# IMPACT OF HUMIC ACID ON SOIL FERTILITY AND RESPONSE OF RICE IN ALFISOL AND INCEPTISOL

Thesis submitted in part fulfillment of the requirements for the degree of
**DOCTOR OF PHILOSOPHY (AGRICULTURE) in**
**Soil Science and Agricultural Chemistry** to the
Tamil Nadu Agricultural University, Coimbatore

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# CERTIFICATE

This is to certify that the thesis entitled "**IMPACT OF HUMIC ACID ON SOIL FERTILITY AND RESPONSE OF RICE IN ALFISOL AND INCEPTISOL**" submitted in part fulfillment of the requirements for the award of the degree of DOCTOR OF PHILOSOPHY (AGRICULTURE) in Soil Science and Agricultural Chemistry to the Tamil Nadu Agricultural University, Coimbatore is a bonafide record of research work carried out by MISS . K. SATHIYA BAMA under my supervision and guidance and that no part of this thesis has been submitted for the award of any degree, diploma, fellowship or other similar titles or prizes and that the work has not been published in part or full in any scientific or popular journal or magazine.

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*(K.SATHIYA BAMA)*

# ABSTRACT

## ABSTRACT

# IMPACT OF HUMIC ACID ON SOIL FERTILITY AND RESPONSE OF RICE IN ALFISOL AND INCEPTISOL

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Humic Acid (HA) is an important component of soil organic matter, which could improve the soil properties and crop nutrition. The optimum dose of HA for getting higher yield may be site specific and also depends on the source from which it is extracted. Hence with a view to study the effect of lignite humic acid on soil fertility and response of rice in Alfisol and Inceptisol the present investigation was undertaken.

The characterisation studies of humic acid showed the presence of functional groups like phenolic and carboxyl and elements like C, H, N and O. The characteristics property of HA was its high CEC (103-125 cmol (p+) kg$^{-1}$) and organic carbon content (29-34 per cent). Delineation of soils of western zone for organic carbon indicated its low

status in most of the soils studied, highlighting the importance of its build up as well as that of humic substances in the soils through external addition of organic matter or any organic material so as to improve the soil fertility and productivity. Adsorption studies conducted using HA and P on Alfisol exhibited a negative influence of HA on P sorption and resulted in an increase of the solution P concentration.

Incubation experiment was conducted with graded levels of HA up to 80 kg ha$^{-1}$ on Alfisol. The results revealed that, a linear trend in the release of N, P and K was observed for the application of HA. But the significant increase was observed up to 20 kg HA ha$^{-1}$ for N and 40 kg HA ha$^{-1}$ for P and K. There was a steep and significant increase of organic carbon and CEC up to 40 kg HA ha$^{-1}$.

A pot experiment was conducted on soil samples of Alfisol and field experiments were also conducted in Alfisol and Inceptisol with similar treatment structure to study the influence of HA on soil properties, crop nutrition and yield of rice. The treatments constituted were control, 75 and 100 percent of NPK fertilisers as main plot treatments and eight HA treatments (soil application of HA @ 0, 10, 20, 30 and 40 kg ha$^{-1}$), 10 kg HA ha$^{-1}$ + foliar spray of 0.1 per cent (FS), 10 kg HA ha$^{-1}$ + root dipping of 0.3 per cent (RD), and 10 kg HA ha$^{-1}$ + FS + RD as subplot treatments with CRD for pot and split plot design for field experiments. The soil and plant samples were collected at critical growth stages of rice and analysed for their nutrient contents. The second set of field experiments was conducted with the best treatments selected from the first experiments conducted in both the soils. Test verification trial was also carried out to confirm the findings from second experiments.

The results showed that the organic carbon and cation exchange capacity were increased with increasing doses of HA. But the significant effect was observed for 20 kg HA ha$^{-1}$ in both Alfisol and Inceptisol. The HA integrated with fertiliser markedly improved the OC and CEC of the soil. Similarly the NPK availability was profoundly affected by HA up to 20 kg $ha^{-1}$ and beyond that there was a diminishing trend in the increase at all the three stages of rice growth. The micronutrient availability showed increasing trend up to 20 kg $ha^{-1}$ in both the soils. The combined application of NPK fertiliser with HA favourably influenced the available nutrients of soil. The NPK at 100 per cent recommended dose with HA was comparable as that of HA with 75 per cent NPK.

The profound effect of HA on root characteristics and rice nutrition was observed, which was further improved in the presence of NPK fertilisers in both the soil types. The HA levels to bring out pronounced effect on rice nutrition would depend largely on soil type, rice variety and yield. In Alfisol, the significant effect on nutrient uptake by a short duration rice variety was observed up to 20 kg $ha^{-1}$, but in Inceptisol the medium duration rice variety recorded at a level higher than 20 kg $ha^{-1}$ especially as growth advanced towards maturity.

Appreciable improvement on the yield and yield attributes such as productive tillers, filled grains, panicle length, thousand grain weight and reduction in chaffy grains were observed with graded dose of HA, but the significant effect was observed for 20 kg $ha^{-1}$ in Alfisol and for 30 kg $ha^{-1}$ in Inceptisol. The application of HA @ 10 kg $ha^{-1}$ along with FS and RD was as effective as application of HA @ 20 kg $ha^{-1}$ in augmenting the rice yields. The grain yield in the combined application of HA with NPK at 100 per cent recommended dose was as good as that of HA with 75 per cent NPK as evident from the high RR, BCR and low PR recorded.

The optimisation of humic acid dose was attempted and the result showed that 18.5 kg $ha^{-1}$ of HA as an economical optimum and 24.0 kg $ha^{-1}$ as physical optimum for getting higher yield of rice in Inceptisol of Tamil Nadu.

The results of the present investigation highlighted that, the fullest benefit of humic acid could be realised only when the sufficient nutrients were present in the soil, which could be achieved by the combined application of NPK fertiliser with HA. The effect of HA was better expressed in reduced dose of NPK (75 per cent NPK) and this result was comparable response in rice as that of higher dose of NPK fertiliser (100 per cent NPK). From the economic point of view, applying 10 kg of HA ha$^{-1}$ with FS and RD was found to be better than 20 kg ha$^{-1}$ of soil application. However, from the fertility point of view, application of HA even up to 40 kg ha-1 had produced beneficial effect such as building up of OC, higher CEC, root proliferation and nutrient availability.

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| | |
|---|---|
| HA | -Humic Acid |
| FA | -Fulvic Acid |
| FTIR | -Fourier Transform Infrared Spectroscopy |
| COOH | -Carboxyl groups |
| OH | -Hydroxyl groups |
| OC | -Organic carbon |
| CEC | -Cation exchange capacity |
| SA | -Soil application |
| FS | -Foliar Spray |
| RD | -Root Dipping |
| RR | -Response Ratio |
| RAE | -Relative Agronomic Effectiveness |
| REE | -Relative Economic Effectiveness |
| PR | -Price Ratio |
| BCR | -Benefit Cost Ratio |

# INTRODUCTION

# CHAPTER I

# INTRODUCTION

**"A soil without organic matter is as barren as a cow without calf"-** (Katyal, 2001)

Maintaining and improving soil fertility for sustainable agriculture is becoming more crucial due to increasing complexity of the nutritional problems. Organic matter is a substance that has many desirable characteristics which influence the soil physical, chemical and biological properties (Stevenson, 1991). Since organic substances constantly undergoing changes in the tropical soils, it must be replenished. The sources of organic matter for incorporation into the soil are becoming scarce. To maintain sustained and high productivity of crops over prolong periods, maintenance of soil organic matter at a satisfactory level is necessary (Govindasamy, 2002).

Organic matter level of a soil is the key property that decides the availability status of essential nutrients (Katyal, 2000). The labile and humified organic matter will have a strong impact on soil fertility. It was reported to be the most influential factor modulating nutrient availability across diverse soils (Stevenson, 1982). Diminishing organic matter led to a significant fall in the availability of secondary and micronutrients (Katyal and Sharma, 1991).

The quantity and quality of organic matter is the representative of humic and non-humic substances. The products of decomposition processes of organic matter are the humic substances. They are thought to be formed by microbial, enzymatic and chemical transformations of plant and animal residues (Flaig *et al.*, 1975). They possess chemically reactive groups, which may influence plant growth directly or indirectly. On the basis of solubility in acids and bases, humic substances are differentiated into humins (insoluble in both acid and base), humic acids (soluble in base but insoluble in acid) and fulvic acids (soluble in both acid and base). These forms are in a state of dynamic equilibrium (Stevenson, 1982).

Humins are highly complex forms that are known to help the soil particles to form aggregates. The fulvic acids are the simplest forms, which are easily absorbed by plants. Humic acids are intermediate in complexity between humins and fulvic acids but their molecular weights have a wide range. Humic acids with high molecular weight are not known to be assimilable while those with low molecular weight are said to be assimilable by the plants (Govindasamy, 2002). Of the three humic substances, humic acids have received by far the most attention. The considerable and wide-ranging action of humic acid is primarily due to the presence of many functional groups, which are capable of forming electrovalent and covalent bonds and intra complex compounds. It forms stable complexes with metal ions and thereby increases the availability of nutrients to the plants.

Humate products for agricultural use are produced through mineral sand mining and recovery operations. The end product contains a majority of organic materials (humic acid) mixed with smaller amounts of mineral matter. Coal and lignite are rich in humic matter. Of the two, lignite is richer in humic matter than coal and is available in large quantities in the open mines at Neyveli, Tamil Nadu. The Neyveli lignite is the youngest among the lignites mined in India, which contains about 25 to 60 per cent humic acid. Though the commercially available humic substances added to the soil at normal rates do not directly contribute significant quantity of nutrients to plants, in modern agriculture they do have significant indirect effects on soil fertility (Orlov, 1995) and crop yields. Humic acid can be applied to soil to improve its fertility. Humic acid when externally supplied was observed to increase the crop growth and yields. It improves the nutritional status of soil and plant system. The high cation exchange capacity of humic acid prevents nutrients from leaching. It absorbs the nutrients from chemical fertiliser and these exchange nutrients are slowly released to the plants.

The Tropical soils are low in organic matter content under intensive farming. The use of chemical fertilisers enhanced the microbial degradation of soil organic matter, resulting in the decrease of soil organic carbon. Maintenance of soil organic matter at a satisfactory level is very important to sustain higher crop yields under Indian farming conditions.

With the ever increasing population, the requirement of larger production of food grains and other agricultural commodities and existing low yield levels of most of the crops suggest the scope and need for increasing the production of almost all crops. Rice is the most important food in the world. More than half of the world population depends on rice for calories and protein, especially in developing countries. The world population particularly that of the rice consuming countries is increasing at a faster rate. By the year 2025, about 758 million tonnes of paddy which is 70 per cent more than the current production will be needed to meet the growing demand (Duwayri, 1999).

The influence of the effect of application of organic manure on increasing the rice yield was well documented. Since, there is a dearth for organic manure, new sources are to be found out which could provide effects similar to that of organic manure. The organic fertiliser such as potassium humate, which is rich in humic acid, has not been studied extensively. Humic acid is one, which can influence rice ecosystem as that of any organic manure added.

Keeping the above points in view, a study was undertaken with the following objectives.

- Characterisation of lignite humic acid obtained as potassium humate
- Delineation of soils of western zone of Tamil nadu for their organic carbon status.
- To study the effect of humic acid applied through potassium humate on soil properties
- To study the effect of humic acid applied through potassium humate on nutrition and yield of rice
- To optimise the dose of humic acid applied through potassium humate for rice under different soil types

# REVIEW OF LITERATURE

# CHAPTER II

# REVIEW OF LITERATURE

The importance of soil organic matter on soil fertility and productivity is a well-established fact. In the formation of a fertile soil, organic substances play a direct role. They are the sources of plant nutrients, which are liberated in available forms during mineralisation and have a fundamental effect on the physical properties of the soil. It determines to a larger degree on physicochemical properties, exchange capacity and buffering properties, which are of great importance in controlling the uptake of nutrients by the plant and their retention in the soil.

In the practical tropical agriculture, the problems are usually more concerned with the nutrient supplying power of humus on the one hand and on the other, the use efficiency of fertilisers. The effect of this compound is based on its composition and characteristics. The literature pertaining to the characteristics of humic acid and its influence on soil properties and crop response are briefly reviewed hereunder.

## 2.1. Sources of humic acid

High content of humic acid substances in peat and lignite as well as lower usability of highly mineralised fractions for industrial heating purpose urged the scientists to test their usability in agriculture. Narayanan (1989) reported that low quality lignite from Neyveli with an ash content of 2-3 per cent and 50 per cent moisture gave high results of 60 per cent humic acid whereas lignite containing higher percentage of ash yielded 50-55 per cent humic acid.

Kadalli *et al.* (2000) found that, the general shape of infra red (IR) spectra of HA isolated from compost resembled those reported for HAs isolated from peat samples. Jothimani *et al.* (2002) extracted humic acid from coir pith by treating with different materials. The results showed that the coir compost with microbial incorporation decreased the humic acid content from 0.389 to 0.358 per cent whereas the coir pith incorporated in soil along with rock phosphate and urea increased the humic acid from 0.362 to 0.385 and 0.352 to 0.395 per cent respectively.

In a study conducted by Satishkumar *et al.* (2002a) Humic acid a low molecular weight humic substance was extracted from peat soil, lignite, farmyard manure, sewage sludge and bio digested slurry. The results indicated that the UV spectra of the humic acids from five organic sources were featureless, the well defined maxima and minima were absent and the optical density decreased as the wavelength increased. The infra red spectra of all the humic acids showed a close similarity in structure.

## 2.2. Nature and distribution of humic acid

Humic acid forms one of the compounds of soil organic matter. The distribution of humic acid fractions of soil organic matter is influenced by the various factors. With progressive humification in peat and decomposing plant samples, the C content, aromatic character of humic acid molecules, number of their alcohol and ether groups, aliphatic side chains and double bonds increased but a decrease in H content, molecular weight, equivalent weight and hydrophilic nature was observed (Visser , 1964).

Rivero *et al.* (1998) observed that $E_4$ / $E_6$ values of humid acid extracted from Inceptisol, Alfisol, Entisol, Vertisol and Oxisol were quite similar. The Spodosol HA exhibited a higher $E_4$ / $E_6$ value, which was characterised by a lower degree of condensation and less aromatic structure as compared to other. The $E_4/E_6$ ratios of humic acid extracted from manures and sewage/sludge were found to be close to those of the soil humic acids (Deiana *et al.*, 1990). Nowadays artificially produced humates getting popularised. A lowering of $E_4/E_6$ ratio was observed for a number of synthetic humic acids with rise in pH (Datta *et al.*, 2001; Kar and Sanyal, 1988).

Humic acid estimations at 0-15 and 15-30 cm depths showed that, the concentration of HA was higher by two times than fulvic acid in Vertic Ustropept soil (Santhy *et al.*, 2001). They also stated that, subsurface soil recorded a very low content of humic acid probably due to very low additions of organic matter and higher degree of oxidation, owing to tropical climate. The content of humic acid and fulvic acid in the soil increased with increasing level of fertiliser application from 50 to 150 per cent. The highest concentration was recorded under 100% NPK + FYM which could be due to the improved soil physical parameters and a conducive environment for the formation of humic acids in this treatment.

With increasing concentration of organic matter, the humic acid content also increased (Santhy *et al.*, 2001). The humic substances are synthesized by polycondensation and polymerisation of different phenols, carbohydrates etc., with or without nitrogen containing compounds (Datta *et al.*, 2001). The synthetic polymers produced are quite similar to natural humus, particularly with respect to elemental analysis, exchange capacity, total acidity, functional group make-up and resistance to microbial degradation (Datta *et al.*, 2001).

## 2.3. Characteristics of humic acid

Humic substances are mixtures of organic compounds differing in molecular weight and cation exchange capacity. The humic acids comprise a group of compounds which are extracted from soil by alkaline solution and precipitated through acidification (Kononova, 1966).

### 2.3.1. Structure of humic acid

The basic structure of soil humic substances is believed to be an aromatic ring at the di or trihydroxy phenol type bridged together by -O-, $-CH_2-$, -NH- and other groups (aliphatics) and also containing carboxylic groups, attached both directly to the ring and on the aliphatic side chains (Stevenson, 1994). In the natural state, humic substances contain attached proteineous and carbohydrate residues, which are also capable of forming complexes with trace and heavy metal ions (Chen and Stevenson, 1986).

The proposed structure of humic acid has oxygen present as carboxyl, phenolic, alcoholic, esters, ethers and ketonic groups. The number of structural voids, inherent in this skeleton, implies high flexibility and microporosity, and hence ability of humic acid to entrap organic and inorganic macromolecules as well as water (Sanyal, 2001). The voids and flexible nature of the polymers could explain the ability of humic substances to bind cations that influence the stereo chemical arrangement of functional groups to form stable complexes (Relan *et al.*, 1993). Oades (1989) noted that these peripheral pores were also capable of accommodating natural and synthetic organic chemicals in clathrate arrangements.

Chen and Pawluk (1995) from their studies on structural variations of HA in Mollisols, proposed that high content of p-hydroxyl phenols could serve as an indicator of humic acids from mineral horizons in different soil environments. Humic acid molecules behave like a linear flexible colloid at lower sample concentrations and rigid rod like or polyelectrolyte colloids at higher sample concentrations. An analysis of the data for particle weight, volume and axial ratio showed the molecular configuration as rod like (Relan *et al.*, 1984).

Sarkar (1987) studied the humic and fulvic acids of some soils of eastern Himalayan regions of varying altitude and found that, the humic acids from the soils of foot hill and of low altitudes showed a wide range of molecular weight distribution than those of the higher altitudes. Malcolm (1990) specified a molecular weight range of some humic acids as 50,000 to 5,00,000 daltons

### 2.3.2. Spectroscopic characteristics of humic acid

Newman and Tate (1991) had characterised the humic acids from soils of a development sequence by using the $^{13}C$ NMR spectroscopy, and found that the degree of oxygen substitution of aromatic rings was negatively correlated with the extent of soil development. Extensive aromaticities were noted in humic acids extracted from least developed soils. The absorption capacity of humic acids from many soils of Punjab has been reported to be in the range of 390 – 450 and of fulvic acids 310 – 390 meq/100g (Bhandari *et al.*, 1970). The absorption capacity may also be affected by blocking of that part of functional groups firmly bound to mineral particles (Krystanov, 1968). The infra red and ultra violet spectroscopic techniques were also followed to study the humic substances.

#### 2.3.2.1. Infra Red Spectroscopic characteristics of humic acid

Singhal and Sharma (1983) reported that the IR spectra of humic acids of Sal forest had sharply developed maxima and minima due to characteristic aromatic functional groups which are responsible for high exchange capacities. Singhal and Pramod Kumar (1992) found that IR Spectra of humic acid extracted from Chakrata forest division of Uttar

Pradesh indicated the presence of oxygen containing functional groups and their high molecular weights.

The presence of carboxyl groups was confirmed by the IR spectra in which the intense absorption band at about 1720 $cm^{-1}$ is predominantly due to the non-ionised carboxyl group and the carboxylate ion is identified from two bands at 1690 and 1390 $cm^{-1}$. The alcoholic OH group is confirmed by bands near 1100 $cm^{-1}$ in the IR spectra (Orlov, 1995). Many authors have found carbonyls of the keto type in peat and coal humic acids. (Orlov, 1995).

Singhal and Sharma (1983) reported that the IR spectra of the humic acids of sal forests were found richer in phenolic and carboxylic groups whereas in miscellaneous forest soils glucosides and other polymeric-substances were in abundance. Govindasamy *et al.* (2002) reported that, $^{13}C$ NMR spectra of humic acid extracted from lignite in the pilot plant at NLC revealed the presence of both aliphatic and aromatic framework. The phenolic, aromatic ester and aromatic amino functions exist along with carboxyl groups.

Of the spectroscopic methods generally used for structural investigations, the infra red (IR) spectroscopic techniques have been used for functional group analysis in soil humic substances (Deiana *et al.*, 1990; Schnitzer, 2000). The IR and FTIR (Fourier transform infra red technique) spectra of humic substances generally showed bands at 3400 $cm^{-1}$ (H bonded OH), 2000 $cm^{-1}$ (aliphatic C-H stretch), 1725 $cm^{-1}$ (C=O of COOH, C=O stretch C=O), 1630 $cm^{-1}$ (COO C=O of carbonyl and quinone), 1450 $cm^{-1}$ (aliphatic C-H), 1400 $cm^{-1}$ (C-O stretch or OH deformation of COOH and 1050 $cm^{-1}$ (Si-O of silicates) (Schnitzer, 2000).

The concentration of carboxyl groups in humic acid was determined directly from FTIR spectra by totaling absorbances at 1720-1710 $cm^{-1}$ (COOH) and 1620-1600 $cm^{-1}$ ($COO^-$) (Celi *et al.*, 1997). Such carboxyl content was in good agreement with that determined by wet chemical method and by $^{13}C$ NMR spectroscopy. Deiana *et al.* (1990) from their studies by $^{13}C$ NMR technique on characterisation of humic acids, extracted from manures and sewage / sludge, demonstrated that the manure HAs were more aromatic than sewage / sludge HA, with greater functional group contents, and were quite similar to soil HAs.

Infrared spectra of all the humic acids of five different sources revealed the presence of hydrogen bonded OH groups which gave a broad absorption band at 3400 – 3300 $cm^{-1}$ due to various degrees of H-bonding, partly NH stretching and free $NH_2$. Biodigested slurry humic acid alone showed weak absorption band at this range indicating poor aliphatic components (Satishkumar *et al*., 2002a).

### 2.3.2.2. Visible spectroscopic characteristics of humic acid

The optical characterisation of humic substances derived from different soils provides an insight into the degree of aromatization and condensation of aromatic rings in the molecules of humic acids. Visible spectra of their natural polymers are useful in elucidating the nature of functional groups and their contribution to optical properties like absorption maxima at different wave lengths (Prasad and Sinha, 1984; Mishra and Srivastava, 1990).

The most widely accepted absorption spectroscopic information of humic substances is the ratio of optical densities at 465 nm and 665 nm i.e., commonly called $E_4$ /$E_6$ ratio. It appears to be independent of the concentration of humic substances but varies with difference in the genesis of the soil organic matter in ambient soil environment

(Kononova, 1966; Stevenson, 1982). The difference in optical density curves and slopes may be attributed to varying degrees of condensation of aromatic rings and also to the ratio of carbon in aromatic nuclei to carbon in aliphatic side chain (Prasad and Kumar, 1989).

The decrease in $E_4/E_6$ ratios on increasing pH above 6.0 appeared to indicate an increase in particle size with increasing pH. Lal and Mishra (1999) reported that, $E_4/E_6$ ratios for lower molecular weight fractions were sensitive to change in pH apparently because they contained more –COOH groups per unit weight than did the higher molecular weight materials. The variations in the $E_4$ / $E_6$ ratios of humic substances of these soils are indicative of the degree of condensation in the aromatic net of carbon atoms in the individual humic and fulvic acid molecules.

Saikh and Chandra (1999) reported that $E_4/E_6$ data of humic substances of Entisol, Alfisol and Vertisol indicate that humic substances of Alfisol is highly humified due to its lower value. HA substance of Entisol contains more carboxyl groups in comparison to phenolic –OH groups due to low humification and short chain polymer humic acid substances (Boul *et al.*, 1980; Stevenson, 1982).

Molecular weight of humic acid did not show any significant association with $E_4$ / $E_6$, phenolic OH and carboxylic acidity (Das *et al.*, 2000). He also reported that based on $E_4$ / $E_6$ ratio the humic acids were humified maximum under vegetable = sal = teak = pine > agroforestry > = fallow = > dairy farming = horticulture > bamboo = pasture. Humic acids with more or less same $E_4$ / $E_6$ ratio showed, morphological similarity irrespective of their origin while humic acids originated under same land use systems were found dissimilar in appearance.

Kar (1998) found that the reduced viscosity against concentration shows that molecules are coiled at high concentration and behave like uncharged polymer and at low concentration, molecules are expanded and behave like charged polymers. The humin residue, HA / FA ratio and $E_4 / E_6$ ratio of HA decreased due to decalcification.

## 2.4. Functional groups of humic acid

The considerable and wide ranging action of humic acid is primarily due to the presence of many functional groups in them, not only such common ones as carboxyls, phenols and alcohols, but also quinones, amines and amides. The diversity and complexity of functions are undoubtedly associated with the polychemical nature of humic substances whose molecules differ in size and functional groups and form a notable range of compounds differing in bonding ability and capacity to complex metal cations (Orlov, 1995).

According to Flaig *et al.* (1975), the C=O content of soil HA is 2.7%. Schnitzer and Gupta (1964) reported values of 5.0 – 5.3 per cent of C=O for HA and 4.8 – 8.4 per cent for FA. Soil humic acid contains 180 –260 meq C=O groups per 100 g (Schnitzer and Skinner, 1966). Theng and Posner (1967) also reported from IR-Spectral analysis not only the presence of carbonyl of COOH groups, but also of keto groups, part of which was hydrogen bonded. Using chemical methods, it was reported 105 meq/100 g of quinoid groups in HA from forest soil and 125 – 340 meq/100 g in HA from peat and coal. According to Naidenova (1968), FA is richer in carboxyl (upto 275 meq/100 g) and phenolic (593 meq/100g) groups than HA.

Schnitzer and Gupta (1964) found that only the COOH, OH and CO groups account for 52 – 75% of the total oxygen of HA and 86 – 100% of the oxygen of FA. The content of functional groups of Haploborale of humic acid were 660 cmol ($p^+$) $kg^{-1}$ of total acidity, 450 cmol ($p^+$) $kg^{-1}$ of COOH, 210 cmol ($p^+$) $kg^{-1}$ of phenolic OH, 280 cmol (p+) $kg^{-1}$ of alcoholic OH, 250 cmol ($p^+$) $kg^{-1}$ of quinonoid C=O, 190 cmol ($p^+$) $kg^{-1}$ of ketonic

C=O and 30 cmol ($p^+$) $kg^{-1}$ of methoxyl groups. The $E_4/E_6$ ratio was 4.3 (Chen *et al.*, 1976).

The content of functional groups was higher in forest surface soils than in cultivated soils (Grace *et al.*, 1986). Ushashree *et al.* (1989) found that, the total acidity, carboxyl and phenolic-OH in lignite humic acid were 5.44, 2.43 and 3.01 meq $g^{-1}$ respectively. Presence of C, H and O was accounted in the form of carboxyl, methoxyl and carbonyl groups strongly conjugated, probably ketonic and chelated to hydroxyls in humic acid was reported by Govindasamy *et al.* (1989). Saha and Sanyal (1988) reported that the contents of carboxyl and phenolic groups in synthetic humic acids ranged from 0.71 to 1.40 and 1.48 to 2.46 meq $g^{-1}$ respectively. The preponderance of phenolic – OH, accompanied by high exchange acidity of humic acids with depth (Udupa *et al.*, 1990).

Humic substances contain per unit weight relatively high concentration of oxygen containing functional groups (COOH, OH and C=O). Through these groups, the organic materials are capable of attacking and degrading soil minerals by complexing and dissolving metals. Fulvic acids were more acidic than humic acids and this acidity was mainly due to the presence of more carboxyl groups (Schnitzer and Gupta, 1964). Soil organic matter is a polymeric weak acid exchanger with carboxyl groups contributing most to the CEC at pH <8. Phenolic hydroxyl groups also contribute to the CEC at pH >7, while other functional groups (alcoholic OH, ketonic OH etc.) contribute only a minor fraction (Stevenson, 1982).

The distribution of oxygen i.e. between 34 and 50 per cent of the total oxygen in the humic acids occurred in carboxyl groups, followed by quinonoidal C=O (16 to 24% of total oxygen) and phenolic OH groups (7-17%). Between 71 and 95 per cent of total oxygen in the HA was in functional groups (Griffith and Schnitzer, 1975). According to

Schnitzer (2000) humic substances contain relatively high concentration of oxygen containing functional groups per unit weight.

## 2.5. Elemental composition of humic acid

According to the analysis done by Sprengel, Hermann, Berzualius and Muldor (1826-1845), the carbon content of humic acids ranges from 56 to 62 per cent, that of hydrogen from 2.5 to 5% and of nitrogen from 2 to 8%. According to Eggertz, humic acids contained 0.6 – 1.1% S and 0.2 – 3.7 per cent P besides C, N, H and O. He also found 5 – 6 per cent Al and Fe oxides, 0.05 – 0.15 per cent Na, up to 0.6% K and traces of Mg and Mn in humic acid.

The variation in the carbon content of HA is very high in all types of soils. The HA of chernozems and humus allophane soils of Japan are noted for their very high C content (about 58 per cent). The lowest C content is the characteristics of HA of sod podzolic soils and podzols (about 53 per cent) for the remaining soils and for HA of plant residues the value is about 55 – 56 per cent (Orlov, 1995). Arya *et al.* (1984) investigated some soils of Uttar Pradesh and reported that humic acid in general contained organic P ranging from 0.5 to 12.8 ppm in surface layer (0-15 cm). The percentage of C, H, S, N and O in humic acid as 61.11, 5.27, 0.66, 0.48 and 24.6 respectively was recorded by Govindasamy *et al.* (1989).

Gupta *et al.* (1989) reported the elemental composition of humic acid of surface soils in respect of weight vis-à-vis atomic ratio of C:N, C:H and O:H. The carbon content ranged from 45.7 to 54.7, H from 4.1 to 8.1, N from 3.9 to 5.4 and O from 35.9 to 42.9 per cent. The percentages of C, H, O, and N of lignite humic acid were 56.3, 4.7, 36.3 and 2.7. The C:N ratio of the above material was 20.0 (Ushashree *et al.*, 1989).

Chandrasekaran (1992) reported that the atomic elementary composition of lignite humic acid are 39.5, 39.8, 19.1, 1.6, 1.01, 0.484 and 24.7 for C, H, O, N, H/C, O/C and C/N ratio in atomic per cent respectively. The contents of C ranged between 52.3 and 56.6 per cent and those of N between 3.2 and 3.9 per cent in humic acids extracted from some soils of the Nile Delta region in Egypt was reported by Abo El-Fadl *et al.,* (1992). Satishkumar (1997) observed that the humic acid extracted from lignite had higher C content of 34.51% and wider C:N ratio of 61.63.

Kadalli *et al.* (2000) reported that, carbon content varied from 38.44 to 42.18 per cent and N content varied from 0.12 to 5.18 per cent in the humic acid extracted from coir dust based compost. The elemental composition of humic acid was $C_{308}$ $H_{334}$ $O_{90}$ $N_5$ with molecular weight of 5540 daltons. The humic acids had higher molecular weight than the corresponding fulvic acid fractions (Sanyal, 2001) due to a greater degree of polycondensation of aromatic rings in humic acids (Stevenson, 1994).

### 2.6. Relationship between organic matter status and humic acid content

Soil organic matter contains 10 per cent humic acid fraction (Palaniappan, 1975) whereas, humic acid was accounted for 18.39 per cent in the soils of Kerala (Ushashree *et al.*, 1989). Humic acid and fulvic acid constitutes 50-80 per cent of soil humus (Felbeck, 1965; Gascho and Stevenson, 1968). The humic acid fraction of soil organic matter ranged from 0.10 to 0.35 per cent with a mean value of 0.21. Humic acids were the first transformation product of soil organic matter whereas fulvic acid was formed by further transformation and destructive synthesis. The review on organic matter status of soils would indirectly give an idea on possible humic acid status.

Thiyagarajan (1998) reported that the organic carbon content of Alfisol and Vertisol profiles of Tamil Nadu uplands surface horizon ranged from 110 to 185 kg $ha^{-1}$ $cm^{-1}$ and 228 to 507 kg $ha^{-1}$ $cm^{-1}$ respectively. Schnitzer (1991) found that the organic matter content of soils ranges from 21 per cent in desert soils and close to 100 per cent in organic soils. The soil organic matter content of agricultural soils usually ranges between 1 and 4 per cent with most soils containing between 2 and 3 per cent (Schnitzer, 2000).

The soil under mixed evergreen forest contains more organic carbon than other sites in the following order. Evergreen forest soil > deciduous forest soil > natural grassland soil > deforested cultivated soil. The quantity of dilute alkali soluble soil humic carbon (humic acid) also follows the same order of soil organic carbon (Saikh, 1999). They also reported that the quantity of soil humin organic carbon was less than the quantity of dilute alkali soluble soil humic organic carbon.

Saikh (1999) reported the positive relationship of organic carbon content and humic acid in various soils of different vegetation. Both the organic carbon and humic acid content followed the same order: Evergreen forest > deciduous forest > natural grassland > deforested cultivated land. The relative content of functional groups in the humus fraction, when totaled, became very close to the values of the functional group content of the whole soil (Sanyal, 2001). The decrease in C/N ratio of humic substances under cultivation suggested accelerated mineralisation of lignins (Martin *et al.*, 1998).

Saikh and Chandra (1999) found that, the organic matter in soils under natural grassland is more highly humified than the organic matter in any other soils. The humification followed the order viz.,Mixed ever green forest soil < deciduous forest soil < deforested cultivated soil < grassland soil (Gupta el al.,1989).

## 2.7. Effect of humic substances on soil properties

### 2.7.1. Effect of humic substances on ion exchange properties

#### 2.7.1.1. *Cation exchange capacity*

Humic matter carries a negative charge and hence contributes towards the CEC of the soil. This charge is due in part to the dissociation of hydrogen ions from carboxylic acids. Also probably in part to their dissociation from phenolic hydroxyls and particularly from groups of the hydroxyls. These groups are in the ortho position with respect to each other on benzene ring for such hydroxlys will begin to dissociate hydrogens at about the same pH as the carboxylic acids become fully dissociated. This is one possible mechanism, which would cause humus to be so evenly buffered over the range of pH values commonly found in agricultural soils.

The exchange capacity of humus is appreciably higher than that of clays being of the order of 200 – 300 milli equivalents per 100 g of dry matter. This has the consequence that the exchange capacities of soils low in clay dependent on their humus content. The oxidised groups responsible for the CEC are mainly in the humic and fulvic acids. An increase in the oxidation and decomposition of the organic matter leads to an increment in the cation exchange capacity (Roig *et al.*, 1988). Cegarra *et al.* (1987) established that, the increase of the CEC of the organic matter in soils is directly related to the degree of humification of this organic matter. The humification process produces functional groups that increase the CEC.

