INTEGRATED USE OF INORGANIC AND ORGANIC AMENDMENTS FOR IMPROVING PHOSPHORUS AVAILABILITY IN SOILS

A thesis submitted in partial fulfillment of the requirements for the degree of **DOCTOR OF PHILOSOPHY**

By

Fakhar Mujeeb
M.Sc. (Hons.) Agriculture

INSTITUTE OF SOIL & ENVIRONMENTAL SCIENCES
FACULTY OF AGRICULTURE, UNIVERSITY OF AGRICULTURE FAISALABAD
2010

The Controller of Examinations,
University of Agriculture,

Faisalabad

"We, the supervisory committee, certify that the contents and format of the thesis submitted by **Fakhar Mujeeb (Reg. No. 82-ag-1076)** have been found satisfactory and recommend that it be processed for evaluation by External Examiner(s) for the award of degree."

Supervisory Committee

Chairman: _____
(Dr. Rahmatullah)

Member: _____
(Dr. Javaid Akhtar)

Member: _____
(Dr. Rashid Ahmad)

DEDICATED TO

PAKISTAN

My home

My identity

ACKNOWLEDGEMENT

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATINS, ACRONYMS AND SYMBOLS USED IN THIS THESIS

%	Percent
@	At the rate of
<	Lesser than
>	Greater than
ADP	Adenosine di-phosphate
Al	Aluminum
ATP	Adenosine tri-phosphate
C	Carbon
C:P	Ratio of C & P
Ca	Calcium
$CaCl_2$	Calcium chloride
$CaCO_3$	Calcium carbonate
$CaSO_4.2H_2O$	Gypsum
CEC	Cation exchange capacity
cm	Centi meter
CO_2	Carbon dioxide
CO_3^-	Carbonate ion
CRD	Completely Randomized Design
DAP	Diammonium phosphate
$dS\ m^{-1}$	Deci siemens per meter
DTPA	Diethylene Triamine Penta Acetic Acid
EC	Electric conductivity
EC_e	EC of soil extract
EDTA	Ethylene Diamine Tetra Acetic Acid
FAO	Food & Agriculture Organization
Fe	Ferrous
$FeSO_4.7H_2O$	Ferrous sulphate hept hydrate
FYM	Farmyard manure
g	Gram
H^+	Hydronim ion
H_2CO_3	Carbonic acid
$H_2PO_4^-$	Primary ortho phosphate
H_2SO_4	Sulfuric acid
H_3PO_4	Phosphoric acid
ha	Hectare
HCl	Hydrochloric acid
HCO_3^-	Bicarbonate ion
HPO_4^-	Secondary ortho phosphate
IPNM	Integrated Plant Nutrient Management
K	Potassium
$K_2Cr_2O_7$	Potassium dichromate
kg	Kilo gram
KH_2PO_4	Potassium dihydrogen phosphate
L	Liter
m	Meter
M	Molar

mg	Milli gram
ml	Milli liter
N	Normal
N	Nitrogen
$NaHCO_3$	Sodium bicarbonate
NFDC	National Fertilizer Development Corporation
NO_2^-	Nitrite
OH^-	Hydroxyl ion
OM	Organic matter
P	Phosphorus
pH	Negative log of H^+ activity
pH_s	pH of saturated soil paste
P_i	Inorganic P
P_o	Organic P
R^2	Co-efficient of determination
S-I,S-II,S-III	Soil-I, Soil-II and Soil-III
SAR	Sodium adsorption ratio
SOP	Sulphate of potash
SSP	Single super phosphate
TSP	Triple super phosphate
USA	Unites States of America
UV	Ultra violet

CHAPTER 1

INTRODUCTION

Maize (*Zea mays* L.) ranks third in the world's cereal production. It is grown in temperate to tropical and sub-tropical regions of the world. It provides food for human beings, feed for animals and raw material for several agro-based industries. Corn oil, corn flakes, corn starch, glucose and leather tanning materials are, some of the commercial products of maize. Its grain contains 72% starch, 10% protein, 4.8% oil, 5.8% fiber, 3% sugar and 1.7 % ash (Chaudhary, 1983). In Pakistan, maize is cultivated on an area of 1,042 thousand hectares and it ranks third after wheat and rice cereals (Economic Survey of Pakistan, 2006-2007).

Maize belongs to the group of crops which has high growth rate, producing large quantity of organic material and therefore, has a higher demand of phosphorus (P). Phosphatase activity and rate of organic P turn over are much higher in the rhizosphere of maize roots than that of bulk soil (Mengel and Kirkby, 2001).

Indeed, the second most important nutrient required by plants, the phosphorus is highly inaccessible for most of the plants (Holford, 1997). Generally the soluble phosphate reacts with soil components to form relatively insoluble compounds (Sayin et al. 1990). Being the most likely to be fixed mineral nutrient, in majority of cropping systems, its availability to plants is very low. Nevertheless, it contributes as a macronutrient for biomass production (Goldstein et al., 1988). It is a "finite and irreplaceable" mineral. With the present pace of international consumption, its economically viable reserves could run out in 60 to 100 years. And without P there will be no agriculture (Osava, 2007).

Generally, soils have hundred-time more reserves of total P than the plant available P (Al-Abbas and Barber, 1964). Like other arid regions of the world, about 80 to 90% soils of Pakistan are deficient in available phosphorus (Sanders, 1986; Memon et al.1992 and NFDC, 2001). Soil fertility survey indicated that, phosphate after nitrogen is the most deficient nutrient in Pakistan soils (Memon, 1985).

Phosphorus is generally applied in excess of immediate plant needs. This result to accumulation of residual P in soil which is either slowly available to plants or even turns in to unavailable P compounds. Type of soil, properties of soil and type and amount of fertilizer P applied, determine the destiny of surplus fertilizer added

(Eghball et al. 1996). Natural equilibrium between solid and solution phases and soil constituents controls P availability in soil. In spite of increased total P contents of fertilized soils, majority of soils respond the application of P (Tandon, 1987). Phosphorus reserves in soils are not the problem, but presence of P in forms unavailable to plants is the problem to be solved.

Agricultural intensification requires increased flow of plant nutrients towards roots and their uptake by crops. Depleting nutrient reserves, in the soil, is a major but often hidden form of land degradation. Inadequate use of plant nutrients creates an insidious depletion of the reserves which is an economic loss (Brinkman, 1998). A future study of FAO for 2010, estimates that about $2/3^{rd}$ increase in crop production will be required by developing countries. This will have to be achieved by yield increase from existing cultivable lands. Plant nutrients will play the most important role in this regard (FAO.1995). Attempts to alleviate nutrient deficiency by adding fertilizer is becoming unaffordable economically and hazardous environmentally. Moreover, efficiency of the added P is just about 10% (Werft and Dekkers, 1996).

Agriculture is generally the basis of economy for developing countries. It fulfills their nutritional requirements and earns an important share of their foreign exchange (Rehm and Espig, 1991). Pakistan is also one of the countries like that. It has presently a population of 156.77 million people with an annual growth rate of 1.8 %. Its cropped area is 23.13 million hectare which has grown by just 2.3% during the last decade (Economic Survey of Pakistan, 2006-2007). Its soils are alkaline (pH > 7.0) and mostly calcareous ($CaCO_3$ > 1.0 %) in nature. Calcareous soils are well known for fixation of added P due to the reaction of phosphate ions with calcium carbonate. This reaction is considered to be an adsorption of phosphate onto the calcium carbonate surfaces, followed by surface precipitation if the concentration of Ca^{2+} is high. Precipitation and specific adsorption can also occur on other reactive surfaces such as hydrous oxides of iron and aluminum and alumino-slicate clays, leading to the conversion of added P into relatively insoluble forms.

Therefore, added P fertilizer is partly taken up by plants through soil solution while most of it is adsorbed or precipitated. Hence, just a small increment in soil solution P takes place (Olsen et al; 1977). On the other hand application of P in either form (organic/inorganic) is essential to increase and maintain high crop yield potential in the prevailing cultivation systems. Moreover, P cannot be added to the soil by biological fixation like N.

In such a scenario, economically more feasible and environment friendly strategies can increase nutrient recovery by crops, utilizing efficiently the existing least available P in soils.

Agriculture in Pakistan is facing various problems. Soils are generally calcareous with low available P. There are no indigenous economic reserves of P in the country. Import of P fertilizers is increasing burden on national exchequer. Price of P fertilizers has increased upto122-125% during the last decade. Therefore, rate of P application is far below the needs of crops and soils (Economic Survey of Pakistan, 2006-7).

On the other hand, amounts of traditional organic wastes like crop residues and farm yard manures have increased rapidly after the green revolution. Non-traditional wastes of poultry and other industries, like press mud from sugar industry, are a cause of environmental concerns. (Economic Survey of Pakistan, 2006-7). It is evident from the perusal of different studies, pertaining to recycling of such wastes, that addition of these wastes to soils may increase the efficiency of applied and native nutrients required by plants. Organic matter is considered as elixir of life for agricultural soils. For many of the cropping systems the P deficiency problems could partially be resolved by well informed, rational and timely decisions taken by farming community to return to the high quality soil organic materials which are locally available but are often ignored. For this purpose farmers have to switch over to nutrient practices like; animal manure, compost, incorporation of crop residues, relay or intercropping of legumes and biomass transfer. Initially, organic resources were given importance only for N. Main focus of researchers remained the quantification and availability of N from organic resources (Palm et al., 2001). Recently, other horizons of organic matter application to soils have been given consideration. Apart from N, organic are profoundly studied for availability and role of other macro and micro-nutrients, reduction of phosphorus sorption capacity, increase in carbon/organic matter, reduction of soil borne pest and disease spectra in rotations, and improvement of soil moisture status (Vanlauwe et al., 2002).

Some plant materials even having low tissue P concentrations provide adequate P for productive use by crops (Nziguheba et al., 2000). In addition, some organic inputs have increased P availability in P fixing soils, thus expanding their potential to increase the availability of soil P beyond the amount contained in their tissues (Hue, 1991). On the addition of organic materials, mineralization of more

recalcitrant fraction of P takes place due to increased microbial biomass associated with increased biological activities (Nziguheba et al; 1998). A general conclusion about the effects of manure on P availability designate it; as a source of P, interacting with soil components to increase P recovery by crops; and enhancing the effectiveness of inorganic P fertilizer (Whalen & Chang, 2001). Similarly humus, being the sink for applied P, releases P through biochemical transformations under P stress. Reddy et al. (1996) and Singh et al. (2001a,b) observed that the application of farmyard manure with fertilizer P enriched long-term P fertility of soil through increase in organic P contents and a short-term P supply as recalcitrant P.

Green manure crops may convert relatively unavailable native and residual P to chemical forms which are more available after decomposition. This process produces CO_2, which forms $H_2CO_3^-$ in the soil solution, resulting in the dissolution of primary P-containing minerals. Organic acids released during decomposition also help to dissolve soil mineral P. In soils with high P-fixing capacities; organic compounds released during decomposition processes may increase P availability by coating P adsorption sites or via anion exchange. Repeated incorporation of green manures can decrease soil bulk density, increase soil aggregation and moisture retention. All these factors may also help to increase P uptake by increasing root and mycorrhizal growth (Cavigelli and Thien, 2004).

Therefore, judicious and efficient use of the existing land, nutrient fertilizers, financial resources and recycling of organic wastes is inevitable. In such circumstances this study has been designed to obtain knowledge regarding;

➢ Increasing the efficiency of applied P fertilizers through integration with organic matter.
➢ Evaluating the effects of various organic amendments, on different pools of P, in calcareous soils.
➢ Dynamics of different forms of P in three calcareous soils amended with inorganic P and different organic materials.
➢ Mobilizing P reserves of calcareous soils to increase plant available pool of P.

CHAPTER 2

REVIEW OF LITERATURE

Importance of phosphorus

Phosphorus is indispensable macronutrient for the continuity and survival of whole living creation. It is listed second to nitrogen in importance. Metabolism of micro to mega living creature owes to presence of P. Taiz and Zeiger (1998), reported that P is the part and parcel of ATP and ADP molecules, component of phospholipids and nucleic acid, manage to construct cellular membranes and provides compounds for photosynthesis in plants and respiration in animals. Gutam and Tumar (1997) also found that P plays a fundamental role in many of the plant physiological processes such as photosynthesis, utilization of sugar and starch and transfer of energy. It is also a part of energy producing process of phosphorylation. Role of P in energy storage and transfer is of paramount importance. In addition to this vital metabolic role, P is an essential structural constituent of numerous biochemicals, including nucleic acids, which are the building blocks of genes and chromosomes and the essence of heredity. It is the component of cell nucleus and is indispensable for cell division and formation of meristematic tissues (Tisdale et al., 1985). It is also required for signal transduction, macro-molecular biosynthesis and respiration. Lacking adequate P supply result into loss of crop yield. Therefore, direct availability of P determines plant growth (Hinsinger, 2001). Plants require adequate P from the very early stage of growth for optimum crop production (Grant et al., 2001). Restricted early-season P supply frequently limits crop production.

Soil phosphorus

Phosphatic fertilizer is commonly applied to ensure that sufficient P is available to optimize crop yield and maturity. Total soil P usually ranges from 100 to 2000 mg P kg^{-1} soil representing approximately 350 to 7000 kg P ha^{-1} in the surface 25 cm of the soil, although only a small portion of this P is immediately available for crop uptake (Morel, 2002).

The relationship between the different forms of phosphate in the soil plant system can be represented by the following scheme.

Non labile–P	Labile–P	P in soil solution	P in plant root
P in soil	slowly available	readily available	

Soluble P compounds when added to the soil react rapidly with various soil components, and are quickly converted to slowly available forms. The reaction between orthophosphate and soil is complex and generally ranges from true adsorption to the precipitation without clear delineation between the two mechanisms (Mott, 1970).

Phosphorus fixation is a serious problem in alkaline and calcareous soils (Sharif et al., 2000). The soils could adsorb large amount of P for rapid and firm adsorption from solution and once adsorbed P was difficult to release from soil (Huang, 1998). In calcareous soils the dynamics of P is controlled by many soil properties that strongly retain P and consequently maintain low P concentration in soil solution (Bertrand et al., 1999). The extent of P sorption was relatively higher in fertilized soil and highly available progressively decreased with increasing rate of fertilizer P in both manured and non-manured soils (Reddy et al., 1999).

Soil P is readily available in solution form. Soils have tendency to retain equilibrium between solution P and adsorbed P. Plants use only the inorganic P (Pi) fraction of soil solution which is the minimum fraction of total P present in soil. The P concentration of soil solution ranges from 0.1 to 1.0 mg L^{-1} (Yagodin, 1984). Phosphorus utilized by plants as the solution P is replenished by P from labile inorganic P (P_i) minerals and by bio-chemical mineralization of labile organic P (P_o). The amount of P available to plant is determined by i) the pool size of labile P_i, ii) the transformation rates between labile and slowly reacting Pi and iii) the cycling rate of mineralizable P_o (Tiessen, 1991) .

Nair et al. (1999) used water soluble P and Mehlich-1 extractable-P as indicators of the potential for P to be released from manure impacted soil. The efficient utilization of nutrients with minimum nutrient losses is the main purpose of sustainable agriculture. This is especially true for phosphorus, since it is a limited resource (Oenema and Velthof, 2000). Plants absorb P for their growth from soil solution. It disturbs equilibrium between soil solution, P concentration and the labile pool at the solid soil phase which leads to release of P into the soil solution. In non labile fraction, about 90% of total P is present as insoluble or fixed forms, including

primary phosphate minerals, humus P, insoluble phosphate of Ca, Fe and Al and P fixed by hydrous oxides and silicate minerals. In labile pool, the proportion of insoluble phosphate is more accessible than that of bulk reserves of non labile fraction (Mengel and Kirkby, 2001). Phosphorus availability in soils is greatly hindered by binding to oxides of iron and aluminum. On the other hand, P moves through soil profiles only by diffusion not with flow of water. Therefore, just about 1 % of P_o pool per year is mineralized, supplying Pi for plant uptake (Tiessen et al., 1984). Hence, a very limited system for the recycling of small amounts of P in soil gets developed.

Phosphorus is comparatively less mobile and least available major plant nutrient in soil. It moves very little from the site of its application. The results are in complex situation as compared with those for other nutrients (Archer, 1988). Due to the reason the efficiency of utilization of fertilizer P by plant is very low and its recovery ranges from 15-25% (Nisar, 1985). It is therefore frequently a major or even the prime limiting factor for plant growth.). Natural equilibrium between solid and solution phases and soil constituents controls P availability in soils. In spite of increased total P contents of fertilized soils, majority of soils respond the application of P (Tandon, 1987). In fact, soil P reserves are sufficient but their availability to plants is quite insufficient. A huge land area (5.7 billion hectares worldwide), contain too little available P to sustain optimal crop production (Batjes, 1997; Gaume, 2000). High reactivity of phosphate ions against various soil constituents and the retention capacity of such constituents results into poor mobility of soil P_i. A considerable part of applied P also binds with Ca, Al and Fe, depending upon the soil pH (Singh et al; 2006a). Thus, only a minor portion of solution P in soil is present as P ions in the soil. Although P ions can be accumulated in larger concentrations in highly fertilized soils, however, it remains in micro molar range of 0.1 and 10µ M which is inadequate for optimal plant growth (Ozanne, 1980; Mengel and Kirkby, 1987; Raghothama1999; Frossard et al., 2000). Average range of P concentration in plough layer is 500-14000 kg P_2O_5 ha^{-1} and 0.2-7.0 g kg^{-1} soil while soil solution has 0.07-0.5 mg P L^{-1} (Hedley et al., 1995). Deficiency of P is the common feature of calcareous/alkaline soils of Mediterranean region and highly weathered soils of tropics and subtropics (Hinsinger, 2001).

Phosphorus plays a fundamental role in many of the plant physiological processes such as photosynthesis, utilization of sugar and starch, transfer of energy etc. It is also a part of energy producing process of phosphorylation (Gutam and

Tomar, 1997). The role of P in plants for energy storage and its transfer is very important. Phosphate compounds act as an energy currency within plants. In addition to this vital metabolic role, P is an important structural component of a wide variety of biochemical, including nucleic acids, which are the building blocks of genes and chromosomes, the essence of heredity. It is the constituent of the cell nucleus and is essential for cell division and for the development of meristematic tissue (Tisdale et al. 1985). It is also required for signal transduction, macro-molecular biosynthesis and respiration, etc. Sub-optimal P levels can cause 5% to 15% yield losses of the maximal yields. Hence, the P availability determines the subsequent growth of plant (Hinsinger, 2001).

Phosphorus status of Pakistan soils

Olsen's method of soil P extraction with 0.5 M NaHCO$_3$ (Olsen et al., 1954) is followed as a routine soil test method by all the soil testing laboratories and research institutes throughout the country. Primarily this method was developed specifically for alkaline and calcareous soils. Using this method a number of workers have attempted to ascertain the available P status of Pakistani soils.

Thousands of simple fertilizer trials have been conducted in Pakistan since 1958 under the auspices of Rapid Soil Fertility Survey Scheme. Soil samples from experimental sites were collected and analyzed in the laboratories. Malik et al. (1973) compiled analytical results and concluded that 86% of 6207 soil samples collected from Punjab were low (< 5 mg P kg^{-1}), 24% medium (5-10 mg P kg^{-1}) and 8% were adequate (> 10 mg P kg^{-1}) in available P (Olsen's P). On the other hand Ansiaux (1977) conducted an inquiry by using different methods for extractions and revealed that approximately 2/3rd of Pakistani soils were low (< 2.6.mg P kg^{-1}), 1/4th medium (2.6 - 4.4 mg P kg^{-1}) and the rest were high (> 4.4 mg P kg^{-1}) in available P. Bhatti (1973) reported in an other study that out of 1110 soils samples taken from 13 districts of the Punjab, 61% contain < 3 mg P kg^{-1} of soil, 34 % contained between 3 to 12 mg P kg^{-1} and only 5% contained >12 mg P kg^{-1}. Malik et al. (1984) again consolidated results from 136,161 soil samples of Punjab soil from 1981 to1984 and reported that about 93% of soil samples, contained <10 mg P kg^{-1} of soil. Thus these soils required supplementary P application to improve their productivity and to raise the crop yield. Wahhab (1985) ascertained the P status by analyzing 200 soil samples collected from various districts of the Punjab and concluded that Olsen's P ranged from < 2 mg

P kg^{-1} to over 25 mg P kg^{-1} with a mode of 4-5 mg P kg^{-1}. Majority of the samples were, however, deficient in P with values of below 10 mg P kg^{-1}. He also compiled results of soil samples analyzed by the soil testing laboratories in the Punjab and observed that in 1986-87 out of total 16841 soil samples, 63% were within range of 0-5 mg P kg^{-1}, 22% between 5-10 mg P kg^{-1} and 5% of the samples had the values above 10 mg P kg^{-1}. In a recent study on the assay of fertility status in the field, Malik et al. (1992) indicated that intensive mining of nutrients have depleted soil reserves at very rapid rate. They reported a declining trend in soil P @ 0.016 mg kg^{-1} year^{-1}. A synopsis of 340 thousands soil samples analyzed in fertility laboratories from 1981-89 depicts 77% soil were poor, 21.7 % medium and only 1.3 % adequate in P status. They further stated that decreasing trend in fertility status with passage of time is also reflected in fertilizer trials conducted in farmer's fields. They reported that regression analysis of wheat yield recovered from control plots revealed a decreasing trend of 22 kg ha^{-1} annum^{-1}. From the foregoing discussion it is apparent that soil testing for P has adequately established that most soils are deficient in P along with further depletion and require P application for optimal crop production.

2.3. Available P as affected by incubation of P sources

Root absorption and soil sorption remove P from soil solution and P from labile pool replenishes the P removed. In this perspective, the term 'P availability' describes the 'instantaneous P concentration in the soil solution' while the term 'available P', describes the quantity of P that will come into solution and be taken up by a specific crop during its life cycle (White and Beckett, 1964).

Khanna et al. (1984) incubated P fertilizers with organic matter before applying to soil and studied the efficiency of the water insoluble phosphates. They found that P uptake by wheat was increased manifold by this treatment over control. They reasoned that it was due to the improved efficiency of the P fertilizers. The increase in the P use efficiency by pre-incubation with cattle dung was owing to the solubilization of insoluble P fraction during the humification and lesser fixation in soil due to the protective action of manure. Afif et al. (1993) working on P incubation experiment on 19 calcareous soils concluded that P reactions in such soils differ according to the P application rate, and raise caution about the incubation conditions in the laboratory that are used to estimate the loss in P availability.

Rahmatullah et al. (2003) mixed a coarse loamy (mixed, hyperthermic Udic Haplustalf) soil with lime (CaCO$_3$) and gypsum (CaSO$_4$.2H$_2$O) at the rate of 200 g amendment kg^{-1} soil. Original soil and amended soils were taken in plastic pots. Phosphorus @ 0, 5, 10, 25, 50, 100, 150 and 300 mg P kg^{-1} soil was applied in duplicate in solution form as KH$_2$PO$_4$. Distilled water was used to maintain soil moisture contents at 60% field capacity of the three soils. The pots were incubated at the room temperature. After eight weeks of incubation P recovery of P applied at different rates was calculated by estimating NaHCO$_3$ extractable P (Kuo, 1996). Results revealed that on an average 17% of the added P was recovered by NaHCO$_3$ extraction from lime-amended soil, 28% from gypsum amended soil and 68% from original soil. In case of soluble/ available P, results indicated that maximum available P was released in case of original soil which was 35-61%, then 10-16% incase of gypsum amended soil and minimum available P 0.03-0.5% was released in case of lime amended soil.

Factors affecting P adsorption

Availability of applied P in soils decreases due to surface adsorption and precipitation. Solubility of P in calcareous soils may be controlled by the dicalcium phosphate of solid phase or by chemisorptions of P on calcite which forms a surface complex of CaCO$_3$-P (Cole and Olsen, 1953). Therefore, application of high rates of P results in to low plant availability of applied P in calcareous soils but no negative relation was developed with Fe oxide, CEC, or clay contents (Afif et al., 1993, Samadi and Gilkes., 1999).

The surfaces on which phosphate ions enter in the sorption reaction are of two main types,

- **Surface of constant charge:** such as crystalline clay minerals, interacting with phosphorus principally through the cations held tightly to their plate like surfaces.

- **Surfaces of variable charge:** such as Fe^{3+}, Al^{3+}oxides and organic matter for which H$^+$ and OH$^-$ ions determine the surface charge and calcite for which Ca^{2+} and CO$_3^{--}$ are responsible for charge development. Phosphorus sorption is highest in oxides of Fe and Al followed by 1:1 and 2:1 type clays.

In addition, several factors may influence relationship between phosphate adsorption and phosphate concentration, such as, soil pH, composition of

adsorption sites, ambient temperature, duration of contact between soil and solution, method of shaking, kind of extracting, moisture contents of the soil prior to shaking, and surface area (Fox and Searle, 1978).

Soil pH exerts indirect effects on soil P availability through two factors;

 a) Possible effect of pH on mineralization of organic phosphate

 b) The possibility of decreased retention of added P over drying the soil after applying lime (Haynes, 1982).

Apart from the importance of these factors some other factors should also be considered.

(i) The range of pH value over which the effects are measured, is the most important, (ii) relation between pH and the electrostatic potentials, which decreased as the pH is increased, (iii) the background electrolyte in which the effects of pH on phosphate retention are measured. Amarasiri and Olsen (1973) found that P retention of a soil can be increased by the application of $CaCl_2$. In case of low salt concentration or in the presence of monovalent salt the P adsorption on a variable-charge material may be decreased with the increase in pH (Barrow et el., 1980) and (iv) the amount of desorbable P in soil. In desorbable P lacking soils, pH affects the ability of soil to retain newly added P. However, in a desorbable P containing soil, changing pH affects differently on P desorption.

Phosphorus fixation reactions in calcareous soils

a.   Precipitation of relatively insoluble calcium phosphate such as orthocalcium phosphate, hydroxy apatite and carbonate apatite favoured by high calcium activity and high pH.

b.   Surface precipitation with free calcium carbonate.

c.   Fixation of phosphate by clays saturated with calcium

Therefore, it is frequently theorized that soils of Pakistan, being highly calcareous, have high P sorption capacity. Memon and Fox (1983) stated that soils of Pakistan may not have strong P fixation capacity compared to soils from India, Tanzania and the USA.

The data available on the clay mineralogy of some soils of Pakistan show the presence of minerals like mica, montmorillonite, kaolinite, vermiculite and calcite etc. to varying degree, depending upon the conditions under which these soils have been developed. Lins et al. (1985) observed that phosphorus sorption is closely related to

clay content. Residual P studies were conducted at three tropical soils of similar clay mineralogy. The applied P rates markedly differed with clay content so that soil test interpretation was created following multiple regression applied upon extractable P and clay percentage for the precise recommendation of fertilizer P application.

The sorption and release of native soil and adsorbed P are governed by oxidation-reduction potential, oxygen supply, microbial activities, soil characteristics and temperature. Among the soil variables that affect the sorption process are pH (Ghanbari et al., 1998; Lu-Wenlong et al., 1998; Reddey et al., 1999), the amount and type of clay minerals (Morais et al., 1996; Sharif, et al., 2000), organic matter (Rashid and Rowell, 1988; Guilherme et al., 2000) and Extractable Fe and Al. Oxides (Bertrand et al., 1999).

A research was designed by Hernandez and Meurer (2000) to determine the ability of soil to sorb inorganic P in anaerobic soil system. They observed that more soil P was released under reduced than oxidized conditions and this increase in soluble P under reduced conditions was significantly related to Bray NO_2 extractable P, clay content and oxalate Fe.

Reaction of soil constituents with P

The surfaces on which phosphate ions enter in the sorption reaction are of two main types. The first group is surfaces of constant charge, such as crystalline clay minerals, which interact with P principally through the cations held tightly to their plate like surfaces. The second category involves surfaces of variable charge including the Fe^{3+}, Al^{3+} oxides and organic matter for which H^+ and OH^- ions determine the surface charge and calcite for which Ca^{2+} and CO_3^{--} are responsible for charge development. Phosphorus sorption is the highest in oxides of Fe and Al followed by 1:1 and 2:1 type clays. In addition, several factors may influence relationship between phosphate adsorption and phosphate concentration, such as: soil pH, composition of adsorption sites, ambient temperature, duration of contact between soil and solution, method of shaking, kind of extracting, moisture contents of the soil prior to shaking, and surface area (Fox and Searle, 1978) of pH on retention.

Adsorption on layer silicate

The nature and mechanism of phosphate adsorption on clay mineral is assumed to be a ligand exchange reaction with the OH^- (H^+) groups coordinated to the exposed Al atoms on the edge of the clay crystal. This is similar to the adsorption

mechanism with metal oxides as reported on kaolinite (Kafkafi et al., 1967). Because clay minerals always exhibit exclusion of anions at the constant charge planar sites, the net adsorption of phosphate by clay should be influenced by the addition of an indifferent electrolyte (at a given pH). De Haan (1955) showed that the phosphate adsorption by montmorillonite increased with increasing ionic strength at neutral pH values. Hall and Baker (1971) revealed that montmorillonite fixed more P as pH was increased as compared to vermiculite.

The adsorption on hydrous oxides

Hydrous oxide surfaces, in calcareous soils are the principal sites on which P is strongly adsorbed (high energy surfaces) as H^+ and OH^- determine the surface charge and potential. The liability of P adsorbed on an oxide surface depends on the formation of ring structure (Parfitt, 1990). Plants can change chemical conditions in the rhizosphere in particularly by releasing H^+ and OH^- or by excreting organic anions (Bertrand et al., 1999). Furthermore, contents of amorphous iron oxides of the soils increased significantly with the decrease in crystalline iron oxides contents during the flooding process and the maximum capacity for P adsorption increased markedly while the adsorption P: desorption P ratio decreased (Su-Ling et al., 2001). Papini et al. (1999) stated that soils differed markedly in their ability to hold P. Presence of the highly reactive iron contents, increased the adsorption of P resulting into decreased P in solution. Therefore, after flooding- drained condition, P availability to plants decreased due to adsorption of P with recently precipitated high reactivity forms of iron oxides (Hernandez and Meurer, 2000). Singh and Singpuri (1986) reported that oxides of Fe and Al were correlated significantly with P adsorption maxima (r = 0.405). Higher value of P adsorption maxima in case of soil containing higher content of oxides of Fe and Al might be due to formation of their respective metal phosphate (Maida, 1980). A significant and positive relationship between P bonding energy constant and free oxides of Fe and Al observed and suggested a mechanism of phosphate adsorption by two point attachments mainly through the colloidal surface and Al. Exchangeable basis and silicate clay minerals strongly influence P adsorption in soils of weak to moderate acidity (minimal exchangeable Al). It is widely known that P adsorption increases as both counter ion valence and ionic strength increase in silicate clay system (Sample et al., 1980). Some P is likely adsorbed at the broken edges of the silicate clay lattice by legand exchange at Al (White, 1980). Kafkafi et al.

(1967) reported that phosphate ions adsorbed on kaolinite edges similar to Fe and Al oxides cannot be desorbed by leaching at constant pH.

Adsorption on organic matter

Organic matter is an ill defined ion exchanger, and has a net negative charge. Organic matter present on hydrous oxides blocks sites on which P could sorb (Parfitt, 1990; Easterwood and Sartain, 1990). Presumably the organic matter itself contains available chelate of Al and Fe. Robert (1969) indicated that applied P, at first stage, made bonds with anion exchange sites of OM and then transformed into less soluble Fe-P and Al-P. The OM and lime significantly increased pH and extractable P of the acidic soils. Therefore, application of OM and lime decreased P adsorption capacity of soil and index of bonding energy of the soil particles for P (Lucresio and Duque, 1999). The maximum buffering capacity was directly correlated with soil OM, potential acidity and was inversely correlated with base saturation (Guilherme et al., 2000).

Holford (1989) in his review paper indicated that there are two principal mechanisms whereby OM may affect the sorptivity and hence availability of P in soils;

i. Negatively charged OM adsorbs or complexes cations such as Al and Fe in acid soils (Bloom et al., 1979) and Ca in calcareous soils (Barrow, 1973) and hence reduces their solution activities and their role in P sorption and precipitation.

ii. Organic anions compete with P ions for adsorption sites on P reactive surfaces.

These reactions may be manifested by a decrease in P adsorption capacity (Lindsay, 1979) or in high affinity adsorption of P (Weir and Soper, 1962). On the other hand correlation studies often indicated a positive relationship between the OM contents of soils and P adsorption (Moreo et al., 1960). This may indicate that organic anions and P ions are adsorbed on the same type of sites on colloidal surfaces; or P adsorption on Al, Fe or Ca complexes on enlarged OM surfaces, may cause it. If OM lowers sorptivity, then increasing P availability without the use of P fertilizers should be achieved. Hence the retention and incorporation of crop residues and green manure crops could, in the long term, have a beneficial effect on P fertility. Studies to test this hypothesis revealed that, while increasing OM, sorption capacity did not decreased necessarily; it did increase the liability of native P in a neutral soil (Weir and Soper, 1962) and of fertilizer P in a very acid soil (Le Mare et al., 1987). On two highly

sorptive bauxitic soils, Weir (1972) recorded substantial increase in uptake of both native and fertilizer P following the addition of two organic complexing agents, and these were accompanied by large decreases in P sorption. These results suggest that it is the affinity aspect of the sorption process, rather than its capacity that is lowered by OM (Le Mare et al., 1987).

Adsorption on the whole soil

Like its constituents, soil itself has a large number of sites charged with H^+ and OH^- as potential determining ions. If this is the case, the soils will behave towards the anions just like hydrous oxide, but with the isotherm shape and pH dependence modified by the presence of OM and other mineral (Lucresio and Duque, 1999). The chief modifier is likely to be Ca^{2+} and $CaCO_3$ in calcareous soils.

Ballaux and Peaslee (1975) working on neutral soils reported increased P sorption maximum with increasing of clay and surface area of soils. Jones et al. (1979) indicated that the clay fraction adsorbed more P than the silt fraction. The former was probably due to the presence of 1:1 type clay (kaolinite) as it accounts for larger amounts of P sorption than 2:1 type clays. They mentioned further that this could be due to the large amount of Fe, Al and Mn hydroxides associated with 1:1 type clay mineral. Elmahi and Mustafa (1980) stated that P retention increased with increase in concentration of electrolyte or decrease in SAR. This effect should be considered when appraising P fertilizer application to salt affected soils.

Adsorption on $CaCO_3$

Calcareous soils inevitably have a soil solution dominated by Ca^{2+} and this ion is likely to form less soluble complexes with weak acid anions like orthophosphate. Lu-Wenlong et al. (1998) stated that organic acids can reduce the P adsorption by soils and the extent of reduction is closely related to the kind of organic acids. The organic acids dissolve large amount of $CaCO_3$ in calcareous soil, thereby considerable reducing P adsorption by soils. The dynamic of P is controlled by calcite, which strongly retains P and consequently maintains low P concentration in soil solution (Bertrand et al., 1999). Papini et al. (1999) stated that low $CaCO_3$ showed alteration in the upper limit of P adsorption from 1.4 to 3.5 g P kg^{-1} which was unchanged by further addition of P in solution. Nonetheless, higher percentage of $CaCO_3$ in soil, augmented P adsorption up to maximum concentration (2 g L^{-1}) of solution P recorded during the experiment.

The cations form a sparingly soluble compound with an anion surface precipitation, following anion adsorption, where the concentration of the cation is high. In calcareous soils, P adsorption occurs on soil carbonates and their impurities result in greater specific surface than that of pure calcite (White, 1980).

The reactivity of $CaCO_3$ in soils depends upon the specific surface area of the carbonate and on its total surface area (Rashid and Rowell, 1988). The P adsorption on pure $CaCO_3$ or lime stone has been measured by Cole et al. (1953). They concluded that there were two different types of reactions corresponding to low and high ranges of P concentration. At the lower range of P concentration (9 mg L^{-1}), adsorption followed the Langmuir isotherm and was directly proportional to the amount of $CaCO_3$ present. Nearly all the phosphate sorbed at low concentration (in a mono layer) was readily exchangeable with P_{32} in solution. At higher concentrations less than one third of the phosphate adsorbed was isotopically exchangeable. This was indication of calcium phosphate precipitation at the expense of $CaCO_3$ which was a relatively soluble source of Ca^{+2}.

Phosphorus availability in calcareous soils

The solid phase of adsorbed P, in the soils, is very complex. Due to the surface adsorption and precipitation processes, all the fertilizer P applied to soil is not available to plants. Application of soluble P and concentration of labile P decreased rapidly with time due to reaction with soil, either due to precipitation or adsorption process of oxides and hydroxides of Fe, in acidic soils and $CaCO_3$ in calcareous soils (Pant and Warman, 2000). Phosphate mobility was high in soils with significant micro pore structure (Cox et al., 2000). In calcareous soils P fertilizer application resulted into formation of least soluble compounds of Ca-P and their precipitation (Afif et al., 1993). Nevertheless, such P compounds may not be the dominant part of calcareous soils in the presence of P-reactive oxides of Fe and Al. For instance, the soils varying in $CaCO_3$ contents from 8 to 244 g kg^{-1} were closely associated with dithionite-soluble Fe (Holford and Mattingly, 1975). Phosphorus retention increases with the ratio of clay (or Fe oxides) to total (or active) $CaCO_3$ equivalent (Castro and Torrent, 1995; Carreira and Lajtha, 1997). By modifying the dissolution / precipitation and adsorption / desorption equilibrium, roots can influence the mobility of soil P (Bertrand et al., 1999) and ultra violet light can induce the release of P from iron P compounds through photo reduction process (Pant and Warman, 2000).

Redox process affects the reactivity of Fe oxides and this in turn affects P availability in soil. For instant, P availability increased during flooding and decreased during drying period even lower than at the initial measurement (Hernandez and Meurer, 2000). They also stated that alternation of the flooded - drained conditions increased the iron contents in high reactivity forms resulting in decreasing P availability to plants.

Coarse texture soil was found to release more P than fine textured soil (Pothuluri et al., 1991). Cumulative release of P had a highly positive relationship with supply parameters irrespective of level of P. From practical point of view, soil test P concentration or P fertilization should increase with increase in the lime concentration in calcareous soil to make available the same quantity of P (Westerman, 1992) such differences in calcareous and non-calcareous soils were also observed by Khan and Rafique (1992). Soil solution P concentration increased with increasing rate of OM and lime; however, P application alone had no significant effect on dry matter yield of maize (Lucresio and Duque, 1999).

Phosphate adsorbed on the $CaCO_3$ surfaces in calcareous soils may be adsorbed on to the surface of other soil constituent like hydrous oxide, clay and OM. The relative importance of these forms of phosphate in contributing to labile P has not been completely defined. Nevertheless, these P forms must provide for the regeneration of solution phase P. Generally, the amount of labile P depends greatly on the amount and the adsorption energy of the P on the soil surfaces and secondly, on the nature and solubility of the dominant compounds occurring in the soil. Although there is no direct proof that $NaHCO_3$ extracts all the exchangeable P first and then from non-exchangeable specific surface area, P adsorption was decreased and desorption increased, but varied for a given soil with soil P status. In another study, Fox and Kamprath (1970) demonstrated that for given level of P in the George Ville soils, P solubility is greater when P is being added to the system than when it is being withdrawn. For these soils it may be necessary to construct separate desorption isotherm in order to make prediction about P solubility, after large amount of P have been extracted by plants.

Previous research work related different P availability parameters with various soil properties. However, the influence of different soil components on P availability in calcareous soils is contradictory in the literature. In calcareous soils precipitation of

P in soluble Ca-P is supposed to be the major factor for P availability (Bramley et al., 1992).

Chhabra et al. (1981) reported significant leaching losses of P from root zone of sodic soils. These studies, however, do not provide an explanation for the increased availability of P in strongly alkaline sodic soil environment. Exchangeable Na and Ca composition and ionic strength have been reported to influence the rate of P sorption, rather than the equilibrium solution P concentration (Ryden and Syers, 1975). Recent studies suggest that exchangeable cation composition significantly influence the equilibrium between surface and solution P (Traina et al., 1986; Smillie et al., 1987; Sharpley et al., 1988

Dalal and Hallsworth (1976) concluded that intensity factor (solution phase) was mainly favoured by soil pH and measured increased labile P with increasing clay content in the soil, presumably because it was less strongly held against leaching. They further concluded that organic anions compete with phosphate ions on the exchange sites in the soil.

