SOME ASPECTS OF CHEMISTRY OF PHOSPHOCOMPOST

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DEDICATED
TO
MY BELOVED PARENTS

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CERTIFICATE

This is to certify that the work recorded in the thesis entitled, "Some aspects of chemistry of phosphocompost" submitted by Srimati Snigdha Mandal for the award of the Degree of Doctor of Philosophy in Agricultural Chemistry and Soil Science of the Bidhan Chandra Krishi Viswavidyalaya, is the faithful and bonafide research work carried out under my guidance and personal supervision. The results of the investigation reported in the thesis have not so far been submitted for any other Degree or Diploma. The assistance and help receiving during the course of investigation have been duly acknowledged.

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APPROVAL OF EXAMINERS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY
IN
AGRICULTURAL CHEMISTRY AND SOIL SCIENCE
OF
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We, the undersigned, having been satisfied with the performance of Srimati Snigdha Mandal, in the Viva-Voce Examination conducted today, the .... 1998, recommend that the thesis be accepted for the award of the Degree of Doctor of Philosophy in Agricultural Chemistry and Soil Science of Bidhan Chandra Krishi Viswavidyalaya.

Examiners	**Signature**
1. External	....
2. Supervisor	....

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Snigdha Mandal
(SNIGDHA MANDAL)

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CHAPTER 1

INTRODUCTION

INTRODUCTION

Composting is a century old biotechnology which proved amenable to modern scientific analysis. From the age of Bible the process of composting is a widely applicable treatment technology of resource recovery.

In recent years, all dimensions of energy crisis and indiscriminate exploitation of plant nutrient reserves recite clearly that no single source of plant nutrients could meet the total nutrient demand of modern agriculture. High output in crops and livestock should be compensated with wide range of organic and mineral additives.

Total population of India has already crossed 880 million in 1993 and would be 987.3 million in the year 2000 (Anon, 1992). Remaining at the second stage of Demographic Transition Theory, India now produces 0.2 tonne of food grain per capita on its 140 mha of total cultivable land which would shrink to 0.088 ha per capita in the year of 2035 with a total food grain requirement of 400 million tonnes per year (Bali, 1988). And the total fertilizer ($N+P_2O_5+K_2O$) requirement of India would be 18.9 million tonnes by 1997-98 and 24.6 million tonnes by 2004-05 (Fert. News, 1996).

Intensive cultivation of High Yielding Varieties (HYV) with high fertilizer input brought about green revolution and surprisingly presented our soil with some complex nutrient and health symptoms (Shinde and Ghosh, 1973; Rao and Ghosh, 1981 and Lal and Mathur, 1988). To contend with the present situation the concept of Integrated Plant Nutrient Supply (IPNS) and Integrated Nutrient Management System (INMS) have evoked world wide emphasis. It has also called out the huge scope for resource recycling. Roy (1989) estimated the total annual availability of solid wastes in India to be 1356.9 tonnes. The city of Delhi

million tonnes?

generates 4000 tonnes, Bombay, 6050 tonnes; Calcutta, 3150 tonnes; Ahmedabad, 1280 tonnes and Bangalore, 850 tonnes of wastes every day (Mehta, 1995).

The table comprised by Tandon (1995) shows the availability and nutrient potential of some crop residues in India (**Appendix I**).

In this context, Nagar (1981) claimed that if 10-20% of the potential is exploited for bioenergy and for soil productivity, organic recycling can contribute significantly in solving food and energy crises. Van Voorhoeve (1974) had also viewed the matter in the same manner.

So it is now a holistic concept to make a positive step towards the environment friendly agriculture by substituting or supplementing inorganic fertilizers ~~by~~ with organic ones for ecological, economic and social reasons (Zeng *et al.*, 1992). This may help us to exploit fully the genetic potentialities of high yielding varieties and to conserve soil health as well.

Many workers have reported in favour of direct incorporation of organic residues into the soils of the tropics (Dhal and Jaiswal, 1966; Prihar *et al.*, 1975: Rao and Mikkelsen, 1977; Randhawa, 1981; Rekhi and Meelu, 1983; Bangur *et al.*, 1990; Nagarajan *et al.*, 1990; Dev and Bhardwaj, 1991; Dhillon and Dhillon, 1991; Sarkar *et al.*, 1991 and Upadhaya *et al.*, 1992). But detrimental effect of direct incorporation of crop residues on the growth of the young seedlings through liberation of toxic substances and immobilization of nutrients has also been reported (Lynch, 1978; Wallace and Whitehead, 1980).

When fresh and partially decomposed organic matters are incorporated into the soil, they may compete with the plant for available nitrogen in the early days of decomposition and may reduce plant growth and yield (Gotoh and Onikura, 1971; Patil and Sarkar; 1993). Addition of undecomposed organic matter in the soil may also lead to deficiency of phosphorus in plants due to it's assimilation by microorganisms (Kaila, 1949 and Birch, 1961). Aliphatic and aromatic acids produced from decomposing organic matters also cause poor plant growth and yield of many crops (Collision and Conn, 1925; Patrick *et al.*, 1963; Lynch, 1976).

Composting is an economically viable and environmentally sound process of microbial degradation of organic wastes to produce an organic fertilizer named compost.

A reasonably mature compost comes quickly into equilibrium with the soil and has profound impact on soil physical (Biswas *et al.*, 1971; Gaur *et al.*, 1972; Hesse and Mishra, 1982), chemical (Katyal *et al.*,1979; Gaur, 1990) and biological (Balasubramanian *et al.*, 1972; Gaur *et al.*, 1973, 1975) quality. It encourages granulation, increases water storage, nutrient supply and soil organism activity and also improves soil fertility and productivity (Allison, 1973; Johnston, 1986).

Composts are truly beneficial to soil health. Humic substances act as a buffering agent and help nutrient mobilization procedures (Russell, 1961). Khaleel *et al.*, (1981) has found a highly significant correlation between the increase in soil organic carbon induced by manure application (ΔC) and the lowering in percent~~s~~ of bulk density (ΔBD) of the soil.

$\Delta BD = 3.99 + 6.62\ \Delta C R^2 = 0.69^{**}$

** 0.01 Confidence level

Farmyard manure~~s~~ stimulate the population of soil microbes and enhance the activities of soil enzymes like amylase, catalase, cellulase, dehydrogenase, phosphatase, urease etc. and thus plays a vital role in nutrient mobilization processes (Chendrayan *et al.*, 1980; Singaram and Kamalakumari, 1995). It also increases amino sugar content of soil (Saha *et al.*, 1981) and decreases NH_3 emission immediately after application (Asmus, 1993).

Composting being a well recognised waste stabilization technique with high productivity and ecological sustainability for the production of low cost organic inputs for eco-agriculture has got no universal definition yet. Connecticut (1974) defines composting as 'a process of rotting down of organic materials in heap before it's application to the field'. The final product of the process 'Composting' - is 'Compost'. And according to Haug (1993) it 'is an organic soil conditioner that has been stabilized to a humus-like product, that is free of viable human and plant pathogens and plant seeds, that does not attract insects or vectors, that can be handled and stored without nuisance and that is beneficial to the growth of plants.'

Connecticut
a state in U.S.
the reference
should not
in the name place
State
should be
corrected

In the last few decades the process of composting has been improved by many a ways, by finding optimum conditions for optimum bioconversion, involving modern technologies to enrich it's ecological and nutritive values etc., and a number of investigators have ~~been~~ concentrated on those aspects (Kapoor *et al.*, 1983; Prasad and Singhania, 1989; Shingte *et al.*, 1990 and Singh *et al.*, 1992).

Indian soils are poor in phosphorus content, it ranges from 0.006 to 0.05 percent (Chakravarty, 1964 and Raheja, 1966) and about 98 percent of Indian soils have inadequate supply of available phosphorus (Kanwar *et al.*, 1982). In this situation phosphorus enriched compost or 'phosphocompost' has drawn due attention of the research workers since last few years (Korovkin 1952; Dhar *et al.*, 1955; Singh *et al.*, 1983., Singh and Amberger, 1990; Tiwari *et al.*, 1992; Yadav *et al.*, 1992 and Hajra *et al.*, 1994).

Infact, most of the soluble forms of phosphorus when applied in soils by means of fertilizers interacts with the hydroxides, carbonates and silicates of Ca, Mg, Al and Fe to give insoluble complexes leaving a very negligible quantity in the soil solution (Cole and Jackson, 1950; De Dutta *et al.,* 1966; Mahapatra and Patrick, 1969, 1971; Debnath and Hajra, 1972). High phosphate fixation is the major growth limiting factor. Supplementing phosphatic fertilization with organic source can minimise the problem (Khanna *et al.*, 1982). The efficiency of phosphatic fertilizer in acid soils can also be impoved if applied with FYM (Sud *et al.*, 1992). Preparation of phosphorus enriched compost is mainly based on the concept of solubilization of phosphate rock during the process of composting.

There are substantial deposits of phosphate rock in India which are estimated to be about one hundred million tonnes (Jhingram and Chowdhuri, 1977). About one sixth of these resources are of high grade ore (>30% P_2O_5) while the rest of the ores are of medium quality (15-25% P_2O_5) or poor grade (5-15% P_2O_5) which are not suitable for super phosphate manufacture (Dash *et al.*, 1981). So there is a nice scope for using these low grade phosphate sources efficiently to get a phosphorus enriched compost or phosphocompost which could serve as an alternative to single super phosphate (Mishra *et al.*, 1982).

Check, it is
Substantially
more, about
800 - 3000 mt

Several factors influence phosphate rock dissolution in soil. In addition to chemical composition and particle size of the phosphate rock, soil poperties like pH, moisture content, phosphate concentration in soil solution are likely to affect the rate and amount of dissolution (Khasawneh and Doll, 1978; Chien *et al.*, 1980; Smyth and Sanchez, 1982; Marwaha, 1983; Wilson and Ellis, 1984; Mishra *et al.*, 1985; Mackay and Syers, 1986; Hammond *et al.,* 1980 and Sanyal and De Dutta, 1991).

The dissolution of phosphate rock has a reciprocal relationship with soil pH (Cabala-Rosand and Wild, 1982; Kanabo and Gilkes, 1987).

Partial acidification with mineral acids convert to some extent, the apatite of the phosphate rock to dicalcium and monocalcium phosphates (Guzman *et al.*, 1980; Golden *et al.*, 1991a,b and Singh and Singh 1991). High agronomic effectiveness has also been shown by these partially acidulated phosphate rock (Rajan 1986; Dalal *et al.*, 1988; Chien and Hammond, 1989; Goedert *et al.*, 1990; Mackay and Wewala, 1990; Rajan and Watkinson, 1993 and Biswas and Narayanswami, 1995). But the mentioned method is capital intensive and does not give so satisfactory input-output relationship in their farm use (Ghani *et al.*, 1994).

Application of elemental sulphur also enhances the rate of dissolution of phosphate rock (Mukherjee, 1982; Basak *et al.*, 1987; Rajan 1986, Kapoor *et al.*, 1991). Pyrites containing sulphur and having a chemical composition similar to FeS_2 oxidises both chemically and biologically to produce sulphuric acid (Somani *et al.*, 1981; Tiwari *et al.*, 1984). So it could be used as a pH lowering agent to enhance the phosphate solubilisation process. Being pyrophoric in nature, pyrite is easily oxidised, when in contact with air and water, producing ferrous sulphate and sulphuric acid. A zero order rate constant is obtained for the formation of sulphuric acid (Brown and Jurinak, 1984). So, both partial acidulation and application of pyrite helps to facilitate phosphate rock dissolution (Manjaiah *et al.*, 1996). The acid so produced may help in solubilisation of phosphate rock in combination with the organic acids produced during decomposition.

The inorganic phosphorus released from rock phosphate enters into the organic pool of phosphorus and thereby enhances the mobilization of phosphorus for eventual plant uptake through mineralization (Khasawneh and Doll, 1978). Preincubation of phosphate rock and cattledung with pyrite is more effective than the control without pyrite in neutral calcareous soils (Tomar *et al.*, 1983,1984). And the quality of compost improves when phosphate rock is applied along with pyrite (Mathur and Debnath,1980). Some well known groups of organisms produce a number of organic acids and thus extracts phosphorus from insoluble phosphates by lowering pH and chelating with cations (Johnston,1956; Duff and Webley, 1959). The most dominant phosphate solubilizers belong to the genera *Bacillus, Pseudomonas* and *Micrococcus* among bacteria; *Aspergillus,* and *Penicillium* among fungi and *Streptomyces* among actinomycetes (Subba Rao, 1982). Nutrient availability of compost with respect to its N,P and humus content could be improved by P solubilizers like *Aspergillus awamori, Bacillus polymyxa* and *Azotobacter chroococcum* suitably ammended with phosphate rock (G~~o~~aur *et al.*, 1980; Sadasivam, 1981: Kapoor *et al.*, 1983; Hajra *et al.*, 1992., and Yadav *et al.*, 1992).

A superior quality phosphocompost prepared from a proper blend of paddy straw, cattledung, low grade phosphate rock, iron pyrite and urea-N along with a a little well-rotted compost as starter was found to perform similarly as single super phosphate when applied @ 10 tonnes per ha~~ctre~~. (Hajra *et al.*,1994).

hectare

All these impressive informations inspire to study some chemical aspects of the process of preparation and functioning of phosphocompost under this investigation ~~project~~ giving special thrust to the availability of phosphorus.

Straw and cattledung were mainly used as wastes and some conventional wastes like water hyacinth (*Eichhornia crassipes*) and mushroom bed wastes were also examined to prove their potentiality as phosphocompost ingredients. The thermal power plant menace, fly ash, was also tried for studying it's efficiency as phosphocompost additive. While studying the process of bioconversion, responsible microorganisms have also been given due importance.

The objective of the research reported herein was to study some of the aspects of chemistry of phosphocompost which could provide informations related to the preparation of phosphocompost and it's utilization criteri~~a~~on.

To delimit the area of research, ~~following~~ investigations were carried out in following fields. Results obtained from the experiments have been presented and discussed in the text of the thesis, entitled "Some Aspects of Chemistry of Phosphocompost".

Isolation and screening of the efficient phosphate solubilizing microorganism.

Effect of amjhore pyrites on the release of phosphorus from mussoorie rock phosphate.

Influence of different inputs on the decomposition of phosphocompost substrates.

Mineralization of carbon, nitrogen and phosphorus during preparation of phosphocompost from paddy straw-water hyacinth mixture: an incubation experiment.

Preparation of phosphocompost from paddy straw - water hyacinth mixture: a field experiment.

Effectiveness of the prepared phosphocomposts in comparison to fertilizer P on the dry matter yield and uptake of P by Rice Bean (*Vigna ambellata Thumb Ohwi and Ohasi*) and Paddy (*Oryza sativa*).

CHAPTER 2

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Phosphorus is an essential constituent of all living organisms. It has been referred as the Master Key element in crop production by Pierre (1938). In plants it exists as the inorganic phosphate ion ($H_2PO_4^-$or HPO_4^{-2}) and in combination with organic compounds. Major phosphorus containing compounds are the nucleic acids, phospholipids and phytin (Ca-Mg salts of inositol hexaphosphate). Other compounds include adenosine di or tri phosphate and the phosphopyridine nucleotides.

The phosphorus status of Indian soil is high only in 2%, medium in 56% and the remainder is of low phosphorus status (Roy and Kanwar,1979).High depletion of phosphorus is replenished through external sources. But more than two third of the applied phosphatic fertilizer is converted to unavailable forms within a very short period of its application due to retention in the soil complex (Hemwall, 1957; Langguth *et al.,* 1957; Wild, 1970; Mandal and Khan, 1972).

Organic matter is known to improve phosphate availability (More and Ghonsikar, 1988; Subramanian and Gopalswami,1991) as it produces organic acids and carbondioxide during decomposition which has a solubilisng effect on iron, aluminium, magnesium and calcium phosphate (Sen and Bains, 1955). It also helps to improve phosphorus availability by producing organic anions and hydroxy acids, which may complex with iron, aluminium and calcium ions and prevent them from reacting with phosphate ions and thus reducing reversion of phosphates to unavailable forms (Metwally and Pollard, 1959; RajaGopal and Idnani, 1963). These findings have influenced several investigators to indulge themselves with the possibility of the union of the two processes, one is the process of decomposition of organic matters and the other is the solubilisation of phosphorus (Midgley and Dunklee, 1945; Korovkin, 1952; Mathur *et al.*, 1980 and Mathur and Debnath, 1983). On this platform of studies, several researchers have prepared and evaluated phosphorus enriched composts from organic wastes properly amended with phosphate rock and other inputs which could serve as supplementary or alternative to costly inorganic phosphatic fertilizers (Basak and Debnath, 1987; Despande *et al.*, 1987; Tiwari *et al.*, 1988 and Hajra *et al.*, 1994).

To comprehend the entire issue of phosphocomposting, proper understanding of the interacting ingredients and the factors that influence the process seems to be a prerequisite. So, all the relevant informations have been reviewed under the following subheads.

2.1 POTENTIAL AND AVAILABLE SOURCES OF COMPOSTABLE SUBSTRATES

Crop residues

Every year India produces a substantial quantity of crop residues. Depending on climatic and other conditions the availability amount varies. In 1994-95 the potential crop residue production was 121.8 million tonnes (mt); wheat straw: 98.2 mt, coarse cereals: 60.8 mt, pulses: 14.1 mt, sugarcane: 54.2 mt and oil seeds: 42.8 mt (Fert. News,1995-96). On an average cereal straw and residues on maturity contain about 0.5% N, 0.6% P_2O_5 and 1.5% K_2O (Tandon, 1995). The nutrient potential of these crops (391.9 million tonnes) thus comes to 1.95 million tonnes of nitrogen, 2.35 million tonnes of P_2O_5 and 5.87 million tonnes of K_2O. Most of the residues are used as cattle feed, thatching and burning material in rural areas, in paper/board industries and as packing material. Even if 50 percent of these residues are recycled, it would be highly beneficial for soils, plants and our environment as well. An estimate of the availability of some crop residues in India and their nutrient potential is given in **Appendix I.**

Cattle wastes

The present cattle population of India is 201-206 million and it is projected to be 204 million heads by the end of this century (Jain and Kumar, 1995).

The annual excretion of dung from cattle amounts to 218.24 million tonnes (dry weight basis) (Tandon, 1995). Nearly 24 percent of produced dung is burnt as fuel cakes, 72 percent is used for making manure and 3.2 percent is used in other purposes (Goel *et al.*, 1973).

The total nutrient potential of the cattle excreta only is estimated to be 2.077 million tonnes of nitrogen, 0.793 million tonnes of P_2O_5 and 1.332 million tonnes of K_2O per annum (Gaur *et al.*, 1984). It cannot be said with any certainty that how much dung is used for fuel and how much for manure. Though in contrast to Goel's report (1973), recent reports mention that almost 71% of total dung may be used as domestic fuel (Biswas *et al.*, 1991).

Water Hyacinth

Although almost every state in India has aquatic weeds, the water bodies in Uttar Pradesh, Punjab, Haryana, Rajasthan, Madhyapradesh, West Bengal, Bihar, Kerala, Andhra Pradesh and Orissa are particularly infested with these. Noxious aquatic vegetation like water hyacinth (*Eichhornia crassipes*) is a serious concern to the fresh water fisheries, irrigation systems and low land paddy cultivation (Gopal, 1981). Composition of *Eichhornia crassipes* varies with location, season and water quality (Parra and Hortenstine, 1974; Poddar *et al.*, 1991). It contains 35% carbon in total, while nitrogen content of root and top are 2.6 and 3.9% respectively and phosphorus content of root and top are 0.68 and 0.45%

respectively (Gupta, 1987). The overall composition of *E.crassipes* invites the idea for utilising it as a composting substrate (Basak, 1948; Jagadeesh and Lakshminarayana, 1971) but the long dormancy period (about 15 yrs.) of the water hyacinth seeds is a major problem (Gupta, 1987). India has a potential of 3.0 million tonnes of hyacinth compost annually and it has proved to be the better way of weed management than the other systems most of which causes water pollution with the decomposed bodies of water hyacinth (Ahmed *et al.*, 1981; Gaur *et al.*, 1995).

Kondap *et al.*, (1981) reported a saving of 40 kg Nitrogen/ha by incorporating *E. crassipes* leaves @ 10t/ha as a green manure, with no adverse effect on the grain yield or spread of the weed.

Elserafy *et al.*, (1980) achieved enough success with *E.crassipes.* They composted it with ammonium sulphate, superphosphate and lime with a moisture content of 60% and a turning interval of 6 weeks. After 185 days of processing the C/N ratio reduced from the initial value of 40.28 to 9.5 and the final compost had a CEC of 75 meq/100 g dry ash free material. Water hyacinth when incorporated @ 2.5 mt ha^{-1} along with straw at the ratio 50:50 into the crop field of Bihar, it responded appreciably to the yield of wheat (Srivastava *et al.*, 1988). Positive influence of water hyacinth compost on the crop yield has also been reported by Boyd, 1974; Mathur and Debnath, 1980 and Berton *et al.*, (1989).

2.2 DECOMPOSITION OF ORGANIC MATTER

Organic substances like straw, tree trimmings, refused paper, agricultural wastes etc., generally used in a compost system, are derived from plant materials. The organic constituents of plants are commonly divided into six broad categories: i) cellulose, the most abundant one, varies in quantity from 15 to 60 percent of the dry weight and provides strength and flexibility to the wood, ii) hemicellulose, 10 to 13 percent of the dry weight, helps bonds of lignin to the cellulose fibrils, iii) lignin, 5 to 30 per cent of the plant, cements the cellulose fibres together and protects against biological and chemical attacts, iv) water soluble fractions which make up 5 to 30 percent of the tissue weight, v) ether and alcohol soluble components which contain fats, oils, waxes resins and a number of pigments and vii) protein parts containing 50 to 55 percent carbon, 15 to 19 percent nitrogen, 6 to 7 percent hydrogen, 21 to 23 percent oxygen and a small amount of sulphur which make up 1 to 20 percent of all plant residues. And the mineral constituents of plants vary from 10 to 13 percent of the total tissue.

Decomposition of plant and animal refuses and remains occur through both biological and chemical path ways. Initially microorganisms attack readily decomposable organic substances. Different constituents of organic residues decompose at different rate. Simple sugars, amino acids, most proteins and certain poly-saccharides decompose very quickly and can be completely utilized in a matter of hours or days. Proteins and simple biochemical compounds decompose quickly whereas cell walls and certain microbial melanins resist decomposition (Hurst and Wagner, 1969 and Haider *et al.*,1974).

Hemicelluloses are complex heteropoly saccharides containing about 50-150 sugar units and is divided into two groups; (i) those containing poly uronides and (ii) those devoid of specific residues. The non-uronide hemicelluloses are usually closely bound to cell wall cellulose.The polyuronide hemicelluloses are composed principally of glucuron-oxyloglycans, but galacturonoarabinoglycans have also been isolated.

Poly uronides give sugars and sugar acids on cleavage. Hemicelluloses decompose more readily than cellulose (Acharya, 1935).Mesophilic (Norman,

1934) and Thermophilic bacteria (Forsyth and Webley, 1948) and Actinomycetes (Waksman and Cordon, 1939) attack hemicellulose more easily.

Many fungal genera are also equally active. The most active species are *Aspergillus, Fusarium, Trichoderma* and *Trichothecium* (Simpson, 1954).

Cellulose is a polymer of glucose having β-D-glucose molecules bound in a long, linear chain at carbon atoms 1 and 4 of the sugar molecule (Figure 2.2.1). The chains of glucose molecules so formed lie parallel to each other, in a regular array to form crystallites. The degree of crystallinity of cellulose depends on age and type of plant. It is important in relation to the enzyme accessibility.

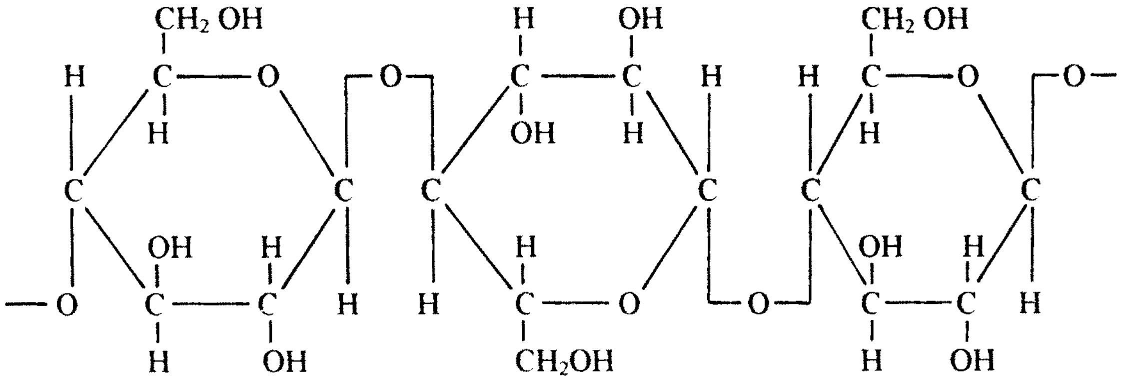


Figure 2.2.1 β-1,4 glucoside

Attacks on the molecule occur considerably more readily in the amorphous regions than in the crystalline regions. Hydrolytic enzymes like cellulases convert cellulose to glucose and oligomers. The plausible mechanism is shown in the next page.

$$\text{Native cellulose} \xrightarrow{\textit{endo-glucanase}} \text{Modified Cellulose}$$

$$\text{Modified cellulose} \xrightarrow{\textit{exo-glucanase}} \text{Cellobiose}$$

$$\text{Cellobiose} \xrightarrow{\textit{glucosidase}} \text{Glucose}$$

Degradation of cellulose due to microbial attack has been studied by Fujio and Young, 1980; Zdlewske and Ur-banek, 1981; Verachtert *et al.*,1982; Mas,1984 and Obarman and Stobinska, 1987.

The most frequent species for cellulose decomposition are *Aspergillus* spp., *Fusarium* spp., *Alternaria alternata, Myrothecium verrucaria, Penicillium* spp. *Humicola orisea, Drechslera spicifera* and *Cladosporium herbarum* (Abdel-Hafez and Abdel Kader, 1980; Fujio and Young,1980).The cellulolytic capacity of *Chaetomium globosum, Trichoderma viride, Fusarium* spp. *Penicillium chrysosporium* were reported by Mishra *et al.*,(1979) and Guerra *et al.*,(1984). Brown *et al.*,(1987) showed that the enzyme production by cellulolytic fungus,*Penicillium pinophilum* mutant strain STG III/6 increased on raising the temperature of incubation from 28-35°C in a fermenter. Availability of nitrogen also plays a vital role in cellulose decomposition (Flaig, 1962).

Cellulose degradation is of paramount importance in the process of composting (Stutzenberger *et al.*, 1970). A large number of microorganisms are cellulose degrading (Mas, 1984) and cellulolytic activity of mixed cultures are higher than pure culture. And it is attributed to the removal of inhibitory end products like cellobiose and to cross feeding (Trojanowski *et al.*, 1984 and Deacon, 1985). On cleavage it produces carbondioxide, some slimy material, certain pigments and a number of cell substances.

Lignins are complex plant component containing 61 to 64 per cent of carbon, 5 to 6 percent hydrogen and 30 percent oxygen and is composed of substituted phenylpropane groups linked together. It never occurs free. Usually it remains with the polysaccharides. The basic unit may be schematically shown as below.

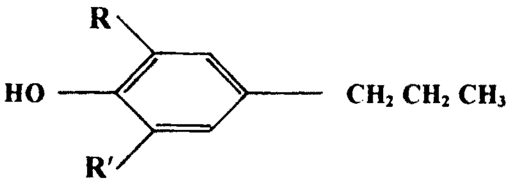


Figure 2.2.2 A polysaccharide unit where R and R′ are either H or methoxyl ($-OCH_3$) group (Sarkanen, 1971).

Lingin is a primary controlling factor of decomposition rate of plant residues. It is highly resistant to biodegradation (Zeikus, 1980) and 15 percent of lignin seriously reduces the decomposition of cellulose. It also affect the decomposition of proteins in some cases. The retardation is thought to be the unavailability of surface area which prevents ready access to the cellulose by invading microbes and their enzymes (Stevenson,1986). ?

It highly requires molecular oxygen for it's biodegradation (Bar-Lev and Kirk, 1981; Reid and Seifert, 1982). Microbial degradation of lignin has been reviewed by Crawford and Crawford, (1980); Kirk *et al.*, (1980); Knapp, (1985); Ulmer *et al.*, (1984) and Faison and Kirk, (1985). ?

The white rot fungi basidiomycetes, (Cowling, 1961; Eriksson and Lindholm, 1971;Hackett *et al.*, 1977) some soil microorganisms (Martin and Haider, 1976; Hackett *et al.*, 1977) and termites (French and Bland, 1975; and Butler and Buckerfield, 1979) are capable of lignin degradation. Brown rot and soft rot fungi also cause some modification of lignin.

Bacterial species like *Nocardia, Streptomyces*, *Bacillus, Pseudomonas, Aeromonas* and *Flavobacterium* can cause lignin degradation. ?

Fungus like *Aspergillus. Penicillium* and *Fusarium* also attack lignin ~~in~~ to some extent but they also utilize cellulose (Alexander, 1961).

The pathway of lignin decompostition by fungi as described by Schubert (1968) is shown in Figure 2.2.3.

Aspergillus spp, *Fusarium solani, Paecilomyces varioti, Penicillium chrysogenum* and *Trichoderma viride* QM 9414 degrade lignin to some extent but *P.varioti* was the most efficient in lignin degradation (Mishra *et al.,* 1979).

Soil microorganisms like bacteria, fungi imperfecti and basidiomycetes efficiently degrade lignin (Kaplan and Hartenstein, 1980). Eriksson and Kolar (1985) reported that *Sporotrichum pulverulentum* degrades chlorolignin. Blue green algaes also degrade lignin in solid as well as in liquid medium (Hussein *et al.,* 1989a and 1989b).

Among various waste lignins, Kraft lignin waste liquor is readily degradable (Bouveng and Solyom, 1973). The lignin rich tracheids in the sawdust tissue undergo no decomposition even after four months of composting (Fujiwara *et al.,* 1980). Nitrogen is a limiting factor for decomposition of lignin (Flaig, 1962). According to Bes *et al.,* (1987) H_2O_2 was essential for lignin degradation. Kirk *et al.,* (1977, 1978) reported that many fungi are able to degrade lignin only in presence of a readily utilizable carbohydrate source.

Proteins make up 1-20 percent of plant residues and vary considerably in nature and functions, depending upon their amino acid make up. On hydrolysis

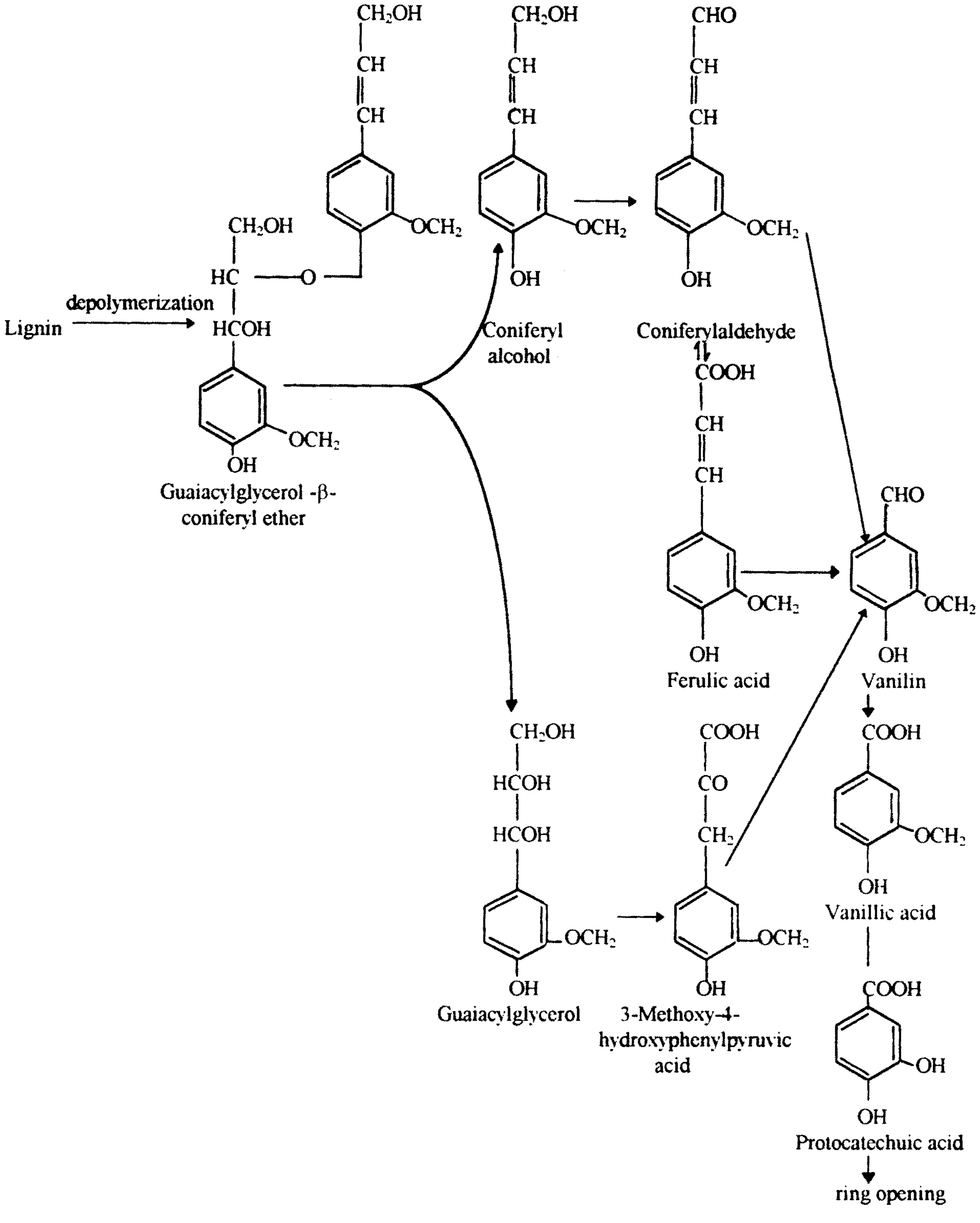


Figure 2.2.3 Proposed pathway for the microbial metabolism of lignin

they split first into various polypeptides and finally into simple amino acids. The latter are further attacked by a great variety of bacteria and fungi, giving rise to ammonia, carbondioxide and various organic acids and alcohols. Under anaerobic conditions, various amines and mercaptans are also formed and these are responsbile for the putrefactive odors produced in the decomposition of protein rich materials.

Considering all these factors, conscious selection of strains is the most important point to ponder in the matter of decomposition of carbonaceous materials.

To operate the composting system successfully, some knowledege about the degradability of composting substrate is also necessary to choose proper substrate or combination of substrates for composting (Haug,1993).

Chandler *et al.,* (1980) have determined a strong correlation between volatile soild's destruction and lignin content of the biodegradable substance and have provided an authentic model for predicting substrate biodegradability with the help of the equation given below:

$B = 100\,[0.830 - (0.028)X]$

B = percent biodegradable fraction of the volatile solids.

X = percent lignin content of the volatile solids (VS)

Based on this equation, Kayhanian and Tchobanoglous (1992) has estimated the biodegradable fraction of food wastes and yard wastes to be 81.9 and 71.5 percent respectively when the lignin content of the former waste was 0.4 percent of VS and that of the latter was 4.1 percent of VS. Chandler *et al.,* (1980) have studied the degradability of some selected substrates during anarobic digestion at 35°C, and have reported that after 120 days of digestion, the degradability of wheat straw, water hyacinth and cow manure was recorded as 55.4 percent, 55.8 percent and 58.8 percent of the volatile solids respectively.

A generalised mass balance on total solids into and out of the process has been expressed by Haug (1993) as:

Solids in = Solids out + Volatile solids out.

2.3 FACTORS AFFECTING RAPID DECOMPOSITION OF ORGANIC MATTERS.

Rapid decomposition of carbonaceous materials is dependent upon the chemical composition and decomposability factor of the material as well as the environmental factors acting on it. It also depends on the presence of viable microbial population (Parr and Papendick, 1978). Important factors involved in the process of decomposition are reviewed under the following subheads.

PHYSICAL FACTORS

Size of the Composting Material

The decomposition process accelerates when raw materials are shredded into smaller pieces to make these more susceptible to microbial attack due to exposure of greater surface area to obtain better initial aeration (Unversity of California, 1953; Gotass, 1956).

Grinding makes it easy to handle the decomposing material.Golueke *et al.*, (1954) found that the shredding permitted more rapid and uniform decomposition while unshredded ones developed anaerobic condition and not restored the desired temperature. During thermophilic stage the evolution of CO_2 might be doubled if proper size of composting materials used for decomposition (Gray and Sherman, 1969).

Air

The composting matrix is a network of solid particles that contain voids and interstices of varying size filled with water and air. Air must be supplied to a composting material for three basic purposes; firstly, to fulil stoichiometric oxygen demand for organic demcomposition, secondly, drying demand and thirdly, heat removal demand. Approximately 30% free air space are found to be the optimum condition (Schluze, 1962). Unless there is adequate aeration, a pile turns pale green and foul smelling gases are produced due to anaerobic decomposition,which may be hazardous if high concentrations are produced (Wiley, 1967). Turning is one of the most useful method of aeration. To maintain adequate aeration,turning at an interval of 2-3 days is enough for rapid decomposition (University of California, 1953). Constant agitation causes cooling, drying and disruption of fungal mycelia (Gray *et al.*,1971).

The stoichiometric oxygen requirment can be determined from the chemical composition of the organic solids (Haug, 1993). For yard wastes, the average composition is $C_{27}H_{38}O_{16}N$ (Kayhanian and Tchobanoglous, 1992), the oxygen demand can be determined as;

$C_{27}H_{38}O_{16}N + 27.75O_2 \rightarrow 27\,CO_2 + NH_3 + 17.5H_2O$....... (i)

632 27.75(32)

Here, carbonaceous oxygen demand = 1.4 O_2/g of substrate of Biodegrable Volatile Solid (BVS). Ammonia released as a result of organic decomposition can be oxidised according to the following nitrification reaction:

$NH_3 + 2O_2 \rightarrow NO_3^- + H_2O + H^+$....... (ii)

2(32)

Assuming all ammonia is oxidised, the maximum nitrification demand would be 0.1 g O_2/g of substrate BVS.

The stoichiometric demand for oxygen varies from a low of about 1.0 g O_2/g organic for highly oxygenated substrates such as starch and cellulose to a high of about 4.0 g O_2/g organic for saturated hydrocarbons.

Moisture

Decomposition of organic matter largely depends on the presence of moisture. The importance of proper moisture control lies in its effect on microbial kinetics, and its influence on the temperature development factor of the composting system and the moisture content quality of the final product (Senn, 1971). Golueke (1977) pointed out that the theoretically ideal moisture content is one that approaches 100% because under such conditions biological decomposition occurs in the absence of any moisture limitation. Whereas, Haug (1993) described that the practical moisture content must be considerably less than 100 percent, as the process includes solid or semisolid materials and necessary conditioning should be done with suitable bulking agents or supplemental water addition. McGauhey and Gotaas (1953) reported that as great as 85% of initial moisture helped composting of mixtures of vegetable trimming and straw but 76% moisture was too great when paper was used in place of straw.

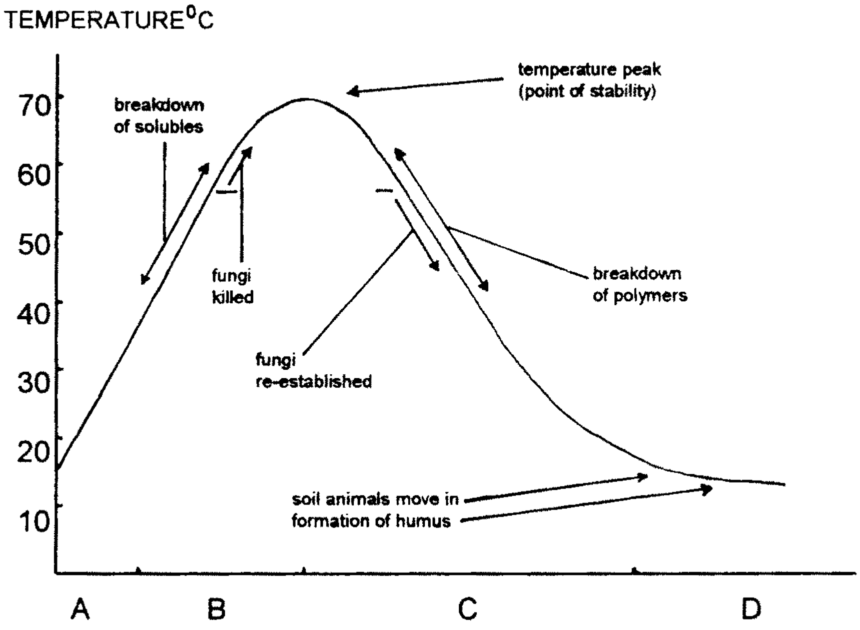
Teensma (1962), Gotaas (1956) and Schulze (1961) concluded that the optimum moisture level is often 50-60 percent for aerobic composting.

Temperature

Composting is very much a dynamic process including biological and chemical ones and it operates successfully over a limited temperature range. The solar energy entrapped into the plant tissues during photosynthesis is again released as heat energy during the microbial break down of plant tissues which is an exothermic reaction.The temperature is equivalent to the metabolic heat output (McGregor *et al.*,1981).

Firstly the temperature rises to 45-50°C within 24 hours of composting and after 2 to 5 days the temperature rises upto 60-70°C. Mesophilic growth is stimulated by the higher temperatures, but as the inhibitive level is reached, this leads to a self-limiting condition (Finstein and Morris, 1975). At high temperature level, thermophilic growth is dominant and the decomposition rate is highest at this stage (Waksman *et al.*, 1939). Microbial activity is highest at the temperature range of 52-60°C and beyond this a steep decline is observed (Carlyle and Norman, 1941; Wiley, 1956; Rothbaum, 1963; Dye and Rothbaum 1964; Jerris and Regan, 1973 and Suler and Finstein, 1977).

Above 70°C a few of thermophilic organisms remain active,so the ? temperature should not exceed 70°C for a long period (Glathe, 1959). But it is necessary to subject all the materials in the compost heap to a temperature of 60°C at least, to destroy the pathogenic organisms (Gotaas, 1956). The final decline in temperature is more gradual than the initial rise and it indicates stabilization of the composting material (University of California , 1953; Chang and Hudson, 1967; Olds, 1968 and Kochtitzky *et al.*, 1969). The temperature variation in a compost heap is shown in Figure 2.3.1(Gray and Biddlestone,1981).



A mesophilic B thermophilic
C cooling D maturing

Figure 2.3.1 Temperature variations in a compost heap

CHEMICAL FACTORS

Carbon-Nitrogen Relationship

The C/N ratio is of high significance in the process of decomposition of organic matter, as carbon is necessary for growth of microorganisms and nitrogen is essential to cellular synthesis. McGaughey and Gotaas (1953) composted mixed refuse materials with initial C/N ratios ranging from 20 to 78 and found 30 and 35 to be the best suited ones for rapid composting of the materials; below which there was an increasing loss of nitrogen through ammonia volatilization and above which the composting time increased. Some research workers have reported optimum values from 26 to 31 (Lambert, 1931; Sinden, 1938; Acharya and Subramanyam, 1939 and Cornfield, 1958). Since living organisms utilise 30 parts of carbon for each part of nitrogen (Waksman, 1938), C/N ratio of 30 would seem most effective for rapid composting (University of California at Berkley, 1953; Bangar and Patil, 1980).

According to Haug (1993), for an aerobic decomposition system, the general energy reaction can be written as:

$$C_6H_{12}O_6 \longrightarrow 6CO_2 + 6H_2O$$

$$5CO_2 + 2H_2O + \text{energy} \xrightarrow{NH_3} C_5H_7O_2N$$

(average cell formulation)

(assuming cellulosic substrate as energy source and ammonia as source of cell nitrogen).

And the net metabolic reaction can be written as:

$$6C_6H_{12}O_6 + 31O_2 + NH_3 \longrightarrow C_5H_7O_2N + 31CO_2 + 34H_2O$$

Here, 36 mole of carbon is used for each mole of nitrogen, so the required C/N ratio is; $36 \times 12 / 1 \times 14 = 30.9$

So, it is necessary to add carbonaceous material to the system to raise the C/N ratio or to add nitrogen to lower it down to attain the desired initial value (Haug, 1993).

Knapp *et al.*, (1983) recorded enhanced rate of microbial respiration during decomposition of wheat straw added with nitrogen which resulted in decrease of C:N ratio from 150:1 to 48:1. Whereas Hajra *et al.*, (1974) considered the C:N ratio of 40:1 as optimum for rapid decomposition of wheat straw.

Nuntagij *et al.*, (1989), Bremer *et al.*, (1991) and Singh *et al.*, (1995) reported that addition of nitrogen enhanced the decomposition of organic matter. Addition of $NaNO_3$ and $(NH_4)_2SO_4$ increases the activity of cellulose decomposers in soil.

The study of Singh (1991) revealed that application of nitrogen did not increase the microbial activity during decomposition of sugar cane trash and suggested that a supply of more easily degradable carbon source was more important.

Addition of nitrogen in the form of chemical fertilizer or non-edible cakes accelerates the pace of mineralisation of nutrients from cereal residues poor in nitrogen and a C/N ratio of 30-40:1 maintains a higher level of NH_4-N and NO_3-N (Gaur *et al.*, 1973; Hajra *et al.*,1974).

Polprasert *et al.*, (1980) raised the C/N ratio of the mixture of water hyacinth and night soil to the level of 20-40 through application of ~~leave~~ leaf falls. To lower down the initial C/N ratio to the desired level activated sewage sludge has been utilised by a number of investigators (Wiley and Spillane, 1962; Wiley, 1967 and Kochtitzky *et al.*,1969). Addition of slaughter house waste, biogas slurry, cattle dung, leguminous plants, water hyacinth and azolla also lower down the C/N ratio of the compostable organic matter to reduce the required time for composting and to lessen nitrogen loss (Manna *et al.*,1989; Gaur, 1995). Lowering the C/N ratio to 60 with addition of urea-N, Debnath and Sinha (1993) recorded maximum decomposition of paddy straw after 88 days of incubation. But high dose of nitrogen were uneconomic in composting of straw due to significant increase in denitrifying bacteria (Zayed *et al.*, 1969).

Reaction (pH) During Composting

Both the hydrogen and hydroxide ions are toxic to microorganisms and for most of the organisms the optimum pH is 6.5 to 7.5 (Haug, 1993). At the early stages of composting, pH lowers down to 4.5 to 5.0 due to production of carbondioxide and organic acids and later it comes to near neutral value as the decomposition continues (University of California, 1953; Kocktitizky *et al.*, 1969 and Gray *et al.*, 1987).

Composting has a rather unique ability to buffer both high and low pHs back to a neutral range as composting proceeds. This is because both weak acid (CO_2) and weak base (NH_3) are produced as a result of microbial decomposition of organic matter and protein respectively (Shell and Byod, 1969; Devis *et al.*, 1991).

Substrates that are both low in nitrogen and low in pH (eg. industrial sludge), neutralization may not occur because ammonia is not available. In this neutralization with $CaCO_3$, NaOH, Na_2CO_3 and NH_3 could be so necessary as it may lead to nitrogen loss through volatilization at higher pH (Gotaas, 1956).

Donnelly *et al.*,(1990) showed that cellulose decomposition and microbial biomass were not affected by soil acidity but Bienkowski (1992) reported a reduction in cellulose decomposition with increasing acidity when cellulose filters were placed in soil.