Schnitzer (1965) suggested that two types of CEC for organic matter i.e. measured CEC as determined by exchange with $NH_4^+$, the potential CEC, the sum of the above and CEC of blocked sites are exposed when organic matter extracted from soil. The incorporation of organic matter into soil induces an increase in HAs exchange capacity due in part to functional acid groups present in the organic matter (Lax, 1991). The pH dependence of the CEC of organic matter is approximately 20% of the total CEC of organic matter resulted from strongly ionized acidic groups (Kamprath and Welch, 1962). Phenolic OH groups were more stable than COOH groups.

According to Titova (1970), the exchange capacity of humic acids of the soils of arid steppes was 607-693 meq/100 g, that of fulvic acids 650-668 meq/100g. For humic acids of spruce humus, values in the range of 230-300 meq/100g have been reported (Czerney and Fiedler, 1968), that for brown and pseudogley soils 274-292 meq/100g and for organic matter as a whole of these soils vary from 41 to 195 meq/100g (Hoffmann, 1966).

The soils have low effective cation exchange capacity values, which decreased with depth and depend primarily on the content of organic matter (Mendonca and Rowell, 1996). The CEC of humic acid extracted from Vertic Ustropept soil was 400 cmol $(p^+)$ $kg^{-1}$ (Santhy *et al.*, 2001). The colloidal surfaces of humus are negatively charged ,the sources of the charge being hydroxyl, carboxyl, and phenolic OH groups. The extent of the negative charge is pH dependent (high at high pH values). At high pH values, the CEC of humus on a mass basis (150-300 cmol (p+) $kg^{-1}$) exceeds that of most silicate clay. McLean *et al.* (1965) inferred that the pH dependent CEC varied greatly from one soil to another and was markedly reduced by liming. Removal of organic matter decreased the pH dependent CEC.

#### 2.7.1.2. *Complexing action of humic acid*

Humus forms complexes with clays by the mutual interaction at the exchange sites resulting thereby a reduction in the total exchange capacities of clays and humus separately particularly under acidic conditions (Mattson, 1931). Sen (1960) observed two types of linkages between clay and humus, i.e., one as a coating on the outer most surface of clay and other as a strong bond where clay, humic acid and the added cations were involved. According to Brydon and Sowden (1959) amino groups might be involved in linking humus with clays.

The humic acid molecules were found to play a role in the formation of organo clay or organo metal complexes with the transfer of charge (Swaby and Ladd, 1966) and reaction of organic matter with inorganic constituents (Schnitzer and Skinner, 1965). Rashid (1972) reported that, large concentration of quinone groups play a role in the chelation of metal ions.

The quinone groups associated with humic compounds are believed to participate in several important reactions of geological, geochemical and biological significance. These groups enter into condensation and oxidation-reduction reactions. The reaction of organic matter with inorganic constituents forming organo clay or organo metal complexes with the transfer of charge was also reported by Schnitzer and Skinner (1965).

Properties of soil humic acids due to incorporation of plant materials was studied in black, laterite and red soil. The amount of proton released and the drop in the initial pH of soil humic acids after addition of different metal ions indicated formation of mono-dihydroxy metal-humic acid complexes which were unstable at pH 8.0 and above (Pal, 1992). Varadachari *et al.* (1991) reported that, Al clay probably forms chelates with the COOH and phenolic OH groups of humic acid. The monovalent cations are held primarily by simple cation exchange through the formation of salts with COOH groups, multivalent cations have the potential for forming coordinate linkages with organic molecules.

Stevenson (1982) found the dominant factors influencing the nature of clay-humus complexation i.e., (1) the nature of the clay mineral, (2) environmental conditions such as pH, cations, anions etc. and (3) the nature of the humic substances. The carboxyl and phenolic hydroxyl groups are mainly responsible for the binding of the humic molecules in the clay minerals (Kononova, 1966).

Smaller and more flexible humic molecules form better complexes than do larger and more rigid structures (Varadachari *et al.,* 1984). Nayak *et al.* (1990) reported that, decreasing content of acidic groups in humic substances promotes their fixation by montmorillonite under dry conditions.

Theng and Posner (1967) have observed different types of carboxyl groups i.e., conjugated ketonic carboxyl groups and H bonded conjugated ketonic carboxyl structures involved in the metal humus complexes. Relan *et al.* (1993) reported the infrared spectral studies on the humic and fulvic acid materials derived from FYM revealed the participation of phenolic OH and COOH groups in complexation with $Zn^{2+}$, $Cu^{2+}$, $Mn^{2+}$, $Fe^{2+}$, $Pb^{2+}$ and $Cd^{2+}$.

According to Schnitzer and Schulten (1995), the carbohydrates and proteineous materials are adsorbed on external humic acid surfaces and in internal voids with hydrogen bonds playing a major role in immobilising them. Neto *et al.* (1991) found that, HAs form two types of complexes with $Cu^{2+}$ ions, one with oxygen containing group, while the other with nitrogen containing groups. In general, HA interaction with metal ions in soil solution increased with pH, humic acid concentration, but decreased with metal ion concentration (Spark *et al.*, 1997). Interlayer adsorption of low molecular weight HAs by Zn and Cu- montmorillonite was reported by Manjaiah and Ghosh (1995).

Shuman (1988) observed that increasing organic matter caused Mn and Fe to move from the less soluble forms to more plant available forms. The organic matter exercises in the maintenance of soil fertility through the complexation of trace metals. Potentiometric titrations of the humic acids in the presence of metal cations showed the formation of metal humic acid complexes through the protons released from functional groups of the humic acids by metallic cations (Khan, 1969).

The interaction of metal ions with humic acid causes the displacement of hydrogen from the functional groups and the formation of complex compounds (Beckwith, 1955). Metal ions forming mainly ionic bonds with humic acids (Tollin *et al.*, 1963). Order of complexation of HA substance with soil Ca-clay is Entisol > Vertisol > Alfisol (Stevenson, 1982). The participation of COOH and phenolic OH groups of humic substances in clay humus complexes is widely accepted (Schnitzer and Kodoma, 1969; Greenland, 1971; Orlov *et al.*, 1973; Theng, 1979).

Direct association between the cation and the anionic groups of humus by ionic or covalent linkage has been envisaged (Edwards and Bremner, 1967; Van Dijk, 1971; Stevenson and Ardakani, 1972). The complex formation reactions between metal ions and humic substances are helpful in understanding the problems of plant nutrition. Reddy and Rao (2000) reported that at pH 7.5, Cu has higher tendency to form complex with humic acid.

### 2.7.1.3. *Adsorption and desorption reaction with humic substances*

Some acid soils have large quantities of organic matter, which appears to be stabilized by complexation with Al released into soil solution. The stabilizing effect of Al on SOM is related to the suppression of Al by enzyme activity and substrate degradation rates (Sollins *et al.*, 1996). Gupta *et al.* (1991) reported the adsorption and desorption of less available P and Cu and more available Fe and Al on humic acid that, changes in partial molar free energy and entropy followed the order Fe > Al > Cu > P. As the initial amount increased, the adsorption and desorption increased. The desorption followed the order of P > Al > Cu > Fe. Both adsorption and desorption followed Freundlich and Langmuir isotherms.

Ionisation constant (pKa) values of humic acid decreased with increasing concentration of electrolyte but increased with rise in temperature (Relan *et al.*, 1986). Singh and De (1990) found that $\alpha$ and $\beta$ humic acids produced from basic slags have greater capacity to release more $Cu^{2+}$, $Fe^{2+}$ and $Zn^{2+}$ than those formed from pressmud or molasses.

Mukherjee *et al.* (1975) reported that, adsorption or release of humic acid increase quantitatively with increase in concentration of electrolytes and for the same concentration with increase of ratio. Basak and Ghosh (1999) found that, adsorption of humic acid and fulvic acid was affected by pH and the adsorption increased with decreasing pH. The amount of HA / FA adsorbed decreased with increasing Si /Al molar ratio.

Lakatus *et al.* (1977) observed that $Mn^{2+}$ ions doped with humic acid are coordinated octahedrally with six oxygen containing functional groups viz., carboxylate, phenolic, hydroxyl, carbonyl ligands. Prasad and Sinha (1981) observed that stable complex formation of $Fe^{3+}$, $Cu^{2+}$ and $Zn^{2+}$ with –OH, -$NH_2$ and –COOH ligands of humic acid fractions involved electrovalent and coordinate-covalent bonds. Intensity of absorption bands of molecularly homogenous fractions of humic acid in IR spectra is differing depending upon the functional group content of humic acid fractions.

The X-ray diffractograms of complexes of HA with Cu, Zn and Co montmorillonite indicate entry of some humic acid into the interlayer of minerals (Manjaiah and Ghosh, 1995). Basu *et al.* (1968) reported that, adsorption of metal ions by humic acid is high because of its high exchange capacity, but the major portion of the adsorbed cations can be released in the usual way.

### 2.7.2. Humic acid on nutrient availability in soil

The incorporation of phenolic moieties into young SOM fractions may influence N cycling and the N supplying capacity of low land soils supporting two or three annual crops of irrigated rice (Olk *et al.*, 1996). The application of crop residues of wider C:N ratio are likely to stabilize the N in slowly biodegradable fractions and on a long term can improve the health of the soil.

Tan and Binger (1986) reported that the increase in P availability may be due to chelation of HA with Al rendering it inactive for reaction with P. The metal chelation increases the solubility and retention of micronutrients which are naturally occurring or applied to soils (Allison, 1973). The SOM form stable complexes with metal ions due to its high content of oxygen containing functional groups of various types (Lobartini and Orioli, 1988). Tan (1978) found that humic and fulvic acids released some of the K fixed by montmorillonite or illite.

Vailliancourt *et al.* (1999) reported that, urea forms an additive compound with humic acid with a resultant decrease in exchange capacity. Considerable amount of nitrogen fixed by fulvic acids also reported by Banerjee and Basak (1978). They added that N containing reaction products had higher negative charges and higher electrophoretic mobilities than the original ones. Chemically, humus influences the solubility of certain soil minerals, forming compounds with certain elements, such as iron (Waksman, 1936), Cu, Zn etc. (Vinogradov, 1959) which render them more easily available for plant growth and finally increasing the buffering capacities of the soil (Waksman, 1936). Khan *et al.* (1997) observed that, among the application of varying levels of Ni and Cr, HA complexes in soils enhanced available $NH_4$-N, $NO_2$-N and P at their respective lower concentrations.

Chandrasekharan (1989) revealed that HA addition along with urea retarded the release of available nitrogen. Such retardation was reported to be due to the inhibition of nitrification by the nearly formed quinone from HA (Flaig, 1964). The beneficial influence of HA in soil to prevent the formation of insoluble forms from the added nutrients was reported by Mortensen (1963). Humic acids from different sources varied significantly in their effect on available nutrient status of soils (Pal and Sengupta, 1985).

Prasad *et al.* (1991) observed that the magnitude of nutrient availability increased with the increase in the level of applied tree leaves. Martinez *et al.* (1984) reported that humic acid from lignite solubilized P from phosphorites. At pH 7.0, humic and fulvic acids were capable of dissolving very small amounts of potassium from the minerals by chelation, complex reactions or both. The amounts of nutrient released increased with time (Tan, 1980).

Pandeya and Singh (1997) reported the loss of iron applied to soil through Fe – FA complex. This might be due to surface adsorption of Fe – FA molecules on the solid matrix was mainly through displacement of iron from the fulvic acid ligand by competing cations of soil solution like $Ca^{2+}$, $Mg^{2+}$, $Zn^{2+}$ and $Cu^{2+}$ and subsequent precipitation of iron into various solid phases.

Mary *et al.* (2002b) found that, the application of 30 kg $ha^{-1}$ of HA increased the available N, P, K content in mine spoil areas of Neyveli. The available nutrient status of the post harvest soil increased due to the application of humic acid. Humic substances would have influenced the rate of release of nutrients from soil mineral components (Tan, 1978; Satishkumar *et al.,* 2002b).

Synthetic or natural chelating ligands have been reported to function as sink of micronutrient cations by increasing their solubility and mobility. It also reduces the ill effects of $Ca^{2+}$ ions present in ambient solution supplying nutrients to plants (Dyanand and Sinha, 1979). Pal and Sengupta (1985) observed that when black soil was incubated with humic acid, the availability of K was enhanced. Tan and Nopamornbodi (1979) reported that the increased P availability in soil may be due to interaction of humic acid with P more through its phenolic hydroxyl groups, which may change the behaviour of P.

### 2.7.3. Humic substances on soil physical properties

Soil organic matter, the backbone of soil, contributes significantly to the improvement of soil physical tilth, particularly for maintenance of adequate and stable soil structure by way of acting as a binding agent thereby facilitating aggregate formation. Chaney and Swift (1984) showed significant correlation between aggregate stability and total organic matter, total carbohydrates and humic materials. The humic materials effect on aggregate stability was associated with the time of incubation rather than the amount of materials added (Dinel *et al.*, 1991).

The aggregate effect of HA-Fe associations on kaolin was smaller than that of HA-Al association, which induced formation of aggregates > 100 μm that were essentially absent in the untreated substrate (Arias *et al.*, 1996). Tarchitzky *et al.* (1993) studied humic acid Na montmorillonite suspension and reported that it increased the stability. They attributed the effect to an interaction between the negatively charged HAs and the positively charged edges of soil clay particles.

Visser and Caillier (1988) observed that small concentrations (25 to 100 mg $dm^{-3}$) of HAs dispersed clay particles from a humic gleysol, whereas larger concentrations caused flocculation. Tisdall and Oades (1982) found that, aggregation caused by soil organic matter seems to be favoured by the presence of metal ions, which can act as bridges between the anionic groups of polymeric organic matter and the negatively charged surfaces of clay particles. Shanmuganathan and Oades (1983) found that the addition of organic anions to soil suspension in which the clay had been flocculated with iron poly cations caused the clay to disperse which they attributed to the clay particles having acquired a negative charge due to lowering of PZC.

The hydrophilic character of humic substances was suggested to lead to their ability to adsorb quick substantial amount of water vapour (Chen and Schnitzer, 1976). Chen and Schnitzer (1978) found both fulvic acid and humic acid to be surface tension-reducing agents for water or as materials which can improve the wetting of silicate surfaces by the solutions. They concluded that humic substances would act as water repelling agents in neutral or acid soils, but not at pH greater than 6.5 possibly due to concomitant increased degree of ionisation of weakly acidic functional groups of humic polymers, leading to stronger association with polar water molecules. Bartoli and Phillippy (1990) found that, the polyvalent cations such as $Al^{3+}$ and $Fe^{3+}$ ions enhance the hydrophobic effect of soil humic polymers. Fortun *et al.* (1989) reported the improved soil aggregate stabilising effect of humic substances, extracted from FYM, compared to that of bulk FYM. Whereas Piccolo and Mbagwu (1990) found that not only soil aggregate stability was highly correlated with humic content of soil, but also the larger the molecular size of humic substances, the greater was the stability of micro aggregates.

### 2.7.4. Humic substances on soil microbial population

Humic substances may produce their beneficial influence on microbes in several ways. They can act as a source of food and energy for many microorganisms. The organic fertilisers cause a greater increase in soil microbial biomass than inorganic fertilisers mainly due to an increase in organic C content. The stimulation of growth of some algae may arise from direct heterotrophic use of humic acid or its breakdown products due to microbial decomposition (Giesy, 1976). Humic acid increases biological activity and release nutrients (McLaughlin and Kuster, 1972). Blondeau (1989) concluded that specific microbial strains were capable of mineralizing the complex humus compounds. Khandelwal and Gaur (1980) reported the degradation of humic acid extracted from manure by actinomycetes and fungi. Additional sources of carbon and nitrogen stimulated microbial degradation of humates.

### 2.7.5. Organic substances on soil enzymes

Deepa and Govindarajan (2002) reported that, addition of humic acid to the soil considerably increased the bacterial, fungal and actinomycetes population. The various biochemical processes are mediated by soil enzymes which are derived from micro organisms, plant roots, and soil animals (Tabatabai, 1982). Incorporation of organic materials in soil promotes microbial and soils enzyme activity (Balasubramanian *et al.*, 1972).

Skujins (1976) reported that the total enzyme activity of a soil depends on the level of extra cellular enzymes present, the amount of active enzymes within dead cells, associated cell fragments and the level of activity associated with living cells. Nannipieri *et al.* (1978) suggested that the increase and decrease in soil enzyme activity in glucose amended soil follows a pattern similar to the microbial biomass. Sparling *et al.* (1981) reported that enzyme activity in glucose amended soil increased with increased levels of glucose applied.

The level of soil enzyme activity increases with increasing soil organic matter content (Speir, 1977). This may be related to the population dynamics of the soil microbiota. Enzymes directly contributed by the organic amendment may also influence the soil enzyme activity in soil. Many of these enzymes are important in the formation of recalcitrant organic molecules that contribute to the chemical stability of the soil ecosystem. The activity of soil enzymes may be inhibited by addition of certain organic amendments. Perucci *et al.* (1984) found that, the addition of organic residues inhibited several soil enzymes (Bonmati *et al.*, 1985).

Soil enzyme activities may also be increased by the addition of organic materials (Nannipieri *et al.*, 1983). This increased activity has generally been attributed to the increased microbial biomass although additional evidence has shown that plant materials and sludges may directly contribute enzymes to soil (Frankenberger and Nelson, 1983). Microorganisms associated with organic residues may also contribute to the enzyme pool in soil. Martens et al. (1992) reported that, increase in enzymatic activity upon the first addition of the organic amendments, suggests a trigger molecule or a promoter could have been released by the decay of the organic amendments stimulated soil organisms to secrete high levels of enzymes.

Speir and Ross (1976) suggested that the organic residue decomposing organisms were major contributors to the soil enzyme activity. The continued application of organic amendments did not further promote the soil enzyme activities (Martens *et al.*, 1992). Saha and Shanker (1981) found that organic matter increased the activity of soil catalase and Kalidurai (1988) also reported the increased dehydrogenase activity.

Subramani and Kannaiyan (1989) found that the dehydrogenase activity was increased with the age of rice crop. Vedavyasa and Parvathappa (1989) studied the microbial dehydrogenase activity in soil by the application of farmyard manure. They reporeted that the application of FYM recorded higher dehydrogenase activity followed by the application of both FYM and NPK. Concheri *et al.* (1996) studied the effect of humic fraction on invertase and peroxidase activity in wheat seedlings. It was found that humic fraction stimulated peroxidase and invertase activity. Development of reduced condition due to increased microbial activity during rapid decomposition of organic matter (Hue, 1992).

## 2.8. Effect of humic substances on use efficiency of fertilisers

Mathur and Guar (1977) proved the greater use efficiency of nitrogenous fertilisers with humus, in a pot culture experiment. Ravindraprasad (1988) reported that 1N KCl extractable ammoniacal nitrogen in soil decreased with the days of incubation, while it gradually increased in the treatment with humic acids at 15 kg $ha^{-1}$ in soil incubation experiment. The increased 1N KCl extractable ammoniacal nitrogen in soil may be due to reduced losses of N by volatilization as described by Flaig (1984). The fertilizing effect of lignite is related to its ability to complex iron, which is subsequently made available for absorption by plants (Guminski *et al.*, 1965). Vaughan (1974) reported that humic acid stimulated cell elongation on roots of *Pisum sativum*. Vaughan and Ord (1983) reported that humic acid enhanced hydroxy proline formation either by mechanism which stimulates the enzyme required for the hydroxylation process or land more ferrous iron available for the hydroxylation of proline to hydroxyproline within the tissue.

## 2.9. Humic substances on crop response

### 2.9.1. Growth and yield

Studies on the role of specific humic substances on the growth and development of plants have received considerable attention during the last two decades. Kononova (1966) described that humic compounds enter the plant during the early stage of growth and were additional sources of polyphenols that act as respiratory catalyte. Gaur and Mathur (1966) obtained significantly increased yields and N uptake by rye grains due to application of sodium humate. Gaur and Bhardwaj (1971) reported increased dry matter yield by the application of humic acid.

According to Khristeva (1953), application of small amount of humic acids acts as a hormone and a respiratory catalyst. Increase in dry matter yield with the application of humic acids can be explained on the basis of the fact that enzyme systems are activated, cell division is accelerated and root system shows greater development (Gaur and Mathur, 1966).

Mylonas and McCants (1980) observed that increasing concentrations of humic acids increased positive effect on growth, although higher humic acid concentrations decreased the yield (Kononova and Pankova, 1950). The fresh and dry weights of 20 day old oats increased significantly with an application of 100 mg of humic acid on carbon basis over control (Mishra and Srivastava ,1988). Solaiappan *et al.* (1995) reported that seed soaking in 1.5 % humic acid and foliar spraying of humic acid improved the crop growth and yield of summer irrigated cotton. The fulvic acid and Ca and $NH_4$ fulvates in concentration less than or equal to 20 ppm C significantly increased the dry matter yield, root mass and growth rate of maize (Raina and Goswami ,1988).

Varshney and Gaur (1974) found that spraying of humic acid solution on soybean crop enhanced crop yields. The shoot length increased in 30 days old paddy seedlings (variety IR 50) was due to the application of humic acid (Balasubramanian *et al.*, 1989). Also, the humic acid upto 15 kg $ha^{-1}$ increased dry matter production in paddy variety IR 20 under green house conditions (Ravindraprasad *et al.*, 1989). Sripriya (1993) observed higher grain and straw yield in paddy when humic acid was coated on fertiliser with the concentration of two per cent or applied through soil at 30 kg $ha^{-1}$.

Khunger and Manoharan (2000) indicated that the per cent increase in the yield with humic acid over control for various crops (vegetables, cereals, pulses, oilseeds and flowers) varied from 14-114. Dubrova *et al.* (1984) reported that addition of humic acids to green house tomatoes increased the fruit yield by 17.3-23.0 per cent. Addition of lignite humic acid upto 15 kg $ha^{-1}$ resulted in escalation of the dry matter production (shoot and root) root / shoot ratio and reduction in dry matter weight with the further increase in doses of lignite humic acids (Ravindraprasad *et al.*,1989). Gowrisankaran *et al.* (1989) reported that urea @ 25 kg $ha^{-1}$ with humic acids @ 12 kg $ha^{-1}$ increased DMP of root by 50 per cent.

Chen and Aviad (1985) observed that stimulation of root growth by humic acid generally more apparent than that of shoot growth. The HA could stimulate cell division and volume of interphase nuclei on onion root tips (Gorovaya and Solocha, 1971). Lisiak and Maria (1984) reported that Na-humate lowered the activity of acid phosphates. Root formation of bean seedlings was stimulated and maximised by application of 3000 ppm fulvic acid solutions (Schnitzer and poapst, 1967). O'donnel (1973) has concluded that, sodium humate, leonardite, HA and fulvic acids possess properties that are extremely beneficial to initiation and growth rate of roots on geranium cuttings.

Yadav (1989) reported the increased shoot and root growth by application of HA in maize. Balasubramanian *et al.* (1989) observed the stimulatory effect of humic acid on plant growth character namely root length, shoot length, dry weight of root and shoot, root number and number of root hairs in blackgram. Mallikarjunarao *et al.* (1987) found that humic acid was found to be very effective in increasing the dry matter yield of root and shoot of sorghum with an increase in the level of HA upto 30 kg $ha^{-1}$ and then a decline.

Fortun and Polo (1982) reported that HA and FA enhanced the growth of maize plants in nutrient medium. Lee and Bartlett (1976) reported that foliar spray of HA produced a small increase in dry matter production of maize. The addition of humic acid either alone or in combination with N increased the rice yield over control. Increasing the level of HA upto 30 kg $ha^{-1}$ gradually increased the rice yield but decreased the yield at 40 kg $ha^{-1}$ (Govindasamy and Chandrasekaran, 2002).

Thenmozhi *et al.* (2002a) reported that, soil application of HA @ 20 kg $ha^{-1}$ with 100 per cent recommended dose of fertiliser significantly influenced the growth and yield of groundnut. A highly positive and significant relationship was obtained between humic acid contents of the soil, yield and nutrient uptake by finger millet, maize and cowpea (Santhy *et al.*, 2001). Bama and Selvakumari (2002) reported that, the dose of humic acid for getting maximum and economic yield was 24 and 18.5 kg $ha^{-1}$ respectively in Inceptisol of Tamil Nadu.

### 2.9.2. Humic acid on nutrition of crops

Thangavel and Ramabadran (1993) reported that, Lignite HA (LHA) upto 20 kg ha$^{-1}$ increased the content of total nitrogen levels and thereafter it gradually decreased in IR 50 and IR 20 varieties. Also they reported that, lignite humic acid (LHA) application increased the uptake of various nutrient elements (N, K, and Ca). Humic acid application had a definite input on the protein synthesis and nucleic acid synthesis. (Guminski, 1968). The different humic acids had significant effect on nitrogen and phosphorus uptake by oats. The efficiency indices of various humic acids ranged between 25 and 65 per cent (Mishra and Srivastava, 1988). The humate migrated from one part of the root system into another, contributing to a more intensive absorption of iron. (Aso and Sakai, 1963).

Tan and Nopamornbodi (1979) reported that the moderate application of HA resulted in a significant increase in N content of corn shoots, while large amounts of HA had a tendency to reduce the N concentration. They also reported that, in the presence of HA treatments, P concentration decreased but the differences in K and Mn content were statistically non-significant and the Zn content showed a tendency to increase with increasing application of HA.

Raina and Goswami (1988) reported a significant increase in the uptake of N, P, Cu, Zn and Fe over control upto 20-ppm carbon as humic acid. At higher levels, their uptake declined except for P and Fe, which increased significantly regardless of the rate of fulvic acid application and dry matter yield response. Saalbach (1956) stated that humic acid enhanced the uptake and content of nitrogen in rye. Jelanic *et al.* (1966) reported that HA from lignite increased the P content and uptake in maize plants. Mei *et al.* (1980) reported that HA / FA enhanced P content in tobacco. Yadav (1989) reported that K, Ca and Mg contents were not affected by humic acid treatments. Sripriya (1993) reported that coating of humic acid to fertiliser at 2 per cent recorded higher nitrogen uptake.

Application of 10 kg HA ha$^{-1}$ as potassium humate along with 75 per cent recommended dose of fertiliser was found to increase the crude protein content and mineral nutrition (P, K, Ca., Mg, Zn, Cu, Fe and Mn) of amaranthus (Bama and Selvakumari, 2001). Govindasamy and Chandrasekaran (2002) reported that, addition of humic acid was found to increase the content and enhance the uptake of N, P, K, Ca, Mg, Fe, Mn and Zn by rice.

Mary *et al.* (2002a) found that, the nitrogen and phosphorus uptake by grain and straw of rice (ADT 38) was influenced by the application of lignite humic acid in open cast mine spoil. Soil application of humic acid @ 20 kg ha$^{-1}$ along with 100 per cent recommended dose of fertiliser gave better nutrient content and uptake of major and trace elements in groundnut (Thenmozhi *et al.*, 2002b). Balasubramanian *et al.* (2002) found that, the addition of humic acid increased the nitrogen and magnesium content and uptake in grains and shoots. The content of P in grain was increased by the addition of HA to soil and uptake was higher due to addition of HA to soil + Rhizobium inoculation. Similar treatments increased the uptake of K in grains and shoots whereas content and uptake of Ca were decreased in shoots and increased in grains in soybean.

# MATERIALS AND METHODS

# CHAPTER III

# MATERIALS AND METHODS

Field and pot experiments were conducted to find out the effect of different levels and methods of application of humic acid on growth, nutrition and yield of rice and soil properties. Laboratory studies were carried out to study the effect of humic acid on nutrient release pattern. In addition characterisation of humic acid was also done. Details of the various experiments carried out for the present investigation are given below.

## 3.1. Characterisation of humic acid

The humic acid material obtained from lignite was studied for its various characteristics. (physical, chemical and physico chemical properties). The carbon, hydrogen and nitrogen contents of humic acid sample were analysed in CHN analyser and the difference in the percentage was taken as that of oxygen. The functional groups were identified in Fourier Transform Infrared Spectroscopy (FTIR). The $E_4/E_6$ ratio i.e. degree of aromatisation of humic substances was measured by UV spectrophotometer at 465 and 665 nm wavelength. The CEC of humic acid was estimated by the procedure of Chapman (1965). The total and carboxyl acidity were estimated and the difference then gave the phenol groups (Schnitzer and Gupta, 1965).

## 3.2. Delineation of soils for organic carbon content

To delineate the major soil series of Coimbatore and Bhavanisagar area for the organic carbon content, surface soil samples upto a depth of 15 cm were collected from different places and analysed for the organic carbon by the procedure outlined by Walkley and Black (1934).

## 3. 3. Laboratory investigations

### 3.3.1. Interaction study of humic acid and phosphorus

To study the effect of humic acid on P sorption, laboratory study was conducted. A known quantity of the soil sample (2g) was transferred into polythene bottles containing different concentrations of P (5 to 80 ppm) as $KH_2PO_4$ and humic acid (0 to 40 ppm) as potassium humate. The contents were kept for 24 hours at 25 ° C with 20 ml of 0.01 M $CaCl_2$ for equilibration and then shaken for two hours. The P concentration was determined by following the procedure of Murphy and Riley (1962).

The adsorption data was fitted to the Freundlich and Langmuir equation and adsorption maxima (b) and the bonding energy constant (k) were computed.

Adsorbed $PO_4$ = Added amount remaining in equilibrium solution

$x/m = kc^{1/n}$ (Freundlich,1926)

$C/x/m = 1/kb + C/b$ (Langmuir, 1916 and 1918)

Where,

x/m - Quantity of adsorbate adsorbed per unit of adsorbant (mg $kg^{-1}$)

C - concentration of ions in solution (mg $l^{-1}$)

b - adsorption maxima (mg $kg^{-1}$)

k, n - constants

### 3.3.2. Clay humus complexation

Clay humic acid complex was prepared as per the procedure given by Nayak *et al.* (1990). A known weight of humic acid (50 mg) is dissolved in distilled water (not in

NaOH as described by Nayak *et al.* (1990), since the substance is completely soluble in water). A calculated amount of clay separated from the soil was added with humic acid so as to get clay-humic acid ratio of 20:1. This suspension was equilibrated over night and finally dried under vacuum at room temperature, powdered and stored in a desiccator. The clay humus complex was prepared for Inceptisol as well as for Alfisol and it was subjected to the estimation of CEC to know the effect of humic acid on cation exchange (Chapman, 1965).

### 3.3.3. Nutrient release pattern -Incubation experiment

Incubation experiment was conducted with humic acid in Noyyal series comes under Alfisol soil order. The details of the incubation study carried out are furnished below.

**Treatment structure**

$T_1$ - Control
$T_2$ - 20 kg HA $ha^{-1}$
$T_3$ - 40 kg HA $ha^{-1}$
$T_4$ - 60 kg HA $ha^{-1}$
$T_5$ - 80 kg HA $ha^{-1}$

Design : Completely Randomised Design
Replications : Three
Period of incubation : Three months
Soil type : Typic Haplustalf
Quantity of soil taken : 500 gms/bottle

The soil moisture was maintained at submerged condition throughout the period of incubation (90 days). Soil samples were drawn at fortnightly intervals and analysed for N, P and K contents. The organic carbon, cation exchange capacity, redox potential and electro chemical properties were analysed on 90th day after incubation.