The phosphate apparently precipitates as Fe and Al phosphates during the dry part of rice culture cycle. Under subsequent reducing conditions, the Fe^{3+} phosphate is reduced to more soluble iron phosphate. This reduction can count for the high availability of phosphate in paddy soils; similarly aerobic soils often supply in adequate phosphate to plants because Fe^{3+} phosphate is insoluble. Patrick and Khalid (1974) observed that anaerobic soils released more P to soil solution low in soluble P and sorbed more P from solution high in soluble than aerobic soils.

The difference in behavior of P under aerobic and anaerobic soil conditions was attributed to the charge brought about in Ferric hydroxide by soil reduction. Khalid et al. (1977) reported that more soil P was released under reduced condition than oxidized conditions and this increase in soluble P under reduced condition was significantly related to Bray No.2 extractable P. The sorption and desorption of native as well as added P are governed by oxidation - reduction potential, oxygen supply, microbial activities, temperature and soil characteristics. Among the soil parameters that affect desorption process were pH (Lopez-Harnandez and Burnham, 1974; Mokwunye, 1975), the amount and type of clay mineral (Fox and Kamprath, 1970), OM (Harter, 1969; Syers et al., 1971) and extractable Fe and Al oxides (Harter, 1969; Shukla et al., 1971; Chen et al., 1973). Gutam and Tomar (1997) reported that $CaCO_3$ has more affinity for the sorption of orthophosphates.

The data available on the clay mineralogy of some soils of Pakistan show the presence of minerals like mica, montmorillonite, kaolinite, vermiculite and calcite etc. to varying degree depending upon the conditions under which these soils have been developed.

The sorption and release of native soil and adsorbed P are governed by oxidation-reduction potential, oxygen supply, microbial activities, soil characteristics and temperature. Among the soil variables that affect the sorption process are pH (Ghanbari et al., 1998; Liu et al., 1999; Reddey et al., 1999), the amount and type of clay minerals (Morais et al., 1996; Sharif, et al., 2000), organic matter (Rashid and Rowell, 1988; Guilherme et al., 2000) and Extractable Fe and Al Oxides (Bertrand et al., 1999). Hernandez and Meure (2000) observed that more soil P was released under reduced than oxidized conditions and this increase in soluble P under reduced conditions was significantly related to Bray NO_2 extractable P, clay content and oxalate Fe. The observation suggests that at low concentrations of P exchanges with:

1. Adsorbed sulphate and silicate
2. With water and OH^- of metal hydrous oxides and edge aluminum of clays.

Munns and Fox, (1976) observed that during the first 20-40 days P decline was faster in soil suspensions that were being shaken than it did in undisturbed soil at 0.1 bar moisture after 40 days of reaction. Shaking time had little effect apart from above mentioned soil factors; soil moisture management played a vital role in P fixation and P availability. Increased P availability with increased available moisture had been widely reported even in quite early studies.

Several mechanisms have been proposed to explain decrease in P adsorption capacity (Iyamuremye and Dick, 1996a) including (i) competition for adsorption sites between phosphate and organic anions released after organic matter decomposition and (ii) saturation of soil adsorption sites by P application. Organic anions differ greatly in their effect on P adsorption. For example, Ohno and Crannell (1996) found the soluble organic matter from green manures was of lighter molecular weight and had a great effect of reducing P adsorption than that of the high molecular weight soluble C from animal manures.

Effects of applied P on different soil fractions

Applied P reacts readily with different soil components including $CaCO_3$, clay, OM and sesqueoxides. This decreases P availability to plants affecting soil

fertility for sustainable crop production. Generally, in the soils responding to P application, poor correlation of soil P test values was observed with P uptake by plants (Rahmatullah et al., 1994). Phosphorus binding to the solid phase is influenced by surface adsorption and precipitation processes in soil from which it may release subsequently. Management practices adopted for the application of P fertilizer and soil properties affect the distribution of applied P into adsorbed and precipitated fractions of P (Afif et al., 1993).

The sequential technique of extraction developed by Hedley et al. (1982a) successfully quantified differentially available inorganic (P_i) and organic (P_o) pools of P. This technique is applied to study the effects of cropping, fertilizer application and management practices on the soil P status regarding incubation and long-term experimentation (Richards et al., 1995; Schmidt et al., 1996; Zhang and McKenzie, 1997; Reddy et al., 1999).

In spite of more P uptake by crops, increase in labile P fraction of manured soil, suggests that manures maintain the larger amount of P in soil. Singh et al. (2001a) and Reddy et al. (1999) found larger quantity of labile P fraction in soil on the application of cattle manure in soybean-wheat sequence. In the same way, a noteworthy increase in NaOH-P_i and NaOH-P_o was also observed on the frequent addition of fertilizer P (Ivarsson, 1990).

Inorganic soil P (P_i) is the dominant component of soil P pool. It is 75-85% proportion of total soil P present in calcareous soils (Liu, 1999). Fractionation of P_i is an efficient way to investigate availability of P_i in soils. It estimates inter-conversion of various P_i fractions of different P pools in soil and available or Olsen-P (Hedley et al., 1982a, b; Gu and Qin, 1997). Therefore, soil Pi is divided into various fractions such as Ca-P (HCl extractable P), Fe and Al-P (non-occluded Fe- and Al-bound P) and O-P (the P occluded within Fe oxides) (Solis and Torrent, 1989).

Hansen et al. (2004) concluded from the analysis of manure-amended soils that in the surface horizon 14-17% of total P exists in the exchangeable phase, while in the subsurface horizon this percentage falls to 5%.The Ca-bound fraction of P comprises 19-24% of the total P for surface soils and 10-17% for subsurface soils. The Fe-oxide fraction of surface and subsurface soils ranged from 9-12% of total P. Only the surface soils had detectable concentrations of P associated with OM, with less than 5% of P.

Sequential P_i fractionation, distinguishing labile (resin-extractable P and NaHCO$_3$-extractable P) and more stable forms (Ca-P, Al-P, Fe-P and O-P) of Pi, was already done (Hedley et al., 1982a, b; Yang and Jacobsen, 1990). The Ca-P was not further fractionated into sub-fractions because the Ca-P fraction in non-calcareous soils was rather small (Otani and Ae, 1997; Sharma and Verma, 2000; Buehler et al., 2002).

Nziguheba et al. (1998) established an incubation trial in a field on a kaolinitic, isohyperthermic Kandiudalf, moderately P-fixing soil. They used two organic materials, Tithonia diversifolia leaves and maize stover and inorganic P fertilizer, TSP (20% P) as the P sources. The following treatments were applied (broadcast and incorporated at 15 cm depth) at an equal rate of 15 kg P ha^{-1} with 4 replicates in a completely randomized block design: (i) control with no additions, (ii) tithonia, (iii) tithonia + TSP, (iv) TSP, (v) maize stover and (vi) maize stover + TSP. No crop was sown in order to eliminate plant uptake as a factor affecting soil P. Soil samples were collected prior to the application of treatments and at 1, 2, 3, 4, 8, and 16 weeks after application. Results revealed that application of P as a high quality organic source, tithonia, or an inorganic source, TSP, either alone or in combination increased labile inorganic P, as determined by resin and bicarbonate extractions. Tithonia and tithonia + TSP application also increased the moderately labile NaOH P_i. The low quality maize stover however generally did not increase labile or moderately labile P fractions, though its combination with TSP slightly increased resin P. There were few changes in the other organic P fractions like the short-term increase in NaHCO$_3$ P_o at week 2 in the tithonia and tithonia+TSP and in NaOH P_o from the sequential extraction in the tithonia+TSP and maize+TSP treatments. Phosphorus adsorption capacity was significantly decreased with the application of high quality tithonia and it was due to competition for adsorption sites between organic anions released after plant material decomposition and the phosphate anions.

El-Dewiny et al., (2006) in a greenhouse experiment distinguished four fractions of P in soils. First, they extracted water soluble and exchangeable fraction (Abul Kashem et al., 2003) which was loosely bound by surface associations and therefore was the most mobile P form observed in soil. The major portion of the most mobile P forms was observed where organic and inorganic (SSP) sources of P were applied. They concluded that small amounts of available P were related to rise in pH and higher CaCO$_3$ contents.

In the succeeding extracting stage, $NaHCO_3$-P was determined by removing adsorbed and weakly bound P. They inferred that in calcareous soils only small amount of P was linked with carbonates. Phosphorus concentration in this fraction was low due to buffering capacity of the calcareous soil and ranged between 5.1 and 22.7 mg kg^{-1}soil. The use of bicarbonate for the extraction of available P was based on the presumption, that plant roots produce CO_2, which forms bicarbonate in the soil that may solublize soil P (Tiessen and Moir, 1993).

The biologically available P consisted of labile P and represented soil solution P. This was soluble P originating from calcium phosphate and weakly adsorbed P on the surfaces of sesqueoxides or carbonates (Phiri et al., 2001). Third fraction contained P extracted by NaOH. The contents of P associated with NaOH were low and did not exceed 17.8 mg P kg^{-1} soil. Thus, this fraction, together with the previous two fractions, constituted minor pool of the total P concentration of the calcareous soil.

Soil extractable fraction of P was predominantly present in the HCl-P fraction (fraction - 4). The amount of P in this fraction was ranged between 15.6 and 56.4 mg P kg^{-1} soil. The HCl fraction contained the highest amount of P where SSP + OM were applied. This was due to organic inputs which were able to increase P availability in P-fixing soils. Iyamuremye and Dick (1996), suggested that organic anions formed by decomposing organic inputs could compete with P for the same adsorption sites and there by increased P availability in soil to allow a more complete use of soil P by plants.

Role of organic sources of P

Soil OM is very important for improved behavior of agricultural soils. It is a good indicator of soil quality, because it mediates many of the chemical, physical and biological processes required for a good soil. Iyamuremye et al. (1996 a, b) studied the influence of OM on chemical, physical and biological soil properties. They found that changes in chemical properties of soil and complex making of P sorption sites at reactive surfaces, caused reduction in P sorption capacity of soil. Van Faassen and Smilde (1985) counted several beneficial effects of OM. Regarding physical properties; OM improves structure and water holding capacity of soils. Chemically, it reduces P fixation, increases cation exchange capacity (CEC) and buffer capacity of soils to resist pH change. Different forms of OM serve as reservoir of the

micronutrients and secondary nutrients required by plants. Biologically, the OM provides energy to a diversity of soil fauna and flora. Organic matter exists in soils as partly decomposed residue of plants and animals, microorganisms and humidified OM or humus. Stable humus constitutes 50-75% of the total soil carbon. Stevenson (1982) reported that OM was the basic source of several mineral nutrients. Almost 95% of N and S reside in OM and P availability was increased with the addition of OM. Fernandez and Sanchez (1990) concluded that more than 95% of the total N and S and up to 75% of the P in surface soils were in organic forms. Dusberg et al. (1989) valued the 20-75% of total soil P as of organic origin. Dorado et al. (2003) found that soil organic matter affected the physical soil parameters relevant to P availability like, water retention, bulk density and aggregate stability.

Organic matter supplied to the soil is one of the most important factors for increasing the productivity in plants. Organic P supplied by OM is an important part of the soil P cycle, contributing to plants' P nutrition (Tarafdar and Claassen, 2003; Richardson et al., 2005). Generally, in the 'A' horizon of soil half of the total soil P is bound to the humic substances. Recent research has proved that only inorganic (HPO_4^{--} and $H_2PO_4^-$ ions) forms of phosphate and orthophosphate are taken up by plants. Therefore P bound to soil humic substances is transformed into plant available form through mineralization. Enzymes, especially phosphatase and phytase are involved in the process of mineralization.

Organic P in soils exists in various chemical forms. Presence of microbial population in soil plays vital role in recycling of organic P compounds. Phytic acid (inositol hexakisphosphate) is the major constituent of the soil organic P and it is stored in plant seeds to fulfill early P requirements of germinating seed. Rest of the organic soil P may be present as mono and diesters, phospholipids and nucleotides, sugar phosphates, phosphoproteins, and phos-phonates (Tate, 1984). Organic fertilizers have equivalent or even better effects on crop yields than P from mineral sources (Sharpley, 1996). Besides serving as the nutrient source, organic fertilizers can also improve the availability of P in soil (Hartikainen, 1989; Gerke, 1994).

Organic fertilization increases the humus content (Hartl and Erhart, 2005) and enhances the microbiological activities in soil (Frossard et al., 2002; Oehl et al., 2004; Oberson and Joner, 2005). Importance of organic substances in soil, for the conversion of P through soil microorganisms, was also reported by Bunemann et al.

(2004). Because of these positive effects, they opined that farming methods leading to high OM contents can effectively reduce the need for external P supply.

Increase in the levels of mycorrhizal colonization under organic treatments than under the conventional fertilizers, was reported by Kafkafi et al. (1988). They also found that OM increased the available P in the soil through the organic anion, preventing P fixation and replacing the P bound to the soil.

Transformation of organic compounds and nutrient release is a complex process. It depends on many factors such as the stability of organic substances (Guster et al., 2005), climatic conditions (Dorado et al., 2003), soil properties (Huffman et al., 1996), type of cropping system (Van den Bossche et al., 2005), and interaction with mineral fertilizers (Kaur et al., 2005). Moreover, the composition of organic fertilizers differs greatly, which influences the contents of organic and inorganic P as well (Traore et al., 1999).

The application of manure and compost in crop production is a common practice of organic fertilization and important for P recycling in agriculture (Emmerling et al., 2000; Nicklasch and Joergensen, 2001). Manure from different animal species is known to contain different P forms and concentrations (Sharpley and Moyer, 2000; Turner,2004) Application of FYM with fertilizer P, enriched long-term P fertility of a Vertisol through increase in organic P content and a short-term P supply as recalcitrant P (Reddy et al.,1996 and Singh et al. 2001a,b). Long-term application of animal manures increases soil organic P concentrations (Zhang and MacKenzie, 1997). The fate of organic P in manure-amended soil is dependent on the chemical forms of the organic P. Orthophosphate diesters appear to be mineralized more rapidly than orthophosphate monoesters (Condron et al., 2004; Turner et al., 2002). Manures and other organic amendments have shown increase in, total, available, and soluble P levels of the surface and subsurface horizons. Reduction in soil P adsorption capacity and increased rates of biologically-mediated turnover of organic P, were also observed due to stimulation of microbial and enzyme activities (Mozaffari & Sims, 1994 and Tiessen et al., 1994). Continuous manure application results into increased P availability to such an extent that it becomes even a matter of concern in some countries (Daniel et al. 1998; Gburek et al. 2000). Surface water P loading with excessive quantities of FYM application in agricultural lands was also noted by Hao et al. (2004).

Singh et al. (2006a) studied the effects of incorporating the on farm available

organic wastes like manures and crop residues on the fate of applied P regarding bioavailability and adsorption/desorption of P. The results of long-term experimentation revealed that incorporation of crop residues increased the P adsorption in soil. On the other hand the use of organic manures not only decreased the adsorption of applied P but also increased the labile P in soil. It was also observed that application of green manure combined with FYM also caused decreased P adsorption and increased P availability, while the separate incorporation of crop residues decreased the available P in soil. It was inferred that in the course of OM decomposition, microbes assimilated P in to the immobile forms of lipids, nucleoproteins, and other organic compounds. This P became available only after the decomposition of organic compounds following the death of microbial cells. Therefore, since the crop residues have wider C: P ratio they decomposed more slowly causing decreased soil solution P, whereas, manures having narrower C: P ratio decomposed rapidly and thus improved the P availability in soil.

Thus, in the P-fixing soils application of manures not only reduce fixation of applied P but it also help sustained P supply to crops. Application of green manure, the popular way for N recycling, also needs further research for its capability to mobilize the unavailable P reserves of soils (Singh et al; 2006b).

Integrated use of organic and inorganic sources of P

Russelle et al. (2007) have described four in vogue modes of agriculture: (i) low input agriculture (requiring more labor and skills to raise production); (ii) expansive agriculture (where land availability is not a limiting factor); (iii) high external input agriculture (where output targets determine input levels, somewhat less environmental friendly); and (iv) new conservation agriculture (in which production goals are harmonized with the resource base to attain both abundance and environmental benefits). It is within this last agricultural mode that we have to adopt for the future.

Opala et al. (2009) observed that due to low P content, separate application of organic matter could not fulfill the P need of crop. But integration of organic materials with inorganic sources of nutrients has an extra benefit over the application of inorganic nutrients alone. Because of low P concentration in tissues organic materials cannot supply sufficient P for crop growth (Palm, 1995), however, these can increase the availability of P in the soil (Iyamuremye and Dick, 1996).

The effects of chemical sources of P application and application of leaf litter of agro forestry plant on maize (*Zea mays L.*) yield were compared in a field study conducted in western Kenya by Kwabiah et al. (2003). The soil under experimentation was sandy clay loam with moderately P fixing characteristics. The authors noted that the plant materials, including Tithonia diversifolia and Croton megalocarpus, applied at 5 Mg ha^{-1} (DW), supplied a maximum of 9-15 kg P ha^{-1} by 35 days after incorporation. It was observed that the effect of plant materials like Tithonia diversifolia and Croton megalocarpus on maize yield was comparable to that of 50 kg P ha^{-1} plus 120 kg N ha^{-1} applied as triple super phosphate (TSP) and urea, respectively. Apart from the fact that the application of only organic sources of P to soil could not maximize crop yield potential, but supply of appropriate quantities of high quality plant materials could evidently reduce the mineral P fertilizer requirements of maize (Nziguheba et al., 1998).They concluded that combining organic and inorganic nutrient sources may provide an efficient use of scarce resources for maintaining or increasing crop yield. Application of chemical fertilizers combined with the on farm available organic sources help to increase the bioavailability of residual soil P (Beri et al. 2002).

Application of TSP in combination with organic fertilizer produced the highest yield and had the strongest positive effect on P uptake. However, application of TSP alone resulted in a lower P uptake (Oberson and Joner, 2005). Scherer (1993), Kaur et al. (2005) and Tittonell et al. (2008) also found higher crop yields when organic manures were combined with inorganic fertilizers compared to treatments with inorganic fertilizers alone. Similar results were recorded by Munir et al. (2007). They found significant effect of different combinations of organic and inorganic fertilizers on achene and biological yield of sunflower. Application of inorganic fertilizers along with organic fertilizers increased the achene and biological yield significantly over the treatments where only organic or inorganic fertilizers were added. This increase could possibly be because of more availability of nutrients and their uptake which increased leaf area index, Crop Growth Rate, Net Assimilation Rate, flowering and biomass.

Parmar and Sharma (2002) conducted a long-term field experiment on sandy loam soil using maize-wheat rotation. They applied different levels of NP alone and in combination with FYM. They found that grain yield of maize and wheat was significantly influenced by different fertility treatments. They noticed that half and full doses of N or NP applied to maize and wheat crops and FYM @10 t.ha^{-1} to maize

crop only, significantly increased the grain yield of maize and subsequent wheat over lowest dose of N or NP applied. The addition of FYM in the absence of fertilizer could not sustain grain yield of maize and wheat. They found that incorporation of FYM to both the crops increased significantly the organic carbon contents in the soil. The available P status of soil decreased in plots receiving only N and K application that was restored with the use of P fertilizer and FYM.

In a field experiment Eichler-Lobermann et al. (2007) applied triple-super phosphate (TSP) alone and in combination with cattle manure and mature biowaste compost. Results revealed that average yields were significantly higher for fertilized plots compared to plots without fertilizer application. Organic fertilization had the same or even a stronger effect on yield increases than annually applied highly soluble mineral P fertilizers. The highest yields were produced when the organic fertilization was combined with spring applied TSP. Organic fertilizer + TSP had the strongest positive effect on P uptake. Organic fertilization increased the OM contents of soil and this increase was significant when biowaste compost was applied.

CHAPTER 3

MATERIALS & METHODS

Bulk surface (0-15cm) samples were collected for the three soils from Chakwal and Gujranwala areas. The samples were air-dried and ground to pass through a 2-mm sieve. Soil colour was estimated according to Munsil Colour Chart notation. A homogeneous portion of the sieved soil samples were analyzed for various physical and chemical properties like texture, pH, ECe, K, Olsen P, solution P, OM and calcium carbonate contents (Table 4.1) following standard procedures as described by Richards (1954).

3.1. Soil analysis

Determination of soil texture

To 40 g of soil 40 ml of 1% sodium hexa metaphosphate solution was added and kept overnight. The whole mixture was transferred to dispersion cup of Bouyoucos stirrer and dispersion of soil was done with stirrer. Reading was recorded with the help of Bouyoucos hydrometer (Moodie et al., 1959). Soil texture was determined with the help of triangle described by International Society of Soil Sciences.

Preparation of saturated soil paste

Paste of 250 g soil was prepared using distilled water (method 2, P 84).

pH of saturated soil paste

To determine pH of soil pastes, pH meter was used with glass and calomel electrodes using buffer solutions of pH 7.0 and 9.2 as standards (method 21a, P 102).

Electric conductivity of saturation extract

Electric conductivities of saturated extracts were determined using EC meter (method 46, P 89).

Extractable K

Extraction of K from soil was made using ammonium acetate ($1N$) and K was determined from extract using flame photometer model PFP.7 Jenway (method 18, P 100-101).

Determination of OM %

Soil OM % was determined by taking 1.0 g soil into a 50 ml conical flask. Ten ml of 1.0 N $K_2Cr_2O_7$ and 20 ml of concentrated H_2SO_4 were added to the flask. Flask

was swirled gently for thorough mixing of the reagents. Then contents of the flask were allowed to stand for 30 minutes. Distilled water (200 ml) was added in the flask and whole contents were again mixed. Diphenylamine was added into the flask as indicator. Contents of flask were titrated against $FeSO_4.7H_2O$ in the presence of 10 ml H_3PO_4 till the appearance of purple to blue end point (Walkley and Black, 1934).

Olsen's P determination

To determine Olsen P, 5 g sieved soil sample was extracted with 0.5 M $NaHCO_3$ solution, filtered through Whatman No. 42 filter paper. Blue colour method was followed (Watnabe and Olsen, 1965). Ten ml filtrate was taken and acidified with 5N H_2SO_4 to pH 5.0 using p-nitrphenol as an indicator. Colour developing agent (ammonium heptamolybdate + antimony potassium tartarate dissolved in 5N sulfuric acid + L-Ascorbic acid) was added. Blank and standards were prepared with 10 ml of 0.5 M $NaHCO_3$ solution, and intensity of blue colour was measured as absorbance of light at 882 nm wavelength on spectrophotometer (Kuo, 1996).

Determination of solution P

Solution P was determined by extracting 1 g soil sample with 20 ml 0.01 M $CaCl_2$ and filtered through Whatman No. 42 filter paper. Blue colour method was adopted (Olsen and Sommers, 1982).

Determination of $CaCO_3$ content

Calcium carbonate content of the soils was determined by the calcimetric method using 6 N HCl solutions. Five g soil sample was treated with 1:1 HCl and volume of CO_2 released from $CaCO_3$ present in the soil was measured (Moodie et al., 1959).

Determination of DTPA extractable Fe

For determination of (DTPA extractable) Fe in soil 10 g soil sample was extracted with 20 ml of DTPA extraction solution and filtered through a Whatman No. 42 filter paper (Lindsay and Norvell, 1978). Iron was measured directly in the filtrate by Atomic Absorption Spectrophotometer.

Determination of inorganic fractions (NaOH-P, CDB-P and HCL-P) in soil

Inorganic fractions of P (NaOH-P, CDB-P and HCL-P) were fractioned following fractionation scheme for the calcareous soils reported by Kuo (1996) after (Chang and Jackson, 1957). For this purpose, 1.0 g soil sample was extracted with 50 ml mixed solution of 0.1 M NaOH and 1M NaCl for 17 h and centrifuged. The soil in

the centrifuge tube was washed with 25-ml portions of 1M NaCl. After this, 40-ml of sodium citrate and 5 ml of 1M NaHCO$_3$ was added to the soil and heated. Then sodium dithionite was added, the soil was washed twice with saturated NaCl and centrifuged and sodium dithionite was allowed to oxidize. Fifty ml of 0.5 M HCl was added to soil, one hour shaking was done prior to centrifuge. Supernatant was decanted into 100 ml flask and the soil was washed twice with 25 ml saturated NaCl. Both washings were mixed with the supernatant/extract. After this, an aliquot containing 2 to 4 µg P (pH maintained with 2M HCl or 2M NaOH using P-nitro phenol as an indicator) was obtained. Concentration of P in each extract (Figure 3.1) was measured colorimetrically after phosphomolybdate reduction with ascorbic acid (Watnabe and Olsen, 1965).

3.2. Analysis of organic amendments

Organic matter %

Five gram sample of amendment was ignited in a crucible at 600 ºC for six hours and organic matter % was calculated by measuring loss in weight (Kalra and Maynard, 1991).

Wet digestion of amendments

One gram oven dried organic amendment was digested in 20 ml concentrated HNO$_3$ and 10 ml of 72% HClO$_4$ cooled the digest, transferred to 100 ml volumetric flask and made the volume (method 54a)

Total P determination

Organic amendment was digested as per method 54a. Five ml of the aliquot taken in 50ml volumetric flask, added 5 ml of ammonium vanadate (0.25%) and ammonium molybdate (5%), made the volume and allowed to stand for 15-30 minutes. Reading was recorded on colorimeter. Then from the standard curve, actual reading was noted.

Determination of total K

Organic amendment was digested as per method 54a. Potassium was determined by flame photometer (58 a).

Determination of total N

One gram of amendment was digested with 25 ml H$_2$SO$_4$ in a Kjeldahl's flask and distillation was made with Micro- Kjeldahl's apparatus (Jackson, 1962).

Soil

Centrifuged at 2400 rpm
for 15 minutes

17 hours
shaking

50 ml 0.1*M* NaOH
+ 1 *M* NaCl

Extract A

Soil

Two times washed with 25 ml
1 *M* NaCl

Soil

40 ml 0.3*M* Sodium citrate + 5ml 1*N*
NaHCO$_3$ +   1g Sodium dithionite

Extract B

Soil

Two washings with
saturated NaCl

Soil

Soil

50 ml
0.5 *M* HCl

Extract C

Soil

FRACTIONATION OF INORGANIC P (Kuo, 1996)
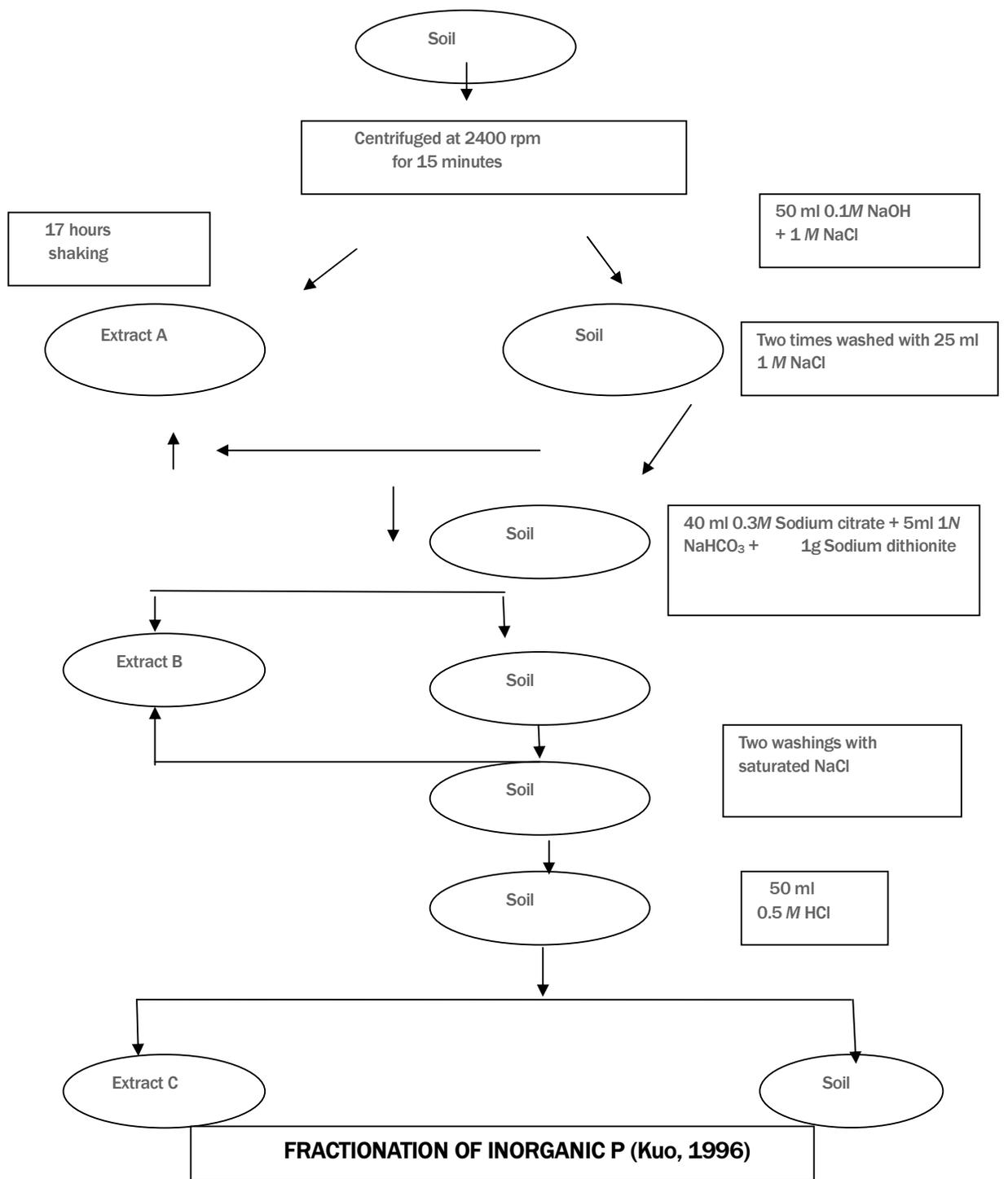
Fig. 3.1 Floe diagram of inorganic P fractionation

3.3. Plant sample preparation and P analysis

Whole plant tops were harvested 45 days after germination. Plant samples were washed with distilled water, and dried to constant weight at 65 ºC in a force-air oven. The plant samples were fine ground in a Wiley mill to pass through 1mm sieve. One gram plant material was wet digested in a di-acid mixture of HNO_3 and $HClO_4$ (3:1) (Miller, 1998). The digest was analyzed for P using vanadate-molybdate yellow colorimetric method (Chapman and Pratt, 1961). According to the procedure, 5 ml of the digested aliquot was taken into a 50 ml volumetric flask and 5 ml of ammonium vanadate (0.25 %) plus ammonium molybdate (5%) were added. Final volume was allowed to stand for 30 minutes. Readings were recorded 400 *nm* absorbance on a *UV*-visible spectrophotometer (*UV*-1201, Shimadzo).. From the standard curve, P concentration (percentage) in plant was calculated (method 54a, US Salinity Lab. Staff, 1954).

Study I

Five kg of air dried, ground and sieved soils were weighed and filled into glazed pots of 8.5″ internal diameter and 9.5″ depth. The treatments included;

    i)   Control

    ii)   Farm yard manure (FYM)

    iii)   Diammonium phosphate (DAP)

    iv)   DAP + FYM

Diammonium phosphate (DAP) was applied to supply 35 mg P kg^{-1} soil while FYM was added at 50 g pot^{-1}. The N (urea) P (DAP) and K (SOP) were applied at the rate of 175, 85 and 65 kg ha^{-1}, respectively to each pot but P was not applied in control pots neither as DAP nor as organic P amendment.

Soils in pots were irrigated with excess amount of distilled water. After a week when soils reached to field capacity, pots were emptied and soils were remixed and refilled in the pots to homogenize the soils and amendments. This process was repeated thrice and treatments were imposed in triplicate.

The experiment was conducted according to Completely Randomized Design (CRD). Maize (cv. Pak Hybrid-7222) was sown and four uniform plants per pot were maintained after germination. Moisture contents in pots were retained with distilled water at about 60 % of the water-holding capacity during the growth period of plants.

Whole plant tops were harvested 45 days after germination. Plant samples were washed with distilled water, and dried to constant weight at 65C° in a forced-air oven. Shoot dry matter and P concentration in plant shoot were measured directly and beneficial effects pertaining to integrated use of organic amendments and DAP on maize growth and P uptake were assessed by calculating following parameters according to Mengel and Kirkby (2001).

$$\text{Agronomic Efficiency (g g}^{-1}) = \frac{\text{Yield}_F - \text{Yield}_C}{\text{Fertilizer P applied}}$$

$$\text{Physiological Efficiency (g mg}^{-1}) = \frac{\text{Yield}_F - \text{Yield}_C}{\text{P uptake}_F - \text{P uptake}_C}$$

$$\text{Apparent P Recovery (\%)} = \frac{\text{P uptake}_F - \text{P uptake}_C}{\text{Fertilizer P applied}} \times 100$$

Where, F = Fertilizer applied and C = Control (without fertilizer)

Study II

Five kg prepared soil was filled in glazed pots of 8.5″ internal diameter and 9.5″ depth. Soil in pots was moistened with excess amount of water. When at field capacity, the pots were emptied and soil was remixed thoroughly. The N (urea) P (DAP) and K (SOP) were applied at the rate of 175, 85 and 65 kgha^{-1}, respectively to each pot. Diammonium phosphate was applied to supply 35 mg P kg^{-1} soil while organic sources of P were added @ 10 g kg^{-1} or equivalent to their carbon content basis.

Soils in pots were irrigated with excess amount of distilled water. After a week when soils reached to field capacity, pots were emptied and soils were remixed and refilled in the pots to homogenize the soils and amendments. This process was repeated thrice to homogenize the soils and amendments (Rahmatullah et al., 1994).

For incubation purpose the moisture contents in pots were maintained with distilled water at about 60 % of the water-holding capacity throughout the incubation

period of trial. Soil samples were collected monthly. At every sampling, OM%, solution P and Olsen's P contents were determined.

Then various treatments were imposed in triplicate. The treatments included;

i)   Control

ii)   Green manure (Sesbania)

iii)   Farm yard manure (FYM)

iv)   Poultry manure

v)   Press mud

vi)   Diammonium phosphate (DAP)

vii)   DAP + green manure

viii)   DAP + FYM

ix)   DAP + poultry manure

x)   DAP+ press mud.

Kinetic models given in the Table 3.1 were used to study the release of solution P, Olsen's P and rate of OM decomposition in the soils.

Table 3.1

Kinetic models used in the study

Sr. no.	Kinetic equation	Model form	References
1	Simplified Elovich	$y = a + b \log t$	Chien and Clayton, 1980; Havlin et al., 1985
2	Parabolic Diffusion	$y = a + b\, t1/2$	Havlin et al., 1985; Li et al., 2005
3	Zero-order	$(y_{max} - y) = a + b\, t$	Martin and Sparks, 1983

a = intercept, b = slope (rate constant) and t = time

Study III

Five kg soil was filled into glazed pots of 8.5″ diameter and 9.5″ depth. Soils in pots were moistened with excess amount of water. The N (urea) P (DAP) and K (SOP) were applied at the rate of 175, 85 and 65 kgha[-1], respectively to each pot. At field capacity, pots were emptied and soils were remixed thoroughly to homogenize

the soils and amendments. This process was repeated thrice to obtain equilibrium (Rahmatullah et al., 1994). Following treatments were imposed in triplicate;

i)   Control
ii)   Green manure (Sesbania aculeata)
iii)   Farm yard manure (FYM)
iv)   Poultry manure
v)   Press mud
vi)   Diammonium phosphate (DAP)
vii)   DAP + green manure
viii)   DAP + FYM
ix)   DAP + poultry manure
x)   DAP+ press mud

Shoot dry matter and P concentration in plant shoot and CDB-P (Citrate dithionate bicarbonate-P), HCl-P (Calcium bound P), NaOH-P (Non occluded Fe and Al P), Olsen-P and solution-P in soils were measured directly and beneficial effects pertaining to integrated use of organic amendments and DAP on maize growth and P uptake were assessed by calculating following parameters according to Mengel and Kirkby (2001) as described for study-I.

Statistical analysis

The data pertaining to Study-I and Study-III were statistically analyzed according to Completely Randomized Factorial Design using software MSTAT-C (Russel and Eisensmith, 1983). Analysis of variance (ANOVA) technique was used and Duncan's Multiple Range (DMR) test was applied to separate the significant treatment means (Steel and Torrie, 1980).

Table: 3.2

Physico-chemical properties of the experimental soils

Sr.No.	Parameters	Soil-I	Soil-II	Soil-III
1	Soil classification	Fluventic Camborthids	Udic Haplustalf	Udorthentic Cromusterts
2	Soil series	Tala Gang	Gujranwala	Satwal
3	Soil colour	Dull yellowish brown	Brownish grey	Brownish grey
4	Sand (%)	74	52	68
5	Silt (%)	11	22	14
6	Clay (%)	15	26	18
7	Textural class	Sandy loam	Sandy clay loam	Sandy loam
8	pH_s	7.74	7.29	7.88
9	EC_e (dS m^{-1})	0.63	1.17	0.59
10	Extractable K (mg kg^{-1})	60.0	100.0	130.0
11	O M (%)	0.62	1.31	0.41
12	Total N (%)	0.030	0.059	0.021
13	Olsen P (mg kg^{-1})	6.65	16.65	5.26
14	Solution P (mg L^{-1})	0.012	0.061	0.010
15	$CaCO_3$ (%)	4.06	2.12	5.5
16	Extractable Fe (ppm)	1.11	5.66	0.66

Table: 3.3
Organic matter and NPK status of amendments

Organic amendments	O M	Total N	Total P	Total K
	%			
Poultry manure	45.40	2.13	0.98	1.11
Press mud	38.20	1.83	0.93	0.32
Farmyard manure	24.34	1.06	0.26	0.74
Green manure (*Sesbania aculeata*)	15.10	0.66	0.22	0.46

CHAPTER 4   STUDY-1

RESPONSE OF MAIZE TO DIAMMONIUM PHOSPHATE AND FARMYARD MANURE APPLICATION ON THREE DIFFERENT SOILS

Abstract

Efficiency of phosphorus applied to correct its wide spread deficiency is very low. An important strategy to improve the efficiency of applied P is the combined application of organic and inorganic sources of phosphorus. A pot experiment was set up to investigate the effect of either alone or combined application of FYM and DAP on maize, grown in three different calcareous soils. The four treatments (control, DAP, FYM and DAP+FYM) and three soils were arranged in factorial set up using completely randomized design (CRD). Diammonium phosphate was applied to supply 35 mg P kg^{-1} soil while FYM was added @ 50g pot^{-1}. Maize (cv. Pak Hybrid-7222) was used as test crop. Shoot dry matter of plants and P uptake were recorded. Physiological and agronomic P efficiencies and apparent P recovery were computed. Results regarding effect of combined P sources on yield parameters (shoot dry matter was 22.24 g pot^{-1} for DAP+FYM, 16.24 g pot^{-1} for FYM and 18.64 g pot^{-1} for DAP) and various P efficiencies were significantly better (agronomic efficiency 22.30 g g^{-1} for DAP+FYM for FYM 7.32 g g^{-1} and 13.31 g g^{-1} for DAP) than organic or inorganic P sources alone. Results of the present study provided basis for further investigation.

4.1. Introduction

Maize (*Zea mays L.*) is an important cereal crop which provides food for human beings, feed for animals and raw material for several agro-based industries. It belongs to the group of crops which have high growth rate, producing large biomass and in turn require more P (Mengel and Kirkby, 2001).

Soils of Pakistan are generally alkaline and calcareous in nature, where maize crop mostly suffers from P deficiency. About 80 to 90 % soils from arid and semiarid regions of the world, including Pakistan, are deficient in available phosphorus (Sanders, 1986; Memon et al., 1992 and NFDC, 2001).