BIOLOGICAL FACTORS

Microbial inoculum

Microbes are of paramount importance in the process of decomposition, whether it is a homogeneous or a heterogeneous substrate system. During early stages the microbial population increases with high O_2 uptake followed by longer period of low O_2 uptake. Fungi and acid producing bacteria appear during the mesophilic stage and above 40°C actinomycetes and thermophilic bacteria and fungus appear (Golueke, 1954; Chang and Hudson, 1967). The size of inoculum depends upon the concentration of microbes in the starting substrate. Golueke (1977) distinguished between "minute" inoculation and "mass" inoculation with microbes. According to him, if the addition of "minute" inoculum contributes anything to facilitate the compost process it is so minute as to be undetectable. Mass inoculation with mesophilic cellulolytic fungi are known to reduce the time needed for completion of the process and improve the quality of the final product (Gaur, 1982; Gaur *et al.*,1981).Gaur, (1987) and Gaur and Mathur,(1990) used homogenised fungal cultures @ 300 gm/tonne to produce a good quality compost. The nutrient status of sorghum stalk and wheat straw compost improved after inoculation with *Aspergillus niger* and phosphate solubilizer (Gaur and Sadasivam, 1993). The beneficial effect of cellulolytic fungi in composting of dairy farm waste has been reported by Tiwari *et al.*, (1989). Inoculation with cellulolytic fungi increases the rate of decomposition of sawdust (Davey, 1953 and Wilde, 1958), sugarcane trash (Jadhav *et al.*,1992) and paddy straw (Hajra *et al.*,1992). Microorganisms like *Trichurus spiralis,* *Paecilomyces fusisporus, Trichoderma* spp. and *Aspergillus* spp. are also known inoculum to speed up the process of composting (Gaur and Singh, 1995). Enrichment of compost with N-fixing bacteria and P-solubilising fungi is one of the possible ways of improving nutrient content of the final product (Gaur and Mathur, 1990). Microbial inoculum also proved to be beneficial for preparation of phosphocompost (Sadasivam *et al.*, 1981: Kapoor *et al.*, 1983; Hajra *et al.*, 1994). Some time other amendments like cattle dung (Yadav *et al.*, 1992), horse manure, rich soil etc. could be as effective as mass inoculum (Haug, 1993).

Other Factors

Proper structural, chemical and energy conditioning are the most important factors to initiate a high rate decomposition process to get an agreeable product. For an efficient organic decomposition process, perfect mass balance for solid, water and gas and balance between total input energy and total output energy including the resultant latent heat should be considered seriously. Haug (1993) has developed simulation models to study the dynamics of composting process with an integrated view of kinetic and thermodynamic principles which governs the processes. A user friendly composting process design computer model has been provided by Person and Shayya, (1993); the package COMPOST has been developed as a design, management and educational tool to assess composting system requirements, e.g., ingredient characteristics, critical operational parameters etc.

Maturity indices

A decreasing value of C/N ratio indicates maturity (Garcia *et al.*, 1990;1991). Generally a C/N ratio of 10 to 12 indicate maturity (Connecticut, 1974). Inoko *et al.* (1982) considered a C/N ratio of 20 and a reducing sugar ratio

(ratio of carbon in hemicellulose and cellulose to total carbon) of <35% to be indicative of maturity.

A well stabilised compost never gives a positive starch test (Lossin, 1971).

The presence of nitrate and absence of ammonia are indicative of maturity (Inbar *et al.*,1993).

Germination test with the aqueous extract from compost is also a stabilization index. The 'germination index' is defined as the product of germination percentage and root growth. If that index is > 50%, it seemed that toxicity level has reduced to an acceptable level (Zucconi *et al.*,1981 a,b).

A respiration rate of 100 mg/kg ds-h is acceptable for most field application and a rate nearer to 20 mg/kg ds-h is desirable for horticulture uses (Wilson and Dalmat, 1986).

The negative charge, i.e. the cation exchange capacity (CEC), of organic matter increases as the compost matures (Harada and Inoko, 1980). Highly significant correlation was observed between the CEC and C/N ratio (r = 0.992***). CEC of the compost pile with turning and aeration increased to 70-80 meq/100g during 5-8 weeks and thereafter was almost constant (Harda *et al.*, 1981). A CEC value of 74 meq/100g was reported by Kakezawa *et al.*, (1992) after 8 weeks of fermentation of a mixture of rice straw, activated sludge, chicken dropping and commercialized organic compost.

The ratio between the optical densities at 465 and 665 nm, called the E_4/E_6 values, which are the measures of degree of humification and aromatisation, increases in both humic acid and fulvic acid with maturation.

N'Dayegamiye and Isfan, (1991) considered the E_4/E_6 value of 6.4 as the index of the maturation stage of compost.

A well rotted compost is not a phytotoxic one. Phytotixic substances like ammonia, phenol and organic acids of low molecular weight decreases below the toxicity level at the final stage of composting (Garcia *et al.*, 1991).

Maturation period

Enough time should be given to the composting process so that a well stabilized compost could be obtained. Necessary odor management strategies should be adopted through wet scrubbing, biofiltering or just enhancing atmospheric dispersion (Williams and Miller, 1992 and Haug, 1993). De Vleeschauwer *et al.*, (1981) concluded that at least 4 months composting would be required for town refuse before the product could be used safely in agriculture. Using batch process Hong *et al.*, (1982) obtained a well stabilized compost from dairy manures in 7 days only. Parr *et al.*, (1982) reported a maturation period of 7 weeks for composting sewage sludge by aerated pile method.

2.4 DYNAMICS OF HUMIFIED SUBSTANCES IN SOIL

Transformations depend largely on the nature and environment of the soil. After application to the field chemoorganotrophs attack the incorporated organic matter and derive their nutritional requirements, as a consequence nutrients are made available to soil (Alexander, 1977). The degree of nutrient availability not only demands upon the quantity and quality of added organic residues (Mukherjee and Gaur, 1980) but also upon the built up of autochthonous population (Gaur *et al.*, 1973).

The addition of organic matter brings about remarkable changes in the composition of microflora in the soil (Gaur, 1973; Sadasivam, 1973 and Das and Mukherjee, 1988). The interactions between nutrient flow and the associated microbes must be understood in order to ascertain the process mechanism and how it is affected by external factors.

Activities and interactions of the components in a complex ecosystem can be examined using laboratory models. A helpful reference for the design and implementation of laboratory models is provided by Giesy, (1980).

The phenomenon of migration and accumulation of various metals in soil is ascribed to the presence and also the type of humic substance (Desai and Ganguly, 1980; Tipping *et al.*, 1988).

Biochemical transformation of organic matters results largely from the enzymatic activities of proliferating microorganisms. Micorrhizal fungal component is also important for nutrient turnover (Voigt, 1982).

Stevenson (1982) reported that three interrelated organic matter fractions should be taken into account when considering nutrient-organic matter interactions in soil. They are (i) plant and animal residues which provide N, P and S for plant growth (ii) microbial biomass and (iii) the resistant humus fraction.

The application of plant and animal residues results in different mineralization and immobilization of nutrients.

$$\text{Organic N,P,S} \xrightleftharpoons[\text{immobilization}]{\text{mineralisation}} NH_4^+, NO_3^-, PO_4^{3-}, SO_4^{2-}$$

The N, P and S contents of the applied material play a major role in regulating the availability phenomenon. As a general rule an initial net mineralization would occur at C/N<20:1,C/P<200:1 and C/S<200:1. An initial net immobilization of N would occur at C/N ratio of 30: 1, that of P at C/P ratios over 300:1 and that of S at C/S ratios over 400:1. Intermediate ratios lead to neither a gain nor a loss of the nutrient (Stevenson, 1986).

The release of N, P and S to available mineral forms can follow a number of pathways, the more common ones are (i) an initial net immobilization followed by net mineralisation in later stages (ii) a steady rate of release with time and (iii) an initial net mineralisation followed by net immobilization. The pattern of nutrient release has not been shown to be related to any given soil property, including the N, P and S content of the soil (Stevenson,1986).

Askinazi (1938) and Ginzb'urg (1960) reported that availability of P_2O_5 was increased in the presence of humic acid. Organic residues increase phosphorus availability through several ways. Firstly, the slow release of inorganic phosphorus during the decomposition of the organic matter provides a continuous supply of phosphorus with a minimum possibility of exposure to different fixation mechanism. And secondly, when applied to neutral or basic soil, organic acids like oxalic, succinic, crotonic, lignoceric, monohydroxy and dihydroxy stearic produced by decomposing organic residue decrease the soil pH and thus increase the availability of phosphorus (Black, 1968).

Components of the organic matter have been found to react chemically with NO_2^- to form N_2 and N_2O gases. Role of humic substances in chemodenitrification has been studied and reported by Stevenson *et al.*, (1970).

Chemical properties of the rusultant humic substances have also significant impact on it, which change systematically with increasing molecular weight, ranging from a few hundreds to several millions (Schnitzer and Khan, 1972).

Humic substances also form complexes with metal, clay, pesticides and other toxicants (Mantoura *et al.*,1978; Carter and Suffet, 1982; Becher *et al.*, 1983 and Stewart *et al.*, 1984). The availability of trace metals are affected by humic substances mainly through chelation (Chen and Stevenson, 1986). In general, the stability constants for reactions between humic substances and metals follow the Irving Williams series for the stability of metal complex. The given sequence is,

Cu > Ni > Co > Zn > Fe(II) > Mn(II) > Mg > Ca > Ba.

2.5 PHOSPHOCOMPOST AND AVAILABILITY OF PHOSPHORUS

Phosphocompost is a P-enriched organic manure generally prepared by mixing mineral phosphate rock and pyrite with the composting mass (Tandon, 1995). Several investigations on the preparation and evaluation of phosphocompost has been reported in the last few decades (Midgley and Dunklee, 1945; Korovkin, 1952; Basak and Debnath, 1987, Tiwari *et al.*, 1988 and Manna and Hajra, 1996).

Composting being a process of bioconversion requires that C/N ratio, moisture, temperatute, aeration, nutrient availability, pH, particle size etc. are properly controlled and monitored. The optimum parameters for efficient composting has been reviewed (Gaur, 1992; Gaur and Sadasivam, 1993) and summerised as:

Parameter	Optimum value for composting
C:N ratio of feed	25 to 35
Particle size	10 mm for agitated systems and forced aeration, 50 mm for long heaps and natural aeration
Moisture content	50 to 60 per cent
Air flow	0.6 to 1.8 m^3 air/day/kg volatile solids during thermophilic stage, or maintain oxygen level at 10 to 18%.
Temperature	55 to 60°C held for 3 days.
Agitation	No agitation to periodic turning in simple systems and short bursts to vigorous agitation in mechanised systems
pH control	Normally not necessary
Activators	Use of efficient cellulolytic fungi and biofertilisers.
Heap size	Any length, 1.5 m high and 2.5 m wide for heaps using natural aeration. With forced aeration, heap size depends on need to avoid overheating

Organic matter is known to improve phosphate avilability. The reasons are mainly the production of organic acids and CO_2 during decomposition which has a solubilizing effect on Fe, Al, Mg and Ca-phosphate (Sen and Bains, 1955), liberation of phosphates present in the organic matter (Somani, 1983) and formation of organic anions and hydroxyacids which chelate Fe, Al and Ca ions and prevents P immobilization (Rajagopal and Indnani, 1963). Subehia and

Minhas (1993) reported that organic amendments incresed the efficiency of Udaipur rock phosphate.

Compost prepared from chopped rice straw and rock phosphate contained more available P than the compost without rock phosphate (Singh and Yadav, 1986) and fulvic acid content of wheat straw compost increased with application of rock phosphate (Singh and Amberger, 1990). Application of pyrite in rock phosphate amended organic residue increased the total N, NH_4-N and NO_3-N of the final product (Hajra *et al.*, 1992).

Use of compost inculants like *Trichurus spiralis, Paecilomyces fusisporus* and *Aspergillus* spp. are known to speed up the process (Tandon, 1995). The beneficial effect of cellulolytic fungi in composting of dairy farm wastes has been reported by Tiwari *et al.*,(1989 a).

Findings of Gaur *et al.*, (1978,1980) show that a phosphorus enriched compost could be prepared from *Aspergillus awamori* or *Bacillus polymyxa* inoculated organic residues, suitably amended with rockphosphate.

Inoculation of *Azotobacter chroococcum* and *Aspergillus awamori* to rockphosphate amended composts increased total nitrogen and humus content (Sadasivam *et al.*, 1981) and citrate soluble phosphorus (Kapoor *et al.*, 1983).

Rock phosphate and microbial inoculum increased the manurial value of municipal waste compost (Gowda *et al.*, 1992).

Mathur *et al.* (1980), Mathur and Debnath (1983) and Debnath and Basak (1986) also reported that charging of compost mass with rock phosphate increased the plant available phosphorus content of the compost significantly.

Tomar *et al.,* (1987) observed that when different mixtures of Mussoorie rock phosphate (MRP) and triple super phosphate (TSP) were incubated for 15 weeks fresh cattledung there was a marked increase in the enhancement in the availability of phosphorus. Their study show that application of pyrites increased available P, Al-P, Fe-P and decreased Ca-P.

Enrichment of cattledung and waste fodder manure with phosphate rock has been also reported by Asija *et al.,* 1984.

The beneficial effect of 10% cattle dung as inoculant and 2% rock phosphate in composting wool waste has been reported by Tiwari *et al.* (1989 b). The final product obtained after 10 weeks of composting contained 20.6% organic carbon and 10.0% N with a C/N ratio of 2:1.

Mathur and Debnath (1980) reported that quality of compost prepared from mixture of paddy straw, grass and water hyacinth was improved when rock phosphate was applied along with pyrite. Efficiency of pyrite and rock phosphate amended cattle dung is more in making phosphorus available than cattle dung mixed with rock phosphate only (Tomar *et al.,* 1983, 1984).

Composting with rock phosphate increased both citrate soluble and water soluble P which further increased by inoculation with *Aspergillus awamori.* A three months rotted enriched compost increased the yield and nodulation of green gram (Tiwari *et al.,* 1988). Higher yield of wheat was given by rock phosphate amended FYM than TSP and rock phosphate alone.

Legume and cereal straw compost amended with MRP helped conservation of N and saved about 30 kg N/ha when added to provide 60 kg P_2O_5/ha for wheat (Singh *et al.,*1992).

Phosphocompost prepared from paddy straw, cattledung using 5% P_2O_5 as phosphate rock, 10% pyrite and 1% urea-N contained higher total P, water soluble and citrate soluble P, total N and NO_3-N and performed similarly as single super phosphate at 30, 40 or 50 kg P_2O_5 /ha, when applied @ 10t/ha in terms of growth, nodulation, dry matter accumulation, seed yield and P uptake by *Vigna radiata* (Hajra *et al.*,1994).

Manna and Hajra, (1996) claims that the use of cattledung slurry @ 5.0 t/ha + RP@ 50 kg P_2O_5 along with N-fixers and P-solubilizers would be at par with 100% recommended dose of inorganic fertilizer and also improve crop productivity and soil health.

2.6 SOME PHOSPHOCOMPOST ADDITIVES

Plant nutrititive value of ordinary composts may be improved by appropriate application of low grade minerals containing phosphate, sulphur and other nutrient elements. Here three phosphocompost additives; rock phosphate, pyrite and flyash have been reviewed under following subheads.

2.6.1 PHOSPHATE ROCK

Phosphate rock or rock phosphate is a trade name of mineral phosphate, which denotes the product obtained from mining and subsequent metallurgical (not chemical) processing of phosphorus containing ores. Phosphate rock containing apatite groups of minerals occur in different geological setting, which may be igneous, metamorphic or sedimentary type. The igneous and metamorphic phosphate rock deposits are quite stable and unreactive. But the sedimentary rock deposits with ~~younger~~ lesser apatite minerals are not so inert. They are microcrystalline or cryptocrystalline in nature and have a fairly open, loosely consolidated aggregates which provides large internal surface area for reactivity.

The total reserve of phosphate rock in India is estimated to be around 140 million tonnes.The deposits occur in Udaipur and Jaisalmir in Rajasthan, Jhabua in M.P., Singhbum in Bihar, Kasipatnam in Andhra Pradesh, Purulia in West Bengal and Mussoorie in U.P. (PPCL, 1987).

Dissolution Phosphate Rock

Dissolution of phosphate rock depends on and is influenced by many a factors, some of them are discussed under the following subheads.

Quality of the Phosphate Rock

i. Mineral Composition

Effectiveness of phosphate rock is very much dependent on the mineralogy and chemistry of the source material (Hammond *et al.*,1986). The reactivity of phosphate rocks differ among themselves regarding their plant utilizable phosphorus releasing capacity in soils (Patnaik, 1988; Dash *et al.* 1991). Their reactivity depends on the isomorphous substitution in the fluro apatite crystal structure (Lehr and McClellan, 1972). Phosphate rocks of value have unique apatite crystal structure in which carbonate and fluorine have substituted for phosphous, and sodium and magnesium have substituted for calcium. McClellan and Gremillion, (1980) reported that the substitution alters the chemical composition of the fluroapatite in proportion to the degree of substitution of $(PO_4)^{3-}$ ion to the $(CO_3)^{2-}$ ion and it could be shown as below:

$$Ca_{10}(PO_4)_6F_2 \xrightarrow{\text{substitution}} Ca_{10\text{-}a\text{-}b}\,Na_a\,Mg_b\,(PO_4)_{6-x}(CO_3)_xF_yF_z$$

(Carbonate fluro apatite or Francolite)

It is a coupled substitution, where, $x/6\text{-}x = 4.90\ (9.374\text{-}a_o)$,

$a = 1.327\ [x/(6\text{-}x)]$, $b = 0.515\ [x/(6\text{-}x)]$ and $y = 0.4x$ (generally)

a_o in these relation refers to the unit cell dimension along the a-axis of the hexagonal apatite crystals. Once the value of a_o is obtained from x-ray diffraction analysis, the above relationships may be used to compute for x, a and b, hence, the empirical formula of the given apatite (Stevenson, 1986).

As there is a difference in ionic radii of the substituted and substituting ions e.g. the ionic radii of Na^+ is about 5% smaller than $Ca^{+2,}$ there is a shrinkage in the unit cell parameters of the crystal lattice structure of francolites as compared to fluroapatite. The a-axis dimension or the CO_3: PO_4 ratio derived from it is recognised as the index of reactivity of the phosphate rocks (Khasawneh and Doll, 1978; Dash *et al.,* 1991: Patnaik, 1988; McClellan and Gremillion, 1980). A negative correlation was also found between the a_o dimension of the apatite and it's reactivity (Marwaha, 1983; Bhujbal and Mistry, 1985; Hughes and Gilkes, 1986b). On the basis of the mole ratio CO_3 / PO_4 of the apatite, Mussoorie phosphate rock of sedimentary origin is about four times more reactive than Purulia phosphate rock which is an igneous rock having fluroapatite mineral and sixteen times more than Jhabua phosphate rock (Bhujbal and Mistry, 1984).

ii. Particle Size

Particle size plays a significant role in the effectiveness of a phosphate rock for direct application or composting. Finely ground rock phosphate of about 150-200 mesh is generally recommended for direct use as fertilizer in acidic soils (Marwaha *et al.,* 1981;Raij and Diest, 1980). But the study of Gaur (1986) shows that more phosphate was rendered soluble when rock phosphate particle size ranged between 66-99 mesh than rock phosphate particles ground to pass through 150-250 mesh. The increase in contact area between the reacting species helps the solubilization process (Hammond *et al.,* 1986). Cooke (1956) and Mathur (1980) has demonstrated that finer particle size<100 mesh does not give economic benefit in further improving the effectiveness. In highly acidic soils and long duration plantation, coarse grinding (80 mesh) is equally effective (Luthra *et al.*, 1983). Marwaha (1989) indicated Mussoorie rock phosphate (MRP) as the most reactive one among all indigenous phosphate rocks according to its particle size.

iii. Accessory Minerals

As in the case of MRP, besides 21.2%, P_2O_5, it contains 4.41% of iron, 4.1% sulphi~~t~~de sulphur and other materials like CaO, MgO and pyrites. Mussoorie rock phosphate also contains iron pyrites occluded within its phosphate containing mineral. This is a property peculiar to Mussoorie rock phosphate alone and is not possessed by any other currently known Indian phosphate rock. Iron pyrites on weathering produce sulphuric acid which can, by acidulation make phosphate in rock more easily utilizable by plants.

As it contains 4.1% sulphide sulphur, 4.1 kg of S (eq. to 12.3 kg. of sulphuric acid) is potentially available in each 100 kg of Mussoorie rock phosphate to affect partial acidulation. It has been reported (Mclean and Wheeler, 1964) that even 10% partial acidulation of a phosphate rock can, under suitable conditions, upgrade it's agronomic efficiency to match that of superphosphate. Some rock phosphates contain 1.1 to 1.4 percent organic carbon which is likely to improve it's internal porosity that may help the process of it's dissolution (Somani, 1994).

iv. Soil Factors

a. pH, Ca and P concentration

Dissolution of phosphate rock and release of phosphorus (P) into soil solution depends largely on H^+ ion activity (Choudhury and Mishra, 1980).

According to Ellis *et al.,*(1955) and Rastogi *et al.,*(1977), soil acidity is the chief factor influencing the effectiveness of phosphate rock. Maximum P availability tends to occur at intermediate pH values of 6 to 7 (Stevenson, 1986). Kanabo and Gilkes (1987) reported that dissolution of phosphate rock in soil increased linearly with decreasing pH. Soils with low pH and high buffering capacities for calcium and phosphates show high rate of phosphate rock solubilization (Cabala-Rosand and Wild, 1982).

The activity of bacteria is maximum at around pH 6 whereas that of the fungi and the yeast is best in the pH range of 5-6, particularly in case of *Aspergillus awamori.* Bajpai and Sundara Rao (1971) reported pH 6 for bacteria and Ahmad and Jha (1968) as pH 4.0 for fungi for maximum phosphate solubilization.

Soils affinity for Ca^{2+} acts as the sink for the Ca^{2+} that is released by the congruous dissolution of apatite and thus promotes dissolution of phosphate rock. Lower Ca^{2+} affinity of soil increases the level of solution Ca^{2+} at the apatite surface and consequently decreases the level of $H_2PO_4^-/HPO_4^=$ according to the solubility product principle. This slows down the process of dissolution of phosphate rock.

Dissolution of phosphate rock increases with the P-sorption capacity and P-fixation capacity of soil (Chien *et al,* 1980; Kumar and Mishra, 1986).

The phospahte rock dissolution in acidic soil solution can be schematically represented as:

$$Ca_{10}(PO_4)_6F_2 + 12H^+ \longrightarrow 10Ca^{2+} + 6H_2PO_4^- + 2F^-$$

The reaction reveals that the law of mass action favours phosphate rock dissolution under conditions of low soil pH, low soil exchangable Ca^{2+} and low concentration of P in soil solution.

b. Soil Organic Matter

The favourable role of organic matter and humic substances in improving the availability of phosphates has been ~~appreciated~~ earlier (Struthers and Sieling, 1950; Mahr and Kaindle, 1959; Gaur, 1972). Soil organic matters bring a change in Ca^{+2} activity in soil solution by chelation of Ca^{+2} ion with organic anions and thus helps dissolution of phosphate rock. Phosphate solubilization during composting of organic matter (Mishra *et al.*,1982; Bang~~u~~ar *et al.*,1985; Tiwari *et al.*,1988) and effect of farm yard manure (FYM) on phosphorus availability from phosphate rock (Hammond *et al.*, 1986) was attributed to the influence of organic acids produced in complexing Ca^{+2} ions in soil solution (Duff and Webley,1959).

reported.

c. Soil Temperature and Soil Moisture

Temperature is a vital factor for the growth of microorganisms and their activity. A range between 20 and 30°C was found suitable for rock phosphate solubilization by strains of *Pseudomonas striata* and for *Aspergillus awamori* and *Penicillium digitatum*, 30°C was the optimum (Gaur,1990).

According to Chien *et al.*,(1980),the phosphate rock dissolution process in tropical soil is hardly affected by soil temperature.

Debnath and Basak (1986) and Kanabo and Gilkes (1988) have taken soil moisture as an important factor in phosphate rock dissolution. Absence of soil moisture shows poor activty of phosphate rock (Quin,1981; Gregg *et al.*,1981;

Bolland *et al.*,1986) due to insufficient soil moisture to effect the dissolution process.

d. Soil micro organisms

Dissolution of insoluble phosphates in soil in directly related to the growth of the phosphate solubilizers (Ahmed and Jha, 1968; Salih *et al.*,1989).There are different groups of microorganisms which convert insoluble phosphatic compounds into soluble forms. The active species are *Psedomonas* spp., *Micrococcus* spp., *Bacillus* spp., *Penicillium* spp., *Fusarium* spp., *Sclerotium* spp., *Aspergillus* spp. *Aspergillus awamori, Penicillium digitatum, Aspergillus niger* and *Schwanniomyces occidentalis* and bacterial isolates. *Bacillus polymyxa, Pseudomonas striata* and *Pseudomonas rathonis* have been reported to be the efficient isolates (Gaur, 1972, 1979, 1985a, b,1990). They produce phosphatase enzymes which help solubilization of phosphorus. Soil phosphatase activity has extensively been reviewed by Cosgrove (1977), and Halstead and Mckercher (1975).

Since these microorganisms solubilize insoluble phosphates by secreting organic acids or enzymes, the role of carbon and nitrogen sources in this context is very much important. And there must remain a good carbon source and a suitable source of nitrogen to activate the microorganisms to get satisfactory results (Gaur, 1992).

v. Plant Factors

Crops vary greatly in their ability to utilize P from phosphate rock under different soil conditions. Plants with fibrous well developed roots utilize phosphorus better from phosphate rock since they provide a large contact area for phosphorus utilization (Dean and Fried,1955).

Root properties like root surface and density, symbiosis with micorrhiza, exudate of exoenzymes, chelating and reducing substances, and high Ca demand affects phosphate rock mobilization greatly, but the most effective property is the acidification of rhizosphere by excretion of protons (Amberger, 1992).

The rhizosphere ecosystem in legumes helps more in the solubilization as well as the utilization procedure as the exudates like sugar, amino acids and other growth promoting substances stimulates them (Dey and Goswami, 1972; Mishra and Srivastava, 1981; Sylvestre-Bradley *et al.*, 1982). Phosphate rock mobilization is also induced by the alkaline uptake pattern of legumes utilizing symbiotically fixed nitrogen (Agoilar and Diest, 1981). Micorrhizal association at the rhizosphere influence the solubilization of insoluble or sparingly soluble phosphates with the organic acids and carbondioxide (Slankis *et al.*, 1964). Accumulation of available phosphate resulting from greater uptake of Ca^{2+} by plants also brings about a shift in mass equilibrium which results in greater solubilization of insoluble phosphates (Fox and Kaear, 1964; Hayman 1975).

Grinsted *et al.*, (1982) suggested the following mechanisms that regulate the increment in P-concentration in the soil solution of rhizosphere,

i) low molecular weight acids are secreted by, or exuded from plant roots or micro organisms, and lower the rhizosphere pH, or accelerate the dissolution of sparingly soluble phosphate minerals by complexing the metal cation of the mineral.

ii) organic acid anions accumulate in sufficient concentrations in the rhizosphere to compete effectively with orthophosphates for adsorption sites on iron and aluminium oxides,

iii) the plant alters the rhizosphere pH, and hence modifies soil phophorus solubility by net excretion of H^+ or HCO_3^- to maintain a balance of electric charge associated with cations and anions crossing the root membrane.

vi. Microbial Factors

Microbial solubilization of phsphate rock especially of the low grade variety has been confirmed by electorn microscopic studies (Gaur *et al.,* 1979), and is receiving greater attention in recent years. In long past, Dox and Golden (1911) showed that three species of *Aspergillus* contained phytase which dephosphorylated phytin. Vidhyasekaran *et al.,*(1973) showed that *Aspergillus awamori* solubilized more phosphorus than *Bacillus polymyxa* when added to four different soils with 1.0 percent of tri-calcium phosphate. Bardiya and Gaur (1974) isolated *Pseudomonas strata, P.ratholis, Bacillus polymyxa, Aspergillus awamori, Penicillium digitatum, Aspergillus niger* and *Schwanniomyces occidentalis* as efficient phosphate rock solubilizers.Ibrahim and Abdel Aziz (1977) isolated forty two strains of *Streptomyces* from soil and found them to solubilize phosphate rock. Zhang *et al.,* (1981) reported that *Aspergillus niger* had a marked phosphate solubilizing effect on phosphate rock. Banik and Dey (1981b, 1982) reported that *Aspergillus* spp. and *Bacillus firmu* possessed the ability of solubilizing phosphate rock. Confirm

Microbial solubilization of phosphate rock proceeds through i) the utilization of initially available small amount of phosphorus by certain organisms, ii) the dissolution of phosphates by microorganisms and iii) the uptake and immobilization of phosphous by microorganisms and it's ultimate release by autolysis (Mayer and Konig, 1960). Phosphate solubilizers bring about a number of transformations of this element which include, 1) alternating the solubility of inorganic compounds of phosphorus, 2) mineralizing organic compounds with release of inorganic phosphates, 3) converting the inorganic available anion into cell components and 4) bringing about an oxidation or reduction of inorganic phosphorus compounds (Alexander, 1977).

Several mechanisms of microbial solubilization of phosphorus have been proposed of which two schools of thoughts have received major attention, one is,- solubilization by production of organic and inorganic acids and the other is, - solubilization by action of enzymes.

A number of investigations show that the solubilization is accompanied with the fall in pH due to **production of organic acids** (Sperber, 1958 a,b; Sethi and Subba Rao,1968; Bardiya and Gaur 1974; Gaur and Sachar, 1980; Venkateswarlu *et al.*, 1984; Kubat *et al.*, 1987). Whereas reports from Chhonkar and Subba Rao (1967) and Ahmed and Jha (1968) show no such trend.

Different organic acids as end product of carbohydrate metabolism of microorganisms have been considered to be responsible for solubilization of insoluble phosphorus. Some of them are Lactic Acid (Lauw and Webley, 1958) glycolic, citric and succinic acids (Sperber, 1958; Venkateswarlu *et al.*, 1984), acetic acid (Craven and Hayasaka, 1982), malic and fumaric acid (Ibrahim and Abdel-Aziz, 1977), Oxalic, malonic, 2-ketogluconic, tartaric and malic acids (Banik and Dey, 1978, 1981, 1982 and 1983).

Pareek and Gaur (1973) reported that aliphatic acids were more effective in solubilization of phosphate than phenolic acids.The role of organic acids in dissolving mineral phosphates and phosphorylated minerals can be attributed to the lowering of pH, which helps in the formation of stable complexes with such cations as Ca^{++}, Mg^{++},Fe^{+++} and Al^{+++}. These complexes are more stable than the original inorganic phosphate compounds. Similar reactions are undoubtedly involved in preventing the fixation of chemical phosphate fertilizer or phosphates formed *in situ* by the weathering of minerals (Stevenson *et al.*,1949; Struthers and Seiling, 1950; Dalton *et al.*,1952; Bradley and Sieling, 1953; Mortenson, 1963).

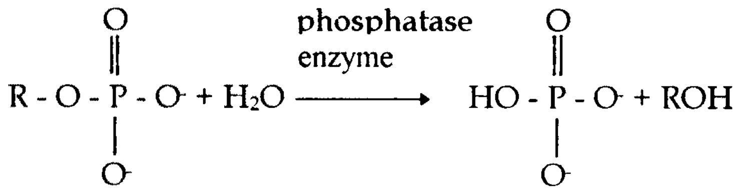
The effectiveness of the organic acids in preventing the precipitation of phosphates by Fe^{+++} and Al^{+++} increased progressively as the number of functional hydroxyl groups were increased in an otherwise unchanged molecule (Struthers and Sieling, 1950). Bradley and Sieling, (1953) found that each organic acid has a specific effectiveness depending on the metal, pH, and the extent to which the organic substances formed a stable metallo-organic molecule or ion. Mehltretter *et al.* (1953) found that 2-keto-gluconic acid has seven times more chelating power towards calcium than lactic acid.

Inorganic acids like sulphuric and nitric acids produced by some chemoautotrophs like *Thiobacillus* (Rajan, 1982,1983) and *Nitrosomonas* are also responsible for solubilization of insoluble phosphorus.
The possible chemical reactions are as follows:

$$Ca_3(PO_4)_2 + 2HNO_3 \rightarrow 2CaHPO_4 + Ca(NO_3)_2$$
$$Ca_3(PO_4)_2 + 4HNO_3 \rightarrow Ca(H_2PO_4)_2 + 2Ca(NO_3)_2$$
$$Ca_3(PO_4)_2 + H_2SO_4 \rightarrow CaHPO_4 + CaSO_4$$
$$Ca_3(PO_4)_2 + 2H_2SO_4 \rightarrow Ca(H_2PO_4)_2 + 2CaSO_4$$

Action of microbial enzymes also influence the dissolution of phosphorus largely,30 to 50 percent of organisms in soil or on plant roots possess an enzyme, phytase which is capable of hydrolyzing N-phytase with the consequent release of phosphorus from inorganic compounds (Greaves *et al.*, 1963). *Aspergillus* and *Penicillium* produces active acid phosphatase enzymes, bacterial isolates produce neutral phosphatase only and actinomycetes produce only negligible quantities of phosphatases (Tarafdar and Chhonkar, 1979). The enzymes acts on the hexaphosphate and cleaves the phosphate,probably one at a time to yield the penta, tetra phosphates etc., and finally, free inositol.

According to Tabatabai and Dick (1979), the general equation for the reaction catalysed by pohsphatases can be written as;



$$R-O-\overset{\overset{\textstyle O}{\|}}{\underset{\underset{\textstyle O^-}{|}}{P}}-O^- + H_2O \xrightarrow{\text{phosphatase enzyme}} HO-\overset{\overset{\textstyle O}{\|}}{\underset{\underset{\textstyle O^-}{|}}{P}}-O^- + ROH$$

$$\text{Phytic acid} + 6\ H_2O \longrightarrow \text{Inositol} + 6\ H_3PO_4$$

2.6.2 PYRITES AND IT'S INFLUENCE ON THE DISSOLUTION OF PHOSPHATE ROCK.

The literature accumulated so far on the dissolution of phosphate rock as influenced by it's mineral composition, characteristics of soil solution, plant and microbial factors have been reviewed under the preceeding part. In the present portion, the influence of pyrite on the dissolution of phosphate rock both in soil and compost pile have been compiled.

Pyrite is a mineral containing iron and sulphur and are found all over the world in igneous and metamorphic rocks and at some places as sedimentary deposits as well. Iron pyrites (FeS_2) occur near Amjhore in Bihar, near Saladipur in Rajasthan and near Ingadohl in Mysore (Ranganathan *et al.*,1970). The largest sedimentary deposits of pyrites in India are in Amjhore and the proven reserves are estimated to be 385 million tonnes (Seppan, 1966).

i. Oxidation of Pyrite

Auto-oxidation of pyrite in soil has been reported to be a sluggish process (Mc George and Breazcale, 1955). The overall stoichiometry for complete pyrite oxidation can be represented schematically as:

$$\begin{array}{l}
FeS_2 + 1/2\,O_2 + 2H^+ \longrightarrow Fe^{2+} + 2S^0 + H_2O \\
Fe^{2+} + 1/4\,O_2 + H^+ \longrightarrow Fe^{3+} + 1/2\,H_2O \\
Fe^{3+} + 3H_2O \longrightarrow Fe\,(OH)_3 + 3H^+ \\
FeS_2 + 14Fe^{3+} + 8H_2O \longrightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \\
\hline
\end{array}$$

$$FeS_2 + 7.5\,O_2 + 2.5\ H_2O \longrightarrow FeOOH + 2SO_4^{2-} + 4H^+$$

The above equation suggests that one mole of iron pyrite results four equivalents of acidity; two equivalents each from oxidation of S and Fe^{2+}.

Pyrite-S can be oxidised in the soil by purely chemical process (Wiklander *et al.*, 1950; Norr and Tabatabi, 1977) but those are usually much slower and therefore of less importance than microbial oxidation (Burns, 1967). The extent of acid production is different under varied conditions. The process becomes faster under the catalytic influence of microorganisms (Stumn and Morgan, 1970). The rate of pyrites oxidation depends on three types of factors: i) those relating to the substrate, ii) the microorganisms and iii) the environment.

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Increase in the fineness of the pyrites enhances it's rate of oxidation (Singh and Mishra, 1986), while higher rate of application retards it (Somani, 1984). Inoculation with autotrophs like *Thiobacillus thiooxidans* (Kittams and Attoe, 1965; Li and Caldwell, 1966) and heterotrophs like *Fusarium solani* (Wainwright and Killham, 1980) have been reported to speed up the oxidation process. The oxidation reaction of pyrites suggests that the process is strongly dependent on the availability of molecular oxygen and water. Lee (1955) considered lack of oxygen as a limiting factor in the pyrite oxidation process. Maximum oxidation was observed when pyrite was incubated at a soil-water content of saturation (Singh *et al.,* 1978). Oxidation of pyrite is partly chemical and partly microbial in nature (Temple and Delchamps, 1953; Hart, 1959; Vamos, 1959; Dixit and Kishore, 1969; Weir, 1975; Somani *et al.,* 1981 and Tiwari *et al.,*1984). The whole sequence of reaction could be depicted as:

$$2FeS_2 + 2H_2O + 7O_2 \longrightarrow 2FeSO_4 + 2H_2SO_4 \text{ (Chemical)}$$

$$4FeSO_4 + O_2 + 2H_2SO_4 \longrightarrow 2Fe_2(SO_4)_3 + 2H_2O\text{(Biological)}$$

$$Fe_2(SO_4)_3 + FeS_2 \longrightarrow 3FeSO_4 + 2S \text{ (Chemical)}$$

$$2S + 3O_2 + 2H_2O \longrightarrow 2H_2SO_4\text{(Biological)}$$

ii. Solubilisation of Phosphate Rock

Acidity may be produced by oxidising pyrite to obtain lower pH, which may enhance the process of Phosphate Rock (PR) solubilisation. Addition of pyrite as a cheap source of sulphur to phosphate rock to improve the phosphate release rate has already proved it's possibility (Rabindra, *et al.,* 1986; Sharma and Kamath, 1991; Somani, 1994; Biswas and Narayanswamy, 1995 and Manjaiah, *et al.,* 1996). The thoroughly mixed pyrite produces sulphuric acid or sulphate ions at the microzones during it's oxidation which eventually react with the phosphate rock at it's vicinity and release phosphorus.

The schematic representation of the reaction is;

Phosphate rock + Sulphuric acid = Monocalcium phosphate + Dicalcium phosphate + Residual phosphate rock
(mainly Calcium and Flurine compounds).

Several interesting investigations have been conducted to findout the efficiency of pyrite in increasing phosphorus availability from phosphate rocks amended in soils. Rastogi, *et al.,* (1976) reported that mobilisation of phosphorus from phosphate rock was less when phosphate rock to pyrite ratio was less and they also reported that increase in proportion from 1:3 to 1:6 offered little change, whereas Singh and Mishra (1986) observed that available phosphorus increased with increase in the proportion of pyrite. Singh *et al.*,(1979) indicated the utility of narrowing the ratio in improving the aviailability of phosphorus from PR. Patel and Bhandari (1992) claimed an increase in available phosphorus from 5 ppm to 9 ppm when the ratios under investigation were 1:0.5 to 1:3. Higher residual effect of the mixture at 1:4 was reported by Tanpure and Mohite, (1986). Tiwari *et al.*, (1986) evaluated the 1:2 ratio as equally effective as superphosphate. Singh *et al.*,(1988) have shown an improved performance of phosphate rock when mixed with pyrite. Hundal and Arora (1988) reported that addition of Amjhore pyrite to Mussoorie of phosphate rock increased the efficiency of Mussoorie phosphate rock for lentil by 12.5% and for gram by 28%.

Incorporation of pyrite in phosphate rock amended cattledung increased the recovery of phosphorus as citric acid soluble, Al-P, Fe-P and organic-P forms but decreased the recovery as Ca-P and NH_4Cl soluble forms (Tomar *et al.*,1987).The quality of compost improved when phosphate rock was applied to the composting material along with pyrite (Mathur and Debnath, 1980). Pyrites, properly amended with straw, cattledung and low grade phosphate rock gave a super quality compost which performed similarly as single super phosphate at 30,40 or 50 kg P_2O_5 ha^{-1}, when applied @ 10 t ha^{-1}, in terms of growth, nodulation, dry matter accumulation, seed yield and P uptake by *Vigna radiata* (Hajra *et al.*, 1994).

2.6.3 FLY ASH

Flyash is chemically an amorphous ferro-alumino-silicate and is produced by coal powered thermal power stations. About 60 million tonnes of flyash enters into the environment every year, one third of which goes into the air and rest is dumped on land or water (Pathak *et al.*, 1996). It contains various trace metals which are toxic to man, plants and animals (Rohrman,1971; Kaufmann, 1974; Cherry and Guthrie, 1979). Direct application of flyash in to the agricultural field is not so beneficial (Pitchtel and Hoyes, 1990; Sharma *et al.*, 1996) but some research reports show it's positive influence on plant growth (Elseewi and Page, 1984). Nass *et al.*, (1993) reported that grasses grown on flyash dumps in Netherlands suffered N,P,K deficiencies but they were high in A1,B.Co, Fe, Mo, Ni, Pd and Se. Maiti *et al.*, (1990) claimed fly ash to be a good source of available P and K. According to Buck *et al.*, (1990) and Kene *et al.*, (1991) it can be used as a soil conditioner or trace element carrier in clay and sandy soils.

Addition of flyash in a sandy soil decreases CO_2 evolution (Wong and Wong, 1989) and reduces nitrification (Cervelli *et al.*, 1986). Hudson and Headley, (1990) and Wong, (1990) and have reported a combination of flyash and compost to be a good growing medium. Pitchtel and Hoyes, (1990) observed detrimental effects of 20 percent flyash on several soil enzymes e.g. phosphatase, sulphatase, dehydrogenase, invertase. Increase in urease and cellulase activity with high levels of fly ash and decrease in phosphatase activity with increasing levels of flyash has been reported by Lal *et al.*, (1996). Possibility of flyash amended compost as a manure for agricultural crops has also been observed by Menon *et al.*,(1993). They also studied the transport of nutrients in soil covered with flyash amended organic compost and reported that the availability of nutrients for plant growth was limited to a depth of 80 cm. from the soil surface.

Flyash when applied with farm yard manure enhanced microbial population of the soil system (Lal *et al.*, 1996).

2.7 BEHAVIOUR OF PHOSPHORUS IN SOIL SYSTEM

Transformation of phosphorus in soil system is a dynamic process involving soils, plants and microorganisms. So it is necessary to have a knowledge of the mechanism of phosphate fixation in soil to understand the behaviour of phosphorus in soil system.

Phosphorus compounds in soil can be placed into following classes (Stevenson, 1986):

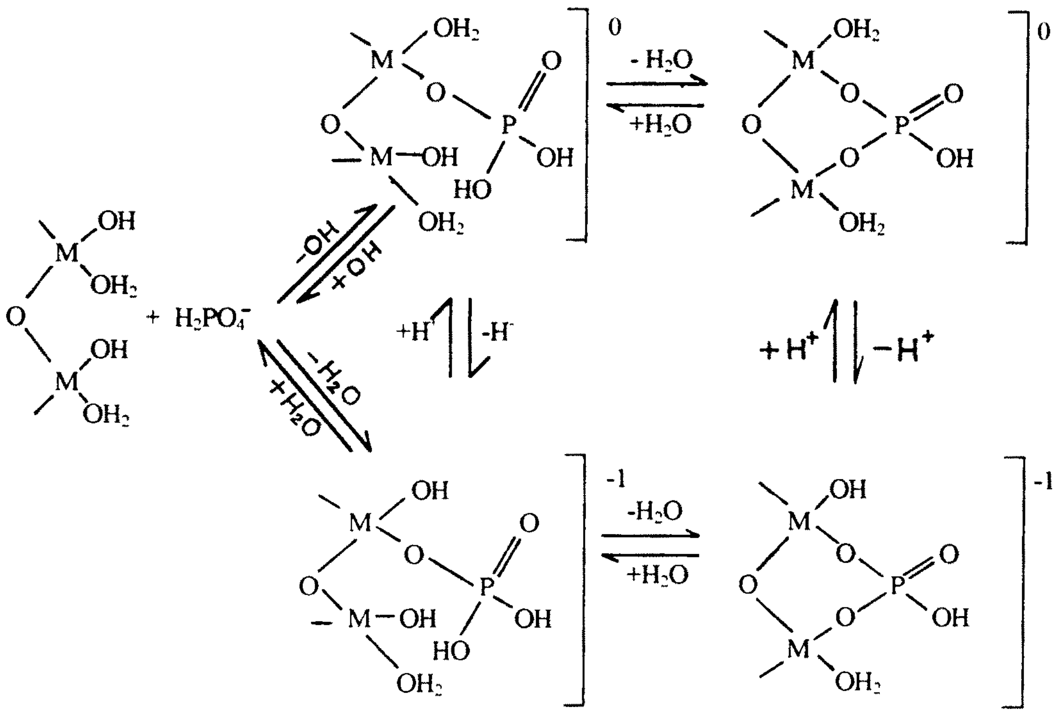
1. Soluble inorganic and organic compounds in the soil solution.
2. Weakly adsorbed inorganic phosphate.
3. Insoluble phosphates
    a. of Ca in calcareous and alkaline soils of arid and semiarid regions.
    b. of Fe and Al in acidic soils.
4. Phosphates strongly adsorbed and /or occluded by hydrous oxides of Fe and Al.
5. Fixed phosphate of silicate minerals.
6. Insoluble organic forms
    a. of the soil biomass.
    b. in undecomposed plant and animal residues.
    c. as part of the soil organic matter.

When phosphate solutions react with soils, phosphates are adsorbed on the surfaces of soil particles and concentration in solution decreases. At the first phase the reaction is very rapid and then it slows down and continues for a long period (Barrow, 1983; Bolan *et al.*, 1985).

Both biological and chemical processes are involved in fixation. Phosphorus fixation in soil involves both adsorption and precipitation reactions (Rajan and Watkinson, 1993; Mehadi and Taylor, 1988).

The precipitation reaction occurs in the presence of calcium and magnesium ions in calcareous soils and in presence of iron and aluminium ions in acid soil (Kelly and Midgley, 1943). Atkinson *et al.*, (1970) proposed that P-sorption is an isotopic exchange process whereas Goldberg and Sposito (1985) suggested a ligand exchange mechanism for that. Adsorption of phosphate at hydrous oxide surfaces through ligand binding mechanism is one of the important processes affecting phosphate availability to plants (Atkinson *et al.*,1972; Hingston *et al.*, 1974; Kyle *et al.*, 1975; Parfitt *et al.*, 1977).

The over all reaction can be represented as;

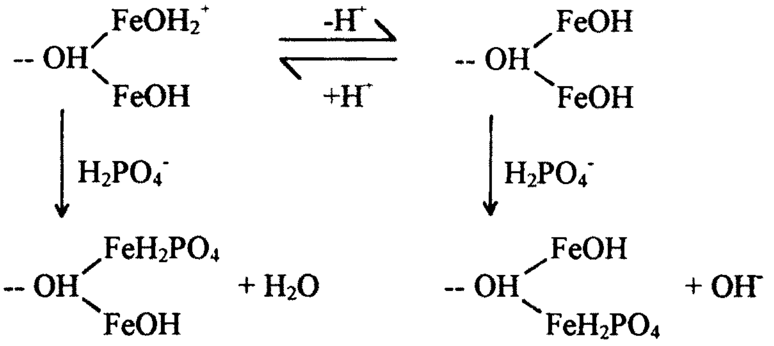


Labile Phosphorus

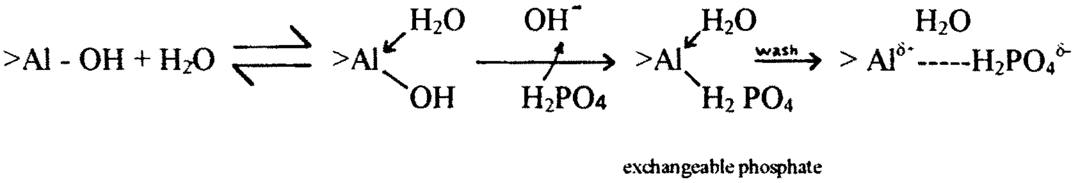
Difficultly available phosphorus

Several investigators have studied the mechanisms of P-adsorption by multi surface langmur equation (Muljadi *et al.*, 1966; Ryden *et al.*, 1977 and Rajan and Fox 1975).

