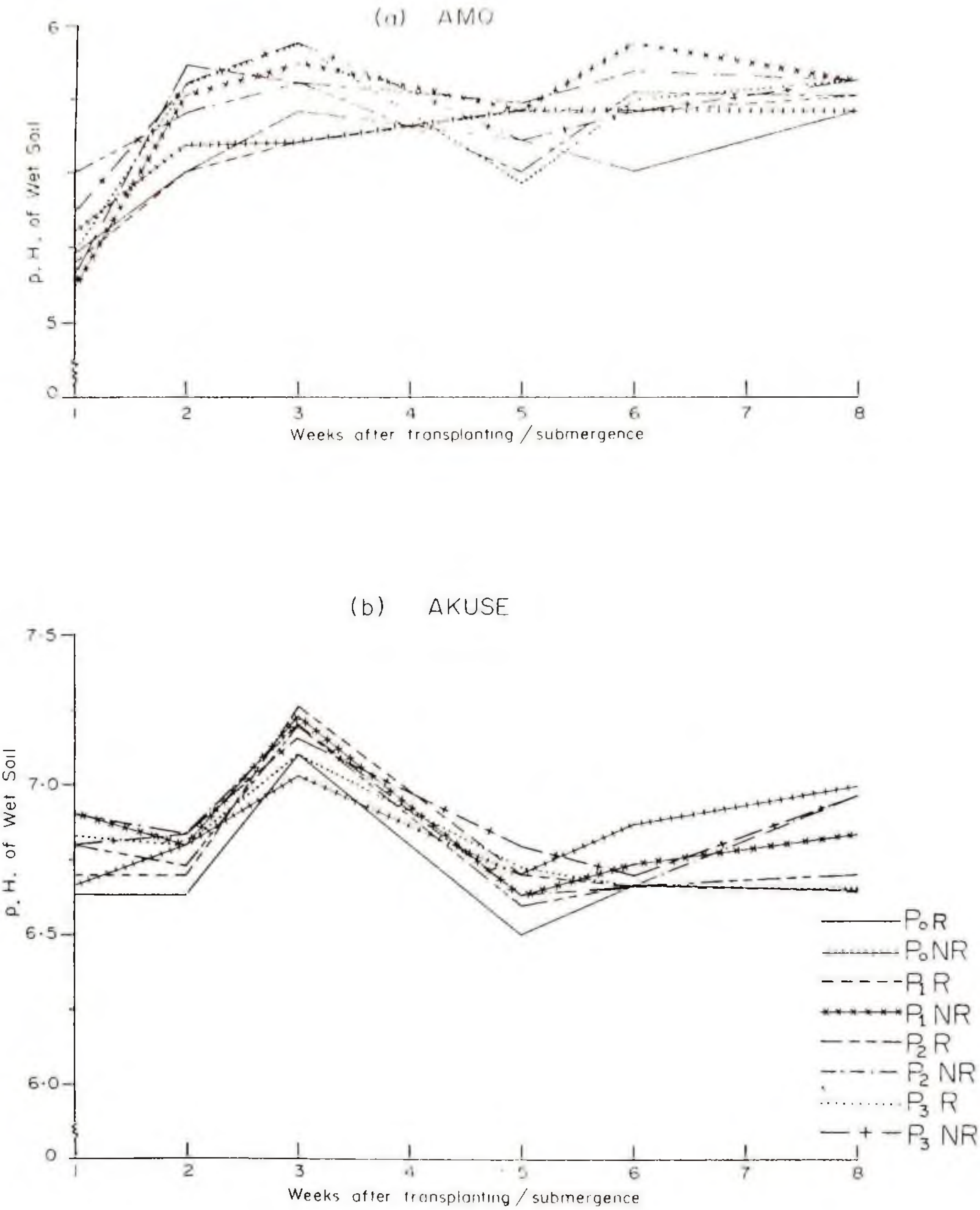


Fig 2 Changes in pH of wet soils in Calcium Chloride vs weeks during Paddy growth in pot experiments carried out in the Green House with different levels of P applications

after transplanting and flooding might have resulted in reduction of Fe in Amo series(Ponnamperuma, 1965) and possibility of $CaCO_3 - CO_2 - H_2O$ equilibrium in Akuse soil series (Ponnamperuma, 1965). The increase in pH was not pronounced in any of the soils. It became approximately constant in all treatments of the two soils from the fifth week (table 3a and b) with values of 5.7 and 6.7 in Amo and Akuse series respectively, these values are pretty close to the original pH of the soils in $CaCl_2$ solution.

3.2.0. Nutrients in the Supernatant liquids

Rice has been proved to yield abundantly under swamp conditions in the tropics. An understanding of the distribution of plant nutrient within the soil, water, plant, system is the prerequisite for the understanding of fertilizer use in paddy fields for optimum yield of rice.

An attempt has been made in these experiments to study the effect of P application on native P and its distribution within the three phases already mentioned, as well as its interaction with manganese and iron existing in the system.

3.2.1 Phosphorus in the Supernatant

The concentration of P in the solution withdrawn from the flooded soils in this investigation varied considerably in the untreated soils as well as those treated with fertilizer as found by Hossner *et al.* (1973). P solution concentration for untreated soils ranged from 0.0 to 0.036 ppm. Soils treated with fertilizer P had average solution P values of 0.0 to 0.08 ppm (Fig. 3a & b). The results indicate at the end of the first week after flooding, values of P in the supernatant liquids of all treatments (Fig. 3a and b) which increased (Shapiro, 1958a, b; Davide, 1960). Because the supernatant liquid from pots of soil with or without rice where no fertilizer P was added also had some P in solution at the end of the first week of submergence, it could be assumed that the results obtained for P in the supernatant must have been native and applied P. The results also show that with flooding not all the triple superhosphate added was available to the plants, most of it became fixed, (Bartholomew, 1931, Mitsui, 1954). The increase in the availability of native as well as added P is thought to be due to hydrolysis of aluminium phosphate and iron III phosphate (Fujiwara, 1950; Ponnamperuma, 1955; Shapiro, 1958a and Mandal, 1964), reduction of iron III phosphate (Valencia, 1962; Ponnamperuma, 1965) in Amo series and mainly solubility of calcium phosphate in Akuse series (USDA, 1957).

P concentration in supernatant in all treatments showed a general decrease either after the first or second week till the third week in Amo series and fifth week in Akuse series. This decrease in soluble P is thought to be due to reprecipitation and fixation of supernatant P (Patrick and Mahapatra, 1968; Mahapatra and Patrick, 1969). The decrease in concentration of solution P with time corroborates the findings of Hossner et al. (1973) Kar et al. (1977). The experimental results of P concentration took similar trends for both cropped and uncropped soils, (Fig. 3a and b).

Further weeks of flooding resulted in a complete change. There was generally a marked increase in the

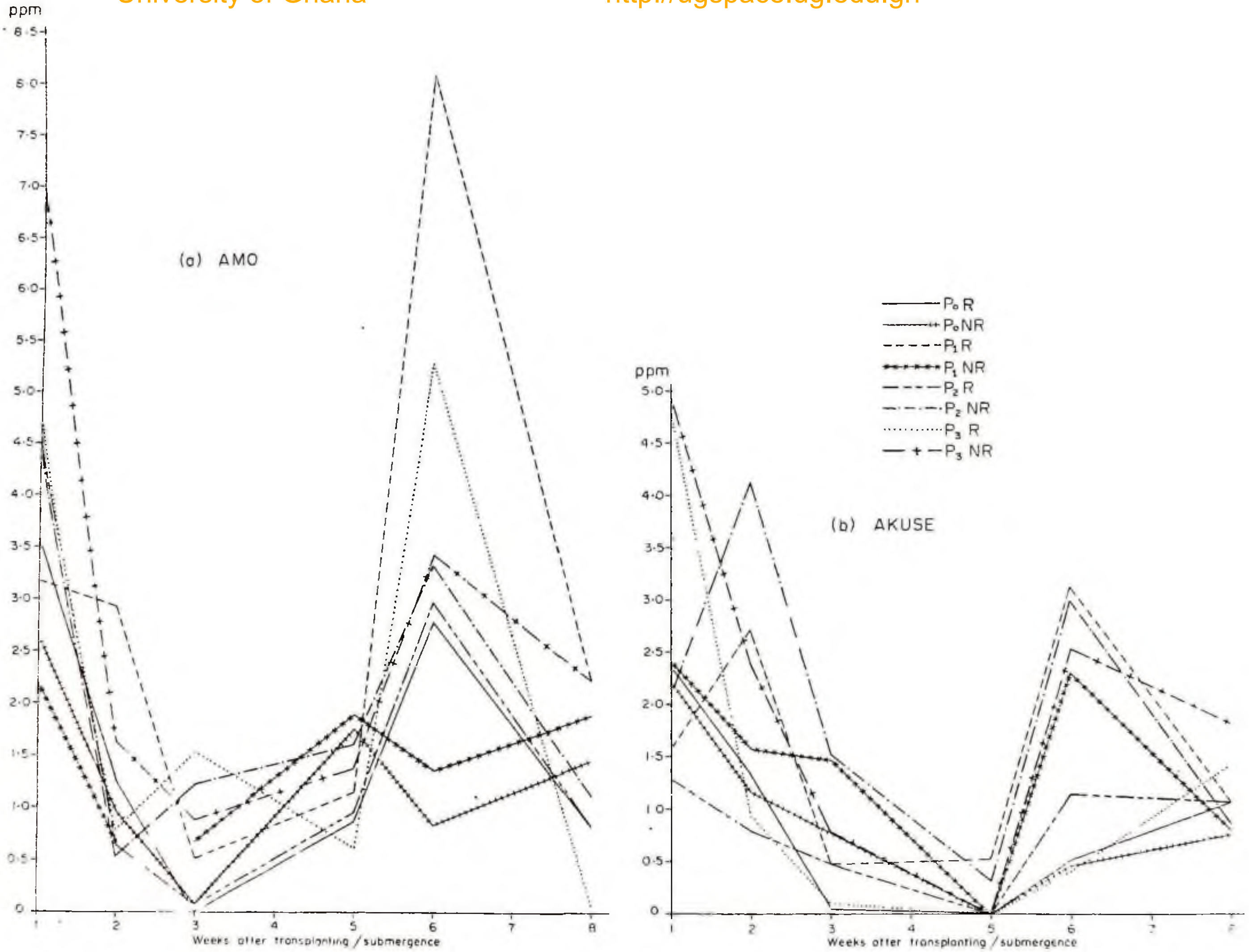


Fig 3 Phosphorus in Supernatant in ppm of soil vs weeks after transplanting / submergence during Paddy, growth in pot experiments carried out in the Green House

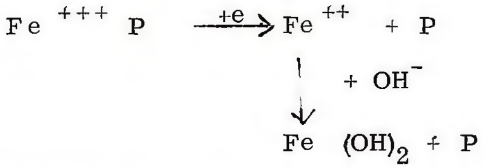
sixth week in available P concentration (Fig. 3a and b) in nearly all the treatments. P_1 treatment in both sets of cropped soils shows the highest P concentration in the sixth week of submergence. Because the increase in availability took place in supernatant from both cropped and uncropped soils, it is possible that the change in pH of the supernatant (table 2a and b) in the sixth week may have been the cause. Organic matter forms stable complex compounds with some metals including iron preventing precipitation of P thus making P available (Bradley and Sieling, 1953; USDA, 1957; Shapiro, 1958b; Mandal and Mandal, 1973; Hossner *et al.*, 1973; and Singh and Ram, 1977). Datta and Srivastava (1963) showed that there was a strong interaction of organic matter and pH with the sesquioxide content. Other than P_1 treatment (Fig. 3a), the other graphs, show increase of P in the supernatant in Amo series in the sixth week with increase in applied P. Whilst the increase in the sixth week of supernatant P in Akuse series was irregular.

In the sixth week, the pH of the supernatant liquids of Amo series was between 6.7 and 7.5 and 7.1 and 8.0 in Akuse series, a decrease from the fifth week in the average pH concentration. These results are contrary to a decrease in availability of P between pH 6.5 and 7.5 under flooded conditions (Aoki 1941; Tseng, 1960) in acidic soils as in Amo series and 7.0 and 8.5 (USDA, 1957) in alkaline soils as in Akuse series. There was however no increase in soluble iron in the supernatant in the sixth week as shown in Fig.5a and b. Similar result was obtained by Mandal (1964). Basak and Bhattacharya (1962), Pathak et al., (1972) discovered that waterlogged soils showed a unique capacity for regenerating an increasing quantity of available phosphoric acid during the active period of crop's life. They suggested that the source of its supply and the cause of its regeneration resulted from the release of phosphoric acid could have resulted in the decrease in pH of the supernatant liquids as well as an increase in its soluble P in the sixth week over and above the requirement of the plants.

In a similar study Ponnamperuma (1965) showed that the solubility of P in flooded soils after seven weeks of submergence increased after a previous decrease. Whilst in my experiments the increase took place after the fifth week. For this increase he gave no explanation. The difference in the results however will depend on the properties of the soils.

The ammonium acetate extracts of the wet Akuse series samples showed an increase in extractable and available calcium over that determined before waterlogging. The pH of the supernatant liquids of the Akuse series samples of the sixth week was between 7.1 and 8.0 units. According to USDA (1957) the solubility of calcium phosphate increases between pH 7.5 and 9 in the presence of excess $CaCO_3$ which is found as concretions in Akuse series. So this may account for the increase of P in Akuse series supernatant samples. There was no increase in soluble and or extractable calcium in the wet Amo series after waterlogging. Hence this cannot be the only explanation for increase in P in the sixth week.

The effect of increased pH of the supernatant can lead to the formation of hydroxides of the metals. The concentration of soluble or available Fe is decreased when soils are kept at constant pH of 6.5 to 7.2 (Ponnamperuma, 1965). The hydroxides being less soluble can be precipitated with the release of soluble P. This should be reflected in decrease in the concentration of Fe and Mn in solution thus:-



$$\begin{tikzcd} Fe^{+++}\,P \arrow[r, "+e"] & Fe^{++} + P \arrow[d, "+\ OH^-"] \\ & Fe(OH)_2 + P \end{tikzcd}$$

Though there was a decrease in pH in the sixth week, the pH values were still within the range of 6.5 to 7.2. It must also be noted that some of the soils were supporting actively growing rice throughout the sampling period. Changes in solution P are influenced by absorption of soluble P by the roots. But the average results of P concentration for the different treatments show pretty much the same trend.

Decrease of P in the eighth week in nearly all the treatments may have been due to a change in the rate or capacity of the roots to absorb phosphorus, or a decrease in $H_2PO_4^-$ ion (USDA, 1957) in the soils or fixation of P due to stabilization of pH values between 6.5 to 7.5 when P becomes unavailable (Aoki, 1941). After long periods of waterlogging, P appears to become less available, probably due to reprecipitation of Fe and Mn phosphate (Valencia, 1962).

The P in the supernatant is what is immediately available to the plant. When considering the average concentration of P in the supernatant for the whole of the sampling period taking the mean of means of the raw data (table 4), P concentration increased with increase in applied P from low to high in pots without rice for both soil series. However, in the pots with rice, this was not consistently so.

From the statistical analysis (table 5a) the level of P applied was significant at 5% and 1% respectively. Therefore application of P at the levels used had a positive effect on the quantity of P in the supernatant. It is therefore reasonable to assume that P application increases the availability of nutrient P in the aqueous milleu. It also means that the availability of P increased with increase in the quantity of applied P, (Shrikhande and Yadav, 1954; Pathak, *et al.*, 1972; Hossner, *et al.*, 1973) hence the general increase of P in the supernatant.

There was significant difference between Amo and Akuse series at 5% level in the amount of P in their supernatant liquids. It is quite clear from the graphs (Fig.3a and b) that there was more P in the supernatant in Amo series than in Akuse series. On the whole P in the supernatant liquids was higher for both cropped and uncropped soils in Amo series than in Akuse series as shown by the mean of means of the raw data (table 4).

Number of weeks of submergence/soil interaction was significant at 5% and 1%respectively. Thus the availability of P in the supernatant is affected by the period of submergence depending on the type of soil in question. Inspection of table 6 of means of transformed values of P in supernatant reveals that, the highest means of Amo series was with P_1 treatment in week six with a value of -6.71and the lowest was with P_3 treatment with a value of 2.18 (week 1). With reference Akuse series, the highest mean was with P_1 treatment in

TABLE 4

MEAN OF MEANS OF NUTRIENTS IN AMO AND AKUSE series

NUTRIENTS IN PPM IN SUPERNATANT LIQUID

Level of P	$P \times 10^{-2}$		Mn		Fe	
	Amo	Akuse	Amo	Akuse	Amo	Akuse
P_oR	1.55	0.89	0.15	0.11	1.37	0.46
P_oNR	1.30	0.90	0.30	0.13	1.05	0.76
P_1R	3.01	1.59	0.17	0.07	0.81	0.71
P_1NR	1.41	1.45	0.24	0.06	1.20	0.43
P_2R	1.69	0.80	0.17	0.12	1.44	0.84
P_2NR	2.06	1.99	0.27	0.11	0.73	0.44
P_3R	2.33	1.28	0.15	0.004	1.01	0.40
P_3NR	2.75	2.07	0.25	0.05	1.24	1.03

NUTRIENT IN PLANT MATERIAL

	%P		$Mn \times 10^2$ ppm		Fe ppm	
P_o	0.27	0.23	14.15	9.46	52.9	49.9
P_1	0.30	0.28	14.70	10.60	67.9	66.9
P_2	0.30	0.28	14.94	13.17	66.4	41.5
P_3	0.34	0.27	14.71	10.28	64.6	49.1

NUTRIENTS IN PPM IN WET SOIL

	Mn		Fe	
	Amo	Akuse	Amo	Akuse
P_oR	173.9	84.8	6.14	7.79
P_oNR	179.1	69.6	6.25	5.81
P_1R	176.5	60.8	3.79	6.99
P_1NR	182.8	80.3	9.56	8.65
P_2R	174.0	24.7	5.29	7.47
P_2NR	159.5	79.6	6.43	8.63
P_3R	157.0	44.9	3.51	7.95
P_3NR	160.1	65.5	15.30	6.61

ANALYSIS OF VARIANCE TABLE 5 a,b,c

SUMMARY OF ANOVA TABLE

PROJECT ON AMO AND AKUSE SOIL SERIES

Level of Factor A = 2 (Soil types)
Level of Factor B = 4 (Level of phosphorus applied)
Level of Factor C = (No. of sampling times/period of submergence/weeks after transplanting).

Supernatant Liquids (a)

1. Phosphorus in Supernatant

Source	DF	SS	MS	F
A	1	16.6502	16.6502	5.2502*
B	3	57.3885	19.1295	6.0435**
C	5	27.0641	5.4128	1.7100
AB	3	8.1810	2.7270	0.8615
AC	5	59.4722	11.8944	3.7577**
BC	15	70.4799	4.6986	1.4844
ABC	15	35.9132	2.3942	0.7563
ERROR	88	278.5453	3.1652	

2. Manganese in Supernatant

Source	DF	SS	MS	F
A	1	0.4143	0.4143	30.1974**
B	3	0.0537	0.0179	1.3046
C	5	0.3011	0.0602	4.3888**
AB	3	0.0171	0.0057	0.4171
AC	5	0.4711	0.0942	6.8670**
BC	15	0.2044	0.0136	0.9931
ABC	15	0.5414	0.0360	2.6304**
ERROR	88	1.2075	0.0137	

* Significant at 5%, ** Significant at 1%, ns not significant.

3. Iron in Supernatant

Source	DF	SS	MS	F
A	1	0.2890	0.2890	0.1305
B	3	21.1070	7.0356	3.1776*
C	5	13.5821	2.7164	1.2268
AB	3	7.6808	2.5602	1.1563
AC	5	42.8834	8.5766	3.8736**
BC	15	57.6799	3.8453	1.7367*
ABC	15	43.2017	2.8801	1.3008
ERROR	88	194.8413	2.2141	

Wet Soil (b)

1. Manganese in Wet Soil

Source	DF	SS	MS	F
A	1	1117.464	1117.464	0.478 ns
B	3	19850.732	6616.910	2.835*
C	5	40266.344	8053.268	3.450**
AB	3	11243.962	3747.987	1.605 ns
AC	5	71326.498	14265.299	6.112**
BC	15	160329.038	10688.602	4.580**
ABC	15	190990.428	12732.695	5.455**
Error	88	205370.497	2333.755	

* Significant at 5%, ** Significant 1%, ns not significant.

Wet Soil (b) cont.

2. Iron in Wet Soil

Source	DF	SS	MS	F
A	1	654.373	654.373	32.143**
B	3	468.419	156.139	7.669**
C	5	921.630	184.326	9.054**
AB	3	465.700	155.233	7.625**
AC	5	942.547	188.509	9.259**
BC	15	3399.420	226.628	11.132**
ABC	15	4406.668	293.777	14.430**
Error	88	1791.480	20.357	

Plant Nutrient (c)

1. Phosphorus in Plant Material

Source	DF	SS	MS	F
A	1	0.047	0.047	9.313**
B	3	0.054	0.018	3.580*
C	5	2.810	0.562	111.252**
AB	3	0.015	0.005	1.024ns
AC	5	0.279	0.055	11.046**
BC	15	0.215	0.014	2.849**
ABC	15	0.207	0.013	2.737**
Error	88	0.444	0.005	

* Significant at 5% ** Significant at 1% ns not significant

Plant Nutrient (c) cont.