Various factors important for controlling P availability in calcareous soils include pH, nature and amount of clay minerals, Fe and Al oxides and presence of free calcium carbonate. Application of inorganic P fertilizer in combination with FYM was found effective in enhancing the effectiveness of inorganic P fertilizers

(Organic manures may convert relatively unavailable native and residual P to (Whalen and Chang, 2001).chemical forms which are more available after decomposition. This process produces CO_2, which forms H_2CO_3 in the soil solution, resulting in the dissolution of primary P-containing minerals. Organic acids released during decomposition also help to dissolve soil mineral P. In soils with high P-fixing capacities; organic compounds released during decomposition processes may increase P availability by coating P adsorption sites or via anion exchange. Repeated incorporation of green manures can decrease soil bulk density, increase soil aggregation and moisture retention. All these factors may also help to increase P uptake by increasing root and mycorrhizal growth (Cavigelli and Thien, 2004).

Therefore, judicious and efficient use of inorganic P fertilizer and recycling of organic wastes is inevitable to maximize agricultural productivity on sustainable basis. The study therefore, was planned for:

- Augmenting the P availability of calcareous soils through addition of organic manures
- Evaluating the solitary and integrated efficiency of organic and inorganic P sources for maize crop

4.2. Results.

Texture of the soils I and III was sandy loam while soil II was sandy clay loam (Table 3.2). The three soils were alkaline in reaction (pH > 7.0), non-saline (ECe < 4.0 dS m^{-1}). Soils I and III were deficient in organic matter content but soil II had 1.31% organic matter. Extractable K ranged from 60 to 130 mg kg^{-1} and Olsen P varied from 5.26 to 16.65 mg kg^{-1}soil. Three soils had 2.12 to 5.5% $CaCO_3$.

4.2.1 Plant growth

There was a significant main and interactive effect of various soils and treatments on shoot dry matter (SDM) of maize (Table 4.1). Application of organic amendment significantly (P≤ 0.05) increased the shoot dry matter of maize grown on all the three soils. Shoot dry matter of maize increased significantly over control when P was applied as DAP or FYM alone as well as in combination. This tremendous response may be due to low available P status of the soils (Table 3.1). Diammonium phosphate proved statistically (P≤ 0.05) significant over FYM. However their combined application produced maximum SDM. Significant difference was also

recorded within the experimental soils. The overall means (19.97 g pot^{-1}) for S-II were the highest followed by S-I (18.78 g pot^{-1}) and S-III (14.07 g pot^{-1}).

4.2.2 Phosphorus concentration in plants

Results regarding P concentration in maize plant depicted significant (P≤ 0.05) main and interactive effect of various soils and treatments (Table 4.2). A significant increase in P concentration over control was observed with the application of inorganic (DAP) and organic (FYM) amendments alone as well as in integrated form. Diammonium phosphate (1.43 mg g^{-1}) proved statistically (P≤ 0.05) superior over FYM (1.28 mg g^{-1}) while their combination caused the highest P concentration in plants (1.47 mg g^{-1}). Difference among experimental soils was also significant statistically and overall means for S-II (1.42 mg g^{-1}) were the highest followed by the soils S-III (1.30 mg g^{-1}) and S-I (1.24 mg g^{-1}).

4.2.3 Phosphorus uptake by plants

Phosphorus uptake by maize plants increased significantly from 15.02 mg pot^{-1} in T$_1$ (control) to the peak value of 32.89 mg pot^{-1} recorded for T$_4$ (DAP + FYM). This was 119% greater over control (Table 4.3). Farmyard manure and DAP were also significantly better over control. However, DAP (26.56 mg pot^{-1}) resulted in more P uptake than FYM (20.97 mg pot^{-1}) alone. Phosphorus uptake also depended upon the characteristics of experimental soils. The differences were also significant statistically and overall means for S-II (28.99 mg pot^{-1}) were the highest followed by S-I (23.71 mg pot^{-1}) and S-III (18.88 mg pot^{-1}). Interactions among soils and amendments were also significant statistically.

4.2.4 Agronomic efficiency (AE)

Agronomic efficiency of P was minimum with FYM followed by DAP (Table 4.4). However, combination of organic and inorganic amendments (DAP + FYM) was found significantly better (22.30 g g^{-1}) than FYM (7.32 g g^{-1}) or DAP alone (13.31 g g^{-1}). Overall means for S-II (12.17 g g^{-1}) were the highest followed by S-I (11.45 g g^{-1}) and S-III (8.58 g g^{-1}). On the other hand the interactions among experimental soils and amendments were also statistically significant.

4.2.5 Physiological P efficiency (PPE)

Physiological efficiency of P, added through organic and inorganic amendments on individual and combined basis was statistically non-significant (Table 4.5). Nevertheless, experimental soils S-I and S-II showed significantly (P≤0.05) higher PPE as compared to soil S-III.

4.2.6 Phosphorus recovery by maize (%)

Apparent P recovery was different in organic and inorganic amendments. Nevertheless, their combined application (DAP +FYM) proved statistically better than their separate application (table 4.6). On individual basis, DAP showed higher P recovery over FYM. The overall means of experimental soils S-I (2.0 %) and S-III (2.18 %) showed no statistical significance while S-II (2.44 %) proved better than S-I and S-III. However, interactions among experimental soils and different P sources were found statistically non-significant.

Table 4.1

Effect of organic and inorganic amendments on shoot dry matter of maize (g pot^{-1})

(Figures are the means of three replications)

Treatments	Soil-I	Soil-II	Soil-III	Mean
Control	14.20	15.13	10.63	13.32
FYM*	17.33	18.43	12.96	16.24
DAP*	19.86	21.13	14.90	18.64
FYM + DAP	23.73	25.20	17.80	22.24
Mean	18.78	19.97	14.07	

	Soil	Treatment	Soil x Treatment
L S D (0.05)	0.389	0.449	0.778

*Farmyard manure was used @ 10 g kg^{-1} soil

*Diammonium phosphate was applied to supply 35 mg P kg^{-1} soil

Table 4.1.1

Analysis of variance table for SDM

Source	DF	SS	MS	F	P
Replication	2	3.204	1.602		
Treatment	3	384.976	128.325	607.20	0.0000
Soil	2	233.594	116.797	552.65	0.0000
Treatment*Soil	6	7.653	1.275	6.04	0.0008
Error	22	4.649	0.211		
Total	35	634.076			

Table 4.2

Effect of organic and inorganic amendments on P concentration of maize plant (g pot^{-1})

(Figures are the means of three replications)

Treatments	Soil-I	Soil-II	Soil-III	Mean
Control	1.10	1.27	0.95	1.10
FYM*	1.24	1.34	1.27	1.28
DAP☼	1.24	1.50	1.54	1.43
FYM + DAP	1.38	1.59	1.44	1.47
Mean	1.24	1.42	1.30	

	Soil	Treatment	Soil x Treatment
L S D (0.05)	0.030	0.035	0.060

*Farmyard manure was used @ 10 g kg^{-1} soil

☼Diammonium phosphate was applied to supply 35 mg P kg^{-1} soil

Table 4.2.1

Analysis of variance table for P concentration

Source	DF	SS	MS	F	P
Replication	2	0.02172	0.01086		
Treatment	3	0.73643	0.24548	190.94	0.0000
Soil	2	0.21132	0.10566	82.19	0.0000
Treatment*Soil	6	0.18653	0.03109	24.18	0.0000
Error	22	0.02828	0.00129		
Total	35	1.18427			

Table 4.3

Effect of organic and inorganic amendments on P uptake by maize (mg pot^{-1})

(Figures are the means of three replications)

Treatments	Soil-I	Soil-II	Soil-III	Mean
Control	15.70	19.20	10.16	15.02
FYM*	21.63	24.66	16.63	20.97
DAP☆	24.80	31.83	23.06	26.56
FYM + DAP	32.73	40.26	25.66	32.89
Mean	23.71	28.99	18.88	

	Soil	Treatment	Soil x Treatment
L S D (0.05)	0.829	0.958	1.659

*Farmyard manure was used @ 10 g kg^{-1} soil

☆Diammonium phosphate was applied to supply 35 mg P kg^{-1} soil

Table 4.3.1

Analysis of variance table for P uptake

Source	DF	SS	MS	F	P
Replication	2	18.60	9.298		
Treatment	3	1577.34	525.781	547.57	0.0000
Soil	2	613.46	306.730	319.44	0.0000
Treatment*Soil	6	58.92	9.820	10.23	0.0000
Error	22	21.12	0.960		
Total	35	2289.44			

Table 4.4

Effect of organic and inorganic amendments on agronomic efficiency of maize (g g^{-1})

(Figures are the means of three replications)

Treatments	Soil-I	Soil-II	Soil-III	Mean
Control	000	000	000	000
FYM*	7.81	8.30	5.85	7.32
DAP¤	14.20	15.10	10.64	13.31
FYM + DAP	23.79	25.29	17.87	22.30
Mean	11.45	12.17	8.58	

	Soil	Treatment	Soil x Treatment
L S D (0.05)	0.329	0.380	0.659

*Farmyard manure was used @ 10 g kg^{-1} soil
¤Diammonium phosphate was applied to supply 35 mg P kg^{-1} soil

Table 4.4.1

Analysis of variance table for AE

Source	DF	SS	MS	F	P
Replication	2	1.23	0.613		
Treatment	3	2406.73	802.245	5289.66	0.0000
Soil	2	86.69	43.344	285.79	0.0000
Treatment*Soil	6	50.25	8.374	55.22	0.0000
Error	22	3.34	0.152		
Total	35	2548.23			

Table 4.5

Effect of organic and inorganic amendments on physiological efficiency of maize (g mg^{-1})

(Figures are the means of three replications)

Treatments	Soil-I	Soil-II	Soil-III	Mean
Control	000	000	000	000
FYM*	0.533	0.619	0.362	0.505
DAP$^{¤}$	0.630	0.478	0.331	0.480
FYM + DAP	0.560	0.480	0.463	0.501
Mean	430	394	289	

	Soil	Treatment	Soil x Treatment
L S D (0.05)	43.13	49.81	86.27

*Farmyard manure was used @ 10 g kg^{-1} soil
$^{¤}$Diammonium phosphate was applied to supply 35 mg P kg^{-1} soil

Table 4.5.1

Analysis of variance table for PPE

Source	DF	SS	MS	F	P
Replication	2	0.00082	0.00041		
Treatment	3	1.66065	0.55355	212.86	0.0000
Soil	2	0.12982	0.06491	24.96	0.0000
Treatment*Soil	6	0.12297	0.02049	7.88	0.0001
Error	22	0.05721	0.00260		
Total	35	1.97147			

Table 4.6

Effect of organic and inorganic amendments on P recovery by maize (%)

(Figures are the means of three replications)

Treatments	Soil-I	Soil-II	Soil-III	Mean
Control	000	000	000	000
FYM*	1.48	1.37	1.62	1.49
DAP¤	2.27	3.16	3.22	2.88
FYM + DAP	4.26	5.26	3.88	4.46
Mean	2.00	2.44	2.18	

	Soil	Treatment	Soil x Treatment
L S D (0.05)	0.190	0.220	0.381

*Farmyard manure was used @ 10 g kg^{-1} soil
¤Diammonium phosphate was applied to supply 35 mg P kg^{-1} soil

Table 4.6.1

Analysis of variance table for P recovery %

Source	DF	SS	MS	F	P
Replication	2	0.154	0.0769		
Treatment	3	98.651	32.8837	646.49	0.0000
Soil	2	1.196	0.5980	11.76	0.0003
Treatment*Soil	6	3.666	0.6109	12.01	0.0000
Error	22	1.119	0.0509		
Total	35	104.786			

4.3. Discussion

Due to low P concentration in tissues, organic materials cannot supply sufficient P for crop growth (Palm, 1995). However, these tissues can increase the availability of P in the soil (Iyamuremye and Dick, 1996). Better response of P with the application of farmyard manure (FYM) had been reported earlier (Reddy et al., 1999 and Singh et al., 2001a, b). This was assumed due to enrichment of long term fertility of soil through increase in organic P and short term supply as recalcitrant P.

In the present study, response of applied P either as inorganic (DAP) or organic amendment (FYM) was significantly better over control in the all soils. However, integration of organic and inorganic amendments proved better than their solitary performance. It might be due to extra benefits of integration of organic and inorganic sources of P over the solitary application of organic and inorganic amendments of P. In soil II (Table: 3.2) the concentration of P in maize shoot and P uptake by maize shoot were significantly high over Soil I and Soil III. This might have been occurred due to the higher OM contents and lower $CaCO_3$ of S II. Since $CaCO_3$ present in soil may react with the solution P of soil and hence transform this P into more insoluble form resulting its least availability in labile form. While, presence of OM not only enhances the microbial activities in soil but the by-product of these activities, the organic acid production, not only blocked the P adsorption sites but it also solublize the native soil P. Nziguheba et al., (1998) also found that the addition of organic materials causes mineralization of more recalcitrant fraction of P through increased microbial activity and biochemical transformation result into increased availability of P. The interactions with soil components, especially clay and lime contents, to increase P uptake by plants are very important and addition of manures not only resulted in to better P recovery but it also enhanced the effectiveness of inorganic P fertilizers (Whalen and Chang, 2001). Application of chemical fertilizers combined with the on farm available organic sources help to increase the bioavailability of residual soil P (Beri et al. 2002). Gibali and Rahmatullah (1982) also concluded that addition of P alone or in combination with manure resulted in higher concentration of P in plants. Therefore, response of P was better in sandy loam soils (S-I and S-III) as compared with the sandy clay loam (S-II) having higher clay contents. Because soils with higher clay contents are more prone to fix the applied P. Nevertheless, manured soils have lower p retaining capacity (Sharpley et al. 2001).

Cong and Merckx (2005) opined that organic amendments increase the amount of negative surface charge which results in increased repulsion against P anions and hence decrease surface adsorption of P.

Similar results were also reported by Chaudhary et al., (1998) about the maximum P uptake by the plants growing in soil treated with both organic and inorganic fertilizers. In general it was observed that high concentration of P was found with inorganic DAP than the organic amendment FYM. From the environmental point of view P from organic amendment is considered better but it alone can not meet the crop requirements as has been observed in the present study. Increase in SDM was more in case of DAP was more than FYM but their combined application proved the best which is also in accordance with the results reported by Kawabiah et al., (2003).

In the present study effect of only FYM was observed while there are several organic wastes in our circumstances which may be used as soil amendments. Effects of these amendments regarding various soil P fractions affected by the application of these amendments separately and as integrated with the inorganic amendments should also be investigated. Secondly, decomposition of these amendments resulting into release of P in labile P also needs attention.

4.4. Conclusions

- Maize response was significant toward organic or inorganic amendment. Shoot dry matter was increased 22 and 40 % over control with the application of organic and inorganic amendments, respectively.

- Integration of organic and inorganic amendment resulted into significant better performance over their separate application. The combined application produced 37% more SDM over separate use of organic amendment and 19% more over inorganic amendment.

CHAPTER 5   STUDY-2

RATE OF ORGANIC MATTER DECOMPOSITION APPLIED FROM VARIOUS SOURCES AND RELEASE OF P IN DIFFERENT SOILS

Abstract

Organic phosphorus (P_o) of manures transforms into plant available inorganic P (P_i) through a series of biochemical reactions of mineralization. Therefore, P kinetic study of a manured soil not only determines the fate of applied P to that soil but it also helps to quantify the appropriate P requirement for a target crop. The present pot experiment was designed to study kinetics of P release/desorption in three calcareous soils of Northern Punjab. For incubation purpose diammonium phosphate was added to soils separately and in integrated form with organic amendments (green manure, farmyard manure, and poultry manure and press mud). Phosphorus from DAP was added to supply 35 mg P kg^{-1} soil while organic amendments were applied @ 10 g kg^{-1} soil. After equilibrium, soil samples were collected to study the rate of OM decomposition and rate of P release. Results depicted faster release of P at initial stage of incubation and afterward slow reaction was observed. Rate of OM decomposition and P release kinetics were best described by Elovich and Zero Order equations. Higher R^2 values up to 1.0 and lower values of standard error up to 0.001 of the equations were observed. Integrated organic and inorganic sources of P showed maximum R^2 values which depicted beneficial effects of integration of organic and inorganic sources of P over their separate use for P release.

5.1. Introduction

Ever increasing waste products of agricultural and industrial origin have craving need for their recycling. These wastes are predominantly used in agriculture as organic manures. Mineralization of these manures provides essential macro and micro nutrients for plant.

Phosphorus is one of these nutrients which are supplied through organic (manures) and inorganic sources. It is the most important essential nutrients for life on the earth but it is often in short supply. Its complex nature of mobility, between the root zone and soil, is of paramount importance. Phosphorus reactions and retention in soil have great concern for plant nutrition and fertilizer use efficiency (Toor and Bahl,

1999). Depressed P availability after fertilizer application owes to adsorption and precipitation mechanisms of P retention in calcareous soil systems (Afif et al., 1993). Studies of P kinetics in soil help to evaluate availability of soil P for agricultural crops. Concentration gradient of P in soil solution facilitates the P uptake by plants. Phosphorus uptake by plants depletes soil solution P and a consequent net release of P from soil solid to liquid phase, takes place. Therefore, in addition to soil P reserves, the amount of soluble P depends on the rate of P release from soil into the solution (Shariatmadari et al. 2006).Study on the rate of P release from soil and its availability to plants have been highlighted by different researchers (Brar and Vig, 1988; Steffens,1994). Studies of P release from soils revealed that the P release reaction from various soils was rapid in the start and declined slowly until the apparent equilibrium approached (Chien and Clayton 1980; Lookman et al. 1995: Toor and Bahl 1999). The processes that cause retention or release of P are summarized in the following scheme (Chardon and Schoumans, 1999), including the main soil types for which the processes are relevant.

Table 5.1

Rate of retention and release of P in different soils

Retention	Release	Soil types
Fast adsorption	Fast desorption	All soils
Slow 'absorption' on amorphous Fe/Al-oxides	Slow desorption	Non-arid soils
Precipitation (mainly Ca-P and NH4-P)	Dissolution	Calcareous soils over-fertilized soils
Particle settling, sedimentation	Detachment	All soils

Phosphorus release kinetics from soils and the ability of kinetic models to describe P desorption have been studied by several researchers (Chien and Clayton 1980; Elkhatib and Hern 1988; Bahl 1990; Yang and Skogley 1992). Evans and Jurinak (1976) studied the fast, intermediate and slow P release reactions following first order kinetic model. They attributed these reactions to the i) dissolution of poorly crystalline metastable indigenous calcium phosphates converting to hydroxyapatite ii) desorption of adsorbed P from the clay mineral and carbonate surfaces and iii) dissolution of calcium hydroxyapatite, respectively. However, Chien and Clayton (1980) suggested Elovich equation for better description of such data. De Smet et al. (1998) concluded that first order kinetic model was best fit for the description of

initial fast release of P from non-calcareous Belgian soils; nevertheless, slower P release with the passage of time was better described by the Elovich equation.

Several equations describing the kinetics of P release have been proposed since long. The parabolic diffusion (Evans and Jurinak1976; Pavlatou and Polyzopoulos 1988; Shariatmadari et al. 2006), Elovich equation (Chien and Clayton 1980; Raven and Hossner 1994; Shariatmadari et al. 2006) and Zero-order (Pavlatou and Polyzopoulos 1988; Lookman et al. 1995; Shariatmadari et al. 2006) are some of these equations which are commonly used for calcareous soils.

Generally, little information is available on the P release kinetics of applied P in calcareous soils of Northern Punjab. Present scenario of fertilizer P availability needs through study of applied P fertilizer kinetics in the calcareous soils. Therefore present study was designed to investigate the suitability of different kinetic equations to describe the P release kinetics in the soils especially with the integrated use of organic and inorganic amendments.

5.3. Results

Texture of the soils I and III was sandy loam while soil II was sandy clay loam (Table 3.1). The three soils were alkaline in reaction (pH > 7.0), calcareous (2.12-5.5% $CaCO_3$) and   non-saline (ECe < 4.0 dS m^{-1}). Soil I and soil III were deficient in organic matter contents but soil II had 1.31% organic matter. Extractable K ranged from 60 to 130 mg kg^{-1} and Olsen P varied from 5.26 to 16.65 mg kg^{-1} soil.

Mechanistic justification of P release models

Mechanistic models are type of regression equations that use quantitative independent variables to explain variation in quantitative dependent variables. Researchers had developed a number of mechanistic models to predict the response of the dependent variables under a given set of experimental or environmental conditions to understand the possible behavior of the variables which could explain how the P release of different organic amendments will be affected over a period of time with respect to crop yields. The "typical goal is to build such a model which could explain the greatest variability in the response variable, and to precisely parameterize regression coefficients" (Graham, 2003).

5.3.1 Decomposition of native OM and P release

Decomposition of organic amendments was followed by applying various kinetic equations. Increase in decomposition regarding the various organic

amendments, might take place owing to difference in C: N ratio (Hussain, 2005) and lignin contents of amendments along external temperature and humidity. Decomposition of native and added OM concluded into release of P in soil. Different kinetic models including Simplified Elovich, Parabolic Diffusion and Zero-order were applied to study the rate of OM decomposition and P release. Results obtained were also described diagrammatically.

Decomposition rate of native and added OM, release of solution and Olsen P were studied following different kinetic models (Table 3.1).

Rate of native OM decomposition in three different soils was studied following Zero order kinetic equation, (Fig. 5.1, a). Results revealed that intercept value in case of S-I was 0.0059 and slope value was -0.009 (Table 5.2). It described that with the average unit change in time, OM decomposed in S-I was 0.0059 %. In case of S-II, slope value was -0.0297 and intercept value described that with the average unit change in time decrease in OM was 0.0131 %. Rate of change in OM contents of S-III was 0.0048 % with the average unit change in time, while slope value was -0.0074.

Values of SE ranked as S-I = S-III < S-II and R^2 ranked as S-II> S-III> S-I

The rate of Solution-P release in three different soils studied under Zero Order kinetic equation (Fig. 5.1, b) showed $2x10^{-5}$ intercept value in case of S-I (Table 5.2) and slope value was -0.0008. This relates that, rate of Solution-P release in S-I was $2x10^{-5}$ % with the average unit change in time. In case of S-II, slope value was -0.0011 and intercept value described that with the average unit change in time Solution-P release was up to $4x10^{-5}$ %. Rate of increase in Solution-P contents of S-III was recorded up to $1x10^{-5}$ % with the average unit change in time, while slope value was -0.0005.

Values of SE ranked as S-I< S-III< S-II and R^2 ranked as S-I> S-II> S-III

Decomposition rate of native OM in S-I studied under different kinetic equations (Parabolic Diffusion, Simplified Elovich and Zero Order) revealed that Zero Order kinetic equation was best fit in case of S-II and S-III due to its highest R^2 and lowest SE values.

In case of Solution-P release, Zero Order kinetic equation was best fit regarding S-I and S-II due to its highest R^2 and lowest SE values. Nevertheless, S-III behaved differently and none of the equations helped to describe P release in S-III.

Rate of Olsen-P release in the three soils was not better described by the three kinetic equations under consideration. It means that clear relation between time and Olsen-P release could not develop in the three soils with the passage of time. However, Comparison of all soils depicted that rate of native OM decomposed was faster in S-I and release rate of Olsen P and Solution P was also higher in this soil.

Table 5.2
Rate of native OM decomposition and P release in three soils following different kinetic plots

Parameter	Soil	Simple Parabolic			Elovich			Zero Order		
		Equation	R^2	SE	Equation	R^2	SE	Equation	R^2	SE
Rate of OM decomposition	Soil-I	Y = 0.6338 - 0.0063x	0.98	0.002	Y = 0.7338 - 0.083x	0.96	0.959	Y = 0.0059x - 0.009	0.96	0.003
	Soil-II	Y = 1.3737 - 0.0144x	0.94	0.013	Y = 1.5923 - 0.1854x	0.87	0.873	Y = 0.0131x - 0.0297	0.98	0.008
	Soil-III	Y = 0.4249 - 0.0051x	0.96	0.003	Y = 0.5056 - 0.0671x	0.93	0.934	Y = 0.0048x - 0.0074	0.97	0.003
	Mean		0.96	0.006		0.92	0.922		0.97	0.005
Release rate of Solution-P	Soil-I	Y = 0.0178 - 0.0004x	0.59	0.001	Y = 0.023 - 0.0047x	0.47	0.001	Y =2x10^{-5} x - 0.0008	0.70	0.001
	Soil-II	Y = 0.0797 - 0.0009x	0.50	0.003	Y = 0.0913 - 0.0109x	0.38	0.004	Y = 4x10^{-5} x - 0.0011	0.61	0.003
	Soil-III	Y = 0.0145 - 0.0002x	0.21	0.001	Y = 0.0167 - 0.0024x	0.12	0.002	Y =1x10^{-5} x - 0.0005	0.31	0.002
	Mean		0.44	0.002		0.32	0.002		0.54	0.002
Release rate Of Olsen-P	Soil-I	Y = 7.1189 + 0.0432x	0.07	0.533	Y = 5.9873 + 0.7693x	0.14	0.515	Y = 1.0175 + 0.0011x	0.03	0.001
	Soil-II	Y = 17.879 + 0.0038x	0	0.867	Y = 17.067 + 0.3844x	0.01	0.861	Y = 1.0887 + 0.0008x	0.01	0.003
	Soil-III	Y = 6.2958 + 0.0246x	0.01	0.866	Y = 5.1207 + 0.6771x	0.04	0.851	Y = 1.254 + 5x10^{-5} x	0.00	0.002
	Mean		0.03	0.756		0.07	0.742		0.01	0.002
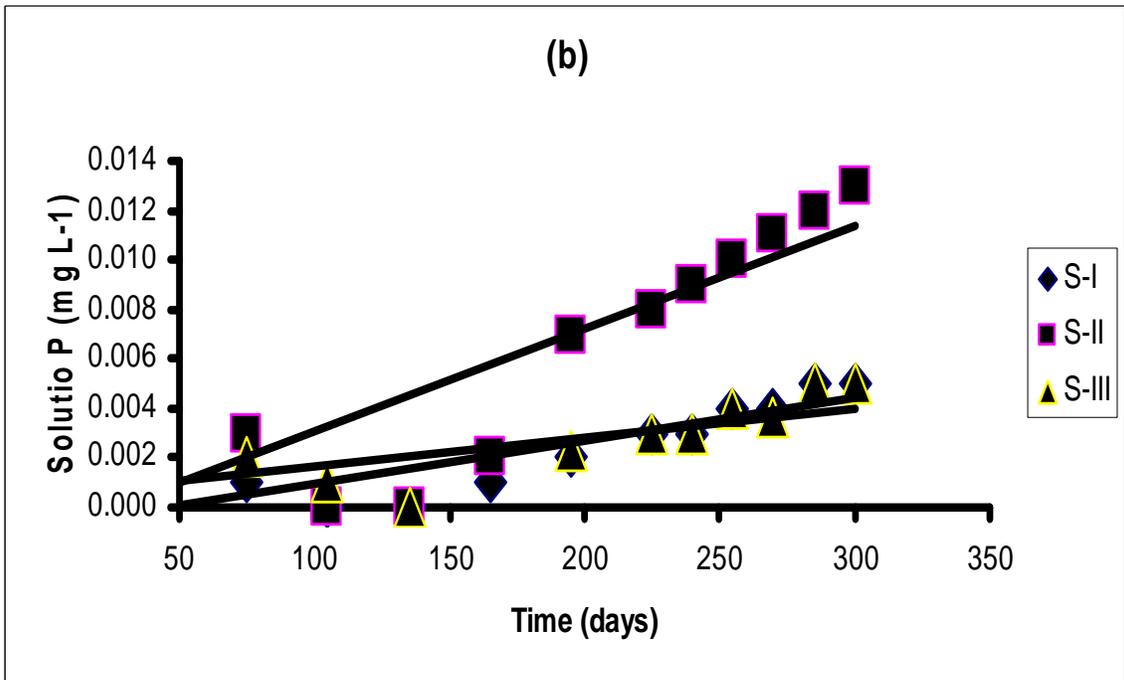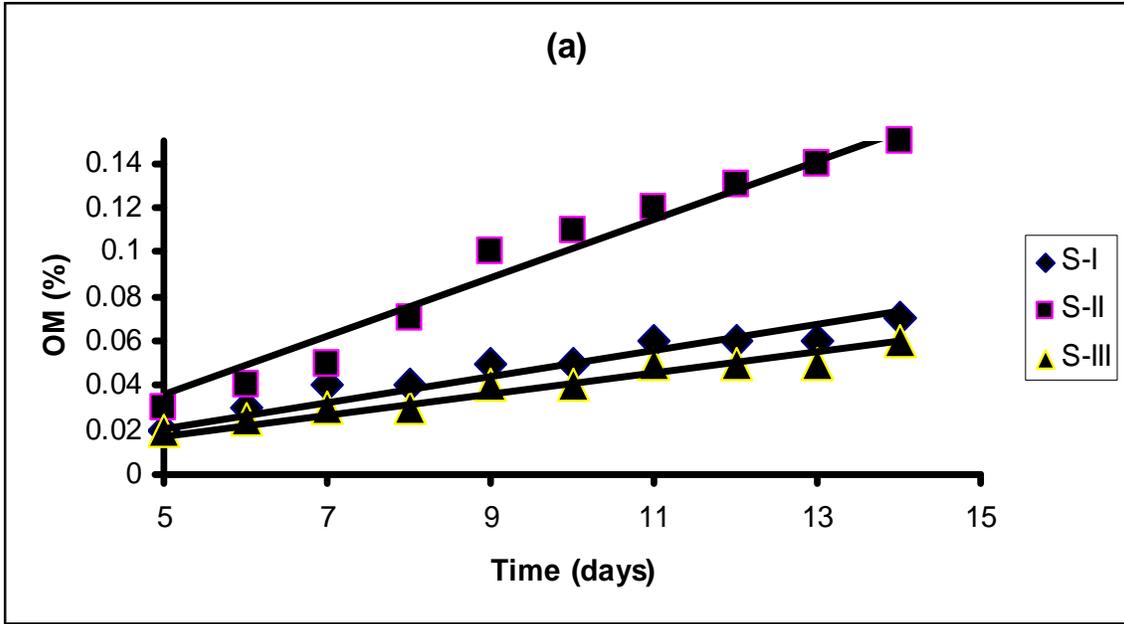
Fig 5.1 Rate of native OM decomposition (a) and Solution-P release (b)

in three soils following Zero order plot

5.3.2. Decomposition of green manure and P release

Green manure was incubated in three soils to study the rate of OM decomposition following Elovich kinetic equation (Fig. 5.2, a). It was found that intercept value in case of S-I was   -0.8356 and slope value was 2.8598 (Table 5.3). This depicts that with the log of the average unit change in time, OM decomposition in S-I was -0.8356 %. In case of S-II, slope value was 3.6385 and intercept value exhibited that with the log of the average unit change in time decrease in OM was -0.6724 %. Rate of change in OM contents of S-III was recorded up to -0.9885 % with the log of the average unit change in time, while slope value was 2.9443.

Values of SE ranked as S-I< S-III< S-II and R^2 ranked as S-I> S-III> S-II

Rate of Olsen-P release in three different soils, incubated with green manure following Elovich kinetic equation (Fig. 5.2, b)., showed intercept value up to 6.1385 in S-I and slope value 5.4807(Table 5.3). This indicates that, Olsen-P release in S-I was 6.1385 % with the log of the average unit change in time. In S-II, slope value was 16.907 and intercept value showed that with the log of the average unit change in time Olsen-P was up to 17.826 %. Rate of change in Olsen-P contents of S-III was 6.2848 % with the log of the average unit change in time, while slope value was 4.4631.

 Decomposition rate of OM studied following green manure addition to S-I and S-III   under kinetic equations (Parabolic Diffusion, Simplified Elovich and Zero Order) depicted that Simple Elovich equation was best fit due to highest R^2 ranging from 0.94 to 0.98 and lowest SE values ranging from 0.030 to.0.046.

Release rate of Olsen-P in the three soils was better described by the Elovich kinetic equation due to its highest R^2 values, ranging from 0.24 to 0.34 and lowest SE values ranging from 2.38 to 7.46.

It was concluded from the comparison of all soils that decomposition rate of green manure (Sesbania aculeata) incubation was faster in S-I, however, release rate of Olsen P and Solution P was comparatively higher in S-III.

Table 5.3
 Rate of OM decomposition and P release in soils after green manure application as following different kinetic plots

| Parameter	Soil	Simple Parabolic			Elovich			Zero Order		
		Equation	R^2	SE	Equation	R^2	SE	Equation	R^2	SE
Rate of OM decomposition	Soil-I	Y = 1.8408 - 0.0625x	0.98	0.032	Y = 2.8598 - 0.8356x	0.98	0.030	Y =0.0025x - 0.0361	0.95	0.051
	Soil-II	Y = 2.8252 - 0.0508x	0.95	0.039	Y = 3.6385 - 0.6724x	0.94	0.046	Y =0.002x - 0.0136	0.95	0.043
	Soil-III	Y = 1.8363 - 0.0663x	0.95	0.054	Y = 2.9443 - 0.8985x	0.98	0.034	Y =0.0026x - 0.0072	0.90	0.079
	Mean		0.96	0.042		0.97	0.037		0.93	0.058
Release rate of Solution-P	Soil-I	Y = 0.0371 - 0.0002x	0.01	0.005	Y = 0.0359 - 0.0006x	0.00	0.005	Y = 0.0047 + 1x10^{-5} x	0.05	0.005
	Soil-II	Y = 0.2706 - 0.0016x	0.02	0.037	Y = 0.2653 - 0.007x	0.00	0.038	Y = 0.0285 + 0.0001x	0.06	0.036
	Soil-III	Y = 0.0338 - 0.0002x	0.02	0.004	Y = 0.0332 - 0.0009x	0.00	0.005	Y = 0.0036 + 1x10^{-5} x	0.06	0.005
	Mean		0.02	0.016		0.00	0.016		0.06	0.015
Release rate Of Olsen-P	Soil-I	Y = 14.067 + 0.3773x	0.16	3.084	Y = 5.4807 + 6.1385x	0.24	2.933	Y = 8.5562 - 0.0117x	0.10	3.205
	Soil-II	Y = 41.336 + 1.1333x	0.21	7.890	Y = 16.907 + 17.826x	0.30	7.463	Y = 19.732 - 0.0368x	0.14	8.256
	Soil-III	Y = 12.9 + 0.4127x	0.26	2.518	Y = 4.4631 + 6.2848x	0.34	2.381	Y = 7.3162 - 0.014x	0.18	2.645
	Mean		0.21	4.497		0.29	4.259		0.14	4.702
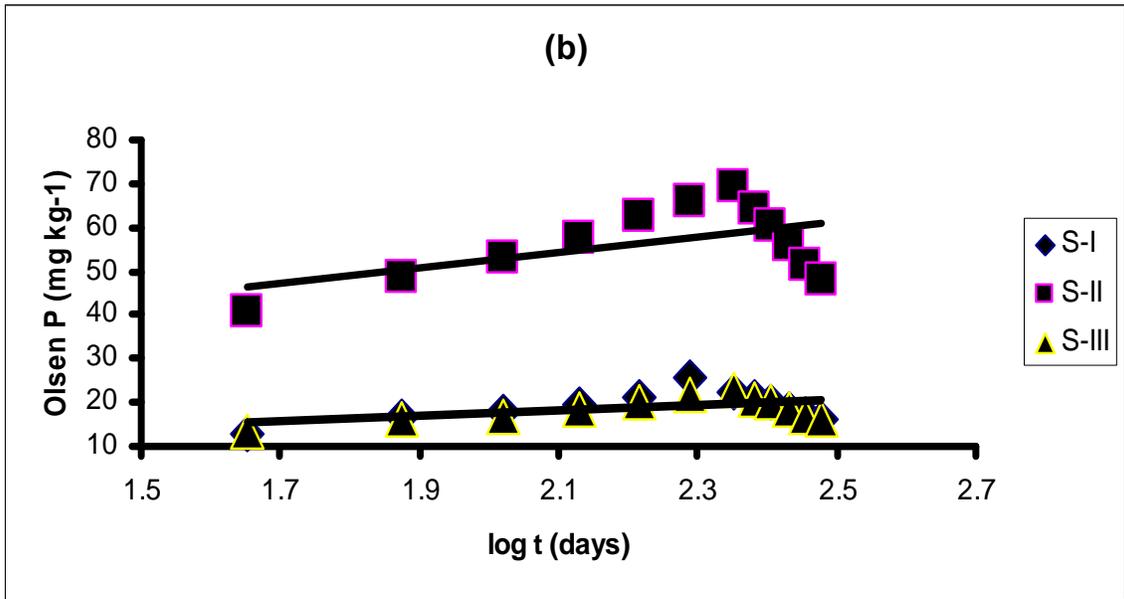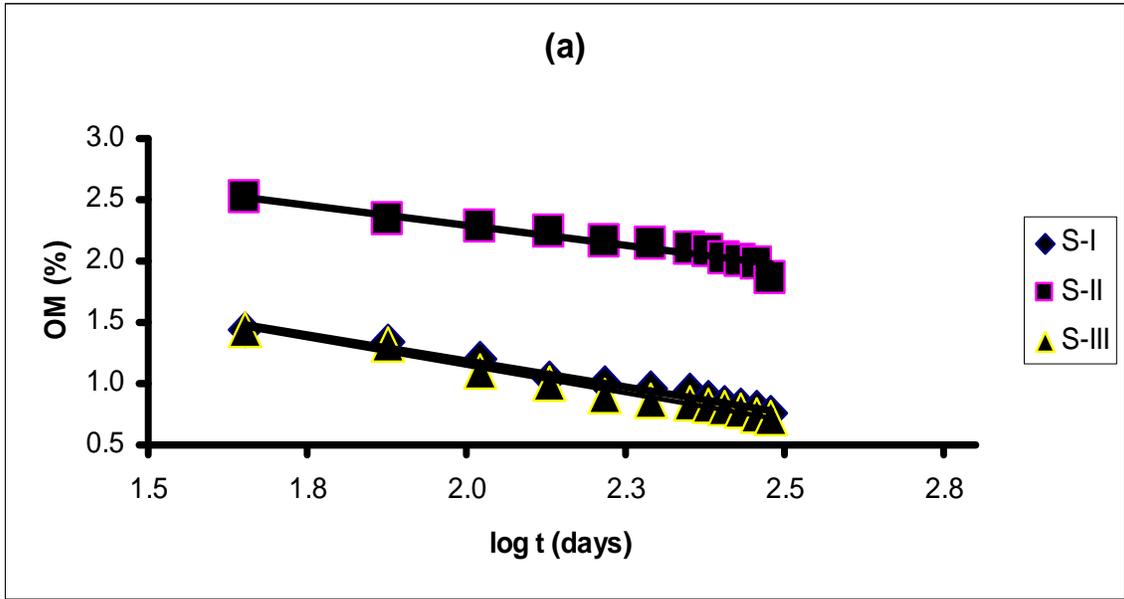
Fig 5.2 Rate of OM decomposition (a) and Olsen-P release (b) in three

soils after green manure application following Elovich plot

5.3.3 Decomposition of FYM and P release

Organic matter decomposition rate according to Elovich kinetic equation, in three different soils amended with FYM (Fig. 5.3, a) revealed that intercept value in case of S-I was -0.9421 and slope value was 3.1896 (Table 5.4). The intercept value expresses that OM decomposition in S-I was -0.9421% with the log of the average unit change in time. Slope value was 3.8281 in case of S-II and intercept value showed that with the log of the average unit change in time decrease in OM was -0.7721%. Rate of change in OM contents of S-III was recorded up to - 0.6937 % with the log of the average unit change in time, while slope value was 2.3911.

Values of SE ranked as S-I< S-III< S-II and R^2 ranked as S-I> S-III> S-II

Rate of Olsen-P release in three different soils following Elovich kinetic equation (Fig. 5.3, b) depicted that intercept value in case of S-I was 7.4698 and slope value was 6.8439 (Table 5.4). This means that, Olsen-P release in S-I was 7.4698 with the log of the average unit change in time. In case of S-II, slope value was 20.532 and intercept value showed that with the log of the average unit change in time Olsen-P was decreased up to 22.409 %. Rate of release in Olsen-P contents of S-III was 6.5512 % in the probable time, while slope value was 8.2486.