Ryden *et al.*, (1977) have proposed three mechanisms for the sorption of phosphates by soils and hydrous ferric oxide gels namely (i) chemisorption at protonated surface sites ($-OH_2^+$) (ii) chemisorption by replacement of surface OH groups and (iii) a more physical sorption of P as a potential determining ion. Chemisorption (i) and (ii) were believed to follow the following reaction mechanism.



Kafkafi *et al.*, (1967) suggested the following reaction for adsorption of phosphate on kaolinite.



Larsen *et al.*, (1959) demonstrated that large contents of sesquioxides of Fe and Al affected positively the P-fixation capacity of the soils studied.

Rajan (1975 a,b,c) showed that low concentration of phosphate could be adsorbed by anion exchange on silica alumina and soil allophanes.

P- availability also depends on the extent to which the inorganic P initially present is converted to microbial organic P and how this is further transformed as decomposition proceeds. Rhizosphere microorganisms are highely credited for the P-transformation mechanisms in soil. (Gerretson,1948; Tate,1984; Elliott *et al.*,1984; Cole and Sanford, 1989 and Gaur, 1990).

Microorganisms can affect the P supply to higher plants in three different ways (Stevenson, 1986);

(i) by decomposition of organic P compounds which release available inorganic phosphate

(ii) by immobilizing available phosphates into cellular material . The P content of microbial tissue has been reported to range from 1.5 to 2.5% for bacteria and 4.8% for fungi (Anderson and Domsch, 1980 and Brookes *et al.*, 1984)

(iii) by promoting the solubilization of fixed or insoluble mineral forms of P.

Studies carried out in the past indicate that the behaviour of phosphates in soil is largely influenced by addition of organic residues to the soil. A positive correlation between organic matter and P sorption by soil have been reported by Bennoah and Acquaye, (1989); Sanyal and De Dutta, (1991) and Sanyal *et al.*, (1993).

Moreover reduction of P sorption by organic matter in soils has also been observed by Yuan, (1980); Sibanda and Young, (1986) and Anderegg and Naylor, (1988).

Sanyal *et al.*,(1993) have reported that P-sorption per unit weight of clay and organic matter content increased with a decrease in clay or soil organic matter content.

Stevenson (1982) suggested that following reactions may be involved in the process of availability enhancement of phosphorus by organic matter.

1. Phosphorus tied up as insoluble Ca,Fe and Al phosphates may be released to soluble forms through the action of organic acids and other chelates that are produced during decomposition of crop residues and excretion products from plant roots.

2. Humates produced during decomposition may compete with phosphate ions for absorbing surfaces, thereby preventing fixation of phosphate.
3. Humates may form a protective surface over colloidal sesquioxides, with reduction in phosphate fixation.
4. The solubility of Ca and Mg phosphates may be increased as a result of the production of carbonic acid from CO_2 released during the decay process.
5. Fresh organic matter may have a priming effect on the decomposition of native humus and thus mineralising the organic P.
6. Phospho-humate complexes may be formed

The phosphorus submodel presented by Sanford (1989) describing the soil P cycle is presented in the following figure.

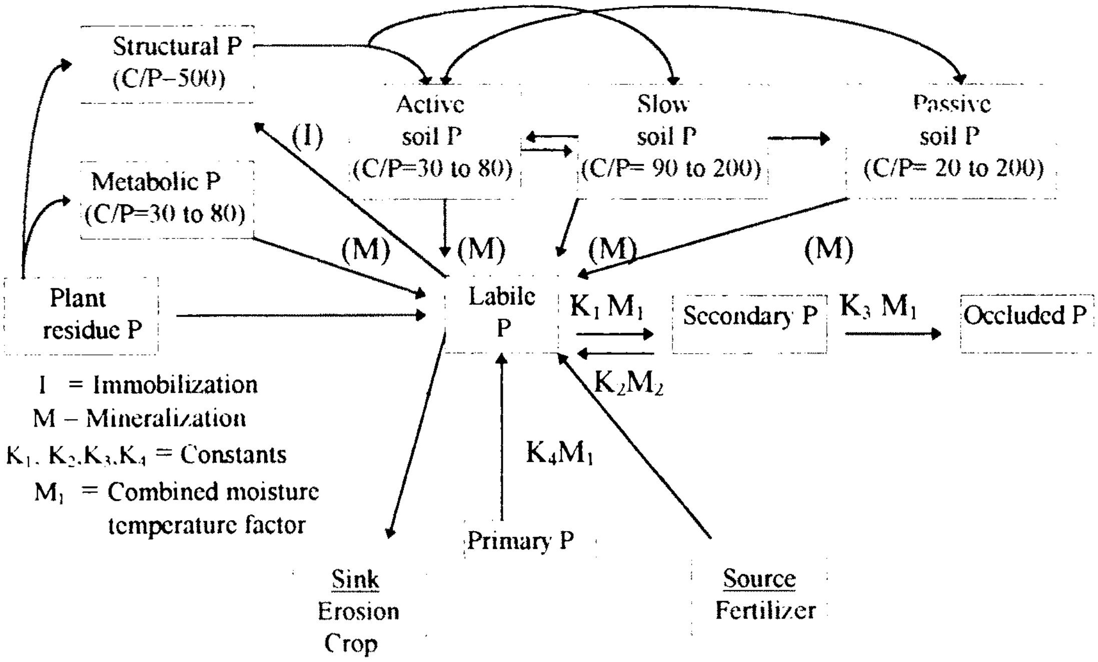


Figure. 2.7.1 Flow diagram for the P submodel (Sanford *et al.*, 1989).

CHAPTER 3

MATERIALS AND METHODS

MATERIALS AND METHODS

3.1 STUDY SITE

Present studies were conducted in laboratory as well as in pots. To study the availability of phosphorus at different conditions and different stages, incubation experiments were carried out in the laboratory. To study the decomposition process in natural condition, decomposition was carried out in plastic packets and specially designed earthen pots of one ft.diameter.

Yield and uptake studies were carried out in an alluvial soil collected from a fallow land in the C-block farm of the Viswavidyalaya and pots were maintained at the green house.

3.2 MATERIALS USED

3.2.1 Phosphate Rock

Finely ground (100 mesh) Mussoorie Rock Phosphate and Purulia Rock Phosphate supplied by M/s Pyrites, Phosphates and Chemicals Ltd. (PPCL), 09, Syed Amir Ali Avenue, Calcutta - 17, were used in the study.

3.2.2 Pyrites

Amjhore pyrite was collected from PPCL. Calcutta -17. It was ground and used in different experiments at different doses.

3.2.3 Fly Ash

Fly ash was collected from Bandel Thermal Power Station and was used as it was in the experiments undertaken to observe it's impact on the decomposition rate and availability of phosphorus during decomposition of different organic materials.

3.2.4 Inorganic fertilizer

Commercial grade urea, single superphosphate and muriate of potash were used as plant nutrient sources to compare with the prepared phosphocompost.

3.2.5 Organic materials

Chopped **rice straw** of one mm. and one cm. in size was used for different studies.

Partly dried and fresh **water hyacinth** were used in different experiments which was chopped to one mm size for incubation studies and one cm. size for packet composting.

Cattledung of different compositions was used for different experiments.

Mushroom bed waste, the waste after harvesting mushroom from a mushroom bed was collected from the Mushroom Centre at the Viswavidyalaya and was used in some experiments.

3.2.6 Microbial Culture

One phosphate solubilizing organism was isolated from compost samples collected from the Microbial Decomposition Project Laboratory at B.C.K.V., Kalyani, and cellulose decomposing isolates (*Trichurus spiralis* and *Paecilomyces fusisporus*) were collected from the Department of Bacteriology, Mahatma Phule Agricultural University, Pune for their use in different experiments.

3.2.7 Media used

Pikovskaja's agar and liquid medium (Pikovsakia, 1948) for isolating and maintaining P-solubilizing fungi.

Potato-dextrose agar medium (Ricker and Ricker, 1936) was used for maintaining and mass culturing of cellulose decomposing fungi.

3.2.8 Seeds

Rice Bean (*Vigna umbellata,* Thumb, Ohwi and Ohasi), Arhar (Var.P-22) and Rice (*Oryza sativa,* var. 4786) were collected from Research Farm of the Viswavidyalaya at Kalyani for ~~their~~ use in the pot experiments. /

3.3 METHODS FOLLOWED

Following experimental techniques were adopted in different experiments of the investigation.

3.3.1 pH

pH value of different samples were determined with a glass electrode pH meter. The ratio of material to water was 1:2.5 and results were reported as pH measured in water.

3.3.2 Loss in Weight

The loss in weight of different organic substances were determined by the equation: [(Initial dryweight - Final dryweight)/Initial dryweight] x 100. The result was expressed as the percent loss in weight over a definite period of decomposition.

3.3.3 Measurement of Carbondioxide

Definite amount of organic material with optimum moisture content was kept in a one litre flask, and a tube containing of NaOH solution was hung ~~hanged~~ Strength from the cork of the flask. The flasks were made air tighted and incubated at a temperature 30 ± 2° C. At periodic intervals, suspended tubes were taken out and the NaOH were transferred to conical flasks containing saturated $BaCl_2$

solution. The excess alkali was back titrated with standard H_2SO_4 using phenolphthalein as indicator and the amount of evolved CO_2 was calculated. The method was provided by Pramer and Schmidt, (1965).

3.3.4 Cation Exchange Capacity

Cation exchange capacity was determined following the method given by Jackson (1967). Samples were added with 1(N) CH_3 $COONH_4$ and kept overnight. It was leached with ammonium acetate until 250 ml of lechate was collected. Finally it was washed with 50% alcohol to remove excess ammonia. Then it was leached with 10% KCl until 250 ml of lechate was collected. The lechate was distilled using MgO as alkali and liberated ammonia was collected in a conical flask containing 4% boric acid with mixed indicator. The distillate was titrated against standard sulphuric acid.

3.3.5 Organic Carbon

Organic carbon of organic materials/compost was determined by dry combustion method. Weighed samples were combusted in a muffle furnace at 580°C-600° for 6 hours and the percent carbon was calculated following the equation:

$$\text{\% organic carbon} = \frac{100 - \text{\% ash}}{1.8}$$

as described by Waggoner (1974). The dry weight percent of organic carbon was taken as 56 percent of the organic matter.

3.3.6 Total Nitrogen

Modified Kjeldahl method (Jackson, 1967) was followed to estimate the total nitrogen of soil, compost and plant samples. One gram of sample was taken in a Kjeldahl flask and was mixed with concentrated sulphuric and salicylic acid (30:1) mixture. A pinch of sodium thiosulphate was added and shaken.

The flask was left for half an hour. Then 3 gm of digestion accelerator (a mixture of K_2SO_4, $FeSO_4$ & $CuSO_4$) was added to it and digested until it became colourless. The temperature was maintained between 360°-410°C to minimise loss of ammonia. The digested material was distilled with 40 percent sodium hydroxide solution and liberated ammonia was collected in 4% boric acid. After a collection of about 250 c.c. it was titrated with standard sulphuric acid.

3.3.7 Total Phosphorus

Total phosphorus was estimated by the Vanadomolybdo phosphoric yellow colour method as described by Jackson (1967). I gm of soil sample or 0.5 gm of plant sample was digested with tri-acid mixture (HNO_3: H_2SO_4:$HC10_4$:: 5:2:1) on a hot plate till dense white fumes come out and phosphorus was estimated colorimetrically at 470 nm.

3.3.8 Total Potassium (Jackson, 1967)

1 gm of sample was digested with 30 ml of triacid mixture, cooled and volume was made upto 100 m., kept overnight. 1 ml aliquot was diluted to 25 ml with distilled water and read against standard in a flame photometer.

3.3.9 Fe and Cd

Iron and cadmium were measured from the tri-acid digested samples with the help of an Atomic Absorption Spectrophotometer and calculated from the standard curve.

3.3.10 Total Sulphur

0.5g of ground compost sample was well mixed with 2 ml $Mg(NO_3)_2$ solution and evaporated to dryness at 70°C on electric hot plate. The residue was heated in an oven at 300°C. Then it was cooled and 5 ml of 25% HNO3 was added and the beaker was covered and digested on a water bath for two and half hours. After cooling and diluting with water, the mixture was filtered and volume was made up. Then the sulphate sulphur was estimated by the turbidimetric method of Chesnin and Yien (1951). A slight modification of this method was adopted according to Hesse (1957c).

3.3.11 Ammonical Nitrogen (Jackson, 1967)

Moist sample of soil or compost was taken in Buchner funnel and leached with 10% KCI solution until 250 ml of leachate was collected. The leachate was then distilled with MgO as alkali and liberated ammonia was collected in a conical flask containing 4% boric acid with mixed indicator. The distillate was titrated with standard H_2SO_4. A blank was run simultaneously. Result was expressed on oven dry weight basis.

3.3.12 Nitrate Nitrogen (Jackson, 1967)

After determination of ammonical nitorgen the flask was cooled and Devarda's alloy was added to it to convert nitrate form to ammonia form and then distilled and estimated as stated in case of ammonical nitrogen estimation.

3.3.13 Humic Acid

The oven dried sample was treated with excess of 0.5 (N) NaOH solution. Obtained coloured extract was precipitated with 0.1 (N) HC1 and then centrifuged at 10000 rpm. The precipitate was dialysed to remove excess ions. Then it was dissolved in 0.1 (N) NaOH solution and the transmittance was measured at 420 nm. with the help of spectrophotometer (UV VIS 108, S1.No. 370,Systronics). The humic acid content was calculated from the standard curve.

3.3.14 Fulvic Acid

After precipitating all humic acids the volume of the supernatent was measured and an aliquot was dried on water bath after dialysis. It was again dried in the hot air oven at 80°C. The amount of fulvic acid was calculated from the weight of the dried residue.

3.3.15 Water Soluble Phosphorus

5 g. of air dried sample was mixed with 50 ml. distilled water, shaken for 5 minutes., then centrifuged and filtered. Aliquot was taken and phosphorus was estimated following the method given by Metson (1961) and John (1970).

3.3.16 Citrate Soluble Phosphorus

1 gm of oven dried sample was mixed with 50 ml of 2% citric acid solution and shaken for 8 hrs. Then it was filtered through whatman No. 1 and 10 ml of filtrate was taken in a china crucible. 2 drops of calcium acetate were added to it and dried on a hot plate. The crucible was then transferred to muffle furnace and ignited at 580°C for 1 hr. The ash was dissolved in 10 ml of 2(N) H_2SO_4 and filtered in a 100 ml volumetric flask with several hot distilled water washings. The volume was made upto 100 ml and phosphorus was determined following the method given by Metson (1961) and John (1970).

3.3.17 $NaHCO_3$ Extractable Phosphorus

Available phosphorus was determined following the method provided by Olsen *et al.*, (1954). 0.5g of sample was taken in a conical flask and shaken with 50 ml of 5 (M) $NaHCO_3$ and a pinch of charcoal for 30 minutes, then filtered through whatmann N0.40. An aliquot was taken and colour was developed with ammonium molybdate and stannous chloride. Read against blank at 660 nm. within 10 minutes.

3.3.18 Fractionation of Inorganic Phosphorus

Fractionation of inorganic phosphorus was done following the modified procedure of Chang and Jackson, (1957) and each fraction was estimated following methods given by Jackson, (1967).

3.3.19 Germination Test (Konishi *et al.*, 1986)

Composts were soaked in distilled water (1:2 w/v) overnight. Extracted solutions were prepared by filtration. Germination test was carried out by placing Arhar seeds in 10 ml of the solution in a petridish. Germination rate was determined after 72 hours.

Table 1. Chemical composition of the materials used in different experiments.

Materials used	Used in experiment	pH	Organic carbon (%)	Total nitrogen (%)	C : N Ratio	NH_4-N (ppm)	NO_3-N (ppm)	Total P (%)	Total K (%)	Total S (%)	CEC (meq/100g)	Fe (%)	Cd (ppm)
Paddy straw	4.3.2,4.3.4, 4.3.6,4.4 & 4.5		46.2	0.516	89.5			0.09	0.635				
Water hyacinth	4.3.3-4.3.6		48.1	2.9	16.6			0.56	2.8				
Do	4.4 & 4.5		39	2.6	15.0			0.49	2.3				
Cattledung	4.3	7.5	41.6	1.31	31.7	51	19	0.418					
Do	4.4	7.4	38.9	1.17	33.2	56	18	0.436					
Do	4.5	7.6	40.8	1.25	32.6	52	21	0.421					
Mushroom bed waste	4.3.5		36.4	0.76	47.9			0.07					
Mussoorie rock phosphate	4.3.1-4.5							8.63				2.9	287
Amjhore pyrite	4.3.1-4.5									20.4		19.7	
Fly ash	4.3.6	8.1	1.4	0.07	20.0			0.22					
Soil	4.3.5 & 4.5.1	7.2	0.71	0.06	11.8			0.08			11.9		

CHAPTER 4

EXPERIMENTALS RESULTS AND DISCUSSION

EXPERIMENTALS, RESULTS AND DISCUSSION

4.1 ISOLATION AND SCREENING OF THE EFFICIENT PHOSPHATE SOLUBILIZING MICROORGANISM.

Microorganisms are capable of dissolving different forms of insoluble phosphate (Zhang *et al.*, 1981; Banik and Dey, 1981, 1982; Bardiya and Gaur, 1974; Gaur and Gaind, 1983; Roy Mahapatra *et al.*, 1985).

But the microorganism efficient in dissolving rockphosphate in the soil system may not be equally effective in the compost system. To inoculate the composting material with native microorganisms, an attempt was made, in the present experiment, to find out the efficient fungal culture from compost for their subsequent use in the preparation of phosphate enriched compost.

EXPERIMENTAL

A compost sample receiving rock phosphate at 2 percent level was collected from the experimental samples of the ICAR's AICRP on Microbiological Decomposition and Recycling of Organic Wastes located at Bidhan Chandra Krishi Viswavidyalaya .

Phosphate solubilizing microorganisms were isolated following the serial dilution technique using the medium suggested by Pikovskaya (1948). 1 gm of compost sample was suspended in 100 ml of sterile water and serial dilutions were made in sterile water blanks. These dilutions were plated on solid Pikovskaya's agar medium and incubated for 4 to 5 days at 28 ± 1°C. The colonies showing transparent zones were picked up and transferred to agar slants and allowed to grow for 3 days at 28 ± 1°C. The cultures then were repeatedly plated till pure strains were obtained. The strains were coded as PS_1,

PS_2 , PS_3 PS_4, PS_5, PS_6, PS_7, PS_8. The organisms were identified upto generic level by morphological studies as shown in Table 2.

The phosphate solubilizing capacity of the isolated microorganisms was examined by an incubation study. Pure fungal cultures were inoculated in large culture tubes containing 50 ml of a medium similar to the Pikovskaya's one; the only exception was that the tricalcium phosphate was replaced by Mussoorie rock phosphate (MRP). 100 ml of the modified Pikovskaya's medium contained 100 mg of P_2O_5. All the inoculated tubes, each containing measured amount of MRP in 50 ml of nutrient medium were incubated at 30 ± 1°C for 32 days. Each tube was shaken gently on alt~~ernative~~ days.
alternate

pH and available P in the form of citrate soluble phosphorus of each tube were measured at an interval of one week throughout the 32 days of experimentation.

RESULTS AND DISCUSSION

The morphological description of the isolates has been shown in Table 2. The predominating fungal genera in the isolating source was *Aspergillus.* In nonrhizosphere and rhizosphere soils also this P solubilizing fungal genera is dominant (Yadav and Singh, 1991). All the isolated fungal genera were spore forming. That kind of fungi had greater demand for P during sporulation (Gilman, 1957) therefore the dominance of the spore forming P-solublizers could be explained in the event of solubilization of insoluble phosphate to meet their greater demand of phosphatic nutrition. The phosphate solubilizing power of the isolated microorganisms has also been shown in Table 2.

Table 2 Comparative phosphate solubilizing efficiency of the isolated microorganisms.

Isolated strains		Days of incubation							
		8		16		24		32	
Coded as	Identified as	pH	P_2O_5 Solubilized (mg)	pH	P_2O_5 Solubilized (mg)	pH	P_2O_5 Solubilized (mg)	pH	P_2O_5 Solubilized (mg)
PS_1	*Fusarium* sp.	6.2	16.8	6.3	17.0	6.0	17.4	5.9	16.9
PS_2	*Aspergillus* sp.	5.8	17.0	5.2	18.6	5.0	19.2	5.1	20.0
PS_3	*Penicillium* sp.	5.8	17.5	5.9	17.9	5.5	18.5	5.3	18.9
PS_4	*Aspergillus* sp.	5.9	17.4	5.7	17.6	5.7	18.1	5.5	18.0
PS_5	*Alternaria* sp.	5.9	17.8	5.5	18.0	5.6	18.5	5.0	17.9
PS_6	*Paecilomyces* sp.	6.1	17.0	5.8	17.5	5.5	18.0	5.6	17.9
PS_7	*Aspergillus* sp.	5.2	20.0	4.8	22.6	4.6	23.4	4.3	24.6
PS_8	*Trichurus* sp.	6.0	16.6	5.9	17.0	5.7	17.2	5.7	16.8
C.D. at 5%		0.09	0.91	0.07	0.68	0.08	0.57	0.07	1.12

It is observed from the data that the isolated fungal strains had significant influence on the solubilization of MRP in liquid medium. They even acted over a wide range of pH. Dissolution of MRP increased with the increasing time of incubation where the inoculum was PS$_2$, PS$_3$ and PS$_7$. pH of the liquid medium also changed appreciably during the course of study. A lowest pH of 4.3 was recorded ~~in the~~ at 32nd day of the incubation period along with the highest amount of dissolved P. The inoculum there was the PS$_7$, which belonged to the spcecies *Aspergillus*. The highest recorded pH was 6.2 and it was measured on the 8th day of the incubation period where the dissolved amount of P_2O_5 was recorded to be 16.8 mg. The PS$_1$ of the genera *Fusarium* was the inoculum there. The behaviour of PS$_5$ and PS$_8$ were a bit different. pH changed slightly in case of PS$_8$ and the solubilization data in both cases showed no large difference. PS$_1$, PS$_3$, PS$_4$, PS$_5$ and PS$_6$ showed a solubilization ranging from 16.8 mg to 18.9 mg of P_2O_5 per 100 ml of liquid medium, ~~W~~ whereas the maximum solubilization was shown by PS$_7$ followed by PS$_2$. Both were from the *Aspergillus* genera and were much efficient to solubilise 24.6 mg and 20 mg of P_2O_5 per 100 ml of liquid medium respectively, on the 32nd day of the incubation study. PS$_3$ of *Penicillium* spp. followed them showing a solubilization of 18.9 mg of P_2O_5 per 100 ml on the last day of the study. The findings of Singh *et al.*, 1984 also revealed the same trend.

The relative efficiency of the organisms for phosphate rock solubilization may have been due to the nature and quantity of organic acids secreted in the medium (Sattar and Gaur, 1986; Thomas and Shantaram, 1986). Here the solubilization might have been helped by the size and concentration of the MRP in the medium (Gaur, 1986) and availability of supporting nutrients (Gaur, 1990).

The decreasing trend of solubilization values in some cases at the latter stages of the study period might be due to shortage of energy material and/or accumulation of products, toxic to the growth of P solubilizers (Banik, 1979). Beside these, precipitation and/or assimilation of phosphates by the organisms may had some role in that phenomenon (Khan and Bhatnagar, 1977).

Change in pH did not affect significantly the solubilization of phosphate rock by fungal cultures. Sometimes increase in pH was recorded where the solubilization was also higher. Sundara Rao and Sinha, (1963) and Wani *et al.*, (1979) also did not find any significant relations between fall in pH and release of P and suggested that solubilization might depend on the type of organic acids produced, rather than the total acidity. Phosphatase enzymes produced by some of the fungal isolates might had some influence on the process of solubilization of MRP (Tarafdar and Chhonkar, 1979). In this connection it may be cited that complete solubilization never occurs because some phosphate fractions of phosphate rocks are ~~in~~ so strongly bound form that even concentrated mineral acids cannot bring them into solution (Adhia, 1969).

Studying the P solubilization data from Table 2 , it was observed that PS_7 was the most efficient P solubilizing fungal culture there. Hence it was selected to be used as phosphate solubilizing inoculum in the phosphocompost system~~m~~s of the following experiments.

4.2 EFFECT OF AMJHORE PYRITES ON THE RELEASE OF PHOSPHORUS FROM MUSSOORIE ROCK PHOSPHATE

Dissolution of phosphate rock is influenced by several factors. Solubilization of phosphate rock has a reciprocal relationship with soil pH (Kanabo and Gilkes, 1987). And partial acidification with mineral acids converts to some extent, the apatite of the phosphate rock to dicalcium and mono calcium phosphates (Singh and Singh,1991). Application of elemental sulphur also enhances the rate of dissolution of phosphate rock (Kapoor *et al.*,1991).

Iron pyrite, containing 20-22% sulphur,oxidises in presence of water and oxygen, to produce sulphuric acid (Somani *et al.*, 1981;Tiwari *et al.*, 1984).So,it could be used as a pH lowering agent.

In this context,another possibility is in situ acidulation of phosphate rock by oxidised pyrite when applied in combination. The objective of the present investigation was to find out a suitable Mussoorie rock phosphate (MRP) to pyrite ratio for greater solubilization of phosphate rock which may be followed in the subsequent composting experiments.

EXPERIMENTAL

A laboratory incubation study was carried out with Mussoorie rock Phosphate containing 18.7 percent P_2O_5 and Amjhore pyrite (Py) containing 20.4 percent sulphur. Seven different ratios of well ground MRP and Py with three replications were taken in small beakers. Distilled water was added to them to attain 100% moisture. All combinations were stirred with glass rod and weighed at intervals to calculate the loss of moisture and the loss was compensated with addition of distilled water. Samples were drawn on the 7th, 15th,30th,45th and 60th days of incubation for estimation of pH and available phosphorus and were measured as per standard procedure described under 'Materials and Methods'.

RESULTS AND DISCUSSION

Changes in pH and that in available P have been shown in Table 3 and 4 respectively.It is observed from the data (Table 3) that the addition of pyrites decreased the pH of the system. pH of the samples treated with pyrite were in acidic range. It varied within 6.8 to 2.7 depending upon the amount and period of contact . The lowest pH recorded on the 30th day of incubation in the sample where the MRP to Py ratio was 1:3. It appeared that the acidity produced due to oxidation of pyrite in presence of oxygen and water was the cause behind the fall of pH. The reaction may be represented as :

$$FeS_2 + 7.5O_2 + 2.5\ H_2O \longrightarrow FeOOH + 2SO_4^{2-} + 4H^+$$

Incomplete

The decrease in pH was a rough measure of the number of non-neutralised H^+ in the solution. The effectiveness of pyrite was also determined by measuring the available P in the incubated mixture (Table 4). For the first two weeks the amount of dissolved P was low but increased substantially after 30 days of incubation. Increase in the amount of pyrite in the mixture caused marked increase in phosphate rock dissolution. The effect was more pronounced where the ratio of MRP to Py was 1:3. The highest rate of dissolution was achieved on the 45th day of incubation with the same 1:3 ratio. Rastogi *et al.*,(1976), Tiwari *et al.* (1986) and Tomar *et al.*(1986) also recorded increased P availability from MRP when applied with pyrites. The superiority of the treatment T_6 might be ascribed to the higher contact area of pyrite due to its higher application. The H_2SO_4 produced from the oxidation of pyrite, could come in direct contact with phosphate rock and solubilized it.

Table 3 Changes in pH in Mussoorie rock phosphate and pyrite mixtures during the period of incubation

Treatments		pH					
	MRP: Py	Initial	7th day	15th day	30th day	45th day	60th day
T_0	1:0	6.25	7.5	7.2	7.15	7.0	7.5
T_1	1:0.5	5.8	6.8	6.7	6.3	5.9	5.5
T_2	1:1	5.4	5.5	6.0	5.8	4.0	3.7
T_3	1:1.5	5.2	4.4	5.2	4.0	5.0	3.1
T_4	1:2	5.0	4.0	3.7	3.8	3.5	2.9
T_5	1:2.5	5.1	4.1	3.3	3.5	3.4	3.0
T_6	1:3	4.2	3.7	3.9	2.7	2.9	2.8
C.D at 5%		0.87	0.93	0.92	0.81	0.75	0.98

Table 4 Changes in available phosphorus in Mussoorie rock phosphate and pyrite mixtures during the period of incubation

Treatments	Available phosphorus (g/treatment)					
	Days of incubation					
	0	7	15	30	45	60
T_0	0.009	0.011	0.017	0.022	0.029	0.038
T_1	0.03	0.200	0.299	0.360	0.385	0.395
T_2	0.035	0.202	0.309	0.376	0.392	0.420
T_3	0.041	0.210	0.329	0.382	0.390	0.440
T_4	0.042	0.280	0.343	0.390	0.421	0.446
T_5	0.046	0.301	0.374	0.393	0.435	0.460
T_6	0.049	0.306	0.390	0.416	0.453	0.480
C.D. at 5%	0.008	0.03	0.04	0.06	0.03	0.011

The reaction might be schematically represented as:

$$Ca_{10}(PO_4)_6F_2 + 12\,H^+ \longrightarrow 10\,Ca^{2+} + 6H_2PO_4^- + 2F^-$$

Slight decrease in the avialbility of P on the later stages of incubation might be a result of formation of some phosphate species which are not extractable by $NaHCO_3$ solution.

Therefore it is observed from the data that the amount as well as the period of contact of pyrite had a direct relations in incresing the available form of phosphorus from Mussoorie rock phosphate. The lowest application of pyrite in treatment T_1 also showed promising effect at the later stages of incubation at 45the and 60th day. Therefore, considering the period required to attain the maturity of compost under natural system, application of pyrite at the lowest level i.e. 1:0.5 ratio of MRP to pyrite could be dissolution effective as well as economic. So, this ratio has been considered beneficial for the enrichment of composts in the following experiments.

4.3 INFLUENCE OF DIFFERENT INPUTS ON THE DECOMPOSITION OF PHOSPHOCOMPOST SUBSTRATES

Plant tissues contain about 50% carbon, most of which are liberated as CO_2 during aerobic docomposition (Waksman, 1938). So, the amount of evolved CO_2 could be considered as an index of the rate of decomposition of carbonaceous material.

The type of organic residues influences, to a great extent, the rate of liberation of CO_2. Mineralisation of carbon from different types of organic residues is not uniform (Gaur *et al.*,1970; Das and Mukherjee, 1988). Some of them liberate CO_2 at a faster rate (Ladatko and Shkarin, 1979), while some liberate at a slower rate (Todorava, 1967; Kamire and Sonar, 1979).

Application of calcium phosphate improves the rate of decomposition of organic materials (Dhar *et al.*,1955; Tepal, 1959 and Dhar and Gupta, 1961). Addition of phosphate rock increases the decomposition and quality of compost prepared from straw and water hyacinth (Gaur *et al.*, 1980; Mathur and Debnath, 1980).

Pyrites containing sulphur also helps the decomposition process as well as improves the nutrient content of the compost. It produces sulphuric acid in presence of air and water and this helps the solubilization of phosphate rock (Manjaiah *et al.*, 1996). Application of pyrite along with phosphate rock in the composting system helps the decomposition process by providing essential nutrients to the microorganisms present in the system and also improves the nutrient content of the compost (Mathur and Debnath, 1980).

Biological transformation of organic matter~~s~~ results largely from the activities of proliferating microorganisms. The process may be intensified by the inoculation of efficient cellulose decomposing and phosphate solubilizing microorganisms which helps the decomposition and mobilization of nutrients (Gaur *et al.*, 1980; Kapoor *et al.*, 1983; Yadav *et al.*, 1992 and Hajra *et al.*,1992).

Therefore, to prepare the phosphate enriched compost, it seem~~ed~~s to be worth while to assess the degradation pattern of different organic materials as influenced by higher doses of MRP, pyrite and other inputs. With that end in view, the following investigations were carried out to obtain a suitable combination of ingradients for the preparation of a better quality phosphocompost.

4.3.1 PREPARATION OF PHOSPHATE ENRICHED CATTLE DUNG MANURE: EFFECT OF PYRITE AND MUSSOORIE ROCK PHOSPHATE ON THE DECOMPOSITION OF CATTLE DUNG.

Cattle dung is a mixture of digested organic materials. Farmers usually store it for months before its application to the soil. The fresh dung needs decomposition for a certain period there is also scope to enrich its P content by the application of low cost minerals like rock phosphate, pyrite and suitable biofertilizer.

Tomar *et al.,* (1987) reported that preincubated Mussoorie rock phosphate with iron pyrite and cattle dung was as effective as incubated triple super phosphate and both the incubated sources were more effective than unincubated fertilizers to wheat crop grown on sodic soil.

In this context, the present experiment was designed to find out the appropriate amount of pyrite to the applied rock phosphate for rapid decomposition and nutrient enrichment of cattle dung manure. CO_2 evolved, as a result of decomposition, was accounted as an index of degradation of the carbonaceous material.

Decomposition of organic matter as well as solubilization of added rock phosphate may be intensified by the inoculation of efficient cellulose decomposing and phosphate solubilizing cultures. So, mixed inoculum of PS_7, *Trichurus spiralis* and *Paecilomyces fusisporus* was used in the present and in the subsequent experiments of the present study.

EXPERIMENTAL

20g each of cattle dung, on dry weight basis, was taken in a series of conical flask of 500 ml capacity. The moisture was adjusted at 70% level by partial drying of cattle dung and mixing of oven dried Mussoorie rock phosphate (MRP) and pyrite. The treated samples were inoculated with mixed cultures (@ 500g mycelial mat/t). The treatments were replicated thrice and the flasks were incubated at 30 ± 1°C. The rate of carbon mineralisation were measured at periodic intervals for 60 days period by absorbing the evolved CO_2 in standard sodium hydroxide and then back titrating the excess alkali with standard H_2SO_4 in presence of excess $BaCl_2$ as per procedure described under 'Materials and Methods'.

The treatment schedule is described below.

Treatment No.	Description of treatment
T_0	Cattle dung only
T_1	T_0 + MRP @ 2% P_2O_5
T_2	T_1 + Pyrite (Py) @ 0.5 time of MRP
T_3	T_1+ Py @ 1.0 time of MRP
T_4	T_1 + Py @ 3.0 times of MRP
T_5	T_0 + Microbial inoculum (MI)
T_6	T_1 + MI
T_7	T_2 + MI
T_8	T_3 + MI
T_9	T_4+ MI

RESULTS AND DISCUSSION

Rate of carbon mineralization

The rate of CO_2 evolution during decomposition of cattle dung over 60 days period as influenced by the application of rock phosphte, pyrite and microbial inoculum has been shown in Table 5 and depicted in Figure 4.3.1.1. It is observed from the data that the rate of decomposition was highest during the first 24 hours of the incubation in all the treatments. It was also recorded that the addition of MRP hastened the rate of decomposition, but presence of higher doses of pyrite decreased the rate of CO_2 evolution. Decomposition was more in the begining and decreased with time. Highest rate (572 mg/24 hrs./20g) was recorded in treatment, T_6, followed by T_7 and other treatments. About 70% of the total amount of evolved CO_2 was obtained within the first 24 to 28 days of decomposition. Pyrite, when applied @ 0.5 time of MRP did not disturb the rate of decomposition to that degree as the higher doses did. The rate of decompostion in T_4 was even below the rate of CO_2 evolution from control (T_0). Inoculation of combined microbial cultures helped the decomposition in MRP amended treatment, T_6. Treatment with lower dose of pyrite (T_7) recorded higher rate of CO_2 evolution during 2nd to 24th day of incubation. But it did not stimulate the decomposition of cattle dung without any external amendment.

Cumulative evolution of CO_2

The cumulative amount of CO_2 evolved from cattle dung during 60 days decomposition has been shown in Table 6 and depicted in Figure 4.3.1.2. The recorded data revealed that the presence of MRP along with Py (@ 0.5 time of MRP) and combined inoculum enhanced the decomposition T_6-T_9. Similar observations were recorded by Virmani (1966) and Tomar *et al.*, (1987). It might be due to the availability of nutrients which encouraged the microbial activity. Increase in number of cellulolytic microorganism with the application of MRP was noted by Korovkin (1952).

Application of Py at lower rate (@ 0.5 time of MRP) resulted highest evolution of CO_2 in T_7 (9642.7 mg). Higher application of Py (1:1) decreased the decomposition in T_8 (8332.6 mg). Further increase in application of Py (@ 3 times of MRP) decreased the decomposition notably in T_4 (5514.5 mg) and T_9 (5939.2 mg).

Table 5 Effect of Mussoorie rock phosphate, pyrite and microbial inoculum on the rate of CO_2 evolution (mg/20g/24hrs) during decomposition cattle dung

	mg CO_2 evolved/20g substrate/24 hrs															
	Days of incubation															
Treatments	1	2	3	4	6	8	10	12	16	20	24	28	36	44	52	60
T_0	450.0	190.6	63.8	215.0	101.6	120.0	139.0	168.5	146.2	101.0	150.3	140.1	80.0	60.1	54.0	50.2
T_1	460.0	220.0	74.8	234.3	145.8	140.6	160.1	161.0	189.7	164.0	199.0	178.4	103.0	64.1	61.6	60.4
T_2	445.0	211.0	72.0	216.5	142.6	136.3	145.0	160.0	178.8	161.0	172.0	163.0	87.0	70.0	60.2	58.4
T_3	470.0	165.0	101.1	223.2	93.3	74.0	151.2	179.0	119.4	108.0	121.1	100.4	81.0	62.1	50.1	50.1
T_4	325.6	162.8	37.4	224.1	112.2	128.1	130.0	133.0	116.3	102.6	130.5	107.3	76.0	61.3	61.1	43.0
T_5	479.0	182.6	102.3	218.0	106.5	126.4	120.6	163.4	143.1	104.2	142.0	137.0	78.6	61.6	53.6	51.8
T_6	572.0	237.8	112.8	251.3	223.6	181.6	197.0	216.5	260.0	247.8	221.2	210.1	101.0	87.6	79.3	77.0
T_7	565.4	272.8	120.2	262.1	243.5	192.0	198.6	240.6	283.6	250.1	230.3	199.8	100.1	92.1	82.0	78.0
T_8	473.6	191.3	141.8	238.3	200.0	146.5	182.3	186.0	211.5	200.3	219.8	178.3	90.1	82.1	81.0	74.1
T_9	479.0	182.6	99.0	211.0	100.5	116.4	122.3	156.2	142.3	103.1	133.0	130.0	78.3	60.0	53.0	51.6

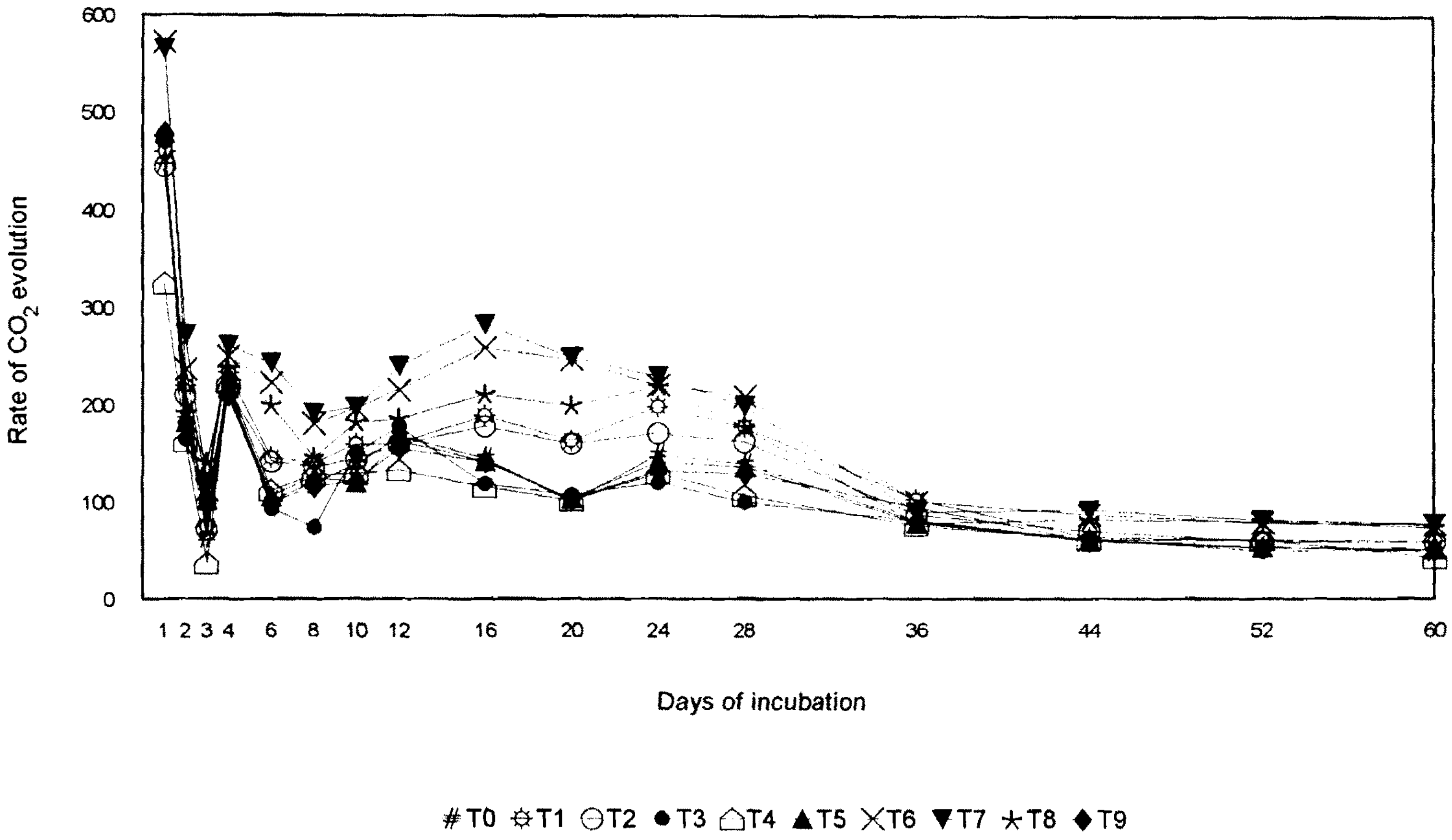


Figure 4.3.1.1 Rate of CO_2 evolution during decomposition of cattle dung

Table 6 Effect of Mussorie rock phosphate, pyrite and microbial inoculum on the cumulative evolution of CO_2 (mg) during decomposition of cattle dung

	mg CO_2 evolved															
	Days of Incubation															
Treatments	1	2	3	4	6	8	10	12	16	20	24	28	36	44	52	60
T_0	450	640.6	704.4	919.4	1122.6	1362.6	1640.6	1977.6	2562.4	2966.4	3567.6	4128.0	4768.0	5248.8	5680.8	6082.4
T_1	460	680.0	754.8	989.1	1280.7	1561.9	1882.1	2204.1	2962.9	3618.9	4414.9	5128.5	5952.5	6465.3	6958.1	7441.3
T_2	445	656	728.0	944.5	1229.7	1502.3	1792.3	2112.3	2827.5	3471.5	4159.5	4811.5	5507.5	6067.5	6549.1	7016.3
T_3	470.0	635.0	736.1	959.3	1145.9	1293.9	1596.3	1954.3	2431.9	2867.1	3351.5	3753.1	4401.1	4897.9	5298.7	5699.5
T_4	325.6	488.4	525.8	749.9	974.3	1230.5	1490.5	1756.5	2221.7	2632.1	3154.1	3583.3	4191.3	4681.7	5170.5	5514.5
T_5	479.0	661.6	763.9	981.9	1194.9	1447.7	1688.9	2015.7	2588.1	3004.9	3572.9	4120.9	4749.7	5242.5	5671.3	6085.7
T_6	572.0	809.8	922.6	1173.9	1621.1	1984.3	2378.3	2811.3	3851.3	4842.5	5727.3	6567.3	7375.3	8076.1	8710.5	9326.5
T_7	565.4	838.2	958.4	1220.5	1707.5	2091.5	2488.7	2969.9	4104.3	5104.7	6025.9	6825.1	7625.9	8362.7	9018.7	9642.7
T_8	473.6	664.9	806.7	1045.0	1445.0	1738.0	2102.6	2474.6	3320.6	4121.8	5001.0	5714.2	6435.0	7091.8	7739.8	8332.6
T_9	479.0	661.6	760.6	971.6	1172.6	1405.4	1650.0	1962.4	2531.6	2944.0	3476.0	3996.0	4622.4	5102.4	5526.4	5939.2

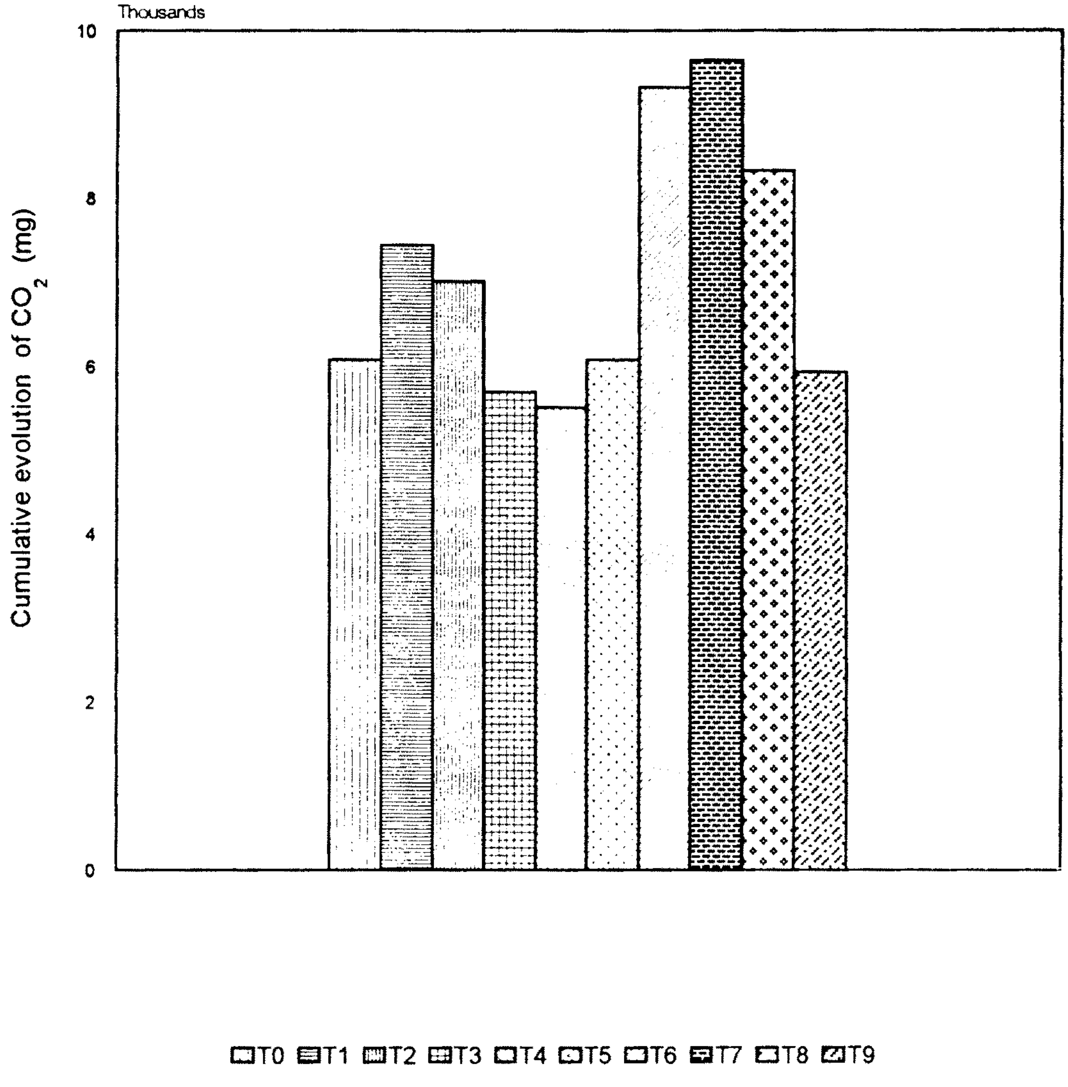


Figure 4.3.1.2 Cumulative evolution of CO_2 during decomposition of cattle dung

This might be attributed to the significant decrease in the pH of the system rendering adverse effect on the microbial activity. Anderson and Malcolm (1974) explained that the increased activity of Fe^{3+} and Ca^{2+} ions due to oxidation of Py and dissolution of MRP might have interacted with organic compounds forming complexes more resistant to microbial degradation.