2. Manganese in Plant Material

Source	DF	SS	MS	F
A	1	454.426	454.426	27.978**
B	3	103.317	34.439	2.120ns
C	5	9860.142	1972.028	121.414**
AB	3	48.236	16.078	0.989ns
AC	5	151.430	30.286	1.864ns
BC	15	368.817	24.587	1.517ns
ABC	15	183.426	12.228	0.752ns
Error	88	1429.311	16.242	

3. Iron in Plant Material

Source	DF	SS	MS	F
A	1	3774.163	3774.163	1.747ns
B	3	1653.957	551.319	0.255ns
C	5	188178.383	37635.676	17.426**
AB	3	3149.479	1049.826	0.486ns
AC	5	19139.116	3827.823	1.772ns
BC	15	49983.250	3332.216	1.542ns
ABC	15	26856.068	1790.404	0.829ns
Error	88	190047.994	2159.636	

* Significant at 5%   ** Significant at 1%   ns not significant.

week 2 with a value of -1.14 and the lowest was with P_1 in week 2 with a value of 3.34. The highest mean of means in Amo series was -2.52 in week 6 (table 6) and the lowest 0.75 in week 5. The highest mean of means of the Akuse series for P was -0.08 in week 8 and the lowest 0.77 in week 6. Therefore it can be assumed that P applied at 22 kg/ha resulted in the greatest quantity of P in the supernatant in the two soil series. Hence 22 kg P/ha in each is the optimum amount that will produce the largest amount of available P that will be immediately available to the plant. It can be concluded that more P was available in the supernatant of Amo series following P application than in the Akuse series. It also appears that in both soils most of the higher levels of P applied were rendered innocuous. With reference to Fig.6, when P in supernatant increased in the cropped pots above that in the control in any week in Amo series that of Akuse series decreased and vice versa. It was only between the fourth and the fifth weeks that Akuse series released more P in its supernatant than Amo series. The rest of the time little P was available in Akuse series supernatant (Fig. 6).

TABLE 6 SUPERNATANT MEANS OF TRANSFORMED VALUES FROM AMO AND AKUSE series

	Amo series					Akuse series				
					Phosphorus					
P Level	P_o	P_1	P_2	P_3	Mean	P_o	P_1	P_2	P_3	Mean
Week 1	-0.93	-0.97	-0.05	2.18	0.05	-0.12	0.86	0.78	0.12	0.41
2	-0.18	-2.26	-0.13	0.82	-0.43	-0.62	-1.14	3.34	1.44	0.75
3	0.09	0.17	1.14	-0.65	0.18	0.73	0.99	1.03	0.68	0.86
5	0.88	0.75	0.64	0.74	0.75	0.00	-0.53	0.35	0.00	-0.04
6	-1.94	-6.71	0.38	-1.85	-2.52	-0.06	-0.81	1.85	2.10	0.77
8	0.64	0.63	0.25	1.25	0.38	-0.32	-0.22	-0.22	0.39	-0.08
Mean	-0.24	-1.61	0.37	0.42		-0.07	-0.14	1.19	0.79	
					MANGANESE					
1	-0.16	-0.19	0.02	-0.01	-0.08	0.08	-0.01	0.06	0.04	0.04
2	-0.01	0.11	0.28	-0.08	0.12	0.06	-0.10	-0.16	0.00	-0.05
3	0.46	0.24	0.12	0.11	0.23	-0.60	0.00	0.00	0.00	-0.01
5	0.22	0.13	0.20	0.24	0.19	0.03	0.04	0.06	0.04	0.04
6	0.36	0.04	-0.01	0.11	0.12	-0.08	-0.02	-0.05	0.00	-0.03
8	0.05	0.11	0.00	0.14	0.07	0.05	0.01	0.0	0.01	0.01
	0.16	0.07	0.10	0.11		0.01	-0.01	-0.02	0.02	
					IRON					
1	-1.89	-0.07	-0.23	0.05	-0.53	0.13	-1.90	-1.53	0.29	-0.75
2	-0.03	-0.63	-3.61	-0.11	-1.09	2.18	0.46	-0.09	3.50	1.51
3	-2.18	2.23	-1.25	2.91	0.36	0.08	0.26	0.20	0.04	0.14
5	1.51	0.42	0.46	-0.85	0.38	0.17	-0.55	-0.42	0.03	0.21
6	0.44	0.25	0.51	0.84	0.50	0.04	0.03	0.07	0.01	0.03
8	0.26	0.17	0.13	0.18	0.18	-0.77	-0.03	-0.65	-0.01	-0.35
	-0.32	0.40	-0.71	0.50		0.31	-0.29	-0.40	0.63	

3.2.2. Manganese in Supernatant

Manganese in the soil solution is the immediate source of this ion for plant absorption. The manganese concentration in the supernatant liquids did not show as regular a pattern as did P concentration in the supernatant (Fig. 4a and b). The increase in solubility, was perhaps due to reduction of higher manganese oxides (MnO_2, Mn_2O_3, Mn_3O_4) which are rendered soluble in flooded soils (Ponnamperuma, 1972). The reduction may have resulted from these compounds functioning as electron acceptors in the respiration of micro-organisms and chemical oxidants of reduction products. (Mann and Quastel, 1946). The maximum values were reached within the first three weeks of submergence in all treatments (Fig. 4a and b) of both soil series except P_0 treatment of Akuse series. This attained its maximum in the sixth week of flooding. The highest manganese concentration recorded for the supernatants were 1.05 ppm and 0.63 ppm for Amo and Akuse series respectively.

Soluble Mn entered the exchange complex within the first week of submergence as was reported by Mandal

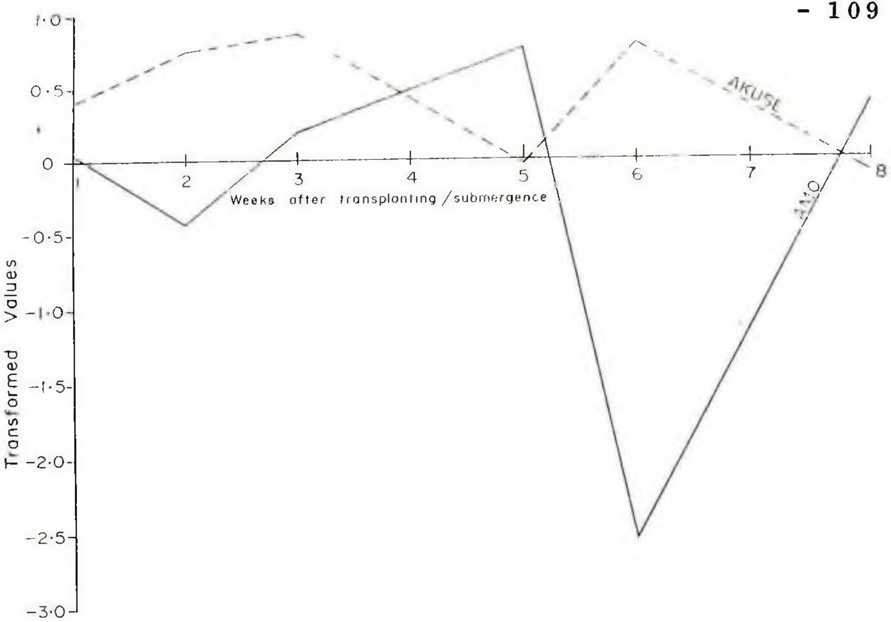


Fig 6 Effect of soil and time after transplanting/submergence interaction on P in Supernatant during Paddy growth

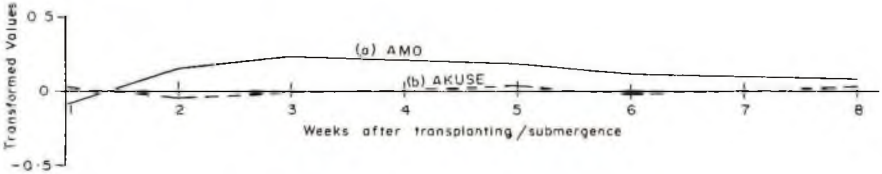


Fig. 7 Effect of soil and time after transplanting interaction on Mn in Supernatant during Paddy growth

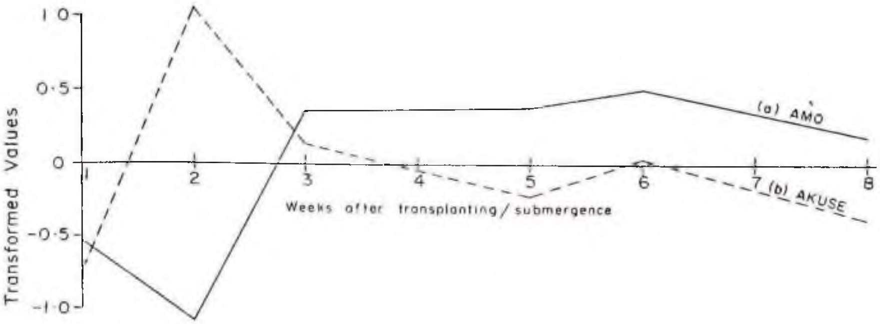


Fig 8 Effect of soil and time after transplanting interaction on Fe in Supernatant during Paddy growth

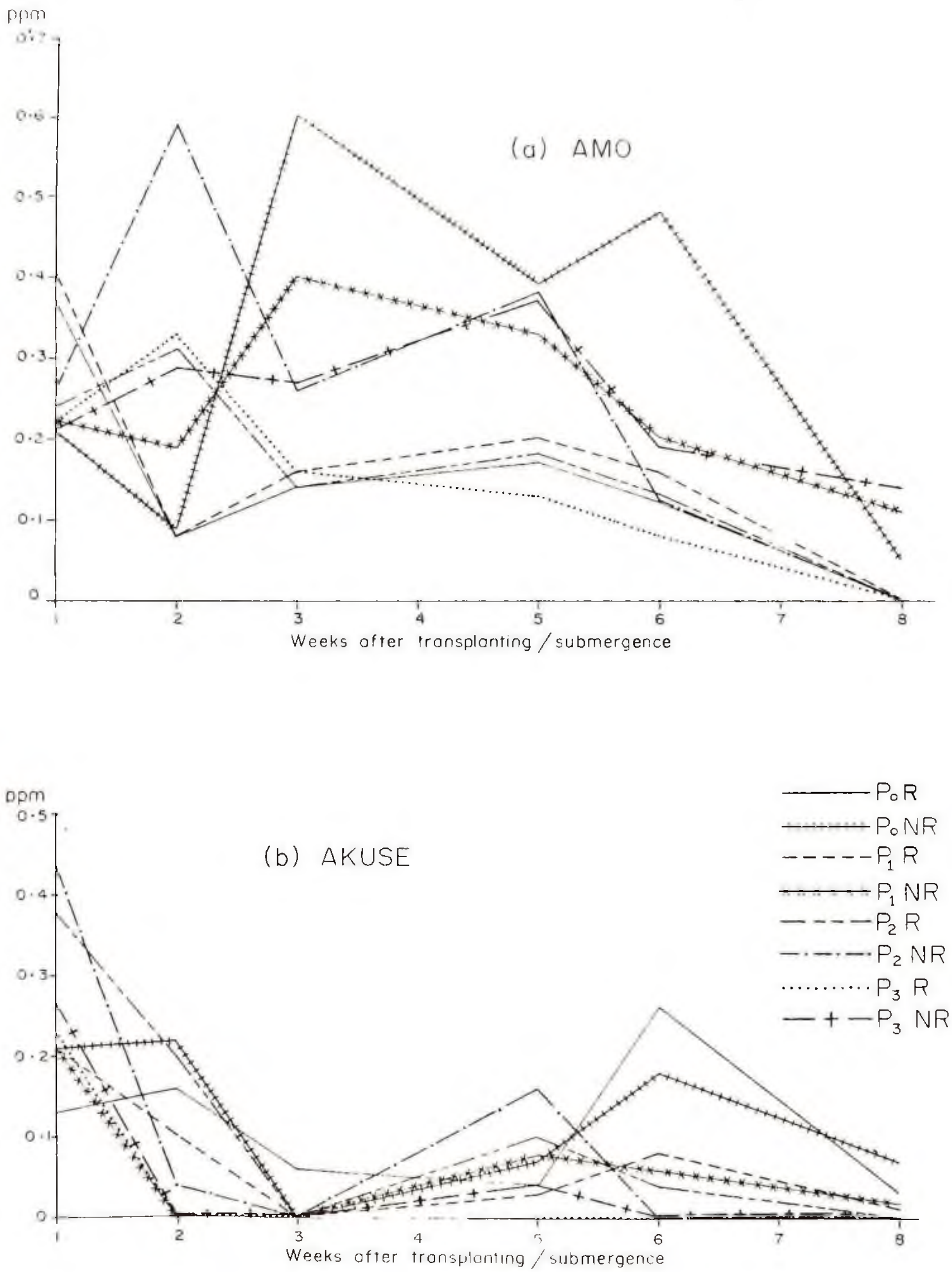


Fig 4. Manganese in Supernatant in ppm of soil vs weeks after transplanting/ submergence during Paddy growth in pot experiments carried out in the Green House

natant. A similar variable soluble Mn pattern shown by Akuse series has been recorded by Olomu et al. (1973). They suggested that this may have been due to change in pH in some soils. The experimental results (table 2a and b) show little or no change in pH from the third to the fifth week in most of the treatments.

In Amo series (Fig. 4a), the increase in Mn in the supernatant of pots with rice reached the highest level in the first week in the P_0 and P_1 treatments. They declined sharply, rose and reduced slowly again. This is similar to the behaviour of soils described by Ponnamperuma (1965) as soils having high manganese content which show steep increase in Mn irrespective of pH value or organic matter content during the first few weeks of submergence and reduce slowly thereafter. In the next two treatments, the Mn concentration increased and reached the highest level in the second week but lower than the previous P_0 and P_1 levels, before following the same trends. With the exception of the second and third week the Mn concentration in the supernatant of P_3 treatment was the least. Other than the second week, the supernatant from P_1 treatment gave the highest values of Mn concentration.

In Akuse series (Fig. 4b) after the appearance of Mn in the supernatant in the first week, very little or none was detected in pots with the highest P level, till the end of the sampling period. From the fifth week of sampling till the eighth, there were detectable quantities of Mn in the supernatant of cropped and uncropped soils with P_0, P_1 and P_2 treatments.

According to the analysis of variance of the transformed values the levels of P application did not affect the solubility of Mn in the supernatant. The types of soil used had a significant effect at 5% and 1% respectively (table 5a) on the Mn in the supernatant liquid. The average concentration of Mn in the supernatants from Amo series was more than double that in supernatants of Akuse series for the different treatments (table 4).

Number of weeks of submergence was significant at 5% and 1% respectively (table 5a). With time the Mn decreased after the initial maximum reached. The general decrease may have been caused by the adsorption of Mn organic complex by clay or absorbed by micro organisms thus making it less available (Meek et al., 1968). There was interaction significant at 5% and 1% between the types of soil and weeks of submergence on the Mn in the supernatant liquid. The highest mean of transformed value was -0.19 in week 1 for Amo series and -0.6 in week 3 for Akuse soil series (table 6). The transformed values for Akuse series were very close to those of the control. Whereas in Amo series there was an initial steep drop followed by a gradual increase (Fig. 7). Except for the first week the figures for Amo soil series were all below those of the control.

The level of P applied, period of submergence and type of soil interaction (table 5a) had significant effect at 5% and 1% on the Mn in the supernatant. In Amo series, the highest mean (table 6) of -0.19 was in the first week and this coincided with the highest mean of means which was also in the first week. The lowest mean was in the third week so was the lowest mean of means. In Akuse series the highest mean (table 6) was -0.60 in week 3 whilst the highest mean of means was in week 2. The lowest mean was in week 1 so was the lowest mean of means. All the mean of means for Amo series were positive for the different levels of fertilizer P added. Hence there was less Mn in the supernatant in the pots with rice of Amo than Akuse soil series when compared with their corresponding control. This suggests high intake of Mn by the plants growing in Amo series compared to those in Akuse series (table 8). These results are indicative of the suggestion by Ponnamperuma (1965) that the pattern of change in concentration of soluble Mn varies from soil to soil.

3.2.3. Iron in Supernatant

Under submergence, the amount of iron reduced in the soil depends on the iron content, and the amount brought into solution depends on the pH (Rodrigo, 1962) of the soil.

Iron was found in the supernatant liquids in all treatments of both soil series in the first week. This is in contrast with most of the results obtained by Olomu *et al.*, (1973) who had no iron present in the soil solution in most of their experiments and Rodrigo (1962) who had none at all in his supernatant liquids. However, Rodrigo's (1962) water percolates (for uncropped soils) gave similar results as those of the supernatant from uncropped soils in the present study.

With reference to fig 5a only P_0 level of fertilizer showed a high value of iron concentration in the supernatant liquids in the first week of submergence in Amo series. The other levels increased to a maximum between two and five weeks and decreased thereafter. The values ranged from 0.05 to 4.61 ppm in the supernatant from pots cropped with rice and 0.22 to 3.53 ppm in supernatant from uncropped pots (Fig. 5a). The concentration of Fe in all the supernatants of pots cropped with rice were the same value in the sixth week. In the case of the supernatants from the treatments of Akuse soil series, the values for the cropped soils ranged from 0.05 to 2.48 ppm and the uncropped soil 0.07 to 4.24 ppm. (Fig. 5b). The maximum values were obtained in the first week for the supernatants of the cropped soils and first and second weeks for the supernatants of the uncropped soil. There was a general decline in the concentration of Fe in the supernatant in the third

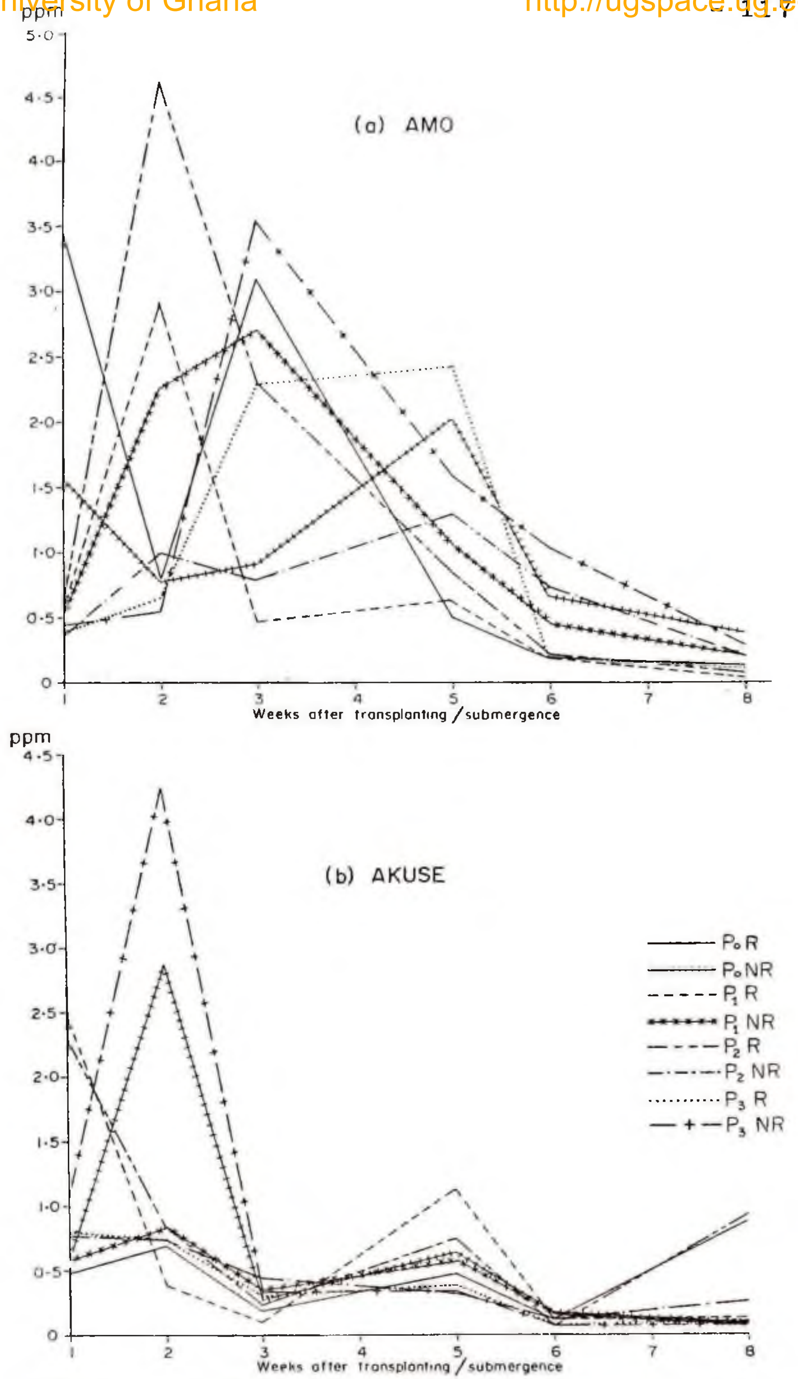


Fig. 5 Iron in Supernatant in ppm of soil vs weeks after transplanting / submergence during Paddy growth in pot experiments carried out in the Green House

week after which the concentration increased in the fifth and eighth weeks with few exceptions. Whilst values for the concentration of Fe in all the treatments were pretty much the same in the sixth week (Fig. 5b). Almost all the treatments in Akuse series followed the same trends, and far more consistent than in Amo series supernatant.