Values of SE ranked as S-III< S-I< S-II and R^2 ranked as S-I = S-II> S-III

Zero Order kinetic equation applied to assess the rate of Solution-P release in three different soils (Fig. 5.3, c) resulted into 1×10^{-4} intercept and -0.0034 slope values in case of S-I. This intercept value described that rate of Solution-P release in S-I was 1×10^{-4} with the average unit change in time. In case of S-II, slope value was -0.0392 and intercept value explained that with the average unit change in the time Solution-P release was decreased up to 0.0008%. Rate of change in Solution-P contents of S-III was recorded up to 9×10^{-5} % in the probable time, while slope value was -0.0044.

Values of SE ranked as S-III< S-I< S-II and R^2 ranked as S-II = S-III> S-I

Rate of OM decomposition was studied in different soils supplied with FYM under different kinetic equations (Parabolic Diffusion, Simplified Elovich and Zero Order). It was conclude that Elovich equation was best fit for S-II and S-III due to highest values of R^2 ranging from 0.94 to 0.96 and lowest SE values ranging from 0.038 to 0.053.

However, Simple Parabolic equation was best fit in case of S-I due to its highest R^2 and lowest SE values.

In case of Solution-P release estimation, Zero Order kinetic equation was best fit regarding S-I , S-II and S-III due to its highest R^2 ranging from 0.62 to 0.64 and lowest SE values ranging from0.006 to 0.051.

Rate of Olsen-P release in the three soils was better described by the Elovich kinetic equation due to its highest R^2, ranging from 0.2216 to 0.2634 and lowest SE value ranging from 3.331 to 10.168

Rate of FYM decomposition was found faster S-I and rate of Olsen P release was also comparatively better in S-I. However, rate of Solution P release was higher in S-III.

Table 5.4

Rate of OM decomposition and P release in soils after FYM application as studied under different kinetic plots

| Parameter	Soil	Simple Parabolic			Elovich			Zero Order		
		Equation	R^2	SE	Equation	R^2	SE	Equation	R^2	SE
Rate of OM decomposition	Soil-I	Y = 2.0477 - 0.071x	0.99	0.024	Y = 3.1896 - 0,9421x	0.98	0.037	Y = 0.0028x + 0.0375	0.98	0.975
	Soil-II	Y = 2.8781 - 0.0571x	0.91	0.062	Y = 3.8281 - 0.7721x	0.94	0.053	Y = 0.0023x + 0.0774	0.88	0.880
	Soil-III	Y = 1.5308 - 0.0508x	0.91	0.054	Y = 2.3911 - 0.6937x	0.96	0.038	Y = 0.002x + 0.0821	0.86	0.862
	Mean		0.94	0.047		0.96	0.042		0.91	0.906
Release rate of Solution-P	Soil-I	Y = 0.0641 - 0.0022x	0.51	0.007	Y = 0.0905 - 0.0249x	0.38	0.009	Y = 1x10^{-4}x - 0.0034	0.62	0.007
	Soil-II	Y = 0.4961 - 0.017x	0.53	0.058	Y = 0.709 - 0.1987x	0.40	0.066	Y = 0.0008x- 0.0392	0.64	0.051
	Soil-III	Y = 0.0567 - 0.0019x	0.53	0.006	Y = 0.081 - 0.0227x	0.40	0.008	Y = 9x10^{-5}x - 0.0044	0.64	0.006
	Mean		0.52	0.024		0.40	0.027		0.64	0.021
Release rate Of Olsen-P	Soil-I	Y = 17.171 + 0.4682x	0.18	3.566	Y = 6.8439 + 7.4698x	0.26	3.389	Y = 8.6264 - 0.0149x	0.12	3.715
	Soil-II	Y = 51.512 + 1.4046x	0.18	10.70	Y = 20.532 + 22.409x	0.26	10.16	Y = 25.869 - 0.0448x	0.12	11.14
	Soil-III	Y = 17.461 + 0.3991x	0.14	3.488	Y = 8.2486 + 6.5512x	0.22	3.331	Y = 7.5342 - 0.0122x	0.08	3.614
	Mean		0.17	5.918		0.25	5.629		0.10	6.158
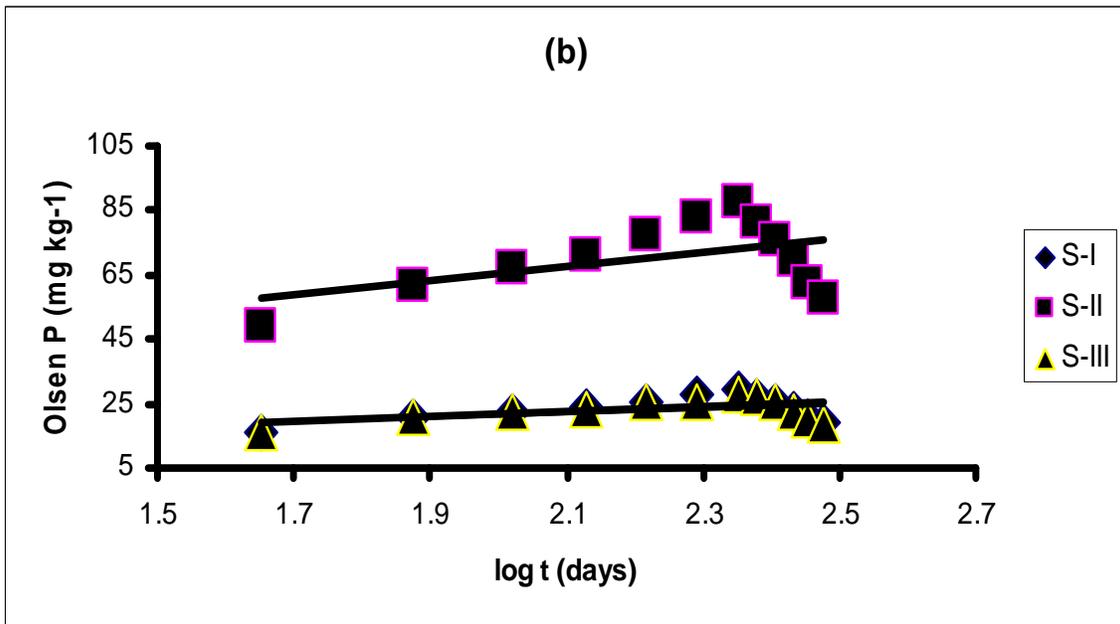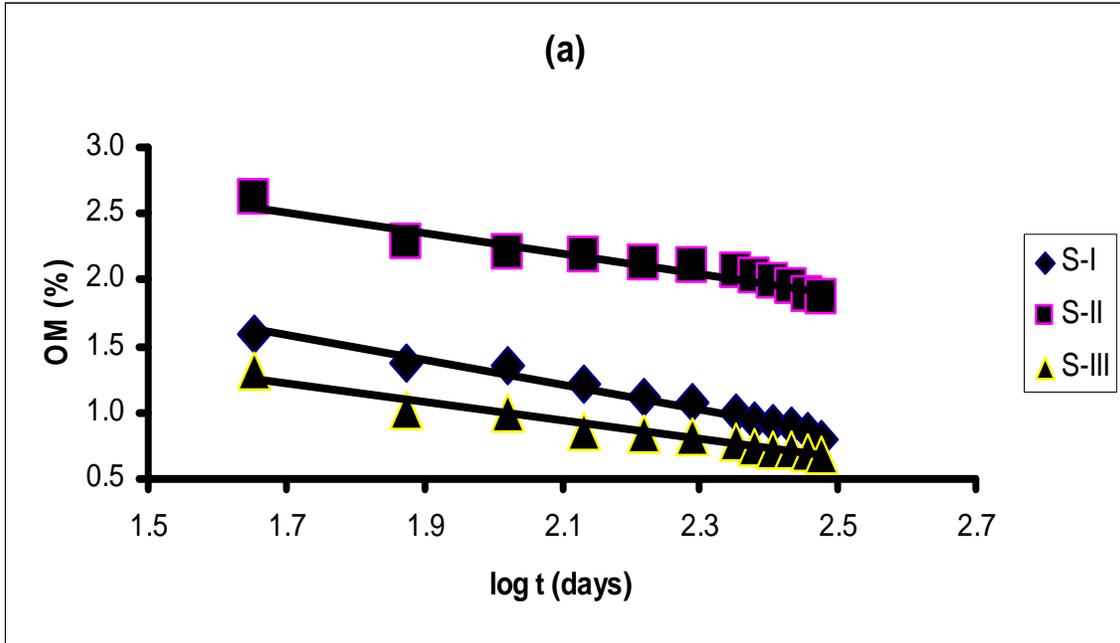
Fig 5.3   Rate of OM decomposition (a) and Olsen-P release (b) in
three soils after FYM application following Elovich plot
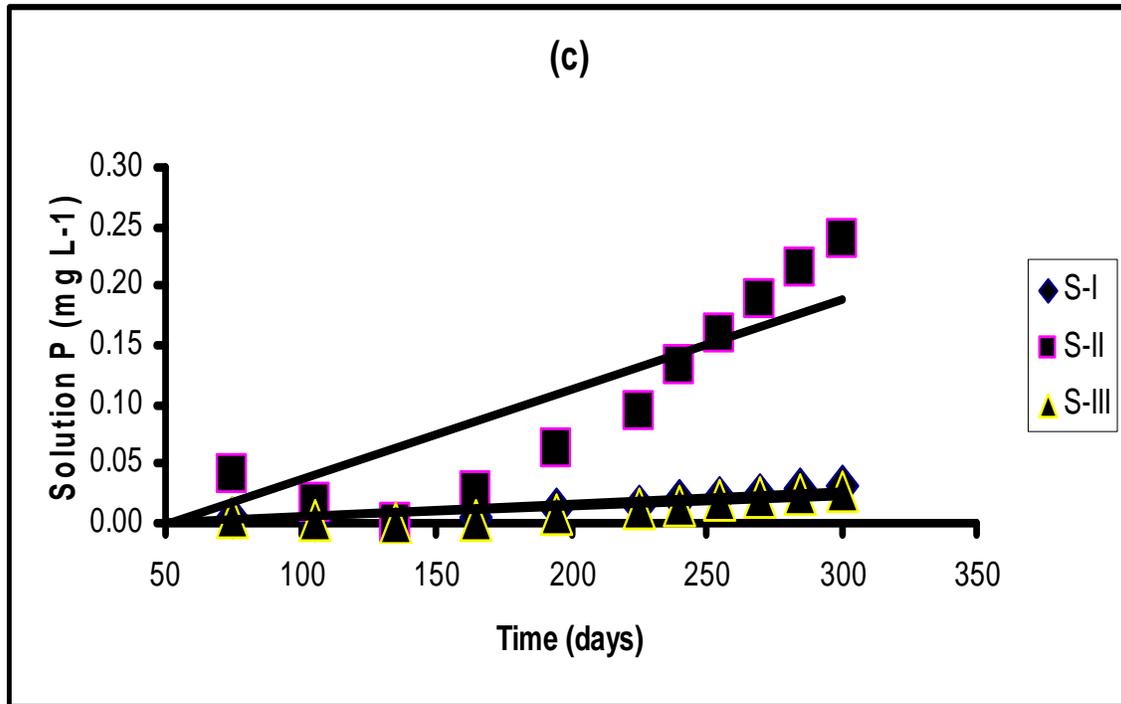
Fig. 5.3 Rate of Solution-P release (c) in three soils after

FYM application following Zero Order plot

5.3.4. Decomposition of poultry manure and P release

Rate of Olsen-P release in three different soils incubated with poultry manure, following Elovich kinetic equation (Fig. 5.4, a) depicted that intercept value in case of S-I was 21.919 (Table5.5). This expressed that Olsen-P release in S-I was 21.919 % with the log of the average unit change in time and slope value was 1.0963. In case of S-II, slope value was 3.2889 and intercept value showed that with the log of the average unit change in time Olsen-P was decreased up to 65.756 %. Rate of change in Olsen-P contents of S-III was 21.468 % with the log of the average unit change in time, while slope value was 1.3053.

Values of SE ranked as S-I = S-III< S-II and R^2 ranked as S-I = S-II> S-III

Rate of OM decomposition with respect to Zero Order kinetic equation, in three different soils fertilized with poultry manure(Fig. 5.4, b) revealed that intercept value in case of S-I was 0.0029 and slope value was 0.0078 (Table5.5). This indicates that with the average unit change in time, OM decomposition in S-I was 0.0029%. Slope value in case of S-II was 0.0103 and intercept value described that with the average unit change in time decrease in OM was 0.0023%. Rate of OM decomposition in S-III was recorded 0.003% per unit change in time and slope value was 0.1639.

Values of SE ranked as S-III< S-I< S-II and R^2 ranked as S-III> S-I> S-II

Zero Order kinetic equation applied to assess the rate of Solution-P release in three different soils incubated with poultry manure (Fig. 5.4, c), revealed that intercept value in case of S-I was 9×10^{-5} and slope value was 0.0013. This indicates that with the average unit change in time, rate of Solution-P release in S-I was 9×10^{-5} %. In case of S-II, slope was 0.0356 while intercept value showed that with the average unit change in time rate of Solution-P release was up to 0.0003 %. Rate of increase in Solution-P contents of S-III was recorded up to 7×10^{-5} % in the average unit change in time, while slope value was 0.0002.

Values of SE ranked as S-III< S-I< S-II and R^2 ranked as S-I> S-III> S-II

Rate of OM decomposition in S-I and S-III studied under different kinetic equations (Parabolic Diffusion, Simplified Elovich and Zero Order) revealed that Simple Parabolic equation was best fit due to highest R^2 ranging from 0.9808 to 0.9827 and

lowest SE values ranging from.030 to.034. However, Elovich equation was best fit in case of S-II due to its highest R^2 and lowest SE values.

In case of Solution-P release, Zero Order kinetic equation was best fit regarding S-I , S-II and S-III due to highest R^2 ranging from 0.0538 to 0.0611 and lowest SE values ranging from 0.0045 to 0.0364.

Rate of Olsen-P release in the three soils was better described by the Elovich kinetic equation due to its highest R^2, ranging from 0.2438 to0.3391 and lowest SE value ranging from2.381 to 7.463.

Comparison of all soils depicted that rate of poultry manure decomposition was faster in S-III but release rate of Olsen-P and Solution-P was comparatively better in S-I.

Table 5.5

Rate of OM decomposition and P release in soils after poultry manure application following different kinetic plots

| Parameter	Soil	Simple Parabolic			Elovich			Zero Order		
		Equation	R^2	SE	Equation	R^2	SE	Equation	R^2	SE
Rate of OM decomposition	Soil-I	Y = 2.0988 - 0.0718x	0.97	0.040	Y = 3.2652 - 0.9578x	0.98	0.041	Y = 0.0029x +0.0078	0.95	0.057
	Soil-II	Y = 3.0058 - 0.0566x	0.93	0.055	Y = 3.9194 - 0.7527x	0.92	0.059	Y = 0.0023x + 0.0103	0.92	0.059
	Soil-III	Y = 2.159 - 0.0736x	0.97	0.040	Y = 3.2971 - 0.9562x	0.93	0.074	Y = 0.003x + 0.1639	1.00	0.016
	Mean		0.96	0.046		0.94	0.058		0.96	0.044
Release rate of Solution-P	Soil-I	Y = 0.0754 - 0.002x	0.36	0.009	Y = 0.0973 - 0.0217x	0.26	0.010	Y =$9x10^{-5}$x + 0.0013	0.48	0.008
	Soil-II	Y = 0.4861 - 0.0053x	0.14	0.046	Y = 0.5243 - 0.0491x	0.07	0.048	Y = 0.0003x + 0.0356	0.23	0.044
	Soil-III	Y = 0.0698 - 0.0016x	0.32	0.008	Y = 0.0866 - 0.017x	0.22	0.009	Y = $7x10^{-5}$x + 0.0002	0.44	0.007
	Mean		0.28	0.021		0.18	0.022		0.38	0.020
Release rate Of Olsen-P	Soil-I	Y = 30.541 + 1.4377x	0.31	7.829	Y = 1.093 + 21.919x	0.40	7.282	Y = 24.669 - 0.049x	0.22	8.311
	Soil-II	Y = 91.623 + 4.313x	0.31	23.480	Y = 3.2889 + 65.756x	0.40	21.84	Y = 74.016 - 0.1469x	0.22	24.93
	Soil-III	Y = 30.113 + 1.4104x	0.30	7.802	Y = 1.3053 + 21.468x	0.39	7.282	Y = 25.075 - 0.0481x	0.21	8.266
	Mean		0.30	13.037		0.40	12.13		0.22	13.83
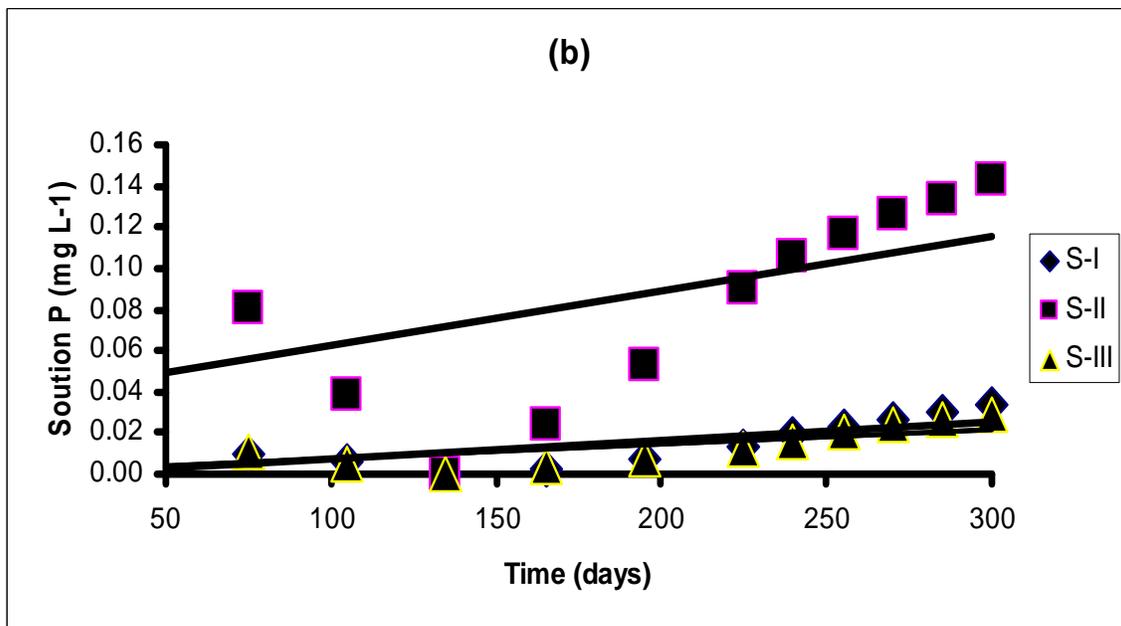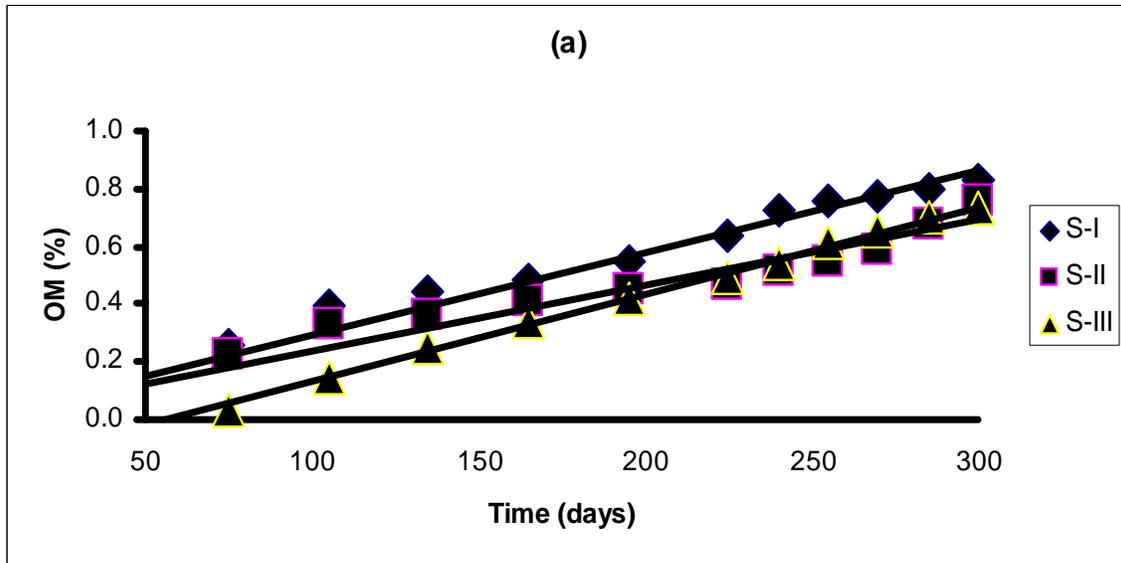
Fig. 5.4 Rate of OM decomposition (a) and Solution-P release (b) in three
soils after poultry manure application following Zero Order plot
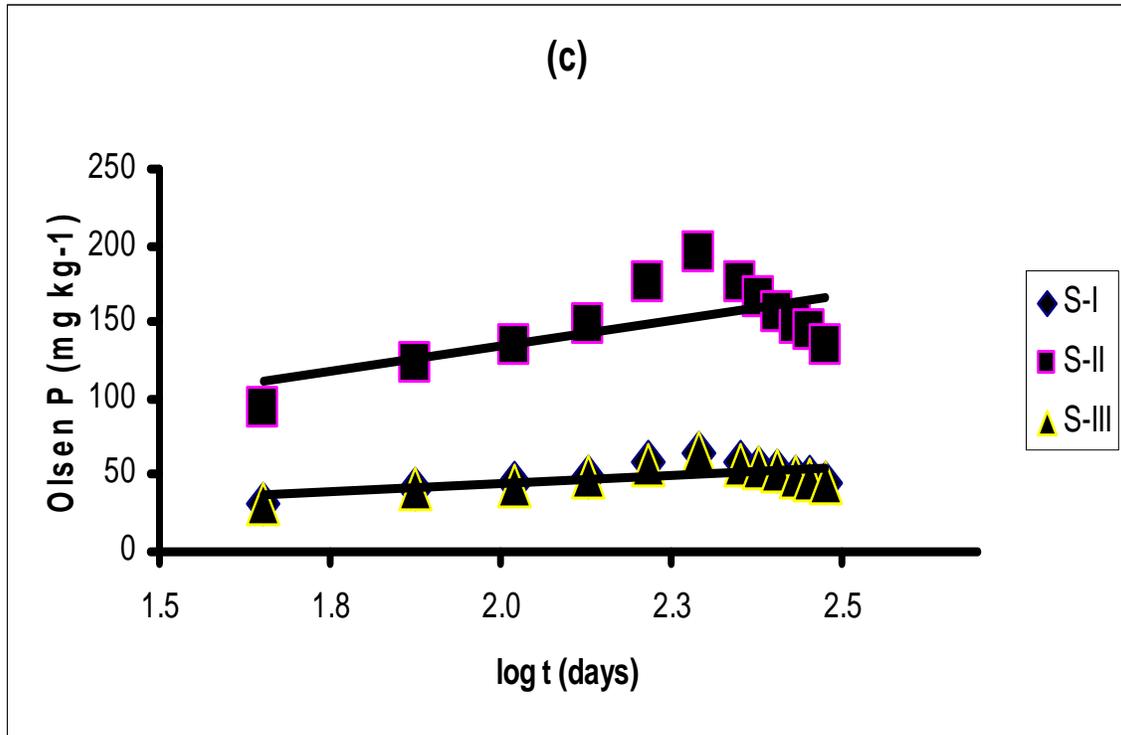
Fig. 5.4   Rate of Olsen-P release (c) in three soils after poultry manure
application following Elovich plot

5.3.5. Decomposition of press mud and P release

Organic matter decomposition rate according to Elovich kinetic equation, in three different soils incubated with press mud (Fig. 5.5, a) revealed that intercept value in case of S-I was -0.8026 and slope value was 2.8209 (Table 5.6). This indicates that with the log of average unit change in time, OM decomposition in S-I was -0.8026 %. In case of S-II, slope value was 4.0212 and intercept value indicated that with the log of average unit change in time, decrease in OM was -0.8614 %. This rate of change in OM contents of S-III was recorded -0.8245 % decrease with the log of average unit change in time while slope value was 2.8213.

Values of SE ranked as S-I< S-II< S-III and R^2 ranked as S-II> S-I> S-III

Rate of Olsen-P release in three different soils incubated with press mud following Elovich kinetic equation(Fig. 5.5, b) depicted that intercept value in case of S-I was 23.748 and slope value was 1.3608(Table 5.6). This means that, Olsen-P release in S-I was 23.748% with the log of average unit change in time. In case of S-II, slope value was 4.0824 and intercept value showed that with the log of average unit change in time, Olsen-P was decreased up to 71.245 %. Rate of decrease in Olsen-P contents of S-III was 23.541 % with the log of average unit change in time, while slope value was 1.1757.

Values of (SE) ranked as S-I< S-III< S-II and R^2 ranked as S-I = S-II> S-III

Zero Order kinetic equation was also applied to assess the rate of Solution-P release in three different soils (Fig. 5.5, c). Intercept value recorded in case of S-I was 4×10^{-5} and slope value was 0.0062. This indicates that with the average unit change in time, rate of Solution-P release in S-I was 4×10^{-5} %. In case of S-II, slope value was 0.0657 and intercept value indicated that with the average unit change in the time Solution-P release was decreased up to 0.000 %. Rate of increase in Solution-P contents of S-III was recorded up to 3×10^{-5} % with the average unit change in time, while slope value was 0.0069.

Values of SE ranked as S-III< S-I< S-II and R^2 ranked as S-II> S-I = S-III

Decomposition rate of OM in S-I and S-III studied under different kinetic equations (Parabolic Diffusion, Simplified Elovich and Zero Order) revealed that Elovich equation was best fit due to highest R^2 ranging from 0.9718 to 0.9781 and lowest SE

values ranging from 0.0325 to 0.0381. However, Simple Parabolic equation was best fit in case of S-II due to its highest R^2 and lowest SE values.

In case of Solution-P release, Zero Order kinetic equation was best fit regarding S-I , S-II and S-III due to its highest R^2 ranging from 0.094 to 0.1276 and lowest SE values ranging from 0.0079 to 0.0752.

Rate of Olsen-P release in the three soils was better described by the Elovich kinetic equation due to its highest R^2, ranging from 0.5809 to 0.5864 and lowest SE value ranging from 5.412 to 16.236.

Comparing decomposition rate in three soils it was observed that press mud was more rapidly decomposed in S-II but release rate of Olsen and Solution was better in S-I as compared to other soils.

Table 5.6

Rate of OM decomposition and P release in soils after press mud application following different kinetic plots

Parameter	Soil	Simple Parabolic			Elovich			Zero Order		
		Equation	R^2	SE	Equation	R^2	SE	Equation	R^2	SE
Rate of OM decomposition	Soil-I	Y = 1.8424 - 0.0601x	0.97	0.034	Y = 2.8209 - 0.8026x	0.98	0.033	Y = 0.0024x + 0.0066	0.95	0.048
	Soil-II	Y = 2.9725 - 0.0646x	0.98	0.032	Y = 4.0212 - 0.8614x	0.98	0.033	Y =0.0026x + 0.0174	0.96	0.049
	Soil-III	Y = 1.8016 - 0.0606x	0.93	0.057	Y = 2.8213 - 0.8245x	0.97	0.038	Y = 0.0024x + 0.0731	0.88	0.078
	Mean		0.96	0.041		0.98	0.035		0.93	0.058
Release rate of Solution-P	Soil-I	Y = 0.0612 - 0.0008x	0.06	0.010	Y = 0.0644 - 0.0062x	0.02	0.011	Y = 0.0062 + 4×10^{-5} x	0.13	0.010
	Soil-II	Y = 0.4468 - 0.0045x	0.04	0.077	Y = 0.4548 - 0.311x	0.01	0.079	Y = 0.0657 + 0.0003x	0.09	0.075
	Soil-III	Y = 0.047 - 0.0005x	0.04	0.008	Y = 0.0479 - 0.0033x	0.01	0.008	Y = 0.0069 + 3×10^{-5} x	0.09	0.008
	Mean		0.05	0.032		0.02	0.033		0.11	0.031
Release rate Of Olsen-P	Soil-I	Y = 32.705 + 1.5993x	0.47	6.104	Y = 1.3608 + 23.748x	0.59	5.412	Y = 20.785 - 0.0566x	0.36	6.708
	Soil-II	Y = 98.114 + 4.7978x	0.47	18.313	Y = 4.0824 + 71.245x	0.59	16.23	Y = 62.355 - 0.1698x	0.36	20.12
	Soil-III	Y = 32.228 + 1.5867x	0.47	6.101	Y = 1.1757 + 23.541x	0.58	5.426	Y = 21.103 - 0.0562x	0.36	6.692
	Mean		0.47	10.173		0.58	9.025		0.36	11.17
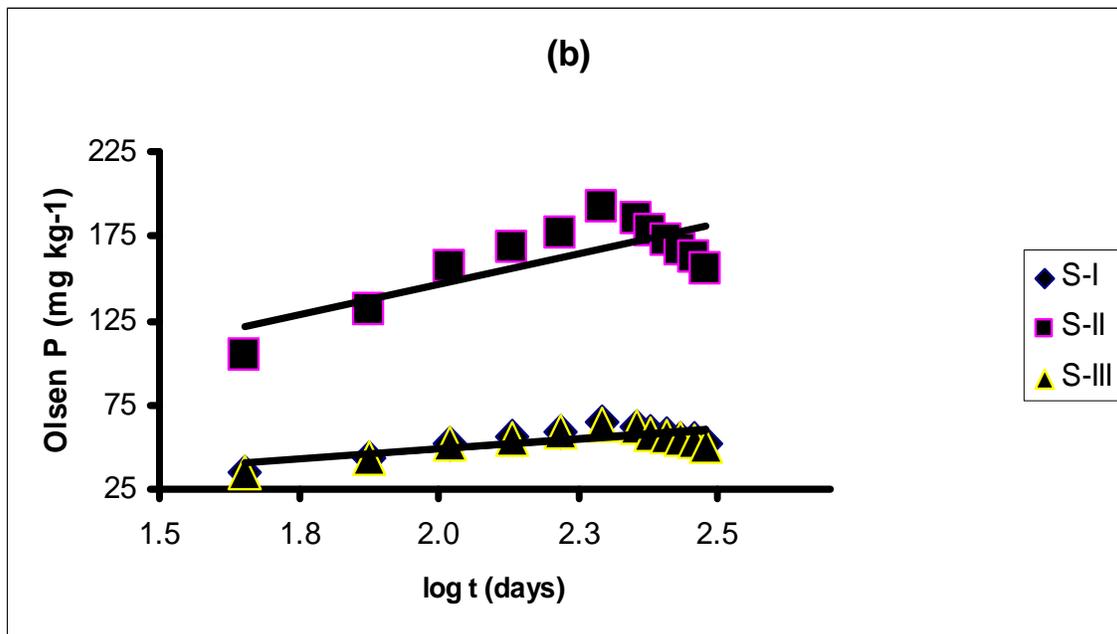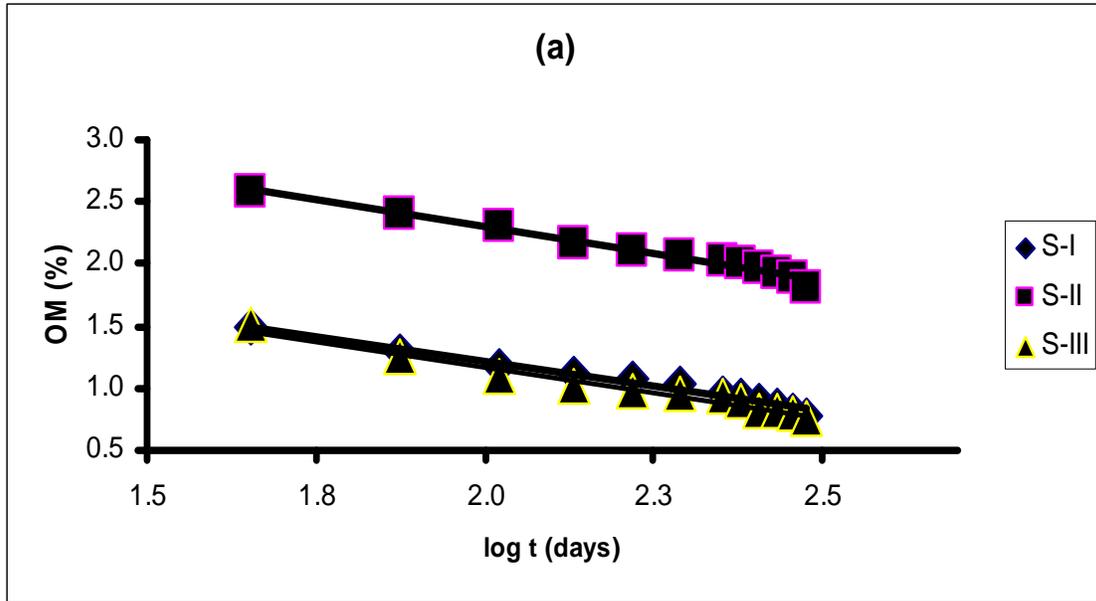
Fig. 5.5   Rate of OM decomposition (a) and Olsen-P release (b) in three
soils after press mud application following Elovich plot
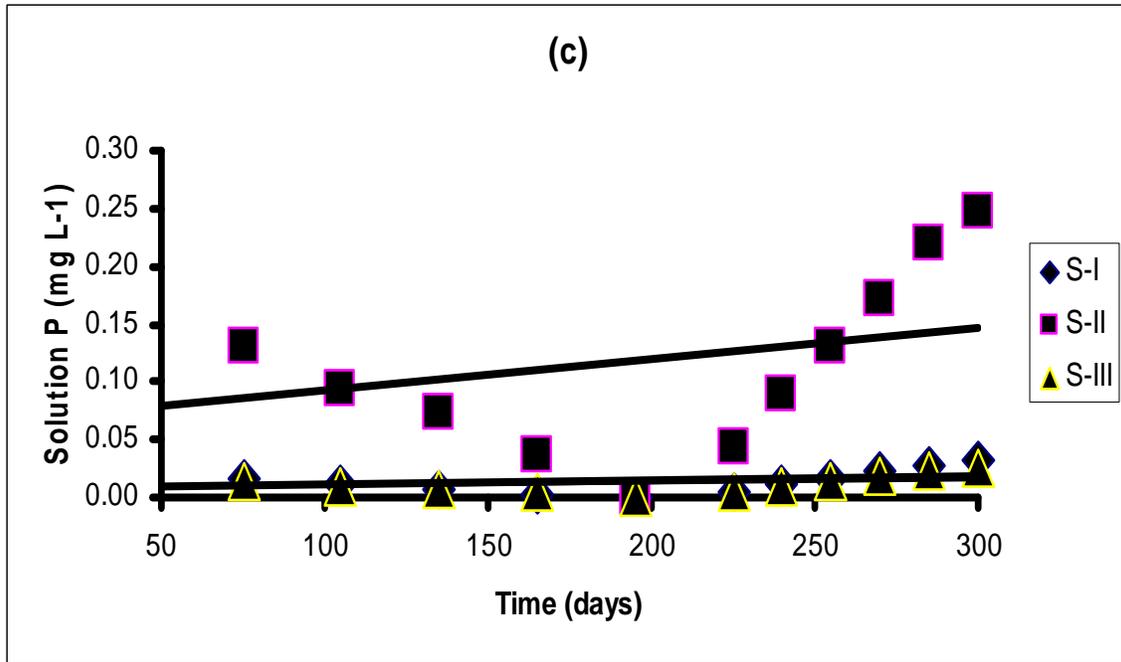
Fig. 5.5   Rate of Solution-P release (c) in three soils after press mud
application following Zero Order plot

5.3.6. Decomposition of native OM + DAP and P release

Organic matter decomposition rate according to Zero Order kinetic equation, in three different soils supplied with DAP (Fig. 5.6, a) revealed that intercept value in case of S-I was 0.0003   and slope value was -0.0158 (Table 5.7). This indicates that with the average unit change in time, OM decomposition in S-I was 0.0003 %. In case of S-II, slope value was -0.0248 and intercept value indicated that with the average unit change in time decrease in OM was 0.0005 %.This rate of change in OM contents of S-III was recorded 0.0002 % decrease in the probable time, while slope value was -0.0072.

Values of SE ranked as S-III< S-I< S-II and R^2 ranked as S-II> S-I> S-III

Zero Order kinetic equation was also applied to assess the rate of Solution-P release in three different soils (Fig. 5.6, b). Intercept value recorded in case of S-I was 0.0001 and slope value was -0.0042 (Table 5.7). This indicates that with the average unit change in time, rate of Solution-P release in S-I was 0.0001%. In case of S-II, slope value was -0.0333 and intercept value indicated that with the average unit change in time Solution-P release was decreased up to 0.001%. Rate of increase in Solution-P contents of S-III was recorded up to 0.0001% with the average unit change in time, while slope value was -0.0041.

Values of SE ranked as S-III< S-I< S-II and R^2 ranked as S-III> S-I = S-II

Rate of Olsen-P release in three different soils following Elovich kinetic equation depicted (Fig. 5.6, c) that intercept value in case of S-I 3.7402   and slope value was -49.001(Table 5.7). This means that, Olsen-P release in S-I was 3.7402 % with the log of average unit change in time. In case of S-II, slope value was -123.88 and intercept value showed that with the log of average unit change in time Olsen-P was decreased up to 131.12 %. Rate of decrease in Olsen-P contents of S-III was 43.705 % with the log of average unit change in time, while slope value was - 42.119.

Values of SE ranked as S-III< S-I< S-II and R^2 ranked as S-II> S-III> S-I

Decomposition rate of OM in S-I, S2 and S-III studied under different kinetic equations (Parabolic Diffusion, Simplified Elovich and Zero Order) revealed ed that Zero Order equation was best fit due to highest R^2 ranging from 0.9680 to 0.9856 and lowest SE values ranging from 0.0035 to 0.0058.

In case of Solution-P release, Zero Order kinetic equation was best fit regarding S-I, S-II and S-III due to its highest R^2 ranging from 0.6755 to 0.7101 and lowest SE values ranging from 0.0073 to 0.0652.

Rate of Olsen-P release in S-II and S3 was better described by the Elovich kinetic equation due to its highest R^2, ranging from 0.7346 to 0.7404 and lowest SE value ranging from 7.129 to 21.067. Neverthe less Zero Order equation was best fit for S-I.

Decomposition rate of native OM studied in all soils revealed that native OM was more rapidly decomposed in S-II with the addition of DAP and release rate of Olsen P was also better in S-II. However, rate of Solution P release was relatively better in S-I.