## 3.4. Pot experiment

The soil samples of Noyyal series was collected from the wetlands, TNAU and used for the conduct of pot experiment. Eight kilograms of soil was taken in each pot and humic acid was added as potassium humate. In each pot three hills were planted and grown to maturity. At harvest, the yield of grain and straw were recorded. The treatment details are given below.

| | | |
|---|---|---|
| Location | : | Dept. of Soil Science and Agrl. Chemistry, TNAU |
| Soil type | : | Typic Haplustalf |
| Soil series | : | Noyyal alluvium |
| Soil order | : | Alfisol |
| Crop | : | Rice (ADT 38) |
| Season | : | Rabi 2000-01 |
| Design | : | Completely Randomised Design |
| Replications | : | Three |

**Treatment details**

**Fertiliser levels**

$M_1$ - No fertiliser

$M_2$ - 75% recommended dose of NPK

$M_3$ - 100% recommended dose of NPK

**Humic acid levels**

$S_1$ - No humic acid (HA)

$S_2$ - 10 kg HA $ha^{-1}$

$S_3$ - 20 kg HA $ha^{-1}$

$S_4$ - 30 kg HA $ha^{-1}$

$S_5$ - 40 kg HA $ha^{-1}$

$S_6$ - $S_2$ + 0.1% Foliar spray

$S_7$ - $S_2$ + 0.3% Root dipping

$S_8$ - $S_6$ + 0.3% Root dipping

## 3.5. Field experiments

### 3.5.1. Field experiments with rice during rabi season (2000-01)

| **Particulars** | **Location I** | **Location II** |
|---|---|---|
| Place | Wet lands , Coimbatore | ARS, Bhavanisagar |
| Soil type | Typic Haplustalf | Typic Ustropept |
| Soil series | Noyyal | Irugur |
| Soil order | Alfisol | Inceptisol |
| Crop | Rice (ADT 36) | Rice (ADT 38) |
| Design | Split plot | Split plot |
| Replications | Three | Three |
| Plot size | 4m ×5m | 4m×5m |

**Treatment structure**

**Main plot treatments**

$M_1$ - No fertiliser

$M_2$ - 75% recommended dose of NPK

$M_3$ - 100% recommended dose of NPK

**Sub plot treatments**

$S_1$ - No humic acid (HA)

$S_2$ - 10 kg HA ha$^{-1}$

$S_3$ - 20 kg HA ha$^{-1}$

$S_4$ - 30 kg HA ha$^{-1}$

$S_5$ - 40 kg HA ha$^{-1}$

$S_6$ - $S_2$ + 0.1% Foliar spray

$S_7$ - $S_2$ + 0.3% Root dipping

$S_8$ - $S_6$ + 0.3% Root dipping

### 3.5.2. Field experiment with rice during kharif season (2001-02)

| **Particulars** | **Location I** | **Location II** |
|---|---|---|
| Place | Wet lands , Coimbatore | ARS, Bhavanisagar |
| Soil type | Typic Haplustalf | Typic Ustropept |
| Soil series | Noyyal | Irugur |
| Soil order | Alfisol | Inceptisol |
| Crop | Rice (ADT 36) | Rice (ADT 36) |
| Design | Split plot | Split plot |
| Replications | Three | Three |
| Plot size | 4m ×5m | 4m ×5m |

**Treatment structure**

**Main plots**

$M_1$ - 75% recommended dose of NPK

$M_2$ - 100% recommended doss of NPK

**Sub plots**

$S_1$ - No humic acid

$S_2$ - 0.1 per cent foliar spray (FS)

$S_3$ - 0.3 per cent root dipping (RD)

$S_4$ - 10 kg HA $ha^{-1}$

$S_5$ - $S_4 + S_2$

$S_6$ - $S_4 + S_3$

$S_7$ - $S_4 + S_2 + S_3$

$S_8$ - 20 kg HA $ha^{-1}$

$S_9$ - $S_8 + S_2$

$S_{10}$ - $S_8 + S_3$

$S_{11}$ - $S_8 + S_2 + S_3$

### 3.5.3. Test verification trial

Based on the results of kharif season, best treatments were selected and tried at Wet lands, TNAU, Coimbatore. Adopting all the improved package of practices, the crop was grown to maturity and harvested. The yield of grain and straw were recorded. The details of the experiment are given below.

| | |
|---|---|
| Location | : Wet lands , TNAU, Coimbatore |
| Soil type | : Typic Haplustalf |
| Soil series | : Noyyal |
| Soil order | : Alfisol |
| Crop | : Rice (CO43) |
| Season | : Rabi 2002 |
| Design | : RBD |
| Treatments | : Nine |
| Replications | : Three |
| Plot size | : 4m×5m |

**Treatment structure**

| | | |
|---|---|---|
| $T_1$ | - | (No fertiliser) Control |
| $T_2$ | - | 75% recommended dose of NPK |
| $T_3$ | - | 100% recommended dose of NPK |
| $T_4$ | - | 10 kg HA $ha^{-1}$ + 0.1per cent HA as FS + 0.3 per cent HA as RD |
| $T_5$ | - | 20 kg HA $ha^{-1}$ + 0.1per cent HA as FS + 0.3 per cent HA as RD |
| $T_6$ | - | $T_2 + T_4$ |
| $T_7$ | - | $T_3 + T_4$ |
| $T_8$ | - | $T_2 + T_5$ |
| $T_9$ | - | $T_3 + T_5$ |

### 3.5.4. Field experiment with rice for optimisation of humic acid in Inceptisol

With a view to ascertain the pattern of response of rice to humic acid, graded levels of humic acid were tried in this experiment. The details of the experiment are given below.

| | | |
|---|---|---|
| Location | | ARS, Bhavanisagar |
| Soil type | : | Typic Ustropept |
| Soil order | : | Inceptisol |
| Crop | : | Rice ADT 36 |
| Season | : | Kharif 2001-02 |
| Design | : | Randomised Block Design |
| Treatments | : | Six |
| Replications | : | Three |
| Plot size | : | 4m×5m |

**Treatment (with recommended dose of fertiliser)**

$T_1$ - No HA

$T_2$ - 10 kg HA $ha^{-1}$

$T_3$ - 20 kg HA $ha^{-1}$

$T_4$ - 30 kg HA $ha^{-1}$

$T_5$ - 40 kg HA $ha^{-1}$

$T_6$ - 50 kg HA $ha^{-1}$

### 3.6. Collection of soil and plant samples

Soil samples were collected initially and at fortnightly intervals from the incubation experiment. From the pot experiment with rice, soil and plant samples were drawn after the harvest of crops. In the field experiments with rice, soil and plant samples were collected at tillering, flowering and harvest stages for the analysis of major and micronutrients.

### 3.7. Preparation of soil and plant samples

The soil samples collected from all the experiments were air dried. The clods were gently broken using wooden mallet and sieved through two mm sieve. The processed samples were stored in polythene bags. The plant samples were first air dried and then in an electric oven at 65 $^0$ C for 72 hours. The oven dried samples were powdered and used for analysis.

### 3.8. Application of humic acid

#### Soil application

Humic acid as potassium humate was applied to soil before transplanting by mixing with sand.

### Foliar spray

Foliar spray (0.1 per cent) was given during tillering stage (15 DAP) by dissolving the required amount of humic acid as potassium humate in water.

### Root Dipping

Root dipping of rice seedlings in humic acid was done 30 minutes before transplanting with 0.3 % humic acid solution.

### 3.9. Biometric observation

The following growth and yield parameters were recorded in the experiments

### 3.9.1. Growth attributes

1. Root length (cm)
2. Root volume ($cm^3$)

### 3.9.2. Yield attributes

1. Panicle length (cm)
2. Number of panicles per hill
3. Number of filled grains per panicle
4. Thousand grain weight (g)
5. Number of chaffy grains per panicle

### 3.10. Analysis of soil and plant samples

The soil was analysed for various physical and chemical properties and plant samples were analysed for their chemical constituents. The procedures for the estimation of various parameters are given in the Table 1.

### 3.10.Statistical analysis

The results recorded in various experiments were statistically analysed for drawing out definite conclusions (Panse and Sukhatme, 1967).

### 3.12. ECONOMIC ANALYSIS

1. Benefit cost ratio (BCR)

$$\frac{\text{Benefit}}{\text{Cost}} = \frac{\text{Yield in kg ha}^{-1} \text{ x cost per kg of rice}}{\text{Cost of the fertilisers + cost of humic acid applied + cost of cultivation.}}$$

2. Response ratio(kg kg$^{-1}$) $= \dfrac{\text{Yield in treated plots – Yield in control}}{\text{Quantity of nutrient applied}}$

3. Relative agronomic efficiency (RAE)

$$= \frac{\text{Incremental yield of test treatment over control}}{\text{Incremental yield of conventional treatment over control}} \text{ x } 100$$

4. Relative economic efficiency (REE)

$$= \frac{\text{Net profit difference of test treatment over control}}{\text{Net profit difference of conventional treatment over control}} \text{ x } 100$$

5. Price ratio

$$= \frac{\text{Cost of conventional treatment}}{\text{Cost of test treatment}}$$

**Table 1. Methods of analysis of soil and plant samples**

| Determinations | Method | Reference |
|---|---|---|
| **A.Physical properties** | | |
| Particle size distribution | Robinson International pipette | Piper (1966) |
| **B.Chemical properties** | | |
| Organic carbon | Chromic acid wet digestion method | Walkley and Black (1934) |
| Total nitrogen | Auto analyser | |
| Total phosphorus | Ammonium phospho molybdate | Pemberton (1945) |
| Total potassium | Flame photometry | Stanford and English (1949) |
| Total calcium | Versenate titration (HCl extract) | Jackson (1973) |
| Total magnesium | Versenate titration (HCl extract) | Jackson (1973) |
| Available nitrogen | Alkaline permanganate method | Subbiah and Asija (1956) |
| Available phosphorus | 0.5 M $NaHCO_3$ (pH 8.5) | Olsen *et al.* (1954) |
| Available potassium | Neutral Normal Ammonium acetate | Stanford and English (1949) |
| Exchangeable calcium | Versenate titration (Neutral Normal Ammonium acetate extract) | Jackson (1973) |
| Exchangeable magnesium | Versenate titration (Neutral Normal Ammonium acetate extract) | Jackson (1973) |
| **C. Physico-chemical Properties** | | |
| Soil reaction (pH) | Potentiometry (1:2.5 soil water suspension) | Jackson (1973) |
| Electrical conductivity (EC) | Conductometry (1:2.5 soil water suspension) | Jackson (1973) |
| Cation exchange capacity (CEC) | Neutral Normal Ammonium acetate | Jackson (1973) |
| **Plant analysis** | | |
| Nitrogen | Micro-kjeldahl (Diacid extraction) | Humphries (1956) |
| Phosphorus | Vanadomolybdate yellow colour in $HClO_4$ system (Triple acid extraction) | Jackson (1973) |
| Potassium | Flame photometry (Triple acid extract) | Toth and Prince (1949) |
| Calcium | Versenate titration (Triple acid extract) | Jackson (1973) |
| Magnesium | Versenate titration (Triple acid extract) | Jackson (1973) |
| Micronutrients (Iron, Zinc, Manganese and Copper) | Atomic absorption Spectrophotometer | Lindsay and Norvell (1978) |

# RESULTS

# CHAPTER IV

# RESULTS

To study the influence of humic acid as potassium humate on soil properties, growth, yield and nutrition of rice, various experiments were conducted. Laboratory studies were carried out to find out the effect of humic acid on nutrient release pattern in Noyyal Alluvium (Typic Haplustalf). Pot and field experiments were conducted to study the rice response to the application of humic acid at graded levels with and without NPK fertilisers. The results recorded in the above experiments are presented in this chapter.

## 4.1. General characteristics of experimental soils (Table 2)

The physical, chemical and physico-chemical properties of the soils of field experiments conducted at Coimbatore and Bhavanisagar are given below:

### 4.1.1. Alfisol - Noyyal series

The experimental soil of the wetlands, Tamil Nadu Agricultural University, Coimbatore was clay loam in texture with the pH and EC of 8.0 and 0.32 dSm$^{-1}$ respectively. The taxonomy of the soil was Typic Haplustalf. The organic carbon content and CEC of the soil were 0.706 per cent and 26.7 cmol (p$^+$) kg$^{-1}$ respectively. The soil was low in $KMnO_4$-N (238 kg ha$^{-1}$), medium in Olsen-P (19 kg ha$^{-1}$) and high in $NH_4OAc$ K (670 kg ha$^{-1}$). The exchangeable Ca, Mg, Na and K were 16.5, 7.1, 2.3 and 1.3 cmol (p$^+$) kg$^{-1}$ respectively. The contents of DTPA-Zn, Fe, Mn and Cu were 3.8, 36.2, 7.8 and 16 ppm respectively. The content of micronutrients was found to be more than the critical limits. The humic acid content of initial soil was 0.252 per cent.

**Table 2. Initial characteristics of soil**

| Properties | Coimbatore | Bhavanisagar |
|---|---|---|
| **Physical properties** | | |
| Clay(%) | 28.2 | 15.8 |
| Silt(%) | 11.2 | 10.3 |
| Fine sand (%) | 16.2 | 41.5 |
| Coarse sand (%) | 44.5 | 31.6 |
| Textural class | Clay loam | Sandy loam |
| Bulk density(Mg $m^{-3}$) | 1.28 | 1.33 |
| Pore space(%) | 48.2 | 31.0 |
| MWHC(%) | 52.5 | 29.7 |
| **Physico-chemical properties** | | |
| PH | 8.0 | 7.7 |
| EC($dSm^{-1}$) | 0.32 | 0.30 |
| CEC(cmol (p+) $kg^{-1}$) | 26.7 | 19.5 |
| **Chemical properties** | | |
| Organic carbon (%) | 0.709 | 0.580 |
| Humic acid content(%) | 0.252 | 0.240 |
| Total N(%) | 0.07 | 0.04 |
| Total P(%) | 0.08 | 0.05 |
| Total K(%) | 0.32 | 0.17 |
| Available N(kg $ha^{-1}$) | 238 | 198 |
| Available P(kg $ha^{-1}$) | 19 | 16 |
| Available K(kg $ha^{-1}$) | 610 | 170 |
| Exchangeable Ca (cmol(p+) $kg^{-1}$) | 16.5 | 11.0 |
| Exchangeable Mg (cmol(p+) $kg^{-1}$) | 7.1 | 4.5 |
| Exchangeable Na (cmol(p+) $kg^{-1}$) | 2.3 | 1.1 |
| Exchangeable K (cmol(p+) $kg^{-1}$) | 1.3 | 1.5 |
| Micronutrients | | |
| DTPA Zn(ppm) | 3.8 | 5.2 |
| DTPA Fe(ppm) | 36.2 | 52.0 |
| DTPA Cu(ppm) | 16.0 | 6.2 |
| DTPA Mn (ppm) | 7.8 | 3.0 |

### 4.1.2. Inceptisol - Irugur series

The soil of the experimental field at Agricultural Research Station, Bhavanisagar was sandy loam in texture with a pH and EC of 7.7 and 0.30 $dSm^{-1}$ respectively. The soil taxonomy was Typic Ustropept. The soil contains 0.58 per cent organic carbon and the cation exchange capacity was 19.5 cmol $(p^+)$ $kg^{-1}$. The soil was low in $KMnO_4$-N (198 kg $ha^{-1}$), medium in Olsen-P (16 kg $ha^{-1}$) and medium in $NH_4OAc$-K (170 kg $ha^{-1}$). The exchangeable Ca, Mg, Na, and K content of the soil were 11.0, 4.5, 1.1 and 1.5 cmol $(p^+)$ $kg^{-1}$ respectively. The content of DTPA extractable Zn, Fe, Cu and Mn of the soil were 5.2, 52.0, 6.2 and 3.00 ppm respectively. The micronutrients content were found to be above the critical limits. The humic acid content of the initial soil was 0.240 per cent.

## 4.2. Characteristics of potassium humate (Table 3)

### 4.2.1. General characteristics

The humic acid as potassium humate obtained from the lignite was analysed for physical, physico-chemical and chemical properties. The humic acid content of the potassium humate used for the experiments ranged from 22 to 65 per cent. From the results it was shown that the bulk density of the potassium humate ranged from 0.606 to 0.716 Mg $m^{-3}$. The pH of the samples was found to be normal to alkaline. The organic carbon content of the material ranged from 28.9 to 33.8 per cent. The CEC was 103 -125 cmol $(p^+)$ $kg^{-1}$. The content of exchangeable K, Ca, Mg and Na ranged from 100.2 to 121.8, 2.80 to 3.08, 0.615 to 0.705 and 0.59 to 0.63 cmol $(p^+)$ $kg^{-1}$ respectively. The total K (6.3 to 7.7 per cent) was higher than total P (0.002 to 0.007 per cent) and N (0.28 to 0.38 per cent). Total Ca, Mg and S content of the material ranged from 0.73 to 0.80, 0.024 to 0.027 and 0.55 to 0.58 per cent respectively. Among the micronutrients, the total Fe recorded 921 to 2406 ppm and it was followed by Mn (750 to 790 ppm), Zn (100 to 321 ppm) and Cu (20 to 22 ppm).

**Table 3. Characteristics of lignite humic acid as potassium humate**

| Characteristics | I | II |
|---|---|---|
| Humic acid content(%) | 22.75 | 65 |
| pH | 8.0 | 7.4 |
| EC(dsm$^{-1}$) | 0.04 | 10.3 |
| Organic carbon(%) | 28.9 | 33.8 |
| CEC(cmol (p+) kg$^{-1}$) | 103 | 125 |
| **Exchangeable cations** | | |
| K (cmol p(+) kg$^{-1}$) | 100.2 | 121.8 |
| Ca (cmol p(+) kg$^{-1}$) | 3.08 | 2.76 |
| Mg (cmol p(+) kg$^{-1}$) | 0.615 | 0.705 |
| Na (cmol p(+) kg$^{-1}$) | 0.63 | 0.59 |
| Bulk density(Mg m$^{-3}$) | 0.606 | 0.716 |
| Buffering capacity (cmol p(+) kg$^{-1}$ | 14.2 | 21.5 |
| Total acidity (cmol p(+) kg$^{-1}$) | 890 | 820 |
| COOH groups (cmol p(+) kg$^{-1}$) | 45 | 40 |
| Phenolic groups (cmol p(+) kg$^{-1}$) | 845 | 780 |
| $E_4/E_6$ ratio | 2.20 | 6.95 |
| Total N (%) | 0.28 | 0.38 |
| Total P (%) | 0.002 | 0.007 |
| Total K (%) | 6.25 | 7.72 |
| Total Ca (%) | 0.8 | 0.73 |
| Total Mg (%) | 0.024 | 0.027 |
| Total S (%) | 0.55 | 0.58 |
| Total Fe (ppm) | 2406 | 921 |
| Total Zn (ppm) | 100 | 321 |
| Total Cu (ppm) | 20 | 22 |
| Total Mn (ppm) | 750 | 790 |
| **Elemental composition** | | |
| Total C | 49.1 | 53.9 |
| Total H | 4.10 | 4.24 |
| Total N | 3.52 | 3.20 |
| Total O | 43.3 | 38.3 |
| C/H ratio | 12.0 | 12.7 |
| C/N ratio | 11.4 | 14.9 |
| O/C ratio | 0.88 | 0.71 |
| O/H ratio | 10.6 | 9.1 |

### 4.2.2. Elemental composition of potassium humate

Analysis was carried out using a Heraeus Elemental analyzer (CHN-O-RAPID), to determine the per cent composition of C, H, O and N (Table 3). The total carbon content ranged from 49.1to 53.9 per cent. The total N ranged from 3.2 to 3.6 per cent. The total H ranged from 4.1 to 4.2 per cent and total O ranged from 43.3 to 38.3 per cent. The atomic ratios of C: H, C: N, O: C and O: H ranged from 12.0 to 12.7, 11.4 to 14.9, 0.8 to 0.7 and 10.6 and 9.1 respectively.

### 4.2.3. Functional group analysis

The potassium humate was analysed to find out and quantify the reactive functional groups. The total acidity of potassium humate ranged from 820 to 890 cmol (p+) kg$^{-1}$ (Table 3). The carboxyl and phenolic groups of the potassium humate ranged from 40 to 45 and 780 to 845 cmol (p+) kg$^{-1}$.

### 4.2.4. Spectrophotometric studies

The optical density was determined with Visible Spectrophotometer in the visible region of spectrum. The absorbance at 465 ($E_4$) and 665 nm ($E_6$) were assessed. From these values the ratio of extinction co-efficient 'E' was determined. The ratio between $E_4$ / $E_6$ was found to range from 1.99 to 2.20 (Table 3). Adopting Fourier Transform Infrared Spectrophotometry (FTIR), the IR spectrum of HA as potassium humate was obtained. Typical IR spectra of materials used for the study are given in Fig. (1a and 1b). The Main absorption bands are in the region of 3747 cm$^{-1}$, 3443 cm$^{-1}$, 2920 cm$^{-1}$, 2360 cm$^{-1}$, 1500 cm$^{-1}$ and 1030 cm$^{-1}$ also the bands at 791, 668, 617, 538 and 471 cm$^{-1}$ were observed.

## 4.3. Delineation of western zone for organic carbon status

One of the objectives of this study is to delineate organic carbon (OC) content. To fulfill this objective the organic carbon was estimated in soil samples collected from parts of Coimbatore and Erode districts representing Western zone of Tamil Nadu. During the period, 109 soil samples collected from depth of 15 cm were analysed for organic carbon status. The data are furnished in the Table 4. The details of the soil samples collected for organic carbon delineation are given in the annexure I (A and B)

### 4.3.1. Coimbatore district

The organic carbon content of Coimbatore district was estimated from the surface soil samples collected from different locations. Among the 89 samples collected, only four samples represent high, 24 samples represent medium and 61 samples represent low organic carbon status of soil. The average organic carbon content was 0.416 per cent.

### 4.3.2. Erode district

The Bhavanisagar area is the part of Erode district covering the major agriculture crops. Among the soil samples collected from this area (20 locations), the 11 samples were represent low, 5 samples represent medium and 4 samples represent high organic carbon status. The minimum, maximum, mean and range of organic carbon present in the soils are furnished in Table 4. The results showed that the organic carbon content of Bhavanisagar area ranged from 0.13 to 1.43 per cent.

Table 4. Delineation of Organic carbon for western zone of Tamil Nadu

| Districts | No. of soil samples | Organic carbon content(%) | | | Organic carbon status(Nos) | | |
|---|---|---|---|---|---|---|---|
| | | Minimum | Maximum | Mean | Low | Medium | High |
| Erode | 20 | 0.130 | 1.430 | 0.470 | 11 | 5 | 4 |
| Coimbatore | 89 | 0.057 | 1.040 | 0.416 | 61 | 24 | 4 |

**Table 6. Cation exchange capacity of clay as influenced by humic acid**

| **Particulars** | **CEC** | |
|---|---|---|
| | Clay alone | Clay humus complex |
| Alfisol | 44.80 | 46.61 |
| Inceptisol | 40.22 | 43.48 |

## 4.4. Laboratory studies

### 4.4.1. Effect of humic acid on P sorption

An incubation experiment was conducted with different doses of HA (0,10,20,40 and 80 ppm). The soil sample used for the study was Typic Haplustalf. The result obtained from the P sorption experiment showed that, the amount of P adsorbed was higher in soils not treated with humic acid. As the concentration of P increased, the adsorbed P also increased in all the HA doses.

The data has been fitted in Langmuir and Freundlich equation. The various sorption parameters were calculated and given in Table 5. The bonding energy co-efficient ranged from 0.38 to 0.522 for Freundlich equation and 1.149 to 0.564 for Langmuir equation. The range of adsorption maxima was 2.618 to 4.045 in Freundlich equation. The adsorption capacity of Langmuir equation ranged from 28.3 to 33.9. The $r^2$ values ranged from 0.9175 to 0.9998 and 0.9592 to 0.9850 recorded in Freundlich and Langmuir equations respectively.

Though the P sorption data confirmed to both Langmuir and Freundlich equation based on their $r^2$ values, the discussion was restricted to Langmuir equation only. Because it fitted well in all the HA doses as compared to Freundlich equation. In case of Langmuir equation, the bonding energy was the highest in no humic acid treatment (1.149) followed by 10 kg HA $ha^{-1}$(0.807), 20 kg HA $ha^{-1}$(0.741), 30 kg HA $ha^{-1}$(0.564) and 40 kg HA $ha^{-1}$ (0.695). The lowest adsorption maxima was recorded in 40 kg HA $ha^{-1}$followed by no humic acid (28.3), 10 kg HA (29.57), 20 kg HA (32.03) and 30 kg HA (33.90).

**Table 5. Effect of humic acid on equilibrium sorption parameters of P in Alfisol**

| Treatments HA(kg $ha^{-1}$) | Freundlich equation | | | | Langmuir equation | | | |
|---|---|---|---|---|---|---|---|---|
| | Adsorption maximum (n) | Bonding energy co-efficient (K) | $R^2$ | Equation | Adsorption maximum | Bonding energy co-efficient | $R^2$ | Equation |
| 0 | 2.618 | 0.380 | 0.9998 | $Y=0.4179x+1.0997$ | 28.30 | 1.149 | 0.9734 | $Y=0.0353x+0.031$ |
| 10 | 3.824 | 0.570 | 0.9358 | $Y=0.5825x+1.0216$ | 29.57 | 0.807 | 0.9855 | $Y=0.0338x+0.042$ |
| 20 | 4.045 | 0.586 | 0.9299 | $Y=0.6069x+1.0364$ | 32.03 | 0.741 | 0.983 | $Y=0.0312x+0.042$ |
| 30 | 3.858 | 0.573 | 0.9391 | $Y=0.5864x+1. 0243$ | 33.90 | 0.564 | 0.9705 | $Y=0.030x+0.052$ |
| 40 | 3.188 | 0.522 | 0.9175 | $Y=0.5035x+0.9649$ | 28.01 | 0.695 | 0.9592 | $Y=0.036x+0.051$ |

### 4.4.2. Effect of humic acid on the ion exchange properties of clay samples

The clay humus complex was prepared by 20:1 ratio. The CEC of clay alone and clay humus complex were estimated and the results are given in Table 6. The results showed that, the clay humus complex recorded higher CEC than clay. Addition of humic acid increased the CEC of the complex from 44.8 to 46.61 cmol (p+) $kg^{-1}$ for Alfisol and 40.22 to 43.38 cmol (p+) $kg^{-1}$ for Inceptisol.

### 4.4.3. Effect of humic acid on nutrient release pattern

An incubation experiment was conducted to study the influence of humic acid on major nutrients release, organic carbon content and CEC of the soil. The humic acid as potassium humate was added at graded doses (20 to 80 kg $ha^{-1}$). The soil belongs to Noyyal series (Typic Haplustalf). The treated soils were incubated for a period of three months by maintaining the soil moisture at submerged condition. The soil samples were drawn at fortnight intervals and $KMnO_4$-N, Olsen-P and $NH_4$ OAc-K were estimated. The organic carbon, CEC, pH, EC and Eh were estimated using the soil samples drawn at 90th day of incubation.

#### 4.4.3.1. Available nitrogen ($KMnO_4$-N)

The initial $KMnO_4$-N content of the soil was 240 kg $ha^{-1}$. Application of HA at graded doses recorded 267,269,271 and 271kg $ha^{-1}$ of $KMnO_4$-N for the application of 20 40, 60 and 80 kg HA $ha^{-1}$ respectively (Table 7). The increase in $KMnO_4$-N content was significant only up to 20 kg HA $ha^{-1}$. Thereafter the differences were not statistically significant.

Regarding the period of incubation, the results indicated significant increase at each stage. The content of $KMnO_4$-N was 253, 262, 273 and 278 kg $ha^{-1}$ on 15, 30, 45 and 60

Table 7. Effect of humic acid on $KMnO_4$-N content in Alfisol

| Treatments HA(kgha$^{-1}$) | Days after incubation(S) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0($S_1$) | 15($S_2$) | 30($S_3$) | 45($S_4$) | 60($S_5$) | 75($S_6$) | 90($S_7$) | Mean |
| 0($L_1$) | 240 | 246 | 250 | 260 | 267 | 272 | 275 | 259 |
| 20($L_2$) | 240 | 251 | 263 | 275 | 277 | 282 | 284 | 267 |
| 40($L_3$) | 240 | 255 | 264 | 277 | 279 | 282 | 286 | 269 |
| 60($L_4$) | 240 | 257 | 266 | 278 | 282 | 285 | 288 | 271 |
| 80($L_5$) | 240 | 258 | 266 | 277 | 283 | 285 | 287 | 271 |
| **Mean** | 240 | 253 | 262 | 273 | 278 | 281 | 284 | 267 |

| | CD ($p$=0.05) |
|---|---|
| T | 2.5 |
| S | 3.5 |
| T at S | 8.5 |

Table 8. Effect of humic acid on Olsen-P content in Alfisol

| Treatments HA(kgha$^{-1}$) | Days after incubation(S) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0($S_1$) | 15($S_2$) | 30($S_3$) | 45($S_4$) | 60($S_5$) | 75($S_6$) | 90($S_7$) | Mean |
| 0($L_1$) | 14.5 | 15.0 | 15.4 | 16.3 | 17.0 | 19.6 | 18.0 | 16.3 |
| 20($L_2$) | 14.5 | 15.3 | 16.5 | 17.6 | 18.6 | 18.9 | 18.8 | 17.2 |
| 40($L_3$) | 14.5 | 15.7 | 16.9 | 17.8 | 19.5 | 20.1 | 20.5 | 17.9 |
| 60($L_4$) | 14.5 | 16.2 | 17.3 | 18.5 | 19.8 | 20.5 | 21.2 | 18.3 |
| 80($L_5$) | 14.5 | 16.8 | 17.9 | 18.7 | 19.8 | 20.9 | 21.8 | 18.6 |
| **Mean** | 14.5 | 15.8 | 16.8 | 17.8 | 19.0 | 19.6 | 20.1 | 17.6 |

| | CD ($p$=0.05) |
|---|---|
| T | 0.6 |
| S | 0.7 |
| T at S | 1.7 |

days after incubation (DAI). The increase in $KMnO_4$-N content was statistically significant upto 60 kg ha$^{-1}$. Thereafter on 75 and 90 DAI the $KMnO_4$-N contents were only 281 and 284 kg ha$^{-1}$. The increase in N availability after 75 th day did not attain the level of significance. Among the interactions, 60 kg HA ha$^{-1}$ on 90 DAI ($L_4S_7$) recorded the highest $KMnO_4$-N content of 288 kg ha$^{-1,}$ which was found to be on par with 40 kg HA ha$^{-1}$ on 90th day ($L_3$ $S_7$) (286 kg ha$^{-1}$).

### 4.4.3.2. Available phosphorus (Olsen-P)

The Olsen-P content of the initial soil was 14.5 kg ha$^{-1}$. The humic acid application @ 20, 40, 60 and 80 kg ha$^{-1}$ recorded 17.2, 17.9, 18.3 and 18.6 kg ha$^{-1}$ of Olsen-P respectively (Table 8). The significant increase in Olsen-P was recorded upto 40 kg ha$^{-1}$. Thereafter only nonsignificant difference was observed. The data on the period of incubation showed significant increase of Olsen-P at each stage. The increase in Olsen-P recorded at 15, 30, 45, and 60 DAI were 15.8,16.8,17.8, and 19.0 kg ha$^{-1}$ respectively. The Olsen-P recorded after the 60 DAI was not statistically significant. The interaction between HA application and days after incubation indicated that on 90 DAI with HA @ 80 kg ha$^{-1}$ ($L_5$ $S_7$) recorded the maximum Olsen-P content of 21.8 kg ha$^{-1}$ which was on par with $L_4S_7$ (21.2 kg ha$^{-1}$), $L_5S_6$ (20.6 kg ha$^{-1}$) , $L_4S_6$ (20.5 kg ha$^{-1}$) and $L_3S_6$ (20.1 kg ha$^{-1}$).

### 4.4.3.3. Available potassium ($NH_4$ OAc-K)

The initial $NH_4$ OAc-K content of the soil was 440 kg ha$^{-1.}$ The application of graded levels of humic acid recorded 471, 475, 476 and 476 kg ha$^{-1}$ of NH4 OAc-K for 20, 40, 60 and 80 kg ha$^{-1}$ of HA respectively (Table 9).

Regarding the effect of period of incubation, the results showed significant increase upto 45 day of incubation. The per cent increase of $NH_4$ OAc-K was 5.0 and 7.4 on 15 and

**Table 9. Effect of humic acid on $NH_4OAc$-K content in Alfisol**

| Treatments HA(kgha$^{-1}$) | Days after incubation (S) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0($S_1$) | 15($S_2$) | 30($S_3$) | 45($S_4$) | 60($S_5$) | 75($S_6$) | 90($S_7$) | Mean |
| 0($L_1$) | 440 | 450 | 455 | 469 | 472 | 475 | 477 | 464 |
| 20($L_2$) | 440 | 460 | 471 | 479 | 479 | 483 | 485 | 471 |
| 40($L_3$) | 440 | 465 | 477 | 485 | 486 | 487 | 487 | 475 |
| 60($L_4$) | 440 | 468 | 479 | 485 | 487 | 485 | 485 | 476 |
| 80($L_5$) | 440 | 470 | 482 | 486 | 486 | 486 | 486 | 476 |
| **Mean** | 440 | 463 | 475 | 481 | 482 | 484 | 484 | 473 |

CD (p=0.05)

| T | S | T*S |
|---|---|---|
| 10 | 12 | 22 |

**Table 10. Effect of humic acid on soil physico-chemical properties and organic carbon content in Alfisol**

| HA(kgha$^{-1}$) | pH | EC(dS m$^{-1}$) | Eh | CEC(cmol (p+)kg$^{-1}$) | Organic Carbon(%) |
|---|---|---|---|---|---|
| 0($L_1$) | 8.1 | 0.64 | +163 | 28.3 | 0.672 |
| 20($L_2$) | 8.1 | 0.72 | +147 | 30.9 | 0.678 |
| 40($L_3$) | 8.2 | 0.73 | +143 | 32.5 | 0.685 |
| 60($L_4$) | 8.2 | 0.79 | +140 | 34.5 | 0.690 |
| 80($L_5$) | 8.3 | 0.81 | +135 | 35.8 | 0.689 |
| CD | NS | 0.08 | 11 | 1.5 | 0.004 |

**Table 11. Effect of humic acid on C: N ratio in Alfisol**

| Treatments HA(kg/ha) | OC(%) | | Total N(%) | | C:N ratio | |
|---|---|---|---|---|---|---|
| | 0 | 90 | 0 | 90 | 0 | 90 |
| 0($L_1$) | 0.705 | 0.672 | 0.071 | 0.070 | 9.93 | 9.60 |
| 20($L_2$) | 0.730 | 0.678 | 0.071 | 0.072 | 10.25 | 9.44 |
| 40($L_3$) | 0.755 | 0.685 | 0.071 | 0.073 | 10.60 | 9.38 |
| 60($L_4$) | 0.788 | 0.689 | 0.071 | 0.074 | 11.07 | 9.35 |
| 80($L_5$) | 0.810 | 0.690 | 0.071 | 0.074 | 11.38 | 9.30 |
| **Mean** | 0.757 | 0.682 | 0.071 | 0.073 | 10.64 | 9.41 |

and 30th day of incubation. Thereafter the increase in $NH_4$ OAc-K at different period of incubation did not attain the level of significance. The interaction result indicated that the application of HA 40 kg $ha^{-1}$ at 90 and 75 DAI ($L_3S_6$, $L_3S_7$) recorded the highest $NH_4$ OAc-K content of 487 kg $ha^{-1}$, which was on par with $L_2S_7$ (485 kg $ha^{-1}$), $L_5S_6$ (486 kg $ha^{-1}$) $L_4S_6$ (485 kg $ha^{-1}$), $L_5S_5$ (486 kg $ha^{-1}$), $L_5S_4$ (486 kg $ha^{-1}$) and $L_3S_6$ (487 kg $ha^{-1}$).

#### 4.4.3.4. Physico-chemical properties

At the end of incubation period, the pH, EC, Eh, CEC and organic carbon content were determined. The initial pH of the soil was 8.0. Addition of HA at graded levels recorded pH value of 8.1, 8.1, 8.2, 8.2 and 8.3 respectively for 0, 20, 40, 60 and 80 kg HA $ha^{-1}$. The variations in pH due to treatments did not attain the level of significance (Table 10). The EC as influenced by the application of HA were 0.64, 0.72, 0.73, 0.79 and 0.81 $dSm^{-1}$ for 0, 20, 40, 60 and 80 kg HA $ha^{-1}$. The results showed that, significant increase of EC was recorded for higher dose of HA *viz.,* 60 and 80 kg $ha^{-1}$. The redox potential (Eh) changed due to the application of HA. The Eh recorded for 20, 40, 60 and 80 kg $ha^{-1}$ were +163, +147, +143, +140 and +135 respectively. With increasing level of HA upto 20 kg $ha^{-1}$ the redox potential was significantly reduced. Thereafter the reduction was not significant.

#### 4.4.3.5. Organic carbon

The organic carbon content increased with the addition of humic acid at graded levels (Table 10). The application of HA @ 20, 40, 60 and 80 kg $ha^{-1}$ recorded 0.678, 0.685, 0.689 and 0.690 per cent of organic carbon respectively while the control recorded only 0.672 per cent. The significant increase in organic carbon was recorded upto 60 kg $ha^{-1}$ of HA application.