The increase in solubility of Fe in the supernatant as a result of submergence was probably a consequence of anaerobic metabolism of bacteria leading to chemical reduction of Fe III by metabolites (Ponnamperuma 1965), although Kumura, Takai, and Ishikawa (1963) have reported that direct bacterial reduction coupled with respiration may be involved. A similar increase in solubility in the supernatant or soil solution as a result of reduction has been reported by Islam and Elahi (1954), Mandal (1964), Ponnamperuma (1965, 1972), Olomu *et al.*, (1963), Jaggi and Russel (1973), Singh and Pasricha (1978) and as a result of mineralization of Fe complex organic matter by Olomu *et al.*, (1973). In the present investigation the increase in soluble Fe rose to a maximum and then decreased as reported by Gericke (1930), Rodrigo (1962), Ponnamperuma (1965), Jaggi and Russel (1973). The small amounts of Fe present in the supernatant liquids throughout the sampling period were due to the fact that the pH of the supernatant in all the treatments were between 6.7 and 8.7. At pH values greater than 7 Fe is presumed to be precipitated around rice roots (IRRI, 1963). The distribution of reduced Fe between the solid and solution phases of the soil is controlled by pH, organic matter, cation exchange capacity and duration of submergence (Ponnamperuma, 1965). The organic matter in both soils is low. So it is not surprising that concentration of Fe in solution was so low. Another reason is that the amount of Fe in the soil depends on its iron content, but the amount brought into solution depends on the pH of the soil. The lower the pH, the more the iron dissolves (Rodrigo 1962). Here pH of Amo series is less than that of Akuse series hence more iron is rendered soluble in Amo than in Akuse series (table 4).

The levels of P applied were significant at 5% to the amount of Fe in the supernatant liquids. The only indication of increase in applied P with increase in Fe concentration from low to high in the supernatant is seen in the fifth week (Fig. 5a) in Amo series in pots with rice. In Akuse series (table 4) there is an increase in Fe concentration with increase from low to high of P applied in pots with rice except in the case of P_3 level which gives the least. The addition of P to soils that are likely to contain iron phosphate will affect the solubility of Fe. The most striking thing (table 6) is that the highest mean was given by P_2 level of applied P as well as the highest mean of means, and the lowest mean was given by P_3 level of applied P as well as the lowest mean of means in Amo series and slight exception in Akuse soil series.

Type of soil and period of submergence interaction (table 5a) was significant at 5% and 1% respectively. When the concentration of Fe in Akuse series decreased below that of the control in the second week to the lowest value, Amo series showed a marked increase (Fig. 8) corresponding to an increase of P in Amo series supernatant and decrease of P in Akuse series supernatant (Fig. 6). This may have been due to a drop in pH of Amo series supernatant whilst that of Akuse series supernatant was on the increase. From the third week onwards, both soils followed almost the same trend more especially in the sixth and eighth weeks. Amo soil series however had far less iron in the supernatant in the pots cropped with rice from the third week onwards than in the control. The mean of means of Fe in Amo series supernatant (table 6) gave the highest value in the second week and the lowest in the sixth week whilst that of Akuse series supernatant gave the highest value in the first week and lowest in week 2.

3.3.0. Nutrients in the Wet Soil

3.3.1. Phosphorus in the Wet Soil

The highest values of extractable P in the wet soil were obtained in the first week of sampling in all the treatments in both soil series. Because P_0 treatment gave comparative values of extractable P in both soil series, it could be assumed that both native and applied

P were extracted in the other treatments. Fe was extracted from the wet soil during the first week of submergence in all treatments. So the high results of extractable P in the first week of submergence may have been due to reducing effect and perhaps hydrolysis of Fe III phosphate as claimed by Fujiwara (1950) and Shapiro (1958a). It is also possible that wet Amo soil series at pH less than 5.5 and wet Akuse soil series at pH between 6.5 and 7 (table 3a and b) enhanced the solubility of P especially in the first week as suggested by Ponnamperuma (1965).

The extractable P decreased sharply in the second week in all treatments. With time, P increased slightly in the third week and then decreased slowly to the eighth week. There were signs of increased availability of P with increase in applied P, but this was not consistent. The trends in the extractable P did not show a clear pattern.

3.3.2 Manganese in Wet Soil

Extractable Mn in wet soil treatments (Fig. 9a) show inconsistent results. The concentration of Mn in these treatments ranged from 73.90 to 282.5 ppm. The treatments were well supplied with available Mn, the values of which reached a maximum in the first or second week of submergence. In fig. 9b the results for Akuse series appear more consistent. In these the Mn concentration reached maximum values in the first week of submergence. The values ranged from zero to 291 ppm during the sampling period. The availability of Mn in the wet treatments increased within the first two weeks of submergence. The sudden increase corresponds to an increase of Mn in the supernatant liquids. Increase in availability of Mn in the wet soil has been reported by Rodrigo (1961), Ponnamperuma (1965), Pathak et al. (1972), and Ghoneim et al. (1974).

The process of reduction of insoluble Mn oxides to more soluble forms, takes place in soils under submergence. In this investigation there was a gradual reduction to the fifth week in extractable manganese in Amo series treatments (Fig. 9a) after the first or second week compared to the steep decline in Akuse series (Fig. 9b) in the second or third week. In normal soils there is usually an equilibrium between soluble

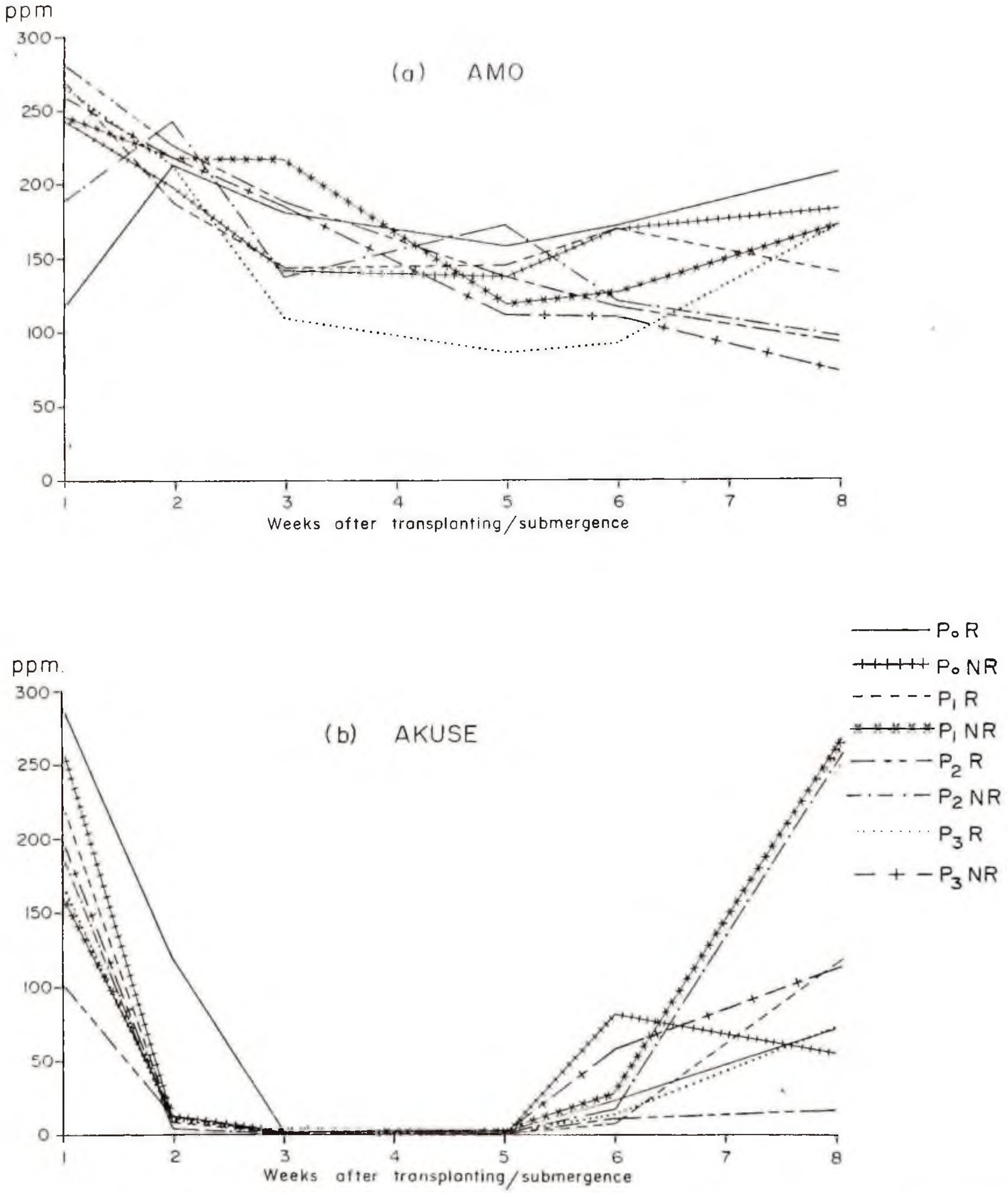


Fig. 9 Manganese in wet soil vs weeks after transplanting/submergence during Paddy growth in pot experiments carried out in the Green House

Mn and insoluble Mn oxides that is affected markedly by soil acidity (Black et al., 1965). With increase in soil pH values, the equilibrium is shifted towards manganese oxides and the availability of Mn is reduced (Boken, 1958). With decrease in soil pH values the equilibrium is shifted towards divalent Mn and increased availability. The pH of wet Amo series treatments (table 3a) showed gradual increase after the first week into the third week, and in a few instances the fifth week, before decreasing to around the pH of the original soil. This is reflected in fig. 9a as the Mn values of the different treatments reduced gradually to a minimum and gradually rose again.

As a contrast the pH values (Table 3b) of the wet Akuse series treatments showed an increase in pH in the third week of sampling and simultaneously all the treatments reflected the low values of extractable Mn and were lowest in the third week (Fig. 9b). By the fifth week, the pH had decreased and the Mn values were on the rise. During the next two weeks of sampling, the pH values were more stable, and nearer the original pH values of the soil. This together with prolonged submergence resulted in increased availability of Mn, with only few treatments reaching peak value before the eighth week of submergence.

The decrease of available Mn after weeks of submergence has been reported by Clark, Nearpass and Specht (1957), Rodrigo (1962), Ponnamperuma (1965), Pathak *et al.* (1972). The decrease could also have been the result of heterotrophic organisms which grow on organic compounds present under waterlogged conditions, and accumulate insoluble Mn salts (Alexander, 1965). Others derive all or part of their energy from the oxidation of soluble inorganic substances such as manganese which may have been present in the reduced state (Waksman, 1952) and many organisms oxidize Mn (Starkey, 1945). As a result of microbial action, the Mn may be precipitated or removed from solution by the organism for growth. When that is satisfied then some of the ions will become available for the plants. The microorganism on the other hand may absorb organic complexes formed with Mn thus making it unavailable.

The organic complex if present could be absorbed by clay particles in the soil resulting in unavailability (Meek et al., 1968).

Manganese values in all treatments generally increased in the sixth or eighth week of sampling. In wet Amo series the increases were not as striking as they were in the wet Akuse series treatments (Fig. 9a and b). A few values of extractable Mn in Akuse series in the eighth week were as high as, if not greater than, those obtained in the first week of submergence, Myttenaere and Masset (1968) have reported that availability of Mn increased at the tillering stage but decreased at the time of harvesting, nevertheless the values in these experiments were still on the increase in the eighth week of sampling. Reduction of insoluble forms into soluble forms may have been the reason for the increase in availability of Mn in both soils after the fifth week of submergence (Mann, and Quastel 1946). Roots probably play an active part in bringing about reduction of Mn in soluble oxide precipitates through their root excretion (Jones and Leeper, 1951).

The type of soil _per se_ did not appear to have affected the amount of extractable Mn in the wet soil statistically (table 5b). Whereas, the level of P was 5% significant and the higher the level (table 4) of P applied the less the extractable Mn to some extent. The period of submergence was significant at 5% and 1% respectively to the amount of Mn available in the wet soil samples (table 5b), and accounts for the availability and disappearance of Mn during the period of submergence. The minimum amount of Mn was extracted from the wet soil treatments between the third and the sixth week of sampling. Interaction between type of soil and period of submergence had significant effect on the Mn in the wet soil treatments (Fig. 10). After the first week of submergence, there was more Mn available in the wet Akuse series, than in the Amo series treatments. The extractable Mn increased in Akuse series above that of the control to the end of the second week, but decreased in Amo series till the end of the third week with no increase in the amount of Mn absorbed by the plants in Akuse series treatment. From the third week onwards the extractable Mn increased in Amo series above that of the control up to the eighth week whilst that of Akuse series decreased first slowly to the fifth week then steeply till the eighth week. (Fig. 10). The latter is reflected in the smaller quantities of Mn absorbed by the plant material from Akuse series treatments.

The interaction between the level of P applied and the period of submergence (table 5b) had 5% and 1% significant effect on the Mn extracted from the wet soils. The highest mean value of Mn above that of the control from Akuse series was -109 from P_0 treatment in week two (table 7). This coincided with the highest mean of means of -26 in week two. The highest mean value of Mn in Amo series treatment was -97 from P_3 in week eight and coincided with the highest mean of means of -22 in the same week. The lowest mean value of Mn for Akuse series was 242 with P_2 treatment in week eight with the lowest mean of means of 104.7 in week eight. The lowest mean value for Amo series was 128 for P_0 treatment in week 1, the lowest mean of means however was in week three. These results also reflect the signifi-

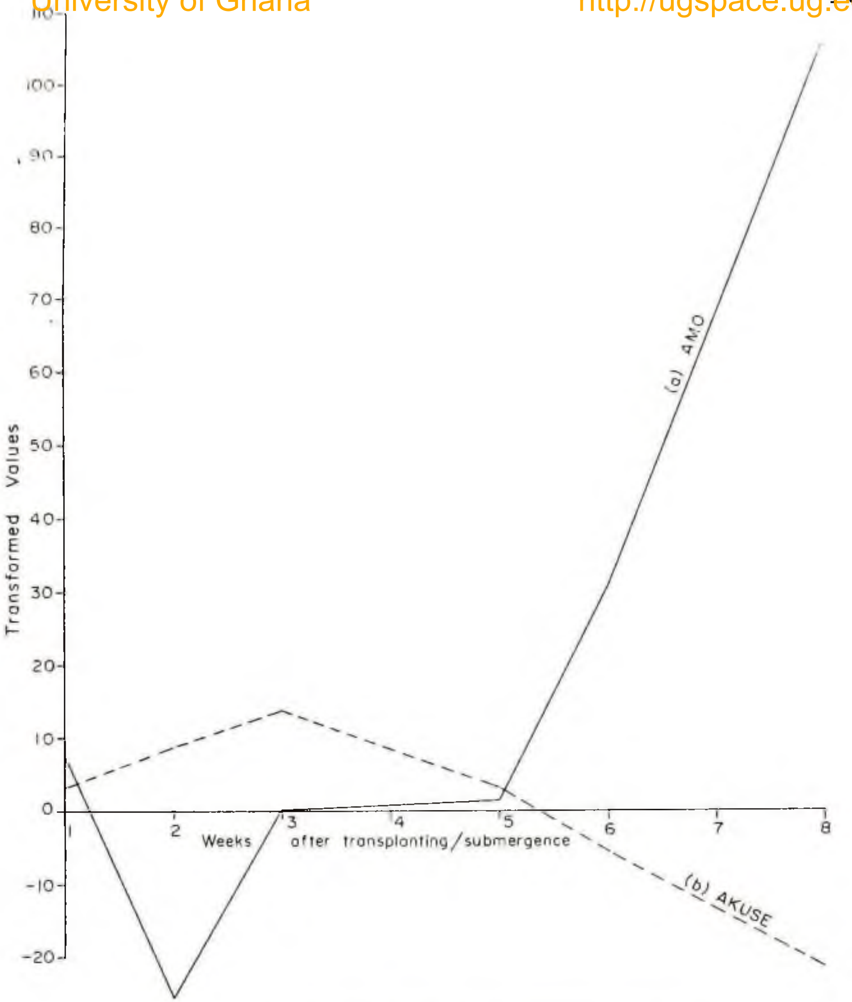


Fig 10 Effect of soil and time after transplanting / submergence interaction on Mn in Wet Soil during Paddy growth

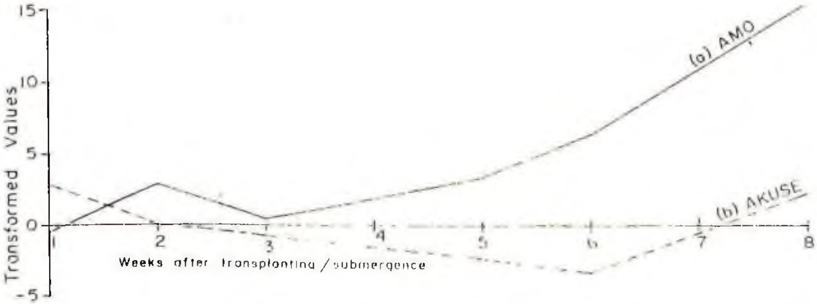


Fig. 12 Effect of soil and time after transplanting / submergence interaction on Fe in Wet Soil during Paddy growth

cant interaction at 5% and 1% between the type of soil, level of P applied, weeks of submergence on the Mn extracted from the wet soil (table 5b). The Amo series produced large quantities of Mn throughout the sampling period, but Akuse series values of extractable Mn decreased sharply from the second week. This probably means that the Mn in the wet Akuse series treatments were in forms not easily extractable or it was just the characteristic of the soil not to release much Mn after the initial first week of submergence.

3.3.3. Iron in the Wet Soil

The amount of Fe reduced in a flooded soil appears to be determined by the active Fe content and availability of organic matter, the pH is relatively unimportant (Ponnamperuma (1965). Amo and Akuse series used in these experiments are well supplied with iron. According to the method of Jackson (1956) the soils contained 106 x 10^2 and 56.93 x 10^2 ppm iron in Amo and Akuse series respectively and by Black *et al*. (1965), 11.74 and 3.84 ppm.

In the wet soil samples, the extractable Fe that is the exchangeable Fe for Amo series ranged from 0.00 to

TABLE -7

WET SOIL MEANS OF TRANSFORMED VALUES OF Mn AND Fe FROM AMO AND AKUSE series

AMO series

	Manganese					Iron				
P Level	P_o	P_1	P_2	P_3	Mean	P_o	P_1	P_2	P_3	Mean
Week 1	128.1	-24.6	-92.6	2.1	3.22	-5.02	7.20	-1.07	-3.10	-0.50
2	-15.0	29-8	15.6	5.5	8.98	2.20	4.03	2.15	3.24	2.91
3	-39.2	71.7	-52.0	75.0	13.86	-0.23	3.45	-2.22	0.88	0.47
5	-19.63	-26.8	34.7	25.2	3.36	-0.12	7.63	5.37	1.29	3.54
6	-0.44	-43.3	4.7	17.0	-5.53	10.15	14.24	-1.88	2.68	6.30
8	-22.8	31.1	2.0	-96.9	-21.66	-6.3	-1.92	4.37	65.7	15.47
	5.16	6.31	-14.61	4.6		0.11	5.77	1.12	11.78	

AKUSE series

	Manganese					Iron				
P Level	P_o	P_1	P_2	P_3	Mean	P_o	P_1	P_2	P_3	Mean
1	-25.2	-62.2	87.3	30.4	7.57	-1.87	0.67	8.33	4.52	2.91
2	-109.2	10.4	-7.3	2.2	-25.95	-0.06	1.15	-0.13	-0.66	0.08
3	0.68	-2.2	-0.8	2.9	0.14	-0.58	-0.16	-1.14	-0.82	-0.68
5	0.0	2.3	2.1	1.5	1.48	-7.04	1.05	-3.49	0.60	-2.22
6	58.3	18.9	6.0	44.2	31.86	2.05	-6.24	-0.49	-9.21	3.47
8	-15.5	150.1	242.0	42.4	104.77	-5.89	13.42	3.88	-2.59	2.21
	-15.1	19.6	54.9	20.6		-2.23	1.65	1.16	-1.36	

67.25 ppm and Akuse series 0.36 to 23.9 ppm (Fig. 11a and b). The exchangeable iron in some of the treatments that showed values greater than 3 ppm in the first week of submergence decreased in the second week (Fig. 11a and b). Those that showed values less than 3ppm in the first increased in the second week. Iron that is reduced from the solid phase may be present as hydroxide, carbonate or sulphide, and the distribution of reduced iron between solid and solution phases would be controlled by pH, organic matter, cation exchange and duration of submergence (Ponnamperuma 1965).