Table 5.7

Rate of native OM decomposition and P release in soils after DAP application following different kinetic plots

Parameter	Soil	Simple Parabolic			Elovich			Zero Order		
		Equation	R^2	SE	Equation	R^2	SE	Equation	R^2	SE
Rate of OM decomposition	Soil-I	Y = 0.6573 - 0.0074x	0.94	0.949	Y = 0.7708 - 0.0959x	0.89	0.009	Y = 0.0003x - 0.0158	0.98	0.004
	Soil-II	Y = 1.3617 - 0.0132x	0.95	0.951	Y = 1.5624 - 0.1697x	0.89	0.016	Y = 0.0005x - 0.0248	0.99	0.006
	Soil-III	Y = 0.4276 - 0.0054x	0.95	0.954	Y = 0.5117 - 0.0703x	0.92	0.006	Y = 0.0002x - 0.0072	0.97	0.004
	Mean		0.95	0.952		0.90	0.010		0.98	0.004
Release rate of Solution-P	Soil-I	Y = 0.1005 - 0.003x	0.57	0.009	Y = 0.1383 - 0.035x	0.44	0.011	Y = 0.0001x - 0.0042	0.68	0.008
	Soil-II	Y = 0.8041 - 0.0238x	0.57	0.075	Y = 1.1068 - 0.2797x	0.44	0.086	Y = 0.001x - 0.0333	0.68	0.065
	Soil-III	Y = 0.0962 - 0.0029x	0.60	0.009	Y = 0.134 - 0.0347x	0.48	0.010	Y = 0.0001x - 0.0041	0.71	0.007
	Mean		0.58	0.031		0.45	0.035		0.69	0.027
Release rate Of Olsen-P	Soil-I	Y = 57.743 + 0.0315x	0.00	9.389	Y = 3.7402x - 49.001	0.01	9.335	Y = 15.361 - 0.0128x	0.02	9.319
	Soil-II	Y = 39.301 + 9.5655x	0.70	22.571	Y = 131.12x -123.88	0.74	21.06	Y = 119.65 - 0.3675x	0.64	24.92
	Soil-III	Y = 12.318 + 3.1849x	0.70	7.642	Y = 43.705x - 42.119	0.73	7.129	Y = 39.449 - 0.1222x	0.63	8.430
	Mean		0.47	13.201		0.50	12.51		0.43	14.22
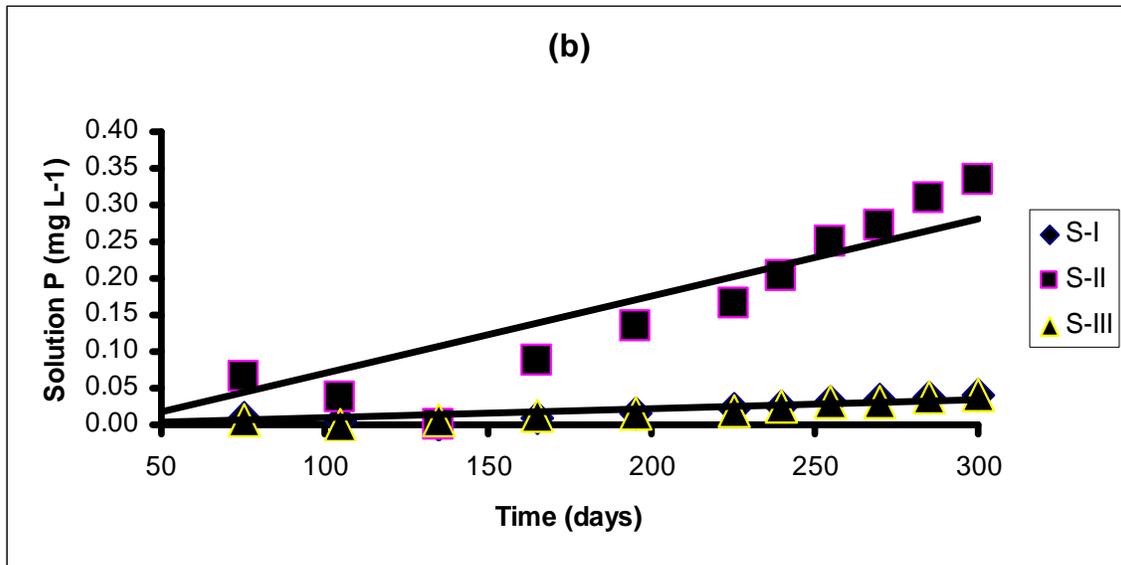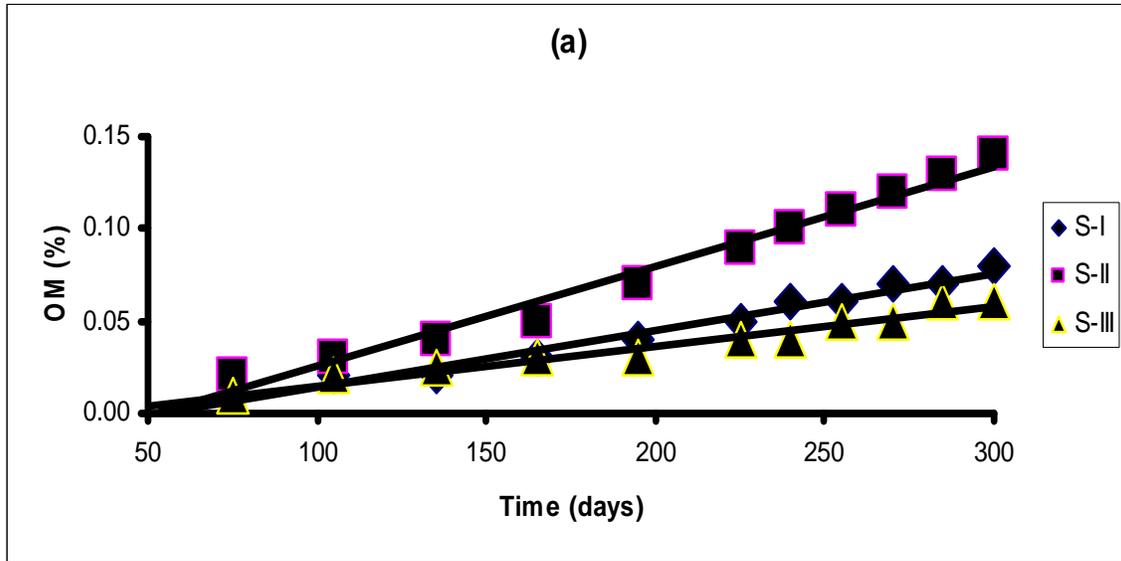
Fig. 5.6 Rate of native OM decomposition (a) and Solution-P release (b) in
three soils after DAP application following Zero Order kinetic model
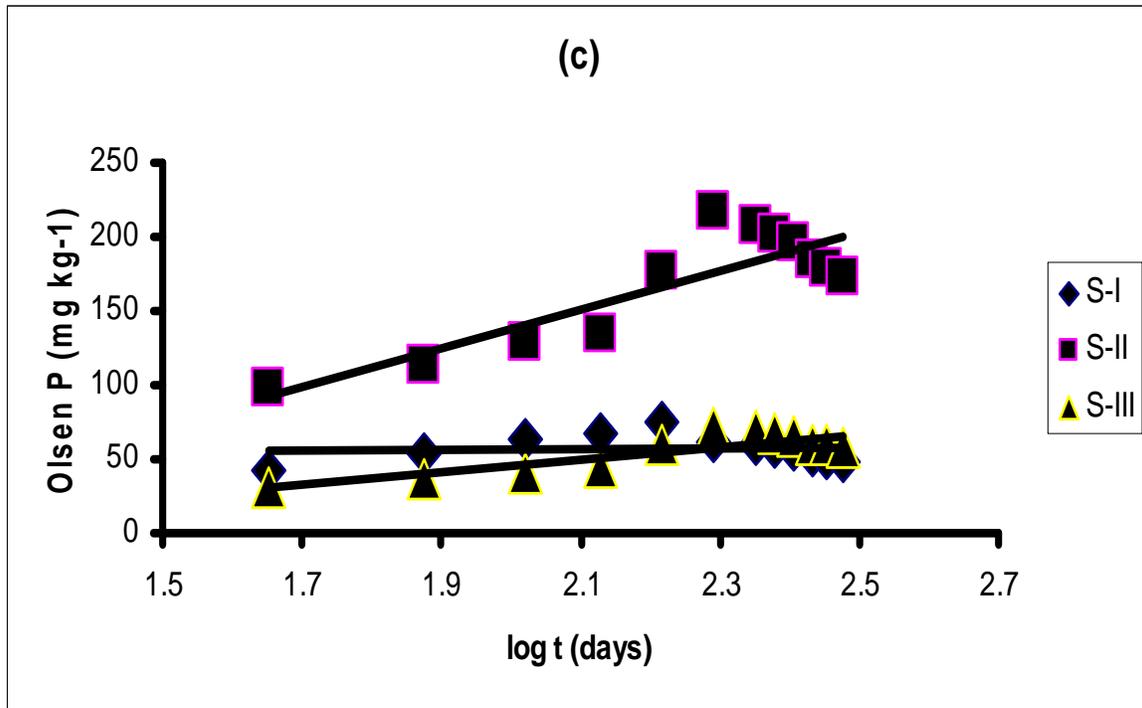
Fig. 5.6 Rate of Olsen-P release (c) in three soils after DAP

application following Elovich plot

5.3.7. Decomposition of green manure + DAP and P release

Organic matter decomposition rate according to Zero Order kinetic equation, in three different soils supplied with green manure +DAP (Fig. 5.7, a) revealed that intercept value in case of S-I was 0.0033 and slope value was -0.17(Table 5.8). This indicates that with the average unit change in time, OM decomposition in S-I was 0.0033. In case of S-II, slope value was -0.0954 and intercept value indicated that with the average unit change in time decrease in OM was 0.0027 %. This rate of change in OM contents of S-III was recorded 0.0025 % decrease in the average unit change in time, while slope value was -0.1016. Values of SE ranked as S-III< S-II< S-I and R^2 ranked as S-III> S-II> S-I.

Rate of Olsen-P release in three soils applied with green manure + DAP following Elovich kinetic equation (Fig. 5.7, b) depicted that intercept value in case of S-I was -23.757 and slope value was 16.095 (Table 5.8). This means that, Olsen-P release in S-I was -23.757 % with the log of average unit change in time. In case of S-II, slope value was 23.863 and intercept value showed that with the log of average unit change in time Olsen-P was decreased up to -101.01 %. Rate of decrease in Olsen-P contents of S-III was -31.837 % with the log of average unit change in time, while slope value was 4.7605.

Values of SE ranked as S-I< S-III< S-II and R^2 ranked as S-II> S-III> S-I

Decomposition rate of OM in S-I, S-II and S-III studied under different kinetic equations (Parabolic Diffusion, Simplified Elovich and Zero Order) revealed that Zero Order equation was best fit due to highest R^2 ranging from 0.9943 to 0.9983 and lowest SE values ranging from 0.0093 to 0.0225.

In case of Solution-P release, Zero Order kinetic equation was best fit regarding S-I, and S-III due to its highest R^2 ranging from 0.0501 to 0.1061 and lowest SE values ranging from 0.0089 to 0.0105(Table 5.8). But S-II was better described by the application of Elovich equation. Rate of Olsen-P release in the three soils was better described by the Elovich kinetic equation due to its highest R^2, ranging from 0.4972 to 0.6476 and lowest SE value ranging from 6.482 to 20.218.

Comparison of decomposition rate of green manure incubated with DAP in all soils depicted that rate decomposition was relatively faster in S-III. Release rate of

Solution P was also better in S-III; however, release rate of Olsen P was relatively better in S-II.

Table 5.8

Rate of OM decomposition and P release in soils after green manure + DAP application following different kinetic plots

Parameter	Soil	Simple Parabolic			Elovich			Zero Order		
		Equation	R^2	SE	Equation	R^2	SE	Equation	R^2	SE
Rate of OM decomposition	Soil-I	Y = 2.1417 - 0.0812x	0.97	0.049	Y = 3.3928 - 1.0526x	0.92	0.085	Y = 0.0033x - 0.17	0.99	0.023
	Soil-II	Y = 2.9993 - 0.0675x	0.99	0.023	Y = 4.0588 - 0.8837x	0.95	0.053	Y = 0.0027x - 0.0954	1.00	0.014
	Soil-III	Y = 1.8511 - 0.0617x	0.99	0.027	Y = 2.8131 - 0.8051x	0.94	0.054	Y = 0.0025x - 0.1016	1.00	0.009
	Mean		0.98	0.033		0.94	0.064		1.00	0.015
Release rate of Solution-P	Soil-I	Y = 0.0727 - 0.0003x	0.01	0.009	Y = 0.0693 - 0.0003x	0.00	0.009	$Y = 0.0099 + 2 \times 10^{-5} x$	0.05	0.009
	Soil-II	Y = 0.5495 - 0.0024x	0.04	0.045	Y = 0.4764 - 0.0473x	0.08	0.044	$Y = 0.0766 + 5 \times 10^{-5} x$	0.01	0.046
	Soil-III	Y = 0.0786 - 0.0007x	0.05	0.011	Y = 0.0789 - 0.0042x	0.01	0.011	$Y = 0.0077 + 4 \times 10^{-5} x$	0.11	0.011
	Mean		0.03	0.022		0.03	0.021		0.06	0.022
Release rate Of Olsen-P	Soil-I	Y = 47.82 + 1.5725x	0.39	7.151	Y = 16.095 - 23.757x	0.50	6.482	Y = 22.204 - 0.0545x	0.29	7.724
	Soil-II	Y = 107.1 + 6.9782x	0.55	22.832	Y = 23.863 - 101.01x	0.65	20.21	Y = 89.897 - 0.2536x	0.45	25.31
	Soil-III	Y = 36.77 + 2.1801x	0.51	7.751	Y = 4.7605 -31.837x	0.61	6.914	Y = 28.474 - 0.0785x	0.41	8.530
	Mean		0.48	12.578		0.58	11.20		0.38	13.85
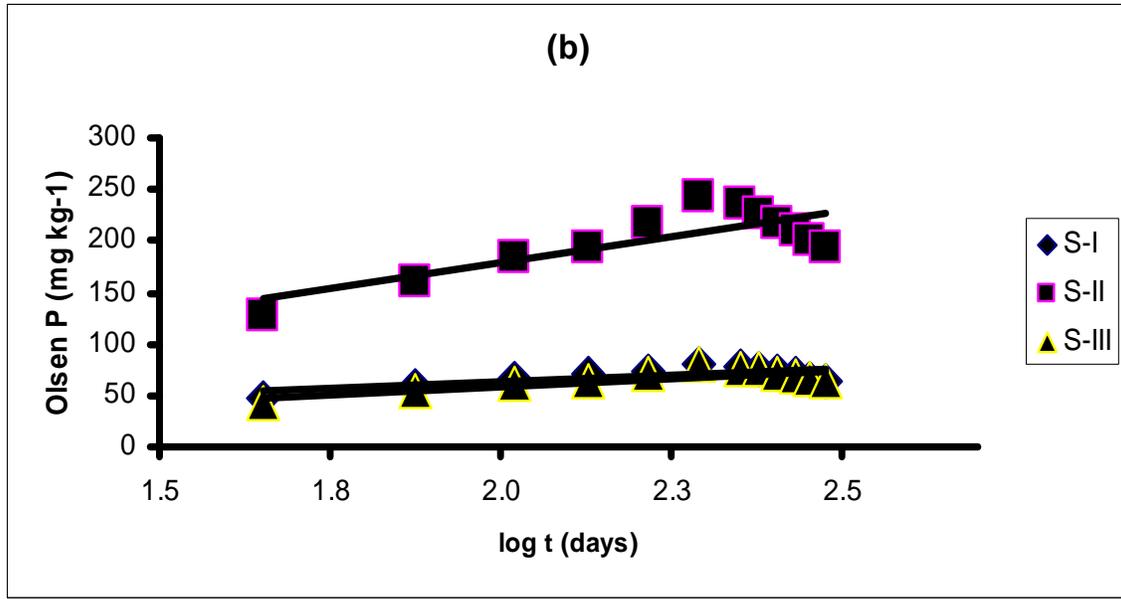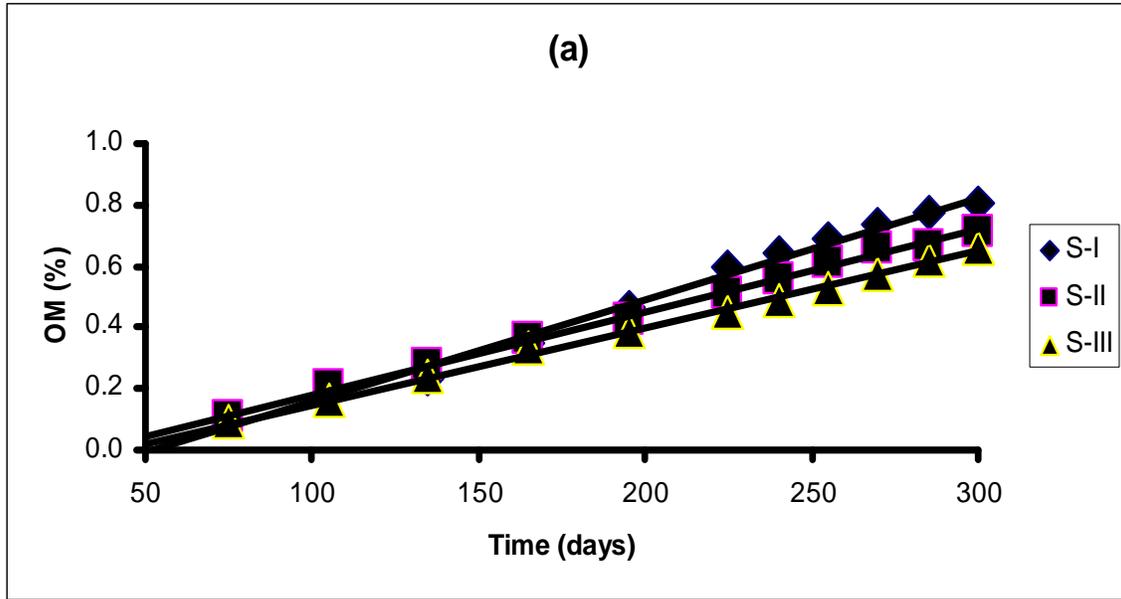
Fig. 5.7 Effect of green manure + DAP application on rate of OM decomposition
(a) following Zero order plot and Olsen-P release (b) following Elovich
plot in three soils.

5.3.8. Decomposition of FYM + DAP and P release

Elovich kinetic equation was also applied to assess the rate of Solution-P release in three different soils incubated with FYM + DAP (Fig. 5.8, a). Intercept value recorded in case of S-I was -0.0183 and slope value was 0.1102(Table 5.9). This indicates that with the log of average unit change in time rate of Solution-P release in S-I was -0.0183%. In case of S-II, slope value was 0.9187 and intercept value indicated that with the log of average unit change in time Solution-P release was up to -0.1358 %. Rate of increase in Solution-P contents of S-III was recorded up to -0.0143 % in the probable time, while slope value was 0.0967.

Values of SE ranked as S-III< S-I< S-II and R^2 ranked as S-I> S-II = S-III

Rate of Olsen-P release in three different soils applied with poultry manure + DAP following Elovich kinetic equation (Fig. 5.8, b) depicted that intercept value in case of S-I was 6.9739 and slope value was 50.057(Table 5.9). This means that, Olsen-P release in S-I was 6.9739 % with the log of average unit change in time. In case of S-II, slope value was 103.04 and intercept value showed that with the log of average unit change in time Olsen-P was decreased up to 40.847 %. Rate of decrease in Olsen-P contents of S-III was 10.639 % with the log of average unit change in time, while slope value was 39.7477.

Values of SE ranked as S-III< S-I< S-II and R^2 ranked as S-II> S-III> S-I.

Decomposition rate of OM in S-I, S-II and S-III studied under different kinetic equations (Parabolic Diffusion, Simplified Elovich and Zero Order) revealed that Simple Parabolic equation was best fit due to highest R^2 ranging from 0.9757 to 0.9852 and lowest SE values ranging from 0.0275 to 0.0340.

In case of Solution-P release, Zero Order kinetic equation was best fit regarding S-I, S-II and S-III due to its highest R^2 ranging from 0.2933 to 0.3161 and lowest SE values ranging from 0.0095 to 0.0907.

Rate of Olsen-P release in the three soils was better described by the Elovich kinetic equation due to its highest R^2, ranging from 0.0455 to 0.1756 and lowest SE value ranging from 8.519 to 24.017.

It was found that rate of FYM decomposition incubated with DAP was faster in S-II. Rate of Olsen P release was also better in S-II, however, rate of solution P release was relatively better in S-I.

Table 5.9

Rate of native OM decomposition and P release in soils after FYM + DAP application following different kinetic plots

Parameter	Soil	Simple Parabolic			Elovich			Zero Order		
		Equation	R^2	SE	Equation	R^2	SE	Equation	R^2	SE
Rate of OM decomposition	Soil-I	Y = 1.7494 - 0.0561x	0.98	0.320	Y = 2.6539 - 0.7451x	0.97	0.037	Y = 0.0022x - 0.0352	0.96	0.042
	Soil-II	Y = 3.3314 - 0.0767x	0.99	0.034	Y = 4.5507 - 1.0112x	0.96	0.055	Y = 0.0031x - 0.0723	0.98	0.038
	Soil-III	Y = 1.7796 - 0.0591x	0.98	0.028	Y = 2.73 - 0.784x	0.97	0.036	Y = 0.0024x - 0.0481	0.97	0.039
	Mean		0.98	0.127		0.97	0.040		0.97	0.043
Release rate of Solution-P	Soil-I	Y = 0.0933 - 0.0018x	0.22	0.012	Y = 0.1102 - 0.0183x	0.13	0.013	Y = 0.0022 + 9x10^{-5} x	0.32	0.011
	Soil-II	Y = 0.7953 - 0.0133x	0.20	0.097	Y = 0.9187 - 0.1358x	0.12	0.101	Y = 0.0149 + 0.0007x	0.29	0.091
	Soil-III	Y = 0.0837 - 0.0014x	0.20	0.010	Y = 0.0967 - 0.0143x	0.12	0.011	Y = 0.0016 + 7x10^{-5} x	0.29	0.010
	Mean		0.21	0.040		0.30	0.037		0.12	0.042
Release rate Of Olsen-P	Soil-I	Y = 62.509 + 0.2278x	0.01	8.838	Y = 50.057 + 6.9739x	0.05	8.672	Y = 15.433- 0.0019x	0.00	8.874
	Soil-II	Y = 163.7 + 2.2487x	0.09	25.166	Y = 103.04 + 40.847x	0.18	24.01	Y = 52.459 - 0.0588x	0.04	25.91
	Soil-III	Y = 56.594 + 0.5075x	0.04	8.805	Y = 39.747 + 10.639x	0.10	8.519	Y = 16.46 - 0.0092x	0.01	8.956
	Mean		0.05	14.270		0.11	13.73		0.02	14.58
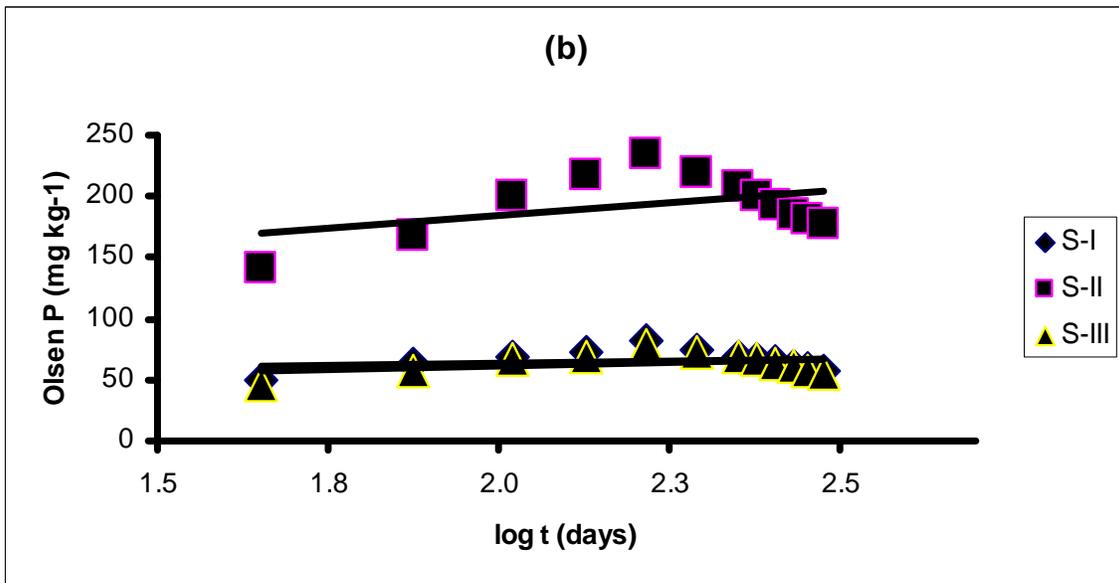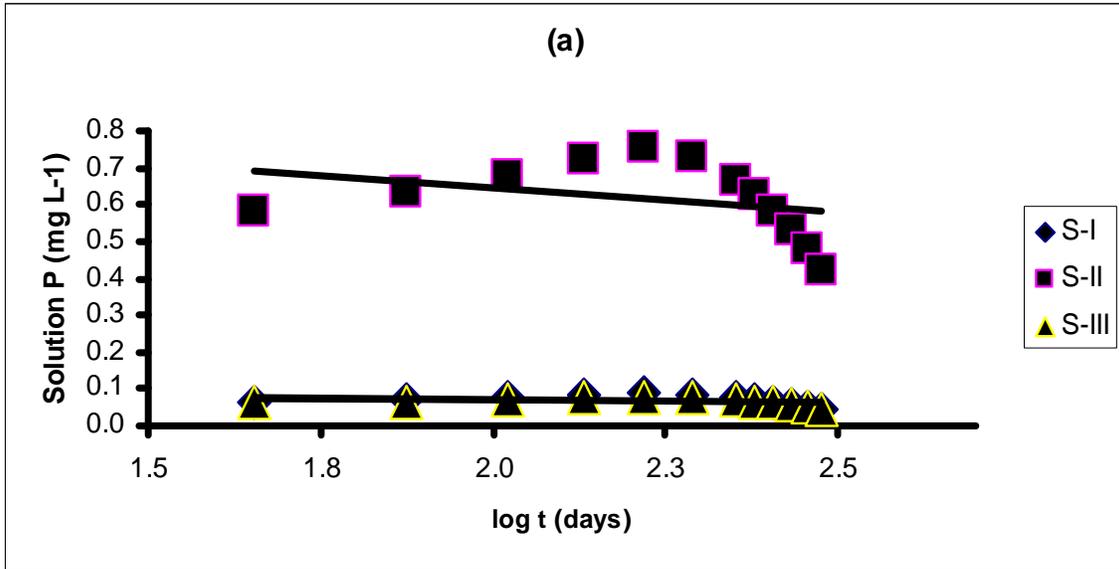
Fig. 5.8   Release rate of Solution-P (a) and Olsen-P (b) in three soils after
FYM + DAP application following Elovich kinetic model

5.3.9. Decomposition of poultry manure + DAP and P release

Rate of OM decomposition with respect to Simple Elovich kinetic equation, in three different soils incubated with poultry manure + DAP (Fig. 5.9, a) revealed that intercept value in case of S-I was -1.0032 and slope value was 3.3863 (Table 5.10). This indicates that with the log of average unit change in time, OM decomposition in S-I was -1.0032. In case of S-II, slope value was 4.3535 and intercept value indicated that with the log of average unit change in time decrease in OM was -0.8689 %. This rate of change in OM contents of S-III was recorded -40.7414 decreases with the log of average unit change in time, while slope value was 2.7414.

Values of SE ranked as S-III< S-I< S-II and R^2 ranked as S-III> S-II> S-I

Rate of Olsen-P release in three different soils incubated with poultry manure + DAP following Zero Order kinetic equation (Fig. 5.9, b), depicted that intercept value in case of S-I was -0.0007 and slope value was 18.11(Table 5.10). This means that, Olsen-P release in S-I was -0.0007 % with the average unit change in time. In case of S-II, slope value was 53.76 and intercept value showed that with the average unit change in time Olsen-P was up to   -0.0476. Rate of decrease in Olsen-P contents of S-III was -0.0134 with the average unit change in time, while slope value was 18.11.

Values of SE ranked as S-III< S-I< S-II and R^2 ranked as S-II> S-I = S-III

Simple Elovich kinetic equation was also applied to assess the rate of Solution-P release in three different soils (Fig. 5.9, c). Intercept value recorded in case of S-I was -0.0207 and slope value was 0.1372(Table 5.10). This indicates that with the log of average unit change in time, rate of Solution-P release in S-I was -0.0207%. In case of S-II, slope value was 1.0978 and intercept value indicated that with the log of average unit change in time Solution-P release was up to -0.1652. Rate of increase in Solution-P contents of S-III was recorded up to -0.0213 with the log of average unit change in time, while slope value was 0.1289.

Values of SE ranked as S-III< S-I< S-II and R^2 ranked as S-II> S-III = S-I

Decomposition rate of OM in S-I and S-II studied under different kinetic equations (Parabolic Diffusion, Simplified Elovich and Zero Order) revealed that Elovich equation was best fit due to highest R^2 and lowest SE. However, Elovich equation was best fit in case of S-III due to its highest R^2 and lowest SE values.

Rate of Solution-P release in the three soils was better described by Zero order kinetic equation. It means that clear relation between time and Solution-P release could not develop in the three soils with the passage of time.

Rate of Olsen-P release in the three soils was better described by the Zero Order kinetic equation due to its highest R^2, ranging from 0.2552 to 0.2648 and lowest SE value ranging from 8.593 to 25.78.

Comparison of decomposition rate of poultry manure incubated with DAP in three soils revealed that relatively faster decomposition took place in S-I. Release rate of Solution P was also better in S-I, however, rate of Olsen P release was relatively better in S-II.

Table 5.10

Rate of OM decomposition and P release in soils after poultry manure + DAP application following different kinetic plots

Parameter	Soil	Simple Parabolic			Elovich			Zero Order		
		Equation	R^2	SE	Equation	R^2	SE	Equation	R^2	SE
Rate of OM decomposition	Soil-I	Y = 2.1717 - 0.0757x	1.00	0.013	Y = 3.3863 - 1.0032x	0.98	0.036	Y = 0.003x - 0.0646	0.98	0.037
	Soil-II	Y = 3.3092 - 0.0662x	0.98	0.034	Y = 4.3535 - 0.8689x	0.95	0.055	Y = 0.0027x - 0.0722	0.98	0.031
	Soil-III	Y = 1.8337 - 0.0552x	0.98	0.030	Y = 2.7414 - 0.7414x	0.99	0.020	Y = 0.0022x - 0.0097	0.94	0.050
	Mean		0.99	0.026		0.97	0.037		0.97	0.039
Release rate of Solution-P	Soil-I	Y = 0.1181 - 0.002x	0.22	0.014	Y = 0.1372 - 0.0207x	0.13	0.014	Y = 0.0043 + 1×10^{-4} x	0.32	0.013
	Soil-II	Y = 0.9445 - 0.016x	0.22	0.109	Y = 1.0978 - 0.1652x	0.13	0.115	Y = 0.035 + 0.0008x	0.32	0.102
	Soil-III	Y = 0.1085 - 0.002x	0.26	0.012	Y = 0.1289 - 0.0213x	0.16	0.013	Y = 0.0028 + 1×10^{-4} x	0.36	0.011
	Mean		0.23	0.045		0.14	0.047		0.33	0.042
Release rate Of Olsen-P	Soil-I	Y = 75.39 + 0.3225x	0.01	9.916	Y = 60.72 + 8.5429x	0.05	9.711	Y = 18.11 - 0.0007x	0.00	9.984
	Soil-II	Y = 209.09 + 2.0343x	0.07	27.165	Y = 149.98 + 38.859x	0.14	26.09	Y = 53.76 - 0.0476x	0.02	27.82
	Soil-III	Y = 69.527 + 0.6211x	0.06	9.248	Y = 50.571 + 12.273x	0.12	8.916	Y = 18.11 - 0.0134x	0.02	9.441
	Mean		0.05	15.443		0.11	14.90		0.01	15.74
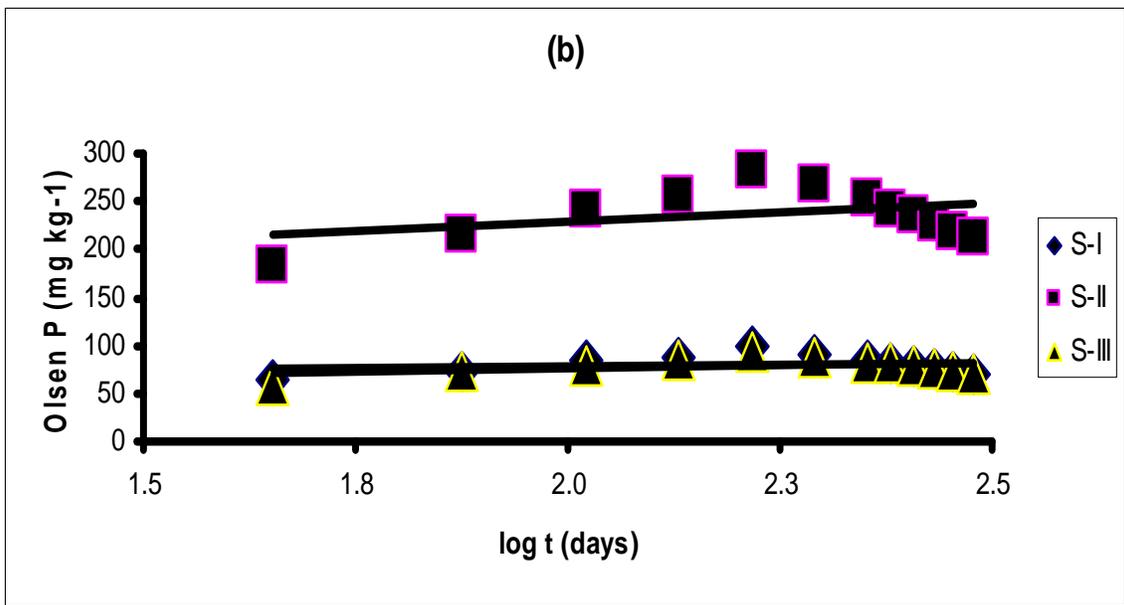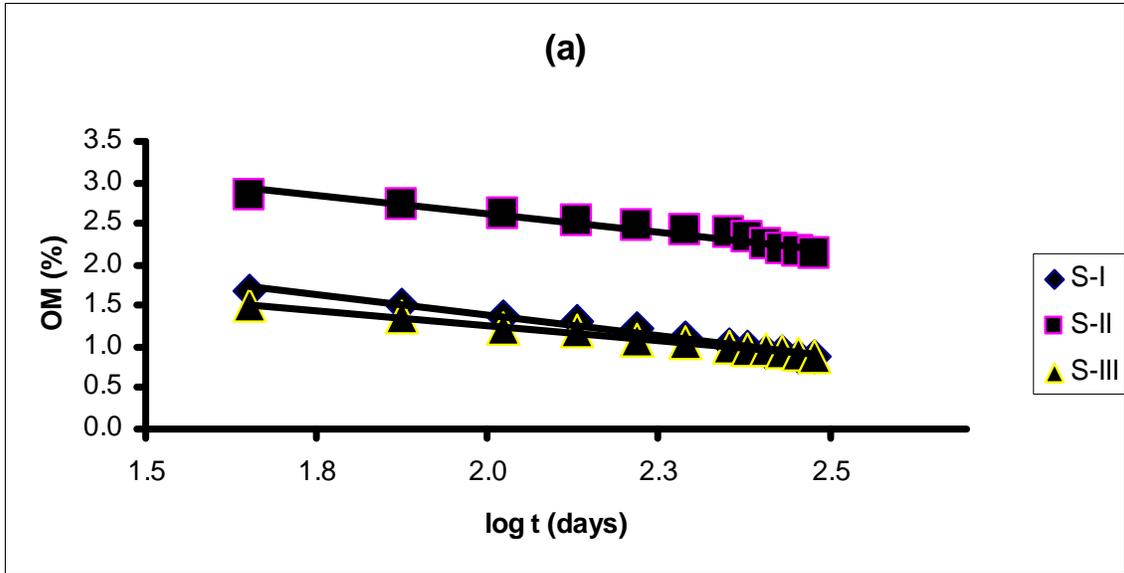
Fig. 5.9 Rate of OM decomposition (a) and Olsen-P release (b) in three soils after application of poultry manure + DAP following Elovich plot
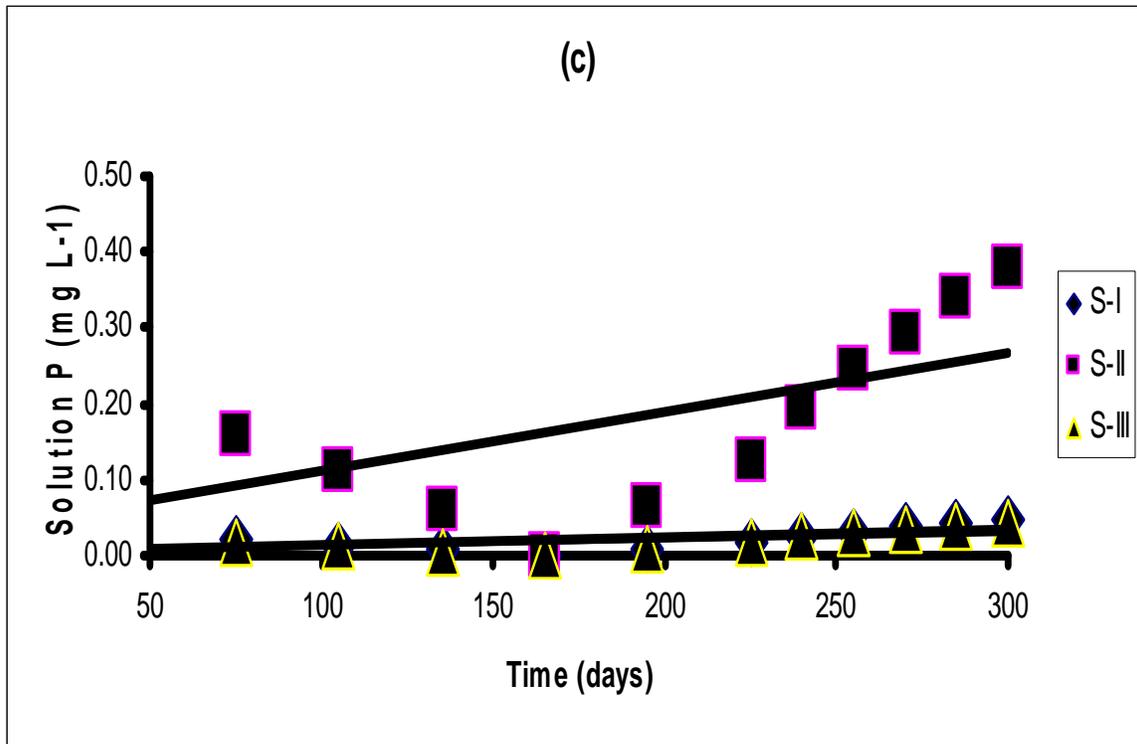
Fig. 5.9 Rate of Solution P release (c) in three soils after poultry manure + DAP addition following Zero order plot

5.3.10. Decomposition of press mud + DAP and P release

Simple Parabolic kinetic equation applied to study the rate of OM decomposition in three different soils incubated with press mud +DAP (Fig. 5.10, a) revealed that intercept value in case of S-I was -0.0719 and slope value was 2.0881(Table 5.11). This shows that with the square root of average unit change in time, OM decomposition in S-I was -0.0719%. In case of S-II, slope value was 3.1151 and intercept value indicated that with the square root of average unit change in time decrease in OM was -0.0695%. This rate of change in OM contents of S-III was recorded -0.0476% decrease with the square root of average unit change in time, while slope value was 1.7219.

Values of SE ranked as S-III< S-I< S-II and R^2 ranked as S-I> S-II> S-III.

Elovich kinetic equation was applied to assess the rate of Solution-P release in three different soils (Fig. 5.10, b). Intercept value recorded in case of S-I was -0.0128 and slope value was 0.115(Table 5.11). This indicates that with the log of average unit change in time, rate of Solution-P release in S-I was -0.0128. In case of S-II, slope value was 0.9198 and intercept value indicated that with the log of average unit change in time Solution-P release was up to -0.1021 %. Rate of increase in Solution-P contents of S-III was recorded up to -0.012 with the log of average unit change in time, while slope value was 0.1027.

Values of SE ranked as S-II< S-I< S-III and R^2 ranked as S-III> S-I = S-II

Rate of Olsen-P release in three different soils incubated with press mud +DAP following Zero Order kinetic equation (Fig. 5.10, c) depicted that intercept value in case of S-I was -0.03.63 and slope value was 21.144 (Table 5.11). This means that, Olsen-P release in S-I was -0.0363% with the average unit change in time. In case of S-II, slope value was 63.432 and intercept value showed that with the average unit change in time Olsen-P was decreased up to -0.109 %. Rate of decrease in Olsen-P contents of S-III was -0.0358% with the average unit change in time, while slope value was 20.704

Values of SE ranked as S-I< S-III< S-II and R^2 ranked as S-I = S-II> S-III.