#### 4.4.3.6. Cation exchange capacity

The cation exchange capacity (CEC) of the soil was significantly influenced by the HA application (Table 10). Higher the amount of HA applied, higher was the CEC. The CEC recorded for the addition of 20, 40, 60 and 80 kg $ha^{-1}$ of HA were 30.9, 32.5, 34.5 and 35.8 cmol (p+) kg $^{-1}$ respectively. Compared to control (28.3 cmol (p+) $kg^{-1}$), the per cent increase in CEC recorded by 20, 40, 60 and 80 kg $ha^{-1}$ of HA application were 8.4, 12.9, 17.9 and 20.9 respectively.

#### 4.4.3.7. Carbon: Nitrogen ratio

Total N content was assessed for the soil samples taken from each treatment (Table 11). Making use of the total N and carbon, the C: N ratios were calculated. The results showed that with increasing doses of HA (0 to 80 kg $ha^{-1}$), the carbon content increased from 0.672 to 0.690 per cent and at the same time the N content also increased from 0.070 to 0.073 per cent. Ultimately the C: N ratio was reduced from 9.6 to 9.3.

### 4.5. Pot experiment

A pot experiment was conducted with rice (ADT 38) using the soils collected from Noyyal series. The treatment structure consisted of three NPK fertiliser levels of 0, 75 and 100 per cent recommended dose and eight HA treatments *viz.*, 10, 20, 30, 40 kg HA $ha^{-1}$, 10 kg HA $ha^{-1}$ plus foliar spray (FS), 10 kg HA $ha^{-1}$ plus root dipping (RD) and 10 kg HA $ha^{-1}$ plus FS and RD. The rice was grown to maturity and harvested. Straw and grain samples were collected. Soil samples were drawn at tillering, flowering as well as at harvest stages. The soil and plant samples collected were analysed chemically for various nutrient contents. The data were statistically analysed and the results are presented below.

### 4.5.1. Soil fertility

#### 4.5.1.1. Organic carbon

The results on the influence of application of humic acid on the organic carbon content of soil with and without NPK fertilisers are given in Table (12). The organic carbon recorded in $M_3$, $M_2$ and $M_1$ were 0.753, 0.751 and 0.734 per cent respectively. Among the humic acid treatments, the highest organic carbon content was observed in $S_5$ (0.811%) and it was followed by $S_4$ (0.786%), $S_3$ (0.757%) and $S_2$ (0.728%). The treatments $S_6$ (0.730%), $S_7$ (0.731%), and $S_8$ (0.731%) were statistically on par with each other. The application of NPK fertiliser with HA recorded higher organic carbon content (0.730 to 0.818 %) than NPK fertiliser (0.710 to 0.712 %). The highest organic carbon content was recorded in $M_3S_5$ (0.818%) and was statistically on par with $M_3S_4$, $M_2S_4$ (0.790%), $M_2S_5$ (0.817%), $M_1S_5$ (0.809%) and $M_1S_4$ (0.787%).

#### 4.5.1.2.Cation exchange capacity

The CEC of the soil was significantly influenced by humic acid and fertiliser treatments (Table 12). The NPK fertiliser treatment $M_3$ and $M_2$ recorded (23.5% over $M_1$for $M_3$) 32.3 and 31.7 (22.1% over $M_1$ for $M_2$) cmol (p+) kg$^{-1}$ respectively, which were comparable with each other. The $M_1$ registered only 24.7 cmol (p+) kg$^{-1.}$

Higher the amount of humic acid applied to the soil, higher was the CEC recorded. The treatment $S_5$ (26.9% over $S_1$) recorded the highest CEC of 37.2 cmol (p+) kg$^{-1}$, which was on par with $S_4$ (24.6% over $S_1$) value of 32.5 cmol (p+) kg$^{-1}$. The $S_4$ was followed by $S_3$ (30.3 cmol (p+) kg$^{-1}$). The treatment $S_6$ (28.3 cmol (p+) kg$^{-1}$) , $S_7$ (29.0 cmol (p+) kg$^{-1}$) and $S_8$ (29.4 cmol (p+) kg$^{-1}$) did not record any significant differences among themselves.

**Table 12. Effect of humic acid and fertilisers on organic carbon (%) and CEC (cmol(p+) kg$^{-1}$) of post harvest soil-pot experiment**

| Treatments | Organic carbon | | | | CEC | | | |
|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 0.700 | 0.710 | 0.712 | 0.707 | 20.5 | 26.8 | 27.5 | 24.9 |
| $S_2$ | 0.722 | 0.730 | 0.732 | 0.728 | 23.1 | 29.8 | 30.3 | 27.9 |
| $S_3$ | 0.755 | 0.762 | 0.765 | 0.757 | 25.1 | 32.6 | 33.1 | 30.3 |
| $S_4$ | 0.787 | 0.790 | 0.790 | 0.786 | 27.5 | 34.8 | 35.2 | 32.5 |
| $S_5$ | 0.809 | 0.817 | 0.818 | 0.811 | 28.2 | 36.9 | 37.2 | 34.1 |
| $S_6$ | 0.723 | 0.733 | 0.735 | 0.730 | 23.9 | 30.1 | 30.9 | 28.3 |
| $S_7$ | 0.725 | 0.733 | 0.734 | 0.731 | 24.2 | 31.1 | 31.8 | 29.0 |
| $S_8$ | 0.725 | 0.734 | 0.734 | 0.731 | 24.8 | 31.5 | 32.0 | 29.4 |
| Mean | 0.743 | 0.751 | 0.753 | 0.749 | 24.7 | 31.7 | 32.3 | 29.6 |
| CD ($p=0.05$) | | | | | | | | |
| M | 0.006 | | | | 3.6 | | | |
| S | 0.02 | | | | 2.6 | | | |
| M at S | 0.01 | | | | 3.8 | | | |
| S at M | 0.04 | | | | 3.0 | | | |

The treatments receiving only NPK fertilisers recorded lower CEC values of 26.8 to 27.5 cmol (p+) kg$^{-1}$ than NPK fertiliser combined with HA (29.8 to 37.2 cmol (p+) kg$^{-1}$). The interaction was found to be significant. The $M_3S_5$ (37.2 cmol (p+) kg$^{-1}$), $M_3S_4$ (35.2 cmol (p+) kg$^{-1}$) and $M_2S_5$ (36.9 cmol (p+) kg$^{-1}$) and $M_2S_4$ (34.8 cmol (p+) kg$^{-1}$) were found to be on par with each other.

#### 4.5.1.3. Available nutrients

The soil samples collected from the pot experiment were analysed for $KMnO_4$-N, Olsen-P and $NH_4OAc$-K. The results of the analysis are presented below.

#### 4.5.1.3.1. Available nitrogen ($KMnO_4$-N)

The $KMnO_4$-N content of the soil was estimated at tillering, flowering and post harvest stages of the rice crop (Table 13). At tillering stage, the $KMnO_4$-N content was significantly increased for the application of NPK fertiliser as compared to no fertiliser. The available N content recorded by $M_3$ (253 kg ha$^{-1}$) was comparable with $M_2$ (246 kg ha$^{-1)}$. The $M_1$ recorded only 216 kg ha$^{-1}$.

Among the humic acid treatments, $S_5$ recorded the highest $KMnO_4$-N content of 248 kg ha$^{-1}$ and it was followed by $S_4$ (243 kg ha$^{-1}$), $S_3$ (239 kg ha$^{-1}$) and $S_2$ (233 kg ha$^{-1}$). Among $S_6$, $S_7$, and $S_8$ the $S_8$ recorded the highest $KMnO_4$-N content of 241 kg ha$^{-1}$ and it was followed by $S_7$ (239 kg ha$^{-1}$) and $S_6$ (236 kg ha$^{-1}$). The $S_8$ was comparable with $S_7$, $S_4$ and $S_3$.

The $KMnO_4$-N content of the treatment receiving NPK fertiliser was compared with those that received NPK fertilisers and HA. The results showed that, the NPK fertiliser treatment recorded 237 to 242 kg ha$^{-1}$ of $KMnO_4$-N whereas, the treatment with NPK fertiliser plus HA recorded 263 to 242 kg ha$^{-1}$ of $KMnO_4$-N. Among the various

**Table 13. Effect of humic acid and fertilisers on $KMnO_4$- N (kg $ha^{-1}$) content of soil -Pot experiment**

| Treatments | Tillering | | | | Flowering | | | | Post harvest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 201 | 237 | 242 | 227 | 194 | 222 | 227 | 214 | 185 | 212 | 218 | 205 |
| $S_2$ | 210 | 242 | 247 | 233 | 203 | 226 | 231 | 220 | 194 | 217 | 221 | 211 |
| $S_3$ | 217 | 246 | 253 | 239 | 209 | 231 | 238 | 226 | 201 | 222 | 229 | 217 |
| $S_4$ | 222 | 250 | 258 | 243 | 214 | 235 | 242 | 230 | 205 | 227 | 231 | 221 |
| $S_5$ | 229 | 252 | 263 | 248 | 219 | 238 | 247 | 235 | 211 | 230 | 240 | 228 |
| $S_6$ | 215 | 243 | 249 | 236 | 204 | 228 | 233 | 222 | 200 | 219 | 224 | 214 |
| $S_7$ | 218 | 247 | 253 | 239 | 207 | 231 | 238 | 225 | 202 | 220 | 226 | 216 |
| $S_8$ | 220 | 249 | 254 | 241 | 210 | 234 | 240 | 228 | 204 | 223 | 230 | 219 |
| Mean | 216 | 246 | 253 | 238 | 208 | 231 | 237 | 225 | 200 | 222 | 227 | 216 |
| CD(p=0.05) | | | | | | | | | | | | |
| M | 6.8 | | | | 5.8 | | | | 7.1 | | | |
| S | 3.8 | | | | 5.1 | | | | 8.5 | | | |
| M at S | 7.4 | | | | 6.5 | | | | 8.8 | | | |
| S at M | 4.1 | | | | 5.7 | | | | 9.2 | | | |

combinations, $M_3S_5$ recorded significantly highest $KMnO_4$-N content of 263 kg ha$^{-1}$ and it was followed by $M_3S_4$ (258 kg ha$^{-1}$), $M_3S_8$ (254 kg ha$^{-1}$) and $M_2S_5$ (252 kg ha$^{-1}$). The combination $M_2S_5$ recorded 252kg ha$^{-1}$ of $KMnO_4$-N which was comparable with $M_2S_4$ (250 kg ha$^{-1}$) and $M_2S_8$ (249 kg ha$^{-1}$).

At flowering stage, the $KMnO_4$-N content recorded in $M_3$ (237kg ha$^{-1}$) was the highest as against $M_2$ (231 kg ha$^{-1}$) and $M_1$ (208 kg ha$^{-1}$). In HA treatments, $S_5$ and $S_4$ recorded 235 and 230 kg ha$^{-1}$ of $KMnO_4$-N and they were comparable with each other. The $S_5$ was followed by $S_3$ (226 kg ha$^{-1}$) and $S_2$ (220 kg ha$^{-1}$). Among $S_6$, $S_7$ and $S_8$, the $S_8$ recorded 228 kg ha$^{-1}$ of $KMnO_4$-N and it was followed by $S_6$ (222 kg ha$^{-1}$) and $S_7$ (225 kg ha$^{-1}$). Again the $S_8$ was found to be on par with $S_7$ and $S_4$.

The NPK fertiliser combined with humic acid recorded higher $KMnO_4$-N (226 to 247 kg ha$^{-1}$) than NPK fertiliser (222-227 kg ha$^{-1}$). Among the various combinations $M_3S_5$ recorded the maximum $KMnO_4$-N content of 247 kg ha$^{-1}$ and it was followed by $M_3S_4$ (242 kg ha$^{-1}$). The $M_2S_5$ recorded 238 kg ha$^{-1}$ of $KMnO_4$-N and it was followed by $M_2S_4$ (235 kg ha$^{-1}$) and $M_2S_8$ (234 kg ha$^{-1}$).

The post harvest soil samples were analysed for $KMnO_4$-N content. The data showed that there was significant increase in $KMnO_4$-N content for fertiliser treatments ($M_2$ and $M_3$) as against no NPK fertiliser ($M_1$). The treatment receiving 100 per cent NPK fertiliser recorded significantly higher $KMnO_4$-N (227 kg ha$^{-1}$) and it was followed by $M_2$ (222 kg ha$^{-1}$) and $M_1$ (200 kg ha$^{-1}$). Among the humic acid treatments, $S_5$ recorded highest $KMnO_4$-N (228 kg ha$^{-1}$) and it was comparable with $S_4$ (221kg ha$^{-1}$) and $S_3$ (217kg ha$^{-1}$). The treatments $S_6$, $S_7$ and $S_8$ registered 214, 216 and 219 kg ha$^{-1}$ of $KMnO_4$-N respectively. Again the $S_5$ and $S_8$ were comparable.

The interaction was found to be significant. The treatment $M_3S_5$ registered the highest $KMnO_4$-N of 240 kg $ha^{-1}$ and it was comparable with $M_3S_4$ (231kg $ha^{-1}$) followed by $M_3S_8$ (230 kg $ha^{-1}$) and $M_3S_7$ (226 kg $ha^{-1}$). The combinations $M_2S_5$ recorded the 230kg $ha^{-1}$ of $KMnO_4$-N and it was followed by $M_2S_4$ (227 kg $ha^{-1}$) and $M_2S_8$ (223 kg $ha^{-1}$).

### 4.5.1.3.2. Available phosphorus (Olsen P)

The data on Olsen-P content of various treatments are given in Table 14. At tillering stage, the application of NPK fertiliser significantly increased the Olsen-P content. The Olsen-P content of $M_3$ was 23.5 kg $ha^{-1}$ and it was followed by $M_2$ (22.8 kg $ha^{-1}$) and $M_1$ (17.1 kg $ha^{-1}$).

In the humic acid treatments, $S_5$ recorded the highest Olsen-P content of 21.9 kg $ha^{-1}$, which was followed by $S_4$ (21.5 kg $ha^{-1}$) and $S_3$ (21.2 kg $ha^{-1}$). The treatments $S_6$, $S_7$ and $S_8$ recorded 20.9, 21.1 and 21.3 kg $ha^{-1}$ of Olsen-P respectively. The treatment with NPK fertiliser recorded lower Olsen-P content of 22.3 to 22.7 kg $ha^{-1}$,while the NPK fertiliser combined with HA recorded the 22.5 to 24.2 kg $ha^{-1}$. Among the treatment combinations, $M_3S_5$ registered the highest Olsen-P content of 24.2 which was on par with $M_3S_4$ (23.9 kg $ha^{-1}$), $M_3$ $S_8$ (23.8 kg $ha^{-1}$) and $M_3$ $S_3$ (23.7 kg $ha^{-1}$). The treatments $M_2S_5$ (23.5 kg $ha^{-1}$), $M_2$ $S_4$ (23.2 kg $ha^{-1}$) and $M_2S_8$ (23.0 kg $ha^{-1}$) were also on par with each other.

At flowering stage, the content of Olsen-P had declined. The treatment $M_3$ (19.3 kg $ha^{-1}$) and $M_2$ (18.6 kg $ha^{-1}$) receiving NPK fertilisers recorded significantly higher Olsen-P than ($M_1$) no fertiliser (14.3 kg $ha^{-1}$). Among HA treatments, the $S_5$ receiving 40 kg $ha^{-1}$ recorded the highest Olsen-P of 18.0 kg $ha^{-1}$. It was statistically on par with $S_4$ (17.8 kg $ha^{-1}$) and $S_3$ (17.5 kg $ha^{-1}$). The treatments $S_6$ (17.1 kg $ha^{-1}$),

Table 14. Effect of humic acid and fertilisers on Olsen -P content (kg ha$^{-1}$) of soil - Pot experiment

| Treatments | Tillering | | | | Flowering | | | | Post harvest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 16.3 | 22.3 | 22.7 | 20.4 | 13.6 | 17.8 | 18.2 | 16.5 | 12.0 | 16.2 | 16.6 | 14.9 |
| $S_2$ | 16.7 | 22.5 | 23.2 | 20.8 | 13.9 | 18.4 | 18.8 | 17.0 | 12.4 | 16.4 | 16.9 | 15.2 |
| $S_3$ | 17.1 | 22.8 | 23.7 | 21.2 | 14.4 | 18.8 | 19.2 | 17.5 | 13.0 | 16.6 | 17.5 | 15.7 |
| $S_4$ | 17.4 | 23.2 | 23.9 | 21.5 | 14.8 | 19.0 | 19.7 | 17.8 | 13.4 | 16.9 | 17.9 | 16.1 |
| $S_5$ | 17.9 | 23.5 | 24.2 | 21.9 | 15.1 | 19.0 | 19.9 | 18.0 | 13.9 | 17.1 | 18.2 | 16.4 |
| $S_6$ | 16.9 | 22.5 | 23.3 | 20.9 | 13.9 | 18.4 | 19.0 | 17.1 | 12.3 | 16.5 | 17.0 | 15.3 |
| $S_7$ | 17.0 | 22.9 | 23.4 | 21.1 | 14.1 | 18.8 | 19.5 | 17.5 | 12.4 | 16.7 | 17.1 | 15.4 |
| $S_8$ | 17.2 | 23.0 | 23.8 | 21.3 | 14.3 | 18.8 | 19.7 | 17.6 | 12.5 | 16.9 | 17.2 | 15.5 |
| Mean | 17.1 | 22.8 | 23.5 | 21.1 | 14.3 | 18.6 | 19.3 | 17.4 | 12.7 | 16.7 | 17.3 | 15.6 |
| CD(p=0.05) | | | | | | | | | | | | |
| M | | 0.8 | | | | 0.8 | | | | 0.8 | | |
| S | | 0.4 | | | | 0.4 | | | | 0.4 | | |
| M at S | | 0.7 | | | | 0.7 | | | | 1.1 | | |
| S at M | | 0.5 | | | | 0.5 | | | | 0.4 | | |

$S_7$ (17.5 kg ha$^{-1}$) and $S_8$ (17.6 kg ha$^{-1}$) were on par with each other. Again the treatments $S_5$, $S_4$ and $S_8$ were comparable.

The results on the combination of NPK fertilisers and HA treatments showed that, the HA combined with NPK fertiliser recorded higher content of Olsen P (19.9 to 18.4 kg ha$^{-1}$) than NPK fertiliser treatments (17.8 to 18.2 kg ha$^{-1}$). The combination $M_3S_5$ registered the highest Olsen-P content of 19.9 kg ha$^{-1}$, which was on par with $M_3S_4$ (19.7 kg ha$^{-1}$), $M_3S_8$ (19.7 kg ha$^{-1}$) and $M_3S_7$ (19.5 kg ha$^{-1}$).

At post harvest, the $M_3$ recorded significantly highest Olsen-P content of 17.3 kg ha$^{-1}$. It was comparable with $M_2$ (16.7kg ha$^{-1}$). The $M_1$ recorded only 12.7 kg ha$^{-1}$ of Olsen-P. In the humic acid treatments, the $S_5$ and $S_4$ recorded the highest Olsen-P content of 16.4 and 16.1kg ha$^{-1}$ respectively and they were on par with each other. The treatment receiving 20 kg HA ha$^{-1}$ ($S_3$) recorded 15.7 kg ha$^{-1}$ of Olsen-P and it was statistically on par with $S_8$ (15.5 kg ha$^{-1}$) and $S_7$ (15.4 kg ha$^{-1}$).

The NPK fertilisers combined with HA recorded higher content of Olsen-P (16.4 to 18.2 kg ha$^{-1}$) than NPK fertiliser treatment (16.2 to 16.6 kg ha$^{-1}$). In the HA and NPK fertiliser interaction, the combination $M_3S_5$ recorded the higher content of Olsen-P (18.2 kg ha$^{-1}$). It was comparable with $M_3S_4$ (17.9 kg ha$^{-1}$) and $M_3S_3$ (17.5 kg ha$^{-1}$) The treatments $M_3S_8$ (17.2 kg ha$^{-1}$) and $M_2$ $S_5$ (17.1 kg ha$^{-1}$) were comparable.

### 4.5.1.3.3. Available potassium ($NH_4OAc$-K)

The data pertaining to the $NH_4OAc$-K are given in the Table 15. The results revealed that the $NH_4OAc$-K status of the soil during the vegetative phase of the crop was high and declined thereafter. The treatments receiving NPK fertilisers recorded significantly high content of $NH_4OAc$-K than no fertiliser. At tillering stage, the treatment

Table 15. Effect of humic acid and fertilisers on $NH_4OAc$-K content (kg $ha^{-1}$) of soil - Pot experiment

| Treatments | Tillering | | | | Flowering | | | | Post harvest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 500 | 735 | 795 | 677 | 470 | 700 | 765 | 645 | 452 | 675 | 735 | 621 |
| $S_2$ | 530 | 755 | 820 | 702 | 502 | 720 | 792 | 671 | 485 | 701 | 759 | 648 |
| $S_3$ | 545 | 765 | 837 | 716 | 518 | 740 | 809 | 689 | 502 | 725 | 775 | 667 |
| $S_4$ | 560 | 777 | 848 | 728 | 525 | 760 | 818 | 701 | 510 | 740 | 787 | 679 |
| $S_5$ | 570 | 787 | 855 | 737 | 535 | 775 | 827 | 712 | 517 | 750 | 799 | 689 |
| $S_6$ | 530 | 760 | 825 | 705 | 495 | 730 | 805 | 677 | 480 | 705 | 760 | 648 |
| $S_7$ | 540 | 770 | 830 | 713 | 500 | 740 | 815 | 685 | 487 | 710 | 769 | 654 |
| $S_8$ | 540 | 770 | 832 | 714 | 510 | 741 | 817 | 689 | 490 | 725 | 775 | 663 |
| Mean | 539 | 765 | 830 | 712 | 507 | 738 | 806 | 684 | 490 | 716 | 770 | 659 |
| CD(p=0.05) | | | | | | | | | | | | |
| M | 19 | | | | 20 | | | | 21 | | | |
| S | 11 | | | | 14 | | | | 18 | | | |
| M at S | 18 | | | | 17 | | | | 23 | | | |
| S at M | 16 | | | | 15 | | | | 22 | | | |

$M_3$ recorded the highest $NH_4OAc$-K of 830 kg ha$^{-1}$. The $M_2$ registered 765 kg ha$^{-1}$of $NH_4OAc$-K, which was significantly higher than that recorded by $M_1$ (539 kg ha$^{-1}$).

In the humic acid treatments $S_5$ (737 kg ha$^{-1}$) and $S_4$ (728 kg ha$^{-1}$) recorded the highest $NH_4OAc$-K, which was on par with each other .The $S_5$ was followed by $S_2$ (702 kg ha$^{-1}$) and $S_3$ (716 kg ha$^{-1}$). The treatment $S_6$ (705 kg ha$^{-1}$), $S_7$ (713 kg ha$^{-1}$) and $S_8$ (714 kg ha$^{-1}$) recorded comparable $NH_4OAc$-K content. The treatments HA integrated with NPK fertiliser recorded higher $NH_4OAc$-K (855 to 755 kg ha$^{-1}$) than NPK fertiliser treatments (735 to 795 kg ha$^{-1}$). Among the interactions, the combination $M_3S_5$ recorded higher $NH_4OAc$-K (855 kg ha$^{-1}$) which was statistically on par with $M_3S_4$ (848 kg ha$^{-1}$) and $M_3$ $S_3$ (837 kg ha$^{-1}$). The $M_3$ $S_3$ was followed by $M_3S_2$ (820 kg ha$^{-1}$), $M_3S_8$ (832 kg ha$^{-1}$) $M_3S_7$ (830 kg ha$^{-1}$) and $M_3S_6$ (825 kg ha$^{-1}$).

At flowering stage, the treatments receiving 100 per cent NPK fertilisers recorded significant increase in $NH_4OAc$-K (806 kg ha$^{-1}$) than $M_2$ (738 kg ha$^{-1}$) while the no fertiliser treatment ($M_1$) recorded only 507 kg ha$^{-1}$. In the humic acid treatments, the treatment receiving 40 kg HA ha$^{-1}$ ($S_5$) recorded 712 kg ha$^{-1}$ of $NH_4$ OAc-K which was comparable with $S_4$ (701 kg ha$^{-1}$). The $S_4$ was followed by $S_3$ (689 kg ha$^{-1}$). The treatments $S_6$ (677 kg ha$^{-1}$), $S_7$(685 kg ha$^{-1}$) and $S_8$ (689 kg ha$^{-1}$) were found to be comparable.

The treatments receiving NPK fertiliser registered lower $NH_4OAc$-K of 700 to 765 kg ha$^{-1}$ than NPK fertilisers combined with HA treatments (720 to 827 kg ha$^{-1}$). The interaction between NPK fertilisers and humid acid were found to be significant. The treatment $M_3$ with $S_5$ (827 kg ha$^{-1}$) recorded the highest $NH_4$ OAc-K content. This was on par with $M_3S_4$ (818 kg ha$^{-1}$), $M_3S_7$ (815 kg ha$^{-1}$) and $M_3$ $S_8$ (817 kg ha$^{-1}$).

At post harvest, the treatment $M_3$ recorded 770 kg ha$^{-1}$ of $NH_4OAc$-K which was significantly higher than $M_2$ (716 kg ha$^{-1}$) and $M_1$ (490 kg ha$^{-1}$). In the humic acid treatments, $S_5$ registered the highest $NH_4OAc$-K of 689 kg ha$^{-1}$. It was on par with $S_4$ (679 kg ha$^{-1}$) and it was followed by $S_3$ (667 kg ha$^{-1}$) and $S_2$ (648 kg ha$^{-1}$). The treatments $S_6$ (648 kg ha$^{-1}$), $S_7$ (654 kg ha$^{-1}$) and $S_8$ (663 kg ha$^{-1}$) were statistically on par with each other. The treatment $S_4$ and $S_8$ were again comparable with each other.

The application of NPK fertilisers combined with HA recorded higher $NH_4OAc$-K (701 to 799 kg ha$^{-1}$) than NPK fertiliser treatments (675 to 735 kg ha$^{-1}$). The interaction treatment of $M_3S_5$ recorded highest $NH_4OAc$-K of 799 kg ha$^{-1}$ and it was statistically on par with $M_3S_4$ (787kg ha$^{-1}$). The treatments $M_3S_2$ (759 kg ha$^{-1}$), $M_3S_3$ (775 kg ha$^{-1}$), $M_3S_6$ (760 kg ha$^{-1}$), $M_3S_7$ (769 kg ha$^{-1}$) and $M_3S_8$ (775 kg ha$^{-1}$) were on par with each other. The $M_3$ $S_2$ was comparable with $M_2$ $S_5$ (750kg ha$^{-1}$) and $M_2S_4$ (740 kg ha$^{-1}$).

### 4.5.2. Nutrient uptake

The uptake of nitrogen, phosphorus and potassium by rice as influenced by application of NPK fertilisers and various levels of HA have been determined. The data on uptake were statistically analysed and the results are presented below.

#### 4.5.2.1. Nutrient uptake by grain (Table 16)

##### 4.5.2.1.1. Nitrogen uptake

The $M_3$ recorded 269 mg pot$^{-1}$ of N uptake, which was significantly higher than $M_2$ (251 mg pot$^{-1}$). The no fertiliser treatment recorded only 154 mg pot$^{-1}$. Soil application of HA from 10 to 40 kg ha$^{-1}$ significantly increased N uptake in grain. The treatment $S_5$ recorded the highest N uptake of 255 mg pot$^{-1}$ and it was followed by $S_4$ (242 mg pot$^{-1}$) and $S_3$ (226 mg pot$^{-1}$). Among $S_6$, $S_7$ and $S_8$, the treatment $S_8$ (235 mg pot$^{-1}$) and $S_6$ (225 mg pot$^{-1}$) were comparable. In general, the NPK fertiliser treatment recorded lesser uptake of N (205 to 230 mg pot$^{-1}$) than NPK fertiliser combined with humic acid

**Table 16. Effect of humic acid and fertilisers on N, P and K uptake (mg pot$^{-1}$) by rice grain-Pot experiment**

| Treatments | Nitrogen | | | | Phosphorus | | | | Potassium | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 122 | 205 | 230 | 186 | 27.9 | 46.6 | 49.2 | 41.2 | 26.2 | 44.3 | 47.0 | 39.2 |
| $S_2$ | 139 | 231 | 249 | 206 | 30.9 | 50.8 | 51.5 | 44.4 | 29.2 | 48.3 | 49.5 | 42.3 |
| $S_3$ | 154 | 255 | 270 | 226 | 33.1 | 53.9 | 54.7 | 47.2 | 31.3 | 50.9 | 52.2 | 44.8 |
| $S_4$ | 169 | 274 | 284 | 242 | 35.1 | 55.7 | 57.3 | 49.4 | 33.3 | 52.9 | 54.4 | 46.9 |
| $S_5$ | 179 | 285 | 300 | 255 | 36.6 | 57.1 | 58.8 | 50.8 | 34.5 | 54.2 | 56.1 | 48.3 |
| $S_6$ | 153 | 250 | 271 | 225 | 32.0 | 51.9 | 53.3 | 45.7 | 30.4 | 49.8 | 51.5 | 43.9 |
| $S_7$ | 154 | 243 | 263 | 220 | 33.3 | 52.8 | 53.9 | 46.7 | 30.6 | 50.7 | 51.8 | 44.4 |
| $S_8$ | 159 | 264 | 283 | 235 | 33.0 | 54.8 | 56.3 | 48.0 | 31.5 | 52.4 | 53.6 | 45.8 |
| Mean | 154 | 251 | 269 | 224 | 32.8 | 52.9 | 54.4 | 46.7 | 30.9 | 50.4 | 52.0 | 44.4 |
| CD(p=0.05) | | | | | | | | | | | | |
| M | 15.1 | | | | 1.8 | | | | 1.7 | | | |
| S | 10.5 | | | | 1.3 | | | | 1.5 | | | |
| M at S | 15.7 | | | | 1.9 | | | | 1.9 | | | |
| S at M | 13.9 | | | | 1.7 | | | | 1.9 | | | |

(231 to 300 mg pot$^{-1}$) did. In the interaction, $M_3S_5$ recorded the highest N uptake of 300 mg pot$^{-1}$ that was followed by the treatments $M_3S_4$ (284 mg pot$^{-1}$), $M_3S_8$ (283 mg pot$^{-1}$), $M_3S_6$ (271 mg pot$^{-1}$) and $M_3S_3$ (270 mg pot$^{-1}$). The treatments $M_3S_4$ was on par with $M_2S_5$ (285 mg pot$^{-1}$) and $M_2S_4$ (274 mg pot$^{-1}$).

#### 4.5.2.1.2. Phosphorus uptake

Between the fertilisers treatment, the maximum uptake of P was recorded in $M_3$ (54.4 mg pot$^{-1}$) which was comparable with $M_2$ (52.9 mg pot$^{-1}$) followed by $M_1$ (32.8 mg pot$^{-1}$). In the HA treatments, the uptake of P by $S_5$ (50.8 mg pot$^{-1}$) and $S_4$ (49.4 mg pot$^{-1}$) were found to be comparable and the $S_4$ was followed by $S_3$ (47.2 mg pot$^{-1}$) and $S_2$ (44.4 mg pot$^{-1}$). The $S_8$ (48.0 mg pot$^{-1}$) recorded statistically higher P uptake than $S_7$ (46.7 mg pot$^{-1}$) and $S_6$ (45.7 mg pot$^{-1}$). Again the treatments $S_5$ and $S_8$ were on par.

In general, the nutrient uptake by grain was found less in NPK fertiliser treatment (46.6 to 49.2 mg pot$^{-1}$) than NPK fertiliser combined with HA (50.8 to 58.8 mg pot$^{-1}$). In the interaction treatments $M_3S_5$ (58.8 mg pot$^{-1}$) and $M_3S_4$ (57.3 mg pot$^{-1}$) recorded the highest P uptake. The treatment $M_3S_8$ (56.3 mg pot$^{-1}$) was on par with $M_2S_4$ (55.7 mg pot$^{-1}$), $M_2S_8$ (54.8 mg pot$^{-1}$) and $M_3S_3$ (54.7 mg pot$^{-1}$).

#### 4.5.2.1.3. Potassium uptake

The fertiliser treatment $M_3$ registered significantly the highest K uptake of 52.0 mgpot$^{-1}$, which was on par with $M_2$ (50.4 mg pot$^{-1}$). The $M_1$ recorded the minimum K uptake of 30.9 mg pot$^{-1}$. In HA treatments, the treatment $S_5$ recorded significantly increased K uptake of 48.3 mg pot$^{-1}$. It was similar to that of $S_4$, which recorded 46.9 mg pot$^{-1}$ and it was followed by $S_3$ (44.8 mg pot$^{-1}$). Among $S_6$, $S_7$ and $S_8$, the treatment $S_8$ recorded 45.8 mg pot$^{-1}$ of K uptake, which was on par with $S_7$ (44.4 mg pot$^{-1}$). In interaction treatment, $M_3S_5$ recorded 56.1 mg pot$^{-1}$ and it was on par with $M_3S_4$ (54.4 mg pot$^{-1}$). The treatments $M_2S_5$ (54.2 mg pot$^{-1}$), $M_3$ $S_8$ (53.6 mg pot$^{-1}$), $M_2S_4$ (52.9 mg pot$^{-1}$) and $M_2S_8$ (52.4 mg pot$^{-1}$) were on par. The $M_3S_3$ (52.2 mg pot$^{-1}$), $M_3S_7$ (51.8 mg pot$^{-1}$) and $M_3S_6$ (51.5 mg pot$^{-1}$) recorded comparable K uptake.

### 4.5.2.2. Nutrient uptake by straw (Table 17)

### 4.5.2.2.1. Nitrogen uptake

Nitrogen uptake in straw recorded significant variations among the treatments. The $M_3$ and $M_2$ recorded significantly higher N uptake of 234.9 and 222 mg pot$^{-1}$respectively as against $M_1$ (120.9 mg pot$^{-1}$). In the HA treatments, $S_5$ recorded significantly higher N uptake of 230.1 mg pot$^{-1}$ followed by $S_4$ (215.6 mg pot$^{-1}$). Among $S_6$, $S_7$ and $S_8$, the $S_8$ (206.2 mg pot$^{-1}$) recorded higher N uptake and $S_7$ (187.2 mg pot$^{-1}$) and $S_6$ (194.2 mg pot$^{-1}$) followed it. In interaction, the treatment $M_3S_5$ (271.8 mg pot$^{-1}$) and $M_3S_4$ (260.8 mg pot$^{-1}$) recorded higher N uptake followed by $M_3S_8$ (253.4 mg pot$^{-1}$). Again the $M_3S_8$ was on par with $M_2S_4$ (248.7 mg pot$^{-1}$).