Presence of combined inoculum hardly affected the decomposition of untreated cattledung (T_5). But it influenced positively the decomposition in MRP and Py treated cattle dung (T_6 - T_9). That might be due to the nutritional effect of cattle dung and also other inorganic inputs which encouraged the microbial activity. Thus, cumulative amount of evolved CO_2 from different treatments followed the order : $T_7 > T_6 > T_8 > T_1 > T_2 > T_5 > T_9 > T_3 > T_4$. Therefore it is observed from the present study that the treatment schedule consisting of 2% P_2O_5 as MRP, Pyrite @ 0.5 time of MRP and microbial inoculum was most effective in rapid decomposition of cattle dung.

4.3.2 PREPARATION OF PHOSPHOCOMPOST FROM PADDY STRAW : EFFECT OF CATTLE DUNG, PYRITE AND HIGHER LEVEL OF ROCK PHOSPHATE ON RAPID DECOMPOSITION.

Application of calcium phosphate increases the rate of decomposition and nitrogen conservation (Chekalov, 1955; Arzamasova and Kuzmenkova, 1962). Preparation of phosphocompost needs selection of amendments to ensure rapid decomposition and phosphate enrichment of the final product. Low grade rock phosphate may be used as a source of phosphorus along with pyrite to increase the available P content of the compost. Pyrite, being a highly reduced compound, oxidises readily in the presence of moist air to form H_2SO_4, which may help in dissolution of added Mussoorie rock phosphate (MRP) during decomposition of the organic residue. But higher application of rock phosphate has been reported to inhibit the rate of decomposition (Dhar and Gupta, 1961).

In the above context, present experiment was undertaken to study the effect of higher application of MRP along with pyrite on the decomposition of paddy straw as influenced by higher application of cattle dung. The rate and amount of evolved CO_2 were considered as the indices of microbial activity leading to decomposition of straw and cattle dung over 60 days incubation.

EXPERIMENTAL

Each 10gm portion of oven dried, chopped (1cm) paddy straw was mixed with three levels of cattle dung, viz; 10, 20 and 40 percent on dry weight basis. Each mixture was treated with two levels of MRP i.e. 2 and 5 percent P_2O_5 equivalent. Rock phosphate to pyrite ratio was maintained at 1:0.5, and microbial inoculum was added @ 500 g mixed spore suspension per tonne of orgnic matter. Inorganic nitrogen @ 0.5% N in the form of urea was added as starter. Moisture was adjusted at 100 percent level. Each treatment was replicated thrice and taken in a series of 500 ml conical flasks for measurement of evolved CO_2 as per procedure described under 'Materials and Methods'.

The schedule of treatment was as under

Treatment	Description of Treatment
T_0	Paddy straw (PS) + Microbial inoculum (MI) + 0.5% N
T_1	T_0 + Mussoorie Rock Phosphate @ 2% P_2O_5 (MRP_1) + Pyrite (Py) @ 0.5 time of MRP_1
T_2	T_1 + Cattle dung @ 10% of straw (CD_1)
T_3	T_1 + Cattle dung @ 20% of straw (CD_2)
T_4	T_1 + Cattle dung @ 40% of straw (CD_3)
T_5	To + Mussoorie Rock Phosphate @ 5% P_2O_5 (MRP_2) + Py @ 0.5 time of MRP_2
T_6	T_5 + CD_1
T_7	T_5 + CD_2
T_8	T_5 + CD_3

RESULTS AND DISCUSSION

The rate of mineralization of carbon during decomposition of paddy straw in presence of cattle dung, MRP and Py has been shown in Table 7 and depicted in Figure 4.3.2.1.

It is observed from the data that the evolution of CO_2 was quite noticeable within first 24 hours of decomposition. This indicates that as soon as optimum condition of temperature and moisture is provided, the microbial activity shoots up without any lag phase. The rate of CO_2 evolution increased

Table 7 Effect of different doses of Mussoorie rock phosphate on the rate of evolution of CO_2 (mg/10g /24 hrs.) during decomposition of paddy straw in presence of varied amount of cattle dung

Treatments	mg CO_2 /10 g substrate /24 hrs															
	Days of Incubation															
	1	2	3	4	6	8	10	12	16	20	24	28	36	44	52	60
T_0	160.6	191.3	201.3	208.0	190.6	185.0	210.3	205.6	187.3	120.1	130.1	90.6	70.6	60.0	49.6	36.8
T_1	180.2	206.0	217.4	227.3	200.4	206.7	198.7	187.6	199.4	170.3	165.2	100.2	66.4	62.1	38.5	37.7
T_2	263.4	291.8	313.5	335.6	318.7	315.0	340.2	308.6	282.6	199.6	220.7	210.5	98.7	81.3	77.6	77.5
T_3	284.6	326.9	340.6	401.7	372.3	353.1	391.8	283.0	251.4	213.9	225.6	169.3	110.6	78.7	69.3	68.8
T_4	280.1	311.7	331.5	345.6	320.3	316.8	339.8	310.6	242.7	231.4	233.2	178.3	105.0	99.6	83.4	83.1
T_5	169.5	171.0	172.0	175.4	170.2	189.2	167.3	164.5	182.6	182.5	170.1	99.0	76.5	59.7	39.0	36.5
T_6	185.1	256.7	263.5	312.0	299.2	263.0	278.5	256.3	220.3	208.0	208.4	180.4	93.0	72.5	65.6	59.0
T_7	300.6	331.7	341.8	408.5	387.6	365.3	392.4	311.6	272.6	236.7	249.2	178.5	120.6	79.8	75.2	73.4
T_8	280.9	326.7	329.8	378.9	300.7	292.3	351.6	300.3	249.2	210.0	230.6	190.6	99.7	99.3	71.1	70.9

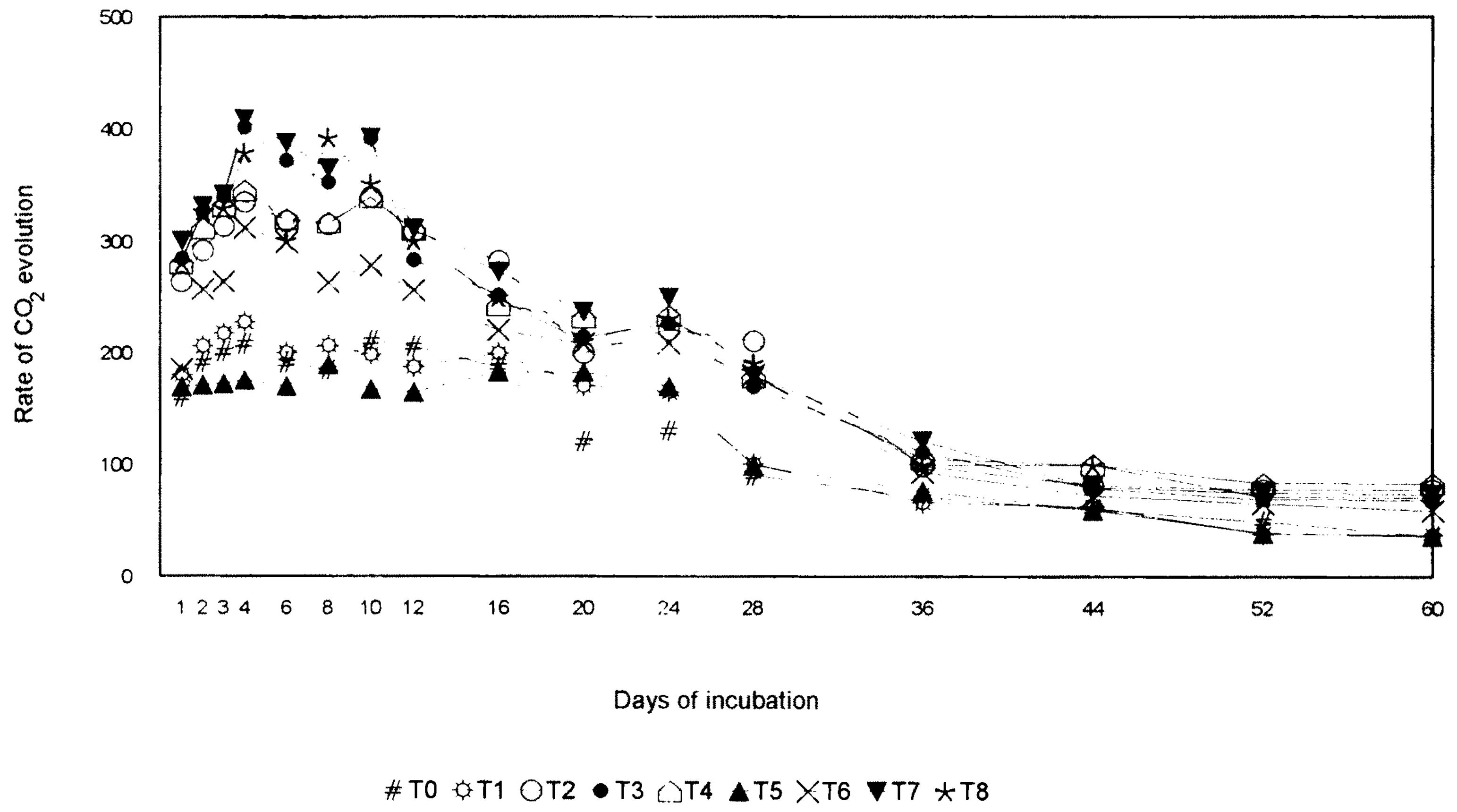


Figure 4.3.2.1 Rate of CO_2 evolution during decomposition of paddy straw as influenced by cattle dung and mussoorie rock phosphate

gradually till 4th day of incubation followed by a gradual decrease in all the treatments including control.

With the progress of incubation the rate of CO_2 evolution followed different pathway in different treatments.

The highest peak for all the treatments, except T_5, was recorded on the 4th day of decomposition. This trend in decomposition was also recorded by Debnath and Sinha (1993). The second peak in CO_2 evolution was recorded on the 8th day in T_1 and T_5 and on the 10th day in the others with a third one on the 16th day in T_1 , T_5 and T_6 and on the 24th day in rest of the treatments indicating differential growth in the cellulose decomposing microorganisms as influenced by the treatments.

Maximum rate of CO_2 evolution (408.5 mg/24 hrs/10g) was recorded on the 4th day of incubation in treatment T_7 where inoculated paddy straw was treated with 5% P_2O_5 as MRP, Py @ 0.5 time of MRP and CD @ 20% of straw by dry weight.

Total amount of CO_2 evolved from straw was lowest in control and highest in treatment T_7. Treatments with lower dose of MRP i.e. T_1 , T_2 and T_4 showed comparatively higher CO_2 evolution than treatments with higher doses of MRP barring T_3. Presence of higher amount of cattle dung resulted in higher amount of evolved CO_2 which might be due to the decomposition of easily available carbon. But treatment, T_8, receiving higher amount of cattle dung @ 40% recorded lower rate and amount of evolved CO_2. Presence of higher amount of MRP and Py might have decreased the microbial activity. It is likely that the increased activities of Fe^{3+} and Ca^{2+} ions due to the oxidation of Py and the solubilization of MRP which interacted with organic compounds forming more

Table 8 Effect of different doses of mussoorie rock phosphate on the cumulative evolution of CO_2 (mg) during decomposition of paddy straw in presence of varied amount of cattle dung

Treatments	mg CO_2 evolved															
	Days of Incubation															
	1	2	3	4	6	8	10	12	16	20	24	28	36	44	52	60
T_0	160.6	351.9	553.2	761.2	1142.8	1512.4	1933.0	2344.2	3093.4	3573.8	4094.2	4456.6	5021.4	5501.4	5898.2	6192.6
T_1	180.2	386.2	603.6	830.9	1231.7	1645.1	2042.5	2417.7	3215.3	3896.5	4557.3	4958.1	5489.3	5986.1	6294.1	6595.7
T_2	263.4	555.2	868.7	1204.3	1841.7	2471.7	3152.1	3769.3	4899.7	5698.1	6580.9	7422.9	8212.5	8862.9	9483.7	10103.7
T_3	284.6	611.5	952.1	1353.8	2098.4	2804.6	3588.2	4154.2	5159.8	6015.4	6917.8	7595.0	8479.8	9109.4	9663.8	10214.2
T_4	280.1	591.8	923.3	1268.9	1909.5	2543.1	3222.7	3843.9	4814.7	5740.3	6673.1	7386.3	8226.3	9023.1	9690.3	10355.1
T_5	169.5	340.5	512.5	687.9	1019.3	1397.7	1732.3	2061.3	2791.7	3521.7	4202.1	4598.1	5210.1	5687.7	5999.7	6291.7
T_6	185.1	441.8	705.3	1017.3	1615.7	2141.7	2698.7	3211.3	4092.5	4924.5	5758.1	6479.7	7223.7	7803.7	8328.5	8800.5
T_7	300.6	632.3	974.1	1382.6	2157.8	2888.4	3673.2	4296.4	5386.8	6333.6	7330.4	8044.4	9009.2	9647.6	10249.2	10836.4
T_8	280.9	607.6	937.4	1316.3	1917.7	2502.3	3205.5	3806.1	4802.9	5642.9	6565.3	7327.7	8125.3	8919.7	9488.5	10055.7

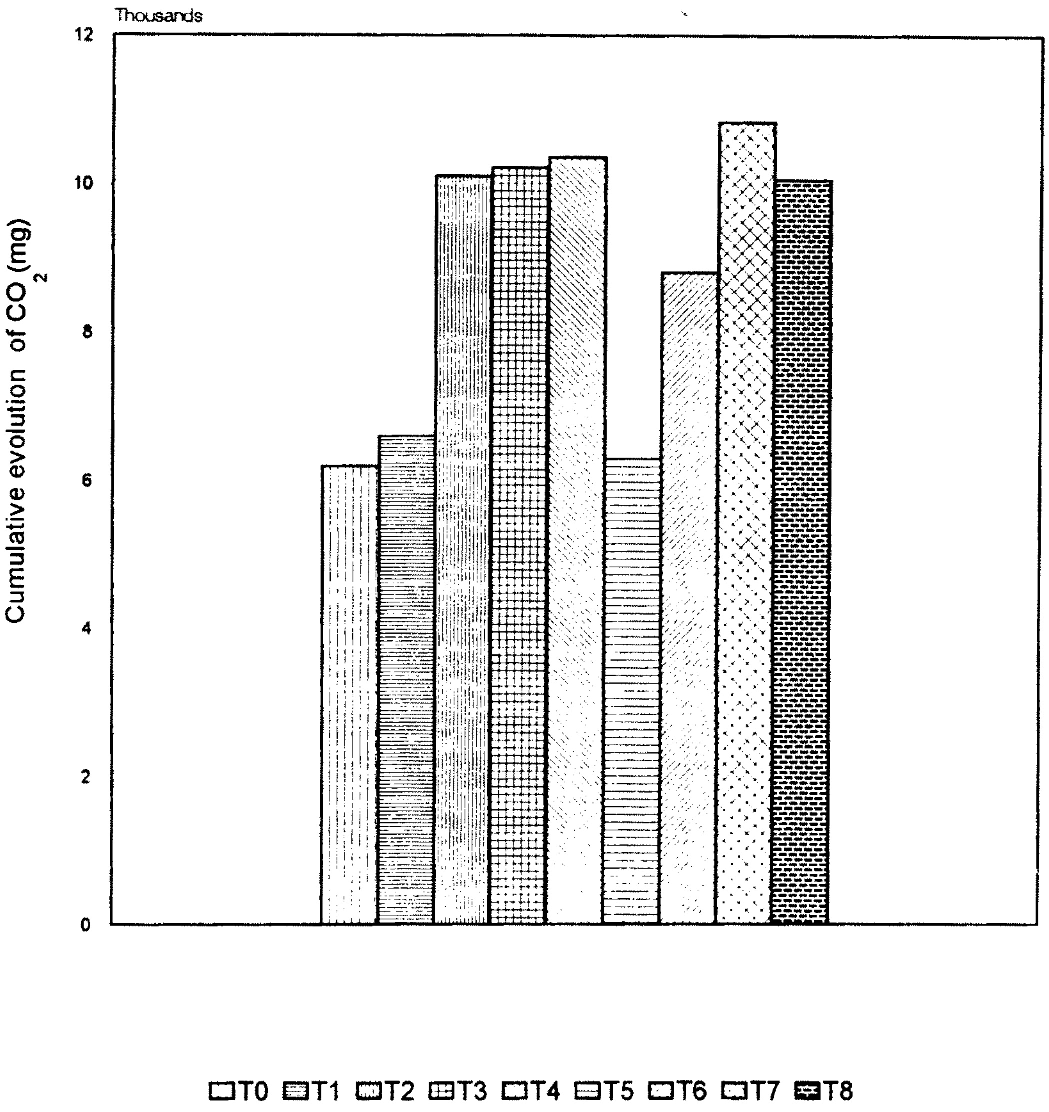


Figure 4.3.2.2 Cumulative evolution of CO_2 during decomposition of paddy straw as influenced by cattle dung and mussoorie rock phosphate

resistant complexes for microbial degradation as observed by Anderson and Malcolm, (1947).

The cumulative amount of CO_2 evolved from different treatments (Table 8 and Figure 4.3.2.2), followed the order: $T_0 < T_5 < T_1 < T_6 < T_8 < T_2 < T_3 < T_4 < T_7$. Therefore, it is observed from the study that the higher application of cattle dung was favourable in decomposition of paddy straw when in association with lower application of rock phosphate and pyrite.

4.3.3 PREPARATION OF PHOSPHOCOMPOST FROM WATER HYACINTH: EFFECT OF CATTLE DUNG, MUSSOORIE ROCK PHOSPHATE AND PYRITE ON RAPID DECOMPOSITION.

Water hyacinth (*Eichhornia crassipes*) is a fast growing aquatic weed and is a serious concern to the fresh water fisheries, irrigation system and low land paddy cultivation (Gopal, 1981). High carbon and nitrogen content of *E. Crassipes* (Gupta, 1987; Gaur *et al.*, 1995) invites the idea for utilizing it as a composting substrate (Jagadish and Lakshminarayana, 1971). The narrower C/N ratio of water hyacinth may be helpful to the process of decomposition, but many off sets and rhizomes of the weed retain viability after their prolonged composting (Gupta, 1987). So, the pattern of degradation of water hyacinth in presence of different doses of cattle dung, phosphate rock and pyrite along with microbial inoculum was studied to find out the effective substrate combination for preparation of phosphocompost from water hyacinth.

7

EXPERIMENTAL

Each 10 gm portion of chopped (1 cm), partly dried water hyacinth was treated with three levels of fresh cattle dung, viz; 10, 20 and 40 percent by weight. Each mixture was treated with two levels of MRP i.e. 2% and 5%

equivalent of P_2O_5 and pyrite was mixed @ 0.5 part of MRP. Microbial inoculum, consisting of cellulose decomposing and phosphate solubilizing fungi was used @ 500 g spore suspension per tonne of the mass. Each treatment was placed in a series of 1 litre conical flask for measurment of CO_2. A control with water hyacinth alone was included. Moisture was maintained at 80% level. The treatments were replicated thrice and all the flasks were incubated at laboratory temperature which varied within 29 ± 2°C. The rate of respiration was measured as an index of decomposition by measuring the amount of evolved CO_2 during 60 days decomposition period as per procedure. The schedule of treatment was as under.

Treatment	**Description of treatment**
T_0	Water hyacinth (WH)
T_1	WH + 10% cattle dung (CD_1) + Microbial Inoculum (MI)
T_2	WH + 20% cattle dung (CD_2) + MI
T_3	WH + 40% cattle dung (CD_3) + MI
T_4	T_1 + Mussoorie Rock Phosphate @ 2% P_2O_5 (MRP_1)
T_5	T_2+ MRP_1
T_6	T_3 + MRP_1
T_7	T_1 + Mussoorie Rock Phosphate @ 5% P_2O_5 (MRP_2)
T_8	T_2 + MRP_2
T_9	T_3 + MRP_2
T_{10}	T_4 + Pyrite @ 0.5 time of MRP_1 (Py_1)
T_{11}	T_5 + Py_1
T_{12}	T_6 + Py_1
T_{13}	T_7 + Pyrite @ 0.5 time of MRP_2 (Py_2)
T_{14}	T_8 + Py_2
T_{15}	T_9 + Py_2

RESULTS AND DISCUSSION

Rate of CO_2 evolution

The rate of CO_2 evolution as a result of decomposition of water hyacinth amended with different doses of cattle dung, MRP and pyrite has been shown in Table 9 and Figure 4.3.3.1. It is observed from the data recorded over 60 days of incubation that the rate of CO_2 evolution increased gradually in all the treatments till 3rd day followed by a decrease on the 4th day and further increase on 6th and 8th day except in T_5 which showed a decrease on the 8th day. All the treatments including control recorded a declining rate of CO_2 evolution after 24th day of incubation. The highest rate of CO_2 evolution (714.1 mg/24 hrs/10g) was recorded on the 8th day of incubation in the treatment, T_{14}, where partly dried water hyacinth was treated with fresh cattle dung, @ 20%; MRP, @ 5% P_2O_5 and Py, @ 0.5 part of MRP along with mixed inoculum.

Rate of CO_2 evolution, when plotted against days of incubation, showed the first peak on the 3rd day in all the treatments including control. The 2nd peak was observed on the 8th day in all the treatments except in T_5 which showed it on 6th day. On the 20th day of incubation, the 3rd peak was observed in all the treatments excluding T_7. Maximum carbon was mineralized during the first couple of weeks indicating maximum microbial activity. It might be due to the presence of adequate moisture, temperature and nutrients available during those days. This trend was also recorded by Sur and Sinha (1982).

Cumulative Evolution of CO_2

The cumulative amount of CO_2 evolved from treatead W.H. during 60 days decomposition has been shown in Table 10 and Figure 4.3.3.2. It is observed from the data that the amount of evolved CO_2 increased with increase in amount of cattle dung (CD), as in T_1 (6383.6 mg), T_2 (6913.1 mg), T_3(7584.3

Table 9 Rate of CO_2 evolution (mg/10g/24 hrs.) during decomposition of water hyacinth amended with cattle dung, phosphate rock and pyrite

Treatments	mg CO_2 evolved /10g/24 hrs															
	Days of Incubation															
	1	2	3	4	6	8	10	12	16	20	24	28	36	44	52	60
T_0	347.8	423.0	574.1	341.0	357.1	392.4	196.1	173.2	110.0	130.1	45.6	30.3	30.4	20.2	20.1	18.2
T_1	356.4	422.4	486.0	347.6	379.3	404.5	193.0	169.8	115.0	135.2	49.8	36.9	36.6	35.8	34.6	34.3
T_2	390.6	446.6	491.0	368.3	403.0	416.0	201.2	170.7	180.2	190.0	76.5	70.4	46.3	40.2	40.0	38.7
T_3	390.5	426.8	500.0	398.0	408.1	419.3	291.2	169.1	175.2	188.6	79.0	60.2	47.0	38.9	37.8	36.5
T_4	412.2	500.0	504.2	330.6	445.1	461.4	299.8	146.1	111.5	179.2	101.4	70.2	62.5	54.1	40.1	35.3
T_5	435.0	508.3	519.3	341.7	481.1	478.0	301.0	149.3	120.2	178.5	110.0	75.0	58.5	49.2	39.9	38.6
T_6	441.0	464.2	508.8	303.6	459.2	472.2	298.9	153.0	119.2	168.4	129.5	78.1	61.7	53.0	43.2	40.8
T_7	314.6	425.4	489.0	341.3	400.1	402.0	196.5	171.2	120.1	114.5	38.9	37.2	35.3	68.9	35.7	36.3
T_8	501.6	606.0	670.0	411.0	535.3	635.0	408.3	230.0	173.3	230.4	140.3	83.0	71.2	70.0	68.7	68.3
T_9	455.4	576.6	597.3	332.2	512.6	586.5	325.0	188.3	175.2	190.1	81.2	65.3	65.3	63.2	60.1	59.8
T_{10}	436.3	513.5	532.3	329.7	406.3	431.0	298.7	145.4	123.7	180.0	93.4	68.9	55.7	55.6	54.7	53.7
T_{11}	435.6	543.0	561.4	423.8	598.7	683.6	468.3	240.3	179.6	251.6	149.3	87.0	68.2	65.3	60.0	58.9
T_{12}	484.0	518.0	573.8	410.3	476.8	522.5	379.0	169.8	168.3	240.3	136.0	74.6	59.8	53.3	44.6	43.2
T_{13}	496.3	579.0	600.7	403.0	495.4	502.0	300.5	139.0	121.0	200.5	87.3	70.3	54.3	53.8	52.7	52.0
T_{14}	499.4	618.2	675.3	501.4	683.0	714.1	500.1	263.1	186.0	300.0	152.5	111.4	70.3	68.9	67.8	67.0
T_{15}	472.1	509.7	556.7	402.8	486.3	531.0	400.6	300.6	190.3	207.4	115.3	69.3	58.3	52.8	52.6	52.2

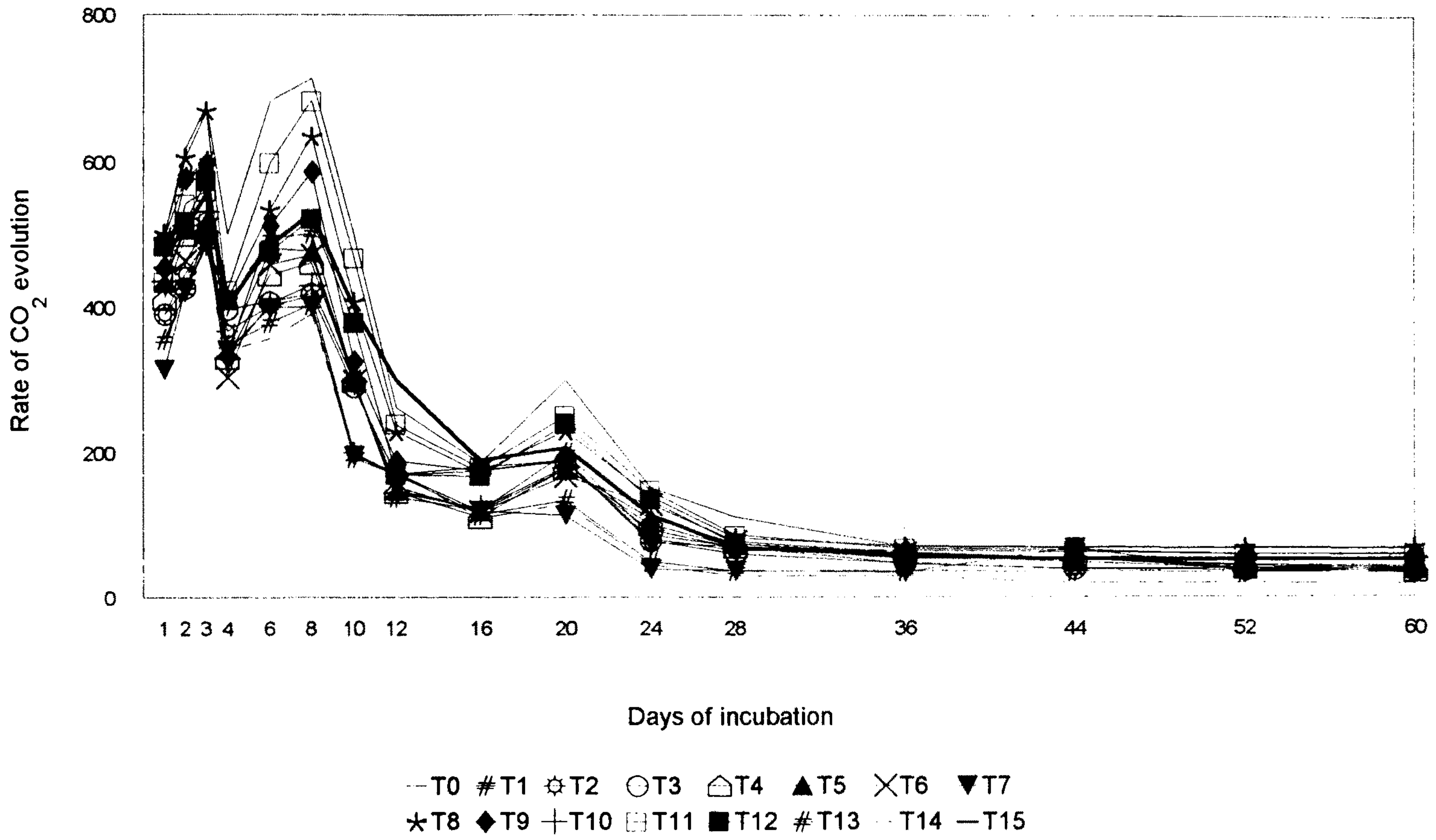


Figure 4.3.3.1 Rate of CO_2 evolution during decomposition of water hyacinth amended with cattle dung, mussoorie rock phosphate and pyrite

Table 10 Cumulative evolution of CO_2 (mg) during decomposition of water hyacinth amended with cattle dung, phosphate rock and pyrite

Treatments	mg CO_2 evolved															
	Days of Incubation															
	1	2	3	4	6	8	10	12	16	20	24	28	36	44	52	60
T_0	347.8	770.8	1344.9	1684.2	2398.4	3183.2	3575.4	3921.8	4361.8	4882.2	5064.6	5185.8	5429.0	5590.6	5751.4	5897.0
T_1	356.4	778.8	1264.8	1612.4	2371.0	3180.0	3566.0	3905.6	4365.6	4906.4	5105.6	5253.2	5546.0	5832.4	6109.2	6383.6
T_2	390.6	837.2	1328.2	1696.5	2502.5	3334.5	3736.9	4078.3	4438.7	4818.7	5124.7	5406.3	5961.9	6283.5	6603.5	6913.1
T_3	390.5	817.3	1317.3	1715.3	2531.5	3370.1	3952.5	4290.7	4991.5	5745.9	6061.9	6302.7	6678.7	6989.9	7292.3	7584.3
T_4	412.2	912.2	1416.4	1747.0	2637.2	3560.0	4159.6	4451.8	4897.8	5614.6	6020.2	6301.0	6801.0	7233.8	7554.6	7837.0
T_5	435.0	943.3	1462.6	1804.3	2766.5	3722.5	4324.5	4623.1	5103.9	5817.9	6257.9	6557.9	7025.9	7419.5	7738.7	8047.5
T_6	441.0	905.2	1414.0	1717.6	2636.0	3580.4	4178.2	4484.2	4961.0	5634.6	6152.6	6465.0	6958.6	7382.6	7728.2	8054.6
T_7	314.6	740.0	1229.0	1570.3	2370.5	3174.5	3567.5	3909.9	4390.3	4848.3	5003.9	5152.7	5435.1	5986.3	6271.9	6562.3
T_8	501.6	1107.6	1777.6	2188.6	3259.2	4529.2	5345.8	5805.8	6499.0	7420.6	7981.8	8313.8	8883.4	9443.4	9993.0	10539.4
T_9	455.4	1032.0	1629.3	1961.5	2986.7	4159.7	4809.7	5186.3	5887.1	6647.5	6972.3	7233.5	7755.9	8261.5	8742.3	9220.7
T_{10}	436.3	949.8	1482.1	1811.8	2624.4	3486.4	4083.8	4374.6	4869.4	5589.4	5963.0	6238.6	6684.2	7129.0	7566.6	7996.2
T_{11}	435.6	978.6	1540.0	1963.8	3161.2	4528.4	5465.0	5945.6	6664.0	7670.4	8267.6	8963.6	9509.2	10031.6	10511.6	10982.8
T_{12}	484.0	1002.0	1575.8	1986.1	2939.7	3984.7	4742.7	5082.3	5755.5	6716.7	7260.7	7559.1	8037.5	8463.9	8820.7	9166.3
T_{13}	496.3	1075.3	1676.0	2079.0	3069.8	4073.8	4674.8	4952.8	5436.8	6238.8	6588.0	6869.2	7303.6	7734.0	8155.6	8571.6
T_{14}	499.4	1117.6	1792.9	2294.3	3660.3	5088.5	6088.7	6614.9	7358.9	8558.9	9168.9	9614.5	10176.9	10728.1	11270.5	11806.5
T_{15}	472.1	981.8	1538.5	2095.2	3067.8	4129.8	4931.0	5532.2	6239.4	7123.0	7584.2	7861.4	8327.8	8750.2	9171.0	9588.6

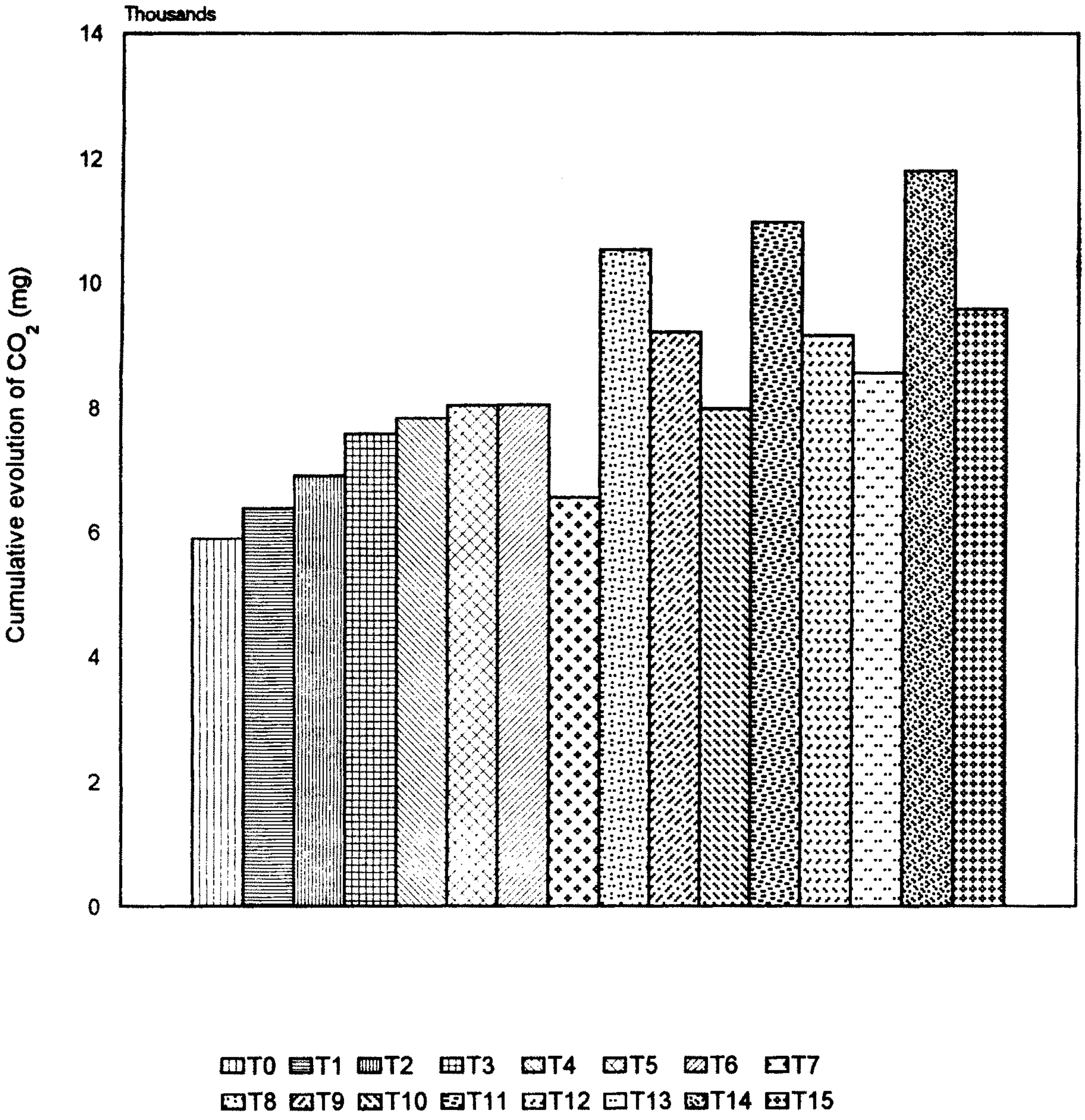


Figure 4.3.3.2 Cumulative evolution of CO_2 during decomposition of water hyacinth amended with cattle dung, mussoorie rock phosphate and pyrite

mg), T_4(7837.8 mg), T_5 (8047.5 mg) and T_6 (8054.6 mg). T_7 recorded less (6562.3 mg) amount of evolved CO_2 which might be due to higher application of MRP. But when the same amount of MRP was applied along with 20% CD in T_8 , it evolved higher amount of CO_2 (10539.4 mg). It increased further in T_{11} (10982.8 mg) when WH was treated with 20% of CD, 2% P_2O_5 as MRP and pyrite. Maximum evolution (11806.5 mg) was recorded in T_{14} which received 20% CD, 5% $P_2 O_5$, pyrite @ 0.5 part of MRP along with microbial inoculum. Higher application of MRP and Py restricted the decomposition but presence of CD ameliorated ~~those~~ this detrimental effect. This might be due to availability of nutrients which boosted up the microbial growth of the system. Treatments receiving higher doses of CD showed higher evolution where no MRP or Py was present. Application of MRP along with 20% CD in T_2, T_5 and T_8 resulted in comparatively higher evolution of CO_2. Performance of T_{11} was much better than T_5, and that of T_{14} was better than T_8, that might be due to the presence of pyrite which helped transformation of MRP into more easily soluble and available forms increasing the availability of nutrients. Pyrite influenced positively the treatments T_{11} and T_{14}, receiving 20% CD along with 2% and 5% P_2O_5 respectively. Thus the cumulative amount of CO_2 evolved from different treatments followed the order; $T_{14} > T_{11} > T_8 > T_{15} > T_9 > T_{12} > T_{13} > T_6 > T_5 > T_{10} > T_4 > T_3 > T_2 > T_7 > T_1 > T_0$. Therefore application of cattledung at 20 per cent level along with MRP and pyrite both at lower and higher levels were considered appropriate for rapid decomposition of water hyacinth for the preparation of phosphocompost.

4.3.4 PREPARATION OF PHOSPHOCOMPOST FROM WATER HYACINTH - PADDY STRAW MIXTURE : EFFECT OF HIGHER RATES OF PHOSPHATE ROCK AND PYRITE ON DECOMPOSITION IN PRESENCE AND ABSENCE OF CATTLE DUNG.

As water hyacinth contains around 90 percent of water, it requires other dry carbonaceous materials as bulking agents for rapid decomposition. In this context, an attempt was taken in the present investigation, to study the effect of mixing water hyacinth with paddy straw in the proportion of 1:1, 2:1 and 3:1 and amending with high rates of Mussoorie rock phosphate (MRP) and pyrite in presence and absence of cattledung for rapid decomposition and production of high quality phosphocompost. Evolved CO_2 was measured as an index of the decomposition rate.

EXPERIMENTAL

The experiment was carried out in three sets. The first set received the substrate, water hyacinth and paddy straw in 1 : 1, the second one in 2 : 1 and the third one in 3 : 1 proportion. Each set received MRP at the rate of 5.0, 7.5 and 10.0 per cent P_2O_5 equivalent and pyrite at the rate of 0.5 part of applied MRP. Cattle dung was selected at 20% level because of its superiority over the other rates (Expt. No. 4.3.3). Each 10 gm portion of the composite mixture of water hyacinth and straw in a definite ratio was mixed with three doses of MRP separately. Each part was inoculated with mixed inoculum @ 500g/tonne organic material. Moisture was adjusted at 80% level. Each treatment was replicated thrice and was placed in a series of 500 ml conical flasks for measurement of evolved CO_2 at intervals during 60 days incubation.

The schedule of treatment was as under:

Treatment	Set-I	Set-II	Set-III
T_0	Water hyacinth (W.H.): Paddy straw (PS) :: 1:1 + Microbial Inoculum (MI)	W.H. : PS :: 2:1 + MI	W.H. : PS :: 3:1 + MI
T_1	To + Mussorrie rock phosphate @ 5% P_2O_5 (MRP_1) + Pyrite @ 0.5 part of MRP_1 (Py_1)	$T_0 + MRP_1 + Py_1$	$T_0 + MRP_1 + Py_1$
T_2	To + MRP @ 7.5% P_2O_5 (MRP_2)+ Py @ 0.5 part of MRP_2 (Py_2)	$T_0 + MRP_2 + Py_2$	$T_0 + MRP_2 + Py_2$
T_3	To + MRP @ 10% P_2O_5 (MRP_3)+ Py @ 0.5 part of MRP_3 (Py_3)	$T_0 + MRP_3 + Py_3$	$T_0 + MRP_3 + Py_3$
T_4	T_1 + 20% cattle dung (CD)	T_1 + 20% CD	T_1 + 20% CD
T_5	T_2 + 20% CD	T_2 + 20% CD	T_2 + 20% CD
T_6	T_3 + 20% CD	T_3 + 20% CD	T_3 + 20% CD

RESULTS AND DISCUSSION

Set I

The rate and cumulative amount of CO_2 evolved as a result of decomposition of water hyacinth - paddy straw mixture (1:1) as influenced by the presence of higher applicatiof MRP and pyrite alone andin combination with cattle dung have been shown in Table 11 and 12 and Figure 4.3.4.1. and 4.3.4.2.

Table 11 Effect of mussoorie rock phosphate, pyrite and cattle dung on the rate of CO_2 evolution during decomposition of water-hyacinth and paddy straw mixed in 1:1 ratio

	mg CO_2 evolved/10g substrate/24 hrs.															
	Days of incubation															
Treatments	1	2	3	4	6	8	10	12	16	20	24	28	36	44	52	60
T_0	188.6	204.6	216.0	249.2	390.2	343.8	340.6	361.0	256.1	265.3	173.2	100.3	72.3	72.1	66.5	65.7
T_1	180.4	205.7	220.3	222.6	392.4	363.2	392.0	265.2	270.3	282.3	250.0	120.1	78.1	75.6	75.5	75.1
T_2	180.2	180.3	184.3	200.3	204.3	182.3	180.5	177.8	170.3	158.5	153.4	100.2	69.2	63.2	59.0	58.8
T_3	178.6	179.7	182.4	190.2	195.6	180.3	173.4	165.6	160.4	137.3	132.6	90.1	67.5	60.4	52.3	51.1
T_4	200.3	260.7	292.5	295.6	405.4	395.7	372.0	398.3	285.5	289.2	270.3	178.2	81.2	80.2	78.7	78.3
T_5	192.3	215.6	253.5	271.0	385.6	386.7	374.6	362.0	225.3	201.1	179.4	105.0	76.3	74.3	65.4	63.1
T_6	182.7	183.4	187.3	207.3	220.0	205.6	156.3	200.0	180.3	157.6	102.0	90.7	77.0	70.3	60.1	52.0

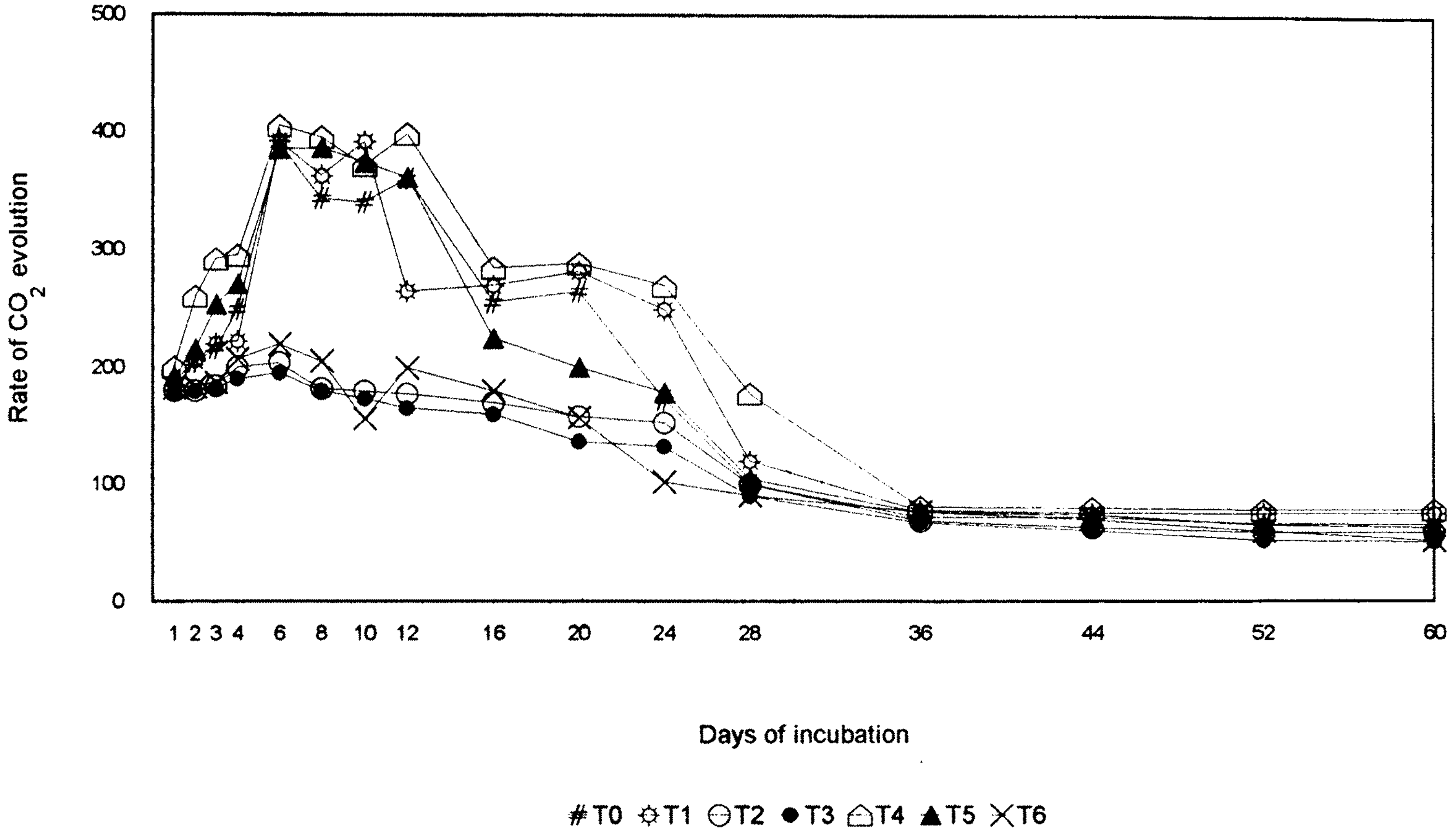


Figure 4.3.4.1 Rate of CO_2 evolution during decomposition of water hyacinth and paddy straw mixed in 1 : 1 ratio

Table 12 Effect of Mussoorie rock phosphate, pyrite and cattle dung on the cumulative evolution of CO_2 during decomposition of water-hyacinth and paddy straw mixed in 1:1 ratio

Treatments	mg CO_2 evolved															
	Days of Incubation															
	1	2	3	4	6	8	10	12	16	20	24	28	36	44	52	60
T_0	188.6	393.2	609.2	858.4	1638.8	2326.4	3007.6	3729.6	4754.0	5815.2	6508.0	6909.2	7487.6	8064.4	8596.4	9122.0
T_1	180.4	386.1	606.4	829.0	1473.8	2200.2	2984.2	3514.6	4595.8	5725.0	6725.0	7205.4	7830.2	8435.0	9039.0	9639.8
T_2	180.2	360.5	544.8	745.1	1153.7	1518.3	1879.3	2234.9	2916.1	3550.1	4163.7	4564.5	5118.1	5623.7	6095.7	6566.1
T_3	178.6	358.3	540.7	730.9	1122.1	1482.7	1829.5	2160.7	2802.3	3351.5	3881.9	4242.3	4782.3	5265.5	5683.9	6092.7
T_4	200.3	461.0	753.5	1049.1	1859.9	2651.3	3395.3	4191.9	5333.9	6490.7	7571.9	8284.7	8934.3	9575.9	10205.5	10831.9
T_5	192.3	407.9	661.4	932.4	1703.6	2477.0	3226.2	3950.2	4851.4	5655.8	6373.4	6793.4	7403.8	7998.2	8521.4	9026.2
T_6	182.7	366.1	553.4	760.7	1200.7	1611.9	1924.5	2324.5	3045.7	3676.1	4084.1	4446.9	5062.9	5625.3	6106.1	6522.1

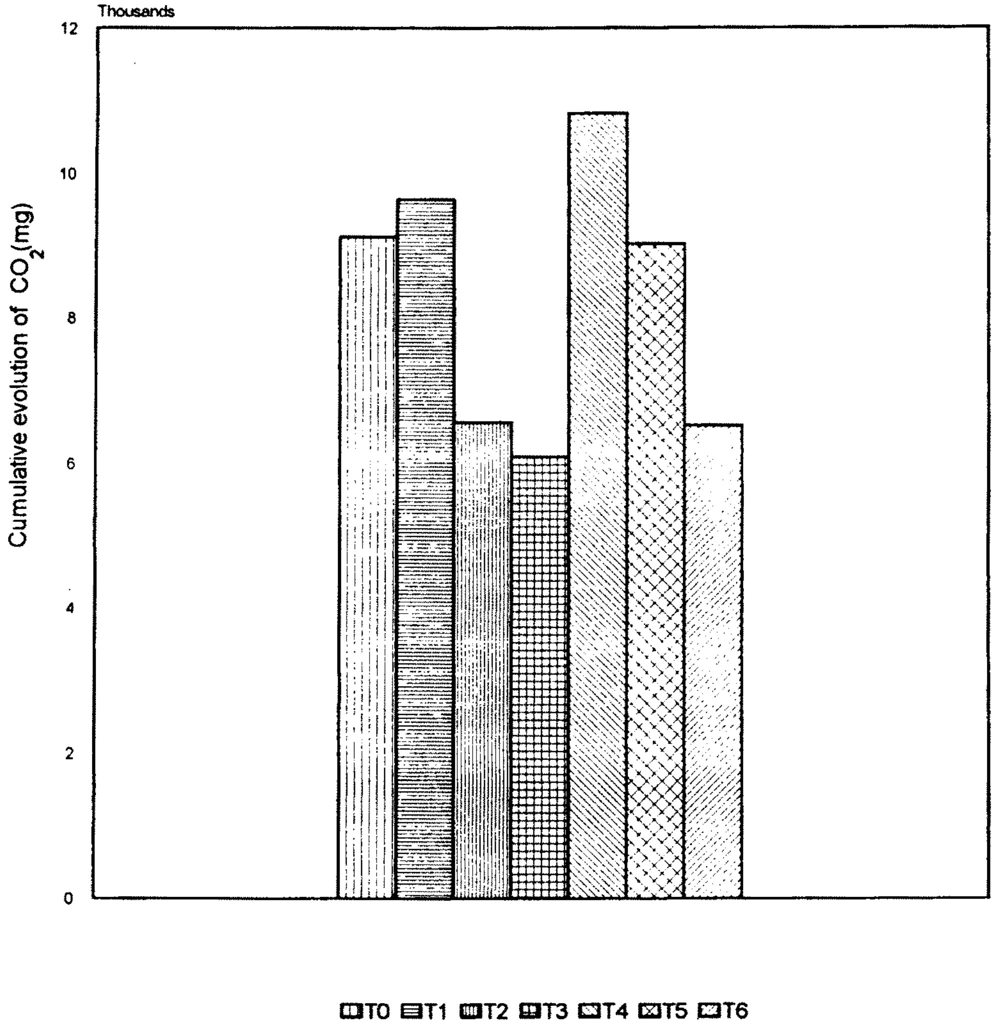


Figure 4.3.4.2 Cumulative evolution of CO_2 during decomposition of water hyacinth and paddy straw mixed in 1 : 1 ratio

It is observed from the data that the rate of evolution of CO_2 increased till 6th day of incubation in all the treatments except in T_5, which recorded a highest rate on the 8th day of incubation followed by a gradual decrease during the remaining period of study. Another rise in CO_2 evolution was observed on the 12th day in all the treatments excepting T_5. The third rise was noted on the 20th day in T_0, T_1 and T_4. Addition of MRP, at 5% P_2O_5 basis enhanced the rate of decomposition but not the other two doses. This may be due to the detrimental effect of higher application of MRP on microbial activity. Similiar results have been ~~reproted~~ reported by Arzamasova and Kuzmenkova (1962).