Decomposition rate of OM in S-I and S-II studied under different kinetic equations (Parabolic Diffusion, Simplified Elovich and Zero Order) revealed that Elovich equation was best fit due to highest R^2 ranging from 0.9927 to 0.9938 and

lowest SE values ranging from 0.0206 to 0.0216. However, Elovich equation was best fit in case of S-III due to its highest R^2 and lowest SE values.

Rate of Solution-P release in the three soils was not better described by the three kinetic equations under consideration. It means that clear relation between time and Solution-P release could not develop in the three soils with the passage of time.

Rate of Olsen-P release in the three soils was better described by the Zero Order kinetic equation due to its highest R^2, ranging from 0.2552 to 0.2648 and lowest SE value ranging from 8.593 to 25.78.

While comparing rate of decomposition of added amendments in different soils it was revealed that rate of press mud decomposition incubated with DAP was relatively faster in S-I and release rate of Solution and Olsen P was also comparatively better in S-I.

Table 5.11

Rate of OM decomposition and P release in soils after press mud + DAP application following different kinetic plots

Parameter	Soil	Simple Parabolic			Elovich			Zero Order		
		Equation	R^2	SE	Equation	R^2	SE	Equation	R^2	SE
Rate of OM decomposition	Soil-I	Y = 2.0881 - 0.0719x	0.99	0.021	Y = 3.2452 - 0.9544x	0.98	0.035	Y = 0.0029x - 0.0521	0.98	0.041
	Soil-II	Y = 3.1151 - 0.0695x	0.99	0.022	Y = 4.2284 - 0.9202x	0.98	0.039	Y = 0.0026x - 0.045	0.98	0.034
	Soil-III	Y = 1.7219 - 0.0476x	0.99	0.018	Y = 2.496 - 0.6353x	0.99	0.018	Y = 0.0019x - 0.0053	0.96	0.033
	Mean		0.99	0.020		0.98	0.030		0.97	0.036
Release rate of Solution-P	Soil-I	Y = 0.1045 - 0.0013x	0.14	0.012	Y = 0.115 - 0.0128x	0.07	0.013	Y = 0.0054 + 7x10^{-5}x	0.22	0.012
	Soil-II	Y = 0.8363 - 0.0107x	0.14	0.097	Y = 0.9198 - 0.1021x	0.07	0.101	Y = 0.0432 + 0.0005x	0.22	0.092
	Soil-III	Y = 0.092 - 0.0013x	0.15	0.011	Y = 0.1027 - 0.012x	0.08	0.012	Y = 0.0042 + 6x10^{-5}x	0.23	0.011
	Mean		0.14	0.040		0.07	0.042		0.22	0.038
Release rate Of Olsen-P	Soil-I	Y = 56.983 + 1.1686x	0.18	9.084	Y = 30.41 + 19.003x	0.26	8.593	Y = 21.144 - 0.0363x	0.11	9.476
	Soil-II	Y = 170.95 + 3.5058x	0.18	27.252	Y = 91.231 + 57.009x	0.26	25.78	Y = 63.432 - 0.109x	0.11	28.42
	Soil-III	Y = 56.242 + 1.1592x	0.17	9.257	Y = 29.717 + 18.924x	0.26	8.772	Y = 20.704 - 0.0358x	0.10	9.642
	Mean		0.18	15.198		0.26	14.38		0.10	15.84
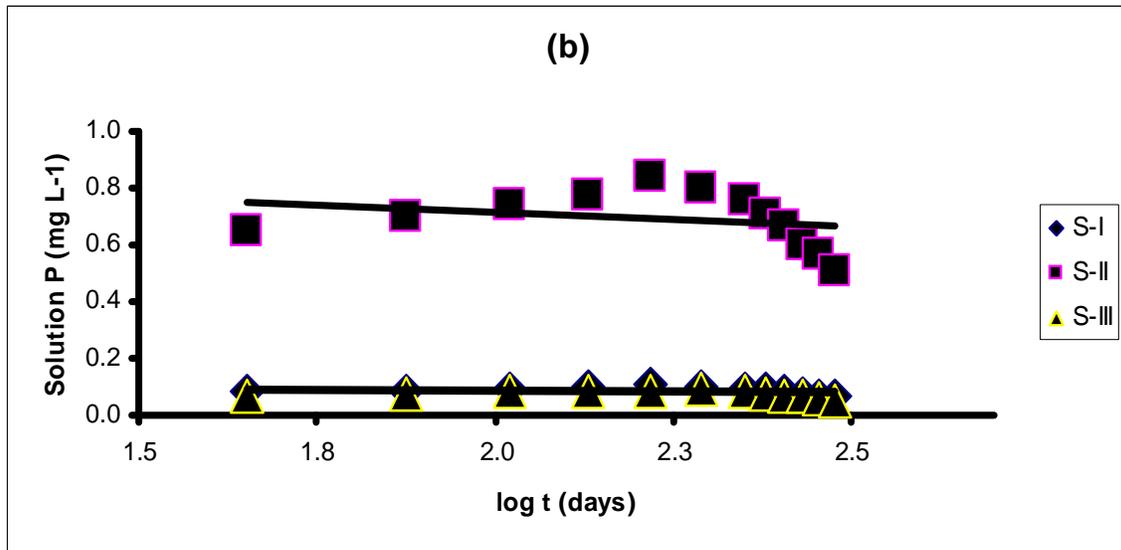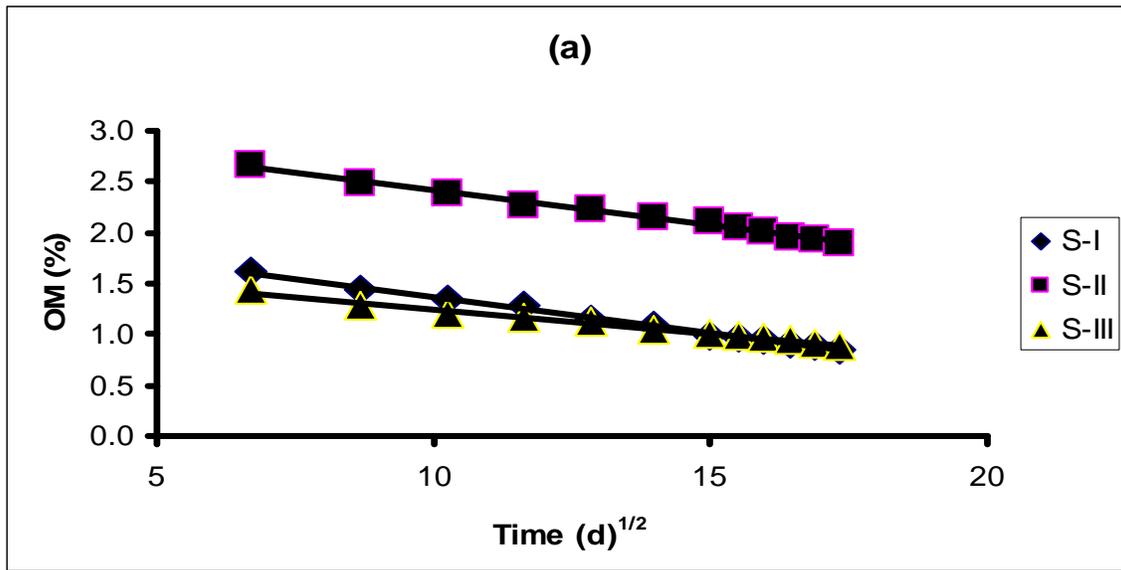
Fig. 5.10 Rate of OM decomposition (a) and Solution P release (b) in three soils after press mud + DAP addition following Elovich plot
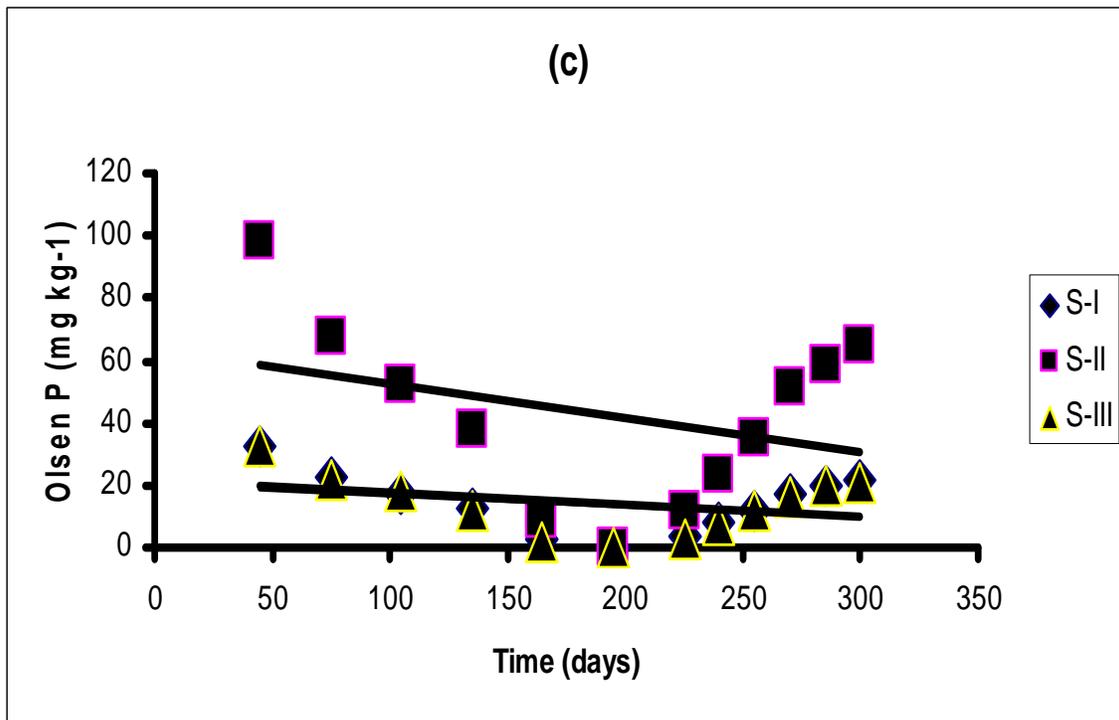
Fig. 5.10 Rate of Olsen P release(c) in three soils after

press mud + DAP addition following Zero Order plot

5.4. Discussion

Tradition of manure application is common in the less productive soils. Manures are considered as a source of P which interacts with soil components to increase P recovery by crops and also augment the efficiency of inorganic P fertilizers. Native OM or added manures exert tremendous effects on P retention potential of soils. Manures have great influence on precipitation and sorption of P and they also contain diversity of nutrients required by plants. However, P added from either manures or other sources tends to become less available to crops with the passage of time (Sample et al. 1980). Native and added organic matter in soils renders significant effect on the P kinetics of soils. Additions of organic matter into soils through various sources (animal manure, green manure and organic wastes) have two pronged effect. It affects sorption/precipitation of P and hence improves subsurface P retention. It also contains various amounts of plant nutrients depending multifarious factors. With the decomposition/breakdown of the total biota of soil's environment a P mobilizing effect takes place (Kelling, 2004).

In the present study, decomposition of added and native OM resulted into relatively fast release of Olsen and solution P. This might happened due to presence of higher contents of organic C at the initial stages which helped the efficiency of microbes involved in the decomposition of organic materials. At this stage increased microbial activity did help for the rapid release of P from the organic amendments. Moreover, organic acids produced during the microbial activities not only helped to solublize the native P but it also blocked the adsorption sites. This resulted into increased quantities of Olsen's P and solution P in the soil. In the meantime atmospheric conditions regarding temperature and humidity were also favourable for decomposition. Evans and Jurinak (1976) attributed this initial fast desorption to native metastable, poorly crystalline Ca-P, transformed into hydroxyl apatite. Kuo and Lotse (1974) separated this initial rapid release as the more labile P and latter fractions were recognized as less mobile proportions of the P occupied sites. The slower secondary reaction of P release was ascribed to desorption of surface labile P and crystalline P compounds in soil. Overall, this biphasic phenomenon indicates the presence of various soil P pools of different stabilities and dissolution rates. Nevertheless, differential availability of added P among

different soils and significant decrease with time of soil P contact was also reported after incubation studies (Afif et al., 1993; Castro and Torrent, 1995)

Due to rapid initial rate of OM decomposition in the organic P treatments, rate of P release (solution P and Olsen P) was also significant up to day 105. Hansen and Strawn (2003) also did not observe the equilibrium regarding P desorption after 21 days from manure amended soil. Lookman et al. (1995) also observed that rate of P desorption did not reach a plateau until after 67 days. They concluded that P desorption equilibrium may take more time in some soils. The rate of P release was further [increased] when the organic P sources were integrated with chemical source (DAP). This rate of OM decomposition was receded with the passage of time and initial fast release of P was also changed into slow secondary reaction. It might occur due to the decreased nutrient availability of organic contents which were consumed fastly at the initial stages of incubation of organic and inorganic amendments. Since at the initial stage P from DAP was in readily available form, therefore, with the passage of time this readily available P was consumed by the microbes and at the completion of their life cycle they returned back the P into soil. In the meanwhile P from organic sources also started to enter into soil system following slow secondary reactions. In the last months of incubation the P available in soil started to decrease which might be the effect of $CaCO_3$ and Fe contents of soil. Abbas and Gilkes (1999) in an incubation study also observed the transformation of added P into less available calcium phosphate. They concluded that decrease in recovery of added P with increase in the incubation period, was the common character of soils.

Several biochemical processes are simultaneously occurring in the soil's environment which determine the ultimate fate of applied and native OM and soil P contents. Three of these processes may be (i) dissolution of P minerals (ii) P desorption from different mineral surfaces and (iii) mineralization of OM causing P release. However rate of release depends on the sorption mechanisms and surface of minerals. Particle size of minerals, their species and crystallinity determine the dissolution rate of P minerals (Hosseinpur and Biabanaki, 2008). Relatively higher rates of OM decomposition and P release in Soil-II may be attributed to these processes. Since this soil of Gujranwala series (Table: 4.1) had comparatively higher contents of OM (1.31%)

and Olsen's P (16.65 mg kg^{-1} soil) therefore, not only native P was released but P from OM was also comparatively in higher quantities.

Amount of soluble P in a soil mainly depends on the rate of P release from the constituents of soil to the solution form. Therefore, studies on the kinetics of P release from a soil are of great concern to assess the labile fraction of soil P for crops. Because the proportion of labile P determines not only the fate of applied P but it also determines the quantity available for the crop. Kinetics of P release from various soils and efficacy of relevant kinetic models have been studied by earlier researchers (Elkhatib and Hern 1988; Bahl 1990; Yang and Skogley 1992). Recently the dwindling natural resources of plant nutrients, especially the rock phosphate has compelled to switch over the researcher for better substitution or prolonging the in hand reserves of natural reserves of P. In the present study three mathematical models were applied to describe release kinetic of P as affected by decomposition of native and applied P sources of organic origin. Comparison of different models applied showed that release of Olsen P was better described by Simplified Elovich equation as suggested by Chien and Clayton (1980). Rate of solution P release was better described by Zero Order equation. Nevertheless, rate of OM decomposition was best related with time by Simplified Elovich and Zero Order equations. Values of coefficient of determination 'R^{2}' were higher in the treatments receiving integrated sources of P (green manure + DAP, FYM + DAP, poultry manure + DAP and press mud + DAP). This indicates that with the integration of organic and inorganic sources of P the decomposition rate of applied manures was augmented. This might happened due to availability of readily available P of DAP, as a starter dose for microbial activities. In case of integrated use of poultry manure with DAP, the decomposition rate was further increased due to comparatively higher P contents (Table:4.2) of poultry manure. Hence, increased microbial activities caused release of organic ligands from the organic manures which physically blocked the P adsorption sites of the soils used. As a result of these phenomena the P released from the mineralization of OM and DAP was added into the labile pool of soils. Therefore, values of R^{2} remained higher in case of integration of organic amendments with inorganic amendment as compared to solitary use of organic and inorganic amendments.

5.5. Conclusion

- Rate of decomposition regarding native OM, added green manure, FYM and poultry manure, was fairly better in Soil-I. Combinations of DAP with poultry manure and press mud also resulted into comparatively better decomposition rate of OM in Soil-I. Due to lower clay and iron contents release rate of Solution P and Olsen P was also better in Soil-I.

- Comparison of decomposition rate revealed that out of various organic amendments poultry manure performed better. Decomposition rate of poultry manure was maximum ($R^2 = 0.9962$) when amendments were applied separately. Decomposition rate of poultry manure was second to green manure when organic amendments were integrated with DAP, nevertheless, this difference was non significant statistically.

- Highest decomposition rates ($R^2 = 0.9983, 0.9976$) were recorded in S-I and S-III, the sandy loam soils. These soils have lower native contents of OM, clay % extractable Fe, Solution P and Olsen P; however their $CaCO_3$ % was more than S-II.

- Maximum release rate of Solution P ($R^2 = 0.6422$) was recorded by separate application of FYM and separate application of press mud showed maximum release rate ($R^2 = 0.5864$) of Olsen P. Nevertheless, appreciable release rates of both, Olsen P ($R^2 = 0.4001$) and Solution P ($R^2 = 0.4825$) were exhibited by a sole amendment i.e., poultry manure. Combined application of DAP with organic amendments also depicted highest release rates of Olsen P and Solution P by poultry manure only after press mud.

CHAPTER 6   STUDY-3

RESPONSE OF MAIZE TO INTEGRATION OF DIFFERENT ORGANIC AMENDMENTS AND INORGANIC P APPLIED TO CALCAREOUS SOILS

Abstract

Better phosphorus management in soils requires more information regarding distribution of applied P into its various forms. In the present study, effect of (Green manure, Farmyard manure, Poultry manure and Press mud and chemical (Diammonium phosphate) amendments of P on different calcareous soils was evaluated. Different efficiency fractions (Agronomic efficiency, Physiological efficiency and Recovery percentage) of P and soil P forms were also studied. The organic amendments of P were applied (keeping in view their carbon contents) @ 10 g kg^{-1} soil and chemical P @ 35 mg kg^{-1} soil. Treatments were equilibrated in triplicates. The dry matter production (90% over control), P concentration(62% over control) and P uptake(205% over control) were significantly (P<0.05) increased in maize shoot by application of P. Various inorganic fractions of soil P like citrate dithionate bicarbonate P (CDB-P) (110% over control), calcium bound P (HCL-P) (63% over control), non occluded Fe and Al-P (NaOH-P) (91% over control), Olsen-P (107% over control) and water soluble or solution P (166% over control), also followed the same trend. Agronomic efficiency (71.61 g g^{-1}) and apparent P recovery (18.6%) rendered statistically (P<0.05) more pronounced effects of integrating organic and inorganic P amendments. However, physiological efficiency of single amendment of P either organic or inorganic proved more efficient. Results suggested that integration of organic amendments of P with inorganic source was significantly better over their separate use. Nevertheless, poultry manure applied in single or integrated form showed better results over other organic amendments.

6.1 Introduction

Phosphorus, as one of the major plant nutrients, is a worldwide matter of great concern for farming community and researchers. It contributes to plant biomass production as a macronutrient (Goldstein et al., 1988). In the developed countries incessant use of P is causing environmental problem of eutrophication while in tropical

environments, the zone of alkaline calcareous soils, there is a two-pronged problem regarding the supply of plant available P. On one side, there is the problem of scarce supply of chemical P fertilizers (due to price hike and depletion of natural P reserves) and on the other side fixation of P in alkaline calcareous soils. Indeed, P is a major mineral nutrient required by plants, but it is one of the most inaccessible nutrients present in soils (Holford, 1997). Generally, the soluble P reacts with soil components to form relatively insoluble compounds (Sayin et al. 1990). Being the most likely to be fixed mineral nutrient, in many cropping environments, its availability to plants is also very low. Nevertheless, many soils have large reserves of total P, often hundred-time more than the P available to crops (Al-Abbas and Barber, 1964). About 80 to 90% soils from arid and semiarid regions of the world are deficient in available P (Sanders, 1986; Memon et al.1992 and NFDC, 2001). Agricultural intensification requires increased flow of plant nutrients towards roots and their uptake by crops. Depleting nutrient reserves in soils is a major but often hidden form of land degradation. Inadequate use of plant nutrients creates an insidious depletion of the reserves, which is an economic loss (Brinkman, 1998). Attempts to alleviate nutrient deficiency by adding fertilizer is becoming an increasingly uneconomical and ecologically unsound practice, as the efficiency of the added P fertilizer is as low as about 10% (Werft and Dekkers, 1996).

Cropped area in Pakistan is 23.13 million hectare, which has increased by just 2.3% during the last decade (Economic Survey of Pakistan, 2006-7). Its soils are alkaline (pH > 7.0) and mostly calcareous ($CaCO_3$ > 3.0 %) in nature. Calcareous soils fix added P due to reaction of phosphate ions with calcium carbonate.

In this perspective, economically more feasible and environment friendly strategies are suggestible for efficient utilization of the existing least available P in soils. Recently, amounts of traditional organic wastes like crop residues and FYM have increased rapidly after the green revolution. Non-traditional wastes of poultry and other industries (like press mud from sugar industry) are a cause of environmental concern (Economic Survey of Pakistan, 2006-7). It is evident from the perusal of different studies, pertaining to recycling of such wastes, that addition of these wastes to soils may increase the efficiency of applied and native nutrients required by plants. Organic matter is considered as elixir of life for agricultural soils. Initially, organic resources were merely

seen as sources of nutrients, mainly nitrogen (N). More recently, other contributions of organics extending beyond fertilizer substitution have been emphasized in research, such as the provision of macro and micro-nutrients, improvement of soil moisture status, increase in OM and reduction in P sorption capacity and soil borne pest and diseases (Vanlauwe et al., 2002).

In addition, some organic inputs have increased P availability in P fixing soils, thus expanding their potential to increase the availability of soil P beyond the amount contained in their tissues (Hue, 1991). On the addition of organic materials, mineralization of more recalcitrant fraction of P takes place due to increased microbial biomass associated with increased biological activities (Nziguheba et al., 1998). General conclusions about the effects of manure on P availability designate it: as a source of P, interacting with soil components to increase P recovery by crops; and enhancing the effectiveness of inorganic P fertilizer (Whalen & Chang, 2001). Reddy et al. (1996) and Singh et al. (2001a,b) observed that the application of farmyard manure with fertilizer P enriched long-term P fertility of soil through increase in organic P contents and a short-term P supply as recalcitrant P.

Green manure crops may convert relatively unavailable native and residual P to chemical forms, which are more available after decomposition. This process produces CO_2, which forms H_2CO_3 in soil solution, resulting in the dissolution of primary P-containing minerals. Organic acids released during decomposition also help to dissolve soil mineral P. In soils with high P-fixing capacities, organic compounds released during decomposition processes may increase P availability by coating P adsorption sites or via anion exchange. Repeated incorporation of green manures can decrease soil bulk density and increase soil aggregation and moisture retention. All these factors may also help to increase P uptake by increasing root and mycorrhizal growth (Cavigelli and Thien, 2004).

Therefore, judicious and efficient use of the existing land, nutrient fertilizers, financial resources and recycling of organic wastes is inevitable. In such circumstances, this study is designed to obtain knowledge regarding:

i) Increasing the efficiency of applied P fertilizers through integration with organic matter

ii) Evaluating the effects of various organic amendments, on different pools of P, in calcareous soils

iii) Dynamics of different forms of P in three calcareous soils amended with inorganic P and different organic materials and

iv) Mobilizing P reserves of calcareous soils to increase plant available pool of P.

6.3. Results

Texture of the soils I (Table: 4.1) and III (Table: 4.1) was sandy loam while soil II (Table: 4.1) was sandy clay loam. The three soils were alkaline in reaction (pH > 7.0), calcareous (2.12-5.5% $CaCO_3$) and non-saline (ECe < 4.0 dS m^{-1}). Soil I and soil III were deficient in organic matter contents but soil II had 1.31% organic matter. Extractable K ranged from 60 to 130 mg kg^{-1} and Olsen P varied from 5.26 to 16.65 mg kg^{-1} soil.

6.3.1. Shoot growth:

There were significant (P<0.05) main and interactive effects of application of various amendments and soils on shoot dry matter (SDM) production (Table 6.1 and 6.1.1). All the amendments produced significantly more SDM than control.

Application of DAP produced significantly (P<0.05) higher SDM. On an average, it increased the SDM by about 40 % as compared to control. Among organic amendments, poultry manure proved to be the best. The relative increase in SDM by the application of poultry manure was 36 % as compared to control.

Combined application of DAP with various organic amendments produced significantly (P<0.05) more SDM. Maximum SDM (26.44 g pot^{-1}) was obtained by the combined application of DAP and poultry manure. This was 90 % more than control, 36 % more than DAP and 39 % more than separate use of poultry manure.

The tested soils also differed significantly (P<0.05) with respect to SDM production. Soil-II produced maximum (21.98 g pot^{-1}) SDM followed by Soil-I (20.31 g pot^{-1}) and Soil-III (15.84g pot^{-1}) in descending order.

Interactive effect of various amendments and soils also increased SDM production with integrated use of organic and inorganic amendments. Maximum (111 %) increase in SDM over control was observed in Soil-III when poultry manure and DAP were applied in integrated form.

Table 6.1 **Effect of different organic P sources and diammonium phosphate (DAP) application on shoot dry matter of maize (g pot^{-1})**

(Figures are the means of three replications)

Treatments	Soil I	Soil II	Soil II	Mean
Control	14.38	16.44	11.03	13.95
GM*	17.38	18.63	13.22	16.41
FYM$^{□}$	17.64	18.86	13.67	16.72
Pol M$^{•}$	20.50	21.52	14.93	18.98
P Mud^{Ǿ}	18.08	18.72	13.01	16.60
DAP$^{☼}$	20.83	21.89	15.73	19.48
GM + DAP	23.13	24.69	17.49	21.77
FYM + DAP	23.68	24.91	18.16	22.25
Pol M + DAP	26.16	29.79	23.36	26.44
P Mud + DAP	21.37	24.49	18.13	21.33
Mean	20.31	21.99	15.87	

	Soil	Treatment	Soil x treatment
L S D (0.05)	0.3090	0.5642	0.9773

*Green manure (Sesbania) was used @ 10 g kg^{-1} soil. $^{□}$Farmyard manure, $^{•}$poultry manure and ^{Ǿ}press mud were used @ carbon contents of green manure. $^{☼}$Diammonium phosphate was applied to supply 35 mg P kg^{-1} soil.

Table 6.1.1
Analysis of variance for shoot dry matter

Source	DF	SS	MS	F	P
Repeat	2	1.87	0.935		
Soil	2	600.30	300.148	839.51	0.0000
Treatment	9	1087.38	120.820	337.93	0.0000
Soil*Treatment	18	22.78	1.266	3.54	0.0001
Error	58	20.74	0.358		
Total	89	1733.07			

6.3.2. Phosphorus concentration

There were significant (P<0.05) main and interactive effects of various soils and organic amendments on P concentration of maize plants (Table 6.2 and 6.2.1). Application of all amendments significantly increased the P concentration when compared to control.

Application of DAP alone, significantly (P<0.05) increased P concentration in maize shoot. This increase was about 40 % over control. However, poultry manure performed better than other organic amendments. The relative increase in P concentration by the application of poultry manure was 36 % as compared to control.

Integration of organic amendments with DAP resulted into significantly (P<0.05) more P concentration in maize shoot. Maximum (26.44 g pot^{-1}) P concentration was recorded with the integrated application of DAP and poultry manure. This was 90 % more than control, 36 % more than DAP and 39 % more than separate application of poultry manure.

Significant (P<0.05) difference with respect to P contents of various soils was recorded. Soil II yielded maximum (21.98 g pot^{-1}) P concentration followed by Soil-I (20.31g pot^{-1}) and Soil-III (15.84g pot^{-1}) in descending order.

Interactive effects of soils and amendments resulted in increased P concentration with integrated use of organic and inorganic amendments. Maximum (111 %) increase in P concentration over control was observed in Soil-III when poultry manure and DAP were applied together.

Table 6.2

Effect of different organic P sources and diammonium phosphate (DAP) application on P concentration (mg g^{-1}) of maize shoot

(Figures are the means of three replications)

Treatments	Soil-I	Soil-II	Soil-III	Mean
Control	1.13	1.25	0.95	1.11
GM*	1.21	1.29	1.11	1.20
FYM$^{\square}$	1.27	1.36	1.25	1.29
Pol M$^{\bullet}$	1.28	1.40	1.27	1.32
P Mud$^{\emptyset}$	1.24	1.31	1.24	1.26
DAP*	1.36	1.45	1.35	1.38
GM + DAP	1.40	1.53	1.38	1.44
FYM + DAP	1.45	1.66	1.50	1.53
Pol M + DAP	1.75	2.05	1.61	1.80
P Mud + DAP 1.55	1.67	1.40	1.54	
Mean	1.36	1.50	1.30	

	Soil	Treatment	Soil x Treatment
L S D (0.05)	0.0183	0.0334	0.0579

*Green manure (Sesbania) was used @ 10 g kg^{-1} soil. $^{\square}$Farmyard manure, $^{\bullet}$poultry manure and $^{\emptyset}$press mud were used @ carbon contents of green manure. *Diammonium phosphate was applied to supply 35 mg P kg^{-1} soil.

Table 6.2.1

Analysis of variance for P concentration

Source	DF	SS	MS	F	P
Repeat	2	0.01291	0.00645		
Soil	2	0.58587	0.29293	233.73	0.0000
Treatment	9	3.23307	0.35923	286.63	0.0000
Soil*Treatment	18	0.20964	0.01165	9.29	0.0000
Error	58	0.07269	0.00125		
Total	89	4.11418			

6.3.3. Phosphorus uptake:

There was significant main and interactive effect of various amendments and soils on P uptake by maize (Table 6.3 and 6.3.1). Application of all the organic amendments significantly ($P<0.05$) increased the P uptake by maize as compared to control.

Combined application of all the organic amendments with DAP produced significantly ($P<0.05$) more P uptake. Maximum P uptake (48.19 mg g^{-1}) was obtained by the combined application of DAP and poultry manure. This was 206 % more than control, 78 % more than DAP and 109 % more than separate use of poultry manure.

Application of DAP alone resulted in significantly ($P<0.05$) higher P uptake by maize shoot. On an average, it enhanced 72 % more P uptake as compared to control. Among organic amendments, poultry manure proved best. The relative increase in P uptake by the application of poultry manure was about 60 % as compared to control.

Interactive effect of various amendments and soils also resulted in increased P uptake with integrated use of organic and inorganic amendments. Maximum (260 %) increase in P uptake over control was observed in Soil-III when poultry manure and DAP were applied together.

The tested soils also differed significantly ($P<0.05$) with respect to P uptake by maize shoot. Soil-II produced maximum (33.84 g pot^{-1}) uptake followed by Soil-I (28.30 g pot^{-1}) and Soil-III (21.32 g pot^{-1}) in descending order.

Table 6.3
Effects of different organic sources of P and diammonium phosphate (DAP) on P uptake (mg g^{-1}) by maize shoot
(Figures are the means of three replications)

Treatments	Soil I	Soil II	Soil III	Mean
Control	16.25	20.66	10.48	15.79
GM*	21.15	24.04	14.73	1997
FYM□	22.46	25.77	17.09	21.77
Pol M•	26.31	30.13	19.07	25.17
P MudØ	22.54	24.64	16.13	21.10
DAP☆	28.32	31.89	21.23	27.14
GM + DAP	32.51	37.86	24.13	31.50
FYM + DAP	34.46	41.43	27.27	34.39
Pol M + DAP	45.80	61.09	37.69	48.19
P Mud + DAP	33.17	40.95	25.44	33.19
Mean	28.30	33.84	21.32	

	Soil	Treatment	Soil x Treatment
L S D (0.05)	0.6140	1.1209	1.9415

*Green manure (Sesbania) was used @ 10 g kg^{-1} soil. □Farmyard manure, •poultry manure and Øpress mud were used @ carbon contents of green manure. ☆Diammonium phosphate was applied to supply 35 mg P kg^{-1} soil.

Table 6.3.1
Analysis of variance for P uptake

Source	DF	SS	MS	F	P
Repeat	2	10.87	5.44		
Soil	2	2361.00	1180.50	836.57	0.0000
Treatment	9	7161.95	795.77	563.93	0.0000
Soil*Treatment	18	326.53	18.14	12.86	0.0000
Error	58	81.84	1.41		
Total	89	9942.19			

6.3.4. Agronomic efficiency (AE) of P:

Significant (P<0.05) main and interactive effects of various soils and treatments on agronomic efficiency of applied P were recorded (Table 6.4 and 6.4.1). Application of all the organic and inorganic amendments significantly (P<0.05) increased the agronomic efficiency of P applied to the soils.

Application of DAP alone significantly (P<0.05) depicted higher (31.72 g g^{-1}) AE. Among organic amendments, poultry manure proved best with higher (28.87 g g^{-1}) AE of applied P.

Integration of organic amendments and DAP showed significantly (P<0.05) more AE of applied P. Maximum AE (71.61 g g^{-1}) was obtained by the combined application of DAP and poultry manure. This was 92 % more than DAP and 113 % more than separate use of poultry manure.

Interactive effect of various amendments and soils also resulted to increased P uptake by maize. Maximum (76.54 g g^{-1}) AE of applied P was observed in Soil-II when poultry manure and DAP were applied in integrated form.

The three soils also differed significantly (P<0.05) with respect to AE of applied P in maize. Soil-I depicted maximum (34.03 g g^{-1}) AE followed by Soil-II (31.86 g g^{-1}) and Soil-III (27.78 g g^{-1}) in descending order.

Table 6.4
Effect of different organic P sources and diammonium phosphate (DAP) application on agronomic efficiency of maize (g g^{-1})
(Figures are the means of three replications)

Treatments	Soil I	Soil II	Soil III	Mean
Control	0.000	0.000	0.000	0.000
GM*	17.22	12.59	12.57	14.13
FYM$^{\square}$	18.69	13.87	15.13	15.90
Pol M$^{\bullet}$	35.09	29.14	22.38	28.87
P Mud$^{\emptyset}$	21.20	13.11	11.37	15.22
DAP*	36.96	31.25	26.96	31.72
GM + DAP	50.15	47.34	37.04	44.84
FYM + DAP	53.34	48.58	40.88	47.60
Pol M + DAP	67.56	76.54	70.73	71.61
P Mud + DAP	40.10	46.15	40.73	42.33
Mean	34.03	31.86	27.78	

	Soil	Treatment	Soil x Treatment
L S D (0.05)	1.8748	3.4229	5.9287

*Green manure (Sesbania) was used @ 10 g kg^{-1} soil. $^{\square}$Farmyard manure, $^{\bullet}$poultry manure and $^{\emptyset}$press mud were used @ carbon contents of green manure. *Diammonium phosphate was applied to supply 35 mg P kg^{-1} soil.

Table 6.4.1
Analysis of variance for agronomic efficiency of maize

Source	DF	SS	MS	F	P
Repeat	2	3.8	1.89		
Soil	2	604.1	302.07	22.96	0.0000
Treatment	9	35750.0	3972.22	301.88	0.0000
Soil*Treatment	18	749.2	41.62	3.16	0.0005
Error	58	763.2	13.16		
Total	89	37870.3			

6.3.5. Physiological efficiency of P (PPE):

Significant (P<0.05) main and interactive effects of various soils and amendments were recorded (Table 6.5 and 6.5.1) regarding physiological efficiency of maize to the applied P on calcareous soils.

Separate application of organic amendments depicted statistically (P<0.05) pronounced increase in PPE when compared to DAP. Maximum PPE (0.591 g mg^{-1}) was computed for the separate application of green manure. This was 22 % more than DAP.

The tested soils also differed significantly (P<0.05) with respect to PPE of applied P to maize. Soil-I depicted maximum (0.471 g mg^{-1}) PPE followed by Soil-II (0.435 g mg^{-1}) and Soil-III (0.399 g mg^{-1}).

Interactive effects of organic amendments and soils also resulted in significant differences with respect to PPE of applied P. Separate application of green manure significantly increased PPE over DAP and integrated use of DAP with green manure. Maximum (0.648 g mg^{-1}) PPE of applied P was observed in Soil-II when green manure was applied separately. This was 34 % more than DAP and 35 % more than integrated application of DAP + green manure.

Nevertheless, integration of organic amendments and DAP showed poor PPE as compared with the PPE obtained by their separate use. On an average maximum (0.648 g mg^{-1}) PPE was achieved by separate application of green manure. This was 34% more than that of DAP and 30% more than integrated application of green manure + DAP.

Table 6.5

Effect of different organic P sources and diammonium phosphate (DAP) application on physiological efficiency of applied P for maize (g mg^{-1})

(Figures are the means of three replications)

Treatments	Soil I	Soil II	Soil III	Mean
Control	0.00	0.000	0.000	0.000
GM*	0.607	0.648	0.520	0.591
FYM$^{\square}$	0.522	0.475	0.400	0.466
Pol M$^{\bullet}$	0.608	0.537	0.455	0.533
P Mud$^{\emptyset}$	0.587	0.590	0.351	0.509
DAP*	0.533	0.484	0.436	0.484
GM + DAP	0.536	0.481	0.473	0.497
FYM + DAP	0.512	0.408	0.425	0.448
Pol M + DAP	0.399	0.331	0.453	0.394
P Mud + DAP	0.412	0.395	0.475	0.427
Mean	0.471	0.435	0.399	

	Soil	Treatment	Soil x Treatment
L S D (0.05)	0.0256	0.0468	0.0810

**Green manure (Sesbania) was used @ 10 g kg^{-1} soil. $^{\square}$Farmyard manure, $^{\bullet}$poultry manure and $^{\emptyset}$press mud were used @ carbon contents of green manure. *Diammonium phosphate was applied to supply 35 mg P kg^{-1} soil.

Table 6.5.1

Analysis of variance for physiological efficiency of applied P

Source	DF	SS	MS	F	P
Repeat	2	0.00874	0.00437		
Soil	2	0.07972	0.03986	16.21	0.0000
Treatment	9	2.14421	0.23825	96.89	0.0000
Soil*Treatment	18	0.18965	0.01054	4.28	0.0000
Error	58	0.14262	0.00246		
Total	89	2.56493			

6.3.6 Phosphorus recovery percentage:

Main and interactive effects of various soils and amendments on P recovery percentage of maize plants (Table 6.6 and 6.6.1) were significant (P<0.05). Application of organic amendments with or without DAP, increased the recovery percentage of applied P.

Combined application of all the organic amendments with DAP showed significantly (P<0.05) more P recovery percentage of applied P in the soils. On an average maximum (18.57 %) P recovery of applied P was obtained with the combined application of DAP and poultry manure. This was 186 % more than DAP and 246 % more than separate use of poultry manure

Results revealed that DAP application resulted in significantly higher (6.51%) recovery of applied P as compared to separate application of organic amendments. However, among organic amendments, poultry manure proved better with 5.37% recovery of P.

The three soils also differed significantly (P<0.05) with respect to P recovery % of applied P by maize. Soil-II depicted maximum (7.56%) recovery of applied P, followed by Soil-I (6.90 %) and Soil-III (6.21%) in descending order.

Interactive effect of amendments and soils also resulted in increased P recovery % of applied P with integrated use of organic amendments and inorganic source of P. Maximum (23.2 %) P recovery of applied P was observed in Soil-II when poultry manure and DAP were applied in integrated form.

Table 6.6
Effect of different organic P sources and diammonium phosphate (DAP) application on apparent P recovery percent by maize (%)
(Figures are the means of three replications)

Treatments	Soil I	Soil II	Soil III	Mean
Control	0.00	0.00	0.00	0.00
GM*	2.81	1.94	2.43	2.39
FYM□	3.56	2.93	3.79	3.42
Pol M•	5.77	5.43	4.92	5.37
P Mud^{Ø}	3.61	2.28	3.24	3.04
DAP☆	6.92	6.44	6.16	6.51
GM + DAP	9.32	9.86	7.82	9.00
FYM + DAP	10.4	11.9	9.63	10.6
Pol M + DAP	16.9	23.2	15.6	18.6
P Mud + DAP	9.70	11.6	8.57	9.97
Mean	6.90	7.56	6.21	

	Soil	Treatment	Soil x Treatment
L S D (0.05)	0.3489	0.6369	1.1032

*Green manure (Sesbania) was used @ 10 g kg^{-1} soil. □Farmyard manure, •poultry manure and ^{Ø}press mud were used @ carbon contents of green manure. ☆Diammonium phosphate was applied to supply 35 mg P kg^{-1} soil.