### 4.5.2.2.2. Phosphorus uptake

Regarding P uptake in straw, the treatment with 100 and 75 per cent NPK fertiliser recorded significantly higher P uptake of 39.5 and 36.7 mg pot$^{-1}$ respectively than $M_1$ (20.7 mg pot$^{-1}$). The treatment HA @ 40 kg ha$^{-1}$ ($S_5$) registered significantly higher P uptake of 37.2 mg pot$^{-1}$ which was on par with $S_4$ (35.4 mg pot$^{-1}$) followed by $S_3$ (32.7 mg pot$^{-1}$). The treatment $S_8$ (33.7 mg pot$^{-1}$) recorded significantly higher P uptake than $S_6$ (31.7 mg pot$^{-1}$) and $S_7$ (31.5 mg pot$^{-1}$). In the interaction treatments, $M_3S_5$ recorded highest P uptake (43.8 mg pot$^{-1}$), which was on par with $M_3S_4$ (42.6 mg pot$^{-1}$) and

**Table 17. Effect of humic acid and fertilisers on N, P and K uptake (mg pot$^{-1}$) by rice straw - Pot experiment**

| Treatments | Nitrogen | | | | Phosphorus | | | | Potassium | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 82.1 | 166.0 | 183.4 | 143.8 | 16.0 | 30.1 | 33.0 | 26.4 | 164.9 | 261.6 | 277.5 | 234.7 |
| $S_2$ | 104.1 | 193.5 | 216.3 | 171.3 | 18.4 | 33.8 | 36.9 | 29.7 | 177.3 | 278.5 | 293.4 | 249.7 |
| $S_3$ | 121.4 | 223.5 | 231.3 | 192.1 | 20.9 | 37.2 | 40.1 | 32.7 | 187.0 | 291.9 | 305.0 | 261.3 |
| $S_4$ | 137.4 | 248.7 | 260.8 | 215.6 | 23.4 | 40.3 | 42.6 | 35.4 | 197.4 | 302.0 | 313.5 | 271.0 |
| $S_5$ | 149.8 | 268.6 | 271.8 | 230.1 | 25.2 | 42.6 | 43.8 | 37.2 | 202.9 | 308.1 | 315.3 | 275.4 |
| $S_6$ | 124.9 | 221.7 | 236.0 | 194.2 | 20.3 | 35.5 | 39.2 | 31.7 | 186.5 | 285.7 | 301.3 | 257.8 |
| $S_7$ | 118.0 | 217.0 | 226.6 | 187.2 | 19.9 | 35.8 | 38.8 | 31.5 | 187.9 | 291.9 | 301.2 | 260.3 |
| $S_8$ | 128.3 | 236.9 | 253.4 | 206.2 | 21.5 | 38.1 | 41.4 | 33.7 | 191.2 | 299.8 | 312.0 | 267.6 |
| Mean | 120.8 | 222.0 | 234.9 | 192.6 | 20.7 | 36.7 | 39.5 | 32.3 | 186.9 | 289.9 | 302.4 | 259.7 |
| CD(p=0.05) | | | | | | | | | | | | |
| M | 13.3 | | | | 2.9 | | | | 7.0 | | | |
| S | 12.3 | | | | 1.2 | | | | 4.9 | | | |
| M at S | 14.5 | | | | 1.7 | | | | 8.6 | | | |
| S at M | 14.7 | | | | 1.4 | | | | 8.5 | | | |

the $M_3S_4$ followed by $M_3S_8$ (41.4 mg pot$^{-1}$) and $M_3S_3$ (40.1 mg pot$^{-1}$). The treatments $M_3S_5$ (43.8 mg pot$^{-1}$ ), $M_3S_4$ (42.6 mg pot$^{-1}$) and $M_2S_5$ (42.6 mg pot$^{-1}$) were comparable.

### 4.5.2.2.3. Potassium uptake

In the straw, the fertiliser treatments $M_3$ recorded highest K uptake of 302.4 mg pot$^{-1}$ and it was followed by $M_2$ (289.9 mg pot$^{-1}$). The $M_1$ recorded only 186.9 mg pot$^{-1}$. In humic acid treatments, the $S_2$, $S_6$, $S_7$ and $S_8$ recorded uptake of 249.7, 257.8, 260.3 and 267.6 mg pot$^{-1}$ respectively.

The treatment $S_5$ (40 kg HA ha$^{-1}$)registered highest K uptake of 275.4 mg pot$^{-1}$ which was on par with $S_4$ (271 mg pot$^{-1}$) and the $S_4$ was followed by $S_3$ (261.3 mg. pot$^{-1}$). Among $S_6$, $S_7$ and $S_8$, the $S_8$ registered higher K uptake (267.6 mg pot$^{-1}$), which was followed by $S_7$ (260.3 mg pot$^{-1}$) and $S_6$ (257.8 mg pot$^{-1}$). In the interaction treatments, $M_3S_5$ recorded the high K uptake of 315.5 mg pot$^{-1}$, which was on par with $M_3S_8$ (312.0 mg pot$^{-1}$) and $M_2S_8$ (308.1 mg pot$^{-1}$). The treatments, $M_3S_3$ (305 mg pot$^{-1}$), $M_3S_6$ (301.3 mg pot$^{-1}$) and $M_3S_7$ (301.2 mg pot$^{-1}$) were on par with each other and $M_3S_3$ was followed by $M_2S_4$ (302 mg pot$^{-1}$) and $M_2S_8$ (299.8 mg pot$^{-1}$).

## 4.5.3.Yield and yield attributes

### 4.5.3.1.Productive tillers per hill

The NPK fertiliser treatments $M_2$ and $M_3$ recorded 7.48 and 7.57 tillers per hill as against 6.21 for no fertiliser (Table 18). The difference in number of tillers per hill due to fertiliser levels was not significant between $M_2$ and $M_3$. In the humic acid applied treatments, $S_5$ and $S_8$ recorded (7.46) more number of tillers per hill (12.2 % over no HA) than $S_4$ (7.% over no HA) and $S_3$ (7.07). The $S_7$ (7.14) and $S_6$ (7.0) recorded significantly lesser number of productive tillers per hill than $S_8$. The $S_5$ and $S_8$ were comparable.

**Table 18. Effect of humic acid and fertilisers on yield attributes of rice - Pot experiment**

| Treatments | No. of productive tillers hill$^{-1}$ | | | | Panicle length (cm) | | | | No. of filled grains per panicle | | | | No. of chaffy grains per panicle | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 5.67 | 6.93 | 7.04 | 6.55 | 19.0 | 19.7 | 20.0 | 19.57 | 58.80 | 88.20 | 91.35 | 79.45 | 23.70 | 18.30 | 17.30 | 19.77 |
| $S_2$ | 5.88 | 7.14 | 7.25 | 6.76 | 19.3 | 19.9 | 20.2 | 19.80 | 60.90 | 92.40 | 94.50 | 82.60 | 17.30 | 12.70 | 11.70 | 13.90 |
| $S_3$ | 6.20 | 7.46 | 7.56 | 7.07 | 19.7 | 20.1 | 20.5 | 20.10 | 64.05 | 95.55 | 97.65 | 85.75 | 17.30 | 12.70 | 9.70 | 13.23 |
| $S_4$ | 6.41 | 7.67 | 7.77 | 7.28 | 19.9 | 20.3 | 20.7 | 20.30 | 66.15 | 97.65 | 98.70 | 87.50 | 15.00 | 12.30 | 9.70 | 12.33 |
| $S_5$ | 6.51 | 7.88 | 7.98 | 7.46 | 19.7 | 20.0 | 20.5 | 20.07 | 68.25 | 99.75 | 99.75 | 89.25 | 15.00 | 10.30 | 9.70 | 11.67 |
| $S_6$ | 6.09 | 7.35 | 7.56 | 7.00 | 19.6 | 20.1 | 20.5 | 20.07 | 60.90 | 94.50 | 95.55 | 83.65 | 26.10 | 10.00 | 9.30 | 15.13 |
| $S_7$ | 6.30 | 7.56 | 7.56 | 7.14 | 19.5 | 20.2 | 20.6 | 20.10 | 63.00 | 97.65 | 97.65 | 86.10 | 15.00 | 5.70 | 7.70 | 9.47 |
| $S_8$ | 6.62 | 7.88 | 7.88 | 7.46 | 19.7 | 20.5 | 20.8 | 20.33 | 69.30 | 100.8 | 100.8 | 90.30 | 15.00 | 6.00 | 5.30 | 8.77 |
| Mean | 6.21 | 7.48 | 7.57 | 7.09 | 19.55 | 20.1 | 20.4 | 20.04 | 63.92 | 95.81 | 96.99 | 85.58 | 18.05 | 11.00 | 10.05 | 13.03 |
| CD(p=0.05) | | | | | | | | | | | | | | | | |
| M | 0.35 | | | | NS | | | | 6.5 | | | | 3.20 | | | |
| S | 0.28 | | | | 0.32 | | | | 4.16 | | | | 2.37 | | | |
| M at S | 0.40 | | | | NS | | | | 7.42 | | | | 4.20 | | | |
| S at M | 0.31 | | | | | | | | 7.18 | | | | 4.11 | | | |

The productive tillers per hill recorded in the treatment receiving NPK fertilisers were lower (8.93 to 7.04) than that of NPK fertiliser with HA application (7.14 to 7.98). Among the various combinations, $M_2S_5$ and $M_2S_8$ recorded significantly higher number of tillers per hill (7.88) than other combinations. (i.e., 12.06 per cent increase over $M_2S_1$ ) The $M_3S_5$ (7.98) and $M_3S_8$ (7.88) combinations recorded 11.78 and 10.66 % increase over $M_3S_1$).

### 4.5.3.2. Panicle length

The fertiliser treatments $M_1$, $M_2$ and $M_3$ showed nonsignificant difference on panicle length (Table 18). Compared to no HA treatments (19.57cm) the increased panicle length was observed in all the HA received treatments (19.8 to 20.3 cm). Among the HA treatments $S_4$ (20.3 cm) recorded more panicle length than other treatments. Among $S_6$, $S_7$ and $S_8$, the $S_8$ recorded longer panicle length of 20.33cm followed by $S_7$ (20.1 cm) and $S_6$ (20.07 cm). The results showed that $S_8$ was comparable with $S_4$. The interaction was found to be nonsignificant.

### 4.5.3.3. Filled grains per panicle

The fertiliser treatments $M_3$ and $M_2$ recorded higher number of filled grains per panicle of 96.9 and 95.81 respectively than $M_1$ (63.92) (Table 18). The $M_2$ and $M_3$ were statistically on par, though $M_3$ recorded 1.22 per cent increase over $M_2$. Among HA treatments $S_5$ recorded 89.25 grains per panicle followed by $S_4$ (87.50), $S_3$ (85.75) and $S_2$ (82.6). The per cent increases over $S_2$ were 7.5, 5.6, and 3.7 by $S_5$, $S_4$ and $S_3$ respectively. Among $S_6$, $S_7$ and $S_8$, $S_8$ recorded 90.3 grains per panicle as compared to $S_7$ (86.10) and $S_6$ (83.65). The $S_8$ was statistically on par with $S_5$. The per cent increase recorded by $S_8$ and $S_5$ were 8.5 and 11.0 over $S_2$.

Regarding the interaction effect, the integration of HA with NPK fertilisers recorded increased number of grains per panicle (88.20 to 91.35) over NPK fertilisers (92.40 to 100.8). The $M_3S_5$ and $M_3S_8$ recorded 99.75 and 100.8 grains per panicle over $M_3S_1$ (91.35), which was on par with the treatment $M_2S_5$ (99.75) and $M_2S_8$ (100.8).

### 4.5.3.4. Chaffy grains per panicle

The minimum number of chaffy grains per panicle was recorded in $M_3$ (10.05). It was on par with $M_2$ (11.0) (Table 18). In the HA treatments, $S_5$ (11.67), $S_4$ (12.33), $S_2$ (13.90) and $S_3$ (13.23) were recorded comparable values. Among the $S_6$, $S_7$ and $S_8$, the $S_8$ (8.77) registered less number of chaffy grains. It was statistically comparable with $S_7$ (9.47) and $S_6$ (15.13). In the interaction effect, the NPK fertiliser combined with HA recorded lower number of chaffy grains (5.3 to 12.7) than NPK fertiliser (17.3 to 18.3). The $M_3$ with $S_8$ recorded lower number of chaffy grain (5.3) than $M_3S_1$ (17.3). The $M_3S_8$ was comparable with $M_3S_3$ (9.7), $M_3S_7$ (7.7) .The $M_2S_7$ (5.70), $M_2S_8$ (6.00) and $M_2S_7$ (10.0) were comparable.

### 4.5.3.5. Thousand grain weight

The increase in thousand grain weight due to fertiliser treatment was significant (Table 19). The $M_3$ (22.28 g) and $M_2$ (21.99 g) registered higher grain weight as against $M_1$ (21.18 g). The treatment $S_1$ recorded 21.23 g and it increased to 22.24 g with increase in humic acid dose to 40 kg ha$^{-1}$. Among $S_6$, $S_7$ and $S_8$, the $S_8$ recorded higher grain weight of 22.03 g . The treatments $S_5$ and $S_8$ were on par with each other. The per cent increase of thousand grain weight over no humic acid was 4.54 and 3.63 respectively for $S_5$ and $S_8$. The NPK fertiliser applied treatment recorded lower grain weight than NPK fertiliser combined with humic acid treatments .The interaction was found to be nonsignificant.

**Table 19. Effect of humic acid and fertilisers on yield of rice - Pot experiment**

| Treatments | Grain yield (g pot$^{-1}$) | | | | Straw yield (g pot$^{-1}$) | | | | 1000 grain weight (g) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 12.65 | 18.87 | 19.58 | 17.03 | 18.43 | 27.17 | 28.64 | 24.75 | 20.43 | 21.48 | 21.79 | 21.23 |
| $S_2$ | 13.57 | 19.99 | 20.20 | 17.92 | 19.66 | 28.75 | 30.02 | 26.14 | 20.87 | 21.71 | 22.08 | 21.55 |
| $S_3$ | 14.18 | 20.71 | 20.91 | 18.60 | 20.57 | 29.95 | 30.98 | 27.17 | 21.16 | 21.98 | 22.26 | 21.80 |
| $S_4$ | 14.69 | 21.11 | 21.22 | 19.01 | 21.58 | 30.79 | 31.65 | 28.01 | 21.51 | 22.13 | 22.50 | 22.05 |
| $S_5$ | 14.99 | 21.32 | 21.52 | 19.28 | 22.03 | 31.32 | 31.70 | 28.35 | 21.73 | 22.37 | 22.61 | 22.24 |
| $S_6$ | 13.97 | 20.40 | 20.50 | 18.29 | 20.55 | 29.28 | 30.66 | 26.83 | 21.06 | 21.95 | 22.19 | 21.73 |
| $S_7$ | 14.48 | 20.91 | 20.91 | 18.77 | 20.81 | 30.02 | 30.75 | 27.19 | 21.29 | 22.11 | 22.26 | 21.89 |
| $S_8$ | 15.10 | 21.32 | 21.42 | 19.28 | 21.00 | 30.78 | 31.65 | 27.81 | 21.37 | 22.19 | 22.53 | 22.03 |
| Mean | 14.20 | 20.58 | 20.78 | 18.52 | 20.58 | 29.76 | 30.76 | 27.03 | 21.18 | 21.99 | 22.28 | 21.82 |
| CD(p=0.05) | | | | | | | | | | | | |
| M | 1.0 | | | | 2.7 | | | | 0.74 | | | |
| S | 0.8 | | | | 2.1 | | | | 0.45 | | | |
| M at S | 1.1 | | | | 3.0 | | | | NS | | | |
| S at M | 0.9 | | | | 2.9 | | | | | | | |

### 4.5.3.6. Grain yield

The grain yield of rice recorded in 0, 75 and 100 per cent recommended dose of NPK were 14.2, 20.58 and 20.78 g pot$^{-1}$ respectively (Table 19). The per cent increase in grain yield over control by 100 and 75 per cent NPK fertiliser were 31.7 and 31.0 respectively. The response for 100 per cent NPK fertiliser was comparable with 75 per cent NPK fertiliser. Among the HA applied treatments higher grain yield of 19.28 g pot$^{-1}$ was recorded in $S_5$ and $S_8$. They were statistically on par with $S_7$ (18.77 g pot$^{-1}$) which was followed by $S_4$ (19.01 g pot$^{-1}$).

When NPK fertilisers applied without HA, the grain yield recorded was significantly lower (18.87 to 19.58 g pot$^{-1}$) than that recorded by NPK fertiliser combined with HA treatments (19.99 to 21.52 g pot$^{-1}$). The combination of $M_2$ with $S_5$ or $S_8$ recorded an increased yield of 11.49 per cent over $M_2$ $S_1$and $M_3$ with $S_5$ recorded 9.01 per cent increase over $M_3$ $S_1$. The combinations $M_2$ $S_5$, $M_2$ $S_8$ and $M_3$ $S_5$ were statistically on par.

### 4.5.3.7. Straw yield

The straw yield of rice was higher in $M_3$ (30.76 g pot$^{-1}$) than $M_2$ (29.76 g pot$^{-1}$) and $M_1$ (20.58 g pot$^{-1}$) (Table 19). However, the $M_2$ was found to be comparable with $M_3$ and the per cent increase were 3.2 by $M_3$ over $M_2$. With regard to humic acid treatments, the $S_5$ (40 kg ha$^{-1}$) recorded significantly higher straw yield of 28.35 g pot$^{-1}$, which was on par with $S_4$ (28.01 g pot$^{-1}$) and $S_3$ (27.17 g pot$^{-1}$). The treatments $S_7$ and $S_8$ were on par with each other and recorded 27.19 g pot$^{-1}$ and 27.81 g pot$^{-1}$ respectively. The effect of interaction showed that the application of NPK fertilisers recorded less straw yield (27.17 to 28.64 g pot$^{-1}$ ) than NPK fertilisers with HA (28.75 to 31.70 g pot$^{-1}$). The higher straw yield of 31.7 and 31.65 g pot$^{-1}$ were recorded in $M_3S_5$ and $M_3S_8$ treatment combinations than $M_3S_1$ (28.64 g pot$^{-1}$) and $M_2S_1$ (27.17 g pot$^{-1}$).

## 4.6. Effect of humic acid and NPK fertilisers on rice in Alfisol –Field experiment

Field experiment was conducted during rabi season with rice variety ADT 36 in Noyyal alluvium soil series representing Alfisol. The treatment structure consisted of three main plot treatments viz., no fertiliser ($M_1$), 75 per cent recommended dose of NPK fertiliser ($M_2$) and 100 per cent recommended dose of NPK fertiliser ($M_3$) and eight subplot treatments with HA (humic acid) *viz.,* 0 ($S_1$), 10 ($S_2$), 20 ($S_3$), 30 ($S_4$), 40 ($S_5$) kg ha$^{-1}$, 10 kg HA ha$^{-1}$ + foliar spray (FS) of 0.1 per cent HA ($S_6$), 10 kg HA ha$^{-1}$ + Root dipping (RD) of 0.3 per cent ($S_7$) and 10 kg HA ha$^{-1}$+FS+RD ($S_8$). The data on yield, nutrient uptake and soil properties were statistically scrutinized and results are presented below:

### 4.6.1. Soil fertility

### 4.6.1.1. Organic carbon (Table 20)

Organic carbon content of soil was estimated from samples collected at post harvest stage. In NPK fertiliser treatment, the 0.768 per cent of organic carbon was recorded in the $M_3$ and it was comparable with ($M_2$) (0.760 %). The lowest organic carbon content was recorded in $M_1$ (0.733 %). Among the HA treatments, $S_5$ recorded higher organic carbon content of 0.790 per cent than by $S_4$ (0.776 %). The treatment $S_8$ recorded higher organic carbon content of 0.748 per cent than $S_6$ (0.743 %) and $S_7$ (0.747 %).

The organic carbon content was significantly increased by the application of NPK fertiliser combined with HA (0.747 to 0.815 %) than the NPK fertiliser alone (0.729 to 0.735 %). In the interaction, $M_3S_5$ (0.815 %) and $M_2S_5$ (0.798 %) $M_3S_4$ (0.792 %), $M_2S_4$ (0.786 %) recorded comparable organic carbon content.

Table 20. **Effect of humic acid and fertilisers on organic carbon (%) and CEC (cmol(p+) kg$^{-1}$) at post harvest in Alfisol**

| Treatments | Organic carbon | | | | CEC | | | |
|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 0.711 | 0.729 | 0.735 | 0.725 | 21.5 | 26.2 | 27.0 | 24.9 |
| $S_2$ | 0.725 | 0.747 | 0.755 | 0.742 | 24.5 | 28.8 | 29.2 | 27.5 |
| $S_3$ | 0.738 | 0.765 | 0.773 | 0.759 | 25.8 | 31.1 | 31.8 | 29.6 |
| $S_4$ | 0.749 | 0.786 | 0.792 | 0.776 | 27.2 | 33.5 | 33.5 | 31.4 |
| $S_5$ | 0.758 | 0.798 | 0.815 | 0.790 | 28.5 | 35.8 | 35.8 | 33.4 |
| $S_6$ | 0.725 | 0.750 | 0.755 | 0.743 | 24.8 | 28.7 | 29.4 | 27.6 |
| $S_7$ | 0.728 | 0.752 | 0.760 | 0.747 | 25.2 | 29.1 | 29.8 | 28.2 |
| $S_8$ | 0.730 | 0.754 | 0.760 | 0.748 | 25.2 | 29.5 | 30.0 | 28.2 |
| Mean | 0.733 | 0.760 | 0.768 | 0.753 | 25.3 | 27.2 | 30.8 | 27.8 |
| CD (P=0.05) | | | | | | | | |
| M | 0.011 | | | | 3.8 | | | |
| S | 0.025 | | | | 2.2 | | | |
| M at S | 0.013 | | | | 4.0 | | | |
| S at M | 0.045 | | | | 2.5 | | | |

### 4.6.1.2. Cation exchange capacity

The results on cation exchange capacity of the post harvest soil samples as affected by various treatments are furnished in the Table 20. The results showed that the treatment $M_2$ and $M_3$ significantly increased the CEC of soil. The $M_2$ recorded 27.2 cmol (p+) $kg^{-1}$ and $M_3$ recorded 30.8 cmol (p+) $kg^{-1}$ while $M_1$ recorded only 25.3 cmol (p+) $kg^{-1}$. The per cent increase of CEC recorded by $M_2$ and $M_3$ over $M_1$ were 7.0 and 17.9 cmol (p+) $kg^{-1}$. With reference to HA treatments, results showed that the increasing level of HA from 10 to 40 kg HA $ha^{-1}$ significantly increased the CEC of soil. The $S_5$ that recorded 33.4 cmol (p+) $kg^{-1}$ and the $S_5$ was on par with $S_4$ (31.4 cmol (p+) $kg^{-1}$) .The $S_4$ was followed by $S_3$ (29.6 cmol (p+) $kg^{-1}$) and $S_2$ (27.5 cmol (p+) $kg^{-1}$). The treatments $S_6$ (27.6 cmol (p+) $kg^{-1}$), $S_7$ (28.2 cmol (p+) $kg^{-1}$) and $S_8$ (28.2 cmol (p+) $kg^{-1}$) were on par with each other. The application of NPK fertiliser recorded a range of CEC, which was lower (26.2 to 27.0 cmol (p+) $kg^{-1}$) than that recorded by NPK fertilisers with HA (28.8 to 35.8 cmol (p+) $kg^{-1}$). The $S_5$ combined with $M_2$ and $M_3$ (35.8 cmol (p+) $kg^{-1}$) recorded higher CEC and this was on par with $S_4$ with $M_2$ and $M_3$ (33.5 cmol (p+) $kg^{-1}$). The treatment $M_3S_3$ (31.8 cmol (p+) $kg^{-1}$), $M_2S_3$ (31.1 cmol (p+) $kg^{-1}$) and $M_3S_8$ (30.0 cmol (p+) $kg^{-1}$), $M_3S_7$ (29.8 cmol (p+) $kg^{-1}$) $M_3S_6$ (29.4 cmol (p+) $kg^{-1}$) recorded comparable CEC.

### 4.6.1.3.Exchangeable cations (Table 21)

#### Exchangeable calcium

Among the NPK fertiliser treatments, $M_3$ recorded 17.4 cmol (p+) $kg^{-1}$ of exchangeable calcium which was comparable with $M_2$ (16.9 cmol (p+) $kg^{-1}$). The $M_1$ treatment recorded only 14.7 cmol (p+) $kg^{-1}$. The per cent increase recorded by $M_2$ and $M_3$ over $M_1$ were 13.0 and 15.5. In the humic acid treatments, $S_5$ recorded the highest exchangeable calcium content of 18.4 cmol (p+) $kg^{-1}$, which was on par with

**Table 21. Effect of humic acid and fertilisers on exchangeable cations (cmol (p+) kg$^{-1}$) at post harvest in Alfisol**

| Treatments | Exch.Ca | | | | Exch.Mg | | | | Exch .K | | | | Exch.Na | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 12.2 | 14.5 | 15.7 | 14.1 | 6.0 | 7.8 | 8.3 | 7.4 | 1.02 | 1.12 | 1.22 | 1.12 | 2.0 | 2.5 | 3.0 | 2.5 |
| $S_2$ | 13.8 | 15.9 | 16.8 | 15.4 | 7.8 | 9.2 | 9.7 | 8.9 | 1.08 | 1.18 | 1.35 | 1.20 | 2.2 | 2.5 | 3.2 | 2.6 |
| $S_3$ | 15.1 | 17.0 | 17.3 | 16.5 | 9.5 | 10.8 | 11.2 | 10.5 | 1.15 | 1.30 | 1.45 | 1.30 | 2.4 | 2.6 | 3.4 | 2.8 |
| $S_4$ | 16.5 | 18.5 | 18.7 | 17.9 | 10.0 | 12.1 | 12.3 | 11.5 | 1.22 | 1.51 | 1.65 | 1.46 | 2.5 | 2.7 | 3.5 | 2.9 |
| $S_5$ | 17.2 | 18.8 | 19.1 | 18.4 | 10.8 | 12.8 | 13.1 | 12.2 | 1.30 | 1.57 | 1.68 | 1.52 | 2.7 | 2.9 | 3.8 | 3.1 |
| $S_6$ | 14.0 | 16.5 | 16.8 | 15.8 | 8.0 | 9.8 | 10.2 | 9.3 | 1.12 | 1.20 | 1.35 | 1.22 | 2.2 | 2.5 | 3.2 | 2.6 |
| $S_7$ | 14.3 | 17.0 | 17.2 | 16.2 | 8.3 | 10.2 | 10.7 | 9.7 | 1.18 | 1.30 | 1.42 | 1.30 | 2.3 | 2.7 | 3.3 | 2.8 |
| $S_8$ | 14.4 | 17.0 | 17.4 | 16.3 | 8.5 | 10.7 | 10.8 | 10.0 | 1.23 | 1.35 | 1.45 | 1.34 | 2.4 | 2.7 | 3.3 | 2.8 |
| Mean | 14.7 | 16.9 | 17.4 | 16.3 | 8.6 | 10.4 | 10.8 | 9.9 | 1.16 | 1.32 | 1.45 | 1.31 | 2.3 | 2.6 | 3.3 | 2.7 |
| CD(p=0.05) | | | | | | | | | | | | | | | | |
| M | 2.4 | | | | 1.6 | | | | 0.22 | | | | 0.81 | | | |
| S | 1.7 | | | | 1.2 | | | | 0.15 | | | | 0.50 | | | |
| M at S | 2.5 | | | | 1.9 | | | | 0.25 | | | | NS | | | |
| S at M | 1.9 | | | | 1.3 | | | | 0.18 | | | | | | | |

$S_4$ (17.9 cmol (p+) kg$^{-1}$) and the $S_4$ was followed by $S_3$ (16.5 cmol (p+) kg$^{-1}$). The treatments $S_8$, $S_7$ and $S_6$ recorded 16.3, 16.2 and 15.8 (cmol (p+) kg$^{-1}$) respectively and they were all on par with each other. The application of NPK fertiliser with HA recorded a higher range of 15.9 to 19.1 cmol (p+) kg$^{-1}$ of exchangeable calcium than fertiliser treatments (14.5 to 15.7 cmol (p+) kg$^{-1}$). The treatment combinations $M_3S_5$ recorded 19.10 cmol (p+) kg$^{-1}$ of exchangeable calcium and it was comparable with $M_2S_5$ (18.8 cmol (p+) kg$^{-1}$), $M_3S_4$ (18.7 cmol (p+) kg$^{-1}$) and $M_2S_4$ (18.5 cmol (p+) kg$^{-1}$).

**Exchangeable magnesium**

The exchangeable Mg content of the post harvest soil significantly increased due to the addition of NPK fertilisers. The $M_3$, $M_2$ and $M_1$ recorded 10.8, 10.4 and 8.6 cmol (p+) kg$^{-1}$respectively. Among the HA treatments, $S_5$ and $S_4$ recorded 12.2 and 11.5 cmol (p+) kg$^{-1}$ and they were on par with each other. The NPK fertilisers combined with HA recorded higher range of exchangeable Mg (9.2 to13.1 cmol (p+) kg$^{-1}$) than NPK fertiliser treatments (7.8 to 8.3 cmol (p+) kg$^{-1}$. The $M_3$ in association with $S_5$ treatment recorded the highest exchangeable Mg content of 13.1 cmol (p+) kg$^{-1}$ and it was comparable with $M_2S_5$ (12.8 cmol (p+) kg$^{-1}$), $M_3S_4$ (12.3 cmol (p+) kg$^{-1}$) and $M_2S_4$ (12.10 cmol (p+) kg$^{-1}$) .

**Exchangeable potassium**

The treatment $M_3$ receiving 100 per cent NPK fertilisers (1.45 cmol (p+) kg$^{-1}$) does not show the statistical difference over $M_2$ receiving 75 per cent NPK fertilisers (1.32 cmol (p+) kg$^{-1}$). Among the HA treatments, the $S_5$ and $S_4$ recorded 1.52 and 1.46 cmol (p+) kg$^{-1}$and the $S_4$ was followed by $S_3$ (1.30 cmol (p+) kg$^{-1}$). The treatments $S_8$, $S_7$ and $S_6$ recorded 1.34, 1.30 and 1.22 cmol (p+) kg$^{-1}$) and they were on par with each other. In the interaction, the treatment $M_3S_5$ recorded the highest exchangeable K content of 1.68 cmol (p+) kg$^{-1}$, which was on par with $M_3S_4$ (1.65 cmol (p+) kg$^{-1}$). The $M_2S_5$ (1.57 cmol (p+) $kg^{-1}$) and $M_2S_4$ (1.51 cmol (p+) $kg^{-1}$) were on par with each other. The exchangeable K recorded in the NPK fertiliser combined with HA showed higher range of exchangeable K content of 1.18 to 1.68 cmol (p+) $kg^{-1}$ than NPK fertiliser (1.12 to1.22 cmol (p+) $kg^{-1}$). The treatment combination of $M_3S_3$ (1.45 cmol (p+) $kg^{-1}$), $M_3S_6$ (1.35 cmol (p+) $kg^{-1}$), $M_3S_7$ (1.42 cmol (p+) $kg^{-1}$), $M_3S_8$ (1.45 cmol (p+) $kg^{-1}$) and $M_3S_2$ (1.35 cmol (p+) $kg^{-1}$) recorded comparable exchangeable K.

**Exchangeable sodium**

Among the NPK fertiliser treatments, the $M_3$ (3.3 cmol (p+) $kg^{-1}$) and $M_2$ (2.6 cmol (p+) $kg^{-1}$) were on par with each other. The $M_1$ recorded significantly lesser exchangeable Na content of 2.3 cmol (p+) $kg^{-1}$ than $M_2$ and $M_3$. Among the HA treatments, the $S_5$ recorded higher exchangeable Na (3.1 cmol (p+) $kg^{-1}$), which was comparable with all other HA treatments. The treatment combination $M_3S_5$ recorded highest exchangeable Na content of 3.8 cmol (p+) $kg^{-1}$. However, the treatment combinations did not attain the level of significance.

### 4.6.1.4. Available nutrients

### 4.6.1.4.1. Available nitrogen [$KMnO_4$-N]

The $KMnO_4$-N content of soil was found to decrease from tillering to post harvest stage of rice (Table 22). At tillering stage, the $KMnO_4$-N recorded in $M_3$ (100 per cent NPK) was 272 kg $ha^{-1}$ which was on par with $M_2$ (75% NPK) (258 kg $ha^{-1}$) but significantly low in $M_1$ (232 kg $ha^{-1}$). The per cent increase recorded by $M_2$ and $M_3$ over $M_1$ were 10.1 and 14.7. The increase in $KMnO_4$-N due to NPK fertiliser application was statistically significant. In HA treatments, $S_5$ recorded 264 kg $ha^{-1}$ of $KMnO_4$-N, which was on par with $S_4$ (258 kg $ha^{-1}$) followed by $S_3$ (253 kg $ha^{-1}$). Among $S_6$, $S_7$ and $S_8$, the $S_8$

Table 22. Effect of humic acid and fertilisers on $KMnO_4$-N content (kg $ha^{-1}$) in Alfisol

| Treatments | Tillering | | | | Flowering | | | | Post harvest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 221 | 242 | 260 | 241 | 211 | 230 | 242 | 228 | 201 | 220 | 232 | 218 |
| $S_2$ | 226 | 251 | 265 | 247 | 217 | 233 | 247 | 232 | 208 | 227 | 238 | 224 |
| $S_3$ | 233 | 255 | 271 | 253 | 223 | 237 | 252 | 237 | 213 | 231 | 241 | 228 |
| $S_4$ | 236 | 262 | 276 | 258 | 227 | 243 | 259 | 243 | 217 | 239 | 249 | 235 |
| $S_5$ | 238 | 271 | 283 | 264 | 230 | 248 | 261 | 246 | 222 | 242 | 254 | 239 |
| $S_6$ | 232 | 252 | 268 | 251 | 223 | 232 | 250 | 235 | 212 | 228 | 241 | 225 |
| $S_7$ | 235 | 261 | 273 | 256 | 225 | 241 | 252 | 239 | 215 | 232 | 240 | 229 |
| $S_8$ | 236 | 266 | 280 | 261 | 225 | 242 | 258 | 242 | 216 | 234 | 243 | 231 |
| Mean | 232 | 258 | 272 | 254 | 223 | 238 | 253 | 238 | 213 | 231 | 242 | 229 |
| CD(p=0.05) | | | | | | | | | | | | |
| M | 15 | | | | 15 | | | | 16 | | | |
| S | 7 | | | | 9 | | | | 8 | | | |
| M at S | 7 | | | | 16 | | | | 12 | | | |
| S at M | 8 | | | | 10 | | | | 9 | | | |

recorded 261 kg ha$^{-1}$ of $KMnO_4$-N and the $S_8$ was followed by $S_6$ (251 kg ha$^{-1}$) and $S_7$ (256 kg ha$^{-1}$). The per cent increase recorded by $S_3$, $S_7$ and $S_8$ over $S_1$ were 4.7, 5.9 and 7.7 respectively. In the interaction treatment, the application of HA integrated with NPK fertiliser recorded 251 to 283 kg ha$^{-1}$ of $KMnO_4$-N whereas the NPK fertiliser registered 242 to 260 kg ha$^{-1}$. The $M_3S_8$ and $M_3S_5$ recorded 280 and 283 kg ha$^{-1}$ of $KMnO_4$-N and they were statistically on par.