Concentration of Fe in all the treatments of the two soil series decreased to a minimum value, in the third week. The increased values of pH in the wet soil treatments in the third week of submergence may have accounted for this disappearance of iron, possibly by precipitation (Hem, 1960, 1963; Rodrigo, 1962; Ponnemperuma, 1965). Sometimes Fe can be precipitated, as a result of chemical oxidation due to increases in pH (Starkey, 1945).

Micro organisms can convert Fe III to Fe II and vice versa. Some of these organisms accumulate Fe III (Alexander, 1965) or derive their energy from soluble inorganic substances such as Fe which may be present in the reduced state (Waksman, 1952), or utilize them for microbial transformations (Brady, 1974), hence they are made unavailable.

Meek et al. (1968) showed how factors other than redox changes could make iron unavailable as in the third week of submergence. They suggested that some of the soluble Fe may be present under flooded conditions in the form of organic complexes. These complexes, they thought were adsorbed by clay or absorbed by microorganisms, thus rendering Fe unavailable.

In the fifth and sixth weeks of submergence, more iron became available (Fig. 11a and b). Similar increase in availability has been recorded by Jeffery (1961a), Rodrigo (1961), Mandal (1961), Pathak et al. (1972). This increase could have been brought about in the fifth week as a result of the slight decrease in pH of the wet soils in all the treatments but more so in Akuse series (table 3 and b). By the sixth week of submergence

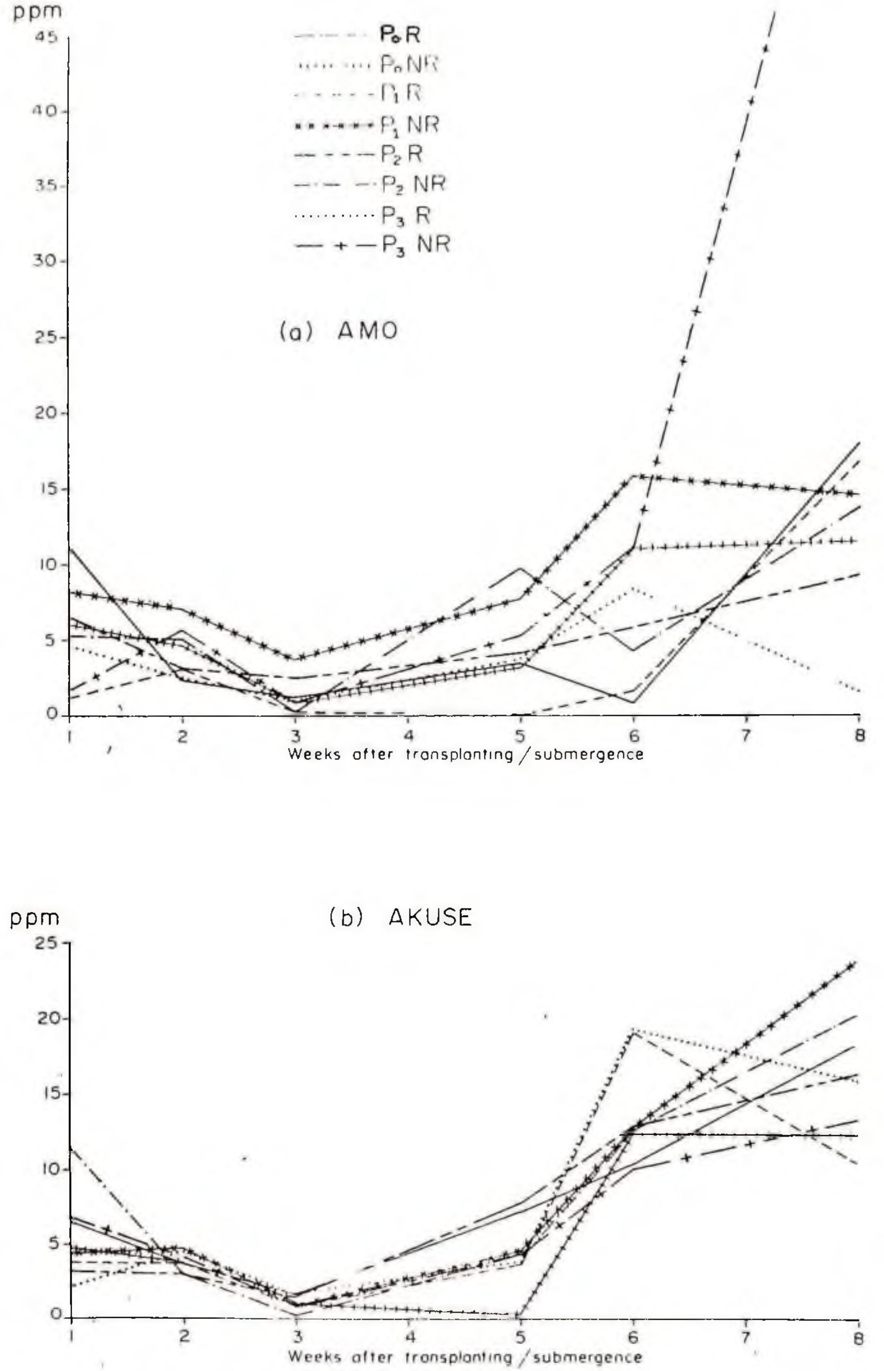


Fig. 11 Iron in wet soil vs weeks after transplanting / submergence during Paddy growth in pot experiments carried out in the Green House

the pH values were pretty constant and close to that of the original soils.

Shapiro (1958b) stated that organic matter may reduce and chelate metallic cations in the soil. These chelated compounds are protected from precipitation, but are still available to plants. Iron has the tendency to be attracted to chelates more so than other ions, thus resulting in increased availability (Brady, 1974) in week five.

Values of Fe concentration in some of the treatments in each soil series including P_3 the highest level of wet cropped treatments showed lower values in the eighth week of flooding (Fig. 11a and b). They reached their maximum peak after weeks of submergence and then decreased by the eighth week. Similar results were obtained by Rodrigo (1961), Ponnamperuma (1965), Pathak et al. (1972), Jaggi and Russel (1973). The rest of the treatments continued to increase as shown in Fig. 11a and b till the end of sampling. This shows that more and more iron became available as flooding was prolonged. All the treatments generally followed the same trends.

The available Fe in the wet soil was very sensitive to the different factors to which it was subjected. The type of series, Amo and Akuse had significant effect on the Fe in the wet soil at 5% and 1% respectively (table 5b). The original Amo series showed higher Fe content than Akuse; but most of the treatments in Akuse series(wet soil)released more extractable Fe than those in Amo wet series. This may be due to the presence of slightly more organic matter present in Akuse than Amo series (Ponnamperuma, 1965). The levels of P applied were significant at 5% and 1% to the available Fe in the wet soil. (table 5b). In the soil, some of the Fe may have been converted to Fe III phosphate which was first insoluble and later reduced to soluble Fe by the fifth and sixth week. In most instances more Fe was obtained at the lower P level (table 4 and fig. 11a and b) than at the higher levels of applied P. These results corroborate those of Gupta _et al_ (1969). Period of submergence too was significant at 5% and 1% (table 5b). Although Fe was extracted in the first week less was available in the third week in all treatments. But as submergence continued increased amounts were rendered soluble than in the first three weeks of submergence.

The interaction between type of soil and period of submergence had 5% and 1% significant effect on the Fe in the wet soil. With reference to fig. 12, Akuse series had less Fe in the wet soil treatments above that of the control than Amo series in the first week. With time the amount of Fe increased to the sixth week and then decreased in the eighth week. There was no time other than the first week when the Fe in Akuse series showed lower values than those of Amo series as has also been pointed out in most of the treatments of the wet soils (table 4). In fact (Fig.12) Amo series had less Fe available for extraction (below that of the control) throughout sampling except for the first week. The original Amo series had more available Fe than Akuse series. More Fe was in supernatants from Amo series than those from Akuse series. Plants from Amo series also had more Fe in them than those from Akuse series. This may explain why there was less Fe in Amo wet soil treatments.

The type of soil, level of fertilizer applied and period of submergence interaction was significant at 5% and 1% to the Fe extracted from the wet soil (Table 5b). A look at the data (table 7) reveals that the highest mean for Amo wet series was -5.02 with P_0 treatment and the highest mean of means in week 1. The highest mean for Akuse series was -9.21 with P_3 treatment in week six and the highest mean of means was in the same week. The lowest mean for Amo series was 65.7 with P_3 treatment in week eight with the lowest mean of means in that week. Whilst Akuse series had the lowest mean with P_1 treatment of 13.42 with the lowest mean of means in week 1, hence the significant differences.

High clay content is related to high exchange capacity hence high values of nutrients in the soil. Higher values of extracted P and Fe in wet Akuse series treatments were because of higher exchange capacity as well as the form in which the ions exist in it. But higher values of extracted Mn in the wet Amo series, and higher values of the three nutrients (P, Mn and Fe) available in the supernatant liquids inspite of the Mn concretions in Akuse series, were because Amo series perhaps more readily releases its nutrients than Akuse series as well as the fact that the original Amo soil series contained more available P, Mn and Fe than the Akuse soil series.

3.4.0. Nutrients in the Plant

3.4.1. Phosphorus in the plant material

The increase in available P concentration in paddy soils during the growth of rice suggests that the rate of the regeneration of P was faster than the uptake capacity of the growing crop. This condition is conducive to the uptake of the ion by the plant (Basak and Bhattacharya, 1962). The P in the plant tissue from Amo series treatments (table 8) ranged from 0.177 to 0.609 per cent of plant material. That of Akuse series treatments (table 8) ranged from 0.043 to 0.849 per cent of plant material. The highest values of P were obtained in the first week, and the lowest were generally obtained in the eighth week.

Increase in concentration of P in the supernatant and wet soil resulted in increasing P concentration in rice tissue and total P uptake by rice plants (Fig. 13a and b). These results corroborate those of Basak and Bhattacharya (1962) Cherian, Paulsen and Murphy (1968), Koyama and Chammek (1971), Hossner *et al.* (1973). The

TABLE 8 MEANS OF P, Mn AND Fe VALUES IN PLANT MATERIAL GROWN IN AMO AND AKUSE series

	Amo series					Akuse series				
	% Phosphorus					% Phosphorus				
P Level	P_o	P_1	P_2	P_3	Mean	P_o	P_1	P_2	P_3	Mean
Week 1	0.43	0.49	0.51	0.61	0.51	0.52	0.71	0.85	0.58	0.67
2	0.26	0.33	0.29	0.33	0.30	0.24	0.21	0.26	0.29	0.25
3	0.30	0.31	0.32	0.34	0.32	0.11	0.21	0.25	0.28	0.21
5	0.26	0.25	0.27	0.29	0.27	0.33	0.24	0.04	0.13	0.19
6	0.19	0.24	0.18	0.21	0.21	0.08	0.15	0.14	0.15	0.13
8	0.19	0.19	0.23	0.25	0.22	0.08	0.14	0.15	0.16	0.13
	0.27	0.30	0.30	0.34		0.23	0.28	0.28	0.27	
	Manganese ppm x 10^2					Manganese ppm x 10^2				
1	32.30	31.13	35.08	32.32	32.71	25.69	27.72	42.00	23.00	29.81
2	10.10	10.46	11.20	11.45	10.80	9.98	10.10	11.65	11.80	10.88
3	10.98	10.98	10.50	9.95	10.39	7.14	7.56	7.59	5.77	7.02
5	9.45	10.69	12.24	12.21	11.14	5.06	6.15	6.25	6.69	6.04
6	12.51	12.73	11.43	12.31	12.25	4.59	6.37	6.00	6.54	5.88
8	10.40	12.23	9.16	10.03	10.46	4.31	5.70	5.53	7.05	5.65
	14.15	14.70	14.94	14.94	14.71	9.46	10.60	13.17	10.28	
	Iron ppm					Iron ppm				
1	114.71	119.73	132.66	99.77	116.72	114.55	48.88	66.92	113.76	86.03
2	79.06	53.11	114.86	77.56	81.15	124.97	116.14	69.36	99.02	102.37
3	67.86	54.04	51.75	115,44	72.27	28.78	53.03	9.89	16.93	27.16
5	4.45	8.30	3.06	7.16	5.74	5.17	3.19	50.55	2.55	15.37
6	13.73	9.00	14.79	8.09	11.40	12.09	16.42	10.65	3.85	10.75
8	37.70	163.18	81.53	79.43	90.46	13.80	163,57	41.30	58.64	69.33
	52.92	67.89	66.44	64.88		49.89	66.87	41.45	49.13	

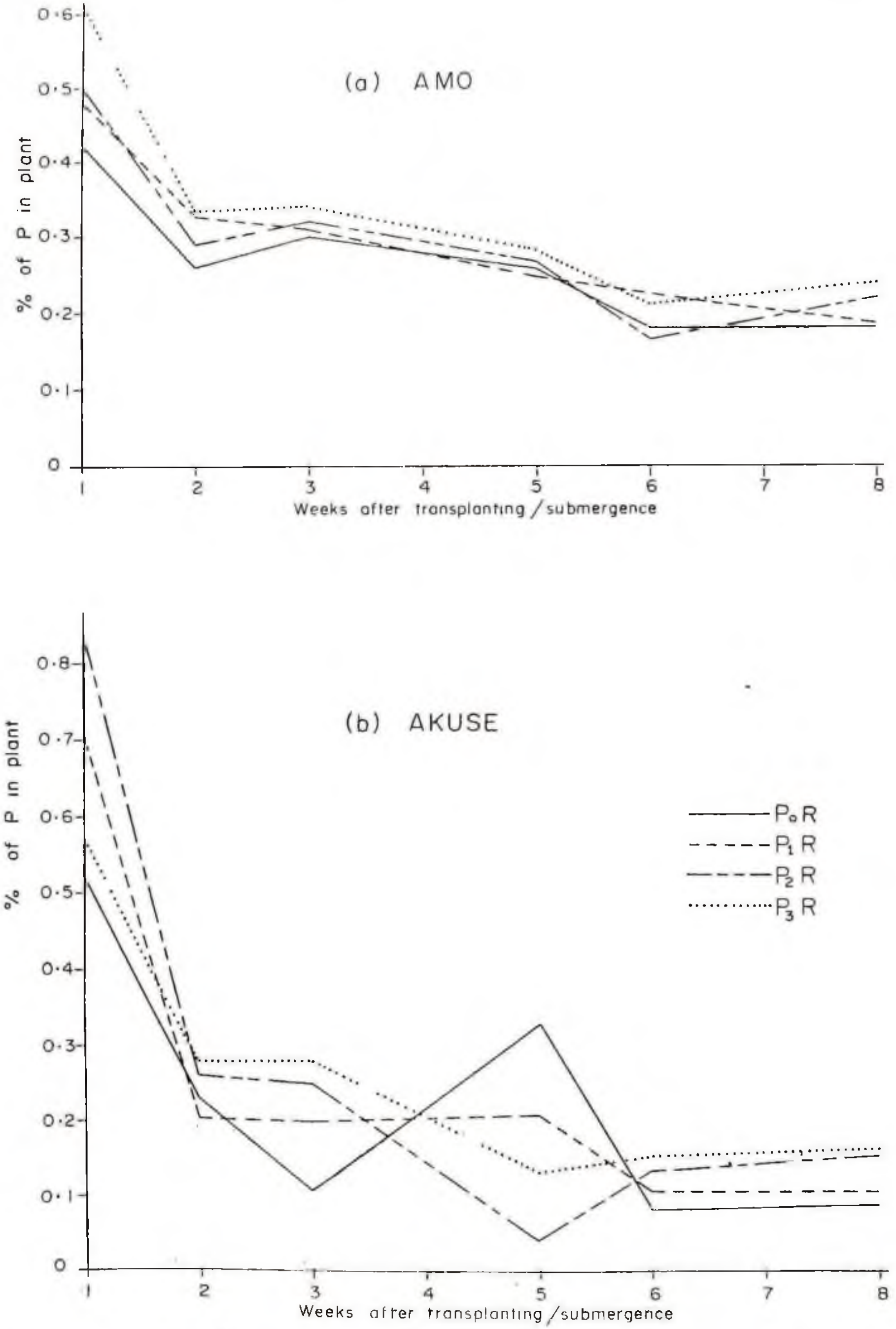


Fig. 13 Phosphorus as percentage of plant material as vs weeks after transplanting/submergence during Paddy growth in pot experiments carried out in the Green House

P in the supernatant in contact with available P in the wet soil, was enough assurance that there was continuity of P supply to the plants. Secondly because the rice was grown under paddy condition, P was released from fixed forms in to the soil solution. As a result of reduction reactions, which ensured adequate supply of P throughout the growing period of the rice plant, especially when there would normally have been P deficiency under upland conditions, Fe phosphate and reductant soluble Fe phosphate may have provided the reduced forms that supplied the required P (Patrick Jr. and Mahapatra, 1968). Thirdly, the rice plant can absorb an adequate amount of P from soil solution with low concentration of phosphate (Okajima, 1965).

It has been suggested that if a soil is deficient in phosphate early application ensures (a) the development of a good root system, (b) high absorbing power of rice roots during the initial growth stages (Takahashi et al., 1955) (c) healthy growth of the young rice plant (Peterson, 1968) (d) efficient utilization of

P absorbed during tillering stages for grain production and any P taken up beyond this point accumulates in the grain, straw and roots (Patnaik _et al_., 1965) (e) Good yield (Mitsui 1954). For these reasons, if there is deficiency of P, retardation of tillering easily takes place. This must have been a very important reason why the rice crops grown on Akuse series with P_0 treatment in particular were quite retarded in growth (plate 2 page 146). Though under submergence the Akuse series had more extractable P than Amo series, the actual P in the supernatant, which is the readily available form to the plants, was greater in Amo series. This may have affected the rice plants.

The percentage of P in plant material (table 8) increased with increase in P application in most of the treatments. The highest values in Amo series were obtained (Fig.13a) in the first week but decreased in the second week. There was a slight increase in the third week followed by a gradual decrease into the sixth week and another slight increase in the eighth week. The shape of this curve for Amo series follows exactly some of the findings of Ishizuka (1965). He reported that the percentage of P is high in the seedling stage. As a seed it contains a certain amount of P, and absorbs large available amounts under paddy. These values decrease rapidly after transplanting to give readings taken in the second week after transplanting/ submergence. There is then a gradual increase as in the third week depending on the recovery of any damage induced during transplanting. Tillering takes place as it reaches a high percentage in the third week that is about the time for the formation of flower primordia. According to Ishizuka (1965) this high percentage of P continues till flowering time. However, under the present investigation there was a very gradual decrease instead until flowering time in the fifth week of sampling. The decrease Ishizuka (1965) expected took place until dough stage in the sixth week. The graph (Fig. 13a) shows a slight increase in P in the eighth week over that at the dough stage. Though there was grain in some of the plants in the eighth week, it was far from being completely formed.

Plate 2

Pots of Akuse soil cropped with rice transplanted/waterlogged for seven weeks. Each pot of plant represents a different level of added fertilizer - shows poor growth.

The curves (Fig. 13b) for Akuse series treatments did not quite follow the same trends as those for Amo series. Percentage of P in the plant did not increase with increase in P application throughout the sampling period. Once again as suggested by Ishizuka, (1965) and adequately exhibited in table 8 and fig. 13b, the percentage of P was high in the seedling stage as shown in the first week of transplanting. The second week reflects the decrease after transplanting. However, this decrease continued in the plants from the pots with P_0 treatment into the third week of sampling. According to Ishizuka (1965) the subsequent increase in absorption of P depends on how quickly the plants recovered from the disorder induced by transplanting. Nevertheless on recovery the plants with P_0 treatment absorbed the greatest amount of P till flowering time in the fifth week as suggested by Ishizuka (1965). The plants in the pots with P_1 treatment also absorbed increased amount of P into the fifth week. Plants grown in soils with P_2 and P_3 treatments did not show any increase in P uptake in the third and fifth week as was expected. From the perusal of the data (table 8) at least one seedling died in one pot in the replications in pots with P_2 and P_3 treatments in the third, fifth and eighth weeks of sampling. Because the plants were small, the average P absorption greatly affected the values for P in the fifth week. The death of the seedlings in the third and eighth weeks does not appear to have significantly affected the results. Consequently the affected P values for the fifth week were much lower than they should have been.

Phosphorus in plant material was significantly affected at 5% and 1% (table 5c) by the type of soil used to grow the rice plants. Plants grown in Amo series absorbed less P in the first week than those grown in Akuse series(table 8). But from the second week onwards plants in Akuse series absorbed far less P (table 4) than those grown in Amo series. The level of P applied was significant only at 5% to the amount of P in the plant material. This is reflected to some extent in table 8 and 4. Thus by and large, there was a tendency for the P in the plant material to increase with increase in applied P though not consistently so.

Period of paddy growth greatly affected the percentage of P in the plants and significant at 5% and 1% levels (table 5c). The values of P (table 8) could be seen to decrease in the plant material with increase in weeks of submergence in most of the treatments. The interaction between type of soil and weeks of submergence was also significant to the amount of P in the plant material at 5% and 1% (table 5c) levels. With reference to fig. 16, there was a steep drop in P absorbed by plants from Akuse series treatments in the second week, but less of a drop in plants from Amo series treatments. The P in Akuse series treatments decreased in the plants until the percentage of P was about constant. Whereas the percentage of P in plants from Amo series treatments increased in the third week slightly, decreased gradually till the sixth week and increased slightly in the eighth week, the patterns were different.