Table 6.6.1
Analysis of Variance for apparent P recovery percent by maize

Source	DF	SS	MS	F	P
Repeat	2	1.07	0.537		
Soil	2	27.09	13.544	29.73	0.0000
Treatment	9	2354.68	261.631	574.28	0.0000
Soil*Treatment	18	107.37	5.965	13.09	0.0000
Error	58	26.42	0.456		
Total	89	2516.63			

6.3.7. Citrate Dithionate Bicarbonate-P (CDB-P):

Effects of various organic amendments and DAP were inorganic sources of P were studied on citrate dithionate bicarbonate P fraction in three calcareous soils (Table 6.7 and 6.7.1). Application of various amendments significantly (P<0.05) increased the CDB-P fraction of soils. Main and interactive effects of various soils and treatments on CDB-P fraction of soils were also found significant (P<0.05).

Comparison of various amendments revealed that DAP produced significantly (P<0.05) higher CDB-P. On an average, it increased the CDB-P about 65 % as compared with control. Among organic amendments, poultry manure proved the best. The relative increase in CDB-P with the application of poultry manure was 57 % as compared to control.

Combined application of organic amendments with DAP produced significantly (P<0.05) more CDB-P. Maximum CDB-P (30.49 mg kg^{-1}) was obtained by the combined application of DAP and poultry manure. This was 110 % more than control, 27 % more than DAP and 34 % more than separate use of poultry manure.

The tested soils also differed significantly (P<0.05) with respect to CDB-P. Soil-III produced maximum (26.38 mg kg^{-1}) CDB-P followed by Soil-I (23.06 mg kg^{-1}) and Soil-II (20.47 mg kg^{-1}).

Interactive effect of different treatments and soils also resulted into increased CDB-P with integrated use of organic amendments and DAP. Maximum (162 %) increase in CDB-P over control was observed in Soil-III when poultry manure and DAP were applied in integrated form.

Table 6.7 **Effect of different organic P sources and diammonium phosphate (DAP) application on CDB-P fraction of soil (mg kg^{-1})**
(Figures are the means of three replications)

Treatments	Soil I	Soil II	Soil III	Mean
Control	15.51	12.84	15.30	14.55
GM*	21.33	16.88	19.11	19.11
FYM$^\square$	19.94	20.88	20.99	20.31
Pol M$^\bullet$	22.47	20.61	25.31	22.80
P Mud$^\varnothing$	21.39	17.99	23.43	20.93
DAP*	25.17	21.14	25.71	24.01
GM + DAP	26.14	24.16	27.75	26.02
FYM + DAP	27.06	24.22	33.62	28.30
Pol M + DAP	26.16	25.17	40.13	30.49
P Mud + DAP	25.48	21.65	32.41	26.51
Mean	23.06	20.47	26.38	

	Soil	Treatment	Soil x treatment
L S D (0.05)	0.5556	1.0162	1.7601

*Green manure (Sesbania) was used @ 10 g kg^{-1} soil. $^\square$Farmyard manure, $^\bullet$poultry manure and $^\varnothing$press mud were used @ carbon contents of green manure. *Diammonium phosphate was applied to supply 35 mg P kg^{-1} soil

.
Table 6.7.1
Analysis of Variance for CDB-P fraction of soil

Source	DF	SS	MS	F	P
Repeat	2	14.34	7.172		
Soil	2	526.24	263.122	226.89	0.0000
Treatment	9	1834.30	203.811	175.75	0.0000
Soil*Treatment	18	392.17	21.787	18.79	0.0000
Error	58	67.26	1.160		
Total	89	2834.32			

6.3.8. Calcium bound P (HCl-P):

There was a significant (P<0.05) main and interactive effect of various soils and treatments on calcium bound P (HCl-P) of soils (Table 6.8 and 6.8.1). Application of all the organic amendments and DAP significantly (P<0.05) increased the HCl-P of all the three soils.

Separate application of DAP and various organic amendments, resulted into significantly (P<0.05) higher HCl-P content of the soils. Nevertheless, quantity of HCl-P recorded under DAP application surpassed the gains of all separate organic amendments. On an average, it increased the HCl-P by about 29 % as compared to control. Among organic amendments, poultry manure proved the best. The relative increase in HCl-P by the application of poultry manure was 28 % as compared to control.

Integration of organic amendments and DAP produced significantly (P<0.05) more HCl-P. Maximum HCl-P (54.24 mg kg^{-1}) was obtained with DAP + poultry manure. This was 63 % more than control, 26 % more than DAP and 27 % more than separate use of poultry manure.

Interactive effect of various treatments sources and soils also resulted in increased HCl-P by integrated use of organic amendments and DAP. Maximum (49 %) increase in HCl-P over control was observed in Soil-II when poultry manure and DAP were applied together.

The tested soils also differed significantly (P<0.05) with respect to HCl-P. Soil-II produced maximum (56.25 mg kg$^{-1)}$ HCl-P followed by Soil-I (40.57 mg kg^{-1}) and Soil-III (34.24 mg kg^{-1}).

Table 6.8

Effect of different organic P sources and diammonium phosphate (DAP) application on HCl-P fraction of soil (mg kg^{-1})
(Figures are the means of three replications)

Treatments	Soil I	Soil II	Soil III	Mean
Control	32.02	45.26	22.51	33.26
GM*	36.62	48.86	27.01	37.50
FYM□	39.41	54.42	29.39	41.07
Pol M•	40.29	57.34	30.18	42.60
P Mud^{Ø}	29.45	49.34	25.46	37.75
DAP☆	38.37	56.10	34.58	43.02
GM + DAP	42.66	59.71	37.52	46.63
FYM + DAP	46.68	65.35	46.54	52.86
Pol M + DAP	49.73	67.59	45.40	54.24
P Mud + DAP	41.44	58.50	43.81	47.92
Mean	40.57	56.25	34.24	

	Soil	Treatment	Soil x Treatment
L S D (0.05)	1.3253	2.4197	4.19

*Green manure (Sesbania) was used @ 10 g kg^{-1} soil. □Farmyard manure, •poultry manure and ^{Ø}press mud were used @ carbon contents of green manure. ☆Diammonium phosphate was applied to supply 35 mg P kg^{-1} soil.

Table 6.8.1
Analysis of variance for HCL-P fraction of soil

Source	DF	SS	MS	F	P
Repeat	2	11.8	5.88		
Soil	2	7701.9	3850.94	585.65	0.0000
Treatment	9	3714.3	412.70	62.76	0.0000
Soil*Treatment	18	387.6	21.53	3.27	0.0003
Error	58	381.4	6.58		
Total	89	12196.9			

6.3.9. Non-occluded Fe and Al phosphorus:

Significant main and interactive effects of different soils and various amendments were observed on non-occluded Fe and Al-P fraction (NaOH-P) of three calcareous soils (Table 6.9 and 6.9.1). Application of organic amendments and DAP in either form (integrated or separate) significantly (P≤0.05) increased the NaOH-P fraction soil P.

Integration of organic amendments and DAP resulted in significantly (P<0.05) more NaOH-P. Maximum NaOH-P (54.24 mg kg^{-1}) was recorded with the combined application of DAP and poultry manure. This was 104 % more than control, 30 % more than DAP and 45 % more than separate use of poultry manure.

Application of DAP alone produced significantly (P<0.05) higher NaOH-P. Average increase by DAP in NaOH-P was about 57 % as compared to control. Among organic amendments, poultry manure remained dominant. The relative increase in NaOH-P with the application of poultry manure was 41 % as compared to control.

Interactive effect of various treatments and soils also augmented NaOH-P production with integrated use of organic amendments and DAP. Maximum (73 %) addition in NaOH-P over control was observed in Soil-II when poultry manure and DAP were applied in integrated form.

The three soils also differed appreciably (P<0.05) with respect to NaOH-P production. Soil-II produced maximum (20.26 mg kg^{-1}) NaOH-P followed by Soil-I (12.25 mg kg^{-1}) and Soil-III (11.36 mg kg^{-1}).

Table 6.9
Effect of different organic P sources and diammonium phosphate (DAP) application on NaOH-P fraction of soil (mg kg^{-1})
(Figures are the means of three replications)

Treatments	Soil I	Soil II	Soil III	Mean
Control	8.45	14.26	6.12	9.61
GM*	9.03	17.56	6.30	10.97
FYM□	10.63	19.51	8.27	12.81
Pol M•	11.01	19.75	10.02	13.59
P Mud^{Ø}	9.61	18.53	8.06	12.07
DAP$^{☆}$	12.38	21.10	11.80	15.09
GM + DAP	14.05	22.48	13.56	16.70
FYM + DAP	14.95	21.25	17.24	17.82
Pol M + DAP	17.11	24.61	17.24	16.65
P Mud + DAP	15.27	23.51	15.02	17.93
Mean	12.25	20.26	11.36	

	Soil	Treatment	Soil x Treatment
L S D (0.05)	0.5274	0.9629	1.6678

*Green manure (Sesbania) was used @ 10 g kg^{-1} soil. □Farmyard manure, •poultry manure and ^{Ø}press mud were used @ carbon contents of green manure. $^{☆}$Diammonium phosphate was applied to supply 35 mg P kg^{-1} soil.

Table 6.9.1
Analysis of variance for NaOH-P fraction of soil

Source	DF	SS	MS	F	P
Repeat	2	0.40	0.199		
Soil	2	1439.43	719.714	691.18	0.0000
Treatment	9	903.51	100.390	96.41	0.0000
Soil*Treatment	18	72.28	4.016	3.86	0.0000
Error	58	60.39	1.041		
Total	89	2476.01			

6.3.10. Olsen-P:

Application of all the organic amendments and DAP significantly (P<0.05) improved the Olsen-P in the soils (Table 6.10 and 6.10.1). Main and interactive effects of different soils and treatments on Olsen-P content of the soils were also significant.

It was noticed that DAP produced significantly (P<0.05) increased content of Olsen-P. This increase in Olsen-P resulted about 42 % more as compared to control. Among organic amendments, paramount performance was shown by poultry manure. The relative increase in Olsen-P with the application of poultry manure was 41 % as compared to control.

All the treatments produced significantly (P<0.05) more Olsen-P. Highest amount of Olsen-P (54.24 mg kg^{-1}) was obtained by the combination of DAP with poultry manure. This was 107 % more than control, 46 % more than DAP and 47 % more than separate use of poultry manure.

Performance of tested soils also differed significantly (P<0.05) with reference to Olsen-P content. Soil-II produced maximum (21.53 mg kg^{-1}) Olsen-P followed by Soil-III (14.19 mg kg^{-1}) and Soil-I (12.42 mg kg^{-1}).

Interactive effects of treatments and soils also increased Olsen-P content due to integrated use of organic amendments and DAP. Maximum (81%) increase in Olsen-P over control was observed in Soil-II when poultry manure and DAP were applied together.

Table 6.10

Effect of different organic P sources and diammonium phosphate (DAP) application on the Olsen-P contents of soil (mg kg $^{-1}$)

(Figures are the means of three replications)

Treatments	Soil I	Soil II	Soil III	Mean
Control	7.59	15.56	9.53	10.89
GM*	9.51	17.43	11.47	12.80
FYM□	10.16	18.47	12.99	13.87
Pol M•	11.25	21.16	13.60	15.33
P Mud^{Ø}	9.92	19.29	12.18	13.80
DAP☆	11.29	21.16	13.76	15.40
GM + DAP	13.11	24.30	15.03	17.48
FYM + DAP	17.06	26.67	16.77	20.16
Pol M + DAP	19.96	28.20	19.29	22.49
P Mud + DAP	14.38	23.03	17.22	18.21
Mean	12.42	21.53	14.19	

	Soil	Treatment	Soil x Treatment
L S D (0.05)	0.5358	0.9782	1.6943

*Green manure (Sesbania) was used @ 10 g kg $^{-1}$ soil. □Farmyard manure, •poultry manure and ^{Ø}press mud were used @ carbon contents of green manure. ☆Diammonium phosphate was applied to supply 35 mg P kg $^{-1}$soil.

Table 6.10.1

Analysis of variance for Olsen-P contents

Source	DF	SS	MS	F	P
Repeat	2	0.21	0.104		
Soil	2	1399.46	699.729	651.10	0.0000
Treatment	9	1016.18	112.908	105.06	0.0000
Soil*Treatment	18	46.05	2.558	2.38	0.0067
Error	58	62.33	1.075		
Total	89	2524.23			

6.3.11. Solution-P:

There were significant (P<0.05) main and interactive effects of various treatments and soils on solution P content of the soils (Table 6.11 and 6.11.1). All the amendments produced significantly more solution P content as compared to control.

Application of DAP produced significantly (P<0.05) higher solution P contents. On an average it increased the solution P by 80 % as compared to control. Among organic amendments, poultry manure proved the best. The relative increase in solution P by the application of poultry manure was 70 % as compared to control.

Combined application of various organic amendments and DAP produced significantly (P<0.05) more solution P. Maximum solution P (mg L^{-1}) was obtained with the combined application of DAP and poultry manure. This was 166 % more than control, 48 % more than DAP and 56 % more than separate use of poultry manure.

The tested soils also differed significantly (P<0.05) with respect to solution P. Soil-II had maximum (3.41 mg L^{-1}) Solution-P followed by Soil-III (0.085 mg L^{-1}) and Soil-I (0.077 mg L^{-1}).

Interactive effect of treatments and soils also resulted in increased solution P by integrated use of organic amendments and DAP. Maximum (166 %) increase in solution P over control was observed in Soil-II when poultry manure and DAP was applied together.

Table 6.11

Effect of different organic P sources and diammonium phosphate (DAP) application on solution P contents of soil (mg L^{-1})

(Figures are the means of three replications)

Treatments	Soil I	Soil II	Soil III	Mean
Control	0.043	1.905	0.047	0.665
GM*	0.056	2.477	0.062	0.865
FYM□	0.065	2.858	0.071	0.998
Pol M•	0.073	3.239	0.081	1.131
P Mud^{Ø}	0.061	2.667	0.066	0.931
DAP☆	0078	3.429	0.085	1.187
GM + DAP	0.086	3.791	0.095	1.324
FYM + DAP	0.096	4.229	0.106	1.477
Pol M + DAP	0.115	5.067	0.126	1.769
P Mud + DAP	0.101	4.438	0.111	1.550
Mean	0.077	3.410	0.085	

	Soil	Treatment	Soil x Treatment
L S D (0.05)	0.917	0.5325	0.9224

*Green manure (Sesbania) was used @ 10 g kg^{-1} soil. □Farmyard manure, •poultry manure and ^{Ø}press mud were used @ carbon contents of green manure. ☆Diammonium phosphate was applied to supply 35 mg P kg^{-1} soil.

Table 6.11.1

Analysis of variance for solution P contents of soil

Source	DF	SS	MS	F	P
Repeat	2	8.471	4.236		
Soil	2	221.586	110.793	347.87	0.0000
Treatment	9	9.489	1.054	3.31	0.0025
Soil*Treatment	18	16.469	0.915	2.87	0.0012
Error	58	18.473	0.318		
Total	89	274.487			

6.4. Discussion

Soil organic matter is very important for improving productivity of agricultural soils. It is a good indicator of soil quality, because it mediates many of the chemical, physical and biological processes required for a good soil. Addition of OM brings changes in chemical properties of soil and causes reduction in soil P sorption capacity. Physically, it improves structure and water holding capacity of soils. Chemically, it reduces P fixation, increases cation exchange capacity (CEC) and buffer capacity of soils to resist pH change. It serves as a reservoir of mineral nutrients. Biologically, the OM is the energy source for soil fauna and microorganisms (Iyamuremye et al. 1996 a, b; Van Faassen and Smilde, 1985). Results of the present study revealed that addition of organic amendments and inorganic P alone or in combination significantly increased the yield parameters of maize. Dry matter, shoot P concentration and P uptake were significantly increased with application of P. It may be attributed to the beneficial effects of OM and synergistic effects of organic and inorganic P applied to crop. Several researchers have also reported similar benefits of organic manures. Fernandez and Sanchez (1990), Stevenson (1982) and Dusberg et al. (1989) reported that OM was the main source of several mineral nutrients and increased P availability with the addition of OM. They concluded that up to 75% of the P in surface soils was in organic forms and 20-75% of total soil P was of organic origin. Dorado et al. (2003) found that soil organic matter affected the physical soil parameters relevant to P availability like water retention, bulk density and aggregate stability.

Phosphorus fixation is a serious problem in alkaline and calcareous soils (Sharif et al., 2000). Therefore, response of calcareous soils to P application from either source was inevitable. Tandon (1987) also found that despite increased total P contents of fertilized soils, two- third of world soils give a universal response to P application. Phosphorus reserves abound in soil but the problem is its presence in forms unavailable to plants. Khanna et al. (1984) incubated P fertilizers with organic matter before applying to soil and studied the efficiency of the water insoluble phosphates. They found that P uptake by wheat was increased manifold by this treatment over control. They reported that it was due to the improved efficiency of the P fertilizers. The increase in P use efficiency by pre-incubation with cattle dung was owing to the solublization of insoluble P fraction

during the humification. Phosphorus fixation in soil was also decreased due to the protective action of manures. Concentration of solution P in soil increased with increase in organic matter and lime. Several mechanisms have been proposed to explain decrease in P adsorption capacity (Iyamuremye and Dick, 1996) including (i) competition with the phosphate anions for adsorption sites by organic anions produced from the decomposition of plant materials and (ii) saturation of the adsorption sites by P added to the soil.

Quantity of inorganic P (Pi), present in the soils dominates the P pool of soils. In calcareous soils, it may account for 75-85% of total soil P (Liu, 1999). Fractionation of Pi enabled researchers for effective investigation of availability of soil Pi and its inter-conversion to different P fractions (Chang and Jackson, 1957; Hedley et al., 1982 a, b; Gu and Qin, 1997). Hence inorganic soil P was divided into various fractions like Ca-P (HCl extractable P), Fe and Al-P (non-occluded Fe- and Al-bound P) and O-P (the P occluded with Fe oxides) (Chang and Jackson, 1957; Solis and Torrent, 1989).

Sequential fractionation of Pi was meant to differentiate labile (resin- extractable P and NaHCO$_3$-extractable P) and more stable forms (Ca-P, Al-P, Fe-P and O-P) of Pi. Fractionation of soil P revealed significant differences in the distribution of organic and inorganic P forms. Amount of P in inorganic fractions was significantly greater in soils receiving manures compared with untreated soils. Organic and residual P fractions (i.e., occluded inorganic P and stable organic P) were also significantly greater in manured soils. Similarly, Gale et al. (2000), Motavalli and Miles (2002) and Sharpley et al. (1998) also showed more Pi in soils receiving different types of manures.

Results revealed that application of organic manures including green manure (Sesbania aculeata), farmyard manure, press mud and poultry manure markedly increased soil Pi fractions. Integration of organic sources with chemical source of P further enhanced the efficiency of organic and inorganic sources resulting in increased quantities of soil Pi fractions. Singh et al. (2006) reported that incorporation of organic manures not only decreased the adsorption of applied P but also in turn increased labile soil P in the soil. Their results revealed that green manure and FYM incorporation lowered the values of both adsorption maxima and bonding energy depicting a favorable effect on P availability of soil. Hundal et al. (1988) also reported the decreased adsorption maxima and bonding energy constant with the incorporation of organic manures. Zhang and

MacKenzie (1997) applied organic and inorganic P fertilizers on a sandy clay loam to study the changes in soil P fractions. They observed that P application of 60 kg ha^{-1} from manure and 44 kg ha^{-1} from inorganic source increased labile inorganic P. El-Dewiny et al. (2006) categorized four fractions of P in soil: Water soluble and exchangeable fraction; NaHCO$_3$; NaOH extracted and HCl-P fraction.

Ryan (2002) opined that P was one of the most important plant nutrients for crop production and emphasized on its efficient use for sustainable crop production. Rapid P uptake was occurred when after 3-4 weeks irrigation was applied (Ali et al., 1988, Alam et al., 1999). At this growth stage demand of P was on peak (Romer and Schilling, 1986). Under our in vogue cropping systems, cost of inputs including fertilizers is high compared to the income received; therefore, there is vivid trend of fertilizer application below recommended levels. In this perspective, the present study also assessed the various efficiency fractions affected by diversified sources of P applied in combinations or as a single source of P. Different indicators of applied P efficiency, including agronomic efficiency, nutrient recovery and physiological efficiency were used.

In the present study, agronomic efficiency and P recovery were increased with the increased rate of P as integration of P sources. Witt (2003) reported low P recovery of 0-40% in cereal crop depending on rate of application. Nevertheless, this was not a marked increase either due to presence of CaCO$_3$ in the soils or due to short duration (45 days) of growth period. Papadopoulos (1994) observed that application of fertilizer P in calcareous soil increased P use efficiency. Effectiveness of inorganic P fertilizers was increased and P recovery was improved with the addition of organic manure (Whalen and Chang, 2001). It was also inferred that lower rates of fertilizers resulted in increased efficiency than the higher rates of fertilizers. Results of the present study regarding increased physiological efficiency due to low P availability from organic sources of P are in accordance with the previous experiences. It was reported that application of P fertilizer @ 22 kg P ha^{-1} led 50% more agronomic efficiency (AE) as compared to full dose of P (Iqbal et al., 2003). Cassman et al. (2002) concluded that nutrient efficiency was greatly affected by the amount of nutrient used and by the synchrony between demand and supply of the nutrients. They observed that nutrient efficiency was generally increased if the fertilizer use was relatively low and crop demand was high.

6.5. Conclusion

- Phosphorus application in calcareous soils, improved agronomic parameters of maize and P uptake by maize. Shoot dry matter, P concentration and P uptake were increased up to 90%, 62% and 205% respectively, over control.

- Integration of organic and inorganic amendments significantly increased different fractions of soil P. Solution-P, Olsen-P, CDB-P, HCl-P and NaOH-P were increased up to 166%, 107%, 110%, 63% and 91% respectively, over control with the combined application of organic and inorganic amendments.

- Performance of P regarding different efficiency fractions was significantly improved with the integration of organic and inorganic amendments of P. Agronomic efficiency was recorded up to 71.61(g g^{-1}) and 18.6% recovery of applied P was achieved.

- Poultry manure, applied either alone or integrated with chemical amendment of P, performed better than all organic amendments tested in the experiment. Highest SDM (26.44 g pot^{-1}) and most prominent recovery of applied P (18.6%) were achieved by the integration of poultry manure with inorganic amendment.

CHAPTER 7

SUMMARY

Maize is one of the important crops grown for food and fodder. It ranks third in world's cereal production. Its exhaustive nature requires sufficient available phosphorus in soils to complete its production cycle. Phosphorus is one of the major nutrients required by plants. Metabolism of micro to mega living creatures owes to the presence of P. It plays a fundamental role in many of the plant physiological processes. Plants require adequate P from the very early stage of growth for optimum crop production. Restricted early-season P supply frequently limits crop production. Its deficiency is widespread in calcareous soils. Application of phosphorus, according to crop requirements, could not be popularized in Pakistan. Moreover, fixation of applied P in calcareous soils further aggravates the problem. Although, phosphorus abounds in most of the soils but it is usually in unavailable form. To solve this problem organic wastes of agricultural and industrial origin are being tested internationally as soil amendments. Two pronged benefits are achieved with the application of these amendments; firstly, recycling of pollutants and secondly, organic amendments release P in soil solution through microbial activities, increase efficiency of inorganic amendments, hinder P adsorption at adsorption sites and improves physico-chemical properties and organic contents of soils. Organic matter supplied to the soil is one of the most important factors for increasing the productivity of soil.

In this perspective three detailed pot studies were conducted during the year 2006-2008. In the first study, farmyard manure was applied separately and in integration with diammonium phosphate to different calcareous soils. Maize (*Zea mays* L) was grown as test crop. Combination of organic and inorganic amendments produced maximum shoot dry matter and provided basis for further investigation. In the next study various organic amendments including green manure (Sesbania aculeata), farmyard manure, poultry manure and press mud were incubated separately and incorporated with diammonium phosphate. Ten treatments in three calcareous soils were employed to study the decomposition rate of organic amendments and P release. Differential behaviour of

different calcareous soils was noted regarding rate of organic matter decomposition and release of P. In the third study maize was grown employing ten treatments of organic and inorganic amendments on three calcareous soils. In this study various yield parameters, different P efficiencies and diverse inorganic fractions of soil P were studied. With the use of organic amendments separately and combined with diammonium phosphate significant improvement in yield parameters, P efficiencies and soil P fractions, were observed. Abridged results of the all studies are given as under;

- Maize gave significant response to the application of phosphorus on calcareous soils.

- Application of phosphorus from either amendment, organic or inorganic was responded by calcareous soils.

- Integrated use of organic amendment along inorganic amendment resulted into significant better performance over their separate application.

- Phosphorus application in calcareous soils, improved agronomic parameters of maize and P uptake by maize. Shoot dry matter, P concentration and P uptake were increased over control

- Decomposition rate of organic amendments was comparatively high in Soil-I. Combinations of poultry manure and press mud with diammonium phosphate resulted into faster decomposition in Soil-I.

- Comparison of decomposition rate revealed that out of various organic amendments poultry manure performed better. Decomposition rate of poultry manure was maximum (R^2 = 0.9962) when amendments were applied separately. Decomposition rate of poultry manure was second to green manure when organic amendments were integrated with DAP, nevertheless, this difference was statistically non significant.

- Highest decomposition rates (R^2 = 0.9983, 0.9976) were recorded in S-I and S-III, the sandy loam soils.

- Maximum release rate of Solution P (R^2 = 0.6422) was recorded by separate application of FYM and separate application of press mud showed maximum release rate (R^2 = 0.5864) of Olsen P.

- Integration of organic and inorganic amendments significantly increased different fractions of soil P. Solution-P, Olsen-P, CDB-P, HCl-P and NaOH-P were increased in soils.

- Performance of P regarding different efficiency fractions was significantly improved with the integration of organic and inorganic amendments of P.

- Poultry manure, applied either alone or integrated with chemical amendment of P, performed better than all organic amendments tested in the experiment. Highest SDM (26.44 g pot^{-1}) and most prominent recovery of applied P (18.6%) were achieved by the integration of poultry manure with inorganic amendment.

- Various calcareous soils also showed significant difference with the application of organic amendments.

Potential for the integrated management of inorganic and organic nutrients

Soil fertility and irrigation are increasingly the potential limiting factors for our agriculture. Majority of our farming community depends on subsistence agriculture for their livelihood. The population pressure, ill planned housing projects and boom of industrialization has decreased the availability of arable land. In this perspective the use of extended fallow periods to restore soil fertility is a bygone story.

Previous research results prove that yield can be increased manifold with the improvement of soil fertility. It may be achieved by using a combination of soil tillage, organic and inorganic fertilizers instead of traditional practices. Crop yields have also been shown to increase substantially using rotation of cereals with legume or intercropping.

Production can be increased through the integration of organic and inorganic nutrient sources coupled with proper land management. Under indigenous circumstances farmer needs clear-cut strategies to integrate available resources regarding inorganic and organic inputs to elevate his production potential. We can utilize efficiently, the available organic resources with some extra effort.

Organic matter is an essential component of healthy soils, and all sound farming practices integrate and allocate available organic materials to maintain or improve soil fertility. However, because organic fertilizers are low in nutrient content, high application rates are needed to meet crop nutrient requirements. In many countries, particularly in developing countries, the availability of organic sources of fertilizers is simply insufficient for crop needs, partly due to competitive uses such as energy production. Moreover, the nutrient content, composition and release rate of organic fertilizers is variable and unpredictable and, therefore, it is extremely difficult to ensure a steady supply and the correct balance of all the essential elements for healthy plant growth. Independent scientific studies show that combining inorganic and organic sources of plant nutrients is a beneficial option for the crop and soil system and hence can be of great benefit to both farmers and the environment. Combined together, organic and inorganic nutrient sources can improve soil fertility, enhance soil organic matter content

and limit both nutrient and soil losses. The integrated plant nutrition approach is an appropriate strategy for effective and long lasting sustainability of plant nutrients required by crop plants.

There are, however, number of potential barriers in the way of adoptability of this idea of IPNM (Integrated Plant Nutrient Management) including illiteracy and preferences of farming community, price hike and least availability of chemical fertilizers, disinterest of policy makers and handling/transport of organic amendments etc. Nevertheless, it is a vast field of research regarding the study of integrated use of organic and inorganic amendments. Following horizons need more attention for further investigation;

- Effect of long-term integration of organic and inorganic amendments on the population and by-products of microbial activities in soils
- Effect on macro and micronutrient availability as affected by the application of these amendments
- Biodegradation of agricultural pollutants as influenced by the application of organic amendments
- Implication of long-term application of organic and inorganic amendments regarding 'green house effects' etc.

Future prospects of this research

The present research may go long for the coming generations. Since the world's population is burgeoning formidably and the available natural resources are dwindling tremendously. In such shaky circumstances agricultural researchers and the true scientist of nature 'the farmer' have to play pivotal role. They have to fill the granary to feed the word. Presently, natural resources like natural gas, rock phosphate and other minerals are being used injudiciously and even ruthlessly among the developing parts of the hemisphere. These resources are diminishing and with the current pace the ongoing century will be blank at its dusk. In this perspective farmers and researchers will have to switch over to some more economical, sustainable and environmental friendly ways of food production.

In the modern era of industrialization mushrooming of industries has facilitated the living on one hand and has produced heaps and mounds of wastes on the other hand. Emergence of industrial pollution is one of the gravest drawbacks of this sector. Presently researchers are paying heed to this sector and trying to achieve success by naturally recycling the organic wastes of industries and animal manures. Nonetheless, still there are several horizons in this regarded which have to be explored. For instance the waste products of huge textile and paper industry feed, food and beverage industry, sports and leather industries etc. also direly need to be taken into account for their polluting thrust and also for their agricultural recycling in our environment. In the present study waste products of sugarcane industry and manures pertaining to poultry and farm animals are touched. Crop production and effect of the amendments on the P uptake and soil P fraction have been studied. Still there are numerous fields which need to be explored. The future studies may be planned to investigate the influence of such amendments on the uptake of other macro and micro nutrients and their concentration in soil and solution. Concentration of heavy metals in soil plant and water as influenced by the application of such amendments needs exhaustive research. Effect of such wastes or byproducts on microbial activities and population may also be taken in to consideration. Physico-chemical properties of soil and other sophisticated analyses also need to be pondered at.

Presently, in the developing countries like ours, certain infrastructural facilities for such research are nominal but policy makers will have to revise their preferences to keep pace with the future needs.

LITERATURE CITED

Abbas, S. and R. J. Gilkes. 1999. Phosphorus Transformation and their Relationships with Calcareous Soil Properties of Southern Western Australia. Soil Sci. Soc. Am. J., 63: 809-815.

Abul Kashem, M.D., O.A. Olalekan and J.R. Geza. 2003. Phosphorus fractions in soil amended with organic and inorganic phosphorus sources. Can. J. Soil Sci., 83: 83-90.

Afif, E., A. Matar, and J. Torrent. 1993. Availability of phosphate applied to calcareous soils of West Asia and North Africa. Soil Sci. Soc. Am. J. 57: 756-760.

Al-Abbas A. H. and S.A. Barber. 1964. A soil test for phosphorus based upon fractionation of soil phosphorus: I Correlation of soil phosphorus fraction with plant available phosphorus. Soil Sci. Soc. Am. Proc. 28: 218-221.

Alam, S. M., I. Zafar and M. Latif. 1999. Fertigation technology for improved phosphorus use efficiency in wheat. Pak. J. Sci. Ind. Res. 42: 380-383.

Ali, A., A.S. Ahmad, M. Ahmad and A. Ali. 1988. Response of Pak-81 wheat to phosphorus application at Faisalabad. Pak. J. Agric. Res. 9: 593-595.

Amarasiri, S. L., and S. R. Olsen. 1973. Liming as related to solubility of phosphorus and plant growth in an acid tropical soil. Soil Sci. Soc. Am. Proc. 37: 716- 721.

Ansiaux, J. R. 1977. The level of soil phosphorus status. Phosphorus Agric.70: 1-10.

Archer, J. 1988. Crop nutrition and fertilizer use. Farming press Ltd., Ipswich, Suffolk.

Bahl, G. S. 1990. Kinetics of P desorption in some alluvial soils and P removal by plants. J. Ind. Soc. Soil Sci. 38: 680-687.

Ballaux, J. G. and D. E. Peaslee. 1975. Relationship between sorption and desorption of phosphorus by soils. Soil Sci. Soc. Am. Proc. 39: 275-278.

Barrow, N. J. 1973. Relationship between soils ability to adsorb phosphate and theresidual effectiveness of superphosphate. Aust. J. Soil Res. 11: 57-63.

Barrow, N. J., J. W. Bowden, A. M. Posner and J. P. Quirk. 1980. Describing the effect of electrolytes on adsorption of phosphate by a variable charge surface.

Batjes, N. H .1997. A world data set of derived soil properties by FAO-UNESCO soil unit for global modeling. Soil Use Manag.13: 9 -16.

Beri, V., B. S. Sidhu and G. S. Bahl . 2002. Crop Residue Management.In: Recent advances in agronomy. Indian Society of Agronomy, New Delhi, India.

Bertrand, I. P. Hinsinger, B. Jaillard, J. C. Arvieu and P.J. Gregory. 1999. Dynamics of phosphorus in the rhizosphere of maize and rape grown on synthetic, phosphated calcite and goethite. New approaches to study chemical and physical changes in the rhizosphere. Plant Soil, 211: 111-119.

Bhatti, H. M. 1973. Annual reports. Agri. Chemist (soils) 1972-73. Punjab Agri. Res. Inst. Lyallpur, Pakistan.

Bigham, J. M. 1996. Methods of Soil Analysis. Part 3, Chemical Methods. SSSA and ASA, Madison, WI, USA.

Bolan, N. S., D. C. Adriano, R. Naidu, M. L. Mora and S. Mahimairaja. 2005. Phosphorus-trace element interactions in soil-plant systems. In: Phosphorus: Agriculture and the environment. J.T. Sims, Andrew N. Sharpley, G. M. Pierzynski, D. T. Westerman, M. L. Cabrera, J. M.Powell, T. C. Daniel, and P.J.A. Withers (eds). Hardcover, ASA-CSSA-SSSA, Agron. Monogr.

Borie, F. and R. Rubio. 2003. Total and organic phosphorus in Chilean volcanic soils. Gayana Bot. 60: 69-78.

Bramley, R. G. V., N. J. Barrow and I. C. Shaw. 1992. The reaction between phosphate and dry soil. The effect of time, temperature and dryness. J. Soil Sci. 43:749-758.

Brar, B. S. and A.C. Vig. 1988. Kinetics of phosphate release from soil and its uptake by wheat. J. Agric. Sci. 110: 505-513.

Brinkman, R. 1998. Guide to efficient plant nutrient management, FAO, Rome.

Buehler, S., A. Oberson, I. M. Rao, D. K. Friesen and E. Frossard. 2002. Sequential phosphorus extraction of a 33P-labeled oxisol under contrasting agricultural systems. Soil Sci. Soc. Am. J. 66: 868-877.

Bunemann, E., P. C. Smithson, B.Jama, E.Frossard, and A.Oberson. 2004. Maize productivity and nutrient dynamics in maize-fallow rotation in Western Kenya. Plant Soil 264: 195-208.

Carreira, J.A. and K.L. Lajtha. 1997. Factors affecting phosphatesorption along a Mediterranean, dolomitic soil and vegetation chronosequence.Eur. J. Soil Sci. 48:139-149.

Cassman, K. G., A. Dobermann and D. T. Walters. 2002 . Agroecosystems, nitrogen use efficiency, and nitrogen management. Ambio 31: 132-140.

Castro, B., and J. Torrent. 1995. Phosphate availability in calcareous Vertisols and Inceptisols in relation to fertilizer type and soil properties. Fert. Res. 40:109-119.

Cavigelli, M. A. and S. J. Thien. 2004. Phosphorus Bioavailability Following Incorporation of Green Manure Crop. Ag. Professional. pp: 46-48.

Chang, S. C., and M. L. Jackson. 1957. Fractionation of soil phosphorus. Soil Sci. 84: 133-144.

Chapman, H. J. and P. F. Pratt. 1961. Methods of analysis for soils, plants and waters. Div. Agric. Sci. Univ. Calif. Pub. March. 1992. USA.

Chaudhary, A. R. 1983. Maize in Pakistan. Punjab Agricultural Research Coordination Board, Univ. of Agri., Faisalabad.

Chaudhary, M. A., M. Shafiq and Attiq-ur-Rahman. 1998. Effect of Organic and Inorganic Fertilizers on Maize Crop Response under eroded loess Soil. Pak. J. Soil Sci. 15: 39-43.

Chardon,W. S., R. G. Menon and S. H. Chien. 1996. Iron oxide impregnated filter paper (Pi test): A review of its development and methodological research. Nutr. Cycling Agroecosyst. 46: 41-51.

Chardon, W. and O. Schoumans.1999. Solubilization of phosphorus: Concepts and process description of chemical mechanisms. COST 832- Meeting, WG 2, Cordoba, Spain, 13-15 May 1999. Online <http://www.alterra.

Chen, Y. S. R., J. M. Butler and W. Stum, 1973. Kinetic study of phosphate reaction with aluminum oxide and kaolinite. Environ. Sci. Technol. 7: 327-332.

Chhabra, R., I. P. Abrol, and M. V. Singh. 1981. Dynamics of phosphorus during reclamation of sodic soil. Soil Sci. 132: 319-324.

Chien, S. H. and W. R. Clayton. 1980. Application of Elovich equation to the kinetics of phosphate release and sorption in soils. Soil Sci. Soc. Am. J. 44: 265-268.

Cole, C. V. and S. R. Olsen. 1959. Phosphorus solubility in calcareous soils: II. Effects of exchangeable phosphorus and soil texture on phosphorus solubility. Soil Sci. Soc. Am. Proc. 23: 116-118.

Cole, C. V., S. R. Olsen and C. O. Scott. 1953. The nature of phosphate sorption by calcium carbonates. Soil Sci. Soc. Am. Proc. 17: 352- 356.

Condron, L. M., B. L. Turner and B. J. Cade-Menun. 2004. Chemistry and dynamics of organic phosphorus. In J. T. Sims and A. N. Sharpley (ed.) Phosphorus: Agriculture and the environment . SSSA. Madison, WI, USA.

Cong, P. T. and R. Merckx.2005. Improving phosphorus availability in two upland soils of Vietnam using Tithonia diversifolia H. Plant Soil 269: 11-23.

Cox, J. W., C. A. Kirkby, D. J. Chittleborough, L. J. Smythe and N. K. Fleming. 2000. Mobility of phosphorus through intact soil cores collected from the Adelaide Hills, South Australia. Aust. J. Soil Res. 38: 973- 990.

Dalal, R. C. and E. G. Hallsworth. 1976. Evaluation of the parameters of soil phosphorus availability factors in predicting yield response and phosphorus uptake. Soil Sci. Soc. Am. J. 40: 541-545.

Daniel, T.C., A. N. Sharpley and J. L. Lemunyon .1998. Agricultural phosphorus and eutrophication: a symposium overview. J. Environ. Qual. 27:251-257.

De Haan, F. A. M. The interaction of certain inorganic anions with clay and soils. Agri. Res. Rep. Wageningen, Netherland, 655, 167p.

De Smet, J., J. Vanderdeelen and G. Hoffman. 1998. Effect of soil properties on the kinetics of phosphate release. Commun. Soil Sci. Plant Anal. 29: 2135-2147.

Dorado, J., M.Zancada, G. Almendros, and C.Lopez-Fando. 2003. Changes in soil properties and humic substances after long-term amendments with manure and crop residues in dry land farming systems. Plant Nutr. Soil Sci. 166: 31-38.

Dusberg. J. M., M. S. Smith and J. W. Doran. 1989 . In Dynamics of SOM in Tropical Ecosystems. Univ. of Hawaii, Hawaii, USA.