At flowering stage, the fertiliser treatment receiving 100 per cent NPK fertiliser registered 253 kg ha$^{-1}$ of $KMnO_4$-N content whereas $M_2$ and $M_1$ recorded 238 and 223 kg ha$^{-1}$ only. The per cent increase recorded by $M_2$ and $M_3$ over $M_1$ were 6.3 and 11.9.

In HA treatments, $S_5$ recorded 246 kg ha$^{-1}$ of $KMnO_4$-N and the $S_5$ was followed by $S_4$ (243 kg ha$^{-1}$). Among the other treatments, $S_8$ registered 242 kg ha$^{-1}$ of $KMnO_4$-N and the $S_8$ was followed by $S_6$ (235 kg ha$^{-1}$), $S_2$ (232 kg ha$^{-1}$) and $S_3$ (237 kg ha$^{-1}$). The per cent increase recorded by $S_5$ over $S_4$ and $S_8$ and $S_7$ were 1.2,1.6 and 2.8.The $KMnO_4$-N recorded in the NPK fertiliser combined with HA treatment was 233 to 261 kg ha$^{-1}$, while in NPK fertiliser treatment the range of $KMnO_4$-N was 230 to 242 kg ha$^{-1}$. In the interaction treatments, $M_3S_5$ (261 kg ha$^{-1}$), $M_3S_4$ (259 kg ha$^{-1}$), $M_3S_3$ (252 kg ha$^{-1}$), $M_3S_7$ (252 kg ha$^{-1}$) and $M_3S_8$ (258 kg ha$^{-1}$) were statistically on par with each other. The treatment combination $M_2S_5$ recorded 248 kg ha$^{-1}$ that was on par with $M_2S_4$ (243 kg ha$^{-1}$), $M_2S_7$ (241 kg ha$^{-1}$) and $M_2S_8$ (242 kg ha$^{-1}$).

At post harvest stage, the $KMnO_4$-N had declined. The $M_1$ recorded 213 kg ha$^{-1}$ of $KMnO_4$-N which was significantly less than that recorded by $M_2$ (231 kg ha$^{-1}$) and $M_3$ (242 kg ha$^{-1}$). Among the HA treatments, the $S_5$ recorded 239 kg ha$^{-1}$ of $KMnO_4$-N which was on par with $S_4$ (235 kg ha$^{-1}$). The $S_4$ was followed by $S_3$ (228 kg ha$^{-1}$) and $S_2$ (224 kg ha$^{-1}$). The treatment $S_8$ recorded 231 kg ha$^{-1}$ of $KMnO_4$-N, which was on par with

$S_6$ (225 kg ha$^{-1}$) and $S_7$ (229 kg ha$^{-1}$). The application of NPK fertiliser integrated with HA recorded 227 to 254 kg ha$^{-1}$of $KMnO_4$-N than NPK fertiliser (220 to 232 kg ha$^{-1}$).

The treatment combination $M_3S_5$ recorded 254 kg ha$^{-1}$ of $KMnO_4$-N, which was on par with $M_3S_4$ (249 kg ha$^{-1}$), $M_3S_3$ (241 kg ha$^{-1}$), $M_3S_6$ (241 kg ha$^{-1}$), $M_3S_7$ (240 kg ha$^{-1}$), $M_3S_8$ (243 kg ha$^{-1}$) and $M_3S_2$ (238 kg ha$^{-1}$). The treatment $M_2S_4$ (239 kg ha$^{-1}$) and $M_2S_8$ (234 kg ha$^{-1}$) were comparable.

### 4.6.1.4.2. Available phosphorus (Olsen-P)

The Olsen-P content was declined from tillering to post harvest. The fertiliser treatments $M_3$ and $M_2$ were on par with each other in all three stages (Table 23). The Olsen-P of the soil at tillering stage was significantly increased by the addition of NPK fertiliser. The $M_3$ and $M_2$ registered 23.0 and 23.2 kg ha$^{-1}$ of Olsen-P respectively. The $M_1$ recorded only 16.8 kg ha$^{-1}$ .The per cent increase of $M_3$ and $M_2$ over $M_1$ were 27.6 and 27.0. The HA treatments $S_5$ recorded 21.9 kg ha$^{-1}$ of Olsen-P which was on par with $S_4$ (21.3 kg ha$^{-1}$) and the $S_4$ was followed by $S_3$ (20.8 kg ha$^{-1}$). The $S_8$ recorded highest Olsen-P content of 21.7 kg ha$^{-1}$ than $S_7$ (21.1 kg ha$^{-1}$) and $S_6$ (20.6 kg ha$^{-1}$). The per cent increase of $S_5$, $S_4$, $S_3$, $S_7$ and $S_8$ over $S_1$ were 9.1, 6.6, 4.3, 5.6 and 8.3 respectively. The treatments $S_5$ and $S_8$ were comparable .The application of NPK fertilisers combined with HA recorded higher Olsen-P content of 22.3 to 24.3 kg ha$^{-1}$ than NPK fertiliser (21.9 to 22.1 kg ha$^{-1}$). In interaction, the treatment combination $M_3S_5$ recorded 24.1 kg ha$^{-1}$ Olsen-P which was on par with $M_2S_5$ (24.0 kg ha$^{-1}$), $M_3S_8$ (24.3 kg ha$^{-1}$) and $M_2S_8$ (23.9 kg ha$^{-1}$). The treatment $M_2S_7$ (23.2 kg ha$^{-1}$), $M_3S_7$ (23.3 kg ha$^{-1}$), $M_2S_4$ (23.2 kg ha$^{-1}$) and $M_3S_4$ (23.3 kg ha$^{-1}$) were comparable.

At flowering stage, the content of Olsen-P recorded in $M_3$ and $M_2$ were 18.3 and 18.1 kg ha$^{-1}$ .The Olsen-P content recorded by $M_1$ was 14.4 kg ha$^{-1}$. The per cent increase

**Table 23. Effect of humic acid and fertilisers on Olsen-P content (kg $ha^{-1}$) in Alfisol**

| Treatments | Tillering | | | | Flowering | | | | Post harvest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 15.8 | 21.9 | 22.1 | 19.9 | 13.2 | 17.3 | 17.3 | 15.9 | 11.9 | 16.0 | 16.1 | 14.7 |
| $S_2$ | 16.3 | 22.3 | 22.6 | 20.4 | 13.9 | 17.7 | 17.7 | 16.4 | 12.3 | 16.3 | 16.4 | 15.0 |
| $S_3$ | 16.7 | 22.7 | 22.9 | 20.8 | 14.3 | 17.9 | 17.9 | 16.7 | 12.8 | 16.5 | 16.6 | 15.3 |
| $S_4$ | 17.3 | 23.2 | 23.3 | 21.3 | 14.7 | 18.2 | 18.5 | 17.7 | 13.1 | 16.9 | 17.1 | 15.7 |
| $S_5$ | 17.7 | 24.0 | 24.1 | 21.9 | 15.4 | 19.2 | 19.6 | 18.1 | 13.7 | 17.5 | 18.2 | 16.5 |
| $S_6$ | 16.8 | 22.4 | 22.7 | 20.6 | 14.7 | 17.6 | 17.9 | 16.7 | 12.5 | 16.3 | 16.3 | 15.0 |
| $S_7$ | 16.8 | 23.2 | 23.3 | 21.1 | 14.6 | 17.9 | 18.6 | 17.0 | 12.6 | 16.4 | 16.7 | 15.2 |
| $S_8$ | 16.9 | 23.9 | 24.3 | 21.7 | 14.5 | 18.6 | 18.7 | 17.3 | 12.4 | 17.0 | 16.9 | 15.4 |
| Mean | 16.8 | 23.0 | 23.2 | 21.0 | 14.4 | 18.1 | 18.3 | 16.9 | 12.7 | 16.6 | 16.8 | 15.4 |
| CD(p=0.05) | | | | | | | | | | | | |
| M | | 0.4 | | | | 0.7 | | | | 0.6 | | |
| S | | 0.6 | | | | 0.5 | | | | 0.4 | | |
| M at S | | 0.7 | | | | 0.8 | | | | 0.6 | | |
| S at M | | 0.7 | | | | 0.6 | | | | 0.5 | | |

for $M_3$ and $M_2$ over $M_1$ were 21.3 and 20.4 .The HA treatment $S_5$ recorded 18.1 kg ha$^{-1}$ of Olsen-P which was on par with $S_4$ (17.7 kg ha$^{-1}$). The $S_3$ (16.7 kg ha$^{-1}$) and $S_2$ (16.4 kg ha$^{-1}$) were on par. The treatment $S_8$ that recorded 17.3 kg ha$^{-1}$ of Olsen-P was on par with $S_7$ (17.0 kg ha$^{-1}$). The treatments $S_8$ and $S_4$ were on par with each other. The per cent increase recorded by $S_5$ over $S_4$, $S_3$ and $S_7$ were 2.2, 7.7 and 6.1.The application of NPK fertiliser combined with HA recorded higher range of Olsen-P (17.7 to 19.6 kg ha$^{-1}$) than that of NPK fertiliser (17.3 kg ha$^{-1}$). The treatment $M_3S_5$ recorded 19.6 kg ha$^{-1}$ of Olsen-P and it was followed by $M_3S_4$ (18.5 kg ha$^{-1}$), $M_3S_8$ (18.7 kg ha$^{-1}$) and $M_3S_7$ (18.6 kg ha$^{-1}$).

The Olsen-P content at post harvest stage had declined. The treatment $M_2$ and $M_3$ recorded comparable Olsen-P content of 16.6 and 16.8 kg ha$^{-1}$. The $M_1$ recorded significantly less Olsen-P content of 12.7 kg ha$^{-1}$. The per cent increase of $M_3$ and $M_2$ over $M_1$ were 24.4 and 23.5.Among the humic acid treatments, $S_5$ recorded the highest Olsen-P content of 16.5 kg ha$^{-1}$ which was significantly higher than $S_4$ (15.7) and the $S_4$ was followed by $S_3$ (15.3 kg ha$^{-1}$). Among $S_6$, $S_7$ and $S_8$, the $S_8$ recorded 15.4 kg ha$^{-1}$ of Olsen-P and it was followed by $S_6$ (15.0 kg ha$^{-1}$) and $S_7$ (15.2 kg ha$^{-1}$). The NPK fertilisers integrated with HA recorded higher range of Olsen-P 16.3 to18.2 kg ha$^{-1}$) than NPK fertiliser (16.0 to 16.1 kg ha$^{-1}$). In the interaction of HA with fertilisers, $M_3S_5$ (18.2 kg ha$^{-1}$) registered higher content of Olsen-P followed by $M_2S_5$ (17.5 kg ha$^{-1}$). The treatment $M_3S_4$ (17.1 kg ha$^{-1}$) and $M_2S_4$ (16.9 kg ha$^{-1}$) were statistically on par with each other.

### 4.6.1.4.3. Available potassium ($NH_4OAc$-K)

The $NH_4OAc$-K of soil was estimated at different growth stages of rice and given in Table 24 At tillering stage, the $M_3$ registered significantly higher content of $NH_4OAc$-K content of 837 kg ha$^{-1}$ and it was followed by $M_2$ (774 kg ha$^{-1}$) and $M_1$ (560 kg ha$^{-1}$). The per cent increase recorded by $M_3$ and $M_2$ over $M_1$ were 33.1 and 27.6.

**Table 24. Effect of humic acid and fertilisers on $NH_4OAc$-K content (kg $ha^{-1}$) in Alfisol**

| Treatments | Tillering | | | | Flowering | | | | Post harvest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 480 | 720 | 793 | 664 | 450 | 680 | 727 | 619 | 430 | 630 | 710 | 590 |
| $S_2$ | 520 | 740 | 810 | 690 | 480 | 690 | 750 | 640 | 450 | 650 | 720 | 607 |
| $S_3$ | 560 | 770 | 830 | 720 | 490 | 727 | 770 | 662 | 443 | 687 | 730 | 620 |
| $S_4$ | 590 | 780 | 840 | 737 | 510 | 737 | 780 | 676 | 470 | 710 | 740 | 640 |
| $S_5$ | 590 | 790 | 850 | 743 | 530 | 740 | 790 | 687 | 490 | 710 | 750 | 660 |
| $S_6$ | 540 | 780 | 830 | 717 | 490 | 747 | 760 | 666 | 440 | 727 | 720 | 629 |
| $S_7$ | 600 | 800 | 860 | 753 | 550 | 753 | 750 | 684 | 500 | 700 | 710 | 637 |
| $S_8$ | 600 | 810 | 883 | 764 | 570 | 763 | 760 | 698 | 510 | 690 | 700 | 633 |
| Mean | 560 | 774 | 837 | 724 | 509 | 730 | 761 | 667 | 467 | 688 | 726 | 627 |
| CD(p=0.05) | | | | | | | | | | | | |
| M | 32 | | | | 33 | | | | 19 | | | |
| S | 27 | | | | 20 | | | | 14 | | | |
| M at S | 35 | | | | 35 | | | | 21 | | | |
| S at M | 33 | | | | 28 | | | | 16 | | | |

The HA treatment $S_2$, $S_3$, $S_4$ and $S_5$ recorded 690, 720, 737 and 743 kg ha$^{-1}$ of $NH_4OAc$-K content respectively. The $S_5$ was on par with $S_4$ and the $S_4$ was followed by $S_3$. The treatment $S_8$ recorded 764 kg ha$^{-1}$ of $NH_4OAc$-K content and it was on par with $S_7$ (753 kg ha$^{-1}$) and $S_6$ (717 kg ha$^{-1}$). The treatments $S_5$ and $S_8$ were comparable. The application of NPK fertiliser combined with HA recorded 740 to 883 kg ha$^{-1}$of $NH_4OAc$-K while NPK fertiliser treatment recorded a lower range of $NH_4OAc$-K content of 720 to 793 kg ha$^{-1}$. The highest $NH_4OAc$-K content of 883 kg ha$^{-1}$ was recorded in $M_3S_8$ and it was on par with $M_3S_7$ (860 kg ha$^{-1}$). The treatments $M_3S_5$ (850 kg ha$^{-1}$), $M_3S_4$ (840 kg ha$^{-1}$), $M_3S_3$ (830 kg ha$^{-1}$) and $M_3S_6$ (830 kg ha$^{-1}$) were comparable with each other.

At flowering stage, the $M_3$ registered 761 kg ha$^{-1}$ of $NH_4OAc$-K, which was comparable with that of $M_2$ (730 kg ha$^{-1}$). The $M_1$ recorded 509 kg ha$^{-1}$ of $NH_4OAc$-K content. The per cent increase registered by $M_2$ and $M_3$ over $M_1$ were 33.1 and 30.3.

In HA treatments, $S_8$ recorded highest $NH_4OAc$-K content of 698 kg ha$^{-1}$, which was comparable with $S_7$ (684 kg ha$^{-1}$) and $S_6$ (666 kg ha$^{-1}$). The $NH_4OAc$-K content recorded by $S_5$ (687 kg ha$^{-1}$) and $S_4$ (676 kg ha$^{-1}$) were on par .The $S_4$ was followed by $S_3$ that recorded 662 kg ha$^{-1}$of $NH_4OAc$-K content. Again the $S_8$ and $S_5$ were comparable.

The application of NPK fertiliser recorded lower range of $NH_4OAc$-K content of 680 to 727 kg ha$^{-1}$ than NPK fertiliser combined with HA (690 to 790 kg ha$^{-1}$). In the interaction, the $NH_4OAc$-K content of $M_3S_5$ was 790 kg ha$^{-1}$, which was comparable with $M_3S_4$ (780 kg ha$^{-1}$) and $M_3S_3$ (770 kg ha$^{-1}$) .The $M_3S_3$ was followed by $M_3S_8$ (760 kg ha$^{-1}$) and $M_3S_6$ (760 kg ha$^{-1}$). The $M_2S_8$ (763 kg ha$^{-1}$), $M_2S_7$ (753 kg ha$^{-1}$), $M_2S_6$ (747 kg ha$^{-1}$), $M_2S_5$ (740 kg ha$^{-1}$) and $M_2S_4$ (737 kg ha$^{-1}$) were comparable.

At post harvest, the $M_3$ recorded 726 kg ha$^{-1}$ of $NH_4OAc$-K, which was followed by $M_2$ (688 kg ha$^{-1}$) and $M_1$ (476 kg ha$^{-1}$). In the HA treatments $S_5$ recorded highest

$NH_4OAc$-K content of 660 kg ha$^{-1}$ and it was followed by $S_4$ (640 kg ha$^{-1}$). The treatments $S_7$ (637 kg ha$^{-1}$), $S_8$ (633 kg ha$^{-1}$) and $S_6$ (629 kg ha$^{-1}$) were recorded comparable $NH_4OAc$-K content. The treatment $S_2$ (607 kg ha$^{-1}$) and $S_3$ (620 kg ha$^{-1}$) were on par with each other. The per cent increase recorded by $S_5$ over $S_4$, $S_7$, $S_8$, $S_6$, $S_3$ and $S_2$ were 3.0, 3.5, 4.1, 4.7, 6.1 and 8.0.

The combination of HA integrated with NPK fertiliser recorded higher range of $NH_4OAc$-K (650 to 750 kg ha$^{-1}$) than that recorded in NPK fertiliser (630 to 710 kg ha$^{-1}$). In the interaction, $M_3S_5$ and $M_3S_4$ recorded 750 and 740 kg ha$^{-1}$ and they were on par. The other combinations $M_3S_3$ (730 kg ha$^{-1}$) and $M_3S_2$ (720 kg ha$^{-1}$) were statistically on par with each other.

### 4.6.1.5. DTPA extractable micro nutrients

The DTPA extractable micronutrients content of the post harvest soil samples were analyzed and the results are given in the Table 25.

**DTPA iron**

Among the fertiliser treatments $M_3$ and $M_2$ recorded 37.1 and 36.9 ppm and they were statistically on par with each other .The $M_1$ recorded 36.1 ppm of DTPA Fe which was significantly less than that recorded by $M_2$ and $M_3$.The per cent increase recorded by $M_2$ and $M_3$ over $M_1$ were 2.7 and 2.2. In the HA treatments the highest content of DTPA Fe was recorded in $S_5$ (39.3 ppm) and it was comparable with $S_4$ (38.7 ppm). The $S_4$ was followed by $S_3$ (37.1 ppm). The treatments $S_8$ and $S_7$ recorded 37.3 and 37.2 ppm of DTPA Fe and that were statistically on par with each other. The application of NPK fertiliser with HA recorded higher range of DTPA Fe (35.2 to 39.7 ppm) than NPK fertiliser (33.3 to 33.5 ppm). The highest DTPA Fe content of 39.7 ppm was recorded by

Table 25. Effect of humic acid and fertilisers on DTPA extractable micro nutrients (ppm) in Alfisol

| Treatments | Iron | | | | Zinc | | | | Manganese | | | | Copper | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 32.5 | 33.3 | 33.5 | 33.1 | 3.6 | 3.8 | 3.9 | 3.8 | 11.5 | 12.5 | 12.8 | 12.3 | 5.92 | 6.03 | 6.06 | 6.00 |
| $S_2$ | 34.2 | 35.2 | 35.3 | 34.9 | 3.7 | 4.0 | 4.0 | 3.9 | 12.0 | 12.8 | 13.0 | 12.6 | 5.96 | 6.04 | 6.08 | 6.03 |
| $S_3$ | 36.3 | 37.2 | 37.7 | 37.1 | 3.8 | 4.1 | 4.2 | 4.0 | 12.3 | 13.0 | 13.2 | 12.8 | 6.07 | 6.10 | 6.10 | 6.09 |
| $S_4$ | 37.8 | 38.8 | 39.3 | 38.7 | 3.8 | 4.2 | 4.2 | 4.1 | 12.5 | 13.2 | 13.3 | 13.0 | 6.12 | 6.14 | 6.10 | 6.12 |
| $S_5$ | 38.9 | 39.3 | 39.7 | 39.3 | 3.7 | 4.2 | 4.2 | 4.0 | 12.1 | 9.1 | 13.1 | 11.4 | 6.08 | 6.12 | 6.08 | 6.09 |
| $S_6$ | 35.4 | 36.2 | 36.4 | 36.0 | 3.8 | 4.0 | 4.1 | 4.0 | 12.1 | 13.0 | 13.0 | 12.7 | 5.98 | 6.02 | 6.08 | 6.03 |
| $S_7$ | 36.9 | 37.4 | 37.4 | 37.2 | 3.8 | 4.1 | 4.1 | 4.0 | 12.2 | 13.1 | 13.2 | 12.8 | 5.79 | 6.10 | 6.10 | 6.00 |
| $S_8$ | 36.3 | 37.8 | 37.9 | 37.3 | 3.8 | 4.1 | 4.1 | 4.0 | 8.9 | 13.2 | 13.3 | 11.8 | 6.16 | 6.14 | 6.10 | 6.13 |
| Mean | 36.1 | 36.9 | 37.1 | 36.7 | 3.8 | 4.1 | 4.1 | 4.0 | 11.7 | 12.5 | 13.1 | 12.4 | 6.01 | 6.09 | 6.09 | 6.06 |
| CD(p=0.05) | | | | | | | | | | | | | | | | |
| M | 0.8 | | | | 0.3 | | | | 1.1 | | | | NS | | | |
| S | 1.0 | | | | 0.2 | | | | 0.6 | | | | | | | |
| M at S | NS | | | | NS | | | | NS | | | | | | | |
| S at M | | | | | | | | | | | | | | | | |

$M_3S_5$. However the differences among the various combinations did not attain the level of significance.

**DTPA zinc**

The fertiliser treatments $M_3$ and $M_2$ recorded 4.1 ppm of DTPA Zn, which was significantly higher than that of $M_1$ (3.8 ppm). Among the HA treatments, the $S_4$ recorded 4.1 ppm of DTPA Zn and all other treatments *viz.*, $S_5$ to $S_8$ recorded 4.0 ppm except $S_2$ which recorded 3.9 ppm. The per cent increase recorded by $S_4$, $S_2$ and other treatments over $S_1$ were 7.3, 2.6 and 7.3. The DTPA Zn content recorded by $S_3$ (4.0 ppm), $S_4$ (4.1 ppm), $S_5$ (4.0 ppm), $S_6$ (4.0 ppm), $S_7$ (4.0 ppm) and $S_8$ (4.0 ppm) were on par with each other. The HA integrated with NPK fertiliser registered higher range of DTPA Zn (4.0 to 4.2 ppm) than NPK fertiliser (3.8 to 3.9ppm) did. The treatment combination $M_3S_5$, $M_2S_5$, $M_2S_4$, $M_3S_4$ and $M_3S_3$ recorded 4.2 ppm of DTPA Zn. However the differences among the various combinations did not attain the level of significance.

**DTPA manganese**

Among the fertiliser treatments, $M_3$ registered higher DTPA Mn content of 13.1 ppm than that of $M_2$ (12.5 ppm) and $M_1$ (11.7 ppm). The per cent increase recorded by $M_2$ and $M_3$ over $M_1$ were 10.7 and 6.4. In the HA treatments, the highest DTPA Mn content of 13.0 ppm was recorded in $S_4$ and it was statistically on par with all other HA applied treatments i.e., $S_3$ (12.8 ppm), $S_7$ (12.8 ppm), $S_6$ (12.7 ppm) and $S_2$ (12.6 ppm). The $S_5$ recorded the lowest DTPA Mn (11.4 ppm) content, which was comparable with $S_8$ (11.8 ppm). The treatment combination $M_3S_8$ recorded higher DTPA Mn content of 13.3 ppm. However the differences among the various combinations did not attain the level of significance.

### DTPA copper

The treatments receiving fertilisers $M_3$, $M_2$ and $M_1$ recorded 6.09,6.09 and 6.01 ppm of DTPA Cu. Among the HA treatments, the $S_8$ recorded highest DTPA Cu content of 6.13 ppm and it was followed by other treatments. However the fertiliser and humic acid does not record any significant differences in DTPA Cu content.

## 4.6.2. Root characteristics

### 4.6.2.1. Root length (Table 26)

Application of NPK fertiliser recorded significant increase in root length at harvest. The $M_3$ and $M_2$ recorded 23.8 and 23.8 cm as against 22.3 cm in $M_1$. The per cent increase registered by $M_2$ and $M_3$ over $M_1$ were 6.3.

The HA treatments recorded significant differences in the root length. The $S_3$ recorded 24.7 cm and it was followed by $S_4$ (24.5 cm) . The $S_4$ was comparable with $S_5$ (24.3 cm). The $S_8$ recorded highest root length of 25.0 cm, which was followed by $S_7$ (23.7 cm) and $S_6$ (23.2 cm). The $S_8$ and $S_3$ were statistically on par with each other, while $S_4$ was on par with $S_3$.

Among the interaction, the root length recorded by $M_3S_8$ was 25.8 cm that was followed by $M_3S_3$ (24.7 cm) and $M_3S_4$ (24.3 cm). The root length recorded by $M_2S_8$ (25.6 cm), $M_2S_4$ (24.3 cm) and $M_2S_3$ (24.9 cm) were found comparable. The results on interaction have indicated the presence of longer roots in the NPK fertiliser plus HA treatments (22.6 to 25.8 cm) as against NPK fertiliser treatments (19.7 to 21.3 cm).

**Table 26. Effect of humic acid and fertilisers on root characteristics of rice- Alfisol**

| Treatments | Root volume ($cm^3$) | | | | Root CEC (cmol (p+) $kg^{-1}$) | | | | Root length (cm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 7.3 | 9.6 | 10.3 | 9.1 | 9.5 | 11.8 | 12.2 | 11.2 | 14.1 | 19.7 | 21.3 | 18.3 |
| $S_2$ | 7.7 | 10.3 | 13.3 | 10.4 | 10.0 | 12.5 | 12.7 | 11.9 | 23.5 | 23.7 | 22.6 | 23.3 |
| $S_3$ | 8.3 | 11.0 | 13.0 | 10.8 | 10.8 | 13.9 | 14.1 | 12.9 | 24.4 | 24.9 | 24.7 | 24.7 |
| $S_4$ | 8.7 | 11.3 | 13.3 | 11.1 | 11.7 | 14.8 | 15.0 | 13.8 | 24.9 | 24.3 | 24.3 | 24.5 |
| $S_5$ | 9.3 | 11.7 | 13.7 | 11.6 | 12.3 | 15.3 | 15.5 | 14.4 | 25.1 | 24.3 | 23.4 | 24.3 |
| $S_6$ | 9.3 | 11.7 | 12.0 | 11.0 | 10.2 | 12.7 | 12.8 | 11.9 | 21.5 | 23.9 | 24.2 | 23.2 |
| $S_7$ | 10.3 | 12.7 | 13.3 | 12.1 | 11.0 | 13.2 | 13.5 | 12.6 | 22.0 | 24.1 | 25.1 | 23.7 |
| $S_8$ | 10.6 | 13.3 | 13.3 | 12.4 | 11.2 | 13.3 | 13.5 | 12.7 | 23.5 | 25.6 | 25.8 | 25.0 |
| Mean | 8.9 | 11.4 | 12.8 | 11.0 | 10.8 | 13.4 | 13.7 | 12.6 | 22.3 | 23.8 | 23.8 | |
| CD(p=0.05) | | | | | | | | | | | | |
| M | 1.5 | | | | 0.5 | | | | 1.1 | | | |
| S | 0.8 | | | | 0.8 | | | | 0.3 | | | |
| M at S | 1.6 | | | | 0.6 | | | | 0.8 | | | |
| S at M | 0.8 | | | | 0.8 | | | | 0.3 | | | |

### 4.6.2.2. Root volume

The results recorded on the effect of NPK fertilisers and HA are furnished in the Table (26). The root volume recorded by $M_2$ and $M_3$ were 11.4 and 12.8 $cm^3$ and the per cent increase registered by them over $M_1$ were 21.9 and 30.5. The increase in root volume recorded by $M_2$ and $M_3$ over $M_1$ was statistically significant.

Among the HA treatments, the root volume recorded by $S_8$ was 12.4 $cm^3$ followed by $S_7$ (12.1 $cm^3$). The $S_5$ recorded 11.6 $cm^3$ and it was followed by $S_4$ (11.1 $cm^3$) and $S_3$ (10.8 $cm^3$). The treatments $S_8$, $S_7$ and $S_5$ were statistically on par and $S_5$ was on par with $S_3$ and $S_4$.

In the interaction, the root volume recorded by $M_3S_5$ combination was 13.7 $cm^3$ and it was followed by $M_3S_8$ and $M_3S_7$ (13.3 $cm^3$). The $M_2S_8$ also recorded 13.3 $cm^3$ and it was comparable with $M_2S_4$ (11.3 $cm^3$) and $M_2S_3$ (11.0 $cm^3$). The $M_2S_7$ (12.7 $cm^3$) and $M_2S_8$ (13.3 $cm^3$) were on par with each other.

### 4.6.2.3. Root cation exchange capacity

Among the fertiliser treatments, the treatment $M_3$ (100 % NPK) recorded significantly the highest root CEC of 13.7 cmol (p+) $kg^{-1}$ which was on par with $M_2$ (13.4 cmol (p+) $kg^{-1}$) but less in $M_1$ (10.9 cmol (p+) $kg^{-1}$) (Table 26). Among the HA treatment, the $S_5$ recorded 14.4 cmol (p+) $kg^{-1}$ and it was on par with $S_4$ (13.8 cmol (p+) $kg^{-1}$). The treatment $S_4$ was followed by $S_3$ (12.9 cmol (p+) $kg^{-1}$) and $S_2$ (11.9 cmol (p+) $kg^{-1}$) .The treatment $S_8$ (12.7 cmol (p+) $kg^{-1}$) and $S_7$ (12.6 cmol (p+) $kg^{-1}$) were statistically on par with each other and the $S_7$ was followed by $S_6$ (11.9 cmol (p+) $kg^{-1}$).

The higher range of root CEC was recorded (12.5 to 15.5 cmol (p+) kg$^{-1}$) in the NPK fertiliser combined with HA than NPK fertiliser treatment (11.8 to 12.2 cmol (p+) kg$^{-1}$). In the interaction treatments, $M_3S_5$ recorded higher root CEC of 15.5 cmol (p+) kg$^{-1}$ which was comparable with $M_2S_5$ (15.3 cmol (p+) kg$^{-1}$) and $M_3S_4$ (15.0 cmol (p+) kg$^{-1}$), $M_2S_4$ (14.8 cmol (p+) kg$^{-1}$). The treatments $M_3S_7$ and $M_3S_8$ (13.5 cmol (p+) kg$^{-1}$) were on par with each other.

### 4.6.3. Nutrient uptake

The nutrient uptake of paddy as affected by the application of NPK fertilisers and HA was estimated. At different growth stages of paddy crop the uptake of N, P and K were determined. At harvest, the uptake of N, P, K, Ca, Mg and micronutrients (Fe, Zn, Mn and Cu) were determined.

#### 4.6.3.1. Nitrogen uptake

The data pertaining to the N uptake at different growth stages are given in Table 27. At tillering stage, the N uptake was increased significantly due to NPK fertiliser treatment. The $M_3$, $M_2$, and $M_1$ recorded 15.99, 14.79 and 6.58 kg ha$^{-1}$ of N uptake and the per cent increase recorded by $M_2$ and $M_3$ over $M_1$ were 58.8 and 55.5. In HA treatments, the $S_5$ recorded 14.26 kg ha$^{-1}$ of N uptake, which was on par with $S_4$ (13.51 kg ha$^{-1}$). The $S_4$ was followed by $S_3$ (12.89 kg ha$^{-1}$) and $S_2$ (11.98 kg ha$^{-1}$). The treatments $S_6$ and $S_8$ recorded 12.57 and 13.13 kg ha$^{-1}$ of N uptake and it was followed by $S_7$ (12.29 kg ha$^{-1}$). Again the $S_8$ and $S_4$ were comparable.