The level of P and number of weeks of submergence interaction was significant at 5% and 1% level to the P in the plant material. Type of soil, level of P applied and length of submergence interaction was significant to the P in the plant material. The highest percentage of

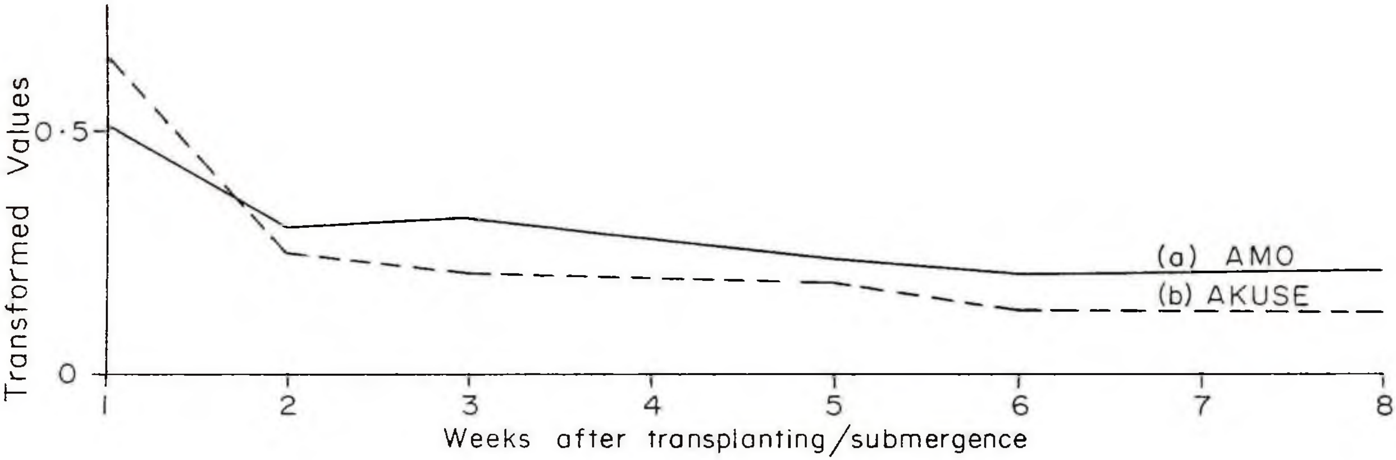


Fig. 16 Effect of soil and time after transplanting/submergence interaction on P in plant tissue during Paddy growth

P in the plant material from Amo series was with 0.61 with P_3 treatment that from Akuse series was 0.85 with P_2 treatment both observed in week 1 (table 8). The lowest percentage of P in plant material from Amo series was 0.18 with P_2 treatment in week six and that from Akuse series was 0.04 with P_2 treatment in week five. The highest mean of means were in week 1 and lowest in week six in both soils. Because of the combination of factors everything being equal, and the types of soil, the dry matter yield (table 9) was more per pot for Amo series than for Akuse series.

3.4.2. Manganese in Plant material

From table 8, the experimental values of Mn in the plant material ranged between 916 and 3508 ppm in Amo series and 431 and 4200 ppm in Akuse series. Similar values of Mn have been reported by Clark *et al*. (1957) who also stated that they had had 10,000 ppm of Mn (unpublished) in plants that appear entirely compatible with good rice growth on waterlogged soils. There was some tendency (table 8) in plants grown in Akuse series to have Mn values that increased with increase in P applied, but less so in plants grown in Amo series.

The highest Mn concentrations were obtained in the first week of sampling. These values correspond to the figures obtained for Mn in the supernatant in the first week of sampling (Fig. 4a and b). Hence an increase of Mn in the supernatant resulted in greater absorption of Mn in the plant. Similarly in the second or third week when the Mn decreased in the supernatant there was a similar decrease in the tissue of the rice shoot. Increase in tissue Mn with increase in Mn in the external medium has been reported by Vlamis and Williams (1964). Flooding conditions were found to be favourable to rice plant uptake of Mn, either through increase solubility of Mn in the soil solution or possible stimulation of root absorption of the nutrient (Cherian, Paulsen, Murphy 1968; Ponnamperuma, 1965; Ghoneim, El-Gibaly and Hassanin 1974). Numerous investigators have highlighted the high requirement of rice plants for Mn (Aiyer, 1946; Ponnamperuma 1965; Vlamis and Williams, 1964). Clark _et al_. (1957) in an investigation, concluded that rice has a high requirement for and an exceptional tolerance to manganese.

Concentration of Mn decreased steeply in the second week in all plants that grew on Amo series (Fig.14a and b), but the decrease continued into the third week of sampling in those that grew on Akuse series. The differences between the values obtained in the second and third week of Mn concentration in plants grown on Amo series were far less than those recorded from plants grown at the same time on Akuse series (table 8). The decline in the concentration of Mn may have been caused as a result of the adjustment the plants had to make because they were transplanted. This appears to have gone on a week later in Akuse series. This decrease continued more or less gradually till the eighth week with slight increase shown in P_3 treatment in the eighth week (Fig. 14b). In the case of plants grown on Amo series (Fig. 14a) there was a further decrease in Mn in treatment P_0 and P_1 in week 5, the concentration of Mn increased in these in the sixth week but decreased again in the eighth week.

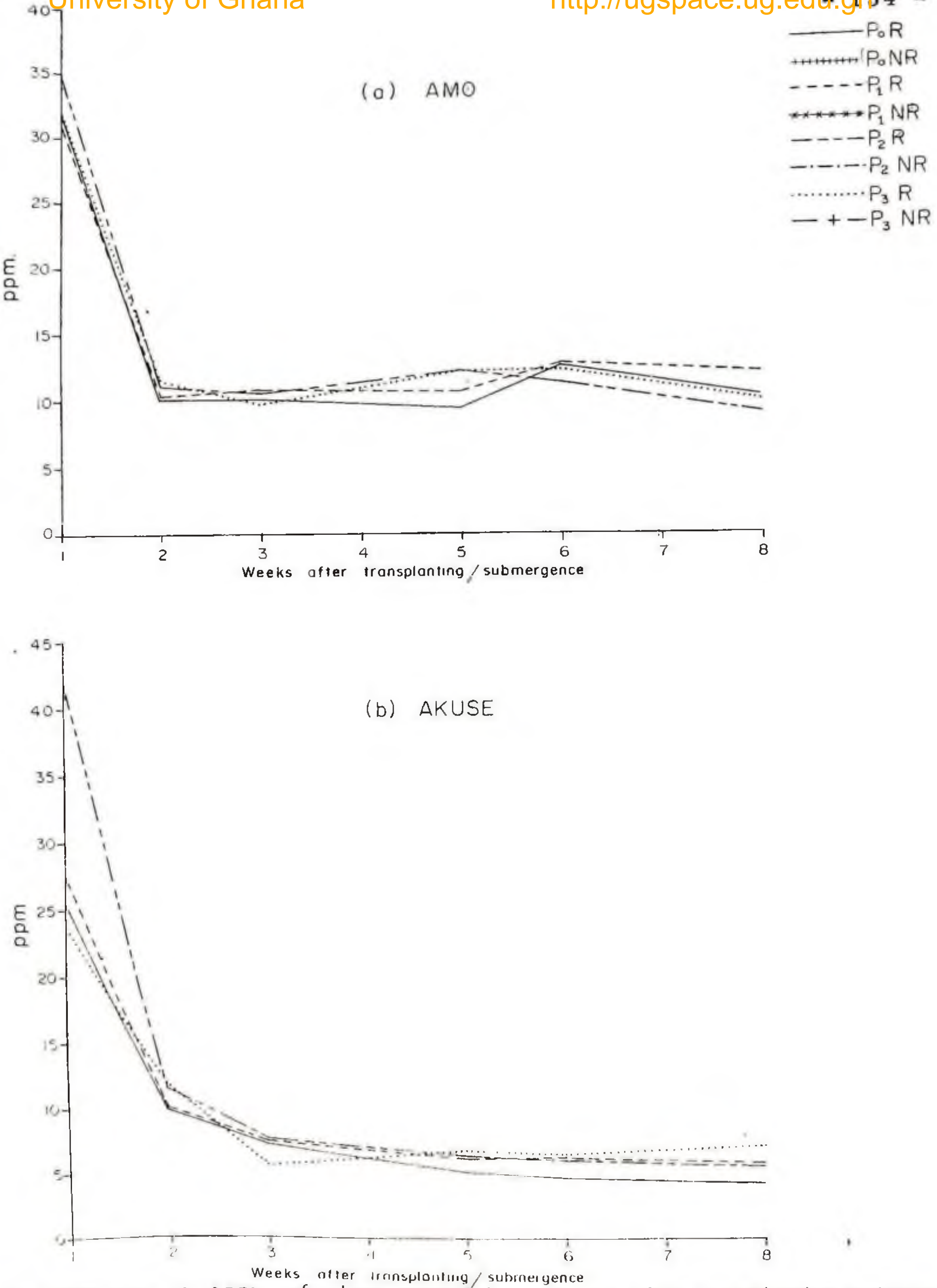


Fig 14 Manganese in ppm. of plant material vs weeks after transplanting/submergence during Paddy growth in pot experiments carried out in the Green House

Whilst plants in treatment P_2 and P_3 had increased Mn concentration in the fifth week but decreased in the eighth week. Due to interaction between nutrients themselves, the availability of one nutrient is influenced by another (Pathak et al. 1972), nor does it remain constant during the crops growth and the performance of the crop very much depends on this changing pattern of nutrient availability (Basak and Bhattacharya 1962). Just as in the case of Mn in the supernatant, the Mn in the plant tissue generally continued to decrease in the eighth week of sampling.

A marked yield response to Mn was observed by Clark et al. (1957). But at low pH, availability of Mn increases to toxic levels (Adams and Wear, 1957) and deficiency of Mn in plant only occurs above pH of 6 (Black et al., 1965)

The types of series used Amo and Akuse were significant at 5% and 1% to the amount of Mn in their plant tissue (table 5). Throughout the sampling (table 8) the Mn level for plants grown in Amo series treatments were always higher than those grown on Akuse series treatments. The differences between the concentration of

Mn in the plant tissue of the different treatments in Amo and Akuse series increased as the weeks went by till the eighth week when those of Akuse series were almost half of those in plants from Amo series (table 8).

The number of weeks of submergence *per se* was significant at 5% and 1% to the Mn present in the plant tissues. This could be related to the decrease in Mn concentration in the plant material with weeks of submergence with slight deviation in the fifth and sixth weeks in Amo series treatments.

3.4.3. Iron in Plant Material

Results obtained from the investigation into the concentration of Fe absorbed by the rice plant under study (Fig.15a and b) show quite different trends from those obtained for other nutrients (Fig.13a and b and Fig. 14a and b). In Amo series treatments the Fe absorbed by the plants ranged between 3.06 and 163.18 ppm (table 8) and for plants grown in Akuse series between 2.55 and 163.57 ppm. Large amounts of Fe were absorbed in the first week of all treatments in Amo series, but some of the values increased in the second week in Akuse series. All values of Fe concentration in the plant material decreased fairly steeply till the fifth week except those of plants grown with P_2 treatment which has one pot of plants with abnormally high value from Akuse series.The data for iron in the plant material are not related to iron concentration in the supernatant except the values obtained in the sixth week for soluble Fe. The concentration of Fe in plant material decreased steeply up to the fifth week because, the pH of the supernatant probably affected the root system and its capacity to absorb nutrients. If the pH of the soil is greater than 7, the plants may not be able to absorb enough Fe. The iron is oxidized and therefore precipitated around rice roots at increased pH values (IRRI, 1963) between third and fifth weeks as reflected in table 2a and b. In the sixth week the pH of the supernatant from the different treatments decreased, so there was a slight increase in the absorption of Fe by the roots. Further reduction took place in the pH of the supernatant in the eighth week hence the increase in iron concentration in the plants from most of the treatments. The increase of Fe

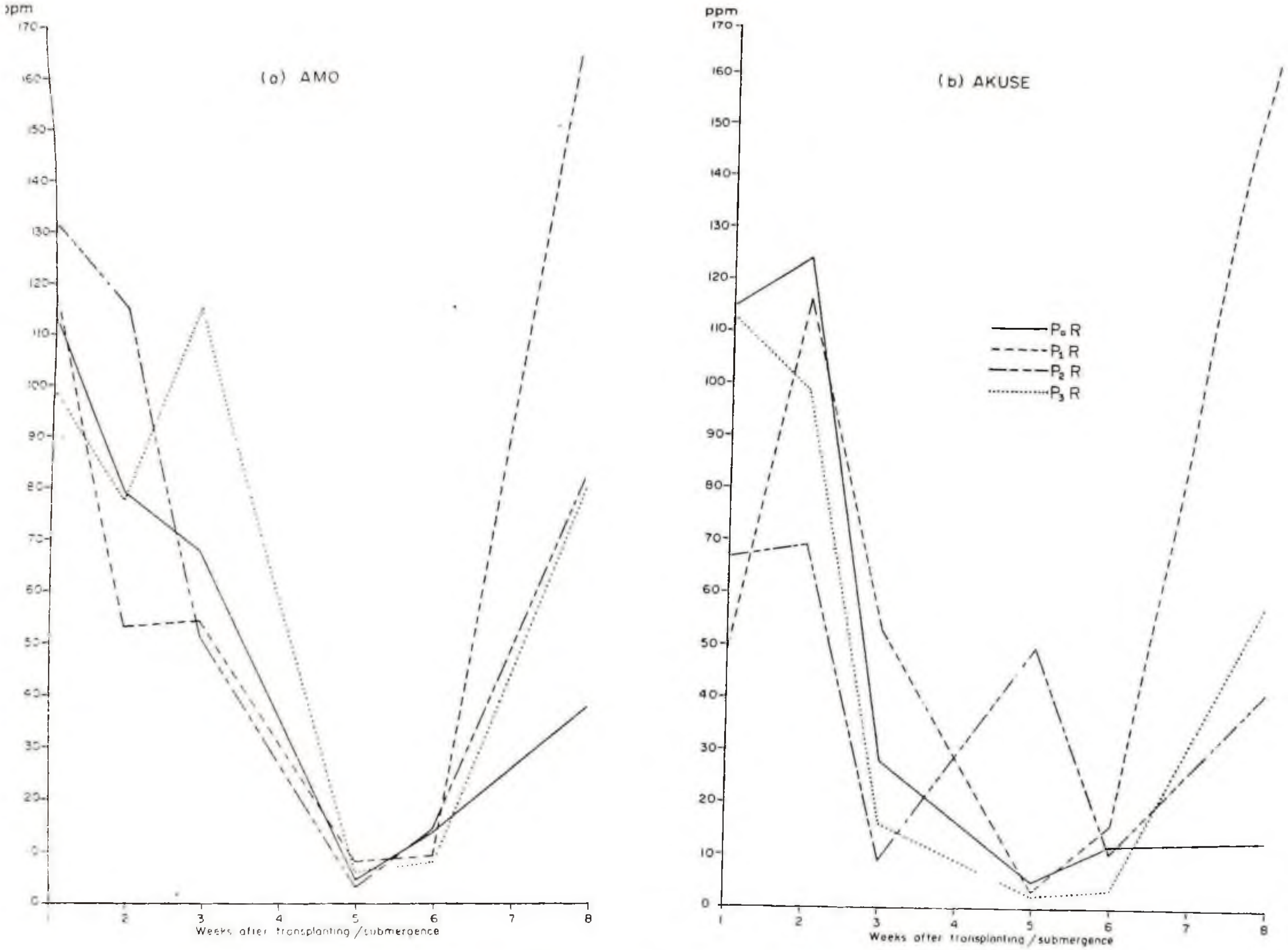


Fig 15 Iron in ppm of plant material vs weeks after transplanting / submergence during Paddy growth in pot experiments carried out in the Green House

in the last samples (eighth week) is in contrast to the decrease of P and Mn in the plant material at the same time but related to Fe in the wet soil.

Period of submergence has been the only factor significant at 5% and 1% to the amount of Fe in the plant material. It appears that the amount of Fe absorbed by the plant depended to a great extent on the pH of the medium and the period of submergence. Weeks of submergence has indeed increased the amount of Fe in both the wet soil and the plant tissue.

Iron and Manganese play an important role in the nutrition of the rice plant (Mandal, 1961). Gericke (1930) studied nutrient requirements of rice in culture solution, and found that iron had to be added to nutrient solution more frequently for young rice seedlings than for any other cereal grown under the same conditions. He also discovered that rice required iron in culture solution longer than other elements except nitrogen and potassium. Aiyer (1946) observed that along with iron, rice required Mn in much larger quantities than other minor elements. Japanese workers (1954) claimed that rice yield increased ten percent by Fe and Mn supply. A marked yield response of rice to Mn was observed by Clark et al. (1957) who concluded that rice has a high requirement for and exceptional high tolerance to Mn. Hence it is important to have an adequate supply not only of P but also of Fe and Mn during the growth of rice, short of which they should be applied as fertilizers.

Conflicting reports about Mn (Senewiratne and Mikkelsen, 1961) and observations (IRRI, 1963) that flooding promotes Mn uptake in neutral soil, compared toa non-flooded soil, emphasized the complexities of the Mn nutrition of the rice plant(Ponnamperuma, 1965). An example being that the oxidized rhizosphere of rice roots precipitates iron more readily than Mn, thus altering the Fe/Mn ratio in the soil solution. Mandal (1961) also suggested that the mechanism of the processes leading to an increase of the reduceable Mn in a waterlogged soil is not properly understood as in fig. 4a,4b and 9a.

The factors that influence Fe II uptake by rice plants are not clearly understood. Controversial reports about toxic levels of Fe suggest complexity of factors regulating Fe uptake by rice (Ponnamperuma 1965) as seen in fig. 5a, 11a and b.

3.5.0. Yield of Rice

The beneficial effect of flooding on rice growth has been attributed to increased availability of mineral nutrients (Aiyer, 1946; Shapiro, 1958ab; Clark et al., 1957; IRRI, 1963, 1965). Gralley and Adair (1943) showed that rice plants grown on continously submerged soil were larger, tillered more profusely, produced higher yields and had a high grain to straw ratio than plants grown on moist but not submerged soils.

Dry matter yield produced in this investigation (table 9) has been represented graphically (Fig. 17a and b). In Amo soil series, the yield ranged from 0.09 g/pot to 12.37 g/pot , and in Akuse series it ranged from 0.04 g/pot to 4.42 g/pot. The curves (Fig. 17a) for plants grown in Amo series were steeper than those (Fig. 17b) grown in Akuse series. This shows that those that grew in Amo series grew more profusely, were bigger and better tillered than those that grew on Akuse series (plate 3 page 165). The control (P_0) of Amo series appeared much the same as any of the other treatments even though figs. 3a, 4a, 11a, 13a, 14a and even 15a all appear to show that P_0 treatment of Amo series had less available nutrient and less was absorbed by plants grown in it (plate 1 page 166). But plants in the P_0 treatment of Akuse series had the most stunted growth (plate 2 page 146) with less nutrient available. In general all the plants grown on Akuse series lagged behind those that grew on Amo series in terms of nutrient absorbed and weight of plant (plate 3 page 165). This was because there was always less readily available nutrient in the supernatant of Akuse series than in that of Amo series, not withstanding the fact that the original Amo series had more of the nutrients under study.

TABLE -9

MEAN VALUES OF DRY MATTER YIELD OF RICE (g) DURING PADDY GROWTH IN POT EXPERIMENTS CARRIED OUT IN THE GREEN HOUSE

AMO series

Treatment	Week 1	2	3	5	6	8
P_o	0.13	0.54	1.94	5.19	7.25	10.03
P_1	0.12	0.55	1.99	5.43	5.62*	12.37
P_2	0.11	0.49	1.73	5.27	7.43	9.07*
P_3	0.09	0.48	1.70	5.02	7.12	8.66*

AKUSE series

P_o	0.08	0.19	0.43	1.07	1.58	2.83
P_1	0.06	0.26	0.98	1.65	2.53*	4.42
P_2	0.04	0.19	0.68	1.85*	3.17	3.21*
P_3	0.06	0.22	0.79	2.52*	3.57	3.45*

*Pots in which one or two seedlings died.