Cattle dung applied along with lower doses of MRP and Py, recorded highest amount of evolved CO_2 (10831.9 mg). Higher doses of MRP might have imposed a repugnant effect on the decomposition process. Though available carbon was almost similar, it might be the microbial population which was much sensitive to the amount of MRP and pH of the system, and thus caused different amount of evolved CO_2 for different systems.

The cumulative amount of evolved CO_2 followed the order $T_4 > T_1 > T_0 > T_5 > T_2 > T_6 > T_3$.

Set II

The rate and the cumulative amount of CO_2 evolved from the mixture of water hyacinth and paddy straw (2:1) as influenced by the higher application of MRP and pyrite alone and in combination with cattle dung have been shown in Table 13 and 14 and Figure 4.3.4.3 and 4.3.4.4. It is observed from the data that the rate of decomposition was greatly influenced by the amount of MRP present in the system. The control showed a higher rate of decomposition till 12th day of incubation. Lower dose of MRP recorded higher rate of evolution. Among the treatments, T_1, T_2, and T_3 the rate of decomposition was highest in T_1 where MRP was applied @ 5% P_2O_5 equivalent followed by T_2 and T_3. This clearly

Table 13 Effect of mussoorie rock phosphate, pyrite and cattle dung on the rate of CO_2 evolution during decomposition of water-hyacinth and paddy straw mixed in 2:1 ratio

	mg CO_2 evolved/10g substrate/ 24 hrs															
	Days of incubation															
Treatments	1	2	3	4	6	8	10	12	16	20	24	28	36	44	52	60
T_0	189.7	193.7	199.8	219.0	301.7	324.7	310.7	328.7	241.7	169.2	171.0	97.3	73.2	70.6	66.4	62.6
T_1	176.8	182.6	215.4	221.4	268.8	282.6	283.6	207.6	223.5	249.0	160.3	85.2	75.2	71.2	70.2	68.4
T_2	172.0	179.5	182.6	193.7	206.7	200.1	165.7	170.2	139.9	130.6	88.8	83.6	70.7	63.6	60.8	56.7
T_3	168.0	176.4	179.9	183.6	188.9	172.0	142.7	157.2	159.6	130.8	87.8	78.9	70.7	59.8	58.4	58.2
T_4	189.9	243.7	272.8	286.7	324.3	301.2	287.6	380.5	260.7	223.6	176.4	83.4	72.6	69.2	68.2	67.7
T_5	180.0	184.6	187.9	206.7	264.4	141.6	128.3	136.7	165.2	140.6	121.5	103.5	74.7	71.2	62.8	60.4
T_6	179.1	182.7	186.6	190.0	204.6	180.7	120.6	160.6	156.5	131.4	101.7	90.0	73.4	69.2	60.2	57.6

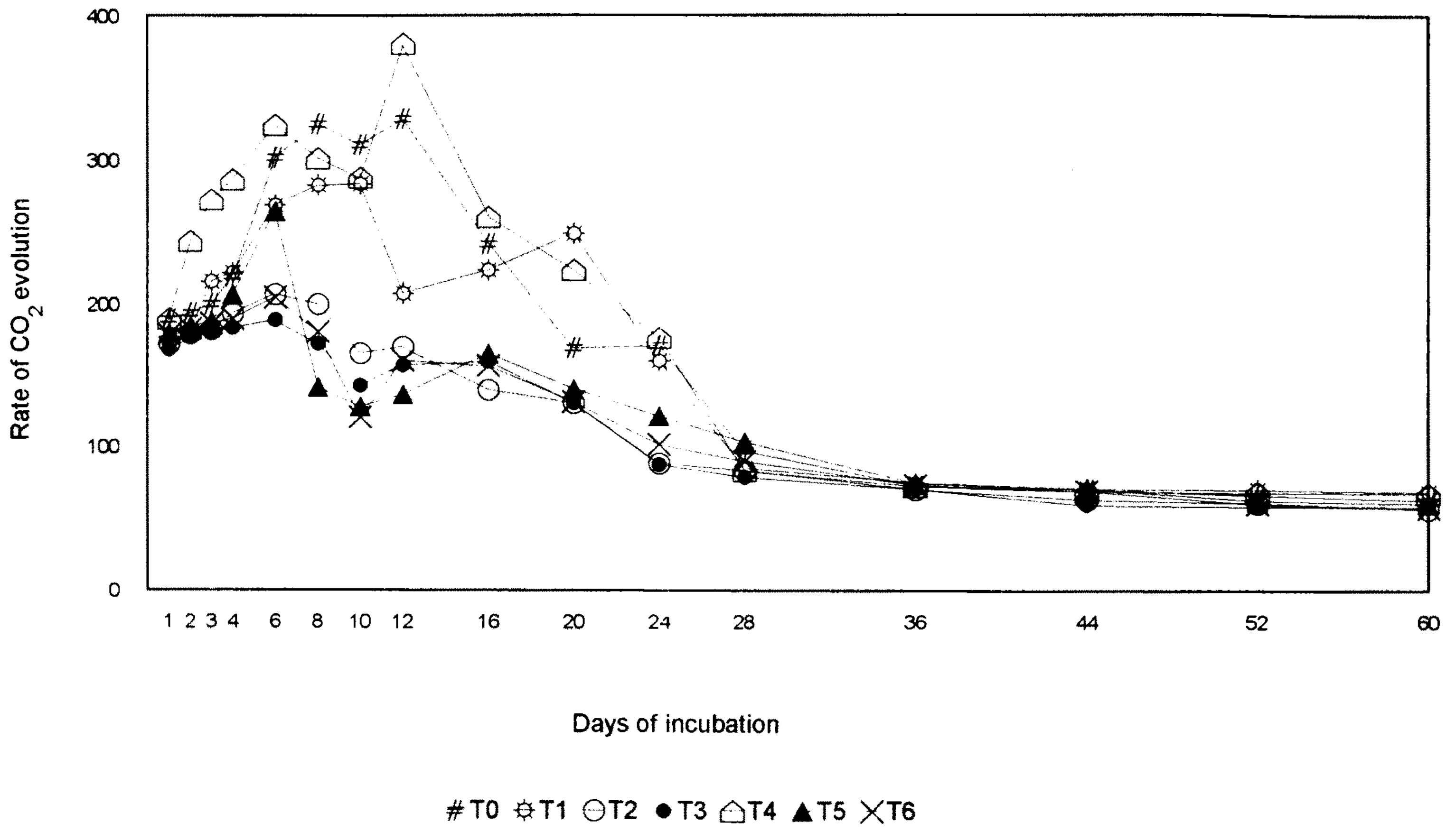


Figure 4.3.4.3 Rate of CO_2 evolution during decomposition of water hyacinth and paddy straw mixed in 2 : 1 ratio

Table 14 Effect of mussoorie rock phosphate, pyrite and cattle dung on the cumulative evolution of CO_2 during decomposition of water-hyacinth and paddy straw mixed in 2:1 ratio

Treatments	mg CO_2 evolved / 24 hrs															
	Days of incubation															
	1	2	3	4	6	8	10	12	16	20	24	28	36	44	52	60
T_0	189.7	383.4	583.2	874.2	1477.6	2127.0	2748.4	3405.8	4372.6	5049.4	5733.4	6122.6	6708.2	7273.0	7804.2	8305.0
T_1	176.8	359.4	574.8	796.2	1333.8	1899.0	2466.2	2881.4	3775.4	4771.4	5412.6	5753.4	6355.0	6924.6	7486.2	8033.4
T_2	172.0	351.5	534.1	727.8	1141.2	1541.4	1872.8	2213.2	2772.8	3295.2	3650.4	3984.8	4550.4	5059.2	5545.6	5999.2
T_3	168.0	344.4	524.3	707.9	1085.7	1429.7	1715.1	2029.5	2667.9	3191.1	3542.3	3857.9	4423.5	4901.9	5369.1	5834.7
T_4	189.9	433.6	706.4	993.1	1641.7	2244.1	2819.3	3580.3	4623.1	5517.5	6223.1	6556.7	7137.5	7691.1	8236.7	8778.3
T_5	180.0	364.6	552.5	759.2	1288.0	1771.2	2027.8	2301.2	2962.0	3524.4	4010.4	4424.4	5022.0	5591.6	6094.0	6577.2
T_6	179.1	361.8	548.4	738.4	1147.6	1509.0	1750.2	2071.4	2697.4	3223.0	3629.8	3989.8	4577.0	5130.6	5612.2	6073.0

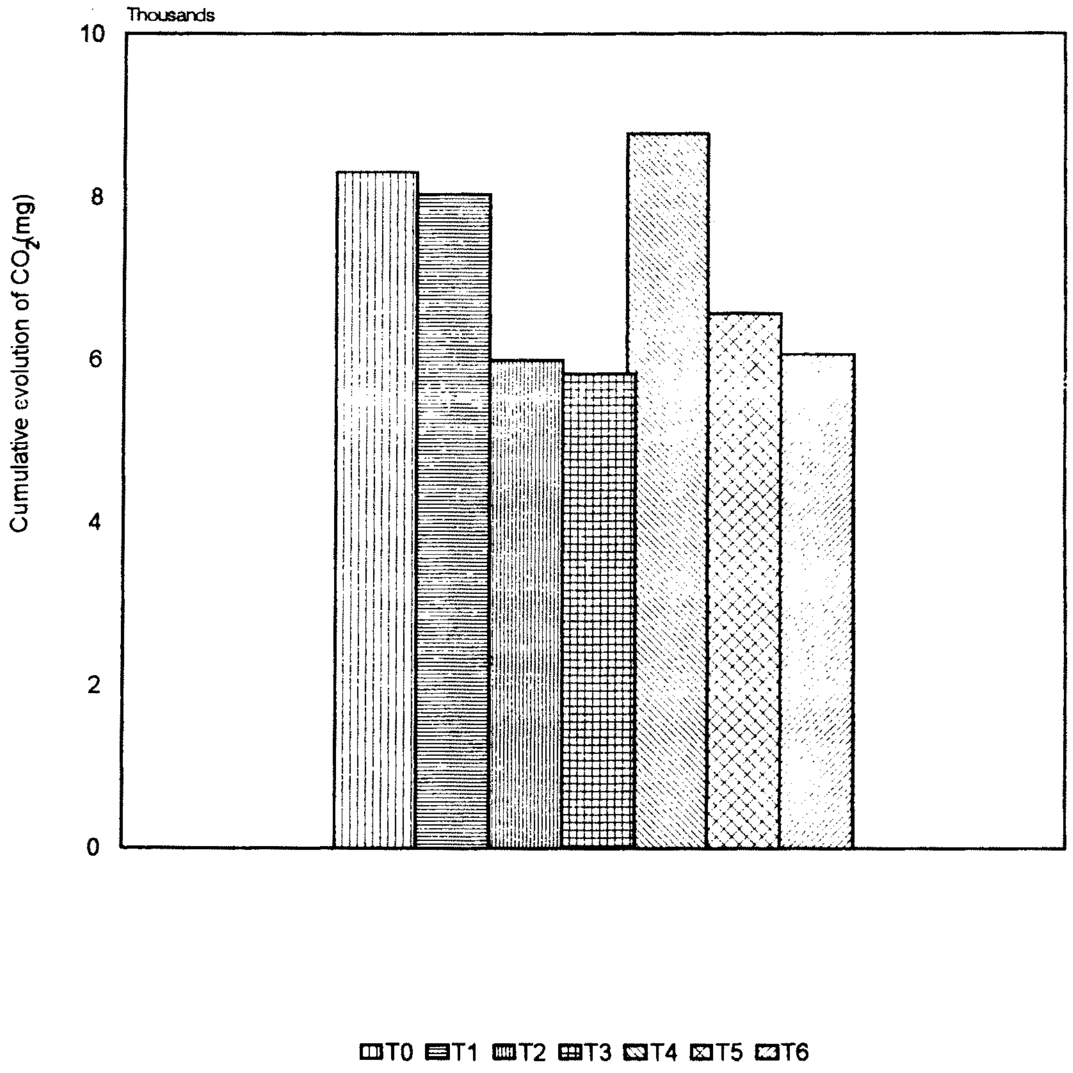


Figure 4.3.4.4 Cumulative evolution of CO_2 duringdecomposition of water hyacinth and paddy straw mixed in 2 : 1 ratio

Table 15 Effect of mussoorie rock phosphate, pyrite and cattle dung on the rate of CO_2 evolution during decomposition of water-hyacinth and paddy straw mixed in 3:1 ratio

	mg CO_2 evolved /10g substrates /24 hrs															
	Days of incubation															
Treatments	1	2	3	4	6	8	10	12	16	20	24	28	36	44	52	60
T_0	191.3	197.6	215.4	251.6	273.7	342.7	312.8	348.4	259.3	170.2	166.5	99.8	78.3	71.8	70.2	65.6
T_1	182.2	192.3	208.7	224.6	268.3	351.6	279.0	349.6	263.5	271.3	170.2	88.3	73.4	73.1	72.2	72.1
T_2	176.8	179.9	185.6	206.7	228.4	181.6	166.7	173.4	180.1	133.4	102.0	87.6	72.5	66.3	61.2	59.2
T_3	160.9	170.2	172.6	190.2	207.6	175.7	146.8	157.8	167.0	128.7	98.2	80.3	71.2	60.2	59.2	56.7
T_4	194.6	253.6	287.7	306.5	382.8	402.6	380.7	399.6	290.0	227.6	180.0	89.6	80.1	74.1	73.2	72.8
T_5	180.3	181.2	187.5	207.0	230.5	190.3	172.2	174.2	186.3	141.6	109.5	90.1	76.6	72.4	62.7	59.7
T_6	169.7	178.3	181.3	205.5	211.3	183.0	152.3	163.7	172.0	135.6	108.1	87.3	76.4	71.2	61.1	58.0

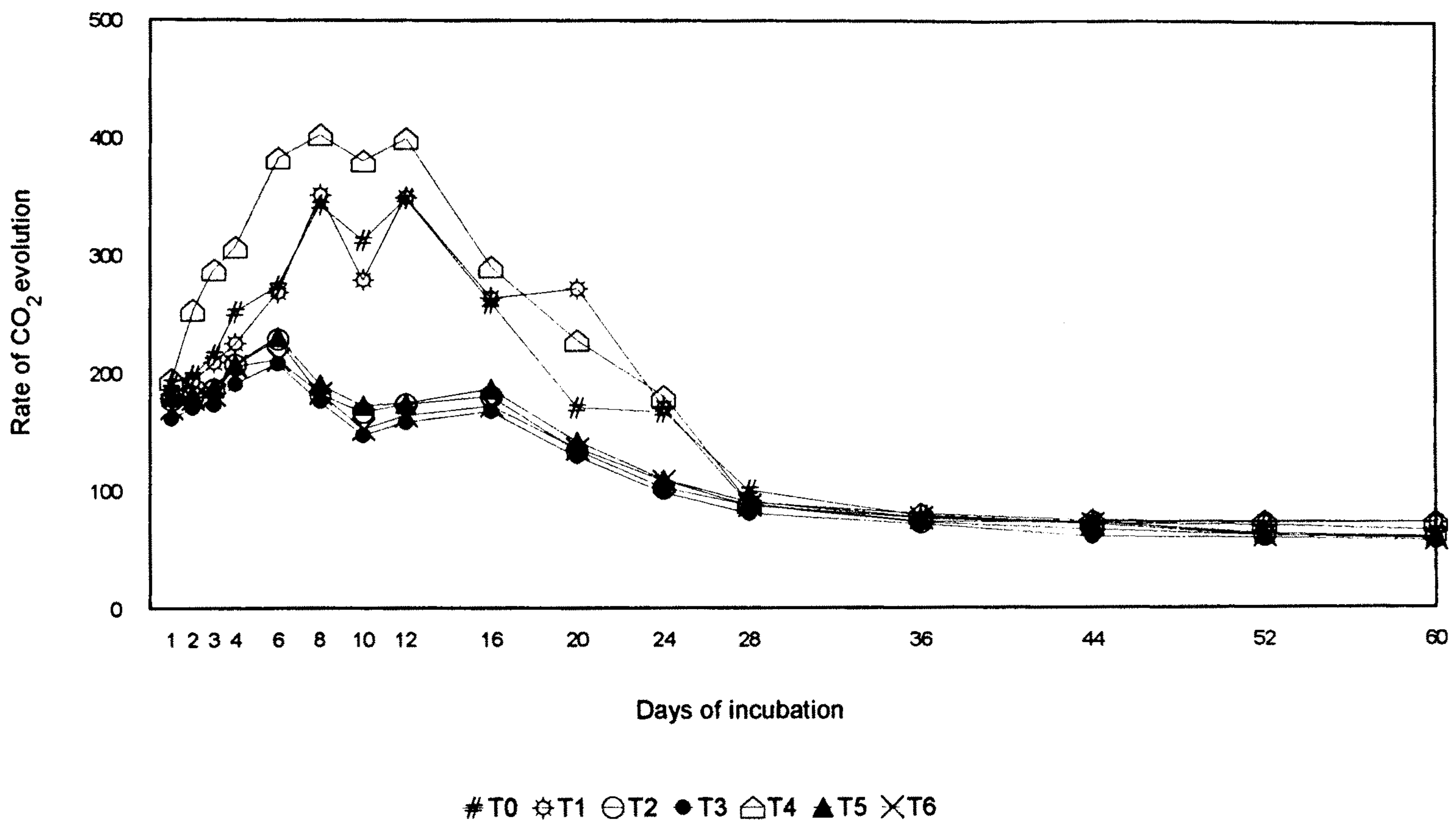


Figure 4.3.4.5 **Rate of CO_2 evolution during decomposition of water hyacinth and paddy straw mixed in 3 : 1 ratio**

Table 16 Effect of mussoorie rock phosphate, pyrite and cattle dung on the cumulative evolution of CO_2 during decomposition of water-hyacinth and paddy straw mixed in 3:1 ratio

	mg CO_2 evolved															
	Days of incubation															
Treatments	1	2	3	4	6	8	10	12	16	20	24	28	36	44	52	60
T_0	191.3	388.9	604.3	855.9	1403.3	2088.7	2714.3	3411.1	4448.3	5529.1	6195.1	6594.3	7220.7	7795.1	8356.7	8881.5
T_1	182.2	374.5	583.2	807.8	1344.4	2047.6	2605.6	3304.8	4358.8	5444.0	6124.8	6478.0	7065.2	7650.0	8227.6	8804.4
T_2	176.8	356.7	542.3	749.0	1205.8	1569.0	1902.4	1249.2	2969.6	3503.2	3911.2	4261.6	4841.6	5372.0	5861.6	6335.2
T_3	160.9	331.1	503.7	693.9	1109.1	1460.5	1754.1	2069.7	2737.7	3252.5	3645.3	3966.5	4536.1	5017.7	5491.8	5944.9
T_4	194.6	448.2	735.9	1042.4	1808.0	2613.2	3374.6	4173.8	5333.8	6244.2	6964.2	7322.6	7963.4	8556.2	9141.8	9724.2
T_5	180.3	361.5	549.0	756.0	1217.0	1597.6	1942.0	2290.4	3035.6	3602.0	4040.0	4400.4	5013.2	5592.4	6142.0	6619.6
T_6	169.7	348.0	529.3	734.8	1157.4	1523.4	1828.0	2155.4	2843.4	3385.8	3818.2	4167.4	4778.6	5063.4	5552.2	6016.2

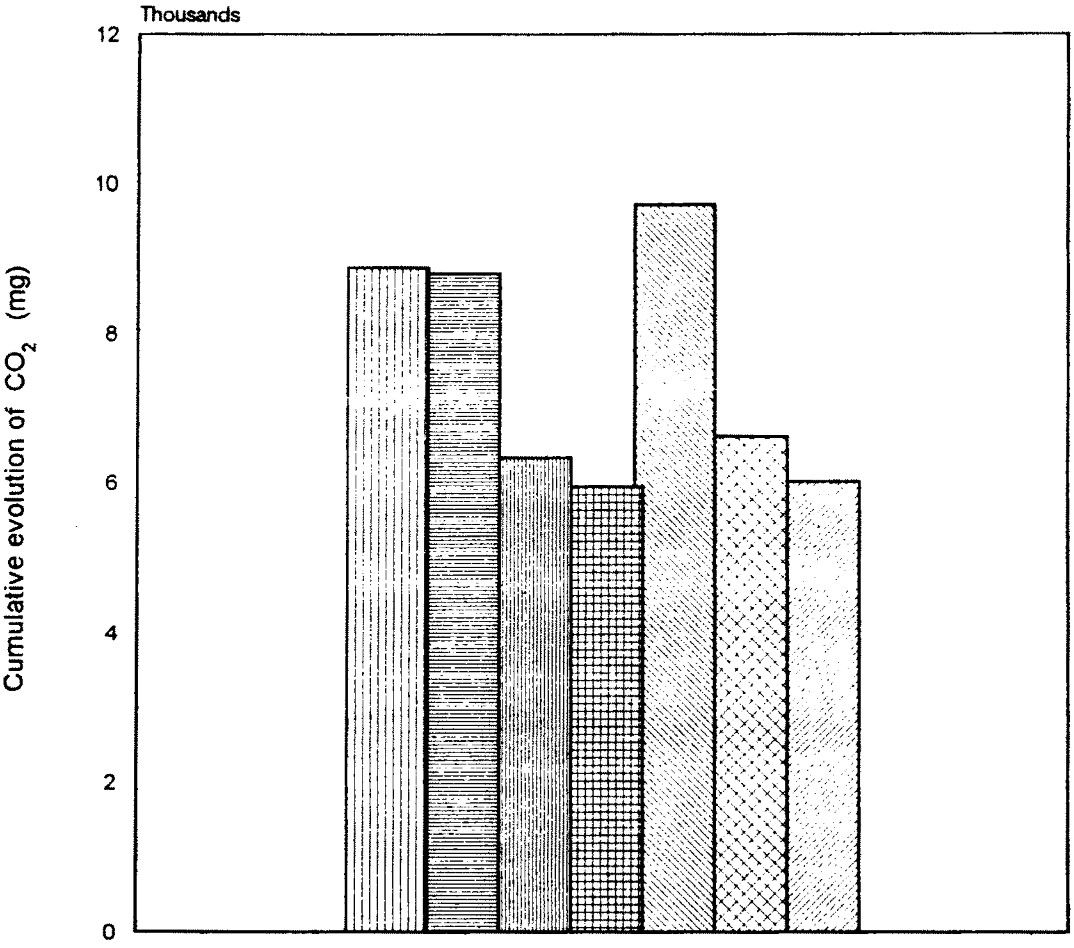


Figure 4.3.4.6 Cumulative evolution of CO_2 during decomposition of water hyacinth and paddy straw mixed in 3 : 1 ratio

evidenced that higher dose of MRP decreasing the rate of decomposition. But when MRP was applied along with CD as in treatment T_4, T_5 and T_6 the rate of decomposition increased. Though rates in T_4, T_5 and T_6 were comparatively higher than that of T_1, T_2 and T_3, it also revealed that MRP @ 10% P_2O_5 equivalent exerted greater negative influence to the decomposition process. The stimulatory effect of CD could be attributed to the preferential utilization of the growth promoting substances by the microorganisms it hosted.

In this set, the highest amount of CO_2 (8778.3 mg) was recorded in T_4. The cumulative amount followed the order : $T_4 > T_0 > T_1 > T_5 > T_6 > T_2 > T_3$.

Set III

The rate and the cumulative amount of CO_2 evolved from the mixture of water hyacinth and paddy straw in the ratio of 3:1 are shown in Table 15 and 16 and Figure 4.3.4.5 and 4.3.4.6. It is observed from the data that the rate of CO_2 evolution increased till 8th day in the treatments, T_1, and T_4 and till 6th day in T_2, T_3, T_5 and T_6. Further increment was found on 12th day in all the treatments. Cattle dung in presence of 5% P_2O_5 as MRP in T_4 recorded highest amount of CO_2 (9724.2 mg) indicating higher degree of decomposition.

The cumulative amount of CO_2 showed the following order : $T_4 > T_0 > T_1 > T_5 > T_2 > T_6 > T_3$. The order reveals that higher amount of MRP and Py were not helpful for the decomposition of W.H. and P.S. mixture prepared in the ratio of 3:1.

Among the treatments of the three sets, T_4 of set I recorded highest decomposition followed by T_4 of Set III which then followed T_1 of set I. It is therefore evident that the decomposition of W.H. was most favoured when proportioned with paddy straw in the ratio of 1:1 and treated with 5% P_2O_5 as MRP, pyrite @ 0.5 part of MRP , CD at 20% level and microbial inoculum.

4.3.5 PREPARATION OF PHOSPHOCOMPOST FROM MUSHROOM BED WASTE-WATER HYACINTH MIXTURE :

I EFFECT OF PHOSPHATE ROCK, PYRITE AND CATTLE DUNG ON THE DECOMPOSITION AND ENRICHMENT OF NUTRIENTS.

II RESPONSE OF PHOSPHOCOMPOST ON THE GROWTH OF ARHAR (VAR. P-22).

The waste generated after harvesting mushroom from the straw bed on which mushrooms are grown are generally used as cattle feed. These wastes contain the lower parts of the mushroom which may contribute to the nutrient of the compost. The carbon content of these wastes are lower but there may be a scope to recycle it along with other carbonaceous materials like water hyacinth and cattle dung.

These spent mushroom beds also contain different actinomycetes like *Streptomyces* spp. and *Thermoactinomyces* spp., fungal species like *Aspergillus, Paecilomyces, Penicillium, Trichurus* and *Trichoderma* and bacterial species like *Bacillus* spp. which help the decomposition process (Kleyn and Wetzler, 1981).

To obtain a P-enrichd compost from the mushroom bed waste, low cost phosphate rocks may be used as amendment. Based on the observations of the earlier studies, this experiment was designed to study the scope of utilizing the mushroom bed waste as a phosphocompost substrate. The microbial species present in the said waste may contribute to the disolution of MRP and thus help to produce a sufficiently enriched phosphocompost.

The decomposition was studied by measuring the evoloved CO_2 at intervals during the decomposition of 60 days period. Chemical parameters of the composts were estimated at the end following the standard procedure as described under 'Materials and Methods.' Its effect on the dry matter yield of Arhar was studied by a pot culture experiment.

EXPERIMENTAL

I. Preparation of phosphocompost

Mushroom bed waste (MW) was mixed with water hyacinth (W H) in the ratio of 1:1 ratio. Cattle dung (CD) was applied at a fixed rate of 20% of the weight of organic matter. Two doses of phosphate rock were applied and pyrite (Py) was applied @ 0.5 part of the MRP by weight. The whole mass was inoculated with mixed microbial inoculum (MI) @ 500g/tonne of organic matter. Each 20 gm portion of the organic material was treated with cattle dung, MRP, Py and MI according to the treatment schedule and placed in a serious of 500 ml conical flasks. Moisture was adjusted with water and the flasks were incubated at room temperature varying from 30 ± 2°C for 60 days. All treatments were replicated thrice. CO_2 was measured following the standard procedure. Decomposed material from each flask was collected and labelled. The C:N ratio and P-content of each sample were determined following standard procedure. Experiment schedule is given below.

Treatment	Description of treatment
T_0	Mushroom bed waste (MW) : Water hyacinth (WH) :: 1:1 + Microbial inoculum (MI)
T_1	T_0 + 20% Cattle dung (CD)
T_2	T_1 + 5% P_2O_5 as MRP + Py(@ 0.5 part of MRP)
T_3	T_1 + 7.5% P_2O_5 as MRP + Py (@ 0.5 part of MRP)

II Pot culture experiment

Indo-gangetic alluvial soil, 0-9 cm (Table 1) collected from a fallow land of seed farm of the Viswavidyalaya was used. Each 1.5 kg portion of soil was taken in a series of earthen pots (10 cm dia). Compost was applied @ 10 t/ha. Inorganic fertilizer @ N_{20} P_{40} K_0 was included as one of the treatments to compare the prepared compost. Each pot was planted with three Arhar seeds. Dry matter yield of each pot was recorded at the end of 60 days growth. Number of nodules per plant were also counted. Pot experiment was designed as under:

Pot	Description of treatment
P_0	Soil alone
P_1	Soil + compost prepared under T_0
P_2	Soil + compost prepared under T_1
P_3	Soil + compost prepared under T_2
P_4	Soil + compost prepared under T_3
P_5	Soil + N_{20} P_{40} K_0

RESULTS AND DISCUSSION

Rate and cumulative evolution of CO_2

The rate and cumulative evolution of CO_2 is shown in Table 17 and 18 and depicted in Figure 4.3.5.1 and 4.3.5.2. Mushroom bed waste readily decomposed in presence of W.H. to produce CO_2 as a decomposition product.

Table 17 Effect of Mussoorie rock phosphate, pyrite and cattle dung on the rate of decomposition of mush room bed waste-water hyacinth mixture

	mg CO_2 evolved/20g/24 hrs															
	Days of Incubation															
Treatments	1	2	3	4	6	8	10	12	16	20	24	28	36	44	52	60
T_0	171.5	180.3	205.6	211.6	175.6	150.6	150.5	160.8	130.4	121.6	90.3	69.6	30.3	27.6	18.2	17.0
T_1	198.6	263.0	311.4	325.5	300.7	278.3	280.0	290.7	257.4	218.7	171.6	120.3	82.6	77.3	70.2	65.0
T_2	196.7	270.3	298.6	330.6	310.0	280.5	256.3	286.9	280.7	260.7	200.4	110.2	90.4	78.1	69.2	67.3
T_3	176.8	280.5	282.4	329.7	330.6	260.7	240.6	278.3	280.6	209.1	173.0	99.6	83.2	72.6	65.7	64.7

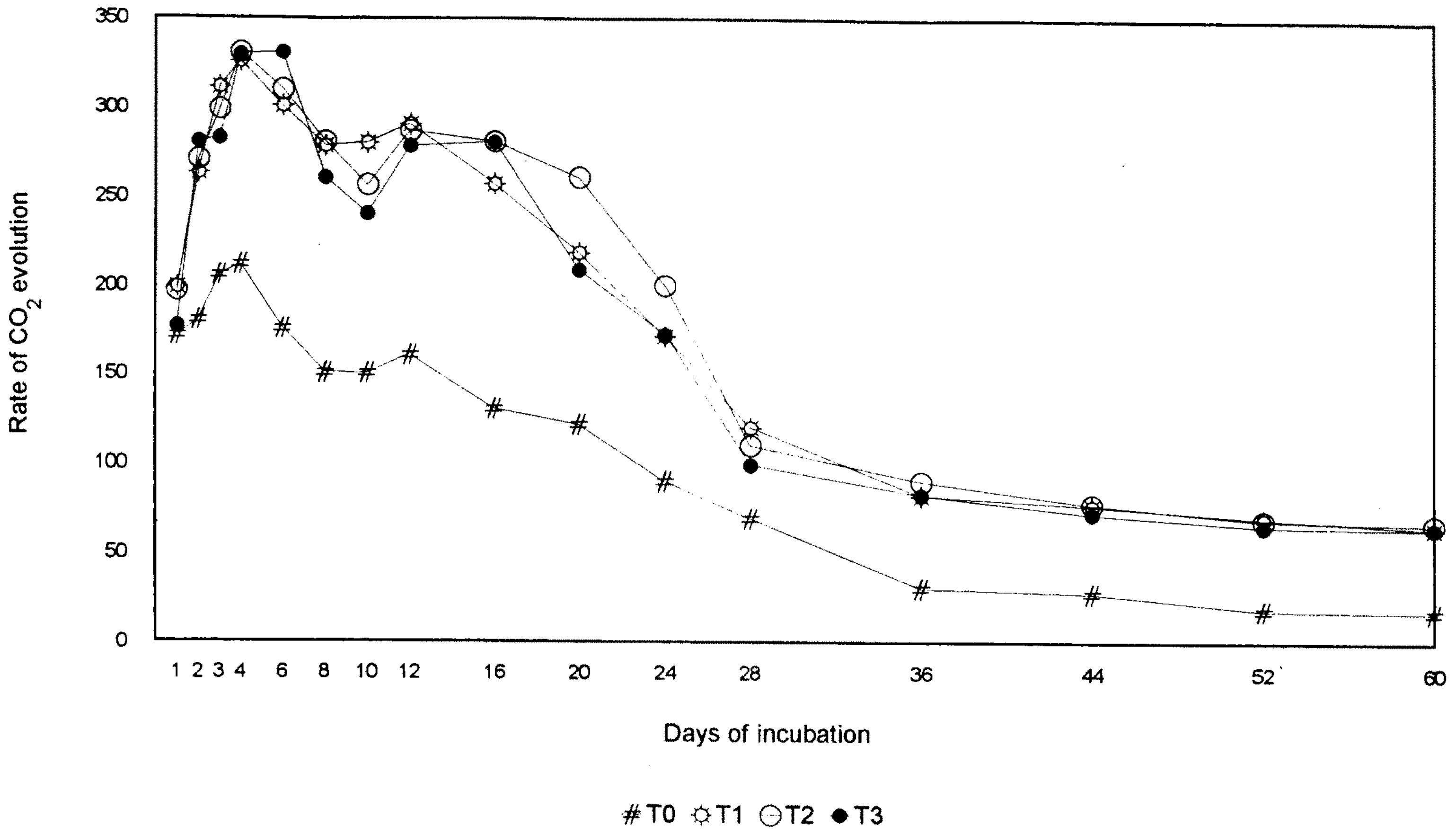


Figure 4.3.5.1 Rate of CO$_2$ evolution during decomposition of mushroom bed waste - water hyacinth mixture

Table 18 Effect of Mussoorie rock phosphate, pyrite and cattle dung on the cumulative evolution of CO_2 (mg) during decomposition of mushroom bed waste - water hyacinth mixture

	mg CO_2 evolved															
	Days of Incubation															
Treatments	1	2	3	4	6	8	10	12	16	20	24	28	36	44	52	60
T_0	171.5	351.8	557.4	769.0	1120.2	1421.4	1722.4	2044.0	2565.6	3052.0	3413.2	3691.6	3934.0	4154.8	4300.4	4436.4
T_1	198.6	461.6	773.0	1098.5	1699.9	2256.5	2816.5	3397.9	4427.5	5302.3	5988.7	6469.9	7130.7	7749.1	8310.7	8830.7
T_2	196.7	467.0	765.6	1096.2	1716.2	2277.2	2789.8	3363.6	4486.4	5529.2	6330.8	6771.6	7494.8	8119.6	8673.2	9211.6
T_3	176.8	457.3	739.7	1069.4	1730.6	2252.0	2733.2	3289.8	4412.2	5248.6	5940.6	6339.0	7004.6	7585.4	8111.0	8628.6

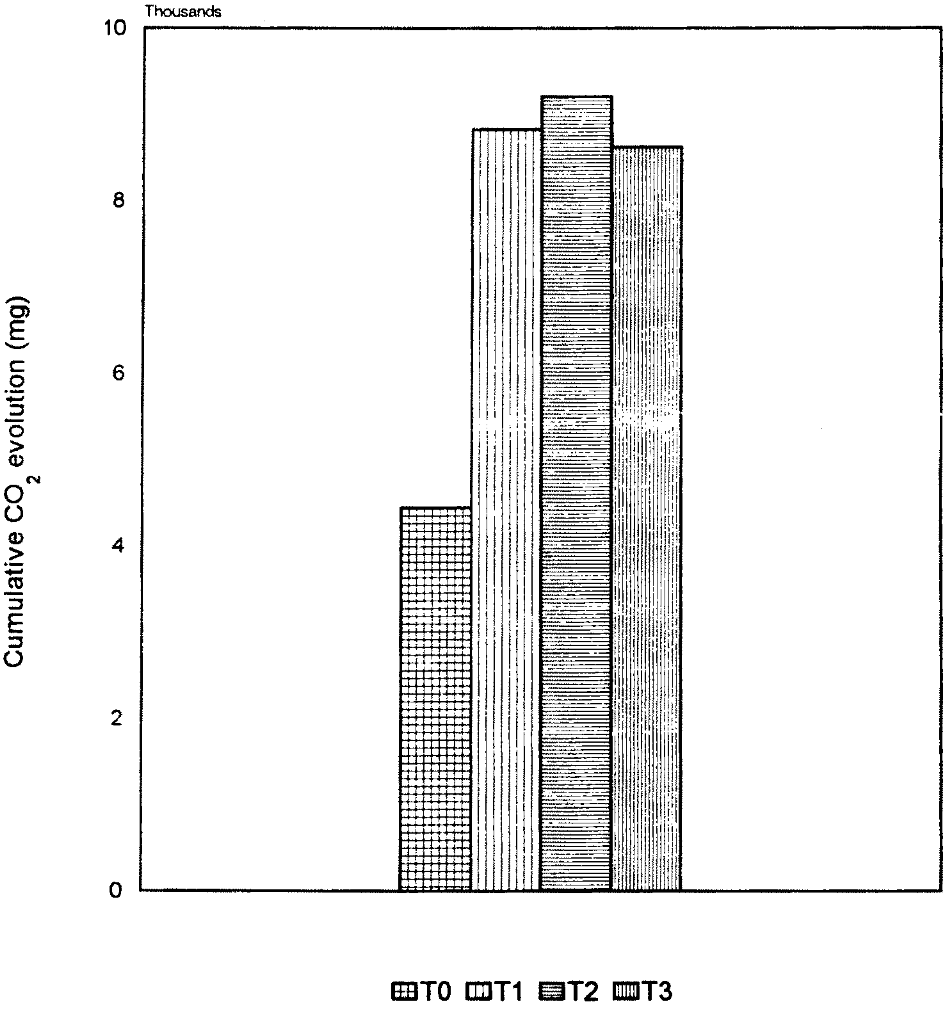


Figure 4.3.5.2 **Cumulative evolution of CO_2 during decomposition of mushroom bed waste - water hyacinth mixture**

Highest recorded rate of evolution was 330.6 mg/day which was claimed by both T_2 and T_3, but on different days. For T_2, it was on the 4th day of decomposition and for T_3, it was on the 6th day of decomposition.

First peak appeared on the 4th day for T_0, T_1 and T_3 and on the 6th day for T_3. Second peak for T_0, T_1 and T_2 was found on the 12th day of decomposition but for T_3 it was on the 16th day of decomposition. Presence of MRP @ P_2O_5 and Py @ 0.5 part of MRP enhanced the decomposition as revealed from the cumulative amount of CO_2 evolved by the treatment T_2. Higher amount of MRP and Py discouraged the rate of decomposition. This might be due to the effect of MRP and Py on the microorganisms present in the system. But it is observed from the data that cumulative amount of evolved CO_2 from T_3 was higher than control. In T_3, the decomposition was a bit delayed but there was consistency in the decomposition pattern and almost 70% of the total evolved CO_2 was recorded within the first 24 days of decomposition. Total amount of mineralised carbon (Table 19) followed the order : T_0 (1209.9 mg) < T_4 (2353.2 mg) < T_1 (2408.3 mg) < T_2 (2512.2 mg).

Yield from the pot culture experiment

Chemical composition of the prepared compost is presented in Table 19 and the yield data is shown in Table 20. Highest dry matter yield was obtained in P_5 receiving inorganic fertiliser ($N_{20} P_{40}K_0$) and the lowest (4.8 g), in P_0 where plants were grown on soil without any fertilizer input.

Every fertilizer amended pot yielded higher than control (P_0) The pot treated with T_0 (P_1) yielded least among the treated pots. Pot P_3 was treated with T_2 and the yield (13.3g/pot) was appreciable. Number of nodules were also highest in P_3 followed by P_5 and P_4. The plants in P_5 recorded maximum average height. The yield followed the order: $P_5 > P_3 > P_4 > P_2 > P_1 > P_0$. It revealed that

Table 19 Chemical parameters of the prepared phosphocomposts

Treatments	Total CO_2 evolved (mg)	Total loss of carbon (mg)	C/N ratio	Citrate soluble phosphorus (ppm)
T_0	4436.4	1209.9	20.1	235
T_1	8830.7	24083	14.3	280
T_2	9211.6	2512.2	13.5	5650
T_3	8628.6	2353.2	15.0	5000
C.D. at 5%	687	189.1	1.4	281.0

Table 20 Effect of the prepared phosphocomposts on the growth and dry matter yield of Arhar

Treatments	Dry weight /pot (gm)	No. of nodules/plant	Height (cm)
P_0	4.3	10	26.5
P_1	5.2	17	27.0
P_2	8.4	21	37.0
P_3	13.3	28	45.5
P_4	10.4	25	37.2
P_5	13.4	27	45.7
C.D. at 5%	1.32	3.04	9.65

higher mount of MRP did not result in so increase in the yield as the lower dose did. Plant available P was lower in T_3 than T_2 though it got higher doses of MRP. This might be due to the immobilization of P in presence of large number of cations and organic sunstances.

4.3.6 FLY ASH AS PHOSPHOCOMPOST AMENDMENT : EFFECT ON THE DECOMPOSITION OF WATER HYACINTH -RICE STRAW MIXTURE ADDED WITH MUSSOORIE ROCK PHOSPHATE.

Fly ash is chemically an amorphous ferro-alumino-silicate. In India about 60 million tonnes of fly ash, produced by the coal powered thermal power stations, enter into the environment every year (Pathak *et al.*, 1996). Possibility of its use in agriculture and industry has got much importance in the present days. Direct application of fly ash into the agricultural field is not so beneficial (Sharma *et al.*, 1996) but some research report show positive influence of fly ash on plant growth (Elseewi and Page, 1984; Maiti *et al.*, 1990). Possibility of fly ash amended compost as a growing medium and manure for agricultural crops has been observed by Hudson and Headley (1990), Wong (1990) and Menon *et al.*, (1993). It has also been reported that the increasing level of fly ash exerts detrimental effects on several soil enzymes (Pitchel and Hayes, 1990). Keeping the above reports in view, fly ash collected from Bandel Thermal Power Station, West Bengal, were tried in laboratory condition as amendment in composting water hyacinth-rice straw mixture inoculated with cellulose decomposing and phosphate solubilizing cultures in presence and absence of Mussoorie rock phosphate. Chopped (1 cm) rice straw and water hyacinth were taken in the ratio of 1:1 to get mixture weighing 25g on dry weight basis. Mixed inoculum of cellulose decomposing and phosphate dissolving fungi was mixed with each 25 gm portion of the straw and water hyacinth mixture @ 500 g mycelial mat/tonne of mixture. Fly ash was applied at two levels, viz, 2.5% and 5% of the said mixture. Mussoorie rock phosphate was applied @ 5% P_2O_5 basis . Moisture was adjusted at 80% level. Treated samples were placed in 1 litre conical flasks for measurement of CO_2 as an index of microbial decomposition. The treatments were replicated thrice and the flasks were incubated at 30 ± 1°C. Evolved CO_2 was determined at periodic intervals by absorbing that in NaOH solution and back titrating with standard H_2SO_4 using phenolphthalein indicator. The schedule of treatment was as under.

Treatment	Description of treatment
T_0	Water hyacinth: Rice straw:: 1:1 + Microbial inoculum
T_1	T_0 + Fly Ash (FA) @ 2.5%
T_2	T_0 + FA @ 5%
T_3	T_1 + Mussoorie Rock Phosphate @ 5% P_2O_5(MRP)
T_4	T_2 + MRP

RESULTS AND DISCUSSION

Rate and Cumulative evolution of CO_2

The rate of CO_2 evolution at intervals has been shown in Table 21 and depicted in Figure 4.3.6.1. The cumulative amount of CO_2 evolved during 60 days decomposition has been shown in Table 22 and Figure 4.3.6.2.