The range of N uptake (10.87 to 11.63 kg ha$^{-1}$) recorded by NPK fertiliser treatment was less than that recorded by NPK fertiliser with HA (14.26 to 17.82 kg ha$^{-1}$). The treatment combination $M_3S_5$ (17.82 kg ha$^{-1}$), $M_3S_4$ (17.00) and $M_3S_8$ (16.91) were on

Table 27. Effect of humic acid and fertilisers on N uptake (kg ha$^{-1}$) by rice in Alfisol

| Treatments | Tillering | | | | Flowering | | | | Grain | | | | Straw | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 4.53 | 10.87 | 11.63 | 9.01 | 16.51 | 36.90 | 44.57 | 32.66 | 9.04 | 40.91 | 42.82 | 30.92 | 6.86 | 31.07 | 34.42 | 24.12 |
| $S_2$ | 5.93 | 14.26 | 15.75 | 11.98 | 18.41 | 47.80 | 50.44 | 38.88 | 12.91 | 51.92 | 53.47 | 39.43 | 9.96 | 38.08 | 42.41 | 30.15 |
| $S_3$ | 6.75 | 15.34 | 16.58 | 12.89 | 20.61 | 51.99 | 54.27 | 42.29 | 15.23 | 55.62 | 56.78 | 42.54 | 12.33 | 42.49 | 43.52 | 32.78 |
| $S_4$ | 7.36 | 16.16 | 17.00 | 13.51 | 22.04 | 54.43 | 55.88 | 44.12 | 16.74 | 57.87 | 59.22 | 44.61 | 14.41 | 47.42 | 48.87 | 36.90 |
| $S_5$ | 8.36 | 16.61 | 17.82 | 14.26 | 23.62 | 56.52 | 57.24 | 45.79 | 17.85 | 59.99 | 60.66 | 46.17 | 15.81 | 52.14 | 52.51 | 40.15 |
| $S_6$ | 6.50 | 14.95 | 16.27 | 12.57 | 21.96 | 53.01 | 53.63 | 42.87 | 14.90 | 56.28 | 56.96 | 42.71 | 11.78 | 45.52 | 45.65 | 34.32 |
| $S_7$ | 6.37 | 14.51 | 15.98 | 12.29 | 19.84 | 53.91 | 55.26 | 43.00 | 14.44 | 53.34 | 54.61 | 40.80 | 11.36 | 41.73 | 42.99 | 32.03 |
| $S_8$ | 6.86 | 15.63 | 16.91 | 13.13 | 23.51 | 54.08 | 56.29 | 44.63 | 16.84 | 57.28 | 58.27 | 44.13 | 13.63 | 47.23 | 48.48 | 36.45 |
| Mean | 6.58 | 14.79 | 15.99 | 12.46 | 20.81 | 51.08 | 53.45 | 41.78 | 14.74 | 54.15 | 55.35 | 41.41 | 12.02 | 43.21 | 44.86 | 33.36 |
| CD(p=0.05) | | | | | | | | | | | | | | | | |
| M | 1.17 | | | | 1.41 | | | | 1.59 | | | | 9.54 | | | |
| S | 0.83 | | | | 2.62 | | | | 2.24 | | | | 7.53 | | | |
| M at S | 1.05 | | | | 3.80 | | | | 4.50 | | | | 15.32 | | | |
| S at M | 1.20 | | | | 3.50 | | | | 4.20 | | | | 13.04 | | | |

par with each other. The $M_2S_5$, $M_2S_4$ and $M_2S_8$ recorded 16.61,16.16 and 15.63 kg $ha^{-1}$ of N uptake respectively. The treatments $M_2S_5$ and $M_3S_5$, $M_3S_8$ were comparable.

At flowering stage, the fertiliser treatment $M_3$ recorded significantly the highest N uptake of 53.45 kg $ha^{-1}$ than $M_2$ (51.08 kg $ha^{-1}$) and $M_1$ (20.81 kg $ha^{-1}$). The per cent increase recorded by $M_2$ and $M_3$ over $M_1$ were 59.3 and 61.1. Among the HA treatments, the highest N uptake of 45.79 kg $ha^{-1}$ was recorded in $S_5$ and it was followed by $S_4$ (44.12 kg $ha^{-1}$) and $S_3$ (42.29 kg $ha^{-1}$). Among $S_6$, $S_7$ and $S_8$, the treatment $S_8$ recorded the highest N uptake of 44.63 kg $ha^{-1}$and it was followed by $S_7$ (43.00) and $S_6$ (42.87 kg $ha^{-1}$).

The application of NPK fertiliser recorded 36.90 to 44.57 kg $ha^{-1}$ of N uptake than NPK fertiliser with HA (47.8 to 57.24 kg $ha^{-1}$). In the interaction treatments, $M_3S_5$ recorded the highest N uptake of 57.24 kg $ha^{-1}$ and it was on par with $M_3S_4$ (55.88 kg $ha^{-1}$), $M_3S_8$ (56.29 kg $ha^{-1}$), $M_3S_7$ (55.26 kg $ha^{-1}$) and $M_3S_3$ (54.27 kg $ha^{-1}$). The treatments $M_2S_5$ (56.52 kg $ha^{-1}$), $M_2S_4$ (54.43 kg $ha^{-1}$), $M_2S_8$ (54.08 kg $ha^{-1}$) and $M_2S_7$ (53.91 kg $ha^{-1}$) were comparable.

At harvest, the N uptake was calculated both in grain and straw samples. In the grain, the NPK fertiliser treatment $M_3$ had recorded the highest N uptake of 55.35 kg $ha^{-1}$ and it was on par with $M_2$ that recorded 54.15 kg $ha^{-1}$. The $M_1$ recorded significantly less uptake of N (14.74 kg $ha^{-1}$) than $M_2$ and $M_3$.The per cent increase recorded by $M_3$ and $M_2$ over $M_1$ were 73.4 and 72.8. Among the HA treatments, $S_5$ recorded 46.17 kg $ha^{-1}$ of N uptake. This was on par with $S_4$ (44.61 kg $ha^{-1}$), which was followed by $S_3$ (42.54 kg $ha^{-1}$). Among $S_6$, $S_7$ and $S_8$, the $S_8$ recorded highest N uptake (44.13 kg $ha^{-1}$) and it was on par with the treatment $S_6$ (42.7 kg $ha^{-1}$) and $S_7$ (40.80 kg $ha^{-1}$). Again the treatments $S_5$, $S_8$ and

$S_4$ were comparable. The per cent increase recorded by $S_5$ over $S_8$, $S_4$ and $S_3$ were 4.4, 3.4 and 7.9.

The interaction of NPK fertiliser and HA on N uptake in grain was significant. The NPK fertiliser combined with HA recorded higher range of N uptake (51.92 to 60.66 kg $ha^{-1}$) than NPK fertiliser (40.91 to 42.82 kg $ha^{-1}$). The treatment combination $M_3S_5$ (60.66 kg $ha^{-1}$), $M_3S_4$ (59.22 kg $ha^{-1}$), $M_3S_8$ (58.27 kg $ha^{-1}$) and $M_3S_6$ (56.96 kg $ha^{-1}$) were comparable. The treatments $M_2S_8$ (57.28 kg $ha^{-1}$) and $M_3S_8$ (58.27 kg $ha^{-1}$) $M_2S_5$ (59.99 kg $ha^{-1}$) and $M_2S_4$ (57.87 kg $ha^{-1}$) were comparable.

In straw samples, the N uptake by the fertiliser treatment $M_3$ (44.86 kg $ha^{-1}$) and $M_2$ (43.21 kg $ha^{-1}$) were comparable. The $M_1$ recorded only 12.02 kg $ha^{-1}$ of N uptake. In the HA treatments, $S_5$ registered the highest N uptake (40.15 kg $ha^{-1}$), which was on par with $S_4$ (36.90 kg $ha^{-1}$) and $S_3$ (32.78 kg $ha^{-1}$). The treatment $S_8$ (36.45 kg $ha^{-1}$), $S_6$ (34.32 kg $ha^{-1}$) and $S_7$ (32.03 kg $ha^{-1}$) were on par with each other. The treatments $S_8$, $S_5$ and $S_4$ were on par with each other. In the interaction treatments, the highest N uptake (52.51 kg $ha^{-1}$) registered in $M_3S_8$, which was on par with $M_3S_4$ (48.87 kg $ha^{-1}$), $M_3S_8$ (48.48 kg $ha^{-1}$), $M_3S_6$ (45.65 kg $ha^{-1}$), $M_3S_3$ (43.52 kg $ha^{-1}$) and $M_3S_7$ (42.99 kg $ha^{-1}$).

### 4.6.3.2. Phosphorus uptake (Table 28)

At tillering stage, $M_3$ recorded significantly increased P uptake of 3.15 kg $ha^{-1}$ as compared to $M_2$ (3.00 kg $ha^{-1}$) and $M_1$ (1.5 kg $ha^{-1}$). In HA treatments, the P uptake recorded in $S_5$ (2.70 kg $ha^{-1}$), $S_4$ (2.67 kg $ha^{-1}$) and $S_3$ (2.59 kg $ha^{-1}$) were statistically on par with each other. The treatments $S_6$ (2.53 kg $ha^{-1}$), $S_7$ (2.51 kg $ha^{-1}$) and $S_8$ (2.58 kg $ha^{-1}$) were comparable. The treatments $S_5$, $S_4$, $S_3$ and $S_8$ were also on par with each other. The interaction of HA with fertiliser significantly influenced the P uptake. The treatment $M_3S_5$ recorded the highest P uptake (3.27 kg $ha^{-1}$) and it was on par with $M_3S_4$ (3.25 kg $ha^{-1}$),

**Table 28. Effect of humic acid and fertilisers on P uptake (kg ha$^{-1}$) by rice in Alfisol**

| Treatments | Tillering | | | | Flowering | | | | Grain | | | | Straw | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 1.34 | 2.73 | 2.96 | 2.34 | 5.31 | 11.21 | 11.74 | 9.42 | 2.18 | 9.07 | 9.41 | 6.89 | 1.52 | 7.58 | 7.88 | 5.66 |
| $S_2$ | 1.45 | 2.90 | 3.09 | 2.48 | 5.67 | 11.73 | 12.32 | 9.90 | 2.52 | 9.60 | 9.86 | 7.33 | 2.03 | 8.19 | 8.25 | 6.16 |
| $S_3$ | 1.53 | 3.05 | 3.19 | 2.59 | 6.01 | 12.15 | 12.75 | 10.30 | 2.74 | 10.02 | 10.13 | 7.63 | 2.31 | 8.67 | 8.71 | 6.56 |
| $S_4$ | 1.61 | 3.16 | 3.25 | 2.67 | 6.26 | 12.47 | 13.05 | 10.60 | 2.94 | 10.26 | 10.44 | 7.88 | 2.52 | 9.13 | 9.37 | 7.01 |
| $S_5$ | 1.66 | 3.19 | 3.27 | 2.70 | 6.55 | 12.86 | 13.31 | 10.91 | 3.06 | 10.47 | 10.67 | 8.07 | 2.70 | 9.67 | 9.57 | 7.31 |
| $S_6$ | 1.48 | 2.98 | 3.14 | 2.53 | 6.02 | 12.17 | 12.76 | 10.31 | 2.62 | 9.81 | 10.02 | 7.49 | 2.14 | 8.79 | 8.82 | 6.58 |
| $S_7$ | 1.43 | 2.99 | 3.10 | 2.51 | 6.20 | 12.29 | 12.86 | 10.45 | 2.74 | 9.77 | 9.97 | 7.49 | 2.22 | 8.72 | 8.61 | 6.52 |
| $S_8$ | 1.54 | 3.00 | 3.20 | 2.58 | 6.30 | 12.57 | 13.12 | 10.67 | 2.97 | 10.05 | 10.15 | 7.72 | 2.46 | 9.08 | 9.01 | 6.85 |
| Mean | 1.50 | 3.00 | 3.15 | 2.55 | 6.04 | 12.18 | 12.74 | 10.32 | 2.72 | 9.88 | 10.08 | 7.56 | 2.24 | 8.73 | 8.78 | 6.58 |
| CD(p=0.05) | | | | | | | | | | | | | | | | |
| M | 0.05 | | | | 0.24 | | | | 0.18 | | | | 0.36 | | | |
| S | 0.11 | | | | 0.44 | | | | 0.40 | | | | 0.45 | | | |
| M at S | 0.19 | | | | NS | | | | NS | | | | NS | | | |
| S at M | 0.20 | | | | | | | | | | | | | | | |

$M_3S_8$ (3.20 kg ha$^{-1}$), $M_3S_3$ (3.19 kg ha$^{-1}$), $M_3S_6$ (3.14 kg ha$^{-1}$) and $M_3S_7$ (3.10 kg ha$^{-1}$). The treatment $M_2S_5$ (3.19 kg ha$^{-1}$) and $M_2S_4$ (3.16 kg ha$^{-1}$) were on par.

At flowering stage, $M_3$ recorded significantly the highest P uptake of 12.74 kg ha$^{-1}$ whereas $M_2$ and $M_1$ registered 12.18 and 6.04 kg ha$^{-1}$ of P uptake. In HA treatments, $S_5$ recorded the highest P uptake of 10.91 kg ha$^{-1}$ and it was on par with $S_4$ (10.60 kg ha$^{-1}$), which was followed by $S_3$ (10.30 kg ha$^{-1}$) .The $S_8$ recorded higher P uptake (10.67 kg ha$^{-1}$) than the treatments $S_7$ (10.45) and $S_6$ (10.31 kg ha$^{-1}$). Again the treatments $S_8$, $S_4$ and $S_3$ were comparable. The application of NPK fertiliser with HA recorded the higher range of P uptake (11.73 to13.31 kg ha$^{-1}$) than NPK fertiliser treatments, which registered only 11.21 to 11.74 kg ha$^{-1}$. The highest P uptake of 13.31 kg ha$^{-1}$ was recorded in $M_3S_5$ and it was on par with $M_3S_8$ (13.12 kg ha$^{-1}$), $M_3S_4$ (13.05 kg ha$^{-1}$), $M_3S_7$ (12.86 kg ha$^{-1}$), $M_3S_3$ (12.75 kg ha$^{-1}$) and $M_3S_6$ (12.76 kg ha$^{-1}$). The treatments $M_2S_5$ (12.86 kg ha$^{-1}$), $M_3S_8$ and $M_3S_5$ were on par with each other.

At harvest the P uptake of grain and straw samples were calculated. In grain among the fertiliser treatments, $M_3$ recorded the highest P uptake of 10.08 kg ha$^{-1}$ and it was followed by $M_2$ (9.88 kg ha$^{-1}$) and $M_1$ (2.72 kg ha$^{-1}$). In the HA treatments, $S_5$ recorded the highest P uptake (8.07 kg ha$^{-1}$) which was on par with $S_4$ (7.88 kg ha$^{-1}$). The $S_4$ was followed by $S_3$ (7.63 kg ha$^{-1}$) and $S_2$ (7.33 kg ha$^{-1}$). The treatment $S_8$ recorded 7.72 kg ha$^{-1}$ of P uptake, which was on par with $S_6$ (7.49 kg ha$^{-1}$) and $S_7$ (7.49 kg ha$^{-1}$). The $S_5$, $S_8$ and $S_4$ were on par with each other. The application of NPK fertiliser with HA recorded higher range of P uptake (9.60 to 10.67 kg ha$^{-1}$) than NPK fertiliser (9.07 to 9.41 kg ha$^{-1}$) did. The interaction was found to be significant. The $M_3S_5$ recorded the highest P uptake of 10.67 kg ha$^{-1}$, which was on par with $M_3S_4$ (10.44 kg ha$^{-1}$), $M_3S_8$ (10.15 kg ha$^{-1}$) and

$M_3S_3$ (10.13 kg ha$^{-1}$). The treatments $M_3S_5$, $M_3S_8$, $M_2S_5$ (10.47 kg ha$^{-1}$) and $M_2S_4$ (10.26 kg ha$^{-1}$) were comparable.

In straw, the NPK fertiliser treatment $M_2$ and $M_3$ recorded 8.73 and 8.78 kg ha$^{-1}$ of P uptake and it was followed by $M_1$ (2.24 kg ha$^{-1}$). The per cent increase recorded by $M_3$ and $M_2$ over $M_1$ were 74.5 and 74.3. Among the HA treatments, the $S_5$ recorded highest P uptake (7.31 kg ha$^{-1}$) and the $S_5$ was on par with $S_4$ (7.01 kg ha$^{-1}$). The $S_4$ was followed by $S_3$ (6.56 kg ha$^{-1}$). The treatment $S_8$ (6.85 kg ha$^{-1}$), $S_6$ (6.58 kg ha$^{-1}$) and $S_7$ (6.52 kg ha$^{-1}$) were comparable. The combination of NPK fertiliser and HA recorded higher range of P uptake of 8.19 to 9.57 kg ha$^{-1}$ than NPK fertiliser (7.58 to7.88 kg ha$^{-1}$). Among the treatment combination, the $M_3S_5$ recorded highest P uptake of 9.57 kg ha$^{-1}$ and it was on par with $M_3S_4$ (9.37 kg ha$^{-1}$), $M_3S_8$ (9.01 kg ha$^{-1}$), $M_3S_6$ (8.82 kg ha$^{-1}$), $M_3S_3$ (8.71 kg ha$^{-1}$), $M_2S_5$ (9.67 kg ha$^{-1}$) and $M_2S_4$ (9.13 kg ha$^{-1}$).

### 4.6.3.3. Potassium uptake

The data pertaining to K uptake are given in the Table 29. At tillering stage, among the fertiliser treatments, the highest K uptake was recorded in $M_3$ (13.51 kg ha$^{-1}$). The $M_2$ and $M_1$ recorded 12.91 and 6.75 kg ha$^{-1}$ of K uptake. The per cent increase recorded by $M_3$ and $M_2$ over $M_1$ were 50.0 and 47.7. In the HA treatments, $S_5$ (11.59 kg ha$^{-1}$), $S_4$ (11.43 kg ha$^{-1}$) and $S_3$ (11.19 kg ha$^{-1}$) recorded comparable K uptake and the $S_3$ was followed by $S_2$ (10.8 kg ha$^{-1}$). The $S_8$ recorded highest K uptake (11.15 kg ha$^{-1}$), which was followed by the treatments $S_7$ (10.99 kg ha$^{-1}$) and $S_6$ (10.86 kg ha$^{-1}$). The per cent increase recorded by $S_5$ over $S_3$, $S_4$ and $S_6$, $S_7$ and $S_8$ were 3.5, 1.4, 6.3, 5.2 and 3.8. The NPK fertiliser with HA recorded higher K uptake (12.6 to 14.01 kg ha$^{-1}$) than NPK fertiliser (12.08 to 12.99 kg ha$^{-1}$). In the treatment combination, $M_3S_5$ recorded the highest K uptake of 14.01 kg ha$^{-1}$ and it was on par with $M_3S_4$ (13.74 kg ha$^{-1}$), $M_3S_8$ (13.58 kg ha$^{-1}$), $M_3S_6$ (13.30 kg ha$^{-1}$) and

### Table 29. Effect of humic acid and fertilisers on K uptake (kg ha$^{-1}$) by rice in Alfisol

| Treatments | Tillering | | | | Flowering | | | | Grain | | | | Straw | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 6.20 | 12.08 | 12.99 | 10.42 | 17.24 | 35.88 | 37.07 | 30.06 | 2.13 | 8.24 | 8.67 | 6.35 | 16.40 | 62.26 | 64.38 | 47.68 |
| $S_2$ | 6.60 | 12.60 | 13.35 | 10.85 | 17.95 | 37.04 | 37.81 | 30.93 | 2.47 | 8.70 | 9.13 | 6.77 | 18.35 | 63.91 | 65.95 | 49.40 |
| $S_3$ | 6.85 | 13.07 | 13.65 | 11.19 | 18.63 | 37.98 | 38.75 | 31.79 | 2.70 | 9.15 | 9.49 | 7.11 | 19.94 | 65.37 | 66.88 | 50.73 |
| $S_4$ | 7.14 | 13.40 | 13.74 | 11.43 | 19.27 | 38.86 | 39.46 | 32.53 | 2.93 | 9.54 | 9.80 | 7.42 | 20.85 | 66.98 | 68.09 | 51.97 |
| $S_5$ | 7.27 | 13.48 | 14.01 | 11.59 | 19.81 | 39.50 | 40.11 | 33.14 | 3.03 | 9.80 | 10.02 | 7.62 | 21.69 | 68.70 | 68.33 | 52.91 |
| $S_6$ | 6.59 | 12.70 | 13.30 | 10.86 | 18.67 | 37.89 | 38.72 | 31.76 | 2.64 | 9.21 | 9.47 | 7.11 | 18.88 | 66.13 | 67.45 | 50.82 |
| $S_7$ | 6.55 | 12.93 | 13.49 | 10.99 | 19.07 | 38.38 | 39.07 | 32.17 | 2.71 | 9.06 | 9.31 | 7.02 | 19.82 | 66.18 | 67.34 | 51.11 |
| $S_8$ | 6.84 | 13.02 | 13.58 | 11.15 | 19.48 | 39.00 | 39.58 | 32.68 | 3.03 | 9.36 | 9.48 | 7.29 | 21.44 | 67.72 | 68.54 | 52.56 |
| Mean | 6.75 | 12.91 | 13.51 | 11.06 | 18.76 | 38.07 | 38.82 | 31.88 | 2.71 | 9.13 | 9.42 | 7.09 | 19.67 | 65.91 | 67.12 | 50.90 |
| CD(p=0.05) | | | | | | | | | | | | | | | | |
| M | 0.12 | | | | 0.13 | | | | 0.19 | | | | 1.43 | | | |
| S | 0.46 | | | | 1.42 | | | | 0.36 | | | | 2.45 | | | |
| M at S<br>S at M | NS | | | | NS | | | | NS | | | | NS | | | |

$M_3S_3$ (13.65 kg ha$^{-1}$). The treatments $M_2S_5$ (13.48 kg ha$^{-1}$), $M_3S_8$, $M_3S_7$ and $M_3S_4$ were comparable.

At flowering stage, the NPK fertiliser treatment $M_3$ recorded 38.82 kg ha$^{-1}$ of K uptake, which was significantly higher than that recorded in $M_2$ (38.07 kg ha$^{-1}$) and $M_1$ (18.76 kg ha$^{-1}$). The per cent increase recorded by $M_3$ and $M_2$ over $M_1$ were 51.7 and 50.7. In HA treatments, $S_5$ recorded 33.14 kg ha$^{-1}$ of K uptake and it was followed by $S_4$ (32.53 kg ha$^{-1}$) and $S_3$ (31.79 kg ha$^{-1}$). The treatment $S_8$ (32.68), $S_7$ (32.17) and $S_6$ (31.76 kg ha$^{-1}$) were on par with each other. The per cent increase recorded by $S_5$ over $S_3$, $S_4$ and $S_6$, $S_7$ and $S_8$ were 4.1, 1.8, 4.2, 2.9 and 1.4. The NPK fertiliser recorded 35.88 to 37.07 kg ha$^{-1}$ of K uptake, whereas the NPK fertiliser with HA recorded 37.04 to 40.11 kg ha$^{-1}$). The treatment combination $M_3S_5$ (40.11 kg ha$^{-1}$), $M_3S_8$ (39.58 kg ha$^{-1}$), $M_3S_4$ (39.46 kg ha$^{-1}$), $M_3S_7$ (39.07 kg ha$^{-1}$), $M_2S_5$ (39.5 kg ha$^{-1}$), $M_2S_4$ (38.86 kg ha$^{-1}$) and $M_3S_3$ (38.75 kg ha$^{-1}$) were on par with each other.

At harvest, the K uptake was estimated both in grain and straw. In the grain the NPK fertiliser treatment $M_3$ recorded 9.42 kg ha$^{-1}$ of K uptake and it was significantly higher than that obtained in $M_2$ (9.13 kg ha$^{-1}$) and $M_1$ (2.71 kg ha$^{-1}$). In HA treatments, $S_5$, $S_4$ and $S_3$ recorded 7.62, 7.42 and 7.11 kg ha$^{-1}$ of K uptake respectively and they were on par with each other. The treatments $S_8$ (7.29 kg ha$^{-1}$), $S_6$ (7.11 kg ha$^{-1}$) and $S_7$ (7.02 kg ha$^{-1}$) were comparable. The per cent increase recorded by $S_5$ over $S_4$ and $S_8$ were 2.6 and 4.3. The application of NPK fertiliser with HA recorded the higher range of K uptake (8.7 to 10.02 kg ha$^{-1}$) than that of NPK fertiliser (8.24 to 8.67 kg ha$^{-1}$).

In straw, the K uptake registered in $M_3$ was 67.12 kg ha$^{-1}$ and it was on par with $M_2$ (65.91 kg ha$^{-1}$). The $M_1$ recorded 19.67 kg ha$^{-1}$. The per cent yield increased by $M_3$ and $M_2$ over $M_1$ were 70.7 and 70.1. In the HA treatments, the $S_5$ (52.91 kg ha$^{-1}$),

$S_4$ (51.97 kg ha$^{-1}$), and $S_3$ (50.73 kg ha$^{-1}$) were on par with each other. The treatments $S_8$ (52.56 kg ha$^{-1}$) and $S_7$ (51.11 kg ha$^{-1}$) recorded higher K uptake than $S_6$ (50.82 kg ha$^{-1}$). Again the treatments $S_5$, $S_8$, $S_7$, $S_3$ and $S_6$ were comparable. The per cent increase recorded by $S_5$ over $S_8$, $S_7$, $S_3$ and $S_4$ were 0.7, 3.4, 4.1 and 1.8.

The NPK fertiliser integrated with HA recorded higher range of K uptake (63.91 to 68.70 kg ha$^{-1}$) than NPK fertiliser (62.26 to 64.38 kg ha$^{-1}$). The treatment combination $M_3S_8$ recorded highest K uptake of 68.70 kg ha$^{-1}$ and it was on par with $M_3S_8$ (68.54 kg ha$^{-1}$), $M_3S_5$ (68.33 kg ha$^{-1}$) , $M_3S_4$ (68.09 kg ha$^{-1}$), $M_3S_6$ (67.45 kg ha$^{-1}$) and $M_3S_7$ (67.34 kg ha$^{-1}$),$M_2S_5$ (68.7 kg ha$^{-1}$), $M_2S_8$ (67.72 kg ha$^{-1}$) and $M_2S_4$ (66.98 kg ha$^{-1}$) .

### 4.6.3.4. Uptake of secondary nutrients

The calcium and magnesium uptake was determined during harvest in grain and straw samples and the data are furnished in Table 30.

### 4.6.3.4.1. Calcium uptake

In grain, the NPK fertiliser treatment $M_3$ registered 17.06 kg ha$^{-1}$ of Ca uptake, that was on par with $M_2$ (16.90 kg ha$^{-1}$). The $M_1$ recorded significantly less Ca uptake of 5.3 kg ha$^{-1}$ than $M_2$ and $M_3$ .The per cent increase recorded by $M_3$ and $M_2$ over $M_1$ were 68.9 and 68.6. In HA treatments, $S_5$ recorded 13.61 kg ha$^{-1}$ of Ca uptake (kg ha$^{-1}$). This was on par with $S_4$ (13.41 kg ha$^{-1}$) and $S_3$ (13.16 kg ha$^{-1}$). The $S_8$ (13.42 kg ha$^{-1}$), $S_7$ (13.12 kg ha$^{-1}$) and $S_6$ (13.00 kg ha$^{-1}$) recorded comparable Ca uptake. The $S_8$, $S_5$, $S_4$ and $S_3$ were on par with each other. The NPK fertiliser with HA recorded higher range of Ca uptake of 16.5 to 17.57 kg ha$^{-1}$ than NPK fertiliser (15.96 to 16.45 kg ha$^{-1}$). The highest Ca uptake of 17.48 kg ha$^{-1}$ was recorded in $M_3S_5$ and it was on par with $M_3S_4$, $M_3S_8$ (17.29 kg ha$^{-1}$) and $M_3S_3$ (17.15 kg ha$^{-1}$), $M_2S_5$ (17.57 kg ha$^{-1}$), $M_2S_4$ (17.31 kg ha$^{-1}$) and $M_2S_8$ (17.15 kg ha$^{-1}$).

**Table 30. Effect of humic acid and fertilisers on Ca and Mg uptake (kg ha$^{-1}$) by rice in Alfisol**

| Treatments | Ca (Grain) | | | | Ca (Straw) | | | | Mg (Grain) | | | | Mg (Straw) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 4.37 | 15.96 | 16.45 | 12.26 | 3.02 | 11.13 | 11.57 | 8.57 | 2.30 | 9.02 | 9.31 | 6.88 | 3.50 | 13.62 | 11.58 | 9.57 |
| $S_2$ | 4.95 | 16.50 | 16.76 | 12.74 | 3.39 | 11.48 | 11.86 | 8.91 | 2.63 | 9.47 | 9.59 | 7.23 | 3.97 | 14.14 | 14.56 | 10.89 |
| $S_3$ | 5.31 | 17.00 | 17.15 | 13.16 | 3.76 | 11.89 | 12.23 | 9.29 | 2.84 | 9.69 | 9.85 | 7.46 | 4.36 | 14.64 | 15.06 | 11.36 |
| $S_4$ | 5.62 | 17.31 | 17.29 | 13.41 | 3.96 | 12.38 | 12.52 | 9.62 | 3.03 | 10.03 | 10.08 | 7.71 | 4.57 | 15.02 | 15.36 | 11.65 |
| $S_5$ | 5.80 | 17.57 | 17.48 | 13.61 | 4.15 | 12.92 | 12.89 | 9.99 | 3.14 | 10.19 | 10.20 | 7.84 | 4.78 | 15.56 | 15.56 | 11.97 |
| $S_6$ | 5.15 | 16.83 | 17.02 | 13.00 | 3.56 | 12.04 | 12.30 | 9.30 | 2.76 | 9.70 | 9.93 | 7.46 | 4.13 | 14.77 | 15.09 | 11.33 |
| $S_7$ | 5.39 | 16.90 | 17.06 | 13.12 | 3.76 | 12.08 | 12.30 | 9.38 | 2.90 | 9.76 | 9.84 | 7.50 | 4.30 | 14.69 | 15.02 | 11.34 |
| $S_8$ | 5.80 | 17.15 | 17.29 | 13.42 | 4.08 | 12.41 | 12.58 | 9.69 | 3.12 | 9.99 | 10.17 | 7.76 | 4.73 | 15.21 | 15.40 | 11.78 |
| Mean | 5.30 | 16.90 | 17.06 | 13.09 | 3.71 | 12.04 | 12.28 | 9.34 | 2.84 | 9.73 | 9.87 | 7.48 | 4.29 | 14.71 | 14.71 | 11.24 |
| CD(p=0.05) | | | | | | | | | | | | | | | | |
| M | 0.18 | | | | 0.31 | | | | 0.08 | | | | 0.51 | | | |
| S | 0.66 | | | | 0.54 | | | | 0.43 | | | | 0.89 | | | |
| M at S | 0.45 | | | | 0.93 | | | | 0.32 | | | | 0.66 | | | |
| S at M | 0.35 | | | | 0.94 | | | | 0.38 | | | | 0.52 | | | |

Regarding calcium uptake in straw, the significant variation was observed in the NPK fertiliser treatments. The $M_3$ recorded 12.28 kg ha$^{-1}$ of Ca uptake, which was on par with $M_2$ (12.04 kg ha$^{-1}$). The $M_1$ registered 3.71 kg ha$^{-1}$ Ca uptake only. Among HA treatments the $S_5$ and $S_4$ recorded highest Ca uptake of 9.49 and 9.62 kg ha$^{-1}$ and the $S_4$ was followed by $S_3$ (9.29 kg ha$^{-1}$) and $S_2$ (8.91 kg ha$^{-1}$). The $S_8$ recorded highest Ca uptake of 9.69 kg ha$^{-1}$ and it was on par with $S_7$ (9.38 kg ha$^{-1}$) and $S_6$ (9.30 kg ha$^{-1}$). The $S_5$, $S_8$ and $S_4$ were comparable .The NPK fertiliser combined with HA recorded higher range of Ca uptake of 11.48 to 12.92 kg ha$^{-1}$ than NPK fertiliser (11.13 to 11.57 kg ha$^{-1}$). The highest Ca uptake was recorded in $M_2S_5$ (12.92 kg ha$^{-1}$), which was on par with $M_3S_5$ (12.89 kg ha$^{-1}$), $M_3S_8$ (12.58 kg ha$^{-1}$), $M_3S_4$ (12.52 kg ha$^{-1}$), $M_2S_4$ (12.38 kg ha$^{-1}$) and $M_2S_8$ (12.41 kg ha$^{-1}$).

### 4.6.3.4.2. Magnesium uptake

The NPK fertiliser treatment $M_3$ recorded significantly higher Mg uptake of 9.87 kg ha$^{-1}$, which was on par with $M_2$ (9.73 kg ha$^{-1}$) and $M_1$ (2.84 kg ha$^{-1}$). In HA treatments, the highest Mg uptake was recorded in $S_5$ (7.84 kg ha$^{-1}$), which was followed by $S_8$ (7.76 kg ha$^{-1}$), $S_4$ (7.71 kg ha$^{-1}$), $S_6$ (7.5 kg ha$^{-1}$), $S_3$ (7.46 kg ha$^{-1}$), and $S_2$ (7.23 kg ha$^{-1}$). The treatments $S_5$, $S_8$, $S_3$ and $S_4$ were comparable. The combination of NPK fertiliser with HA recorded higher range of Mg uptake (9.47 to 10.2 kg ha$^{-1}$) than that of NPK fertiliser (9.02 to 9.31 kg ha$^{-1}$). The highest Mg uptake of 10.2 kg ha$^{-1}$ recorded in $M_3S_5$ was comparable with $M_3S_4$ (10.08 kg ha$^{-1}$), $M_3S_8$ (10.17 kg ha$^{-1}$), $M_3S_6$ (9.93 kg ha$^{-1}$), $M_3S_3$ (9.85 kg ha$^{-1}$), $M_3S_7$ (9.84 kg ha$^{-1}$), $M_2S_5$ (10.19 kg ha$^{-1}$), $M_2S_4$ (10.03 kg ha$^{-1}$) and $M_2S_8$ (9.99 kg ha$^{-1}$).

In straw, among the NPK fertiliser treatments, the maximum uptake of Mg was recorded in $M_3$ (14.71 kg ha$^{-1}$) and $M_2$ (14.71 kg ha$^{-1}$). The $M_1$ recorded 4.29 kg ha$^{-1}$ of Mg uptake. The per cent increase recorded by both $M_3$ and $M_2$ over $M_1$ was 70.8. In the HA treatments, Mg uptake recorded in $S_5$ , $S_4$ , $S_3$ and $S_2$ were 11.97 , 11.65, 11.36 and 10.89 kg ha$^{-1}$. The treatments $S_6$ (11.33 kg ha$^{-1}$), $S_7$ (11.34 kg ha$^{-1}$) and $S_8$ (11.78 kg ha$^{-1}$) were on par. Again the $S_5$, $S_4$ and $S_8$ were on par with each other. The per cent increase recorded by $S_5$ over $S_4$ and $S_8$ were 2.7 and 1.6. The NPK fertiliser integrated with HA registered higher range of Mg uptake (14.14 to 15.56 kg ha$^{-1}$) than that of NPK fertiliser (11.58 to 13.62kg ha-1). The treatment combination $M_3S_5$ (15.56 kg ha$^{-1}$) recorded highest Mg uptake and it was followed by $M_3S_8$ (15.4 kg ha$^{-1}$), $M_3S_4$ (15.56 kg ha$^{-1}$), $M_3S_6$ (15.09 kg ha$^{-1}$) , $M_3S_3$ (15.06 kg ha$^{-1}$),$M_2S_5$ (15.56 kg ha$^{-1}$) and $M_2S_8$ (15.21 kg ha$^{-1}$).