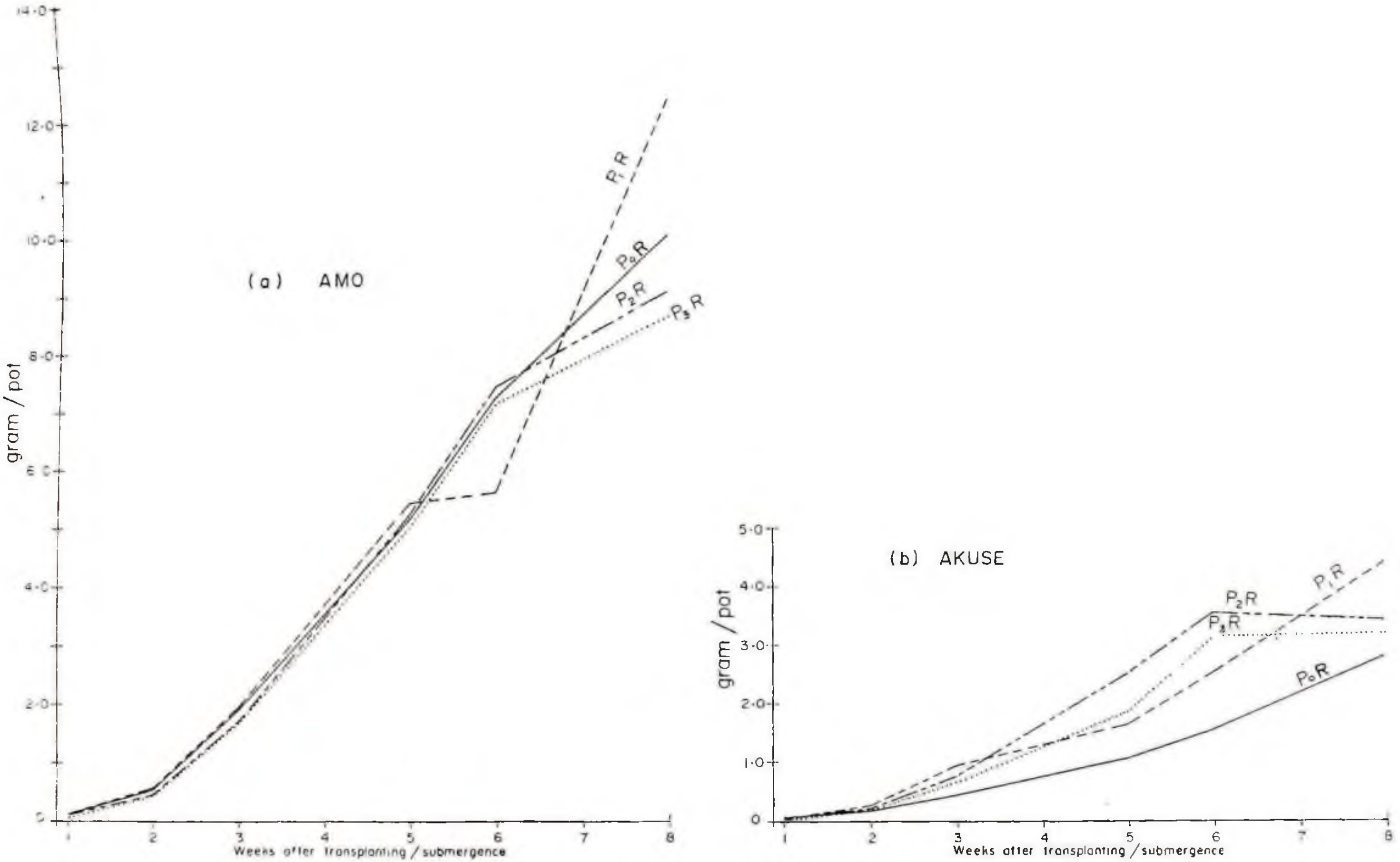


Fig 17 Dry matter yield of Rice vs weeks after transplanting / submergence in pot experiments carried out in the Green House

Amo and Akuse series 3

Plate 3

Pots of Amo soil (left) and Akuse soil (right) transplanted/water logged for seven weeks. This shows the obvious contrast in growth of the rice plants in the two soils series under the same conditions.

Plate 1

Pots of Amo soil cropped with rice transplanted, waterlogged for seven weeks. Each pot of plant represents a different level of added fertilizer - shows healthy growth.

CHAPTER FOUR

SUMMARY AND CONCLUSION

Introduction

A greenhouse pot experiment was set up to find the effect of added phosphorus on the availability and uptake of P, Mn and Fe by rice plant under flooded conditions. Two soil series Akuse and Amo (Vertisol and Inceptisol, respectively) were used. The experiment was of a simple factorial design comprising of four levels of P with and without rice plant on both soils under continuous submergence. Samples of growing rice plants, supernatant soil solution, and the wet soils were taken for laboratory analysis at one, two, three, five, six and eight weeks of age during an eight week period. The soluble P, Mn and Fe in the supernatant liquids, the uptake of these ions by the plant and the extractable Mn and Fe from the wet soil were determined.

Supernatant Liquids

Phosphorus

P_0 treatment produced the least amount of P in the supernatant liquids of Amo cropped series whilst P_1 treatment produced the most. P_3 treatment produced the least amount of P in the supernatant of cropped Akuse series and P_1 the most.

Generally the cropped and uncropped (control) soils followed similar trends in both soil series. From the mean of means table 4, and statistical analysis the two soils had significant effect on the P in the supernatant liquids.

Manganese

The supernatant from pots with cropped Amo series with P_0 treatment contained the least amount of Mn on an average (table 4). Manganese concentration in cropped Amo series pots containing P_1 treatment was the highest. P_3 treatment produced just about as much Mn in the supernatant as P_0 treatment for the cropped pots. In Akuse series treatments, the higher the level of P treatment the smaller the quantity of Mn in the supernatant. Supernatants from uncropped pots (control) of both soil series gave most irregular results. Manganese concentration in the supernatant liquids was greater in Amo than in Akuse series treatments, and the differences in the soils were quite significant.

Iron

Concentration of Fe in the supernatant liquids was greater in Amo than in Akuse series treatments though not supported satistically. In Akuse series treatment there was generally an increase in Fe concentration with increase in P applied and supported statistically.

Both Fe and Mn entered the exchange complex within a week. The concentration of water soluble Mn was however found to be less than that of Fe in all treatments.

Wet Soil

Phosphorus

Trends in the concentration of extractable P were much the same for the two soil series treatments.

Phosphorus in the wet Akuse series was generally greater in concentration than that from wet Amo series. Because the results did not show a clear pattern this may be a reason why results of information on the changes in concentration of P in soil extractants with time is scarce.

Manganese

Graphs drawn of extractable Mn against time for both soil series had generally the same trends, an increase in the first week, decrease in the second or third up to the fifth and another increase thereafter. Increase or decrease was much steeper in Akuse than Amo series treatments P_0 treatment had amongst the highest values of Mn concentration extracted.

Iron

The general pattern of extractable Fe in the treatments was the same for both soil series and most of the treatments had still not reached maximum concentration of extractable Fe by the eighth week. Values of Fe concentration were higher in Akuse than in Amo series in most of the treatments, though the original Amo series contained more iron.

The Plants

Phosphorus

Percentage of P in the plants generally increased with increase in P application from low to high . P in plant tissue of Amo series treatments was greater than that in Akuse series treatments. All values decreased with weeks of submergence.

Manganese

There was increase in Mn in plant material with increase in applied P in Akuse but not in Amo series treatments. There was a steep decline in the second week and gradual decrease till the eighth week. Plants from Amo series treatments had more Mn throughout than those from Akuse series treatments.

Iron

Iron in the plant material did not appear to have been affected by the application of P. Nevertheless after a steep decline in the fifth week generally in all treatments, the concentration rose again to the eighth week. There appears to be some relationship between the eighth week (Fig.15a and b) and the sixth week (Fig.3a and b). The results for Fe in plant tissue are markedly different from those of Mn and P in plant tissue. Once again the figures for Amo series treatments are greater than those for Akuse series treatments.

Phosphorus, manganese and iron in the plant material were about a thousand times or more than the corresponding amounts in the supernatant liquids especially in the first two or three weeks of paddy growth. P_0 treatment did not seriously affect the amount of nutrients in the plants from Amo series, but in the plants from Akuse series P_0 treatment had the lowest concentration of nutrients. The plants grown in Akuse series were stunted compared to all those grown in Amo series (plate 3 page 165). Hence Akuse series needs fertilizer treatment far more than Amo series does for the two soil series to produce comparative dry matter yield.

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APPENDIX 1a

PHOSPHORUS IN SUPERNATANT ppm
DURING STAGES OF PADDY GROWTH IN POT EXPERIMENTS
(AMO series

Level of P	Week 1	2	3	5	6	8
$P_o\ R_1$	1.514	1.887	0.00	0.966	3.951	0.820
2	4.523	1.071	0.00	0.828	2.599	0.820
3	4.623	0.804	0.00	0.828	1.806	NS
Mean	3.59	1.254	0.00	0.87	2.79	0.82
P_oNR_1	3.051	1.071	0.279	1.380	0.769	1.366
2	2.274	1.071	0.00	2.797	1.026	1.366
3	2.667	0.804	0.00	1.104	0.769	1.644
Mean	2.664	0.98	0.09	1.76	0.85	1.46
$P_1\ R_1$	4.235	7.061	0.977	1.242	14.895	3.057
2	3.441	0.268	0.558	0.828	0.513	1.366
3	1.892	1.473	0.00	1.380	8.823	NS
Mean	3.19	2.93	0.51	1.15	8.08	2.21
P_1NR_1	1.514	0.804	0.838	2.082	0.641	1.640
2	2.667	0.670	0.00	1.806	1.410	1.640
3	2.477	0.536	1.208	1.806	2.062	1.504
Mean	2.22	0.67	0.68	1.90	1.37	1.50
P_2R_1	5.024	0.670	0.00	0.690	3.671	0.957
2	3.234	0.268	0.00	1.104	1.538	0.820
3	5.419	1.071	0.279	1.104	3.671	NS
Mean	4.56	0.67	0.09	0.97	2.96	0.89
P_2NR_1	5.830	0.268	0.00	1.380	0.513	0.547
2	2.667	1.071	2.830	1.944	8.229	1.790
3	5.024	0.268	0.558	1.518	1.282	1.094
Mean	4.51	0.54	1.23	1.61	3.34	1.14

NS - No Sample; R - Rice; NR - No Rice.

APPENDIX 1a (cont'd.)

Level of P	Week 1	2	3	4	5	6
P_3 R_1	5.024	0.536	0.00	0.276	2.600	0.820
2	5.024	1.071	0.00	1.104	6.760	1.094
3	4.232	0.804	4.594	0.552	6.469	NS
Mean	4.76	0.80	1.53	0.64	5.28	0.96
P_3NR_1	5.832	1.340	0.00	1.380	5.058	3.629
2	5.024	1.071	0.977	1.104	1.575	1.366
3	9.987	2.435	1.675	1.656	3.671	1.640
Mean	6.95	1.62	0.884	1.38	3.43	2.21

P - Phosphorus Level; NS - No Sample; R - Rice-
NR - No rice.

APPENDIX 1b

PHOSPHORUS IN SUPERNATANT IN PPM DURING STAGES OF PADDY GROWTH IN POT EXPERIMENTS

AKUSE series

Treatment	Week 1	2	3	5	6	8
P_o R_1	2.754	2.154	0.146	0.00	0.621	1.146
2	1.172	1.339	0.00	0.00	0.621	1.003
3	3.144	1.862	0.00	0.00	0.310	NS
Mean	2.36	1.34	0.05	0.00	0.52	1.075
$P_o NR_1$	1.563	1.862	0.293	0.00	0.310	1.146
2	1.563	0.803	0.585	0.00	0.931	0.859
3	3.552	0.803	2.354	0.00	0.124	1.432
Mean	2.23	1.16	0.78	0.00	0.46	0.76
P_1 R_1	1.172	7.080	1.170	1.590	7.827	1.289
2	1.954	0.842	0.00	0.00	0.621	0.859
3	1.563	0.281	0.293	0.00	0.931	NS
Mean	1.56	2.73	0.49	0.53	3.13	1.074
P_1 NR_1	2.345	1.123	0.878	0.00	0.931	0.716
2	1.759	1.403	1.463	0.00	0.931	0.716
3	3.144	2.258	2.061	0.00	5.105	1.146
Mean	2.42	1.59	1.48	0.0	2.32	0.86
P_2 R_1	1.563	0.842	1.463	0.00	0.310	0.859
2	1.563	0.982	0.00	0.00	2.821	1.289
3	0.782	0.561	0.00	0.00	0.310	NS
Mean	1.30	0.80	0.49	0.0	1.15	1.074
$P_2 NR_1$	2.345	0.842	0.878	0.867	0.931	0.573
2	1.563	1.544	0.731	0.00	0.931	0.573
3	2.345	9.989	2.965	0.145	7.122	1.432
Mean	2.08	4.13	1.52	0.34	3.00	0.86

NS - No Sample; R - Rice; NR - No Rice.

APPENDIX 1b (contd.)

AKUSE series

Treatment	Week 1	2	3	5	6	8
P_3 R_1	4.422	0.842	0.293	0.00	0.310	1.719
2	3.144	0.842	0.00	0.00	0.310	1.146
3	6.856	1.123	0.00	0.00	0.621	NS
Mean	4.81	0.94	0.10	0.00	0.41	1.43
P_3NR_1	5.187	1.977	0.438	0.00	1.551	2.018
2	6.856	3.725	0.438	0.00	4.118	1.146
3	2.754	1.403	1.463	0.00	1.861	2.305
Mean	4.93	2.37	0.78	0.00	2.51	1.823

R - Rice NR - No Rice NS - No Sample

APPENDIX 2a

MANGANESE IN SUPERNATANT (ppm) DURING STAGES OF PADDY GROWTH IN POT EXPERIMENTS

AMO series

Treatment	Week 1	2	3	5	6	8
P_o R_1	0.191	0.00	0.236	0.124	0.155	0.00
R_2	0.287	0.058	0.177	0.099	0.103	0.00
R_3	0.634	0.173	0.00	0.298	0.103	NS
Mean	0.37	0.08	0.14	0.17	0.12	0.00
P_oNR_1	0.239	0.00	0.416	0.635	0.026	0.000
2	0.239	0.259	0.855	0.325	1.046	0.000
3	0.143	0.00	0.537	0.224	0.129	0.158
Mean	0.21	0.09	0.60	0.39	0.48	0.05
P_1 R_1	0.385	0.00	0.236	0.224	0.129	0.00
2	0.634	0.231	0.118	0.224	0.206	0.00
3	0.215	0.00	0.118	0.149	0.155	NS
Mean	0.41	0.08	0.16	0.20	0.16	0.00
P_1NR_1	0.287	0.00	0.354	0.248	0.129	0.00
2	0.191	0.346	0.236	0.556	0.363	0.315
3	0.191	0.231	0.598	0.174	0.103	0.00
Mean	0.223	0.19	0.40	0.33	0.20	0.11
P_2 R_1	0.191	0.346	0.00	0.174	0.206	0.00
2	0.337	0.289	0.295	0.248	0.026	0.00
3	0.191	0.289	0.118	0.124	0.155	NS
Mean	0.24	0.31	0.14	0.18	0.13	0.00
P_2NR_1	0.215	0.465	0.236	0.504	0.103	0.0
2	0.287	0.827	0.177	0.325	0.155	0.0
3	0.287	0.465	0.354	0.325	0.103	0.0
Mean	0.263	0.59	0.26	0.38	0.12	0.00

APPENDIX 2a (contd.)

Treatment	Week 1	2	3	5	6	8
$P_3 R_1$	0.143	0.346	0.236	0.099	0.077	0.0
2	0.385	0.407	0.236	0.099	0.052	0.0
3	0.143	0.231	0.00	0.199	0.103	NS
Mean	0.22	0.33	0.16	0.13	0.08	0.00
P_3NR_1	0.143	0.231	0.059	0.248	0.206	0.00
2	0.143	0.407	0.475	0.400	0.052	0.423
3	0.337	0.231	0.236	0.452	0.310	0.00
Mean	0.21	0.29	0.27	0.37	0.19	0.14

R = Rice, NR = No Rice, NS = No Sample

APPENDIX 2b

MANGANESE IN SUPERNATANT (ppm) DURING STAGES OF PADDY GROWTH IN POT EXPERIMENTS

AKUSE series

Treatment	Week 1	2	3	5	6	8
$P_o R_1$	0.099	0.121	0.179	0.104	0.548	0.0551
2	0.148	0.242	0.00	0.026	0.135	0.00
3	0.148	0.121	0.00	0.00	0.108	NS
Mean	0.13	0.16	0.06	0.04	0.26	0.03
$P_o NR_1$	0.049	0.181	0.00	0.052	0.297	0.00
2	0.148	0.242	0.00	0.026	0.00	0.193
3	0.419	0.242	0.00	0.130	0.243	0.028
Mean	0.21	0.22	0.00	0.07	0.18	0.07
$P_1 R_1$	0.247	0.181	0.00	0.026	0.135	0.00
2	0.148	0.061	0.00	0.00	0.081	0.028
3	0.247	0.061	0.00	0.078	0.027	NS
Mean	0.21	0.10	0.00	0.03	0.08	0.01
$P_1 NR_1$	0.148	0.00	0.00	0.078	0.162	0.028
2	0.222	0.00	0.00	0.00	0.026	0.00
3	0.247	0.00	0.00	0.00	0.130	0.027
Mean	0.21	0.00	0.00	0.08	0.061	0.02
$P_2 R_1$	0.500	0.00	0.00	0.078	0.135	0.00
2	0.348	0.613	0.00	0.182	0.00	0.00
3	0.298	0.00	0.00	0.026	0.00	NS
Mean	0.38	0.20	0.00	0.10	0.045	0.00
$P_2 NR_1$	0.630	0.121	0.00	0.156	0.00	0.00
2	0.323	0.00	0.00	0.182	0.00	0.00
3	0.372	0.00	0.00	0.156	0.00	0.00
Mean	0.44	0.04	0.00	0.16	0.0	0.00

APPENDIX 2b (Contd.)

Treatment	Week 1	2	3	5	6	8
P_3 R_1	0.449	0.00	0.00	0.00	0.00	0.00
2	0.049	0.00	0.00	0.00	0.00	0.00
3	0.197	0.00	0.00	0.00	0.00	NS
Mean	0.23	0.00	0.00	0.00	0.00	0.00
P_3 NR_1	0.222	0.00	0.00	0.130	0.00	0.00
2	0.372	0.00	0.00	0.00	0.00	0.00
3	0.222	0.00	0.00	0.00	0.00	0.028
Mean	0.27	0.00	0.00	0.04	0.00	0.01

R - Rice NR - No Rice NS - No Sample.

APPENDIX 3a

IRON IN SUPERNATANT (ppm) DURING STAGES OF PADDY GROWTH IN POT EXPERIMENTS

AMO series

Treatment	Week 1	2	3	5	6	8
$P_o\ R_1$	0.880	0.985	8.666	0.769	0.390	0.115
2	2.702	0.892	0.257	0.369	0.180	0.155
3	6.841	0.546	0.361	0.348	0.037	NS
Mean	3.47	0.81	3.09	0.50	0.20	0.14
P_oNR_1	3.442	0.985	0.759	1.448	0.804	0.214
2	0.676	0.892	0.807	4.172	0.839	0.155
3	0.611	0.464	1.207	0.417	0.269	0.815
Mean	1.58	0.78	0.92	2.01	0.64	0.39
$P_1\ R_1$	0.392	0.405	0.361	0.140	0.161	0.048
2	0.88	7.806	0.807	0.308	0.220	0.048
3	0.527	0.474	0.237	1.471	0.229	NS
Mean	0.60	2.90	0.47	0.64	0.20	0.05
P_1NR_1	0.527	6.013	1.103	0.612	0.302	0.096
2	0.485	0.385	4.715	1.130	0.279	0.317
3	0.569	0.385	2.286	1.426	0.758	0.255
Mean	0.53	2.26	2.70	1.06	0.45	0.22
$P_2\ R_1$	0.383	8.706	3.360	1.421	0.065	0.077
2	0.699	4.283	0.577	0.515	0.474	0.077
3	0.699	0.848	3.009	0.526	0.132	NS
Mean	0.59	4.61	2.32	0.82	0.22	0.08
P_2NR_1	0.323	0.464	0.467	2.148	0.580	0.155
2	0.383	1.600	1.260	1.031	1.392	0.265
3	0.383	0.938	0.678	0.667	0.229	0.203
Mean	0.36	1.00	0.80	1.28	0.73	0.21

APPENDIX 3a (contd.)

Treatment	Week 1	2	3	5	6	8
P_3 R_1	0.167	0.661	0.446	2.955	0.113	0.115
2	0.505	0.505	0.381	2.285	0.279	0.115
3	0.505	0.825	6.035	2.033	0.210	NS
Mean	0.39	0.66	2.29	2.42	0.20	0.12
P_3NR_1	0.423	0.505	0.667	1.339	2.195	0.453
2	0.443	0.567	3.738	1.118	0.591	0.275
3	0.474	0.567	6.189	2.285	0.329	0.145
Mean	0.45	0.55	3.53	1.58	1.04	0.29

R - Rice NR - No Rice NS - No Sample.