Table 21 Effect of fly ash on the rate of CO_2 evolution (mg/25g/24hrs) during decomposition of water hyacinth-rice straw mixture

	mg CO_2 evolved/25g/24hrs.															
	Days of Incubation															
Treatments	1	2	3	4	6	8	10	12	16	20	24	28	36	44	52	60
T_0	444.4	448.8	451.0	459.2	313.6	335.6	341.7	309.2	247.0	256.3	250.8	107.1	83.8	72.2	52.2	49.8
T_1	454.2	531.4	478.9	501.2	366.1	373.5	382.3	302.8	239.1	250.9	218.0	108.6	59.6	76.4	50.3	40.7
T_2	440.0	446.7	420.2	448.8	311.3	323.4	336.0	300.2	240.2	250.0	212.4	100.6	42.4	69.0	48.8	47.7
T_3	445.1	490.3	442.2	468.3	325.6	378.3	380.2	310.0	221.4	229.8	215.6	97.2	43.1	68.2	49.8	48.6
T_4	435.2	442.0	407.1	421.0	300.0	315.3	322.6	298.8	170.3	172.6	101.3	69.2	23.6	60.7	40.7	40.3

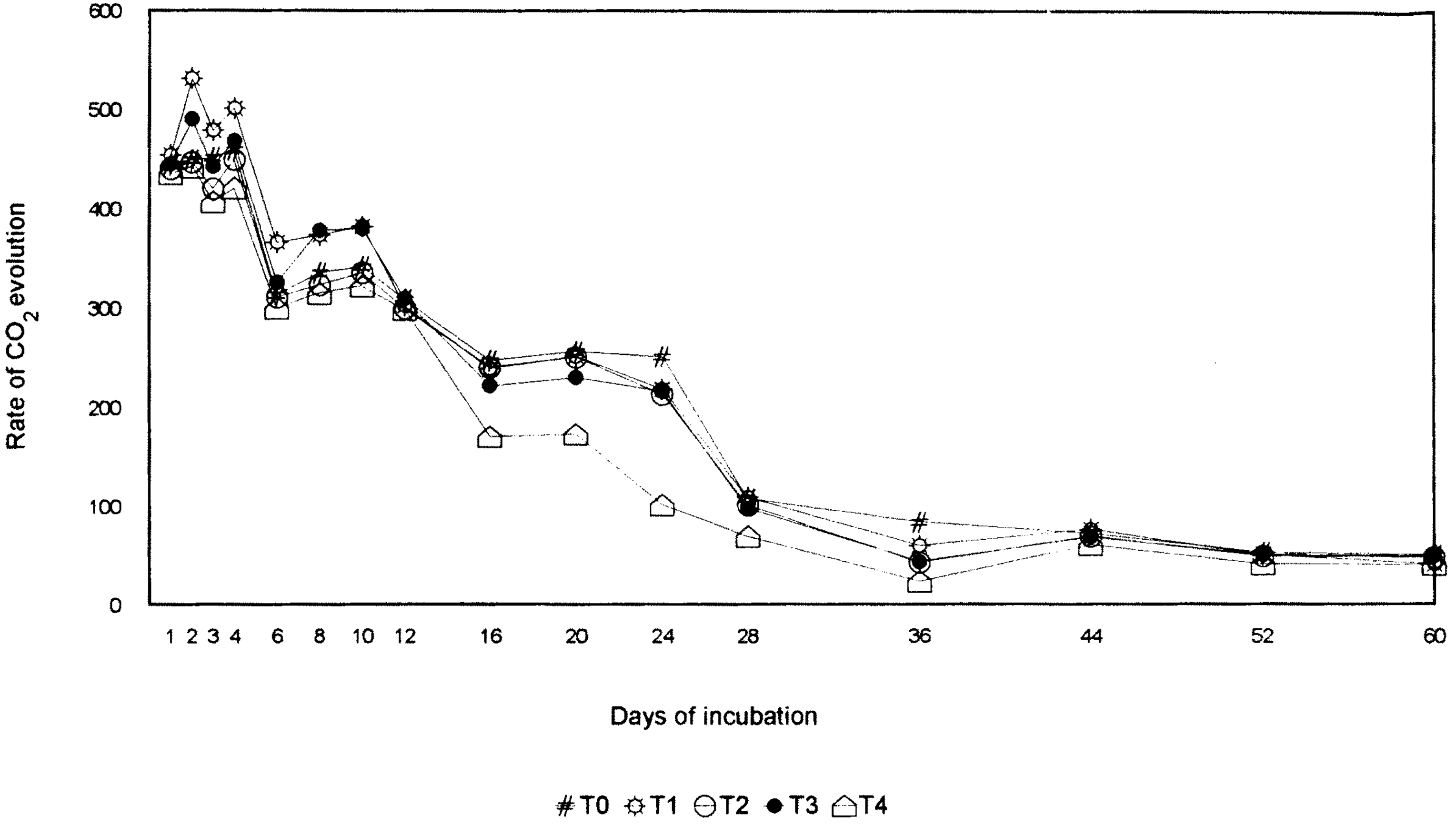


Figure 4.3.6.1 Effect of fly ash on the rate of CO_2 evolution during decomposition of water hyacinth - rice straw mixture

Table 22 Effect of flyash on the cumulative evolution of CO_2(mg) during decomposition water hyacinth-rice straw mixture

	mg CO_2 evolved															
	Days of Incubation															
Treatments	1	2	3	4	6	8	10	12	16	20	24	28	36	44	52	60
T_0	444.4	893.2	1344.2	1803.4	2430.6	3101.8	3785.2	4403.6	5391.6	6416.8	7420.0	7848.4	8518.8	9096.4	9514.0	9912.4
T_1	454.2	985.6	1464.5	1965.7	2697.9	3444.9	4209.5	4815.1	5771.5	6775.1	7647.1	8081.5	8558.3	9169.5	9571.9	9897.5
T_2	440.0	886.7	1306.9	1755.7	2378.3	3025.1	3697.1	4297.5	5258.3	6258.3	7107.9	7510.3	7849.5	8401.5	8791.9	9174.3
T_3	445.1	935.4	1377.6	1845.9	2497.1	3253.7	4014.1	4634.1	5519.7	6438.9	7301.3	7690.1	8034.9	8580.5	8978.9	9367.7
T_4	435.2	877.2	1284.3	1705.3	2305.3	2935.9	3581.1	4178.7	4859.9	5550.3	5955.2	6232.0	6420.8	6906.4	7232.0	7554.4

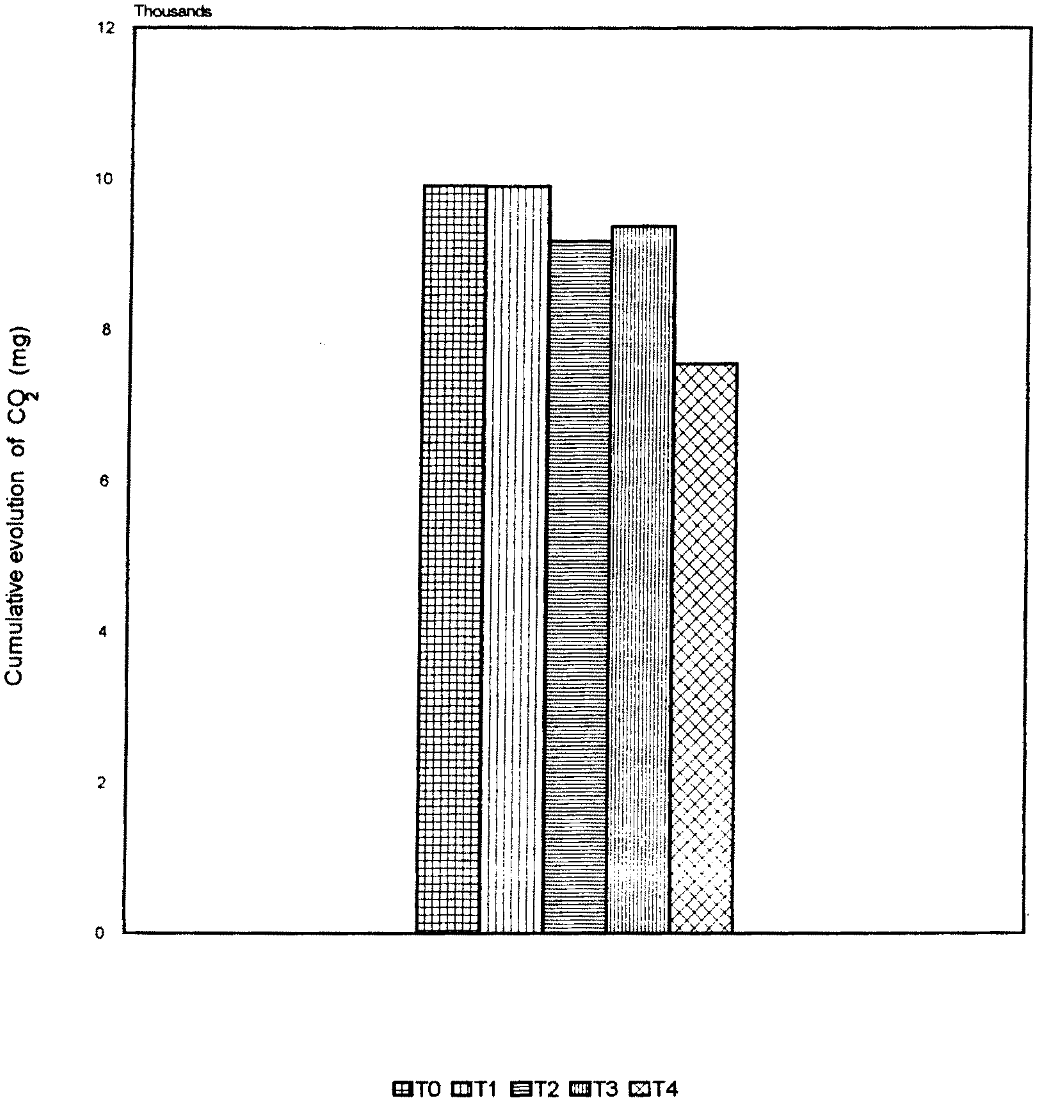


Figure 4.3.6.2 **Effect of fly ash on the cumulative evolution of CO_2 during decomposition of water hyacinth - rice straw mixture**

The data obtained from different treatments revealed that the rate of CO_2 evolution increased gradually till 4th day of incubation followed by a decrease on the 6th day. On the 10 th and 20th day, the rate increased in all the treatments which then gradually decreased till 60th day of incubation period. It is observed that in every treatment, 70-75% of the total CO_2 was evolved during the first 24 days of incubation. The rate was higher in the treatment, where the amount of fly ash was less and where MRP was amended along with lower dose of fly ash. Higher amount of fly ash hindered the decomposition markedly. MRP, when applied with higher dose of fly ash retarded the rate of decomposition. Highest cumulative amount of CO_2 (9912.4 mg) was recorded in T_0. Treatment T_4 evolved lowest amount of CO_2, i.e. 7554.4 mg. It might be due to the presence of heavy metals in fly ash which was toxic to the microbial population. Higher dose of fly ash restricted the decomposition process.

It has been observed from the study that fly ash could be used as an amendment of phosphocompost as decomposition was not much hindered when it was applied @ 2.5% of the total organic matter (Paddy straw+Water hyacinth) Profused microbial growth was observed in T_1 and T_3 which was identified to belong to the genera; *Aspergillus, Penicillium. Trichurus* and *Fusarium.* The final product after 60 days caused wilting to the Arhar P-22 seedlings when applied @ 10 t/ha which might be due to the presence of cotton like growth of the microbial species, which was found to be Tannic acid negative and was identified as *Fusarium auxisporum*. But there was no wilting when the end product of the 60 days decomposition was left for another 20 days and then applied @ 10 t/ha to the Arhar plants.

4.4 MINERALIZATION OF CARBON, NITROGEN AND PHOSPHORUS DURING PREPARATION OF PHOSPHOCOMPOST FROM PADDY STRAW-WATER HYACINTH MIXTURE : AN INCUBATION EXPERIMENT.

Biochemical transformations depend largely on the nature of the organic matter (Das and Mukherjee, 1989; Mukherjee *et al.*,1990, 1991and Debnath *et al.*, 1991), and the built up of the microbial population of the system (Gaur *et al.*, 1973; Bhardwaj and Patil, 1982 and Debnath *et al.*, 1994).

Chemoorganotrophs attack the incorporated organic matter and derive their nutritional requirements, as a consequence, nutrients are made available to the system (Alexander, 1977). Rate of mineralization of different nutrient elements are different for different organic matters (Das and Mukherjee, 1988 and Tipping *et al.*, 1988).

In the present investigation, mineralization of carbon, nitrogen and phosphorus was observed at intervals during decomposition of phosphocompost components over 56 days period.

EXPERIMENTAL

In the previous investigation (Expt. No 4.3.4) paddy straw-water hyacinth mixture (1:1) along with 20% cattle dung and 5% P_2O_5 as MRP showed higher rate of decomposition. So, for the present experiment, that combination of organic substrates along with different amounts of MRP and Py was selected for the preparation of phosphocompost to study the mineralization of carbon, nitrogen and phosphorus during the process of decomposition.

Each 125g portion of paddy straw-water hyacinth mixture was treated with 20% cattle dung and microbial inoculum, @ 500 gm t^{-1}. Mussoorie rock phosphate was applied at two levels, i.e. @ 5.00 and 7.5 per cent P_2O_5 equivalent, and Py @ 0.5 part of the weight of MRP. Moisture was made at 80% levels with addition of distilled water. The treated samples were put in plastic beakers, mouths closed with holed plastic sheets and strings. Each treatment was replicated thrice. Four sets of five treatments in replication were incubated at 30 ± 1°C for 56 days. Each set was drawn on the 1st, 14th, 35th and 56th day of incubation for the estimation of pH, org C, Total N, Total P, NH_4 -N, NO_3 -N, water soluble P (WSP) and citrate soluble P (CSP). Standard methods described under 'Materials and Methods' were followed in the present study.

The schedule of treatment was as under :

Treatment	**Description of Treatment**
T_0	Paddy Straw-Water hyacinth mixture (1:1) + 20% cattle dung + Microbial inoculum
T_1	To + MRP (5% P_2O_5 equivalent)
T_2	To + MRP (7.5% P_2O_5 equivalent)
T_3	T_1 + Py (@ 0.5 time of MRP)
T_4	T_2 + Py (@ 0.5 time of MRP)

RESULTS AND DISCUSSION

The pH, organic carbon, total nitrogen, C/N ratio, NH_4-N, NO_3-N, total P, water soluble P and citrate soluble P content of the composting mass are presented in Table 23,24,25,26,27,28,29,30 and 31 respectively.

Table 23 Changes in pH of the composting mass during preparation of phosphocompost

	pH				
Days of Incubation / Treatments	Initial	14	35	56	Mean
T_0	7.2	7.6	7.4	7.1	7.32
T_1	8.2	8.0	7.1	6.8	7.52
T_2	8.5	7.9	6.8	6.7	7.47
T_3	7.8	6.6	6.0	5.9	6.57
T_4	7.7	6.7	6.3	6.1	6.70
Mean	7.88	7.36	6.72	6.52	

C.D. at 5%

Treatment (T)	0.11
Incubation (I)	0.12
Interaction (T x I)	0.17

Table 24 Changes in organic carbon content of the composting mass during preparation of phosphocompost

	Organic Carbon (%)				
Days of Incubation / Treatments	Initial	14	35	56	Mean
T_0	45.8	41.2	37.4	35.7	40.0
T_1	44.3	40.0	34.7	26.3	36.3
T_2	44.4	42.5	37.3	35.1	39.8
T_3	44.6	40.1	34.1	27.1	40.1
T_4	44.1	42.0	36.8	35.6	39.6
Mean	44.6	41.1	36.0	31.90	

C.D. at 5%

Treatment (T)	1.8
Incubation (I)	2.0
Interaction (T x I)	not significant

Table 25 Changes in total nitrogen content of the composting mass during preparation of phosphocompost

Days of Incubation Treatments	Total Nitrogen (%)				
	Initial	14	35	56	Mean
T_0	1.77	1.77	1.83	1.82	1.79
T_1	1.17	1.17	1.27	1.73	1.33
T_2	1.18	1.18	1.26	1.46	1.27
T_3	1.18	1.26	1.26	1.78	1.37
T_4	1.16	1.14	1.26	1.47	1.25
Mean	1.29	1.30	1.37	1.65	

C.D. at 5%

Treatment (T) 0.05
Incubation (I) 0.06
Interaction (T x I) 0.19

Table 26 Changes in C/N ratio of the composting mass during preparation of phosphocompost

Days of Incubation Treatments	C/N ratio				
	Initial	14	35	56	Mean
T_0	25.8	23.2	20.4	19.6	22.2
T_1	37.8	34.1	27.3	15.2	28.6
T_2	37.6	36.0	29.6	24.0	31.8
T_3	37.7	31.8	27.0	15.2	27.9
T_4	38.0	36.8	29.2	24.2	32.0
Mean	35.3	32.3	26.7	19.6	

C.D. at 5%

Treatment (T) 1.85
Incubation (I) 2.06
Interaction (T x I) not significant

Table 27 Changes in NH_4-N content of the composting mass during preparation of phosphocompost

	NH_4 - N (ppm)				
Days of Incubation / Treatments	Initial	14	35	56	Mean
T_0	108.5	123.5	171.5	231.5	158.6
T_1	111.5	214.5	270.0	355.0	237.5
T_2	109.5	123.5	213.0	250.0	174.0
T_3	107.5	201.0	252.0	361.5	230.5
T_4	108.0	132.5	185.5	256.0	170.5
Mean	109.0	159.0	218.5	290.8	

C.D. at 5%

Treatment (T)	19.7
Incubation (I)	22.0
Interaction (T x I)	not significant

Table 28 Changes in NO_3-N content of the composting mass during preparation of phosphocompost

	NO_3 - N (ppm)				
Days of Incubation / Treatments	Initial	14	35	56	Mean
T_0	118.0	205.0	290.0	407.0	255.0
T_1	117.7	330.0	555.0	670.0	418.1
T_2	118.4	260.0	410.0	530.0	329.6
T_3	118.9	340.0	550.0	675.0	420.9
T_4	117.6	275.0	425.0	580.0	349.4
Mean	118.1	282.0	446.0	572.4	

C.D. at 5%

Treatment (T)	23.9
Incubation (I)	26.8
Interaction (T x I)	not significant

Table 29 Changes in total phosphorus content of the composting mass during preparation of phosphocompost

Days of Incubation / Treatments	Total Phosphorus (%)				
	Initial	14	35	56	Mean
T_0	0.2	0.19	0.18	0.18	0.18
T_1	1.88	1.9	1.9	1.88	1.89
T_2	1.99	1.98	1.96	1.95	1.97
T_3	1.87	1.89	1.9	1.88	1.88
T_4	1.96	1.95	1.96	1.94	1.95
Mean	1.58	1.582	1.58	1.56	
C.D. at 5%					
Treatment (T)	0.02				
Incubation (I)	0.02				
Interaction (T x I)	not significant				

Table 30 Changes in water soluble phosphorus content of the composting mass during preparation of phosphocompost

Days of Incubation / Treatments	Water Soluble Phosphorus (ppm)				
	Initial	14	35	56	Mean
T_0	83	95	115	187	120
T_1	120	300	555	789	441
T_2	180	290	309	325	276
T_3	290	330	485	850	488.7
T_4	245	330	340	375	322.5
Mean	183.6	269.0	360.8	505.2	
C.D. at 5%					
Treatment (T)	91				
Incubation (I)	101				
Interaction (T x I)	not significant				

Table 31 Changes in citrate soluble phosphorus content of the composting mass during preparation of phosphocompost

Days of Incubation / Treatments	Citrate soluble phosphorus (ppm)				
	Initial	14	35	56	Mean
T_0	520	610	663	800	648.2
T_1	2166	2900	4025	5465	3637.5
T_2	930	1060	1100	1200	1072.5
T_3	2600	2854	4262	5480	3779.0
T_4	890	1080	1160	1240	1092.5
Mean	1420.0	1700.8	2242 0	2821.0	

C.D. at 5%

Treatment (T)	203
Incubation (I)	227
Interaction (T x I)	not significant

The pH of the phosphocompost samples recorded on different days of incubation are shown in Table 23 and Figure 4.4.1(a). At the initial stage, pH of all samples were in the alkaline range, presumably due to production of NH_3. The pH of the treatment, T_0, varied from 7.2 - 7.1 and the pH of the MRP treated samples (T_1 and T_2) ranged from 8.2 - 6.7. Samples treated with pyrite recorded acidic pH on the 14th, 35th and 56th days of incubation. This might be due to the production of inorganic acids on the oxidation of pyrite.

The changes in organic carbon during decomposition of the organic materials has been shown in Table 24. Organic carbon content decreased in all treatments as the decomposition progressed. After 56 days of decomposition the lowest value of 26.3% and highest value of 35.7% were recorded in T_1 and T_0 respectively. The data also revealed that organic carbon content was lower in treatments receiving 5% P_2O_5 than the treatments with 7.5% P_2O_5 including control. This suggests that the lower level of MRP accelerated the mineralization of carbon. The reasons for the lower rate of carbon mineralization in T_2 and T_4 might be due to the toxic effect of MRP on the microbial population of the system.

Total nitrogen content of the compost ranged from 1.14 to 1.83 per cent (Table 25). On an average, total nitrogen content was significantly higher than the treated series. After 56 days of decomposition total nitrogen content of treatments T_2 and T_4 were significantly lower than T_1, T_3 and T_0. The value of nitrogen content increased with increase in incubation period, this might be due to the reduction in the volume of compost mass through mineralization and immobilization of carbon.

Why
The N%
higher in
non phos
(1.73) compost
phospho?
at initial
(1.18%)

It is observed from Table 26 and Figure 4.4.2(a), that the C/N ratio decreased in all the treatments (T_1 - T_4) including T_0 as incubation period

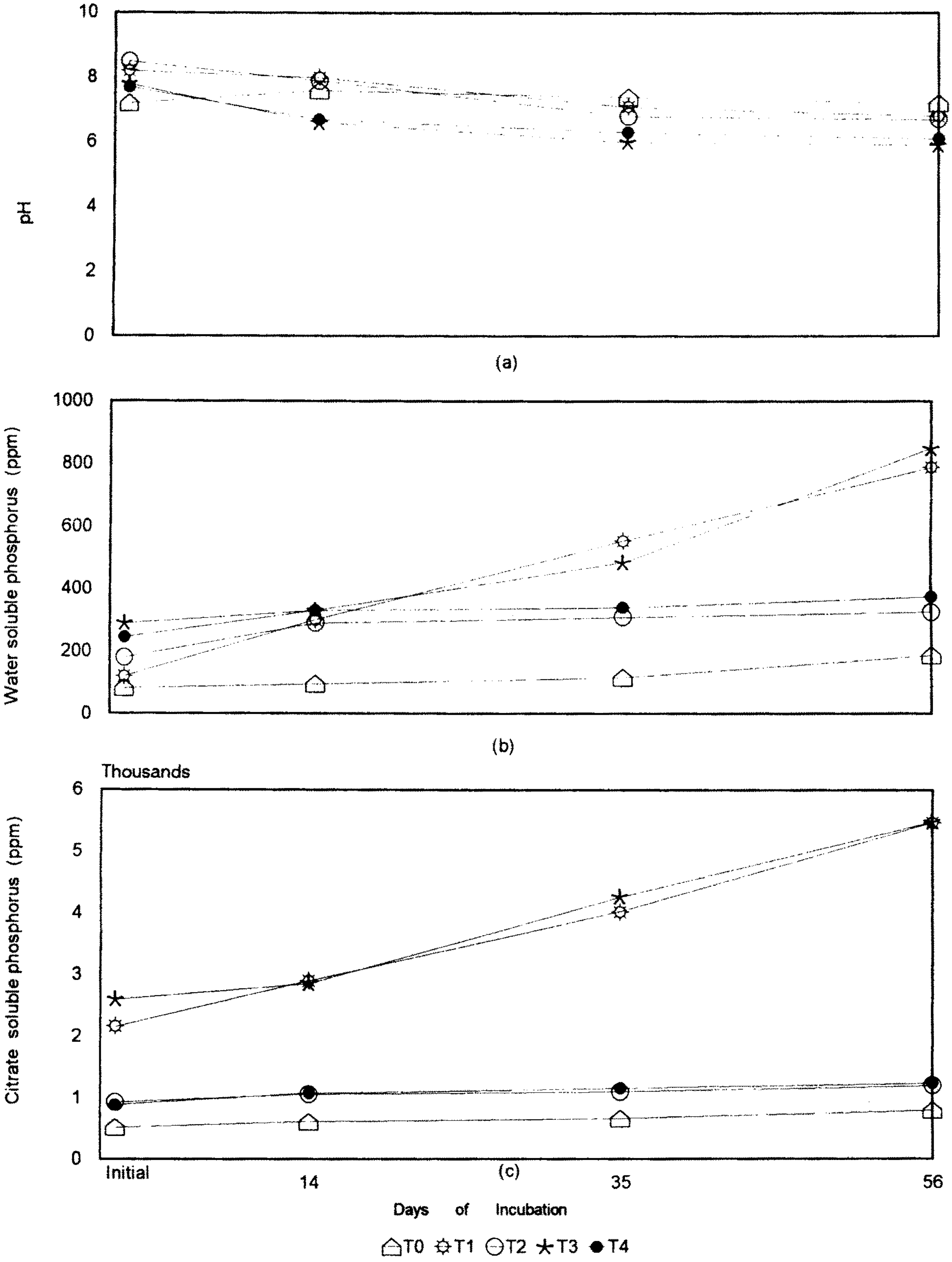


Figure 4.4.1 Changes in (a) pH,(b) water soluble P and (c) citrate soluble P during preparation of phosphocompost

advanced. Higher (7.5% P_2O_5) as well as lower (5% P_2O_5) application of MRP did not result any decrease in C/N ratio as compared to T_0. But decrease in organic carbon and increase in total N resulted concomitant decrease in C/N ratio in all the treatments after 56 days decomposition. This may be due to the mineralization of lesser amount of organic carbon in these treatments.

It was observed from Table 27 and 28 and Figure 4.4.2(b) and (c) that both NH_4 - N and NO_3 - N in phosphocomposts increased over ordinary compost (T_0). Higher accumulation of both NH_4-N and NO_3-N were recorded in all MRP treated samples (T_1-T_4). There was significant increase in NH_4-N and NO_3-N content of T_1 and T_3 as compared to T_0. Pyrite treated samples (T_3 and T_4) recorded comparatively lower NH_4-N and NO_3-N values than samples treated with MRP only (T_1 and T_2). It is also revealed from the data that the nitrification proceeded with incubation period. Generally, compost organisms prefer NH_4-N, and NO_3-N begins to form at the expense of soluble organic N.

From Table 29 it was observed that the total P content of the composting material was significantly higher in rock phosphate amended treatments (T_1 - T_4) as compared to control (T_0). Higher quantities of total P of the said treatments were due to additive effect of the phosphate rock.

It was observed from Table 30 and 31 and Figure 4.4.1 (b) and (c) that water soluble phosphorus (WSP) and citrate soluble phosphorus (CSP) content of the compost samples increased significantly in all the treatments (T_1-T_4) as compared to T_0 (T_1, 268 %; T_2, 130%; T_3, 307% and T_4, 169% as WSP and T_1, 461%; T_2, 65%; T_3, 482% and T_4, 68% as CSP). Treatments receiving 5.0 percent P_2O_5 as MRP (T_1 - T_3) resulted significantly higher amount of water soluble phosphorus and citrate soluble phosphorus than the treatments receiving 7.5 per cent P_2O_5 as MRP (T_2 and T_4) and no significant difference among themselves due to the higher level

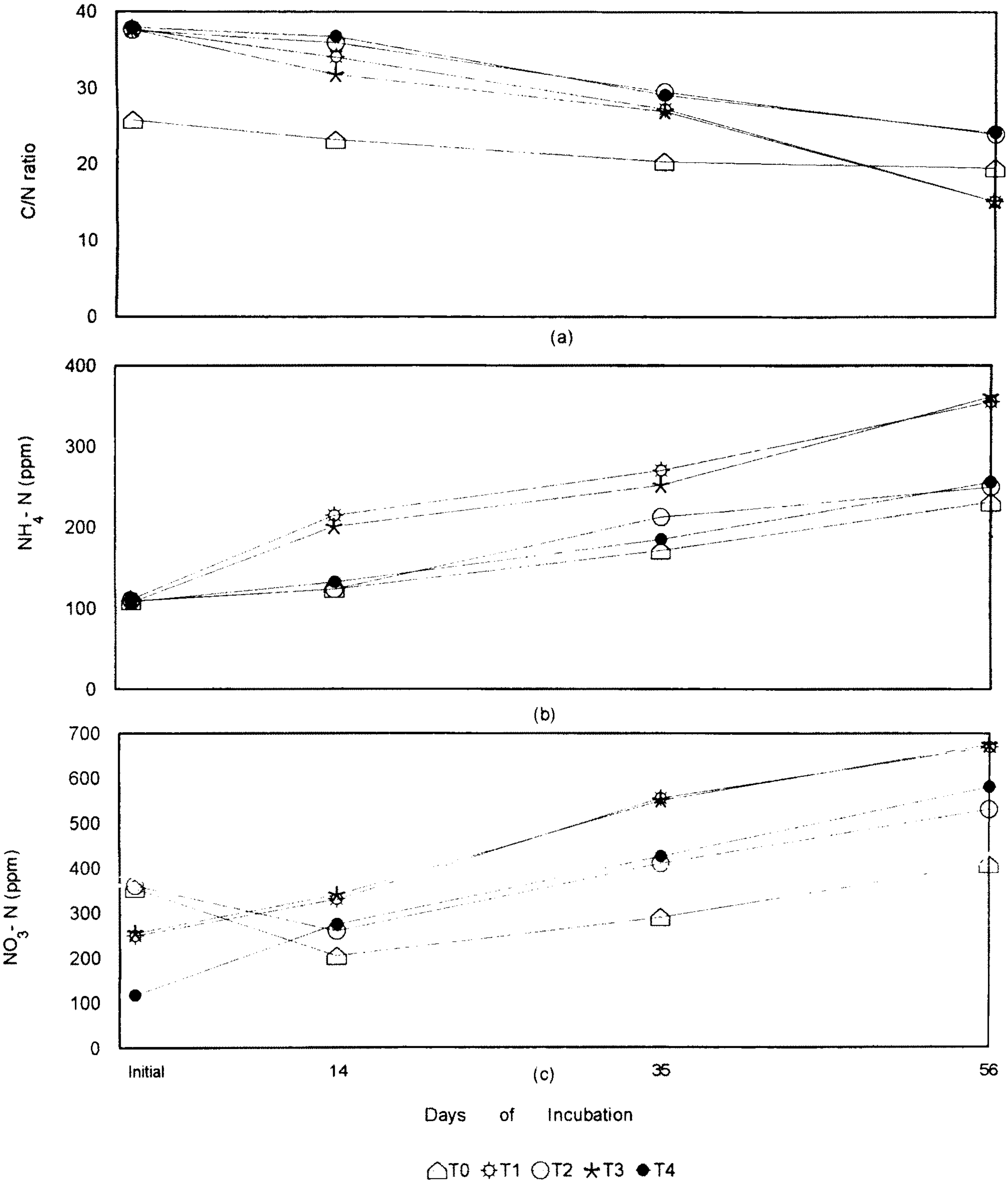


Figure 4.4.2 **Changes in (a) C/N ratio, (b) NH$_4$ - N and (c) NO$_3$ - N during preparation of phosphocompost**

of MRP which hampers microbial proliferation and decreases the availability of carbon per unit volume of the composting mass. This might be due to release of higher amount of Al^{3+} Fe^{3+}, Ca^{2+} and F^- or other elements toxic to the organisms responsible for transformation (Khan and Bhatnagar, 1977). The data also revealed that addition of pyrite caused higher amount of dissolution ($T_4 > T_2$ and $T_3 > T_1$). This might be due to production of inorganic acids through oxidation of pyrite and effect of associated microbial population. WSP content increased with increase in incubation period upto 56 days. It enhanced remarkably on 56th day as compared to 35th day. CSP also increased significantly as decomposition proceeded. This indicates that a long exposure is required for dissolution of MRP in compost system.

Correlation coefficient values of the above mentioned parameters studied during preparation of phosphocompost revealed that total P content of compost samples was positively correlated with C/N ratio (0.906**) and NO_3-N (0.778*) and negatively correlated with total N (-0.985**). Both WSP and CSP content positively correlated with NH_4-N (0.901 **, 0.994**) and NO_3-N (0.995 **, 0.912**) with a highly positive correlation between themselves (0.905**).

* Significant at 5% level.

** Significant at 1% level.

4.5 PREPARATION OF PHOSPHOCOMPOST FROM PADDY STRAW - WATER HYACINTH MIXTURE : A FIELD EXPERIMENT.

Paddy straw and water hyacinth are easily available carbonaceous materials. High nitrogen content of water hyacinth lowers down the C/N ratio of the compostable mixture which is helpful for the initiation of the decomposition process.

Several investigations have reported the preparation of phosphocompost from farm and municipal wastes (Dhar *et al.*, 1955; Sadasivam *et al.*, 1981; Kapoor *et al.*, 1983; Shingte *et al.*, 1990 and Hajra *et al.*, 1994).

EXPERIMENTAL

The phosphocompost components comprising of paddy straw-water hyacinth (1:1), cattle dung, MRP, pyrite and microbial inoculum as used in Expt. No. 4.4 were used in the present experiment in larger quantity i.e. 1.5 kg (dry weight) in polyethylene bag to study the decomposition under field condition. The bags containing the compostable materials were placed in a big decomposing compost pile for 90 days period. A turning was performed after 45 days of decomposition. At the end, the packets were removed and composite samples were prepared. Standard methods of estimation as described under 'Materials and Methods' were followd to study the minerological composition of the prepared phosphocompost.

The schedule of tretment was as under.

Treatment	Description of Treatment
T_0	Paddy Straw-Water hyacinth (1:1) + 20% cattle dung + Microbial inoculum
T_1	T_0 + 5.0 percent P_2O_5 as MRP
T_2	T_0 + 7.5 percent P_2O_5 as MRP
T_3	T_1 + Py @ 0.5 part of MRP
T_4	T_2 + Py @ 0.5 part of MRP

RESULTS AND DISCUSSION

Perusal of the data presented in Table 32 indicates that the pH of the composts ranged within 6.4 to 7.8. The lowest pH was recorded in T_3 followed by T_4. Both treatments received MRP along with pyrite. Oxidation of pyrite in presence of moisture and air produces H_2SO_4 that might have caused decline in pH (Tomar *et al.*, 1987). Slightly highter pH in T_1 and T_2 may be attributed to the presence of nitrogen rich water hyacinth in the compost system. On an average, all composts showed pH close to the neutral range. This might be due to the unique ability of composting process to buffer both high and low pH back to a neutral range through simultaneous production of CO_2 and NH_3 during decomposition of organic matter protein respectively (Davis *et al.*, 1991).

Moisture content of the final compost ranged between 60.2 to 65.1% . Variation in moisture content may be due to the difference in humus content of the mature compost.

Table 32 Minerological composition of phosphocompost after 90 days decomposition

Treatments	pH	Moisture (%)	Loss in wt. (%)	Organic C (%)	Total N (%)	C/N ratio	NH_4-N (ppm)	NO_3-N (ppm)	Total P (%)	WSP (ppm)	CSP (ppm)	Ca-P (ppm)	Fe-P (ppm)	Al-P (ppm)	HA (%)	FA (%)	CEC (meq/ 100g)	Total S (%)	Cd (ppm)	Fe (%)	Germ-ination (%)
T_0	7.2	65.1	36.6	32.2	1.60	20.1	216	371	0.37	198	869	trace	trace	trace	9.6	9.9	60	0.17	0.85	0.03	84
T_1	7.6	63.3	60.2	17.5	1.74	10.0	390	572	3.72	907	5340	3604	149	73	10.0	10.2	110	0.19	1.00	0.44	89
T_2	7.8	62.2	48.4	29.2	1.49	19.6	247	496	5.21	460	1300	6655	416	290	8.8	8.9	106	0.18	1.10	0.52	89
T_3	6.8	61.5	62.1	17.7	1.80	9.8	387	609	3.77	993	6200	2800	2407	2020	10.8	11.1	116	1.86	1.10	0.49	97
T_4	6.9	60.2	46.6	30.0	1.56	19.2	263	533	5.09	530	2100	4880	3350	3100	9.9	10.2	100	2.22	1.15	0.58	91
C.D. at 5%	0.26	1.12	9.93	1.55	0.08	1.7	36.2	48.6	0.85	55.7	97.0	307	188.9	101.6	0.73	0.98	21.2	0.06	0.08	0.08	6.6

Loss in weight, as a result of decomposition of organic materials, increased in all the treatments over control. It varied within the range of 36.6 to 62.1%. T_3 recorded highest loss followed by T_1, T_2, T_4 and T_0. This indicated the positive effect of the application at lower level of MRP and pyrite in combination with microbial inoculum in enhancing the decompostion, while in T_2 and T_4 adverse effect of higher level of MRP and and pyrite were indicated.

The stimulation in the decomposition resulting higher loss in presence of MRP in T_1 and T_3 might be due to the availability of P and Ca present in the MRP. Similar observation was reported by Dash *et al.,* (1981). The decrease in weight loss in treatments receiving higher amount of MRP and pyrite (T_2 and T_4) might be due the toxicity of high iron content of pyrite to the microorganisms under partial aerobic conditions. Findings of Singh *et al.,* (1983) supports this observation.

It is observed from the data that the organic C of mature phosphocompost varied within the range of 17.5-32.2 percent. The decrease in organic C of phosphocompost differed significantly from control the lowest was recorded in T_1 and highest in control. The lower organic C in MRP treated composts (T_1-T_4) indicated higher decomposition over control. Pyrite treated composts (T_2 and T_4) recorded comparatively higher organic C. This decrease in decomposition may be attributed to the decreased microbial activity due to pyrite amendment. Tomar *et al.,* (1987 b) also reported similar observations, where they noted that activities of Fe^{3+} and Ca^{2+} increased due to oxidation of pyrite and simultaneous solubilization of MRP. The ions might have interacted with organic compounds forming complexes more resistant for microbial degradation.

Total nitrogen of the composts ranged within 1.4 to 1.8 percent (Table 32). Highest value of total N was observed in T_3 where the paddy straw-water hyacinth mixture (1:1) was treated with MRP (5% P_2O_5) and pyrite (0.5 part of MRP). Increase in N in T_1 over T_0 might be due to the increase in the activity of cellulose decomposing fungi due to the application of phosphate rock as reported by Chang (1939) and decrease in the number of denitrifier (Korovkin, 1952). Increase in N due to the application of pyrite might be due to the reduction in pH arresting the loss of N. Similar results were recorded by Hajra *et al.*, (1994).

Decrease in organic C and increase in total N resulted ~~a~~ m concomitant decline ~~decrease resulted~~ in C/N ratio of the treatments. After 90 days decomposition the highest recorded C/N ratio was 20.1~~%~~ in T_0. The minimum C/N ratio, 9.8 ~~was~~ shown by T_3, might be due to higher decomposition of the Substrate during compost preparation.

NH_4-N and NO_3-N of the composts ranged within 216-390 ppm and 371-609 ppm respectively (Table 32). Higher levels of NO_3-N indicated the attainment of maturity of the composts. Both forms were recorded lowest in T_0. Highest NH_4-N was recorded in T_1 and highest NO_3-N in T_3. Composts treated with high phosphate rock recorded higher amount of both forms. Phosphate rock has been reported to increase the number of nitrifying bacteria and decrease the number of denitrifying bacteria (Chekalov, 1955; Gaur *et al.*, 1995). Pyrite helps in conserving N by reducing the volatilisation loss (Bangar and Patil, 1980). Prevalance of greater amount of NO_3-N compared to NH_4-N in the treatments might be due to higher mineralisation at later stages of composting due to better aeration and decreased temperature (Inbar *et al.*, 1993).

Total P of the composts varied within 0.37 - 5.21%. All treatments (T_1 -T_4) receiving MRP recorded higher amount of total P than control (T_0) .

Citrate soluble and water soluble P of composts ranged within 869-6200 ppm and 198-993 ppm respectively. Lowest amount of both forms were recorded in control (T_0). Treatments receiving pyrite resulted greater amount of citrate and water soluble P, but T_1 and T_3 recorded higher amount of available P forms than T_2 and T_4, possibly due to the presence of higher amount of MRP and pyrite which caused refixation of P with its free cations (Chakravarti and Talibudeen, 1962).

The CEC of composts varied within 60 meq/100g (T_0) to 116 meq/100g (T_3). It increased with increasing formation of humic and fulvic acid. The increase in CEC also had a direct relationship with the loss of orgnic matter due to decomposition.

Total sulphur content of composts were in the range of 0.17 - 2.22%. The lowest was found in control (T_0) and the highest in T_4. Pyrite treated composts recorded greater amount of total S.

The data in Table 32 revealed that Cd and Fe content of the prepared compost ranged within 0.85-1.15 ppm and 0.03 - 0.58% respectively. Cadmium content of each compost was much lower than the Soil Association Limits for micronutrients provided by Giller and McGrath (1989) and are safe for application to the field.

Ca, Fe and Al bound P in the MRP treated samples ranged within 800-6655 ppm, 149 - 3350 ppm and 73-3100 ppm respectively. Trace amount of Ca, Fe and Al bound P were obtained in the control (T_0). The recovery of P in these fractions increased with levels of MRP application. Ca-P in T_2 and T_4 were higher than that in T_1 and T_3 might be due to the presence of greater amount of Ca^{2+} in the system. The amount of Al-P and Fe-P prevailed where the pH were in the acidic range. Observation of Tomar *et al.,* (1987) corroborates this result.

The humic and fulvic acid content of the control (T_0) were recorded to be 9.6 and 9.9% respectively. The lowest humic and fulvic acid values (8.8 and 8.9% respectively) were shown by T_2 while T_3 showed the highest values (10.8 and 11.1% respectively). Both humic and fulvic acids were higher in MRP treated composts (T_1 and T_3) than composts treated with pyrite along with MRP (T_2 and T_4).

Germination percentage of the prepared phosphocomposts ranged within 84 to 97 which indicated their maturity for application to the field.

The results of the present study indicate that the quality of composts prepared from paddy straw-water hyacinth mixture (1:1) amended with MRP and pyrite (T_1-T_4); were superior to ordinary compost prepared from paddy straw-water hyacinth mixture only. Therefore the following experiment was under taken to evaluate these four P enriched composts by their effect on the growth and uptake of P of a cereal test crop, paddy and a leguminous test crop, Rice Bean in pot culture experiments.

4 5.1 EFFECTIVENESS OF THE PREPARED PHOSPHOCOMPOSTS IN COMPARISON TO FERTILIZER P ON THE DRY MATTER YIELD AND UPTAKE OF P BY RICE BEAN (*VIGNA AMBELLATA THUMB OHWI AND OHASI*) AND PADDY (*ORYZA SATIVA*)

In the present study, the quality of ordinary compost and phosphocomposts prepared under experiment No. 4.5, treatment No. T_0-T_4 were compared with inorganic fertilizer P by their effect on the dry matter yield and uptake of P by rice bean and paddy separately in a pot culture experiment carried out in an alluvial soil of Indo-gangetic plain.

EXPERIMENTAL

An Indo gangetic alluvial soil (0.9 cm) (Table 1) collected from a fallow land of C - Block Seed Farm of the Viswavidyalaya at Kalyani was used in this experiment. Each 1.5 kg portion of processed soil was taken in a series of earthen pot. Ordinary compost (Sample No. T_0) and phophocomposts (Sample Nos. T_1-T_4, Expt. No. 4.5) were applied @ 10 t ha^{-1}. The experiment was divided in two sets.

In the first set, four seedlings of Paddy (var. 4786) were planted in each pot. One pot received recommended inorganic fertilizer i.e. N_{60} P_{40} K_{40} in the form of Urea, single super phosphate and muriate of potash for comparison.

low for
Paddy soil
Which treatment
number has
been given
to inorganic
fertiliser
It has not
been shown
in table.
What is treatment
No P6 & R6

In the second set, three seeds of Rice Bean were planted. The recommended fertilizer was N_{20} P_{80} K_{40}. Each treatment was replicated thrice. Pots were placed in the net house. Paddy was harvested after 90 days (22.07.95 to 22.10.95) and Rice Bean (var. K_1) after 45 days (22.06.95 to 06.08.95) of the date of sowing. Dry matter yield was recorded and the uptake of P in composite plant sample was estimated following standard procedures.

The schedule of treatment was as under.

Set I		Set II	
Treatment	**Description of treatment**	**Treatment**	**Description of treatment**
P_1	Soil + Compost obtd. from T_0 of Expt. 4.5 (C_0)	R_1	Soil + C_0
P_2	Soil + Compost obtd. from T_1 of Expt. 4.5 (C_1)	R_2	Soil + C_1
P_3	Soil + Compost obtd. from T_2 of Expt. 4.5 (C_2)	R_3	Soil + C_2
P_4	Soil + Compost obtd. from T_3 of Expt. 4.5 (C_3)	R_4	Soil + C_3
P_5	Soil + Compost obtd. from T_4 of Expt. 4.5 (C_4)	R_5	Soil + C_4
P_6	Soil + Compost obtd. from T_5 of Expt. 4.5 (C_5)	R_6	Soil + C_5

There is no T_5 in Expt
No 4.5. This may be Corrected

RESULTS AND DISCUSSION

The results of the pot experiment carried out with the composts prepared in Expt. 4.5 are shown in Table 33 and 34.

Set I

The total dry matter yield (DMY) of Paddy (var.4786) varied from 15.4 to 24.2 g/pot. The lowest was recorded in R_1 due to absence of sufficient nutrients. The DMY increased in P_2 (31.1%), P_3(29.8%), P_4 (42.8%) and P_5 (31.8%) over P_1. Maximum increase (57.1%) was recorded in P_6, where the soil received inorganic nutrient sources. The highest uptake of phosphorus (0.902%) was also recorded in P_6 followed by P_4 (0.849%), P_5 (0.842%), P_2 (0.839%), P_3 (0.836%) and P_1 (0.653%). The uptake of phosphorus was significantly higher in P_2-P_6 as compared to P_1.

This might be due to the steady availability of plant nutrient components in the phosphocomposts and ready release of nutrients in the inorganic fertilizer.

Set II

Dry matter yield of Rice Bean (var K_1) varied from 10.8 g/pot to 19.1 g/pot and it increased significantly in R_2, R_4 and R_6 as compared to R_1. This might be due to the protracted and steady release of assimilable phosphate, nitrogen and (or) sulphur from the P composts and the easy availability of them from inorganic fertilizer. The uptake of phosphrus and number of nodules also recorded a significant increase in all treatments (R_2 -R_6) as compared to R_1. This might be attributed to the ability of legumes to utilize P more and effect of phosphate on root proliferation.

The results of the present experiment indicate that P enriched composts were effective to both cereal and leguminous crops with a better response from the later. Though inorganic fertilizers recorded higher dry matter yield and

Where is the data. It should be incorporated in table and then critically discussed vis a vis compost yield. [illegible] only the significance of phosphate compost can be judged.

Table 33 Effect of phosphocompost on dry matter yield and uptake of P by Paddy

Treatment	Dry matter yield/pot (gm)			P uptake (%)		
	Straw	Grain	Total	Straw	Grain	Total
P_1	0.9	5.5	15.4	0.292	0.361	0.653
P_2	12.0	8.2	20.2	0.365	0.444	0.839
P_3	12.5	7.5	20.0	0.363	0.473	0.836
P_4	13.5	8.5	22.0	0.367	0.482	0.849
P_5	12.6	7.7	20.3	0.365	0.477	0.842
P_6	15.2	9.0	24.2	0.410	0.492	0.902
C.D. at 5%			3.06			0.04

9.9

Table 34 Effect phosphocompost on the dry matter yield and uptake of P by Rice Bean

Treatment	No. of Nodules/ plants	Dry matter yield /Pot (g)	P uptake (g)/100 g of plants
R_1	18	10.8	10.1
R_2	21	14.3	19.8
R_3	21	13.3	18.7
R_4	23	16.4	21.2
R_5	20	14.2	19.0
R_6	28	19.1	27.1
C.D. at 5%	2.03	4.07	3.02

uptake of phosphorus, phosphocomposts prepared with 5% P_2O_5 as MRP and pyrite along with microbial inoculum also resulted in appreciable yield and P uptake values. Considering economic and environmental reasons, inorgnic superphosphates may successfully be substituted by phosphocomposts for sustainable agriculture if prepared from a suitably designed system, which could provide optimum physico-chemical and biological conditions necessary for getting a highly enriched, stable and usable end product.