Easterwood, G. M and J. B. Sartain. 1990. Clover residue effectiveness in reducing orthophosphate sorption on ferric hydroxide coated soil. Soil Sci. Soc. Am. J.54: 1345- 1350.

Economic Survey. 2006-2007. MINFAL, Islamabad, Pakistan.

Eghball, B., G. Binford and D. Baltenspreger. 1996. Phosphorus movement and adsorption in a soil receiving long term manure and fertilizer application. J. Environ. Qual. 25: 1339-1343.

Eichler-Lobermann, B., S. Kohne and D. Koppen. 2007. Effect of organic, inorganic, and combined organic and inorganic P fertilization on plant P uptake and soil P pools. J. Plant Nutr. Soil Sci. 170:263-268.

El-Dewiny, C. Y., Kh. S. Moursy and H.I. El-Aila. 2006 . Effect of Organic Matter on the Release and Availability of Phosphorus and their effects on Spinach and Radish Plants. J. Agri. Biol. Sci. 2(3): 103-108.

Elkhatib, E. A. and J. L. Hern. 1988. Kinetics of P desorption from Appalachian soils. Soil Sci. 145: 222-229.

Elmahi, Y. E. and M. A. Mustafa. 1980. The effect of electrolyte concentration and 0sodium adsorption ratio on phosphate retention by soils. Soil Sci. 130: 321-325.

Emmerling, C., C. Liebner, M. Haubold-Rosar, J. Katzur and D. Schroder. 2000. Impact of application of organic waste materials on microbial and enzyme activities of mine soils in the Lusatian coal mining region. Plant Soil 220: 129-138.

Evans, R. L. and J. J. Jurinak. 1976. Kinetics of phosphorus release from a desert soil. Soil Sci. 121: 205-211.

FAO. 1995. World Agriculture towards 2010. N. Alexandratos (Ed). John Wiley. Chichester, UK, 488 p.

Fernandez, E. C. M. and P. A. Sanchez. 1990 . The role of organic inputs and soil organic matter for nutrient cycling in tropical soils. In: Organic Matter Management and Tillage in Humidand Subhumid Africa, E. Pushparajah and M. Latham (Eds). Bangkok, Thailand. International Board for Soil Research and Management, Bangkok, Thailand, 10: 169-212.

Fox, R.L. and E.J. Kamprath. 1970. Phosphate sorption isotherm for evaluating the phosphate requirement of soils. Soil Sci. Soc. Am. Proc. 34: 902-907.

Fox, R.L. and P.G.E. Searle. 1978. Phosphate adsorption by soils of the Tropics. Diversity of soils in the Tropics (Drosdoff. M. Ed) 97- 119. Am. Soc. Agron. Special Pub. 34-97.

Frossard, E., L. M Condron, A. Oberson, S. Sinaj and J. C. Fardeau. 2000. Processes governing phosphorus availability in temperate soils. J. Environ. Qual. 29: 12-53.

Frossard, E., P. Skrabal, S. Sinaj, F. Bangerter and O Traore. 2002. Exchangeability of norganic phosphate in composted soil organic wastes. Nutr. Cycl. Agroecosys. 62: 103-113.

Gale, P. m., M. D. Mullen, C. Cieslik, D.D. Tyler, B. N. Duck, M. Kirchener and McClure. 2000. Phosphorus distribution and availability in response to dairy manure applications. Commun Soil Sci. Plant Anal. 31: 553-565.

Gaume, A. 2000. Low-P tolerance of various maize cultivars: the contribution of the root exudation. PhD Dissertation, Swiss Federal Institute of Technology, Zurich, Switzerland.

Gburek, W. J., A. N. Sharpley, L. Heathwaite and G. J. Folmar. 2000. Phosphorus Management at the watershed scale: a modification of the phosphorus index. J Environ. Qual. 29:130-134.

Gerke, J. 1994. Kinetic of soil phosphate desorption as affected by citric acid. Z. P. flanzenernahr. Bodenkd. 157: 17-22.

Ghanbari, A., M. Maftoun and N. Karimian. 1998. Phosphorus adsorption-desorption characteristics of some selected highly calcareous soils of Fars province. Iranian J. Agri. Sci. 29: 181- 194.

Gibali, A. S. and Rahmatullah. 1982. Effect of Manure and Soil-Carbonates on the Availability and Uptake of Superphosphate-Phosphorus by Wheat Plants under Greenhouse Conditions. Libyan J. Agric. 11: 159-164.

Goldstein, A. H., D. A. Baertiein, and R. G. McDaniel. 1988. Phosphate starvation inducible metabolism in Lycopersicon esculentum. Plant Physiol. 87:711-715.

Graham, M. H. 2003. Confronting Multicollinearity in Ecological Multiple Regression. Ecology 84: 2809-2815.

Grant, C. A., Flaten, D. N., Tomasiewicz, D. J. and Sheppard, S. C. 2001. The importance of early season P nutrition. Can. J. Plant Sci. 81: 211-224.

Gu, Y.C. and S. W. Qin. 1997. Phosphorus accumulation, transformation and availability under long-term application of phosphorus fertilizer. Chin. Soil Sci. 29, 13-17.

Guilherme, L. R. G., N. Curi, M. L. N. Silva, N. B. Reno and R. A. F. Machado. 2000. Phosphorus adsorption in lowland soils from Minas Gerais State [Brazil]. Revista-Brasileira-de-Ciencia-do-olo 24 (1): 27-34.

Guster, R., T. Ebertseder, M. Schraml and U. Schmidhalter. 2005. Short-term and residual availability of organic fertilizers on arable land. J. Plant Nutr. Soil Sci. 168: 439-446.

Gutam, K., and N. K. Tomar. 1997. Sorption of orthophosphate and pyrophosphate in calcareous soil. Haryana Agric. Univ., J. Res. 27:171-181.

Hall, J. K. and D. E. Baker. 1971. Phosphorus fixation by montmorillonite and vermiculite clays as influenced by pH and soluble aluminum. Soil Sci. Soc. Am. Proc. 35: 215-219.

Hansen, J., and D. G. Strawn. 2003. Kinetics and Mechanism of Phosphorus Release from manure-Amended Alkaline Soils. Soil Science, 168: 869-879.

Hansen, J. C., B. J. Cade-Menun and D. G. Strawn. 2004 . Phosphorus Speciation in Manure-Amended Alkaline Soils. J. Environ. Qual. 33:1521-1527.

Hao, X., C. Chang, and X. Li. 2004. Long-term and residual effects of cattle manure application on distribution of P in soil aggregates. Soil Sci. 169:715-728.

Harter, R. D. 1969. Phosphorus adsorption sites in soils. Soil Sci. Soc. Am. Proc. 33: 630-631.

Hartikainen, H. 1989. Effect of cation species on the desorption of phosphorus in soils treated with carbonate. Z. Pflanzenernahr. Bodenkd. 152: 435-439.

Hartl, W and E. Erhart. 2005. Crop nitrogen recovery and soil nitrogen dynamics in a 10 year field experiment with biowaste compost. J. Plant Nutr. Soil Sci. 168: 781-788.

Havlin, J. L., D. G. Westfall and S. R. Olsen. 1985. Mathemetical models for potassium release kinetics in calcareous soil. Soil Sci. Soc. Am. J. 49: 371-376.

Haynes, R. J. 1982. Effect of liming on phosphate availability in aci soils. A critical review. Plant Soil 68: 289-308.

Hedley, M. J., J. J. Mortvedt, N. S. Bolan and J. K. Syers. 1995. Phosphorus fertility management in Agro-eco system. In: Tiessen, H. (Ed). Phosphorus in the global environment. Transfers, Cycles and the management. Wiley. Chichester, UK. pp. 59-92.

Hedley, M.J., J.W.B. Stewart and B. S. Chauhan. 1982a. Changes in inorganic and organic soil phosphorus fractions induced by cultivation practices and by laboratory incubations. Soil Sci. Soc. Am. J. 46, 970-976.

Hedley, M.J., R. E. White and P. H. Nye. 1982b. Plant-induced changes in the rhizosphere of rape (Brassica napus var. Emerald) seedlings. III. Changesin L value, soil phosphate fractions and phosphatase activity. New Phytol. 91: 45-56.

Hernandez, J. and E. J. Meurer. 2000. Phosphorus availability in six Uruguayan soilsaffected by temporal variation of oxidising-reducing conditions. Revista-Brasileira-de-Ciencia-do-Solo. 24:19-26.

Hinsinger, P. 2001. Bio-availability of soil inorganic P in the rhizosphere as affected by root induced chemical changes: a review. Plant Soil 237:173-95.

Holford, I. 1989. Phosphorous behavior in soils. Agri. Sci. 12: 15-20.

Holford, I. C. R .1997. Soil phosphorus: its measurement and its uptake. Aust. J. Soil Res. 35: 227-239

Holford, J.C.R. and G.E.G. Mattingly. 1975. The high and low-energy phosphate adsorbing surfaces in calcareous soils. J. Soil Sci. 26: 407-417.

Hosseinpur, A. R. and F. S. Biabanaki 2008. Release Kinetics and the Correlation between Kinetics Models Constants and Soil Properties and Plant Indices. J. Sci. Tech. Agric. Natural Resources. 11: 504-504.

Huang, Q. N. 1998. Properties of phosphorus adsorption and desorption in red soil under a stand of Chinese fir in Fujian. J. Nanjing Forestry Uni. 22(2): 39-44.

Hue, N.V., 1991. Effects of organic acids/anions on P sorption and phytoavailability in soils with different mineralogies. Soil Sci. 152, 463- 471.

Huffman, S. A., C. V. Cole and Scott, N. A. 1996. Soil texture and residue addition effects on soil phosphorus transformations. Soil Sci. Soc. Am. J. 60: 1095-1101.

Hundal, H. S., C. R. Biswas and A. C. Vig. 1988. Phosphorus sorption characteristics of flooded soil amended with green manure. Trop. Agric. 65: 185-187.

Hussain, T. 2005. Manures and organic wastes. In: E. Bashir and R. Bantel (Editors), Soil Science, pp. 387-404. National Book Foundation, Islamabad, Pakistan.

Ivarsson, L. 1990. The long-term soil fertility experiments in southern Sweden. IV. Changes in inorganic and organic soil phosphorus after a pot trial. Acta Agric. Scand.40: 205-215.

Iyamuremye, F. and R. P. Dick. 1996 . Organic amendments and phosphorus sorption by soils. Adv. Agron. 56: 139-185.

Iyamuremye, F., R. P. Dick and J. Baham. 1996a. Organic amendments and phosphorus dynamics: I. Phosphorus chemistry and sorption. Soil Sci. 161: 426-435.

Iyamuremye, F., R. P. Dick and J. Baham. 1996b. Organic amendments and phosphorus dynamics: II. Distribution of soil phosphorus fractions. Soil Sci. 161: 436-443.

Jones, J. P., B. B. Singh, M. A. Fosberg and A. L. Falen. 1979. Physical, chemical and mineralogical characteristics of soils from volcanic ash in northern Idaho, II. Phosphate sorption. Soil Sci. Soc. Am. J. 43: 547-552.

Kafkafi, U., A. M. Posner and J. P. Quirk. 1967. Desorption of phosphate from kaolinite. Soil Sci. Soc. Am. Proc. 31: 348- 353.

Kafkafi, U., B. Bar-Yosef, R. Rosenbery, and G. Sposito. 1988. Phosphorus adsorption by kaolinite and montmorillonite: II. Organic anion competition. Soil Sci. Soc. Am. J. 52: 1585-1589.

Kalra, Y. P. and D. G. Maynard. 1991. Methods manual for forest soil and plant analysis. Northwest Region, Information Report NOR-X-319, Forestry Canada.

Kaur, K., K. K. Kapoor and A. P Gupta. 2005. Impact of organic manures with and without mineral fertilizers on soil chemical and biological properties under tropical condition. J. Plant Nutr. Soil Sci. 168: 117-122.

Kelling, K. A. 2004. Nonconventional soil additives:Products, companies, ingredients and claims (staff). Committee on non-traditional Soil Amendments and Growth Stimulants. [http:// alfi.soils.wisc.edu/extension/hottopics/nonconventional.pdf].

Khalid, R. A., W. H. Patrick, Jr. and R. D. Delaune. 1977. Phosphate adsorption characteristics of flooded soils. Soil Sci. Soc. Am. J. 41: 305-310.

Khan, G. S. and M. Rafique. 1992. Soil variability and Phosphorus fertilization. p. 245-250. Proc. "Role of P in crop Prod." NFDC. Islamabad, Pak.

Khanna, S. S., N. K. Tomar and A. P. Gupta. 1984. Efficiency of incubated phosphatic fertilizers varying in water solubility with organic matter to wheat. Fert. News, India 29(5): 30-32.

Kuo, S. and E.G.Lotse. 1974. Kinetics of phosphate adsorption and desorption by lake sediments. Soil Sci. Soc. Am. Proc. 38: 50-54.

Kuo, S. 1996. Phosphorus. In Sparks, ed., Methods of Soil Analysis, Part 3: Chemical and Microbiological Properties. Am. Soc. Agron., Madison, Wisconsin. 869-919.

Kwabiah, A. B., N.C. Stoskopf, C.A. Palm, R.P. Voroney, M.R. Rao and E. Gacheru. 2003. Phosphorus availability and maize response to organic and inorganic fertilizer inputs in a short-term study in western Kenya. Agric. Ecosys. Environ. 95:49-59.

Le Mare, P. H., Pereira, J. and W. J. Goedert. 1987. Effect of green manure on isotopically exchangeable phosphate in a dark red latosol in Brazil. J. Soil Sci. 38: 199-209.

Li, S. T., J. M. Zhou, H. Y. Wang, C. W. Du and X. Q. Chen. 2005. Kinetics of phosphate release from three phosphate-treated soils. Pedosphere 15: 518-525.

Lindsay, W. L, and W. A. Norwell. 1978. Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Sci. Soc. Am. J. 42: 421-428.

Lindsay, W. L. 1979. Chemical equilibrium in soils. p 129. Jhon Wily and sons, NY. USA.

Lins, I. D. G., F. R. Cox and J. J. Nicholaides. 1985. Optimizing phosphorus fertilization rate for soybeans grown on Oxisols and associated Entisols. Soil Sci. Soc. Am. J. 49: 1457-1460.

Liu, J. 1999. Transformation of fertilizer phosphorus in calcareous soil and its influencing factors. Ph.D. Dissertation. China Agriculture University and W. H. VanRiemsdijk. 1995. Long-term kinetics of phosphate release from soil. Environ. Sci. Technol. 29: 569-1575.

Lopez- Hernandez, D. and C. D. Burnham.1974. The effect of pH on phosphate adsorption in soils. J. Soil Sci. 25: 207-216.

Lu-Wenlong, F. S. Zhang, Y. P. Cao, J. G. Wang, W. L. Lu, F. S. Zhang, Y. P. Cao and J. G. Wang. 1998. Influence of low-molecular weight organic acids on kinetics of phosphorus adsorption by soils. Acta-Pedologica-Sinica. 36 (2): 189-197.

Lucresio, E. S. and C. M. Duque. 1999. Alleviating soil acidity with organic matter, lime and phosphorus application. CMU-J. Sci. 8(1): 2-20.

Maida, J. H. A. 1980. Phosphate availability indices related to fractions in selected Malawi soils. J. Sci. Food Agri. 29: 423-428.

Malik, D. M., Chaudhary, A. G. and M. I. Salim. 1973. Available status of Punjab soils. J. Agric. Res. 551- 560.

Malik, D. M., R. A. Chaudhary and S. J. A. Sherazi.1992. Management of phosphorus for wheat production inPunjab. Proc. "Role of P in Crop Prod." Islamabad NFDC Pak. pp. 175-195.

Malik, D. M., B. Ahmed and M. Ahmed. 1984. Survey of soil fertility status and quality of ground waters. Punjab Digest 1981- 84. Dept. Agri. Pak.

Martin, H.W. and D. L. Sparks. 1983. Kinetics of non-exchangeable potassium release from two coastal plain soils. Soil Sci. Soc. Am. J. 47: 781-783.

Memon, K. S. 1985. Annual report of the project, micronutrient status of Pakistan soils 1984-84. Pak. Agri. Res. Council, Islamabad, Pakistan.

Memon, K. S., A. Rashid and H. K. Puno. 1992. Phosphorus deficiency diagnosis and P soil test calibration in Pakistan. pp. 125. In: Proc. Phosphorous Decision Support Sys. College Station, TX. Memon, K. S. and R. L. Fox. 1983. Utility of Phosphate sorption curves in estimating P requirements of cereal crops. Wheat (Triticum Aestivium) Proc. 3rd Int. Cong. On Phosphorus Compounds, Brussels, Belgium, Oct. 4-6.

Mengel, K. and E. A. Kirkby.1987. Principles of Plant Nutrition. 4th ed. International Potash Institute, Bern, Switzerland, pp. 687.

Mengel, K. and E. A. Kirkby. 2001. Principles of Plant Nutrition. 5th ed., Kluwer Academic Publishers, London.

Mokwunye, U. 1975. The influence of pH on the adsorption of phosphate by soil from the Guinea and Savannah Zone of Nigeria. Soil Sci. Soc. Am. Proc. 39: 1100-1102.

Moodie, C. D., H.W. Smith and R. A. Mcreery. 1959. Laboratory manual for soil fertility. State College of Washington, Mimeograph, Pullman, Washigton D.C. USA, pp. 31-39.

Morais F. I. O. de, H. B. Martins Jr, J. F. Teizeira Neto and W.S. Couto. 1996. Adsorption of phosphorus in a plinthic soil of the Ilha de Marago, PA. Boletim-da-Faculdade-de-Ciencias-Agrarias-do-Para 26: 67-76.

Morel, C. 2002. Caractérisation de la phytodisponiblité du P du sol par la modélisation du transfert des ions phosphate entre le sol la solution. Habilitation à Diriger des Recherches. INPL-ENSA-IA Nancy. 80 pp. [Online] Available: http://www.bordeaux.inra.fr/tcem/ rubrique:Actualités [2004 May 04].

Moreo, E. C., W. L. Lindsay and G. Osborn. 1960. Reaction of dicalcium phosphate Dihydrate in soils. Soil Sci. 20: 58-68.

Motavalli, P. P. and R.J. Miles. 2002. Soil phosphorus fractions after three years of animal manure and fertilizer applications. Biol. Fertil. Soils. 36: 35-42.

Mott, C. J. B. 1970. Sorption of anions by soils. p 40-53. In GREGORY, J. G. (ed) Sorption and transport processes in soils.

Mozaffari, M. and J. T. Sims. 1994. Phosphorus availability and sorption in an Atlantic coastal plain watershed dominated by animal-based agriculture. Soil Sci. 157: 97-107.

Munir, M.A., M.A.Malik and M.F.Saleem. 2007. Impact of Integration of Crop Manuring and Nitrogen Application on Growth Yield and Quality of Spring Planted Sunflower. Pak. J. Bot. 39(2): 441-449.

Munns, D. N. and R. L. Fox.1976. The slow reactions which continues after phosphate adsorption. Kinetics and Equilibrium in sone tropical soils. Soil Sci. Soc. Am. J. 40: 41-46.

Nair., V. D. , R. R. Villapando and D. A. Greatz. 1999. Phosphorus retention capacity of the spodic horizon under varying environmental conditions. J. Envron. Qual. 31: 1279-1285.

NFDC. 2001. Balanced fertilization through phosphate promotion. Project terminal report. NFDC, Islamabad, Pakistan.

Nisar, A. 1985. Phosphorus requirement of wheat crops in different cropping systems. Fertilizer News 30(7): 38- 42.

Nziguheba, G., C. A. Palm., R. J. Buresh and P. C. Smithson. 1998. Soil phosphorus fractions and adsorption as affected by organic and inorganic sources. Plant Soil 198: 159-68.

Nziguheba, G., Merckx, R., Palm, C.A., Rao, M.R., 2000. Organic residues affect phosphorus availability and maize yields in a Nitisol of western Kenya. Biol. Fert. Soils 32, 328-339.

Niklasch, H and Joergensen. 2001. Decomposition of peat, biogenic municipal waste compost, and shrub/grass compost asses in different rates to a silt loam. J. Plant Nutr. Soil Sci. 164: 365-368.

Oberson, A and E.J. Joner. 2005. Microbial turnover of phosphorus in soil, In Turner, B. L., Frossard, E., Baldwin, D. S.: Organic phosphorus in the Environment. CABI Publishing, Wallingford, Oxford shire, UK, pp. 133-164.

Oehl, F., E. Frossard, A. Fliessbach, D. Dubois, and Oberson. 2004. Basal organic phosphorus mineralization in soils under different farming systems. Soil Biol. Biochem. 36: 667-675.

Oenema, O. and G. L. Velthof. 2000. Developing nutrient management strategies at national and regional levels in the Netherlands, in Sapek. A (ed.): Scientific basis to mitigate the nutrient dispersion into the environment. Falenty IMUZ Publisher, pp. 36-55.

Ohno, T. and B.S. Crannell. 1996 . Green and animal manure-derived dissolved organic matter effects on phosphorus sorption .J. Environ. Qual. 25:1137-1143.

Olsen, S. R., and L. E. Sommers. 1982. Phosphorus. P. 403-430 In: A. L. Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agronomy Monogr 9. ASA and SSSA, Madison, WI.

Olsen, S. R., R. A. Bowman and F. S. Watanabe. 1977. Behavior of phosphorus in the soil and interaction with other nutrients. In: Symp. "The Importance of Phosphorus in agriculture" held in Paris 22-23 Feb.

Olsen, S. R., C. V. Cole, F. Watanabe and L. A. Dean. 1954. Estimation of available phosphorus in soils. US Dept. Agri. Circular No. 939.

Opala, P. A., C. O. Othieno, J. Rokalebo and P. O. Kisinyo. 2010. Effects of combining organic materials with inorganic P sources on maize yield and financial   benefits   in Western Kenya. Exp. Agric. 46 (1): 23-34.

Osava, M. 2007. Farming faces phosphate shortfall. Energy Bulletin. 15 Oct. 2007:1.

Otani, T., and N. Ae. 1997. The status of inorganic and organic phosphorus in some soils in relation to plant availability. Soil Sci. Plant Nutr. 43: 419-429.

Ozanne, P. G. 1980. Phosphate nutrition of plants-general treatise. In The role of phosphorus in agriculture. Eds. F. E. Khasawneh, E. C. Sample and E. J. Kamprath. pp. 559-589. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, WI, USA.

Palm,C. A.1995. Contribution of agro-forestry trees to nutrient requirements of intercropped plants. Agrofor. Sys. 30: 105-124.

Palm, C.A., C.N. Gachengo, R.J. Delve, G. Cadisch, and K. E. Giller. 2001. Organic inputs for soil fertility management in tropical agroecosystems: application of an organic resource database. Agriculture, Ecosystems and Environment 83, 27-42

Pant, H. K. and P. R. Warman. 2000. Phosphorus release from soils upon exposure to ultra-violet light. Comm. in Soil Sci. Plant Anal. 31 (3-4): 321-329.

Papadopoulos, I. 1994. Use of labeled fertilizers in fertigation research. Proceedings of an international symposium on nuclear and related techniques in soil-plant studies, held in Vienna: 399-410.

Papini, R., F. Castelli and A. Panichi. 1999. Phosphorus retention and leaching in some sandy soils of Northern Italy. Italian J. Agron. 3 (2): 101-107.

Parfitt. R. L. 1990. Phosphate reactions with natural allophane, ferrihydrite and goethite. J. Soil Sci. 40: 359-369.

Parmar, D. K. and V. Sharma. 2002. Studies on long-term application of fertilizers and manure on yield of maize-wheat rotation and soil properties under rain fed conditions in Western-Himalayas. Journal of the Indian Society of Soil Science. 50, 3: 311-312.

Patrick, W. H. Jr. and R. A. Khalid. 1974. Phosphate release and sorption by soils and sediments: Effect of anaerobic conditions. Soil Sci. 186: 53-55.

Pavlatou, A. and N. A. polyzopoulos. 1988. The role of diffusion in the kinetics of phosphate desorption: the relevance of the Elovich equation. J. Soil Sci. 36: 425-436.

Phiri, S., E. Barrios, I.M. Rao and B.R. Singh. 2001. Changes in soil organic matter and phosphorus fractions under planted fallows and a crop rotation system on a Colombian volcanic ash soil. Plant Soil 231: 211-223.

Pothuluri, J. V., D. A. Whitney and D. E. Kissel. 1991. Residual value of fertilizer phosphours in selected Kansas's soils. Soil Sci. Soc. Am. J. 55: 399-404.

Raghothama, K. G. 1999. Phosphate acquisition. Ann. Rev. Plant Physiol. Mol. Biol. 50: 665-693.

Rahmatullah., M.A. Gill, B. Z. Shaikh, and M. Salim. 1994. Bioavailability and distribution of phosphorus among inorganic fractions in calcareous soils. Arid Soil Res Rehab. 8: 227-234.

Rahmatullah, M. Salim, I. Ahmad, M. A. Gill and K. Hussain. 2003. Phosphorus Retention in an Alfisol amended with Lime and Gypsum. Pak. J. Agri. Sci., 40: 1-2.

Rashid, A. and D.L. Rowell. 1988. Phosphate sorption and release: 1.Isotopically exchangeable and non-exchangeable adsorbed phosphate in relation to soil properties. Pak. J. Soil Sci. 3(1-2): 17-20.

Raven, K. P. and L.R. Hossner. 1994. Soil phosphorus desorption kinetic and its relationship with plant growth. Soil Sci. Soc. Am. J.58: 416-423.

Reddy, K.S., A. S. Rao, and P. N. Takkar. 1996. Transformation of fertilizer P in a Vertisol amended with farmyard manure. Biol. Fertil. Soils 22: 279-282.

Reddy, K.S., A. S. Rao and P. N.Takkar. 1999. Effects of repeated manure and fertilizer phosphorus additions on soil phosphorus dynamics under a soybean-wheat rotation. Biol. Fertil. Soils 28: 150-155.

Rehm, S. and G. Espig. 1991. The cultivated plants of the tropics and subtropics: Cultivation, Economic value and utilization. Verlag Josef, Margraf, W. Germany.

Rhoades, J. D., and J. D. Oster. 1986. Solute content. p. 985-1006. In: A. Klute (ed.) Methods of soil analysis. 2nd ed. Agron Monogr. 9. ASA and SSSA, Madison, WI, USA.

Richards, A. L. 1954. Diagnosis and improvement of saline and alkali soils. USDA. Handbook 60, Washington, DC, USA.

Richards, J.E., T.E. Bates and S.C. Sheppard. 1995. Changes in the forms and distribution of soil phosphorus due to long-term corn production. Can. J. Soil Sci. 75: 311-318.

Richardson, A. E., T. S. George, M. Hens and R. J. Simpson. 2005. Utilization of soil organic phosphorus by higher plants, in Turner, B.L., Frossard, E., Baldwin, D. S.: Organic phosphorus in the Environment. CABI, Publishing, Wallingford, Oxfordshire, UK. pp. 165-184.

Robert, D. H. 1969. Phosphorus adsorption in soils. Soil. Sci. Am. Proc. 33: 630-663.

Robert, W. T. and J. Wood. 1981. Inorganic phosphate in calcareous rock land soils of the Bahamas, Soil Sci. Soc. Am. J. 45: 730-734.

Romer, W. and G. Schilling. 1986. Phosphorus requirement of wheat plants in various stages of its life cycle. Plant Soil 9: 221-229.

Russelle, M.P., H.E. Martin and A. J. Franzluebbers. 2007. Reconsidering Integrated Crop–Livestock Systems in North America. Agron. J. 99: 325-334.

Ryan, I. 2002. Efficient use of phosphate fertilizers for sustainable crop production in WANA. IMPHOS: Phosphate Newsletter: 2-5.

Ryden, J. C. and J. K. Syers. 1975. Rationalization of ionic strength and cation effects 0on phosphate sorption by soils. J. Soil Sci. 26: 395-406.

Russel, D. F. and S. P. Eisensmith. 1983. MSTA-C. Crop and Soil Science Department, Michigan State University, East Lancing, MI.

Samadi, A. and R. J. Gilkes. 1999 . Phosphorus Transformations and Their Relationships with Calcareous Soil Properties of Southern Western Australia. Soil Sci.Soc.Am. J 63: 809-815.

Sample, E. C., R. J. Soper and G. J. Racz. 1980. Reaction of phosphate fertilization in soils. p 263-310. In F. E. Khasawneh et al. (ed) The role of phosphorus in Agri. ASA. CSSA. and SSSA. Madison, WI. USA.

Sanders, L. J. 1986. Phosphorus for international agriculture. p. 87-90. In: P for Agri. A situation Anal. Potash and phosphate Inst. Atlanta, GA, USA.

Sayin, M., A. R. Mermut and H. Tiessen. 1990. Phosphate sorption-desorption characteristics by magnetically separated soil fraction. Soil Sci. Soc. Am. 54:1298-1304.

Scherer, E. E. 1993. Wechselwirkung zwischen mineralischer Phosphatdungung und organischer Dungung in Abhangigkeit vom Plazierungsverfahren sowie Besonderheiten der Phosphatdynamik in Latosolen Sudbrasilliens. PhD thesis, University of Bonn, Germany.

Schmidt, J. P., S. W. Buol and Kamprath, E.J. 1996. Soil phosphorus dynamics during seventeen years of continuous cultivation: fractionation analysis. Soil Sci. Soc. Am. J. 60: 1168-1172.

Shariatmadari, H., M. Shirvani and A. Jafari. 2006. Phosphorus release kinetics and availability in calcareous soils of selected arid and semiarid toposequences. Geoderma 132: 261-272.

Sharif, M., M. S. Sarir and F. Rabi. 2000. Biological and chemical transformation of phosphorus in some important soil series of NWFP. Sarhad J. Agri.16 (6): 587-592.

Sharma, R.P. and T. S. Verma. 2000. Effect of long-term lantana addition on soil phosphorus fractions, crop yields and phosphorus uptake in rice-wheat cropping in north-west Himalayan acid Alfisols. J. Ind. Soc. Soil Sci. 48: 107-112.

Sharpley, A. N., D. Curtin and J. K. Sayers. 1988. Charges in water extractability of soil inorganic phosphate induced by sodium saturation. Soil Sci. Soc. Am. J. 52: 637-640.

Sharpley, A. N. 1996. Availability of residual phosphorus in manured soils. Soil Sci. Soc. Am. J. 60: 1459-1466.

Sharpley, A. N., W. Gburek and L. Heathwaite. 1988. Agricultural phosphorus and water quality: Sources, transport and management Agric. Food Sci. Finl. 7: 297-314.

Sharpley, A. N., and B. Moyer. 2000. Phosphorus forms in manure and compost and their release during simulated rainfall. J. Environ. Qual. 29:1462-1469.

Sharpley, A.N., R. W. Mcdowell and P. J. A. Kleinman. 2001. Phosphorus loss from land to water. Integrating agricultural and environment management. Plant Soil 237: 287-307.

Shukla, S. S., J. K. Syers, J. D. H. William, D. E. Armstrong and R. F. Harris. 1971. Sorption of inorganic phosphate by lake sediments. Soil Sci. Soc. Am. Proc. 35: 193- 196.

Singh, M., K. S. Reddy, V. P. Singh and T. R. Rupa. 2006. Phosphorus availability to rice-wheat in a vertisol after eight years of inorganic and organic fertilizer additions. Bioresource Technology 98: 1474-1481.

Singh, V., N.S. Dhillon and B.S. Brar. 2006b. Effect of incorporation of crop residues and organic manures on adsorption/desorption and bio-availability of phosphate. Nutr. Cycle Agroecosyst. 76: 95-108.

Singh, M., A.K. Tripathi, K.S. Reddy, and K. N. Singh. 2001a. Soil phosphorus dynamics in a Vertisol as affected by cattle manure and nitrogen fertilization in soybean-wheat system. J. Plant Nutr. Soil Sci.164: 69-696.

Singh, M., V.P. Singh and K.S. Reddy. 2001b. Effect of integrated use of fertilizernitrogen and farmyard manure or green manure on transformation of N, K and S and productivity of rice–wheat system on a Vertisol. J. Indian Soc. Soil Sci. 49: 430-435.

Singh, K.P. and M.K. Singpuri. 1986. Sorption of phosphorus as related to properties of soils of Bihar. Indian Soc. Soil Sci. 34: 603-604.

Smillie, G. W., D. Curtin and J. K. Syers. 1987. Influence of exchangeable calcium on phosphate retention by weakly acid soils. Soil Sci. Soc. Am. J. 51: 1169-1172.

Solis, P. and J.Torrent.1989. Phosphate fractions in calcareous Vertisols and Inceptisols of Spain. Soil Sci. Soc. Am. J. 53:462-466.

Steel, R. G. D. and J. H. Torrie. 1980. Principles and Procedures of Statistics. McGraw Hill Book Co., Inc. New York, USA.

Steffens, D. 1994. Phosphorus release kinetics and extractable phosphorus after long-term fertilization. Soil Sci. Soc. Am. J. 58: 1702-1708.

Stevenson, F. J. 1982 . In Non-symbiotic Nitrogen fixation and organic matter in the tropics. Trans. 12th Int. Congr. Soil Sci. New Delhi, pp. 137-151.

Su- Ling, X. Y. Lin, Y. S. Zhang, Yu. Ai. Yang, L. Su, X. Y. Lin, Y. S. Zhang, and Y. A. Yang. 2001. Effects of flooding on iron transformation and phosphorus adsorption-desorption properties in different layers of the paddy soils. J. Zhejiang Uni. Agri. Life Sci. 27(2): 124-128.

Syers, J. D., T. D. Evans and H. Williams. 1971. Phosphate sorption parameters of representative soils from Ri Grande do Sul, Brazil. Soil Sci. 112: 267-275.

Taiz, L. and E. Zeiger. 1998. Plant Physiology. Second edition. Sinauer Associates, Inc. Publishers. Massachusetts. USA. pp. 792.

Tandon, H.L.S. 1987. Phosphorus research and agricultural production in India. Fertilization Development Consultation Organization, New Delhi.

Tarafdar, J. C and N. Claassen. 2003. Organic phosphorus utilization by wheat plants under sterile conditions. Biol. Fert. Soils 39: 25-29.

Tate, K.R. 1984. The biological transformation of P in soil. Plant Soil 76:245-256.

Tiessen., H. 1991. Characterization of soil Pand its availability in different ecosystems. Trends in soil science. Counc. Sci. Res. Integration, Trivendrum, India. pp: 83-99.

Tiessen, H., J. W. B.Stewart, and A. Oberson. 1994. Innovative soil phosphorus availability indices: assessing organic phosphorus. In: Havlin, J., Jacobsen, J. (Eds.), Soil testing: prospective for improving nutrient recommendation (SSSA special publication 40). Soil Society of America, Madison, WI, USA. pp. 143-162.

Tiessen H., J.W.B. Stewart and C.V. Cole.1984. Pathway transformation in soils of differing pedogenesis. Soil Sc. Soc. Am. J. 48: 853-858.

Tiessen, H. and O. Moir, 1993. Characterization of available P by sequential extraction. In Soil Sampling and Methods of Analysis. Ed. M. R. Carter, pp.75-86, Lewis Publishers, Boca Raton, Fl. USA.

Tisdale, S.I., W.L. Nelson and J.D. Beaton. 1985. Soil Fertility and Fertilizers. 4[th]edition. McMillan, New York, USA.

Tittonell, P., M. Corbeels, M. T. van Wijk, B. Vanlauwe, and K. E. Giller. 2008. Combining Organic and Mineral Fertilizers for Integrated Soil Fertility Management in

Smallholder Farming Systems of Kenya: Explorations Using the Crop-Soil Model FIELD. Agron. J. 100: 1511–1526.

Toor, G.S. and G. S. Bahl. 1999. Kinetics of phosphate desorption from different soils as influenced by application of poultry manure and fertilizer phosphorus and its uptake by soybean. Bioresour Technol. 69: 117-121.

Traina, S. J., G. Sposito, D. Hesterberg and U. Kafkafi. 1986. Effect of ionic strength, calcium, and citrate on orthophosphate solubility in an acidic, montmorillonitic soil. Soil Sci. Soc. Am. J. 50: 623-627.

Traore, O., S. Sinaj, E. Frossard and J. M. Van de Kerkhove. 1999. Effect of composting time on phosphate availability. Nutr. Cycl. Agroecosys. 55: 123-131.

Turner, B. L. 2004 . Optimizing phosphorus characterization in animal manures by solution phosphorus-31 nuclear magnetic resonance spectroscopy. J. Environ. Qual. 33:757-766.

Turner, B. L., M. J. Paphazy, P. M. Haygarth and I. D. McKelvie. 2002. Inositol phosphates in the environment. Philos. Trans. R. Soc. London Ser. B 357:449-469.

U. S. Salinity Lab. Staff. 1954. Diagnosis and Improvement of Saline and Alkali Soils. USDA Handbook No. 60, Washington, DC, USA.

Vanden Bossche, A., S. De Neve and G. Hofman. 2005. Soil phosphorus status of organic farming in Flanders: an overview and comparison with the conventional management. Soil Use Managem. 21: 415-421.

Vanlauwe, B., J. Diels, N. Sanginga and R. Merckx . 2002. Integrated Plant Nutrient Management in sub-Saharan Africa: From Concept to Practice. CABI, Wallingford, UK. pp. 352.

Van Faassen, H. G. and K. W. Smilde. 1985 . Organic matter and nitrogen turnover in soils. In: Proceedings of Symposium, Nitrogen Management in Farming Systems in Humid and Sub humid Tropics, B. T. Kang and J. van der Heide (eds.). International Institute of Tropical Agriculture. Ibadan, Nigeria, and Institute of Soil Fertility, Haren, The Netherlands, pp. 39-55.

Wahhab, A. 1985. Report on crop response to fertilizer and soil test data in Pakistan. FAO / NFDC Islamabad, Pakistan.

Walkley, A. and C. A. Black. 1934. An examination of the method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37: 29-38.

Watanabe, F. S. and S. R. Olsen. 1965. Test of an Ascorbic Acid Method for determination of phosphate in water and NaHCO3 extracts from soil. Soil Sci. Soc. Am. Proc. 29:677-678.

Weir, C. C. 1972. Phosphate studies on the Jamaica bauxite soils. Trop. (Trinidad) 49: 89-96.

Weir, C. C. and R. J. Soper. 1962. Adsorption and exchange studies of phosphorus in some Manitoba soils. Can. J. Soil Sci. 42: 31-42.

Werft van der P and D. Dekkers .1996. Biological processes and phosphorous. Abstract E8, 11th IFOAM Scientific Conference, 11-15 Aug, Copenhagen, Denmark.

Westermann, D. T. 1992. Lime effects on phosphorus availability in a calcareous soil. Soil Sci. Soc. Am. J. 56: 489-494

Whalen J.K. and C. Chang . 2001. Phosphorus accumulation in cultivated soils from long-term annual applications of cattle feedlot manure. Journal of Environmental Quality 30: 229-237.

White, R. E. 1980. Retention and release of phosphate by soils and soil constituents. Crit. Rep. App. Chem. 2: 71-114. In P, B. Tinker (ed) Soils and Agriculture. Jhon Wiley & Sons NY. USA.

White R. E., and P.H.T. Beckett .1964 .Studies on phosphorus potential of soils. The measurement of phosphate potential. Plant Soil 20: 1-16.

Witt, Ch. 2003. Fertilizer use efficiencies in irrigated rice in Asia. IFA Regional Conference, Cheju Island, Korea, 6-8 October 2003.

Yagodin, B. A. (Ed). 1984. Agricultural Chemistry I. Mir Publishers, Moscow.

Yang, J. E. and E.O. Skogley. 1992. Diffusion kinetics of multinutrient accumulation by mixed-bed ion-exchange resin. Soil Sci. Soc. Am. J. 56: 408-414.

Yang, J.E. and J. S. Jacobsen. 1990. Soil inorganic P fractions and their uptake relationships in calcareous soils. Soil Sci. Soc. Am. J. 54: 1666-1669.

Zhang, T.Q. and A. F. McKenzie. 1997. Changes of soil phosphorus fractions under long-term corn monoculture. Soil Sci. Soc. Am. J. 61: 485-493.