APPENDIX 3b

IRON IN SUPERNATANT (ppm)
DURING STAGES OF PADDY GROWTH IN POT EXPERIMENTS

AKUSE series

Treatment	Week 1	2	3	5	6	8
P_o R_1	0.554	0.424	0.206	0.517	0.087	0.080
2	0.232	1.183	0.184	0.506	0.098	1.611
3	0.609	0.445	0.143	0.365	0.158	NS
Mean	0.47	0.68	0.18	0.46	0.11	0.85
P_oNR_1	0.373	7.294	0.400	0.966	0.240	0.080
2	0.778	0.529	0.206	0.517	0.138	0.091
3	0.609	0.749	0.164	0.419	0.087	0.070
Mean	0.59	2.86	0.26	0.63	0.16	0.08
P_1 R_1	0.353	0.282	0.081	1.914	0.056	0.176
2	6.788	0.529	0.101	0.484	0.138	0.080
3	0.511	0.322	0.060	0.928	0.118	NS
Mean	2.48	0.38	0.08	1.11	0.10	0.13
P_1NR_1	0.384	0.935	0.174	0.322	0.189	0.142
2	1.105	0.795	0.226	0.284	0.189	0.162
3	0.251	0.795	0.605	1.080	0.029	0.00003
Mean	0.58	0.84	0.34	0.56	0.14	0.10
P_2 R_1	1.067	1.234	0.226	0.250	0.087	0.204
2	4.845	0.572	0.226	0.830	0.010	1.611
3	0.981	0.659	0.269	1.106	0.039	NS
Mean	2.30	0.82	0.24	0.73	0.05	0.91
P_2NR_1	1.055	0.572	0.226	0.250	0.179	0.100
2	0.587	1.033	0.305	0.284	0.109	0.051
3	0.653	0.594	0.796	0.408	0.059	0.601
Mean	0.77	0.73	0.44	0.31	0.12	0.25

APPENDIX 3b (contd.)

Treatment	Week 1	2	3	5	6	8
P_3 R_1	0.687	0.983	0.821	0.365	0.138	0.194
2	0.698	0.445	0.060	0.281	0.029	0.00
3	0.981	0.795	0.020	0.506	0.019	NS
Mean	0.79	0.74	0.30	0.38	0.06	0.10
P_3NR_1	0.825	0.322	0.143	0.239	0.029	0.020
2	0.790	0.529	0.651	0.397	0.049	0.040
3	1.620	11.862	0.226	0.375	0.138	0.214
Mean	1.08	4.24	0.34	0.34	0.07	0.09

R - Rice NR - No Rice NS - No Sample.

APPENDIX 4a

TRANSFORMED VALUES OF PHOSPHORUS IN SUPERNATANT

AMD	1	2	3	5	6	8	Weeks
P_o	1.15	-0.90	0.09	0.79	-3.10	0.64	
	-1.98	-0.09	0.09	0.93	-1.75	0.64	
	-1.98	0.45	0.09	0.93	-0.96	NS	
Mean	-0.94	-0.18	0.09	0.88	-1.94	0.64	
P_1	-2.02	-6.39	-0.30	0.66	-13.53	-1.47	
	-1.22	0.40	0.12	1.07	0.86	0.22	
	0.33	-0.80	0.68	0.52	-7.45	NS	
Mean	-0.97	-2.26	0.17	0.75	-6.70	-0.63	
P_2	-0.51	-0.13	1.23	0.92	-0.33	0.18	
	1.28	0.27	1.23	0.51	1.80	0.32	
	-0.91	-0.53	0.95	0.51	-0.33	NS	
Mean	-0.05	-0.13	1.14	0.65	0.38	0.25	
P_3	1.91	1.08	0.88	1.10	0.83	1.39	
	1.91	0.55	0.88	0.28	-3.33	1.12	
	2.72	0.82	-3.71	0.83	-3.04	NS	
Mean	2.18	0.82	-0.65	0.74	-1.85	1.26	

NS - No sample.

APPENDIX 4a (contd.)

TRANSFORMED VALUES OF PHOSPHORUS IN SUPERNATANT

AKUSE	1	2	3	5	6	8	Weeks
P_o	-0.52	-0.99	0.63	0.00	-0.16	-0.39	
	1.06	-0.18	0.78	0.00	-0.16	-0.24	
	-0.91	-0.70	0.78	0.00	0.15	NS	
Mean	-0.12	-0.62	0.73	0.00	-0.06	-0.32	
P_1	1.25	-5.49	0.31	-1.59	-5.51	-0.43	
	0.47	0.75	1.48	0.00	1.70	0.00	
	0.86	1.31	1.19	0.00	1.39	NS	
Mean	0.86	-1.140	0.99	-0.53	-0.81	-0.22	
P_2	0.52	3.29	0.06	0.34	2.69	0.00	
	0.52	3.15	1.52	0.34	0.18	-0.43	
	1.30	3.57	1.52	0.34	2.69	NS	
Mean	0.78	3.34	1.03	0.34	1.85	-0.22	
P_3	0.51	1.53	0.49	0.00	2.20	0.10	
	1.79	1.53	0.78	0.00	2.20	0.68	
	-1.93	1.25	0.78	0.00	1.89	NS	
Mean	0.12	1.44	0.68	0.00	2.10	0.39	

NS → No sample.

APPENDIX 4b

TRANSFORMED VALUES OF MANGANESE IN SUPERNATANT

AMO	1	2	3	5	6	8	Weeks
P_0	0.02	0.09	0.36	0.27	0.33	0.05	
	-0.08	0.03	0.42	0.29	0.38	0.05	
	-0.42	-0.08	0.60	0.09	0.38	NS	
Mean	-0.16	0.01	0.46	0.22	0.36	0.05	
P_1	-0.16	0.19	0.16	0.11	0.07	0.11	
	-0.41	-0.04	0.28	0.11	-0.01	0.11	
	0.01	0.19	0.28	0.18	0.05	NS	
Mean	-0.19	0.11	0.24	0.13	0.04	0.11	
P_2	0.07	0.24	0.26	0.21	-0.09	0.00	
	-0.07	0.30	-0.04	0.13	0.09	0.00	
	0.07	0.30	0.14	0.26	-0.04	NS	
Mean	0.02	0.28	0.12	0.20	-0.01	0.00	
P_3	0.07	0.06	0.03	0.27	0.11	0.14	
	-0.18	0.12	0.03	0.27	0.14	0.14	
	0.07	0.06	0.27	0.17	0.09	NS	
Mean	-0.01	0.08	0.11	0.24	0.11	0.14	

NS - No sample.

APPENDIX 4b (contd.)

TRANSFORMED VALUES OF MANGANESE IN SUPERNATANT

AKUSE	1	2	3	5	6	8	Weeks
P_o	0.11	0.10	-0.18	-0.03	-0.37	0.02	
	0.06	-0.02	0.00	0.04	0.05	0.07	
	0.06	0.10	0.00	0.07	0.07	NS	
Mean	0.08	0.06	-0.60	0.03	-0.08	0.05	
P_1	-0.04	-0.18	0.00	0.05	-0.07	0.02	
	0.06	-0.06	0.00	0.08	-0.02	-0.01	
	-0.04	-0.06	0.00	0.00	0.04	NS	
Mean	0.010	-0.10	0.00	0.04	-0.02	0.01	
P_2	-0.06	0.04	0.00	0.08	-0.14	0.0	
	0.09	-0.57	0.00	-0.02	0.00	0.0	
	0.14	0.04	0.00	0.13	0.00	NS	
Mean	0.06	-0.16	0.00	0.06	-0.05	0.00	
P_3	-0.18	0.00	0.00	0.04	0.00	0.01	
	0.22	0.00	0.00	0.04	0.00	0.01	
	0.07	0.00	0.00	0.04	0.00	NS	
Mean	0.04	0.00	0.00	0.04	0.00	0.01	

NS - No sample

APPENDIX 4C

TRANSFORMED VALUES OF IRON IN SUPERNATANT

AMO	1	2	3	5	6	8 Weeks after transplanting
P_o	0.70	-0.21	-7.75	1.24	0.25	0.28
	-1.12	-0.11	0.66	1.64	0.46	0.24
	-5.26	0.23	0.56	1.66	0.60	NS
Mean	-1.89	-0.03	-2.18	1.51	0.44	0.26
P_1	0.14	1.86	2.34	0.92	0.29	0.17
	-0.35	-5.55	1.89	0.75	0.23	0.17
	0.00	1.79	2.46	-0.41	0.22	NS
Mean	-0.07	-0.63	2.23	0.42	0.25	0.17
P_2	-0.02	-7.71	-2.56	-0.14	0.67	0.13
	-0.34	-3.28	0.22	0.77	0.26	0.13
	-0.34	0.15	-2.21	0.75	0.60	NS
Mean	-0.23	-3.61	-1.52	0.46	0.51	0.13
P_3	0.28	-0.11	3.08	-1.38	0.93	0.18
	-0.06	0.05	3.15	-0.71	0.76	0.18
	-0.06	-0.28	2.51	-0.45	0.83	NS
Mean	0.05	-0.11	2.91	-0.85	0.84	0.18

NS - No sample.

APPENDIX 4C (contd.)

AKUSE	1	2	3	5	6	8 Weeks
P_o	0.04	2.44	0.05	0.11	0.07	0.00
	0.36	1.68	0.08	0.12	0.06	-1.53
	-0.02	2.42	0.12	0.27	0.00	NS
Means	0.13	2.18	0.08	0.17	0.04	-0.77
P_1	0.23	0.56	0.26	-1.35	0.08	-0.08
	-6.01	0.31	0.24	0.08	0.00	0.02
	0.07	0.52	0.28	-0.37	0.02	NS
Mean	-1.90	0.46	0.26	-0.55	0.03	-0.03
P_2	-0.30	-0.50	0.21	0.06	0.03	0.05
	-4.08	0.16	0.21	-0.52	0.11	-1.36
	-0.21	0.07	0.17	-0.80	0.08	NS
Mean	-1.53	-0.09	0.20	-0.42	0.07	-0.65
P_3	0.39	3.26	-0.48	-0.03	-0.07	-0.10
	0.38	3.80	0.28	0.06	0.04	0.09
	0.10	3.45	0.32	-0.17	0.05	NS
Mean	0.29	3.50	0.40	-0.03	0.01	-0.01

NS - No sample

APPENDIX 5a

MANGANESE IN WET SOIL PPM (OVEN DRY BASIS) DURING STAGES OF PADDY GROWTH IN POT EXPERIMENTS

AMO series

Weeks after transplanting	1	2	3	5	6	8
$P_o R_1$	11.53	218.9	168.3	92.71	199.661	199.57
2	165.4	207.3	183.2	188.4	153.905	212.01
3	173.0	214.7	192.9	187.3	156.546	NS
Mean	116.6	213.6	181.5	156.1	170.04	205.79
$P_o NR_1$	160.8	220.8	86.4	192.2	203.36	186.58
2	284.9	172.8	185.7	128.74	96.21	170.54
3	288.5	202.3	154.9	84.5	209.16	191.79
Mean	244.7	198.6	142.3	136.5	169.6	182.97
$P_1 R_1$	259.8	201.2	160.4	139.0	181.94	117.79
2	242.7	222.1	138.7	149.54	170.00	161.34
3	311.2	142.2	135.4	147.4	156.88	NS
Mean	271.2	188.5	144.8	145.3	169.6	139.57
$P_1 NR_1$	264.6	189.0	173.9	124.3	179.86	171.74
2	187.0	241.8	245.3	128.1	100.27	174.03
3	288.3	224.2	230.3	103.0	98.67	166.47
Mean	246.6	218.3	216.5	118.5	126.3	170.75
$P_2 R_1$	276.4	235.7	153.0	157.8	33.19	181.60
2	273.2	228.8	197.9	68.5	164.68	3.81
3	298.0	216.1	215.9	183.5	150.38	NS
Mean	282.5	226.9	188.9	136.6	116.1	92.71
$P_2 NR_1$	242.2	224.7	58.9	176.2	37.56	37.28
2	195.3	256.8	157.6	150.4	195.92	77.94
3	132.1	246.0	194.1	187.3	129.11	172.02
Mean	189.9	242.5	136.9	171.3	120.86	95.75

APPENDIX 5a (contd.)

MANGANESE IN WET SOIL PPM (OVEN DRY BASIS) DURING STAGES OF PADDY GROWTH IN POT EXPERIMENTS

AMO series

Weeks after transplanting	1	2	3	5	6	8
P_3 R_1	285.6	204.5	147.1	171.1	116.93	173.13
2	281.4	216.5	171.4	34.9	145.04	168.63
3	235.0	220.6	12.22	53.0	18.28	NS
Mean	267.3	213.9	110.2	86.3	93.42	170.88
P_3NR_1	235.6	200.6	192.1	174.0	169.05	158.49
2	252.9	232.8	181.9	56.7	21.88	36.04
3	292.6	224.8	181.6	103.7	140.30	27.18
Mean	260.4	219.4	185.3	111.5	110.41	73.9

APPENDIX 5b

MANGANESE IN WET SOIL IN PPM (OVEN DRY BASIS) DURING STAGES OF PADDY GROWTH IN POT EXPERIMENTS

AKUSE series

Weeks after transplanting	1	2	3	5	6	8
P_o R_1	313.9	190.93	2.41	0.00	13.59	42.26
2	291.3	5.22	3.28	0.00	8.61	99.51
3	270.5	162.9	1.93	0.00	48.99	NS
Mean	291.9	119.7	2.54	0.00	23.73	70.89
$P_o NR_1$	119.2	5.24	1.93	0.00	169.32	163.26
2	357.6	9.55	2.90	0.00	38.38	2.0
3	323.0	16.76	4.83	0.00	38.44	1.0
Mean	266.6	10.52	3.22	0.00	82.05	55.42
P_1 R_1	189.3	10.64	1.87	0.00	5.69	0.5
2	116.0	3.15	4.82	0.00	10.61	236.67
3	373.9	12.23	3.85	0.00	5.68	NS
Mean	226.4	8.67	3.51	0.00	7.33	118.59
$P_1 NR_1$	199.3	37.46	0.97	0.00	53.93	249.79
2	168.5	6.29	0.49	3.94	18.59	133.17
3	124.7	13.38	2.41	2.96	6.26	423.35
Mean	164.2	19.04	1.29	2.3	26.26	268.77
P_2 R_1	86.0	20.65	2.89	0.00	11.19	7.06
2	115.0	9.51	2.89	0.00	3.80	27.11
3	113.1	5.74	2.88	0.00	19.25	NS
Mean	104.7	11.97	2.89	0.00	11.41	17.09
P_2 NR_1	139.7	5.78	3.38	0.00	25.64	252.83
2	263.7	4.19	0.96	4.40	19.28	312.16
3	172.7	4.18	1.93	1.99	7.18	212.30
Mean	192.0	4.72	2.09	2.13	17.37	259.10

APPENDIX 5b (contd.)

MANGANESE IN WET SOIL IN PPM (OVEN DRY BASIS) DURING STAGES OF PADDY GROWTH IN POT EXPERIMENTS

AKUSE series

Weeks after transplanting	1	2	3	5	6	8
P_3 R_1	207.5	5.78	2.41	0.99	6.59	0.0
2	179.6	6.24	5.26	0.00	5.70	142.82
3	132.0	6.30	2.90	0.99	31.56	NS
Mean	173.0	6.11	3.52	0.66	14.62	71.41
P_3 NR_1	197.7	2.63	3.96	1.43	138.45	189.55
2	115.6	8.45	2.41	2.97	6.50	0.498
3	297.5	13.97	12.84	1.98	31.59	151.52
Mean	203.6	8.35	6.40	2.13	58.85	113.86

APPENDIX 6a

IRON IN WET SOIL IN PPM (OVEN DRY BASIS) DURING STAGES OF PADDY GROWTH IN POT EXPERIMENT

AMO series

Weeks after transplanting	1	2	3	5	6	8
P_o R_1	9.63	5.07	0.00	0.00	1.394	19.017
2	10.80	0.26	0.00	0.42	0.025	16.623
3	12.87	1.93	3.34	10.04	1.218	NS
Mean	11.10	2.42	1.11	3.49	0.88	17.82
P_oNR_1	1.78	5.66	2.65	0.42	17.422	0.246
2	11.82	0.91	0.00	0.42	0.703	15.958
2	4.65	7.29	0.00	9.28	14.961	18.350
Mean	6.08	4.62	0.88	3.37	11.03	11.52
P_1 R_1	0.91	5.06	0.00	0.00	1.040	16.188
2	1.22	0.93	0.82	0.00	3.440	17.031
3	1.21	3.41	0.00	0.00	0.283	NS
Mean	1.11	3.13	0.27	0.00	1.59	16.61
P_1NR_1	3.19	5.55	0.39	1.63	14.052	2.07
2	2.30	10.75	1.08	10.00	19.838	24.520
3	19.44	5.18	9.69	11.26	13.614	17.485
Mean	8.31	7.16	3.72	7.63	15.83	14.69
P_2 R_1	1.49	4.35	3.21	1.45	11.994	2.248
2	16.53	0.16	0.30	11.05	0.545	16.399
3	1.49	4.84	4.07	0.24	5.919	NS
Mean	6.50	3.12	2.53	4.25	5.99	9.32
P_2NR_1	3.17	0.71	0.00	10.68	1.459	15.591
2	3.50	14.28	0.00	9.87	6.835	20.124
3	9.63	0.82	0.94	8.31	4.511	5.362
Mean	5.43	5.27	0.31	9.62	4.27	13.68

APPENDIX 6a (contd.)

IRON IN WET SOIL IN PPM (OVEN DRY BASIS) DURING STAGES OF PADDY GROWTH IN POT EXPERIMENT

AMO series

Weeks after transplanting

	1	2	3	5	6	8
P_3 R_1	3.19	6.94	0.00	0.00	0.703	1.719
2	9.62	0.38	0.29	10.05	11.179	1.400
3	1.21	0.17	0.00	1.62	13.186	NS
Mean	4.67	2.50	0.10	3.89	8.36	1.56
P_3NR_1	1.45	6.20	0.00	6.45	16.113	19.011
2	0.91	10.53	2.57	0.00	0.701	165.363
3	2.36	0.48	0.38	9.09	16.316	17.439
Mean	1.57	5.74	0.98	5.18	11.04	67.27

APPENDIX 6b

IRON IN WET SOIL IN PPM (OVEN DRY BASIS) DURING STAGES OF PADDY GROWTH IN POT EXPERIMENT

AKUSE series

Weeks after transplanting	1	2	3	5	6	8
$P_o\ R_1$	8.94	10.30	2.00	8.76	11.76	20.61
2	9.34	0.62	3.29	12.94	18.70	16.456
3	1.59	0.17	0.00	0.00	0.578	NS
Mean	6.62	3.70	1.76	7.23	10.35	18.26
P_oNR_1	4.28	5.21	0.00	0.00	18.469	16.506
2	0.70	1.10	1.82	1.18	1.297	18.221
3	9.26	4.96	1.72	0.60	17.441	2.379
Mean	4.75	3.76	1.18	0.39	12.40	12.37
$P_1\ R_1$	8.96	5.96	0.00	0.00	16.047	2.545
2	1.29	1.55	2.69	11.36	19.437	18.410
3	1.30	3.95	0.00	0.00	21.732	NS
Mean	3.85	3.82	0.90	3.79	19.07	10.48
P_1NR_1	1.30	1.92	0.00	2.64	19.058	18.210
2	4.97	4.08	0.50	11.43	1.081	48.373
3	7.30	8.91	2.00	0.45	18.346	5.105
Mean	4.52	4.97	0.83	4.84	12.83	23.90
$P_2\ R_1$	1.61	0.86	1.82	11.20	17.789	16.212
2	6.72	5.96	0.47	11.23	1.295	16.279
3	1.60	2.37	2.20	0.64	19.879	NS
Mean	3.31	3.06	1.50	7.69	12.99	16.25
P_2NR_1	20.21	0.29	0.40	1.19	2.183	27.073
2	7.66	3.70	0.68	0.00	16.531	17.471
3	7.05	4.81	0.00	11.42	18.790	15.821
Mean	11.64	2.93	0.36	4.20	12.50	20.12

APPENDIX 6b (contd.)

IRON IN WET SOIL IN PPM (OVEN DRY BASIS) DURING STAGES OF PADDY GROWTH IN POT EXPERIMENT

AKUSE series

Weeks after transplanting	1	2	3	5	6	8
P_3 R_1	1.31	4.70	1.60	11.25	20.570	15.943
2	1.30	4.53	2.49	0.00	19.463	15.964
3	3.96	5.21	0.95	0.27	18.075	NS
Mean	2.19	4.68	1.68	3.84	19.37	15.95
P_3NR_1	8.91	1.33	2.40	0.81	6.238	19.552
2	9.90	4.08	0.18	0.00	19.491	16.888
3	1.32	7.04	0.00	12.52	4.742	3.631
Mean	6.71	4.15	0.86	4.44	10.16	13.36

APPENDIX 7a

TRANSFORMED VALUES OF MANGANESE IN WET SOIL

AMO	1	2	3	5	6	8	Weeks after transplantir
P_o	233.17	-20.3	-26.00	43.8	-30.06	-16.60	
	79.30	-8.70	-40.90	-51.90	15.69	-29.04	
	71.70	-16.10	-50.60	-50.80	13.05	NS	
Mean	128.06	-15.03	-39.16	-19.63	-0.44	-22.82	
P_1	-13.20	17.10	56.10	-20.50	-55.64	52.91	
	3.90	-3.8	77.80	-31.04	-43.70	9.36	
	-64.6	76.10	81.10	-28.90	-30.58	NS	
Mean	-24.63	29.80	71.67	-26.81	-43.31	31.14	
P_2	-86.5	6.80	-16.10	13.50	87.67	-85.85	
	-83.3	13.70	-61.00	102.8	-44.00	91.94	
	-108.1	26.40	-79.00	-12.2	-29.70	NS	
Mean	-92.63	15.63	-52.03	34.70	4.66	2.03	
P_3	1.80	14.9	38.10	-59.60	-6.52	-99.23	
	-21.0	2.90	13.80	76.60	-34.63	-94.73	
	25.40	-1.20	172.98	58.50	92.13	NS	
	2.07	5.53	74.96	25.17	16.99	-96.98	

NS - No sample.