CHAPTER 5

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

Intensive cultivation of High Yielding Varieties with high fertilizer input brought about green revolution and surprisingly presented our soil with some complex nutrient and health symptoms. To sustain the productivity of agricultural soils, especially that of tropics, Integrated Plant Nutrient Supply and Integrated Plant Nutrient Management have evoked world wide emphasis. It has also called out the huge scope for recycling and reuse of resources to perpetuate the living soil.

Indian soils are poor in phosphorus content and about 98 percent of them have inadequate supply of available phosphorus. Low grade rock phosphates are advocated these days for direct application to the field soil, especially of acidic reaction. But if they are used after predigestion with suitable organic amendments and microbial inputs, better manurial values can be obtained. With this end in view, phosphorus enriched compost or 'phosphocompost' has emerged, which can serve as an alternative to single super phosphate. In this context, Studies were undertaken ~~in the following direction~~ to assess ~~study~~ the decomposition pattern of water hyacinth, paddy straw and cattle dung ~~alone~~ in isolat and in combination, for preparation of phosphocompost and to study some chemical aspects of it, related to its enrichment and application.

To obtain the efficient phosphate rock solubilizing fungi, compost samples was collected from the ICAR's AICRP at the Viswavidyalaya and eight P-solubilizing strains were isolated from it (Expt. 4.1). P-solubilizing power of the isolated strains were observed and it was found that the isolate, coded as PS_7, was the most efficient P-solubilizing organism among the isolated microorganisms. It solubilized 24.6 mg P_2O_5, which was significantly higher than the solubilization data obtained from other isolates. So, it was used in the compost systems as P-solubilizing inoculum.

To obtain a suitable ratio of Mussoorie rock phosphate (MRP) to pyrite (Py) for its use in the preparation of P-enriched compost, different ratios of MRP and Py were mixed and incubated for 60 days. pH and available P of each treatment were estimated at intervals (Expt. 4.2). Maximum solubilization was recorded in T_6 (0.480 g) where the ratio was 1:3 and the pH of the mixture was very low and ranged from 4.2-2.7, which could be harmful to the microbial biomass. So, considering the period required to attain the maturity of compost under natural condition, the ratio ~~of T i.e.~~ 1:0.5 was considered to be dissolution effective and economic, and choosen for its use in the phosphocompost systems of the following experiments.

To study the response of different organic substrates separately or in combination with different amounts of organic and inorganic inputs to the decomposition process, the degradation pattern of water hyacinth, paddy straw and cattle dung was studied separately and in combination with other organic or inorganic inputs like mushroom spent straw, MRP, Py and fly ash to obtain a suitable substrate combination for rapid preparation of enriched compost (Expt. 4.3.1-4.3.6).

During decomposition of cattle dung (Expt. 4.3.1), maximum evolution of CO_2 (9642.7 mg) as a result of decomposition was recorded, where the combination was, Cattle dung (CD) + MRP (@ 2% P_2O_5) + Py (@ 0.5 time of MRP) + mixed inoculum (PS_7 + *Trichurus spiralis* + *Paecilomyces fusisporus*). This indicates that lower level of MRP and Py in combination with mixed inoculum (MI) helps decomposition.

While studying the influence of different doses of MRP on the decomposition of paddy straw in presence of varied amount of cattle dung (Expt. 4.3.2), the combination of T_7 (Paddy straw + MRP @ 5% P_2O_5 + Py @ 0.5 time of MRP + 20% CD + MI) recorded maximum amount of evolved CO_2 (10836.4 mg) during decomposition. Application of 20% cattle dung and 5% P_2O_5 as MRP favoured the decomposition process.

Water hyacinth decomposed readily, when treated with fresh cattle dung (@ 20%), MRP (@ 5% P_2O_5), Py (@ 0.5 time of MRP) and mixed inoculum to produce 11806.5 mg CO_2 (Expt. 4.3.3). Higher rate of MRP and Py restricted decomposition but presence of cattle dung ameliorated those detrimental effects in a great extent. So, application of both lower and higher level of MRP and pyrite in presence of 20% cattle dung were quite appropriate for rapid decomposition of water hyacinth.

While studying the decomposition of different ratios of water hyacinth-rice straw mixture in presence of higher amounts of MRP and Py (Expt. 4.3.4), it was observed that the lower level of MRP i.e. 5% P_2O_5 equivalent, influenced the decomposition positively. But the higher application of MRP retarded it. The decomposition of water hyacinth was most favoured when proportioned with paddy straw in the ratio of 1:1 and treated with 5% P_2O_5 as MRP, Py (@ 0.5 part of MRP), 20% cattle dung and microbial inoculum (T_4 of Set I) than the other two ratios i.e. 2:1 (Set II), and 3:1 (Set III). The total amount of evolved CO_2 in T_4 of Set I, was 10831.9 mg.

Spent mushroom bed was composted with MRP and Py (Expt. 4.3.5) to find its suitability as phosphocompost substrates. As it contains lower parts of the mushroom and micro organisms of different species, it might help the decomposition to a large extent. Results show that the mushroom bed waste and water hyacinth mixture of 1:1 ratio, treated with 5% P_2O_5 as MRP, Py and microbial inoculum (T_2) yielded a P-enriched compost with C/N ratio, 13.5 and CSP, 5650 ppm. The dry matter yield of Arhar after 60 days growth also show that the compost from T_2 (yield, 13.3 g) performed quite similarly as the inorganic fertilizer (yield, 13.4 g).

The suitability of fly ash as phosphocompost additive was studied in Expt. 4.2.6, by applying it at two levels, viz, 2.5% and 5.0% to the composting substrate (a mixture of paddy straw and water hyacinth, with or without MRP). Studying the rate of decomposition it was found that higher dose of fly ash restricted decomposition greatly. Lower level of fly ash along with MRP did not hinder the rate of decomposition much, so this level of fly ash might be used as an amendment of phosphocompost.

To study the mineralization of carbon, nitrogen and phosphorus during decomposition of water hyacinth and paddy straw mixture, an incubation experiment was carried out for 56 days. The pH, org C, total N, total P, NH_4-N, NO_3-N, WSP and CSP were estimated on the 1st, 14th, 35th and 56th day of the incubation study (Expt. 4.4).

The pH of the samples without MRP ranged from 7.2 to 7.1 and with MRP, it varied from 8.2 to 6.7, while the pyrite treated samples recorded a pH range of 7.8 to 5.9. Organic carbon content decreased in all treatment as the decomposition progressed and it was lowest in the treatment receiving lower doses of MRP (T_1). Total nitrogen content of compost ranged from 1.14 to 1.83 per cent. The C/N ratio decreased in all treatments after 56 days decomposition and T_1 and T_3 recorded the minimum (15.2). Mineralization of nitrogen was quite appreciable in the MRP treated samples with pyrite (T_3 and T_4) or without pyrite (T_1 and T_2). Total mineralized nitrogen ranged from 229.2 ppm to 1025.0

ppm in T_1, 227.9 ppm to 780.0 ppm in T_2, 225.9 ppm to 1036.5 ppm in T_3 and 225.6 ppm to 836.0 ppm in T_4. The citrate soluble and water soluble P content of the compost samples increased significantly in all treatments (T_1, 268%; T_2, 130%; T_3, 307% and T_4, 169% as WSP and T_1, 461%; T_2, 65%; T_3, 482% and T_4, 68% as CSP) as compared to T_0. Both WSP and CSP content was positively correlated with NH_4-N (0.901**, 0.994**) and NO_3-N (0.995**, 0.912**). These values indicate that phsophocompost system is very much an active one and it contains appreciable amount of available plant nutrients in mature condition.

To prepare a P-enriched compost, a 1:1 combination of paddy straw and water hyacinth along with cattle dung was decomposed in presence and absence of two levels of MRP (5% and 7.5% P_2O_5) and Py for 90 days and quality parameters were estimated (Expt. 4.5). The treatment, T_3, receiving MRP @ 5% P_2O_5 and Py @ 0.5 time of the weight of MRP, showed to be of better quality in terms of nutrient content and germination percentage.

✓ [The phosphocompost prepared ~~(under Expt. 4.5)~~ ~~were~~ was evaluated by a pot experiment ~~(Expt. 4.5.1)~~ with Paddy and Rice Bean. ~~Their yield and P uptake values were recorded after 90 and 45 days respectively~~. Though the highest yield (24.2 g and 19.1 g) and P uptake (0.902% and 27.1 g/100 g plant) values were given by the fertilizer treated pots, for Paddy and Rice Bean respectively, ~~T~~the pots treated with phosphocompost ~~obtained from T_3 of Expt. 4.5~~ also recorded higher yield and uptake values.] For Paddy, the yield and P uptake were 22.0 g and 0.849% respectively and for Rice Bean, they were 16.4 g and 21.2 g/100 g of plant respectively. So, enriched phosphocomposts may successfully be prepared and applied to the soil for better crop yield. And considering the wide spread energy crisis, inorganic superphosphates can efficiently be substituted by the P enriched compost produced from a well managed composting system.

CHAPTER 6

FUTURE SCOPE OF RESEARCH

FUTURE SCOPE OF RESEARCH

The investigations embodied in the present thesis, **'Some Aspects of Chemistry of Phosphocompost'**, reports the results of research carried out to study the decomposition of paddy straw, water hyacinth and cattle dung alone and in combination for the preparation of phosphocompost. Chemical aspects like mineralization of C, N, P and changes in pH and C/N ratio of the compost system during the process of decomposition were also studied. Most of the experiments were carried out with small amounts of organic matter to assess their pattern of degradation in the laboratory and pot culture experiments were choosen for the uptake study. So it may not be enough to draw a sweeping conclusion based on the results of these experiments. However, the observations of the present investigation brings out some points to invite renewed interest in this field.

I. Studies should be carried out for the optimization of plant nutrient availability of phosphocomposts prepared with phosphate rocks of different sources.

II. Effect of different physical conditions on the transformation of major nutrients during decomposition of conventional and non-conventional wastes should be continued.

III. Changes in physico-chemical and microbiological properties of soils treated with phosphocomposts under different agroclimatic condition should be studied with due importance.

IV. Evaluation of the prepared phosphocomposts should be carried out under field condition with sufficient number of replications and a balance sheet of major nutrients in the phosphocompost amended crop field should be prepared.

V. Persistence of manure P availability in different phosphocompost amended soils and effect of crop rotation on the availability of the plant nutrient components should be studied.

VI. Heavy metal content and phytotoxicity of the prepared phosphocompost should be studied for the preparation of a pollution free organic manure.

REFERENCES

REFERENCES

Abdel-Hafez, S. I. I. and Abdel Kader, M. I. A. (1980) Cellulose decomposing fungi of barley grains in Egypt, *Mycopathologia.*, **70**: 72-82.

Acharya, C. N. (1935) *Biochem. J.* **29**: 1116-1120. [Introduction to Soil Microbiology, Alexander, M. Wiley Eastern Limited, New Delhi, 1961].

Acharya, C. N. and Subrahamanyan, V. (1939) *Indian J. Agric. Sci.,* **9**: 741-749.

Adhia, J. D. (1969) Indigenus rock phosphate for superphosphate manufacture. *Fertilizer News.*, **14** : 13-19.

Agoilar, S. A. and Diest, A.Van. (1981) *Plant Soil,* **61** (1/2): 27-42

Ahmed, N. and Jha, K.K.(1968) Solubilization of rock phosphate by microorganisms isolated from Bihar Soils. *J.Gen. Appl. Microbiol.,* **14**: 89-95.

Ahmed, I. U.; Faiz, S. M. A. and Islam, N. (1981) Utilization of water hyacinth as a source of organic fertilizer. *Current Agriculture,* **5** (3 & 4): 99-104.

Alexander, M. (1961) Introduction to Soil Microbiology. Wiley Eastern Limited, New Delhi.

Alexander, M. (1977) *Introduction to Soil Microbiology,* John Wiley and Sons, New York.

Allison, F. E. (1973) Soil Organic Matter and its Role in Crop Production, Elsevier, New York.

Amberger, A. (1992) Humus, its structure and role in agriculture and environment: proceedings of 10th symposium humus et planta, Ed. Kubat, *J., Elsevier Science Publisheres.* ISBN 0-444-88980-9: 47-55.

Anderegg, J. C. and Naylor, D. V. (1988) *Plant Soil,* **107**: 273-78.

Anderson, G. and Malcolm, R. B. (1974) *J. Soil Sci.,* **25**: 282.

Anderson, J. P. E. and Domsch, K. H. (1980) *Soil Sci.,* **130**: 211.

Anonimous, (1992) Agricultural Statistics at a Glance, Dir. of Eco. Sta., Min. of Agri., New Delhi.

Arzamasova, Z. A. and Kuzmenkova, A. M. (1962). *Sb. Nauchn. Rabot. Akad, Kommun. Khoz.*, **14**: 103-16.

Asija, A. K.; Pareek, R. P.; Singhania, R. A. and Singh, S. (1984) *J. Indian Soc. Soil Sci.*, **32**: 323-329.

Askinazi, D. L. (1938) Trudy nauchissled. Inst. Udobr. Insektisid. Fungisid.,**147**

Asmus, F. (1993) Application of FYM in cultivation, Darmstadt, Germany; KTBL - Arbe its papier., **182**: 32-44.

Atkinson, R. J.; Posner, A. M. and Quirk J. P. (1972) *J. Inorg. Nucl. Chem.*, **34**: 2201.

Atkinson, R. J.; Hingston, F. J.; Posner, A. M. and Quirk, J. P. (1970) *Nature*, **226**: 148-49.

Bajpai, P. D. and Sundara Rao, W. V. B. (1971) Phosphate solubilizing bacteria. I. Solubilization of phosphate in liquid culture by selected bacteria as affected by different pH values. *Soil Sci. Plant Nut.*, **17**: 41-43.

Balasubramaniam, A. *et al.* (1972) *Plant and Soil*, **37** : 319-28.

Bali, J. S. (1988) A Critical Appraisal of the Past and Present Policies and Strategies of Watershed Development and Management in India and Role of Government and non-Governmental Organisations in Small Scale Watershed Development, Soc. for Promotion of Wastelands Development, 1, Copernicus Marg, New Delhi, 147.

Bangar, S. G. and Patil, P. L. (1980) *J. Indian Soc. Soil Sci.*, **28** (4): 543-545.

Banger, K. C. ; Kapoor, K. K. and Mishra, M. M. (1990) *Indian J. Microbiol*, **30** (3): 263-78.

Bangur, K. C.; Yadav, K. S. and Mishra, M. M. (1985) *Plant Soil*, **85**: 259-66.

Banik, S. and Dey, B. K. (1978) *Indian Agric.*, **22**: 93-97.

Banik, S. (1979) Studies on microbial transformation of soil phosphorus. *Ph. D.* Thesis, University College of Agriculture, Calcutta University.

Banik, S. and Dey, B. K. (1981) Phosphate solubilizing micro-organisms of a lateritic soil. II. Effect of some tricalcium phosphate solubilizing micro-organisms on available phosphorus content of the soil. *Zbl.Bakt. 11.Abt.,***136**: 487-492.

Banik, S. and Dey, B. K. (1982) Available phosphate content of an alluvial soil as influenced by inoculation of some isolated phosphate solubilizing micro-organisms. *Pl.Soil.,***69**: 353-364.

Banik, S. and Dey, B. K. (1983b) *Zbl. Mikrobiol.,* **138** : 437-442.

Bardiya, M. C. and Gaur, A. C. (1974) Isolation and screening of micro-organisms dissolving low-grade rock phosphate. *Folia Microbiol.,* **19**: 386-389.

Bar-Lev, S. S. and Kirk, T. K. (1981) Effect of molecular oxygen on lignin degradation of *P.chrysosporium. Biochemical and Biophysical Research Communications.,* **99**: 373-378.

Barrow, N. J. (1983) *Fert. Res.,* **4**: 51-61.

Basak, M. N. (1948) Water hyacinth compost. In Handbook of Utilization of Aquatic Plants (Little E. C. S. Ed.) F. A. O.

Basak, R. K. and Debnath, N. C. (1987) Efficiency of Composted Rockphosphates and Basic Slag as Phosphatic Fertilizers for Wheat in Neutral Soil of West Bengal. *Env. & Eco.,* **5**: 4.

Becher, G.; Ostrold, G.; Paus, P. and Scip, H. M. (1983) Complexation of copper by aquatic humic matter studies by reverse phase liquid chromatography and absorption spectroscopy. *Chemosphere,* **12**: 1209-1215.

Bennoah, E. O. and Acquaye, D. K. (1989) *Soil Sci.,* **148**: 114-23.

Berton, S. and Mouketo, F. (1989) Experimentation and use of a new source of org. matter: Water hyacinth compost in Brazzaville. DCV/Labortoire Agro-Economic Programme Maraichage **1**: 41-47.

Bes, B.; Petersson, B.; Lennholm, H.; Iversen, T. and Eriksson, K. E. (1987) Synthesis, structure and enzymatic degradation of an extracellular glucan produced in nitrogen starved culture of the white-rot fungus *Phenerochaete chrysosporium. Biotechnol. Appl. Biochem.,* **9**: 310-318.

Bhardwaj, K. K. R. and Patil, R. B. (1982) In: *Rev. Soil Res. In India,* **1**: 258.

Bhujbal, B. M. and Wheeler, R. W. (1964) *Soil Sci. Soc. Am.. Proc,***28**. 545-550.

Bhujbal, B. M. and Mistry, K. B. (1985) *J. Indian Soc. Soil Sci.,* **33**: 568-73.

Bhujbal, B. M. and Mistry, K. B. (1984) *Fert. News,* **29** (8): 26.

Bienkowski, P. (1992) *Polish Ecological Studies,***16** (4): 235-244.

Birch, H. F. (1961) *Pl. Soil,* **15**: 347.

Biswas, T.D. *et al.* (1971) *J. Indian Soc. Soil Sci.,* **19**: 31-34.

Biswas *et al.* (1991) *Fert. News,* **36**.

Text.

Name

Biswas, D. R. and Narayanswamy, G.(1995) Characterisation of partially acidulated phosphate rocks. *J.Indian Soc. Soil Sci.,* **43**(4): 618-623.

Black, C. A. (1968) in *Soil Plant Relationship.* John Wiley and Sons, Inoculation. N. Y. Second Ed. pp. 792.

Bolland, M. D. A.; Weatherley, A. J.; Gilkes, R. J. and Bowden, J. W. (1986) *Aust. J. Exp. Agric.,* **26**: 217-225.

Bolan, N. S.; Barrow, N. J. and Posner, A. M. (1985) *J. Soil Sci.,* **36**: 187-197.

Bouveng, H. O. and Solyom, P. (1973) Long term stability of waste lignins in aquatic systems. *Seven Papperstiodn,* **76**: 26-29.

Boyd, C. E. (1974) Utilization of aquatic plants. In : Mitchell, Aquatic vegetation and its use and control. *Unesco Paris,* pp. 107-115.

Bradley, D. B. and Sieling, D. H. (1953) Effect of organic anions and sugars on phosphate precipitates by iron and aluminium as influenced by pH. *Soil Sci.,* **76**: 175-179.

Bremer, W.; Hontum, W. Van and Kessel, C. Van. (1991). *Biol. Fertil. Soils.,* **11**: 221-227.

Brookes, P. C.; Powlson, D. S. and Jenkinson, D. S. (1984) *Soil Biol. Biochem.,* **16**: 169.

Brown, A. C. and Jurinak, J. J. (1984) Non-biological pyrite oxidation in alkali soils. *Agron. Abst.,* p 175.

Brown, J. A.; Collin, S. A. and Wood, T. M. (1987) Enhanced enzyme production by the cellulolytic fungus *Penicillium pinophilum,* mutant strain NT GIII,/6. *Enzyme Microb. Technol.,* **9**: 176-180.

Buck, J. K.; Houston, R. J. and Beimborn, W.A. (1990) Direct seeding of anthracite refuse using coal fly ash as a major soil amendment. In proceeding of the Mining and Reclamation Conference and Exhibition, Ed, Skousen, *et al.,* Morgan town, WV 26506, USA; *West Virginia Univ. Publications Service,* **2**: 603.

Burns, G. R. (1967) Oxidation of sulphur in soils. *Tech. Bull. Sulphur Inst.,* **13**: 1-14.

Burns, G. R. (1968) Oxidation of sulphur in soils. *Sulphur Instt. Tech. Bull.,* **13**: 1-41.

Butler, J. H. A. and Buckerfield, J. C. (1979) Digestion of lignin by termites. *Soil Biology and Biochemistry,* **11**.(5): 507-513.

Cabala-Rosand, P. and Wild, A. (1982) Direct use of low grade phosphate rock from Brazil as fertilizer. I. Effcet of reaction time in soil. *Pl.Soil,* **65**:351-362.

Carlyle, R. E. and Norman, A. G. (1941) Microbial thermogenesis in decomposition of plant materials. Patr II. Iactors Involved. J. Bact., **41**: 699.

Carter, C. W. and Suffet, I. H. (1982) Binding of DDT to dissolved humic materials. *Environ. Sci. & Technol.,* **16**(11): 735-740.

Cervelli, S. G.; Petruzzelli, A.; Pern. A. and Menicgli, R. (1986) *Agro. Chemicals,* **30**: 27.

Chakravarty, S. N. (1964) *Sci. Cult.,* **30**: 475 (Cited in Khanna, *et al.,* 1982).

Chakravarty, S. N. and Talibudeen, O. (1962) *J. Indian Soc. Soil Sci.*, **29**: 559-562.

Chandler, J. A.; Jewell, W. J.; Gossett, J. M.; Ven Soest, P. J. and Robertson, J. B. (1980) "Predicting Methane Fermentation Biodegradability" in *Biotechnology and Bioengineering Symposium* No. 10, New York : John Wiley and Sons, Inoculation.

Chang, S. C. (1939) The transformation of phosphorus during the decomposition of plant materials. *Soil Sci.*, **48**: 85-99.

Chang and Jackson (1957) *Soil Sci.*,**84**: 133-144.

Chang, Y. and Hudson, H.J. (1967) *J. Ecol, Studies.Trans. Br. mycol. Soc.*, **50** (4): 649-666.

Chekalov, K. I. (1955) Increasing the quality of organo-mineral fertiliser by composting. *Zemledelie* **3** (7) 56-61 [Connecticut Agril. Exptl. Station Bull. 754, Sept, 1974].

Chendrayan, K.; Adhya, T. K. and Sethuna~~s~~than, N. (1980) *Soil Biol. Biochem*, **12**: 271.

Chen, Y. and Stevenson, F. J. (1986) Soil organic matter interactions with trace elements. In the role of organic matter in modern agriculture. Eds. Chen, Y. Avnimelech Martinus Nijoff, Dordreeht, pp, 73-115.

Cherry, W. J. and Guthrie, R. K. (1979) The science of total environemt, **13**: 27.

Chesnin, L. and Yien, C.H. (1951) *Proc. Soil Sci. Soc. Am.*, **15**: 149.

Chien, S. H.; Clayton, W. R. and McClellan, G. H. (1980) Kinetics of dissolution of phosphate rocks in soil. *Soil Sci. Sco.Am.. J.*,**44**:260-264.

Chien, S. H.; Hammond, L. L.and Leon, L. A. (1987) Long term reactions of phosphate rocks with an oxisol in Colombia. *Soil Sci.*, **144**: 257-265.

Chien, S. H.; Hammond, L.L. (1989) General publication, IFDC-P7, **12** p, ISBN 0-88090-070-9, Musele Shoals, AL, 35662, USA.

Chien, S. H.; Hammond, L. L. (1989) *soils Ferts.*, **52**: 10.

Cole, C. V. and Jackson, M. L. (1950) *J.Phys.Coll.Chem.*, **54**: 128.

Cole, C. V.and Sanford, R. L. Jr. (1989) Biological aspects of the phosphorus cycle. Paper, Symp. 6-10 March, 1989, IRRI, Philippines.

Collison, R. C. and Conn, H. J. (1925) The effect of straw on plant growth. *New York (Geneva) Agriclutural Experiment Station Tech. Bull., 114.*

Connecticut (1974) *Connecticut Agril. Exptl. Station Bull.,* 754, Sept.

Cooke, G. W. (1956) *Emp. J. Exp. Agric.,* **24**: 295-306.

Chhonkar, P. K. and Subba Rao, N. S. (1967) *Can J. Microbiol.,* **13**: 749-753.

Choudhury, M. L. and Mishra, B. (1980) Factors affecting transformation of rock phosphate in soils. *J. Indian Soc. Soil Sci.,* **28**: 295-301.

Cornfield, A. H. (1958) Composting of straw in Small Units. *Plant and Soil,* **10**: 183-193.

Cosgrove, D. J. (1977) *Adv. Microbial Ecol.,* **1**: 95.

Cowling, E. B. (1961) Comparative Biochemistry of the Decay of Sweetgum Sapwood by white-rot and brown-rot fungi. *USDA Forest Service, Technical Bulletin No. 1258.*

Craven, P. A. and Hayasaka, S. s. (1982) *Can. J. Microbiol.,* **28**: 605-610.

Crawford, D. L. and Crawford, R. L. (1980) Microbial degradation of lignin. *Enzyme Microb. Technol.,* **2**: 11-22.

Dalal, R. C.; Oades, J. M. and Lewis, D. G. (1988) Fertilizer effectiveness of acid extracted phosphorus from low grade phosphate rock. *Fertilizer Research,* **17**(2): 165-176 [En, 12 ref. 3 fig., 4 tab.] Waite Agric. Res. Inst., Glen Osmond, SA 5064, Australia.

Dalton, J. D.; Russell, G. C. and Sieling, D. H. (1952) Effect of organic matter on phosphate availability. *Soil Sci,***73**: 173-181.

Das, A. C. and Mukherjee, D. (1988) Decomposition of neem cake and wheat straw in alluvial soil. *Environment and Ecology.,* **6**: 1002-1005.

Das, A. C. and Mukherjee, D. (1989) *Environ. Ecol.,* **7**: 615.

Dash, R. N.; Mohanty, S. K. and Patnaik, S. (1981) *J. Indian Soc. Soil Sci.,* **29**; 559-562.

Davey, C. B. (1953) *Soil Soc.m. Proc.,* **17**: 53-60.

Davis, P. A.; Fitzpatrick, G. E.; Goscicki, E.; Wohlgemuth, G. and Svenson, S. E. (1991) Paper presented at the WPCF 64th Ann. Conf., Toronto. AC91-08-002.

Deacon, J. W. (1985) Decomposition of filter paper cellulose by thermophilic fungi acting singly, in combination, and in sequence. *Trans.Br.Mycol.Soc.,* **85**: 663-670.

Dean, L. A. and Fried, M. (1955) Soil and Fertilizer Phosphorus in Crop Nutrition. Academi Press, New York. **4**: 189-242.

Debnath, N. C. and Hajra, J. N. (1972) Inorganic transformation of added phosphorus in soil in relation to soil characteristics and moisture regime. *J.Indian Soc. Soil Sci.,* **20**: 327-335.

Debnath, N. C. and Basak, R. K. (1986) *J. Indian Soc. Soil Sci.,* **34**: 464-70.

Debnath, A.; Das, A. C. and Mukherjee, D. (1991) *Environ. Ecol.,* **9**: 315.

Debnath, M. and Sinha, N. B. (1993) *Env. Eco.,* **11** (1): 1-6.

Debnath, A.; Das, A. C. and Mukherjee, D. (1994) *Microbiol. Res.,* **149**: 195.

De Dutta, S. K.; Moomaw, J. C.; Racho, V. V. and Simsiman, G. V. (1966) Phosphorus supplying capacity of lowland rice soils. *Proc.Soil, Sci.Soc. Am.,***30**: 613-617.

Desai, M. V.M. and Ganguly, A. K. (1980) Organo-metallic interactions of manganese and other heavy metals in the marine environment; Geology and Geochemistry of Manganese. *Vol. 1* pp 389-410. Publishing House of the Hungarian Academy of Sciences, Budapest.

Deshpande, A. N.; Patil, S. S. and Daftardar, S. Y. (1987) *Indian J. Agric. Chem.,* **15** (3); 163-167.

Dey, B. K. and Goswami, M. (1972) *Indian Agric.,* **16**; 121-28.

De Vleeschauwer, D.; Verdonck, O. and Van Assche, P. (1981) *Biocycle,* **22** (1).

Dhar, N. R.; Bose, S. M. and Gaur, A. C. (1955) Influence of calcium phosphate in composting of organic matter. *Proc. Natl. Acad. Sci. India,* **24** (A) : 473-488.

Dhar, N. R. and Gupta, V. P. (1961) *Proc. Natl. Acad. Sci. India,* **31** (A); 240-245.

Dhar, N. R. and Jaiswal, S. P. (1966) Influence of direct application of organic materials and basic slags on crop yield and soil fertility. Proc. National Academy Sciences India, **36A**: 1017-1022.

Dhillon, K. S. and Dhillon, K. S. (1991) Effect of crop residues and phosphorus levels on yield of groundnut and wheat grown in a rotation. *J. Indian Soc. Soil Sci.,* **39**: 104-108.

Dev, S.P. and Bhardwaj, K. K. R. (1991) Recycling of crop residues for improving crop yields and nitrogen use efficiency in wheat-maize system. *Bioresource Technology,* **37**: 135-139.

Dixit, V. K. and Kishore, N. (1969) Transformation of inorganic sulphur in soils. *Labdev J. Sci. Technol,* **7** B: 251-253.

Donnelly, P. K.; Entry, J. A.; Crawford, D. L. and Cromack, K. Jr. (1990) Microbial. Ecology, **20** (3): 289.

Dox, A. W. and Golden, R. (1911) Phytase in lower fungi. *J.Biol. Chem.,* **10**: 183-186.

Duff, R. B. and Webley, D. M. (1959) *Chem. Ind.,* (Lond.) 1376.

Dye, M. H. and Rothbaum, H. P. (1964) *J. Sci.,* **7**: 97-118.

Elliot, E. T., Horton, K.; Moore, J. C.; Coleman, D. C. and Cole, D. C. (1984) *Plant Soil,* **76**: 149-155.

Ellis, R.; Quader, M. A. Jr. and Truog, E. (1955) Rock phosphate availability as influenced by soil pH. *Proc. Soil Sci. Soc. Am.,* **19**: 484.

Elseewi, A. A. and Page, A.L.(1984) *J. Envir. Qual.,* **13**: 395.

Elserafy, Z. M.; Sonbol, H. A. and Eltanawy, I. M. (1980) The problem of water hyacinth in rivers and canels. I. Production of compost from plants, *Soil Sci. Pl. Nutr.*, **26** (1): 135-138.

Eriksson, K. E. and Lindholm, J. (1971) Ligninets Mikrobiella Nedbrytning. *Svensk Papperstidning*, **74**: 701-706.

Eriksson, K. E. and Kolar, M. C. (1985) Microbial degradation of chlorolignins. *Environ.Sci. Technol.*, **19** : 1086-1089.

Faison, B. D. and Kirk, T. K. (1985) Factors involved in the regulation of a ligninase activity in *Phanerochaete chrysosporium. Applied and Environmental Microbiogy.*,**49**: 299-304.

Fertilizer News, (Sept.,1996) FAI, New Delhi. p-120.

Finstein, M. S. and Morris, M. L. (1975) *Adv. Appl. Microbiol.,* **19**: 113-151.

Flaig, W. (1962) Zur Umwandlung von Lignin in Humusstoffe. Freiberger Forschungshefte. **A-25A**: 39-56.

Forsyth, W. G. C. and Webley, D. M. (1948) The microbiology of composting. II. A study of the aerobic thermophilic bacterial flora developing in grass composts. *Proc.Soc. Appl.Bact.*, **3**: 34-39.

Fox, R. L. and Kaer, B. (1964) *Pl. Soil.*, **20**: 319-30.

French, J. R. J. and Bland, D. E. (1975) Lignin degradation in the termites *Coptotermes lacteus and Nasutitermes exitiosus. Material und organismen.* **10**: 281-288.

Fujio, Y. and Murray Moo - Young. (1980) Isolation of cellulolytic fungi and some properties of isolated fungi for cellulose biodegradation. *J.Gen.Appl.Microbiol.*,**26**: 37-44.

Fujiwara, S.; Kamat, H. and Inoko, A. (1980) *Jl. Soc.Soil and Manure, Japan,* **51**(3): 203-09.

Garcia, C.; Hernandez, T. and Costa, A. (1990) *Soil Sci. Pl. Nutr.* , **36**(2): 243-250

Garcia, C. ; Hernandez, T. and Costa, F. (1991) *Soil Sci. Pl. Nutr.,* **37** (3): 399-408.

Gaur, A. C.; Mathur, R. S. and Varshney, T. N. (1970) Decomposition of different types of added organic matter in soil. *Agroclimatica,* **14**: 524-532.

Gaur, A. C. (1972) Role of phosphate solubilizing microorganisms and organic matter in soil productivity. *Symp. Soil Productivity,* National Academy of Sciences, 259-68.

Gaur, A. C. *et al.,* (1972) Soil structure as influenced by organic matter and inorganic fertilizers. Labdev. *J. Sci. and Technol. India,* IOB, 55-56.

Gaur, A. C.; Subba Rao, R. V. and Sadasivam, K. V. (1973) *Labdeve J.Sci.Tech.* India, 10B,55.

Gaur, A. C.; Madan, M. and Ostwal, K. P. (1973) *Indian J. Exptl. Biol.,* **11**: 427-429.

Gaur, A. C. *et al.,* (1975) Detoxication of lindane by farmyard manure, *Indian J. Agric. Sci.,* **40**: 329-332.

Gaur, A. C.; Sadasivam, K. V.; Magu, S.P. and Mathur, R. S. (1978) Progress Report of AICRP on Microbiological Decomposition and Recycling of Farm and city Wastes. I. A. R. I., New Delhi.

Gaur, A. C. (1979) Phosphate solubilizing micro-organisms increase phosphate nutrition and crop yields. *Krishi Chanekya,* **1**: 7-10.

Gaur, A. C.; Arora, D. and Prakash, N. (1979) *Folia Microbiol.,* **24** : 314-317.

Gaur, A. C and Sachar, S. (1980) *Curr. Sci.,* **49**: 553-54.

Gaur, A. C.; Sadasivam, K. V.; Mathur, R. S. and Magu, S. P. (1980) *Indian J. Agron.,* **25** (3): 501-3. text

Gaur, A. C.; Sadasivam, K. V.; Mathur, R. S. and Magu, S. P. (1981) *Zbl. Bakt.*

Gaur, A. C.; Sadasivam, K. V.; Mathur, R. S. and Magu, S. P. (1981) *Agril, Wastes.* **4**: 273.

Gaur, A. C. (1982) Organic manures and biofertilizers. A review of soil research in India. pp 279-305.

Gaur, A. C. and Gaind, S. (1983) Microbial solubilization of phosphates with particular reference to iron and aluminium phosphate. *Sci. Cult.* **49**: 110-112.

Gaur, A. C.; Neelakantan, S. and Dergan, K. S. (1984) Organic Manures. ICAR, New Delhi. pp. **159**.

Gaur, A. C. (1985a) Phosphate solubilizing microorganisms and their role in plant growth and crop yields. *Proc. Nat. symposium on Soil Biology.* Hissar, 125-38.

Gaur, A. C. (1985b) Phosphate solubilizing bacteria as biofertilizer. *Proc. National Seminar on Development and Use of Biofertilizer.* Min. of Agri., New Delhi.

Gaur, A. C. (1986) Particle size of rock phosphate and microbial solubilization. *Zentralbl Microbiol.,* **14**: 103-105.

Gaur, A. C. (1987) *Resources and conservation,* **13** (2-4): 157-174.

Gaur, A. C. (1990) In Phosphate Solubilizing Microorganisms, Biofertilizers, Omega Sci. Publishers, New Delhi.

Gaur, A. C.; and Mathur, R. S. (1990) Organic manures in soil fertility and fertilizer use IV (Eds. Kumar V. *et al.,*) , IFFCO, New Delhi. 149-159.

Gaur, A. C. (1992) In Fertilser, Organic Manures, Recylable Wastes and Biofertilisers. (Ed. HLS Tandon). FDCO, New Delhi, 36-51.

Gaur, A. C. and Sadasivam, K. V. (1993) In Organics in Soil Health and Crop Production (Ed Pk Thampan), PTCDF, Cochin. 1-22.

Gaur, A. C. and Singh, G. (1995) Recycling of rural and urban wastes through conventional and vermi-composting. In Recycling of Crop, Animal, Human and Industrial Wastes in Agriculture, Ed. H. L. S. Tandon, F. D. C. O. New Delhi.

Gerretsen, F. C. (1948) *Pl. Soil,* **1**: 51-81.

Ghani, A.; Rajan, S. S. S. and Lee, A. (1994). *Soil Biol. Biochem.,* **26** (1): 127-136.

Glathe, H. (1959) Biological press in the composting of refuse International Res. Group on refuse disposal, IGFR Inform. Bull. 7.

Giesey, J. P. (1980) *Microcosms in Ecological Research.* Springfield, Va., Technical Information Center, U. S. Department of Energy. 1110 pp.

Giller, K. and McGrath, S. (1989) *New Scientist*, 4/11/89: 31-32.

Gilman, J. C. (1957) *A manual of soil fungi. 2nd Edn.* Iowa State College Press. 450.

Ginzburg, K. E. (1960) Trudy Pochv. Inst. Dokuchaeva, **55**: 239.

Godert, W. J.; Rein, T. A. and Souza, D. M. G. (1990) *Pesquisa Agropecuaria Brasilerica,* **25** (4): 521-530. [Potassium, Cn, 22 ref] Embrapa/Cepac, Caixa postal 700023, 73300, Planaltina, DF. Brazil.

Goel, B. B.; Singh, K B. and Singh, R. P. (1973) Availability and disposal of dung in India. *Indian J. Anim. Sci.*, **43**: 617.

Goldberg, S. and Sposito, G. (1985) *Soil Sci. Plant Anal.*, **16**: 801-23.

Golden, D. C.; Stewart, R. B.; Tillman, R. W. and White, R. E. (1991a) I Partially acidulated reactive phosphate rock (PAPR) fertilizer and its reactions in soil.
II Mineralogy and morphology of the reaction products. *Fertilizer Research*, **28**(3): 295-304. Lynden B. Johnson Space Centre Houston, TX 77058 USA.

Golden, D. C.; White, R. E.; Tillman, R. W. and Stewart, R. B. (1991 b) Partially acidulated reactive phosphate rock (PAPR) fertilizer and its reaction in soil. Initial movement of dissolved ions and solubility of the phosphate rock residue. *Fertiliser Research*, **28** (3) : 281-293. Dept of Soil Sc., Massey Univ., Palmerston Noth, New Zeeiand.

Golueke, C. G.; Card, B. J. and McGauhey, P. H. (1954) A Critical Evaluation of Inoculums in Composting. *APPL. Microbiol.*, **2**: 45-53.

Golueke, C. G. (1977) Biological reclamation of solid waste (Rodale. Pres. Emmaus. PA. USA).

Gopal, B. (1981) Water hyacinth (*E. Crassipes*), most troublesome weed of the world. Hindasia Publ. , Delhi, p 128.

Gotaas, H. B. (1956) World Health Organization. Monograph Series. **31**, Geneva, 205 p.

Gotoh, S. and Onikura, Y. (1971) Organic acids in a flooded soil receiving added rice straw and their effect on the growth of rice. *Soil Sci. Pl. Nutr.* (Tokyo), **17**: 1-8.

Gowda, T. K. S.; Radhakrishna, D.; Balakrishna, A. N. and Sreenivas, K. N. (1992) Proc. Nat. Seminar Organic Farming, MPKV, Pune. 39-41.

Gray, K. R. and Sherman, K. (1969) Accelerated Composting of Organic Wastes. Birmingham Univ. Chem. Eng., **20** (3); 64-74.

Gray, K. R.; Sherman, K. and Biddlestone, A. J. (1971) A Review of Composting - Part I. Process Biochem., 32-36 pp.

Gray, K. R. and Biddlestone, A. J. (1981) The composting of agricultural wastes. In : Stone house. B. (ed.) *Biological Husbandry- a scientific approach to organic farming.* Butterworths.

Gray, K. *et al.* (1987) FAO *Soils Bulletin,* **56.**

Greaves, M. P.; Anderson, G. and Webley, D. M. (1963) *Nature,* **200**: 1231-32.

Gregg, P. E. H.; Syers, J. K. and Mackay, A. D. (1981) In Proc. Tech. Workshop on Potential of Phosphate Rock as a Direct Application Fertilizer in N. Z. **3**: 4-10.

Grinsted, M. J. ; Hedley, M. J.; White, R. E. and Nye, P. M. (1982) *New Phytol.,* **91**: 19-29.

Guerra, G.; Abin, L. and Herrera, A. (1984) Isolation and characterization of cellulolytic filamentous fungi. *Rev. Cienc. Biol.,* **15**: 17-38.

Gupta, O. P. (1987) Aquatic Weed Management. Today and Tomorrow's Printers and Publishers. 24 B/5 Desh Bandhu Gupta Rd., Karol Bagh, New Delhi, 05.

Guzman, E. C.; Nunezescobar, R. and Martinez Garza, A. (1980) Solubilization of two national rock phosphates with addition of sulphur, nitrogen fertilizer or cattle manure under aerobic and anaerobic fermentation, **41**: 145-164. [Es, en, 13 ref.] Colegio de Postgraduados, Chapingo, Mexico.

Hackett, W. F.; Connors, W. J.; Kirk, T. K. and Zeikus, J. G. (1977) Microbial decomposition of synthetic C-labelled lignins in nature: Lignin degradation in a variety of natural materials. *Applied and Environmental Microbiology,* **33**: 43-51.

Haider, K.; Martin, J. P. and Filip, Zi. (1974) Humus Biochemistry, In *Soil Biochemistry,* **4**: 195-244.

Hajra, J. N.; Bhattacharya, A. K. and Nandi, P. (1974) *Indian Agric.,* **18** (3): 225-233.

Hajra, J. N.; Manna, M. C and Kole, S. C. (1992) *Indian J. Agric. Sci.,* **62**(8): 540-544.

Hajra, J. N.; Sinha, N. B.; Manna, M. C.; Islam, N. and Banerjee, N. C. (1994) Comparative quality of phosphocompost and single superphosphate and response of green gram (Vigna radiata L. Wilczek). *Trop. Agric.* (Trinidad), **71** (2): 147-149.

Halstead, R. L. and Mckercher, R. B. (1975) *Soil Biochemistry,* **4**: 31-63.

Hammond, L. L.; Chien, S. H.and Polo, J. R. (1980) Phosphorus availability from partial acidulation of two phosphate rocks. *Fertilizer Research,* **1** (1): 37-49. [En, 17 ref.] *Agro-Economic and Fertilizer Technology Divisions.* International Fertilizer Development Centre, Muscle Shoals, AL 35660, USA.

Hammond, L. L.; Chien, S. H. and Mokwunye, A. U. (1986) Agronomic value of unacidulated and partially acidulated phosphate rocks indigenous to the tropics. *Adv. Agron.,***40**: 89-140.

Harada, Y ; Inoko, A. (1980) *Soil Sci. Plant Nutr.,***26**: 127-34.

Harada, Y.; Inoko, A.; Tadaki, M. and Izawa, T. (1981) *Soil Sci. Plant Nutr.,***27**: 357-64.

Hart, M. G. R. (1959) Sulphur oxidation in tidal Mangrove soils of sierra Leone. *Pl.Soil,* **9**: 215-236.

Haug, R. T. (1993) The Practical Handbook of Compost Engineering. Lewis Publishers. Boca Raton, Ann Arbor, London, Tokyo.

Hayman, D. S. (1975) *Soil Microbiology,* (Wlker. N. ed), Butler-Worths, London, 67-91.

Hemwell, J. B. (1957) The fixation of phosphorus by soils. *Adv. Agron.,* **9**: 95-112.

Hesse, P. R. (1957c) *Analyst,* **82**; 710.

Hesse,. P. R. and Mishra, R. V. (1982) Field Doc. No. **14** RAS/75/004 FAO.UNDP, Rome.

Hingston, F. J.; Posner, A. M. and Quirk, J. P. (1974) *J. Soil Sci.,* **25**: 16.

Hong, J. H.; Matusda, J. and Ikeuchi, Y. (1983) *Am. Soc. Agri. Engrs.,* **26** (2): 533-41.

Hudson, C. and Headley, Q. (1990) Composts as soil ameliorants. In Proceedings - Annual Conference, Barbados Society of Technologists in Agriculture. Christ Church, B.S.T.A., 35-37.

Hughes, J. C. and Gilkes, R. J. (1984) *Aust. J. Soil Res.,* **22**: 475-481.

Hughes, J. C. and Gilkes, R. J. (1986) *Aust. J. Soil Res.,* **24**: 219-227.

Hundal, H. S. and Arora, B. R. (1988) Efficiency of Mussoorie rock phosphate as a source of P for gram and lentil. *Indian. J. of Ecology,* **15** (2): 133-136.

Hurst, H. M. and Wagner, G. H. (1969) *Soil Sci. Soc. Amer. Proc.,* **33**: 707.

Hussein, Y. A.; Shalan, S. N.; Abd-El-Wahab, S. M. and Hassan, M. E. (1989a) The degradation of lignin by blue green algae. *Phyton (Buenos Aires)* **49** (1/2): 1-4.

Hussein, Y. A.; Shalan, S. N.; Abd-El-Wahab, S. M. and Hassan, M. E. (1989b) The specific degradation of lignin by blue green algae. *Phyton (Buenos Aires).* **49** (1/2): 13-15.

Inoko, A.; Harada, Y. and Sugahara, K. (1982) Agricultural use of municipal refuse compost with special reference to the degree of maturity. *Bull. Natl. Inst. Agric. Sci., Jpn. Ser. B.,* **33**; 165-213.

Inbar, Y.; Hadar, Y. and Chen, Y. (1993) *Journal of Environmental Quality,* **22** (4): 857-863.

Ibrahim, A. N. and Abdel-Aziz, I. M. (1977) Solubilization of rock phosphate by *Streptomyces. Agrokemia es Talaitan.* **26**: 424-434. *Soils & Fert.,* (1978). **41**: 5769.

Jackson, M. L. (1967) In: *Soil Chemical Analysis,* Prentice Hall of India Pvt. Ltd., New Delhi, 498.

Jadhav, B. R.; Bhanvase, D. B.; Rasal, P. H. and Patil, P. L. (1992) Studies on composting of unchopped sugrcane trash by different methods and its evalution on whet. Proc. Nat. Seminar on Organic Farming, M. P. K. V.; Pune: 69-70.

Jagadeesh, K. M. and Lakshminarayana, C. S. (1971) Eradication and utilization of water hyacinth - A review. *Curr. Sci.*, **40** (7): 148-149.

Jain, M. C. and Kumar, S. (1995) Recycling of Animal Wastes in Agriculture in Recycling of Crop, Animal, Human and Industrial Wastes in Agriculture, Ed. H.L.S.Tandon, pp. **5**.

Jeris, J. S. and Regan, R. W. (1973) *Compost Sci.*, **14** (1): 10-15.

Jhingram, I. G. and Chowdhuri, R. I. (1977) *Fert. News*, **22**: 56-62.

John, M. K. (1970) Colorimetric determination of phosphorus in soil and plant materials. *Soil Sci.*, **109**: 214-220.

Johnston, H. W. (1956) Chelation between calcium and organic anions. *New Zealand J. Sci. Technol.*, **37**: 522-537.

Johnston, A. F. (1986) *Soil Use Mngt.*, **2**: 97-105.

Kafkafi, V.; Posner, A. M. and Quirk, J. P. (1967) *Soil Sci. Soc. Amer. Proc.*, **31**: 348.

Kaila, A, (1949) Biological absorption of phosphorus. *Soil Sci.*, **68**: 279-289.

Kakezawa, M.; Minura, A. and Takahara, Y. (1992) *Soil Sci. Pl. Nutr.*, **6** (1): 43-50.

Kanabo, I. A. K. and Gilkes, R. J.(1987) The role of soil pH in the dissolution of phosphate rock fertilizers. *Fert. Res.*, **12**: 165-173.