APPENDIX 7a

TRANSFORMED VALUES OF MANGANESE IN WET SOIL

AKUSE	1	2	3	5	6	8	Weeks after transplanting
P_o	-47.3	-180.4	0.81	0	68.46	13.16	
	-24.7	5.30	-0.06	0	73.44	-44.09	
	-3.90	-152.38	1.29	0	33.06	NS	
Mean	-25.2	-109.16	0.68	0.0	58.32	-15.47	
P_1	-25.1	8.40	-0.58	2.3	20.57	268.2	
	48.2	15.89	-3.53	2.3	15.65	32.03	
	-209.7	6.81	-2.56	2.3	20.58	NS	
Mean	-62.2	10.37	-2.22	2.3	18.93	150.12	
P_2	106.0	-15.93	-0.8	2.13	6.18	252.04	
	77.0	- 4.79	-0.8	2.13	13.57	231.99	
	78.9	-1.02	-0.79	2.13	-1.88	NS	
Mean	87.3	-7.25	-0.8	2.13	5.96	242.02	
P_3	-3.9	2.57	3.99	1.14	52.26	113.81	
	24.00	2.11	1.14	2.13	53.15	-29.01	
	71.60	2.05	3.50	1.14	27.29	NS	
Mean	30.37	2.24	2.88	1.47	44.23	42.4	

APPENDIX 7b

TRANSFORMED VALUES OF IRON IN WET SOIL PER POT

Weeks after transplanting

AMO	1	2	3	5	6	8
P_o	-3.55	-0.45	0.88	3.37	9.64	-7.50
	-4.72	4.36	0.88	2.95	11.0	-5.10
	-6.79	2.69	-2.46	-6.67	9.81	NS
Mean	-5.02	2.20	-0.23	-0.12	10.15	-6.3
P_1	7.40	2.10	3.72	7.63	14.79	-1.50
	7.09	6.23	2.90	7.63	12.39	-2.34
	7.10	3.75	3.72	7.63	15.55	NS
Mean	7.20	4.03	3.45	7.63	14.24	-1.92
P_2	3.94	0.92	-2.9	8.17	-7.72	11.44
	11.10	5.11	0.01	-1.43	3.72	-2.71
	3.94	0.43	-3.76	9.38	-1.65	NS
Mean	1.07	2.15	-2.22	5.37	-1.88	4.37
P_3	-1.62	-1.20	0.98	5.18	10.34	65.55
	-8.05	5.36	0.69	-4.87	-0.14	65.87
	0.36	5.57	0.98	3.56	-2.15	NS
Mean	-3.10	3.24	0.88	1.29	2.68	65.71

NS - No sample

APPENDIX 7b (contd.)

TRANSFORMED VALUES OF IRON IN WET SOIL PER POT

AKUSE	1	2	3	5	6	8	Weeks after transplanting
P_o	-4.19	-6.54	-0.82	-8.37	0.63	-7.69	
	-4.59	3.14	-2.11	-12.55	-6.30	-4.09	
	3.16	3.59	1.18	0.39	11.82	NS	
Mean	1.87	-0.06	-0.58	-7.04	2.05	-5.89	
P_1	-4.44	-0.99	0.83	4.84	-3.22	21.35	
	3.23	3.42	-2.13	-6.52	-6.61	5.49	
	3.22	1.02	0.83	4.84	-8.90	NS	
Mean	0.67	1.15	-0.16	1.05	-6.24	13.42	
P_2	10.03	2.07	-1.46	-7.0	-5.29	3.91	
	4.92	-3.03	-0.11	-7.03	11.20	3.84	
	10.04	0.56	-1.84	3.56	-7.38	NS	
Mean	8.33	-0.13	-1.14	-3.49	-0.49	3.88	
P_3	5.40	-0.55	-0.74	-6.81	-10.41	-2.58	
	5.41	-0.38	-1.63	4.44	-9.30	-2.60	
	2.75	-1.06	-0.09	4.17	-7.92	NS	
Mean	4.52	-0.66	-0.82	0.60	-9.21	-2.59	

NS - No Sample.

APPENDIX 8a

PHOSPHORUS IN % OF PLANT MATERIAL DURING STAGES OF PADDY GROWTH IN POT EXPERIMENTS

AMO series

Weeks after transplanting	1	2	3	5	6	8
P_o R_1	0.425	0.278	0.30	0.258	0.183	0.181
2	0.339	0.218	0.26	0.262	0.200	0.195
3	0.510	0.284	0.33	0.267	0.174	NS
P_1 R_1	0.439	0.357	0.31	0.248	0.201	0.188
2	0.497	0.335	0.30	0.262	0.156	0.194
3	0.526	0.294	0.31	0.251	0.349	NS
P_2 R_1	0.531	0.282	0.27	0.273	0.184	0.180
2	0.482	0.295	0.34	0.271	0.188	0.271
3	0.512	0.302	0.35	0.266	0.160	NS
P_3 R_1	0.622	0.340	0.35	0.291	0.221	0.205
2	0.567	0.327	0.32	0.263	0.223	0.282
3	0.637	0.325	0.36	0.303	0.199	NS

APPENDIX 8b

PHOSPHORUS IN % OF PLANT MATERIAL DURING STAGES OF PADDY GROWTH IN POT EXPERIMENTS

AKUSE series

Weeks after transplanting	1	2	3	5	6	8
P_o R_1	0.579	0.365	0.09	0.167	0.084	0.081
2	0.401	0.116	0.13	0.147	0.079	0.084
3	0.579	0.237	0.10	0.404	0.077	NS
P_1 R_1	0.621	0.220	0.23	0.194	0.146	0.137
2	0.611	0.212	0.19	0.299	0.179	0.133
3	0.888	0.191	0.22	0.215	0.130	NS
P_2 R_1	0.521	0.152	0.28	0.047	0.120	0.152
2	1.080	0.213	0.20	0.042	0.154	0.150
3	0.947	0.419	0.27	0.039	0.134	NS
P_3 R_1	0.595	0.272	0.26	0.134	0.149	0.173
2	0.618	0.336	0.28	0.112	0.161	0.150
3	0.515	0.258	0.31	0.157	0.148	NS

APPENDIX 9a

MANGANESE IN PLANT MATERIAL DURING STAGES OF PADDY GROWTH IN POT EXPERIMENTS (ppm 10^2 ovendry basis)

AMO series

Weeks after transplanting	1	2	3	5	6	8
P_o R_1	29.55	10.65	9.07	9.99	12.0	9.94
2	31.28	10.67	10.38	9.65	11.77	10.85
3	36.08	8.97	10.97	8.66	13.75	NS
P_1 R_1	33.98	11.52	11.05	8.60	13.57	12.36
2	28.83	9.25	10.74	10.94	13.75	12.10
3	30.59	10.62	11.16	12.54	10.88	NS
P_2 R_1	28.80	11.33	11.61	13.41	13.75	10.14
2	38.87	10.86	13.65	10.78	10.88	8.17
3	37.58	11.41	6.23	12.54	9.67	NS
P_3 R_1	35.33	11.82	10.26	12.82	12.94	11.39
2	25.59	10.97	11.55	12.72	12.00	8.66
3	36.04	11.56	8.05	11.10	12.00	NS

APPENDIX 9b

MANGANESE IN PLANT MATERIAL DURING STAGES OF PADDY GROWTH IN POT EXPERIMENTS (ppm 10^2 ovendry basis)

AKUSE series

Weeks after transplanting	1	2	3	5	6	8
P_o R_1	23.76	10.90	7.19	4.31	3.54	4.35
2	25.99	10.05	7.36	4.98	5.03	4.27
3	27.31	8.99	6.87	5.90	5.20	NS
P_1 R_1	33.87	9.62	7.40	5.30	6.28	6.36
2	30.32	12.24	6.83	6.93	6.99	5.03
3	18.98	8.44	8.45	6.22	5.85	NS
P_2 R_1	24.86	10.22	7.76	3.83	6.36	5.20
2	65.71	11.95	6.81	8.88	5.58	5.85
3	35.42	12.77	8.20	6.05	6.07	NS
P_3 R_1	17.81	11.29	2.92	6.68	5.92	6.42
2	24.15	15.59	7.22	5.53	6.87	7.67
3	29.52	8.52	7.18	7.85	6.82	NS

APPENDIX 10a

IRON IN PLANT MATERIAL DURING STAGES OF PADDY GROWTH (ppm ovendry basis)

AMO series

Weeks after transplanting						
	1	2	3	5	6	8
P_o R_1	60.94	66.23	69.60	2.069	18.0	27.18
2	152.91	115.05	30.52	3.31	8.33	48.21
3	130.27	55.91	103,45	7.97	14.86	NS
P_1 R_1	143.57	50.72	33.58	11.44	13.11	53.07
	97.23	29.69	16.36	10.57	6.27	273.29
	118.38	78.92	112.19	2.90	7.63	NS
P_2 R_1	101.28	199.07	46.72	7.52	17.55	24.05
2	187.34	52.24	17.52	0.41	25.40	139.00
3	109.37	93.28	91.02	1.24	1.43	NS
P_3 R_1	142.19	79.12	188.38	3.31	5.38	94.93
2	45.06	75.25	128.84	13.20	4.93	63.92
3	112.07	78.32	29.11	4.97	13.97	NS

NS = No Sample

APPENDIX 10b

IRON IN PLANT MATERIAL DURING STAGES OF PADDY GROWTH (ppm ovendry basis)

AKUSE series

Weeks after transplanting

	1	2	3	5	6	8
P_o R_1	167.28	227.00	86.34	0.00	2.37	17.35
2	96.89	87.75	0.00	0.00	26.03	10.24
3	79.49	60.16	0.00	15.51	7.88	NS
P_1 R_1	44.53	91.98	130.55	4.46	39.02	278.92
2	57.58	172.46	10.60	1.34	7.95	48.21
3	44.53	83.98	17.93	3.762	2.31	NS
P_2 R_1	44.53	50.68	4.39	147.19	1.08	72.16
2	62.01	65.28	12.97	1.06	10.05	10.44
3	94.23	92.12	12.30	3.41	20.81	NS
P_3 R1	169.46	68.48	4.89	0.536	4.11	72.16
2	81.72	192.67	29.94	4.55	2.05	45.11
3	90.09	35.91	15.95	2.57	5.38	NS

NS = No Sample

APPENDIX 11 a

DRY MATTER YIELD OF RICE PLANTS FOR DIFFERENT LEVELS OF PHOSPHORUS ADDED TO 1 KG. OF SOIL DURING PADDY GROWTH IN POT EXPERIMENTS (Oven dry basis in g)

AMO Series

Treatment	Week 1	2	3	5	6	8
$P_0 R_1$	0.14	0.47	2.07	5.17	7.24	10.31
	0.11	0.44	1.98	5.48	7.20	9.76
	0.13	0.70	1.76	4.92	7.32	NS
Mean	0.13	0.54	1.94	5.19	7.25	10.03
$P_1 R_1$	0.11	0.50	2.01	5.86	7.37	12.24
	0.11	0.66	1.87	5.24	8.05	12.5
	0.14	0.49	2.10	5.20	1.44*	NS
Mean	0.12	0.55	1.99	5.43	5.62	12.37
$P_2 R_1$	0.11	0.46	2.02	5.28	7.76	12.68
	0.10	0.51	1.51	5.32	7.32	5.46*
	0.12	0.51	1.67	5.20	7.21	NS
Mean	0.11	0.49	1.73	5.27	7.43	6.05
$P_3 R_1$	0.08	0.46	1.73	4.92	6.65	11.33
	0.10	0.51	1.83	5.34	6.69	5.88*
	0.10	0.46	1.54	4.84	8.05	NS
Mean	0.09	0.48	1.70	5.02	7.12	8.66

P - Level of Phosphorus. NS - No sample

* - Pots in which one or two seedling died.

APPENDIX 11b

DRY MATTER YIELD OF RICE PLANT FOR DIFFERENT LEVELS OF PHOSPHORUS ADDED TO 1 KG. OF SOIL IN POT EXPERIMENTS DURING PADDY GROWTH (Oven dry basis g.)

AKUSE Series

Treatment	Week 1	2	3	5	6	8
P_0R_1	0.07	0.15	0.56	1.36	1.65	2.75
2	0.08	0.19	0.31	0.09	1.57	2.90
3	0.09	0.23	0.44	0.78	1.51	NS
Mean	0.08	0.19	0.43	1.07	1.58	2.83
P_1R_1	0.06	0.29	0.84	1.78	3.30	4.54
2	0.07	0.17	1.28	1.52	0.74*	4.29
3	0.06	0.32	0.83	1.64	3.54	NS
Mean	0.06	0.26	0.98	1.65	2.53	4.42
P_2R_1	0.05	0.25	0.49	2.11	4.23	4.70
2	0.03	0.16	0.83	1.92	2.86	1.72*
3	0.03	0.15	0.72	1.51	2.43	NS
Mean	0.04	0.19	0.68	1.85	3.17	3.21
P_3R_1	0.08	0.20	0.90	1.89*	2.52	5.11
2	0.03	0.16	0.90	3.70	4.51	1.80*
3	0.06	0.30	0.56	1.96*	3.68	NS
Mean	0.06	0.22	0.79	2.52	3.57	3.45

NS - No sample; P - level of phosphorus.

APPENDIX 12a

pH OF WET SOIL IN $CaCl_2$ (AMO series)

Weeks after transplanting

Level of P	1	2	3	5	6	8
P_o R_1	5.3	5.5	5.6	5.6	5.5	5.7
2	5.2	5.3	5.7	5.7	5.5	5.7
	5.2	5.5	5.7	5.6	5.5	5.7
P_oNR_1	5.2	5.6	5.6	5.8	5.7	5.7
2	5.3	5.6	5.7	5.7	5.7	5.8
3	5.3	5.5	5.6	5.7	5.8	5.6
P_1 R_1	5.2	5.5	5.6	5.7	5.7	5.8
2	5.2	5.5	5.6	5.7	5.7	5.7
3	5.2	5.7	5.6	5.7	5.8	NS
P_1NR_1	5.2	5.8	5.8	5.7	5.9	5.8
2	5.0	5.8	5.9	5.7	6.0	5.8
3	5.2	5.7	5.9	5.7	5.9	5.8
P_2 R_1	5.4	5.7	5.8	5.5	5.8	5.8
2	5.6	5.7	5.8	5.5	5.8	5.7
3	5.5	5.7	5.8	5.6	5.7	NS
P_2NR_1	5.3	5.8	5.8	5.7	5.8	5.8
R_2	5.2	5.9	5.8	5.7	5.8	5.8
R_3	5.0	5.9	5.8	5.8	5.9	5.8
P_3 R_1	5.3	5.8	6.0	5.5	5.8	5.8
2	5.2	5.8	5.9	5.5	5.7	5.8
3	5.2	5.8	5.9	5.4	5.7	NS
P_3NR_1	5.3	5.8	6.0	5.6	5.7	5.8
2	5.2	5.8	5.9	5.6	5.8	5.8
3	5.6	5.8	5.9	5.6	5.8	5.8

NS - No sample. R - Rice. NR - No Rice

P - Level of Phosphorus.

APPENDIX 12b

pH OF WET SOIL IN $CaCl_2$ (AKUSE series)

Weeks after transplanting						
Level of P	1	2	3	5	6	8
P_o R_1	6.6	6.6	7.1	6.4	6.4	6.6
2	6.6	6.6	7.0	6.5	6.6	6.7
3	6.7	6.7	7.2	6.6	6.7	NS
P_oNR_1	6.6	6.7	7.0	6.6	6.8	7.0
2	6.7	6.8	7.1	6.7	6.9	7.0
3	6.7	6.9	7.0	6.7	6.9	7.0
P_1 R_1	6.7	6.7	7.1	6.7	6.4	6.6
2	6.7	6.7	7.2	6.7	6.6	6.7
3	6.7	6.7	7.2	6.7	6.7	NS
P_1NR_1	6.9	6.8	7.2	6.7	6.7	6.7
2	6.8	6.8	7.2	6.7	6.7	6.8
3	7.0	6.8	7.3	6.5	6.8	7.0
P_2 R_1	6.8	6.7	7.2	6.6	6.6	6.6
2	6.8	6.8	7.2	6.6	6.6	6.8
3	6.8	6.8	7.3	6.6	6.6	NS
P_2NR_1	6.8	6.8	7.2	6.5	6.7	6.9
2	6.9	6.8	7.2	6.6	6.6	7.0
3	6.9	6.9	7.2	6.8	6.7	7.1
P_3 R_1	6.9	6.8	7.1	6.7	6.8	6.6
2	6.8	6.8	7.1	6.7	6.6	6.7
3	6.8	6.8	7.1	6.8	6.6	NS
P_3NR_1	6.8	6.8	7.1	6.8	6.7	6.9
2	6.8	6.8	7.0	6.8	6.7	7.0
3	6.8	6.9	7.1	6.8	6.7	7.0

P - level of phosphorus. NS - No Sample. R - Rice

NR - No Rice.

APPENDIX 13a

pH OF SUPERNATANT DURING STAGES OF PADDY IN POT EXPERIMENTS (AMO series)

Treatment	Week 1	2	3	5	6	8
P_o R_1	7.9	7.3	7.2	6.8	6.7	6.8
2	7.8	7.3	7.0	7.0	6.8	6.9
3	8.1	7.3	6.9	6.8	6.8	NS
P_o NR_1	7.6	7.6	8.1	8.2	7.5	6.8
2	7.6	7.6	8.1	8.2	7.6	6.9
3	7.9	7.8	8.1	8.2	7.7	7.0
P_1 R_1	8.3	7.3	7.0	7.0	6.8	7.2
2	7.9	7.2	7.0	7.1	6.8	7.0
3	8.0	7.3	6.9	6.8	6.7	NS
P_1 NR_1	7.6	7.6	8.0	8.2	7.3	6.8
2	7.9	7.6	8.1	8.2	7.4	6.9
3	8.0	7.7	8.1	8.3	7.5	7.0
P_2 R_1	8.1	7.1	6.8	6.8	6.7	7.0
2	8.1	7.2	6.9	6.9	6.0	7.0
3	7.8	7.2	6.7	6.8	6.7	NS
P_2 NR_1	7.4	7.6	8.0	8.2	7.5	6.8
2	8.2	7.6	8.0	8.3	7.5	7.0
3	8.0	7.7	8.2	8.3	7.5	7.0
P_3 R_1	7.7	7.7	6.8	7.4	6.8	6.9
2	8.0	7.2	6.7	7.7	6.9	7.0
3	8.0	7.2	7.0	7.6	6.9	NS
P_3 NR_1	7.5	7.7	8.1	8.6	7.4	6.8
2	7.6	7.7	8.1	8.3	7.4	7.0
3	7.9	7.9	8.1	8.2	7.4	7.2

P - level of phosphorus   R - Rice   NR - No rice
NS - No Sample

APPENDIX 13b

pH OF SUPERNATANT DURING STAGES OF PADDY GROWTH IN POT EXPERIMENTS (AKUSE series)

Treatment	Week 1	2	3	5	6	8
P_o R_1	7.3	8.2	8.3	8.2	7.5	6.8
2	8.0	8.2	8.3	8.3	7.4	6.9
3	7.8	8.2	8.3	8.3	7.5	NS
P_o NR_1	8.0	8.3	8.4	8.4	7.7	7.0
	8.1	8.3	8.4	8.3	7.7	7.1
	7.6	8.3	8.3	8.3	7.8	7.2
P_1 R_1	7.4	8.2	8.8	8.2	7.9	6.9
2	7.8	8.2	8.1	8.2	7.8	7.0
3	7.7	8.2	8.2	8.2	7.8	NS
P_1 NR_1	8.0	8.1	8.7	8.3	7.9	7.2
2	7.8	8.0	8.3	8.5	8.0	7.3
3	7.7	8.1	8.4	8.4	7.9	7.4
P_2 R_1	7.6	8.1	8.3	8.0	7.5	7.0
2	7.4	8.1	8.3	8.0	7.4	6.9
3	7.7	8.0	8.2	8.1	7.5	NS
P_2 NR_1	7.7	8.0	8.4	8.2	7.8	7.2
2	7.1	8.0	8.3	8.3	7.8	7.1
3	7.8	8.0	8.3	8.4	7.8	7.3
P_3 R_1	6.8	8.1	8.2	8.1	7.1	7.1
2	8.1	8.1	8.1	8.2	7.1	6.9
3	7.7	8.1	8.2	8.3	7.2	NS
P_3 NR_1	7.4	8.0	8.2	8.5	7.7	7.1
2	7.5	8.2	8.2	8.2	7.7	7.2
3	7.8	8.0	8.4	8.4	7.7	7.4

P – level of phosphorus; R-Rice; NR – No Rice

NS – No Sample