Kanabo, I. A. K. and Gilkes, R. J.(1988) *Aust. J. Soil Res.*, **25**: 313-22.

Kane, B. E and Mullins, J. T. (1973) Thermophillic fungi in a municipal waste compost system. Mycologia, **65**: 1087-1100.

Kanmire, K. K. and Sonar, K. R. (1979) Mineralization of urea-N with neem (Azadirachta indica Juss.) and Karanj (Pongamia glabry vent.) cakes, *J. Mau.*, **4**: 10-13.

Kanwar, J. S.; Goswami, N. N. and Kamath, M. B.(1982) Phosphorus management of Indian soils - problems and prospects. *Fert. News.* 12th International Cong. Soil Sci. , 1982: 43-52.

Kaplan, David, L. and Roy Hartenstein. (1980) Decomposition of lignins by microorganisms. *Soil Biol. Biochem.,* **12**: 65-76.

Kapoor, K. K.; Yadav, K. S.; Singh, D. P.; Mishra, M. M. and Tauro, P. (1983) Enrichment of Compost by *Azotobacter* and phosphate solubilizing microorganisms. *Agril. Wastes,* **5**(3): 125-133.

Kapoor, K. K.; Mishra, M. M.; Malik, R. S. and Banger, K. C., (1991) *Environ. Ecol.,*
9: 635.

Katyal, J. C. *et al.* (1979) The micronutrient problems in agriculture. India/FAO/Norway Seminar on Micronutrients in Agriculture, New Delhi.

name the aut

Kayhanian, M. and Tchobanoglous, G. (1992) "Computation of C/N Ratios for Various Organic Fractions," *Bio Cycle,* **33** (5).

Kelly, J. B. and Midgley, A. R. (1943) *Soil Sci.,* **55** : 167-176.

Kene, D. R.; Lanjenwar, S. A.; Ingole, B. M. and Chaphale, S. D. (1991) *J. Soils and Crops.,* **1** (1): 11-18.

Khaleel, R.; Reddy, K. R. and Overcash, M. R. (1981) Changes in soil physical properties due to orgnic waste applications: a review. *J. of Env. Quality.* **10**(2): 133-141. [En, Review, 50 ref.] Dept. of Hydrol., New Mexico Inst. of Mining and Technol., Socorro, New Mexico USA.

Khan, J. A. and Bhatnagar, R. M. (1977) Studies on solubilization of insoluble phosphates by microrganisms. Part I. Solubilization of Indian phosphate rocks by *Aspergillus niger* and *Penicillium* sp. *Fert. Technol.,* **14**: 329-333.

Khanna, S. S.; Pathak, A. K. and Saxena, S. N. (1982) In Review of Soil Research in India. Indian Soc. Soil. Sci., New Delhi, India, pp.323-330.

Khasawneh, F. E. and Doll, E. C. (1978) The use of phosphate rock for direct application to soils. *Adv.Agron.,* **30**: 159-206.

Kirk, T. K.; Connors, W. J and Zeikus, J. G. (1977) Advances in understanding the microbiological degradation of lignin, *Recent Adv. Phytochem*, **11**: 369-394.

Kirk, T. K.; Yang, H. H. and Keyser, P. (1978) The chemistry and physiology of fungal degradation of lignin. *Dev. Ind. Microbiol.*, **19**: 51-61

Kirk, T. K.; Higuchi, T. and Chang, H. M. (1980) Lignin Biodegradation: Summary and Perspectives. In Lignin Biodegradation, ed. T. K. Kirk, T. Higuchi and H. M.Chang. **2** (16): 235-243. CRC Press, Boca Raton, FL.

Kittams, H. A. and Attoe, O. J. (1965) Availability of phosphorus in rock phosphate sulfur fusion. *Agron. J.*, **57**:331-334.

Kleyn, J. G. and Wetzler, T. F. (1981) The microbiology of spent mushroom compost and its dust. *Canadian Jl. of Microbiol.*, **27** (8): 748-53.

Knapp, E. B.; Elliot, L. F. and Campbell, G. S. (1983) *Soil Biol. Biochem.*, **15** (3): 319-323.

Knapp, J. S. (1985) In Robinson, C. W. and J. A. Howell. eds. Comprehensive Biotechnology. **4**: 835-846.

Kochtitzky, O. W.; Seanan, W. K. and Wiley, J. S. (1969). *Compost Sci.*, **9** (4): 5-16.

Kondap, S. N.; Yogeswara Rao, Y.; Mirza, W. A.; Ramachandra Rao, H. and Srirama Raju, K. (1981) Proc.-8th Asian-Pacific Weed *Sci. Soc. Conf.*

Konishi, S.; Wakazawa, H.; Aoyama, J.; Nakamura, M. and Yamashita, H. (1986) A new method for testing the degree of compost maturity using pollen tube culture (Part 1)_Method and characteristics. *Jpn. J. Soil Sci. Plant Nutr.*, **57**: 456-461.

Korovkin, M. A. (1952) The utilisation of rock phosphate flour for organo-mineral composts. *Soviet Agron.*, **10** (2) : 57-60.

Kubat, J.; Novak, B. and Kalinov, S. (1987) *Soils Fert.*, 1988, **51**: 6601.

Kumar, P. and Mishra, B. (1986) Dissolution pattern of Indian rock phosphate in acid soils. *J. Indian Soc. Soil Sci.*, **34**: 611-613.

Kyle, J. H.; Posner, A. M. and Quirk, J. P. (1975) *J. Soil Sci.*, **26**: 32.

Ladatko, A. C. and Shkarin, B. I. (1979) The decomposition of rice straw labelled with 14 C in Flooded soils. *Izvestiya Selskokhzyaistvennoi Akademii,* **5**: 73-78.

Lal, S. and Mathur, B. S. (1988) Effect of long term manuring, fertilization and timing on crop yield and some physicochemical properties of acid soil. *J.Indian Soc.Soil Sci.,* **36**: 113.

Lal, J. K.; Mishra, B. and Sarkar, A. K. (1996) *J. Indian Soc. Soil Sci.,* **44** (1): 77-80. text

Lambert, E. B. (1931) *Journal Agro, Research,* **48**: 971-980.

Langguth, R. P.; Brautigam, G. F.Jr. and Loveless, L. E. (1957) A soil-column study to compare the chemical avaiability and movement of phosphates from liquid and dry fertilizers. *Soil Sci.Soc.Amer. Proc.,* **21** : 416-9.

Larsen, J. E.; Warren, G. G. and Langston, R. (1959) *Soil Sci. Soc. Am. Proc.,* **23**: 438-40.

Lauw, H. A. and Webley, D. M. (1958) *Nature,* **182**: 1317-18.

Lee, H. (1955) *Biochemistry of Autotrophic Bacteria.* Butteworths Scientific Publication, London.

Lehr, J. R. and McClellan, G. H. (1972) Natural Fert. Div. Cent. Bull. Y. 43, TVA, Muscle Shoals, Ala.

Li, P. and Caldwell, A. C. (1966) The oxidation of elemental sulphur in soil. *Soil Sci. Soc. Am. Proc.,* **30**: 370-372.

Lossin, R. D. (1971) Compost Studies, Part III: Disposing of animal wastes, measurement of the chemical oxygen demand of compost. *Compost Sci.,* (March/April).

Luthra, K. L.; Saha, S. K. and Awasthi, P. K. (1983) *Indian J. Agric. Chem.,* **15**:13.

Lynch, J. M. (1976) Products of soil micro-orgnisms in relation to plant growth. *CRC Crit. Rev. Microbiol.,* **5**: 67-107.

Lynch, J. M. (1978) Production and phytotoxicity of acetic acid in anaerobic soils containing plant residues. *Soil Biol. Biochem.,* **10**: 131-135.

Mackay, A. D. and Syers, J. K. (1986) Effect of phosphate, Calcium and pH on the dissolution of a phosphate rock in soil. *Fert. Res.*, **10**:175- 184

Manjaiah, K. M.; Ganeshamurthy, A. N. and Subba Rao, A. (1996) *J. Indian Soc. Soil Sci.*, **44** (2): 275-78.

Mahr, N. H. and Kaindle, K. (1959) *Agrochemica*, **3**: 270.

Manna, M.C.; Kole, S. C. and Hajr, J. N. (1989) *Indian Agric.*,**33** (4): 193-8.

Marwaha, B. C. (1989) *Fert. News*, **34** (3): 23-29.

Mathur, B. S. (1980) Use of indegenous rock phosphate as a source of phosphate for acidic soils of Chotanagpur plateau, Bihar, *Proc. Symp.* on Incresing Productivity of Acid Soils in the Eastern Region. FAI (ER), Calcutta. 63-67.

[illegible]

Mathur, B. S. and Debnath, D. (1980) Studies on increased efficiency of compost through charging it with MPR. In: organic manures (Gaur, A. C., S. Neelakantha and K. S. Dargn) ICAR, New Delhi **159**.

Mahapatra, I. C. and Patrick, W. H. Jr. (1969) Inorganic phosphate transformation in water logged soils. *Soil Sci.*, **107**: 281-288.

Mahapatra, I. C. and Patrick, W. H. Jr. (1971) Evaluation of phosphate fertility in waterlogged soils. *Int. Symp. Soil.Fert.Eval. Proc.*, **1**: 53-61.

Maiti, S. S.; Mukhopadhyay, M.; Gupta, S. K. and Banerjee, S. K.(1990) Evaluation of Fly Ash as a Useful Material in Agriculture. *Indin Soc. Soil Sci.*, **38**: 342-344.

Mandal, L. N. and Khan, S. K. (1972) Release of phosphorus from insoluble phosphatic materials in acidic lowland rice soils. *J. Indian Soc.Soil Sci.*, **20** : 19-25.

Manna, M. C. and Hajra, J. N. (1996) *J. Indian Soc. Soil Sci.*, **44** (3): 526-28. text of the article.

Mantoura, R. F. C.; Dickson A. and Riley, J. P. (1978) The complexation of metals with humic materials in natural waters. *Estura. Coast. Mar. Sci.*, **6**: 387-408.

Martin, J. P. and Haider, K.(1976) Decomposition of specifically ^{14}C-labelled ferulic acid: Free and linked into model humic acid type polymers. *Soil Sci. Soc. of Am. Jl.,* **40**: 377-380.

Marwaha, B. C.; Kanwar, B. S. and Tripathi, B.R.(1981) Direct and residual effect of Mussoorie rock phosphate related to the crop species in an acid soil. *J.Indian Soc. Soil.Sci.,* **29**: 349.

Marwaha, B. C. (1983) *J. Indian Soc. Soil Sci.,* **31**: 539-44.

Mas, M. (1984) Synergism in the vitro cellulolytic capacity among micro-organisms isolated from straw. *Microbiol. ESP.,* **37**: 69-72.

Mathur, B. S.; Sarkar, A. K. and Mishra, B. (1980) Release of nitrogen and phosphate from compost charged with rock phosphate. *J. Indian Soc. Soil Sci.,* **28** (2): 206-212.

Mathur, B. S. and Debnath, D. (1983) *J. Indian Soc. Soil Sci.,* **31**: 545-548.

Mayer, L. and Konig, E. (1960). *Landw. For. Sch.,* **13**: 7-24 (Cited in Wani, P. A.; 1980).

McClellan, G. H. and Gremillion, L. R. (1980) In Khasawneh *et al.*.(eds). The Role of Phosphorus in Agriculture. Soil Sci. Soc. Am., pp 43-80.

McGauhey, P. H. and Gotaas, H. G. (1953) Stabilisation of municipal refuse by composting. Trans. Am. Soc. Civil Eng. Paper No. 2767.

McGeorge, W. T. and Breazeale, E. L. (1955) The value of pyrite and pyrrhotite as soil conditioner. *Rep. Agric. Exp. Sta.* Univ. Arizona, Tucson, **12**.

McGregor, S. T.; Miller, F. C.; Psarianos, K. M. and Finstein, M. S. (1981) *Appl. Env. Microbiol.,* **1** (6): 1321-1330.

Mckay, A. D. and Wewala, G. S. (1990) *Fertilizer Research.***21**: 149-156.

Mclean, E. O. and Wheeler, R. W. (1964) *Soi Sci.Soc. Am. Proc.,* **28.** 545-550

Mclean and Wheeler (1964) as quoted in Adv. in Agron. (1978) vol **30**: 202.

Mehadi, A. A. and Taylor, R. W. (1988) *Soil Sci. Soc. Am. J.,* **52**: 627-32.

Mehltretter, C. L.; Alexander, B. H. and Rest, C. E. (1953) Sequestration by sugar acids. *Industr. Engng. Chem.*,**45**: 2782.

Mehta, D. (1995) Urban Waste Management: Future Prospects. Survey of the Environment, *The Hindu.*

Menon, M. P.; Sajwan, K. S.; Ghuman, G. S.; James, J. and Chandra, K. (1993) Fly ash amended compost as a manure for agricultural crops. *J. Env. Sci. & Health. Part A Env. Sci. and Engg.*, **28**(9): 2167-3182.

Metson, A. J. (1961) *N. Z. C. S. I. R. Soils Bull. No.*, **12.**

Metwally, S. Y. and Pollard, A. G. (1959) The influence of organic matter on the uptake of phosphorus from calcareous soils by barley. *Sci. J. Roy. Coll. Sci.*, **27**: 46-51.

Midgley, A. R. and Dunklee, D. E. (1945) *Vt. Agric. Exp. Stn. Bull.*, **625**: 1-22.

Mishra, B. and Srivastava, L. L. (1981) *J. Indian Soc. Soil Sci.*, **29**: 140-141.

Mishra, B.; Kumar, P. and Dwivedi, G. K. (1985) *J. Indian Soc. Soil Sci.*, **33**:574.

Mishra, M. M.; Singh, C. P.; Kapoor, K. K. and Jain, M. K. (1979) Degradation of lignocellulosic material and humus formation by fungi *Annales de Microbiologie.* **130A** (4): 481-486.

Mishra, M. M.; Kapoor, K. K. and Yadav, K. S. (1982) Preparation of P-enriched compost with rock phosphate and its effect on crop yield. *Indian J. Agril. Sci.*, **52**: 674-678.

More, S. D. and Ghonsikar, C. P. (1988) *J. Indian Soc. Soil Sci.*, **36**: 372-74.

Mortensen, J. L. (1963) Complexing of metals by soil organic matter. *Soil Sci. Soc. Am. Proc.*, **27**: 179-186.

Mukherjee, D and Gaur, A. C. (1980) A study on the influence of straw incorporation on soil organic matter maintenance, nutrient release and asymbiotic nitrogen fixation. Zbl. Bakt. II Abt.,**135**: 663-668.

Mukherjee, D.; Ghosh, S. K. and Das. A. C. (1990) *Indian Agric.*, **34** (1):1-10.

Mukherjee, D.; Mitra, S. and Das, A. C. (1991). *J. Indian Soc. Soil Sci.*, **39**: 457-62.

Mukherjee, S. (1982) In: M.Sc. (Ag.) thesis B. C. K. V., Mohanpur, India.

Muljadi, D.; Posner, A. M. and Quirk, J. P. (1966) *J. Soil Sci.,* **17**:212.

Nagar, B. R. (1981) Energy Crisis, Food Crisis, Desertification and Organic Recycling. *Journal of Scientific and Industrial Research.* **40**: 147-153.

Nagarajan, R.; Ramaswamy, K.; Savithri, P. and Manickam, T. S. (1990). Coir Waste in crop production. Bulletin TNAU Coimbatore.

Nass, M. M.; Lexmond, T. M.; Beusichem, M. L. Van and Janssen - Jurkovicova, M. (1993) Long term supply and uptake by plants of elements from coal fly ash. Communication in *Soil Science and Plant Analysis,* **24**: (9-10) 899-913.

N' Dayegaamiye, A. and Isfan, D. (1991) Chemical and biological chnges in compost of wood shavings, sawdust and peat moss. *Cnadian Journal,* **71**(4): 475-484.

Nor, Y. M. and Tabatabai, M. A. (1977) Oxidation of elemental sulfur in soils. *Soil Sci. Soc.Am. J.,* **41**: 736-741.

Norman, A. G. (1934) *Ann. Applied Biol.* **21**: 454 - 475. [Introduction to soil microbiology. Alexander, M. (1961), Wiley Eastern Limited, New Delhi, pp. 188-190]

Nuntagij, A.; Lassus, C. De; Sayag, D. and Andre, L. (1989) *Biological Wastes,* **29** (1): 43-61.

Oberman, Helena and Helena Stobinska, (1987) Cellulose utilization ability in *Trichosporon cutaneum. Acta. Aliment Poe.,***13**: 149-159.

Olds, J. (1968) Houston Compost Plant, Second Year Report. *Compost Sci.,* **9**(1): 18-19.

Olsen, S. R.; Cole, C. V.; Watanable, F. S. and Dean, L. A. (1954) Estimation of available phosphorus in soils by extraction with sodiumbicarbonate. *U.S.Dept. Agr.Cir.,* 939.

Pareek, R. P. and Gaur, A. C. (1973) Release of phosphate from tricalcium phosphates by organic acids. *Curr. Sci.,* **42**: 278-279.

Parfitt, R. L.; Fraser, A. R.; Russell, J. D. and Farmer, V. C. (1977) *J. Soil Sci.,* **28:** 40.

Parr, J. F. and Papendick, R. I. (1978). In: Crop Residue Management System. (W.R. Oschwald, Ed.). pp. 109-209. American Society of Agronomy Special Publication **31**, Madison, Wisconsin.

Parr, J. F.; Willson, G. B. and Colacicco, D. (1982) *FAO Soils Pollution,* **45**: 52-65.

Parra, J. V. and Hortenstine, C.C. (1974) *Hyacinth control Journal,* **12** : 85-90.

Patel, J. J. and Bhandari, S. C. (1992) Release of nutrients from rockphosphate and pyrites applied in conjugation with FYM and phosphate solubilizing bacteria. *Proc. Int. Symp. Nutrient Management. Sustained Productivity,* Ludhiana, **2**: 157-158.

Pathak, H.; Kalra, N.; Sharma, S. and Joshi, H.C.(1996) Use of fly ash in agriculture potentialities and constraints. *Yojana,* **40** (6); 24.

Patil, R. G. and Sarkar, M. C. (1993) Mineralisation and immobilisation of nitrogen mixed with wheat straw. *J.Indian Soc. Soil Sci.,* **41**: 33-37.

Patnaik, S. (1988) Reactivity of Indian phosphate rocks in relation to crystal chemical structure of their apatites. *J. Indian Soc. Soil Sci.,* **36**: 619-635.

Patrick, Z. A., Toussoun, T. A. and Synder, W. C. (1963) Phytotoxic substances in arable soils associated with decomposition of plant residues. *Phytopathology,* **53**: 152-161.

Person, H. L. and Shayya, W. H. (1993) *American Society of Agricultural Engineers,* **93-4030**: 16.

Pierre, W. H. (1938) Phosphorus deficiency and soil fertility. Soils and Men. *Year book of Agric. USDA,* Washington, D. C., 377-96.

Pitchel, J. R. and Hayes, J. M. (1990) *J.Envir. Qual.,***19**: 593.

Pikovskaia, R. I. (1948) Mobilization of phosphates in soil in connection with vital activity of some microbial species. *Microbiologiya,* **17**: 362-370.

Poddar, K.; Mandal, L. and Banerjee, G. C. (1991) *Indian Veterinary Journal,* **68** (9): 833-837.

Polprasert, C.; Wangsuphachert, S and Multamar, S. (1980) Compost Science/Land utilization, **21** (2): 25-27, Asian Inst. of Tech. P. O. Box - 2754, Bangkok, Thailand.

PPCL (1987) Mussoorie-Phos-A Natl. Phosphatic Fert. for Direct Application. Pyrites Phosphates & Chemicals Ltd., New Delhi.

Pramer, D. and Schimidt, E. L. (1965) Experimental soil microbiology. Burgess Publishing Co., Minnesota, USA.

Prasad, R. A. and Singhania, R. A. (1989) Effect of different types of Enriched Manures and time of incubation on soil proportion. *J. Indian Soc. Soil Sci.,* **37**: 319-322.

Prihar, S. S.; Verma, K. S. and Bhajan Singh. (1972) Indian J. Agron.,**17** 344-47.

Quin, B. F. (1981) Proc. Tech. Workshop on the potential of Phosphate Rock as a Direct Application Fertilizer in New Zealand, **3**: 13-20.

Rabindra, B.; Bhaskara Rao, Y. and Gowda, S. (1986) Rock phosphate as a source of phosphorus in saline soil. *Proc. Natn. Sem. Rockphosphate in Agriculture, TNAU-PPCL Coimbatore,* 1985, P-148.

Raheja, P. C. (1966) Phosphate in crop production. *In Soil Productivity and Crop Growth.* Asia Publishing House, 152-204.

Raij, B. Van. and Diest, A.Van. (1980) Phosphate supplying power of rock phosphates in an oxisol. *Plants Soil*, **55**: 97-104.

Rajagopal, G. K. and Idnani, M. A. (1963) Some aspects of phosphorus fertilisation in Nilgiri soils. *J. Indian Soc. Soil Sci.,* **II**: 141-150.

Rajan, S. S. S (1975a) *N. Z. J. Agric. Sci.,* **18**: 93-101.

Rajan, S. S. S (1975b) *Nature,* **253**: 434-36.

Rajan, S. S. S (1975c) *J. Soil Sci.,* **26**: 250-56.

Rajan, S. S. S (1982) *Fert. Res.,* **3**: 3-12.

Rajan, S. S. S (1983) *Fert, Res.,* **4**: 287-96.

Rajan, S. S. S (1986) *Fertilizer Research*,**4**: 287-296.

Rajan, S. S. S. and Edge, E. A. (1980) *Fertilizer Research,* **11**: 43-60.

Rajan, S. S. S. and Fox, R. L. (1975) *Soils Sci. Soc. Am. Proc.,* **39**: 846-51.

Rajan, S. S. S. and Watkinson, J.H. (1993) *Fertilizer Res.,* **33**: 267-77.

Randhawa, N. S. (1981) Maintenance of soil fertility through organic manures. *Indian J. Agric. Chem.,***14**: 1-200.

Ranganathan, C. R.; Chari, K. S.; Subramaniam, J. B. and Sivashankaran (1970) *Fertiliser News,* **15**(3): 36-39.

Rao, D. N. and Mikkelson, D. S. (1977) Effect of rice straw additions on production of orgnic acid in a flooded soil. *Plant and Soil,* **47**: 303-311.

Rao, A. S. and Ghosh, A. B. (1981) Effect of continuous cropping and fertilizer use on the org. nitrogen fractions in a Typic Ustochrept soil,plant and soil, **62** (3): 377-383. [En, 18ref.] *Div of Soil Sci. & Agricultural Chem.,* IARI, New Delhi 110012, India.

Rastogi, R. C.; Mishra, B. and Ghildyal, B.P. (1976) Effect of pyrites and organic matter on release of phosphorus from rock phosphate. *J.Indian Soc. Soil. Sci.,***24**: 175-181.

Rastogi, R. C.; Mishra, B. and Ghildyal, B. P. (1977) *J. Resepectively, Panthanagar.* **2** 261.

Reid, I. D. and Seifert, K. A. (1982) Effect of an atmosphere of oxygen on growth, respiration and lignin degradation of white rot fungi. *Can. Jl. of Botany,* **60**: 252-260.

Rekki, R. S. and Meelu, O. P. (1983) Effect of complementary use of mung straw and inorganic fertilizer nitrogen on the nitrogen availability and yield of rice *Oryza,* **20**: 125-129.

Ricker, A. J. and Ricker, R. S. (1936) Introduction to research on plant diseases. John, S. Swift Co., St.Loius.

Rohrman, F. A. (1971) *Power,* **115** (8): 76.

Rothbaum, H. P. (1963) *J. Appl. Chem.,* **13**: 291-302.

Roy, R. N. and Kanwar, J. S. (1979) *Fert. News,* **24** (6): 12-25.

Roy, G. K. (1989) Biogas from Solid Waste. Science Reporter, June: 267-271.

Roy Mahapatra, S. S.; Mishra, A. K. and Chandra, D. (1985) Solubilizaion of rock phosphate by *Thiobacillus ferroxidans. Curr. Sci.,* **54**: 235-237.

Russell, E. W. (1961) Soil Conditions and Plant Growth. The English Language Book Society and Longmans Green and Co. Ltd., London.

Ryden, J. C.; McLaughlin, J. R. and Syers, J. K. (1977) *J. Soil Sci.,* **28**; 62,72,585.

Sadasivam, K. V.; Mathur, R. S. ; Magu, S. P. and Gaur, A. C. (1981) Enrichment of compost by *Azotobacter* and phosphate solubilizer. *Zbl. Bakl. II Abt.,* **136**: 628-630.

Saha, S. K.; Shankar, J. and De, S. K. (1981) Effect of fertilizers and green manure on soil amino sugar. *Allahabadi Egyetem, Agrokemiai Tanszek,* Allahabad, India. **30**: 79-82.

Salih, H. M.; Yahya, A. I.; Abdul-Rahem, A. M. and Munam, B. H. (1989) *Pl. Soil.,* **120**: 181-85.

Sanford, R. L. , Jr.; Parton, W. J. and Cole, C. V. (1989) In H. Tiessen (ed.). Phosphorus Cycles in Terrestrial and Aquatic Ecosystem, Regional Workshop 1. Eurorpe. pp 30-41.

Sanyal, S. K. and De Dutta, S. (1991) Chemistry of P-transformations in soil. *Adv.Soil Sci.,* **16**: 1-120.

Sanyal, S. K. and De Dutta, S. K. and Chan, P. Y. (1993) *Soil Sci. Soc. Am. J.,* **57**: 937-45.

Sarkanen, K. V. (1971) Precursors and their polymerization. In Lignins: Occurance, Formation, Structure and Reactions (K.V.Sarkanen and C.H.Ludwig, Eds.). PP. 95-164. Wiley, New York.

Sarkar, S.; Rathore, T. R. and Sachar, R. S. (1991) Influence of wheat straw on the yield of rice and ammonium and nitrate contents of a soil. *J. Indian Soc. Soil Sci.,* **39**: 377-379.

Sattar, M. A. and Gaur, A. C. (1986) Dissolution of rock phosphate by rhizosphere microorganisms isolated from Bangladesh soils. *Bangladesh J. Agric.*, **11**: 27-34.

Schnitzer, M. and Khan, S. U. (1972) *Humic Substances in the Environment*, Dekker, New York.

Schubert, W. J. (1968) In M. Florkin and E. H. Stutz, eds, *Comprehensive Biochemistry*. Elsevier Publishing Co., Amsterdam, **20**: 193-230.

Schulze, K. L. (1962) Continuous Thermophilic composting. *Appl. Microbiol.*, **10**: 108-122.

Schulze, K. (1961) Aerobic Decomposition of Organic Waste Materials, (Continuous Thermophilic Composting), Final Report Project RG-4180.

Sen, S. and Bains, S. S. (1955) Effect of farm yard manure and superphosphate on berseem yield, nodulation and on nitrogen and available phosphorus content of the soil. *J. Indian Soc. Soil Sci.*, **3**: 41-49.

Senn, C. L. (1971) Dairy Waste Management Project-Final Report. University of California Agricultural Extension Service, Public Health Foundation of Los Angeles County.

Seppan, W. E. (1966) Report on the development and production of pyrites in India. USAID. *New Delhi.*

Sethi, R. P. and Subba Rao, N. S. (1968) *J. Gen. Appl. Microbiol.*, **14**: 329-331.

Slankis, V.; Runekles, V. C. and Krotkov. G. (1964) *Physiol. Potassium.*, **17**: 30.

Sharma, V. K. and Kamath, M. B. (1991) Phosphate utilisation by soyabean from Udaipur rockphosphate amended with microbial cultures, pyrite, biogas slurry and single superphosphate. *Fertil. News*,**36** (8): 31-37.

Sharma, S. K.; Harit, R. C.; Kumar, V.; Vatsa, B. K. and Kalra, N. (1996) Environmental issue associated with coal ash. Employment News, xxi (45): **1**

Shell, G. L. and Byod, J. L. (1969) Composting dewatered sewage sludge. Public Health Service Publication No. 1936, U. S. Department of Health.

Shinde, D. A. and Ghosh, A. B. (1973) as cited in Chattopadhyay *et al.* (1986) *Indian Agric.*, **30** (1): 39-47.

Sibananda, H. M. Young, S. D. (1986) *J. Soil Sci.*, **37**: 197-204.

Simpson, F. J. (1954) *Canad. J. Microbiol.*, **1**: 131-139. Introduction to soil microbiology. Alexander, M. (1961). Wiley Eastern Limited, New Delhi. P. 189.

Sinden, J. W. (1938) *Penn. Agric. Expt. Sta. Bull.,365* **27** p.

Singaram, P. and Kamalakumari, K. (1995) Long Term Effect of FYM and Fertilizers on Enzyme Dynamics of Soil, *J.Indian Soc. Soil Sci.*, **43** (3): 378-381.

Singh, C. P.; Ruhal, D. S. and Singh, M. (1983) Solubilisation of low grade rock phosphate by composting with paddy straw as farm waste. *Indian J. Microbiol.*, **23** (3):164-168.

Singh, C. P. (1987) Preparation of high grade compost by an enrichment technique. I Effect of enrichment on Organic matter decomposition. *Biological Agriculture and Horticulture.* **5**(1): 41-49.

Singh, C. P. and Amberger, A. (1990) Humic substances in straw compost with rock phosphate. *Biological Wastes* **31** (3): 165-174. (En. 20 ref.) Inst. Plant Nutrition. Tech. Univ. Munich, 8050 Freising Weihenstephan GFR.

Singh, D.; Mannikar, N. D. and Srinivas, N. C (1979) Efficiency of indigenous rock phosphates as influenced by pyrite:Laboratory studies. *J.Indian Soc. Soil Sci.*,**27**:334-337.

Singh , G. P.; Beri, V and Sidhu, B. S. (1995) Humification of rice and wheat residues in soil. *J. Indian Soc. Soil Sci.*, **43** (1): 17-20.

Singh, H. P.; Pareek, R. P. and Singh, T. A. (1984) Solubilization of rock phosphate by phosphate solubilizer in broth. *Curr. Sci.*,**53** : 1212-13.

Singh, H. and Mishra, B. (1986) Kinetics of pyrite oxidation in relation to solubilization of rock phosphate in a neutral soil. *J. Indian Soc. Soil Sci.*,**34**: 52-55.

Singh, K. D. N.; Rai, Y.; Singh, D. and Prasad, C. R. (1988) Relative performance of rock phosphate as compared to super phosphate in an amended calcareous saline-sodic soil. *J. Indian Soc. Soil Sci.*, **36**; 733-738.

Singh, M. (1991) *J. Indian Soc. Soil Sci.*, **39**: 811-13.

Singh, N. T.; Hira, G. S. and Singh, R. (1978) Comparative effect of pyrites and gypsum on physico-chemical properties of a sodic soil. *Proc.* FAI-PPCL-DAUP *Sem. on Use of Sedimentary Pyrites in Reclamation of Alkali soils, Lucknow*, 69-80.

Singh, R. D. and Yadav, D. V. (1986) *Agril. Wastes*, **18** (37): 247-51.

Singh, S.; Mishra, M. M.; Goyal, S. and Kapoor, K. K. (1992) Preparation of N and P enriched compost and its effect on wheat. *Indian J. of Agril. Sci.*, **62** (12): 810-814.

Singh, T. A. and Singh, G. R. (1991) Evaluation of partially acidulated phosphate rock and liquid ammonium polyphosphate as P soruces for wheat. *J. Indian Soc. Soil Sci.*, **39**(1) : 191-193.

Singte, V. V.; Patil, P. L.; Rasal, P. H.; Bhanavase, D. B. and Patil, U. R. (1990) Production and analysis of enriched sugarcane trash compost. Proc. VIII Southern Regional Conf. Microbial Inoculants, College of Agriculture, Pune, PP. 56-57.

Smyth, T. J. and Sanchez, P. A. (1982) *Soil Sci. Soc. Amer. Jl.*, **46** (2): 339-45.

Somani, L. L.; Joshi, R. S. and Mehta, H. C. (1981) Pyrites to reclaim alkali soils. *Indian Farmer's Digest*, **14**(7): 26-28.

Somani, L. L. (1983) *An. Edafol. Agrobiol.*, **42**: 523-29.

Somani, L. L. (1984) Use of low grade pyrites as an amendment for alkali soils and to improve soil fertility - A review. *Fertil. New*, **29**(7): 13-27.

Somani, L. L. (1994) Use of pyrites in agriculture. Agrotech Publishing Academy, 1-G-24 Sector-5, Gayatri Nagar, Hiran Magri, Udaipur-313001.

Sperber, J. I. (1958 a) *Aust. J.Agric. Res.*, **9**: 778-781.

Sperber, J. I. (1958 b) *Aust. J.Agric. Res.*, **9**: 782-787.

Srivastava, L. L.; Mishra, B. and Srivastava, N. C. (1988) J. of *Indian Soc.* of *Soil Sci.*,36(4):693.

Stevenson, F. J.; Harrison, R. M.; Wetselaar, R. and Leeper, R. A. (1970) *Soil Sci. Soc. Amer. Proc.*, **34**: 430.

Stevenson, R. M.; Cole, C. V. and Sieling, D. H. (1949) *Soil Sci.*, **67**: 3-22.

Stevenson, F. J. (1982) In Humus chemistry : Genesis, composition, reaction, John Wiley and Sons. N.Y., USA.

Stevenson, F. J. (1986) In cycles of soil. A Wiley-Interscience publication, John Wiley & Sons. N.Y, U.S.A.

Stevenson, R. M.; Cole, C. V. and Sieling , D. H. (1949) Fixation of phosphate by iron and aluminium and replacement by organic and inorganic ions. *Soil Sci.* **67**: 3-22.

Stewart, A. J. (1984) and Interactions between dissolved humic materials and organic toxicants. In: Synthetic fossil fuel to results of health and environmental studies. *Eds: Cowser, K. E.*, pp 505-521.

Struthers, P. H. and Sieling, D. H. (1950) Effect of organic anions and phosphate precipitation by iron and aluminium as influenced by pH. *Soil Sci.*, **69**: 205-213.

Stumm, W. and Morgan, J. J. (1970) Aquatic, Chemistry - An Introduction Emphasizing Chemical Equilibria in Natural Waters. John Wiley Interscience, New York. p 583.

Stutzenberger, F. J.; Kaufman, A. J. and Lossin, R. D. (1970) Cellulolytic activity in Municipal solid waste composting. *Can. J. Microbiol.*, **16**: 553-560.

Subba Rao, N. S. (1982) In : *Advances in Agricultural Microbiology.* (Subba Rao, N. S. Ed.) Oxford. IBF. New Delhi, pp. 295-303.

Subba Rao, (1988) Aerobic composting of spent wash. Paper in National Seminar on Sugar Factory and Allied Industrial Wastes-A new focus. name

Subramanian, S. and Gopalswami, A. (1991). *J. Indian Soc. Soil Sci.*, **39**: 99-103.

Sud, K. C.; Sharma, R. C. and Govindakrishan, P. M. (1992) *J.Indian Potato Assoc.*, **19** (5): 1-2.

Suebhia, S. S. and Minhas, R. S. (1993) *J. Indian Soc. Soil Sci.,* **41**(1): 96-90.

Suler, D. J. and Finstein, M. S. (1977) Effect of temperature, aeration and moisture on CO_2 formation in bench-scale, CTC of solid waste. *Appl. Environ. Microbiol.,* **33**: 345-350.

Sundara Rao, W. V. B. and Sinha, M. K. (1963) Phosphate dissolving microorganisms in the soil and rhizosphere. *Indian J. Agric. Sci.,* **33**; 272-278.

Sur, H. S. and Sinha, M. K. (1982) *J. Indian Soc. Soil Sci.,* **30** (3): 270-274.

Sylvestre-Bradley, R.; Askawa, N.; Torrac, S. La.; Magalhaes, F. M. M.; Olivaira, L. A. and Pereira, R. M. (1982) *Soils Fert.,* 1984. **47**: 7161.

Tabatabai, M. A. and Dick, W. A. (1979) *Soil Biol. Biochem.,* **11**: 655.

Tandon, H. L. S. (1995) Recycling of Crop, Animal, Human and Industrial Wastes in Agriculture. Fertiliser Development and Consultation Organisation, New Delhi.

Tanpure, H. B. and Mohite, A. N. (1986) Effect of Mussoorie rockphosphate with without iron pyrite on nutrient uptake and yield of green gram in black calcareous soil. *Proc. Natn. Sem. Rockphosphates in Agriculture. TNAU - PPCL Coimbatore,* 1985. PP 131-136.

Tarafdar, J. C. and Chhonkar, P. K. (1979) Phosphate production by microorganisms isolated from diverse type of soils. *Zbl. Bakt.* **134**: 119-124. *Soils Fert.,* 1979. **42**: 6569.

Tate, K. R. (1984) *Pl. Soil,* **76**: 245-46.

Teensma, B. (1962) *IRGR Information Bull.* **16**, English Translation by U. S. Dept. Health, Education and Welfare, Public Health Service.

Temple, K. L.; and Delchamps, E. W. (1953) Autotrophic bacteria and the formation of acid in bituminous coal mines. *Appl. Microbaiol.,* **1**: 255-258.

Tepal, N. I. (1959) *Agrobiologia:* 623-626.

Thomas, G. V. and Shantaram, M. V. (1986) *J. Plantation Crops,* **14** (1): 42-48.

Tipping, E. ; Woof, C; Backes, C. A. and Ohnstad, M. (1988) Aluminium speciation in acidic natural waters, Testing of a Al-complexation. *Water Res.,* **22** (3): 321-326.

Tiwari, K. N.; Dwivedi, B. S. and Upadhyay and Pathak, A. N. (1984) Sedimentary iron pyrites as amendment for sodic soils and carrier of fertiliser sulphur and iron - *A.Review. Fertil. News,* **29** (10) : 31-41.

Tiwari, K. N.; Dwivedi, B. S.; Dagur, B. S. and Pathak, A. N. (1986) Evaluation of Mussorie rockphosphate mixed with pyrite or superphosphate as phosphatic fertilizer for alluvial soils of Uttar Pradesh. *Proc. Natn. Sem. Rockphosphates in Agriculture. TNAU-PPCL Coimbatore* 1985. pp 249.

Tiwari, V. N.; Pathak, A. N. and Lehri, L. K. (1988) Manurial value of compost enriched with rock phosphate and microbial inoculant to green gram. *J. Indian Soc. Soil Sci.,* **36**: 280-283.

Tiwari, V. N.; Lehri, L. K. and Singh H. (1992) Degradation of wheat straw nodes as influenced by pyrite, mussoorie rock phosphate and cowdung and their effects on crop yield. *Proc. Nat. Seminar on Organic Farming, M.P.K.V.Pune:* 75-76.

Todorava, B. (1967) Investigation of certain organic materials in alluvial meadow and leached cinnamon forest soils. *Pochv. Agrokhim,* **2**:95-104.

Tomar, N. K.; Khanna, S. S. and Gupta A. P. (1983) *Indian J. Agric. Sci.,* **53**: 330.

Tomar, N. K.; Khanna, S. S. and Gupta, A. P. (1984) *Haryana Agric. Univ. J. Res.* , **14** (3): 324-333.

Tomar, N. K.; Sharma, A. K. and Gupta, A. P. (1986) In *Rock phosphates in Agriculture* (G.V.Kothandaraman, T. S. Manickam and K. Natarajan, Ed.), TNAU, Coimbatore, Tamil Nadu, p. iii.

Tomar, N. K.; Sharma, A. K. and Gupta, A. P. (1987b) Effect of pyrite on the transformation of rock phosphate and triple superphosphate during decomposition of cattle dung. *J. Indian. Soc.Soil Sci.,* **35**: 244-248.

Trojanowski, J.; Haider, K.; Szczodrak, J. and Kochmanska-Rdest, G. (1984) Screening for Lignocellulose degrading fungi and bacteria by means of radioisotope method. In Soil biology and conservation of the biosphere. Volume No.1, edited by Szegi, J. pp. 375-381.

Ulmer, D. C.; Leisola, M. S. A. and Fiechter, A. (1984) Possible induction of the lignolytic system of *Phanerochaete chrysosporium*. *Journal of Biotechnology*. **1**: 13-24.

University of California at Berkeley (1953) *Tech. Bull.* **9**, Sanitary Engineering Research Project.

Upadhaya, S. K.; Pettygrove, S.; Glancey, J. L.; Sime, M. and Williams, J. F. (1992) *Amer. Soc. Agril. Enggs.*, **92-1020**: 25

Van-Voorhoeve, J. J. C. (1974) Organic fertilisers, problems and potential for developing countries. World Bank Fertiliser Study. Background Paper No.4 (IFC office of the Economic Advisor, World Bank, Washington D.C.)

Vamos, R. (1959) Prevention of the formation of hydrogen sulfide in flooded soils. *Agrokem. Telajtan.* **8**: 321-330.

Venkateswarlu, B.; Rao, A. V. and Raina, P. (1984) *J. Indian Soc. Soil Sci.,* **32**: 273-277.

Verachtert, H.; Ramaswamy, K.; Meyers, M. and Bevers, J. (1982) Investigations on cellulose biodegradation in activated sludge plants. *J.Appl. Bacteriol.,* **52**: 185-190.

Vidhyasekaran, P.; Balaraman, N.; Deiveekasundaram, M. and Viswanathan, G.(1973) Phosphate dissolving activity of *Aspergillus awamori. Indian Jl.Microbiol.,* **13**: 51-53.

Virmani, S. M. (1966) *Indin J. Agric. Sci.,* **36**: 100-104.

Voigt, K. A.; Grier, C. C.; Meler, C. E. and Edmonds, R. L. (1982) *Ecology,* **63**: 370-80. In: Natural Resources Management for Sustainable Agriculture and Environment. [Ed. Prof. D.I. Deb.] Angkor Publishers.

Waggoner, P. E. (1974) The biochemistry and methodology of composting. *Connecticut Agril. Exptl. Stn. Bull.No,* **754**: 9.

Wainwright, M. and Killham, K. (1980) Sulphur oxidation by *Fusarium solani*. *Soil Biol. Biochem.*,**12**: 555-558.

Wallace, J. M. and Whitehead, L. C. (1980) Adverse synergistic effects between acetic, propionic, butyric and valeric acids on the growth of wheat seedling roots. *Soil Biol.Biochem.*, **12**: 445-446.

Waksman, S. A. (1938) Humus, Williams and Wilkins Co., Baltimore, Maryland.

Waksman, S. A. and Cordon, T. C. (1939) Thermophilic decomposition of plant residues in composts by pure and mixed cultures of microorganisms. *Soil Sci.*,**47** (3): 217-225.

Wani, P. V.; More, B. B. and Patil, P. L. (1979) Physiological studies on the activity of phosphorus solubilizing microorganisms. *Indian J. Microbiol.*,**19**: 23-25.

Weir, R. G. (1975) The oxidation of elemental sulphur and sulphides in soil. *In:* Sulphur in Australasian Agriculture (R.D.Mclachlan, ed.) 40-49. Sydney University Press, Sydney.

Wiklander, L.; Hallgren, G. and Jonsson, E. (1950) Studies on Gyttja soils. III-Rate of sulfur oxidation. *Ann. Royal Agr. Coll. Sweden*,**17**: 425-440.

Wild, A. (1970) The retention of phosphate by soil. A review . *J. Soil Sci.*, **1**: 221-38.

Wilde, S. A. (1958) Preparation of sawdust compost. *Forest Proc. J.*, **8**: 323.

Wiley, J.S. (1956) *Proc. Ind. Waste Conf.*, **11**; 334-341.

Wiley, J. S. (1967) *Compost Sci.*, **8**, (1): 22-27.

Wiley, J. S. and Spillane, J. T. (1962) Refuse-Sludge Composting in Windrows and Bins. *Compost Sci.*, **2** (4): 18-25.

Williams, T. O. and Miller, F.C. (1992) *Bio Cycle*, **33** (11): 75-79.

Wilson, G. B. and Dalmat, D. (1986) *Bio Cycle, :* **27** (7).

Wilson, M. A. and Ellis, B. G. (1984) *Soil Sci. Soc. Am. J.*, **44**: 951-55.

Wong, M. H. and Wong, J. W.C. (1989) *Agric. Ecosystem Environ.,* **26**; 23.

Wong, M. H. (1990) Comparison of several solid wastes on the growth of vegetable crops. *Agriculture, Ecosystem & Environment,* **30** (1-2): 49-60.

Wood, J. M. (1974) Science, **199**:1049.

Yadav, K. and Singh, T. (1991) *J. Indian Soc. Soil Sci.,* **39**: 89-93.

Yadav, K.; Prasad, D.; Prasad, C. R. and Mandal, K. (1992) Effect of enriched compost and *Rhizobium* culture on the yield of green gram. *J.Indian Soc. Soil Sci.,* **40**: 71-75.

Yuan, T. (1980) *Soil Sci. Soc. Am. J.,* **44**; 951-55.

Zayed, M. N.; Zohdy, L. and Taha, S. M. (1969) *Zentralbl. Bakteriol. Parasitenk., Infektionskr. Hyg., Abt. 2,* **123** (5): 561.

Zdlewske-Spbczak, Jadwiga and Ur-banek, Henryk (1981) Cellulose degrading enzymes of *Fusarium avenaceum. Arch. Microbiol.,***129**: 247-250.

Zeikus, J. G. (1980) Fate of lignin and related aromatic substrates in anaerobic environments. In Lignin Biodegradation, ed. T.K.Kirk, T.Higuchi and H.M.Chang, **1** (**5**): 101-109, CRC Press, Boca Raton, FL.

Zeng, M. X.; Jin, W. X.; Yao, Y. X. and Yang, Y. F. (1992) Advantages of application of manure with chemical fertilizers in a long term in situ experiment. *Soils and Fertilizers* (Beijing), **1**: 1-6. [Ch, 5 ref.] *Soils & Fertilizers Instt., Academy of Agricultural Science,* Beijing 100081, China.

Zhang, S. F.; Yang, Y.; Han, L. P.; Wang, D. M. and Zhang, J. W. (1981) Physiological characters of phosphorus dissolving fungi F028 and its, effect on the conversion of ground phosphate rock. *Turang Tongbao.* **4**: 40-42. *Soils & Fert.,*(1983) **46**. 4010.

Zucconi, F.; Forte, M.; Monaco, A. and de bertoldi, M. (1981 b) *Bio Cycle,* **22** (4).

Zucconi, F.; Forte, M.; Pera, A. and de Bertoldi, (1981 a) *Bio Cycle,***22** (2).

APPENDIX

APPENDIX - I

Estimates of the availability of some crop residues in India and their nutrient potential

Crop	Residue to economic yield ratio	Residue yield* (‘000 t)	Nutrient (%)			Nutrient potential (‘000 t)		
			N	P_2O_5	K_2O	Total	Uti-lisable **	Fertiliser equivalent ***
Rice	1.5	110,495	0.61	0.18	1.38	2,398	799	399
Wheat	1.5	82,631	0.48	0.16	1.18	1,504	501	250
Sorghum	1.5	12,535	0.52	0.23	1.34	262	87	43
Maize	1.5	11,974	0.52	0.18	1.35	252	84	42
Pearl millet	1.5	6,967	0.45	0.16	1.14	121	40	20
Barley	1.5	2,475	0.52	0.18	1.30	51	17	8
Finger millet	2.0	5,351	1.00	0.20	1.00	118	39	19
Sugarcane (Stripped cane)	0.1	22,736	0.40	0.18	1.28	423	423	211
Potato tuber	0.5	7,867	0.52	0.21	1.06	141	141	70
Groundnut (Pods)	1.5	10,598	1.60	0.23	1.37	339	339	169
Total	**-**	**273,629**	**-**	**-**	**-**	**5,609**	**2,470**	**1,231**

* Arrived at by multiplying the economic yield by the given residue to economic yield ratio

** One third of the total N,P and K potential assuming that two-thirds of the total residue is used as animal feed
on national basis

*** 50% of the utilisable N,P and K assuming 50% mineralisation of N,P and K per season

Source : Tandon, H. L. S. (1995) Recycling of Crop, Animal, Human and Industrial Wastes in Agriculture. Fertiliser Development and Consultation Organisation, New Delhi.