### 4.6.3.5. Uptake of micronutrients

The uptake of micronutrients determined in grain and straw samples is given below.

### 4.6.3.5.1. Uptake of micronutrients in grain (Table 31)

**Iron uptake**

The Fe uptake registered by $M_3$ was 976 g ha$^{-1}$ and it was on par with $M_2$ (964 g ha$^{-1}$). The $M_1$ recorded only 295 g ha$^{-1}$ of K uptake. Among the HA treatments $S_5$ recorded the highest Fe uptake of 891 g ha$^{-1}$, which was followed by $S_4$ (830 g ha$^{-1}$) and $S_3$ (765 g ha$^{-1}$). The treatment $S_8$ recorded highest Fe uptake of 753 g ha$^{-1}$ and it was followed by $S_6$ (703 g ha$^{-1}$) and $S_7$ (725 g ha$^{-1}$) . The per cent increase recorded by $S_5$ over $S_4$, $S_3$ and $S_8$ were 6.9, 14.1 and 15.5. The application of NPK fertiliser with HA recorded higher range of Fe uptake (893 to 1144 g ha$^{-1}$) as compared to NPK fertiliser application (792 to 819 g ha$^{-1}$). In the interaction, the highest Fe uptake of 1144 g ha$^{-1}$ was registered in $M_3S_5$, which was comparable with $M_2S_5$ (1115 g ha$^{-1}$) and $M_3S_4$ (1087 g ha$^{-1}$) and $M_2S_4$ (1075 g ha$^{-1}$).

**Table 31.· Effect of humic acid and fertilisers on micronutrients uptake (g $ha^{-1}$) by rice grain in Alfisol**

| Treatments | Iron | | | | Zinc | | | | Manganese | | | | Copper | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 208 | 792 | 819 | 606 | 39 | 171 | 184 | 131 | 31 | 128 | 131 | 97 | 12 | 60 | 70 | 47 |
| $S_2$ | 255 | 893 | 913 | 687 | 57 | 211 | 231 | 166 | 41 | 149 | 160 | 117 | 16 | 48 | 53 | 39 |
| $S_3$ | 297 | 996 | 1002 | 765 | 71 | 240 | 259 | 190 | 49 | 169 | 170 | 129 | 20 | 62 | 63 | 48 |
| $S_4$ | 328 | 1075 | 1087 | 830 | 87 | 269 | 278 | 211 | 60 | 188 | 179 | 143 | 21 | 63 | 63 | 49 |
| $S_5$ | 413 | 1115 | 1144 | 891 | 98 | 289 | 297 | 228 | 61 | 181 | 180 | 141 | 21 | 72 | 72 | 55 |
| $S_6$ | 264 | 918 | 927 | 703 | 66 | 230 | 241 | 179 | 47 | 159 | 170 | 125 | 19 | 62 | 71 | 51 |
| $S_7$ | 285 | 942 | 948 | 725 | 73 | 231 | 233 | 179 | 46 | 151 | 161 | 120 | 20 | 62 | 63 | 48 |
| $S_8$ | 311 | 979 | 968 | 753 | 81 | 252 | 262 | 198 | 53 | 162 | 172 | 129 | 22 | 63 | 72 | 52 |
| Mean | 295 | 964 | 976 | 745 | 71 | 237 | 248 | 185 | 48 | 161 | 165 | 125 | 19 | 62 | 66 | 49 |
| CD(p=0.05) | | | | | | | | | | | | | | | | |
| M | 22 | | | | 6 | | | | 4 | | | | 4 | | | |
| S | 39 | | | | 10 | | | | 7 | | | | 5 | | | |
| M at S | 62 | | | | 17 | | | | 11 | | | | NS | | | |
| S at M | 68 | | | | 17 | | | | 11 | | | | | | | |

The treatments $M_3S_3$ (1002 g $ha^{-1}$), $M_3S_8$ (968 g $ha^{-1}$) and $M_3S_7$ (948 g $ha^{-1}$), $M_2S_3$ (996 g $ha^{-1}$), $M_2S_8$ (979 g $ha^{-1}$) and $M_2S_7$ (942 g $ha^{-1}$) were comparable.

### Zinc uptake

In grain, the Zn uptake recorded by $M_3$ was 248 g $ha^{-1}$, which was significantly higher than that of $M_2$ (237 g $ha^{-1}$) and $M_1$ (71 g $ha^{-1}$). In HA treatment, $S_5$ recorded the highest Zn uptake (228 g $ha^{-1}$) and it was followed by $S_4$ (211 g $ha^{-1}$) . The $S_3$ (190 g $ha^{-1}$) and $S_8$ (198 g $ha^{-1}$) recorded comparable Zn uptake .The per cent increase recorded by $S_5$ over $S_4$, $S_3$ and $S_8$ were 7.5, 16.7 and 13.2. The application of NPK fertiliser with HA recorded higher Zn uptake of 211 to 297 g $ha^{-1}$ than NPK fertiliser (171 to 184 g $ha^{-1}$) did. In the treatment combination, $M_3S_5$ (297 g $ha^{-1}$) and $M_2S_5$ (289 g $ha^{-1}$) were on par .The treatments $M_3S_4$ (278 g $ha^{-1}$) and $M_2S_4$ (269 g $ha^{-1}$) were comparable.

### Manganese uptake

Among the fertiliser treatments, $M_3$ recorded 165 g $ha^{-1}$ of Mn uptake and it was statistically on par with $M_2$ (161 g $ha^{-1}$). The $M_1$ recorded only 48 g $ha^{-1}$ of Mn uptake. In the HA treatments, $S_4$ recorded the highest Mn uptake of 143 g $ha^{-1}$ and it was followed by $S_5$ (141 g $ha^{-1}$). The treatment $S_3$ (129 g $ha^{-1}$) and $S_8$ (129 g $ha^{-1}$) were on par with each other. The per cent increase recorded by $S_4$ over $S_5$ , $S_8$ and $S_3$ were 1.4 ,9.8 and 9.8 . The Mn uptake recorded in NPK fertilisers with HA was 149 to 188 g $ha^{-1}$ than NPK fertiliser (128 to 131 g $ha^{-1}$). In the interaction treatments, $M_2S_4$ (188 g $ha^{-1}$) registered higher Mn uptake and this was on par with $M_2S_5$ (181 g $ha^{-1}$) , $M_3S_5$ (180 g $ha^{-1}$) and $M_3S_4$ (179 g $ha^{-1}$).

**Copper uptake**

The fertiliser treatments $M_3$(66 g ha$^{-1}$) and $M_2$(62 g ha$^{-1}$) were statistically on par with each other. The $M_1$ recorded 19 g ha$^{-1}$ of Cu uptake. In HA treatments, the $S_5$ recorded the highest Cu uptake of 55 g ha$^{-1}$ and it was followed by $S_4$ (49 g ha$^{-1}$) and $S_3$ (148 g ha$^{-1}$). The treatment $S_5$ was on par with $S_6$ (51 g ha$^{-1}$) and $S_7$ (48 g ha$^{-1}$) and $S_8$ (52 g ha$^{-1}$). The treatment $S_5$ was comparable with $S_4$. In the interaction treatments, the $M_3S_5$ (72 g ha$^{-1}$), $M_2S_5$ (72 g ha$^{-1}$), $M_3S_8$ (72 g ha$^{-1}$), $M_3S_6$ (71 g ha$^{-1}$) and $M_3S_1$ recorded higher Cu uptake than $M_3S_1$. However the treatments effect on Cu uptake did not attain the level of significance.

**4.6.3.5.2. Uptake of micronutrients in straw (Table 32)**

The straw samples collected from different treatments were analyzed for their nutrient status and the results were as follows:

**Iron uptake**

Iron uptake of straw recorded in $M_1$, $M_2$ and $M_3$ were 1157, 3692 and 3784 g ha$^{-1}$ respectively. The $M_2$ and $M_3$ were on par. In HA treatments, the highest Fe uptake of 3157 g ha$^{-1}$ recorded in $S_5$. This was on par with $S_4$ (3056 g ha$^{-1}$). The treatment $S_8$ recorded the highest Fe uptake of 2945 g ha$^{-1}$, which was on par with $S_7$ (2862 g ha$^{-1}$) and $S_6$ (2817 g ha$^{-1}$) . The per cent increase recorded by $S_5$ over $S_4$, $S_8$ and $S_3$ were 3.2, 6.7 and 7.8. The NPK fertiliser with HA recorded higher range of Fe uptake (3498 to 4090 g ha$^{-1}$) than the NPK fertiliser (3290 to 3406 g ha$^{-1}$) did. In the interaction, the treatment $M_2S_5$ recorded highest Fe uptake (4090 g ha$^{-1}$) and it was followed by $M_3S_5$ (4051 g ha$^{-1}$), $M_2S_4$ (3923 g ha$^{-1}$) and $M_3S_4$ (3981 g ha$^{-1}$).

**Table 32. Effect of humic acid and fertilisers on micronutrients uptake (g ha$^{-1}$) by rice straw in Alfisol**

| Treatments | Iron | | | | Zinc | | | | Manganese | | | | Copper | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 919 | 3290 | 3406 | 2538 | 18 | 114 | 144 | 92 | 305 | 1143 | 1214 | 887 | 22 | 89 | 91 | 67 |
| $S_2$ | 1062 | 3498 | 3652 | 2737 | 36 | 194 | 213 | 148 | 362 | 1229 | 1277 | 956 | 32 | 103 | 120 | 85 |
| $S_3$ | 1184 | 3717 | 3829 | 2910 | 56 | 250 | 201 | 169 | 408 | 1300 | 1328 | 1012 | 39 | 118 | 121 | 93 |
| $S_4$ | 1266 | 3923 | 3981 | 3056 | 71 | 307 | 312 | 230 | 437 | 1323 | 1356 | 1039 | 45 | 134 | 136 | 105 |
| $S_5$ | 1329 | 4090 | 4051 | 3157 | 88 | 341 | 313 | 247 | 444 | 1297 | 1305 | 1015 | 46 | 123 | 150 | 106 |
| $S_6$ | 1087 | 3624 | 3739 | 2817 | 45 | 212 | 250 | 169 | 385 | 1272 | 1305 | 987 | 36 | 133 | 135 | 101 |
| $S_7$ | 1156 | 3658 | 3773 | 2862 | 43 | 213 | 229 | 162 | 407 | 1279 | 1296 | 994 | 34 | 107 | 121 | 87 |
| $S_8$ | 1252 | 3739 | 3843 | 2945 | 65 | 257 | 259 | 194 | 444 | 1314 | 1338 | 1032 | 42 | 135 | 137 | 105 |
| Mean | 1157 | 3692 | 3784 | 2878 | 53 | 236 | 241 | 177 | 399 | 1270 | 1302 | 990 | 37 | 118 | 126 | 94 |
| CD(p=0.05) | | | | | | | | | | | | | | | | |
| M | 135 | | | | 9 | | | | 46 | | | | 1 | | | |
| S | 142 | | | | 10 | | | | 49 | | | | 3 | | | |
| M at S | NS | | | | 18 | | | | NS | | | | 4 | | | |
| S at M | | | | | 17 | | | | | | | | 4 | | | |

### Zinc uptake

In fertiliser treatment, $M_3$ recorded highest Zn uptake of 241 g ha$^{-1}$ than $M_2$ (236 g ha$^{-1}$) and $M_1$ (53 g ha$^{-1}$). The per cent recorded by $M_3$ and $M_2$ over $M_1$ were 78.0 and 77.5. The increase in zinc uptake due to application of HA was significant. The highest Zn uptake was registered in $S_5$ (247 g ha$^{-1}$) and it was followed by $S_4$ (230 g ha$^{-1}$). The treatments $S_8$ (194 g ha$^{-1}$) recorded higher Zn uptake than $S_6$ (169 g ha$^{-1}$) and $S_7$ (162 g ha$^{-1}$). The per cent increase recorded by $S_5$ over $S_4$, $S_8$ and $S_6$ were 6.9, 21.6 and 31.6. The application of NPK fertiliser with HA registered 194 to 341 g ha$^{-1}$ of Zn uptake than NPK fertiliser (114 to 144 g ha$^{-1}$). In the interaction treatments $M_2S_5$ registered 341 g ha$^{-1}$of Zn uptake and it was followed by $M_3S_5$ (314 g ha$^{-1}$), $M_3S_4$ (312 g ha$^{-1}$) and $M_2S_4$ (307 g ha$^{-1}$).

### Manganese uptake

The NPK fertiliser treatment $M_3$ registered 1302 g ha$^{-1}$ of Mn uptake and it was on par with $M_2$ (1270 g ha$^{-1}$). The $M_1$ recorded only 399 g ha$^{-1}$. The HA treatment $S_4$ recorded the highest Mn uptake of 1039 g ha$^{-1}$ which was on par with $S_5$ (1015 g ha$^{-1}$), $S_3$ (1012 g ha$^{-1}$) and $S_8$ (1032 g ha$^{-1}$). The Mn uptake recorded by $S_6$ (987 g ha$^{-1}$), $S_7$ (994 g ha$^{-1}$) and $S_8$ were on par with each other. The application of NPK fertiliser with HA registered 1229 to 1356 g ha$^{-1}$ of Mn uptake than NPK fertiliser (1143 to 1214 g ha$^{-1}$). The interaction treatment; $M_3S_4$ recorded higher Mn uptake of 1356 g ha$^{-1}$ and it was on par with $M_3S_8$ (1338 g ha$^{-1}$), $M_2S_4$ (1323 g ha$^{-1}$), $M_3S_5$ and $M_3S_6$ (1305 g ha$^{-1}$).

### Copper uptake

In the fertiliser treatments, $M_3$ recorded the highest Cu uptake of 126 g ha$^{-1}$, which was significantly higher than $M_2$ (118 g ha$^{-1}$) and $M_1$ (37 g ha$^{-1}$). Among the HA treatments, $S_5$ recorded highest Cu uptake 106 g ha$^{-1}$, which was comparable with

$S_4$ (105 g ha$^{-1}$) and $S_8$ (105 g ha$^{-1}$). The $S_5$, $S_4$ and $S_8$ were comparable. The application of NPK fertiliser with HA registered higher Cu uptake (103 to 150 g ha$^{-1}$) than NPK fertiliser (89 to 91 g ha$^{-1}$) did. In the treatment combination $M_3S_5$ recorded the higher Cu uptake of 150 g ha$^{-1}$ and it was followed by $M_3S_8$ (137 g ha$^{-1}$), $M_3S_4$ (136 g ha$^{-1}$), $M_3S_6$ (135 g ha$^{-1}$), $M_2S_8$ (135 g ha$^{-1}$), $M_2S_4$ (134 g ha$^{-1}$) and $M_2S_6$ (133 g ha$^{-1}$).

### 4.6.4. Yield and yield attributes of rice

#### 4.6.4.1. Productive tillers per hill (Table 33)

The number of productive tillers per hill recorded in $M_1$, $M_2$ and $M_3$ were 5.25, 6.30 and 6.54 respectively. The treatments $M_2$ and $M_3$ were on par with each other. In HA treatments the $S_5$ (soil application of HA @ 40 kg ha$^{-1}$) registered maximum number of 6.44 tillers per hill. In $S_2$ (10 kg ha$^{-1}$) and $S_3$ (20 kg ha$^{-1}$) the tiller number recorded was 5.71 and 6.02. The per cent increase recorded by $S_5$, $S_4$, $S_3$ and $S_2$ over $S_1$ (no humic acid) were 16.3, 13.5, 10.5 and 5.6 respectively. The other treatment *viz.*, $S_6$, $S_7$ and $S_8$ registered 5.99, 6.02 and 6.44 tillers per hill .The $S_8$, which received 10 kg ha$^{-1}$ of HA with FS and RD was statistically on par with $S_5$ and $S_4$. With regard to interaction, NPK fertiliser with HA recorded more number of productive tillers than NPK fertiliser .The tiller number ranged from 5.99 to 7.04 in the former and 5.57 to 5.88 in the later. Among the various combinations, $M_3S_5$ and $M_3S_8$ recorded the maximum number of 7.04 tillers per hill and they were statistically on par with $M_2S_5$, $M_2S_8$ and $M_3S_4$ (6.72). The treatments $M_3S_7$, $M_3S_3$ and $M_2S_4$ (6.51), $M_3S_6$ (6.41), $M_2S_6$ (6.30), $M_2S_7$ (6.30), $M_2S_3$ (6.30) $M_3S_2$ (6.20) recorded tiller counts were statistically comparable.

**Table 33. Effect of humic acid and fertilisers on yield attributes of rice in Alfisol**

| Treatments | No. of productive tillers hill$^{-1}$ | | | | Panicle length (cm) | | | | No. of filled grains per panicle | | | | No. of chaffy grains per panicle | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 4.73 | 5.57 | 5.88 | 5.39 | 19.30 | 20.50 | 20.70 | 20.17 | 53.0 | 78.0 | 83.0 | 71.3 | 22.0 | 14.3 | 13.3 | 16.5 |
| $S_2$ | 4.94 | 5.99 | 6.20 | 5.71 | 19.50 | 20.70 | 20.70 | 20.30 | 56.0 | 80.0 | 86.0 | 74.0 | 18.7 | 10.3 | 9.3 | 12.8 |
| $S_3$ | 5.25 | 6.30 | 6.51 | 6.02 | 19.70 | 20.90 | 20.10 | 20.23 | 59.0 | 83.0 | 89.0 | 77.0 | 18.0 | 9.3 | 8.6 | 12.0 |
| $S_4$ | 5.46 | 6.51 | 6.72 | 6.23 | 19.80 | 21.20 | 21.20 | 20.73 | 60.0 | 85.0 | 92.0 | 79.0 | 17.0 | 9.5 | 7.5 | 11.3 |
| $S_5$ | 5.57 | 6.72 | 7.04 | 6.44 | 19.70 | 21.20 | 21.20 | 20.70 | 61.0 | 86.0 | 94.0 | 80.3 | 17.3 | 11.0 | 7.7 | 12.0 |
| $S_6$ | 5.25 | 6.30 | 6.41 | 5.99 | 19.50 | 20.90 | 21.00 | 20.47 | 58.0 | 82.0 | 88.0 | 76.0 | 15.7 | 8.7 | 6.0 | 10.1 |
| $S_7$ | 5.25 | 6.30 | 6.51 | 6.02 | 19.60 | 21.00 | 21.10 | 20.57 | 59.0 | 84.0 | 90.0 | 77.7 | 14.0 | 6.7 | 4.7 | 8.5 |
| $S_8$ | 5.57 | 6.72 | 7.04 | 6.44 | 19.70 | 21.10 | 21.20 | 20.67 | 62.0 | 85.0 | 96.0 | 81.0 | 12.7 | 4.7 | 3.0 | 6.8 |
| Mean | 5.25 | 6.30 | 6.54 | 6.03 | 19.60 | 20.94 | 20.90 | 20.48 | 58.5 | 82.9 | 89.8 | 77.0 | 16.9 | 9.3 | 7.5 | 11.3 |
| CD(p=0.05) | | | | | | | | | | | | | | | | |
| M | 0.73 | | | | 0.78 | | | | 7.1 | | | | 7.1 | | | |
| S | 0.24 | | | | 0.36 | | | | 4.0 | | | | 3.5 | | | |
| M at S | 0.75 | | | | NS | | | | 7.6 | | | | 7.6 | | | |
| S at M | 0.42 | | | | | | | | 7.0 | | | | 6.1 | | | |

### 4.6.4.2. Panicle length (Table33)

The application of NPK fertiliser recorded significant increase in panicle length. The $M_3$ and $M_2$ treatments recorded 20.90 and 20.94 cm long panicle as against $M_1$ (19.60 cm) and the per cent increase registered by $M_3$ and $M_2$ over $M_1$ were 6.2 and 6.4. Regarding the HA treatments, $S_5$, $S_4$, $S_3$, and $S_2$ recorded 20.7, 20.73, 20.23 and 20.3 cm long panicle as against the $S_1$ which recorded only 20.17 cm long panicle. The other treatments *viz.*, $S_6$, $S_7$ and $S_8$ recorded 20.47, 20.57 and 20.67 cm respectively. Again the $S_4$ was found to be comparable with $S_5$ to $S_8$. Regarding interaction effect, the NPK with HA recorded increased panicle length. But the increase was not statistically significant. Among various combinations, the $S_4$ with $M_2$ as well as $M_3$ recorded longer (21.2 cm) panicles than the other combinations (20.5 to 21.0 cm).

### 4.6.4.3. Filled grains per panicle (Table33)

The data on the effect of treatments on filled grains per panicle are presented in Table 33. Application of NPK fertilisers increased the filled grains per panicle significantly compared to no fertiliser. The treatment $M_3$ recorded 89.8 grains per panicle, which was on par with $M_2$ that recorded 82.9 grains per panicle. The per cent increase registered by $M_3$ and $M_2$ over $M_1$ were 34.9 and 29.4. Among the HA treatments, $S_5$ recorded 80.3 grains per panicle and it was on par with $S_3$ (77.0) and $S_4$ (79.0). The treatment $S_8$ recorded 81.0 grains per panicle and was on par with $S_7$ (77.7) as well as $S_5$, $S_3$ and $S_4$. The per cent increase recorded by $S_8$ over $S_5$, $S_4$ and $S_3$ were 0.86, 2.5, 4.9 respectively.

In interaction, the variations among the combinations were significant. The NPK fertiliser treatments recorded lesser number of filled grains per panicle (78.0 to 83.0) than NPK fertiliser with HA (80.0 to 96.0). The combination $M_3S_8$ registered 96.0 grains per panicle and it was followed by $M_3S_5$, which had 94.0 grains per panicle. They were comparable with $M_3S_4$ (92.0), $M_3S_7$ (90.0) .The $M_3$ with HA recorded increased number of grains per panicle over $M_2$ with HA. But the increase was statistically nonsignificant.

### 4.6.4.4. Number of chaffy grains per panicle (Table 33)

The reduction of chaffy grains per panicle by the application of recommended dose of fertiliser was significant. The $M_3$ (7.5) and $M_2$ (9.3) recorded the significantly less chaffy grains compared to no fertiliser (16.9).

Among the HA treatments, the $S_4$ (11.3), $S_5$ (12.0), $S_3$ (12.0) and $S_2$ (12.8) were comparable in chaffy grains per panicle. The $S_8$ recorded 6.8 and it was statistically on par with $S_7$ (8.5) and $S_6$ (10.1). In interaction treatments, the application of NPK fertiliser combined with HA recorded less number of chaffy grains (10.0 to 3.0) than NPK fertiliser (14.3 to 13.3). The combination $M_3S_8$ (3.0) $M_3S_7$ (4.7), $M_3S_6$ (6.0), $M_2S_8$ (4.7) and $M_2S_7$ (6.7) were statistically on par with each other.

### 4.6.4.5. Thousand grain weight (Table34)

The thousand grain weight recorded by $M_3$ was 21.02 g, which was followed by $M_2$ (20.74 g) and $M_1$ (19.96 g). The per cent increase recorded by $M_2$ and $M_3$ over $M_1$ was 5.0 and 3.8 respectively and the increase was statistically significant. The results on the effect of application of HA on grain weight indicated that soil application of HA at graded doses recorded significant variations. The results revealed that, the addition of HA @ 10, 20, 30 and 40 kg $ha^{-1}$ recorded 20.32, 20.56, 20.79 and 20.97 g respectively. The other treatments *viz.*, $S_6$, $S_7$ and $S_8$ recorded 20.49, 20.64 and 20.78 g respectively. The result brought out that $S_5$ was statistically comparable with $S_4$ and $S_8$. With regard to interaction the thousand grain weight recorded by the application of NPK fertiliser with HA ranged from 20.47 to 21.33 g while NPK fertiliser recorded 20.25 to 20.55 g only. The combination $M_3S_5$

**Table 34. Effect of humic acid and fertilisers on yield of rice – Alfisol**

| Treatments | Grain yield (kg ha$^{-1}$) | | | | Straw yield (kg ha$^{-1}$) | | | | Thousand grain weight (g) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 1290 | 4280 | 4380 | 3317 | 1793 | 6357 | 6522 | 4891 | 19.25 | 20.25 | 20.55 | 20.02 |
| $S_2$ | 1350 | 4390 | 4440 | 3393 | 1991 | 6463 | 6651 | 5035 | 19.67 | 20.47 | 20.83 | 20.32 |
| $S_3$ | 1430 | 4450 | 4470 | 3450 | 2148 | 6566 | 6703 | 5139 | 19.95 | 20.73 | 21.00 | 20.56 |
| $S_4$ | 1500 | 4490 | 4490 | 3493 | 2231 | 6688 | 6778 | 5232 | 20.28 | 20.87 | 21.23 | 20.79 |
| $S_5$ | 1530 | 4520 | 4500 | 3517 | 2311 | 6824 | 6796 | 5310 | 20.49 | 21.10 | 21.33 | 20.97 |
| $S_6$ | 1380 | 4420 | 4460 | 3420 | 2026 | 6624 | 6730 | 5127 | 19.85 | 20.70 | 20.93 | 20.49 |
| $S_7$ | 1450 | 4450 | 4475 | 3458 | 2139 | 6668 | 6746 | 5184 | 20.07 | 20.85 | 21.00 | 20.64 |
| $S_8$ | 1550 | 4490 | 4520 | 3520 | 2309 | 6770 | 6824 | 5301 | 20.15 | 20.93 | 21.25 | 20.78 |
| Mean | 1435 | 4438 | 4467 | 3446 | 2119 | 6620 | 6719 | 5152 | 19.96 | 20.74 | 21.02 | 20.57 |
| CD($p$=0.05) | | | | | | | | | | | | |
| M | 86 | | | | 173 | | | | 0.54 | | | |
| S | 84 | | | | 103 | | | | 0.26 | | | |
| M at S | 90 | | | | 142 | | | | NS | | | |
| S at M | 89 | | | | 112 | | | | | | | |

recorded the maximum weight of 21.33 g. However, the increases in grain weight recorded by various combinations did not attain the level of significance.

### 4.6.4.6. Grain yield (Table 34)

Among the NPK fertiliser levels, $M_3$ recorded the highest grain yield of 4467 kg $ha^{-1}$ which was statistically on par with $M_2$ (4438 kg $ha^{-1}$). The no fertiliser treatment recorded 1435 kg $ha^{-1}$of grain yield. The per cent increase in grain yield recorded by $M_2$ and $M_3$ over $M_1$ were 68.0 and 68.3 .The increase in grain yield due to addition of graded levels of humic acid was statistically significant. The highest grain yield of 3517 kg $ha^{-1}$ was recorded by $S_5$. The $S_5$ was statistically on par with $S_4$ (3493 kg $ha^{-1}$), $S_3$ (3450 kg $ha^{-1}$) and $S_2$ (3393 kg $ha^{-1}$). Among $S_6$, $S_7$ and $S_8$, the $S_8$ recorded significantly higher grain yield of 3520 kg $ha^{-1}$ than $S_6$ (3420 kg $ha^{-1}$) but it was on par with $S_7$ (3458 kg $ha^{-1}$). The per cent increase recorded by $S_5$, $S_4$, $S_3$ and $S_2$ over $S_1$were 6.3, 5.8, 5.6 and 2.9 respectively. The per cent increase recorded by $S_8$ over $S_5$ was 0.09 only. The treatments $S_4$ and $S_5$ were comparable with $S_7$ and $S_8$.

All the treatments receiving humic acid in the presence of NPK fertilisers recorded higher range of yield 4390 to 4500 kg $ha^{-1}$ than NPK fertiliser treatment (4280 to 4380 kg $ha^{-1}$). The treatment combinations $M_3S_8$ recorded 4520 kg of grain yield per hectare and it was on par with $M_3S_5$ (4500 kg $ha^{-1}$), $M_3S_4$ (4490 kg $ha^{-1}$) and $M_3S_3$ (4470 kg $ha^{-1}$) .The treatments $M_2S_5$ (4520 kg $ha^{-1}$) and $M_3S_8$ (4520 kg $ha^{-1}$) recorded comparable grain yield.

### 4.6.4.7. Straw yield (Table 34)

The straw yield recorded in $M_3$ (6719 kg $ha^{-1}$) was statistically on par with $M_2$ (6620 kg $ha^{-1}$). The increase recorded in $M_2$ and $M_3$ were significantly higher than $M_1$ (2119 kg $ha^{-1}$). The per cent increase in straw yield recorded by $M_2$ and $M_3$ over $M_1$ were 68.0 and 68.5.

The increase in straw yield due to addition of graded levels of humic acid was statistically significant. Among the HA treatments, $S_5$ recorded 5310 kg ha$^{-1}$ of straw yield and it was followed by $S_4$ (5232 kg ha$^{-1}$) and $S_3$ (5139 kg ha$^{-1}$). The $S_6$ , $S_7$ and $S_8$ recorded 5127, 5184 and 5301 kg ha$^{-1}$ of straw yield respectively. The $S_5$ was comparable with $S_8$ whereas $S_6$ and $S_7$ were on par with $S_3$. The per cent increase recorded by $S_5$, $S_4$, $S_3$ and $S_2$ over $S_1$ were 7.9,6.5,4.8 and 2.9 respectively.

The results on interaction effect recorded significant differences in straw yield. The range of straw yield recorded by NPK fertilisers with HA was higher (6463 to 6824 kg ha$^{-1}$) than that recorded by NPK fertilisers (6357 to 6522 kg ha$^{-1}$). The $M_3S_8$ registered 6824 kg ha$^{-1}$ of straw yield, which was statistically on par with $M_3S_5$ (6796 kg ha$^{-1}$) and $M_3S_7$ (6746 kg ha$^{-1}$), $M_3S_4$ (6778 kg ha$^{-1}$), $M_3S_6$ (6730 kg ha$^{-1}$) and $M_3S_3$ (6703 kg ha$^{-1}$). The straw yield of the results indicated that combinations $M_3S_8$ and $M_2S_5$ (6824 kg ha$^{-1}$) were found to be comparable with each other. The fertiliser treatments with graded levels of humic acid recorded significant increase in the straw yield.

## 4.7. Effect of humic acid and NPK fertilisers on rice in Inceptisol –Field experiment

Field experiment was conducted during rabi season with rice variety ADT 39 in Irugur alluvium soil series representing Inceptisol. The treatment structure consisted of three main plot treatment *viz.*, no fertiliser ($M_1$), 75 per cent recommended dose of NPK fertiliser ($M_2$) and 100 per cent recommended dose of NPK fertiliser ($M_3$) and eight subplot treatments with HA (humic acid) *viz.*, 0 ($S_1$), 10 ($S_2$), 20 ($S_3$), 30 ($S_4$), 40 ($S_5$) kg$^1$of HA ha$^{-1}$, 10 kg HA ha$^{-1}$ + foliar spray of 0.1 per cent HA (FS) ($S_6$), 10 kg HA ha$^{-1}$ + root dipping of 0.3 per cent HA (RD) ($S_7$) and 10 kg HA ha$^{-1}$+ FS + RD ($S_8$). The data on yield, nutrient uptake and soil properties were statistically scrutinized and results are presented below:

### 4.7.1. Soil fertility

#### 4.7.1.1. Organic carbon

The organic carbon content of the post harvest samples was analysed and the results are given in Table 35. The $S_5$ recorded the highest organic carbon content of 0.603 %, which was on par with $S_4$ (0.573 %) and it was followed by $S_3$ (0.550 %) and $S_2$ (0.534 %). The treatments $S_6$ (0.532 %), $S_7$ (0.536 %) and $S_8$ (0.537 per cent) were on par with each other. The $S_5$ and $S_4$ were found to record significantly higher organic carbon content than others. The per cent increase recorded $S_5$ and $S_4$ over $S_2$ were 11.3 and 6.8. The application of NPK fertiliser with HA recorded higher organic carbon content of 0.535 to 0.607 % than NPK fertiliser (0.509 to 0.510 %). The highest organic carbon was recorded in the treatment combination $M_3S_5$ (0.607%). This was on par with $M_2S_5$ (0.605%). The $M_1S_5$ (0.598%), $M_2S_4$ (0.575%) and $M_3S_4$ (0.575 %).

#### 4.7.1.2. Cation exchange capacity (Table 35)

Fertilisers and humic acid influenced CEC of the soil. Among the NPK fertiliser treatments, the CEC recorded in $M_3$ (25.0 cmol (p+) kg$^{-1}$) and $M_2$ (24.2 cmol (p+) kg$^{-1}$) were significantly higher than $M_1$. In the HA treatments, $S_5$ recorded higher CEC of (25.9 cmol (p+) kg$^{-1}$) and it was on par with $S_4$ (24.8 cmol (p+) kg$^{-1}$). The $S_4$ followed by the treatment $S_3$ (23.7 cmol (p+) kg$^{-1}$) and $S_2$ (22.1 cmol (p+) kg$^{-1}$). The $S_6$ (22.3 cmol (p+) kg$^{-1}$), $S_7$ (22.6 cmol (p+) kg$^{-1}$) and $S_8$ (22.9 cmol (p+) kg$^{-1}$) were statistically comparable with each other. The $S_5$ and $S_4$ were found to be significantly higher than other treatments.

The NPK fertiliser integrated with HA recorded higher CEC of 23.2 to 28.0 cmol (p+) kg $^{-1}$ than NPK fertiliser (19.5 to 19.9 cmol (p+) kg$^{-1}$). In the interaction treatments, $M_3S_5$ recorded the highest CEC of 28.0 cmol (p+) kg$^{-1}$. This was on par with

**Table 35. Effect of humic acid and fertilisers on organic carbon (%) and CEC (cmol (p+) $kg^{-1}$) at post harvest in Inceptisol**

| Treatments | Organic carbon | | | | CEC | | | |
|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 0.503 | 0.509 | 0.510 | 0.507 | 16.2 | 19.5 | 19.9 | 18.5 |
| $S_2$ | 0.530 | 0.535 | 0.537 | 0.534 | 18.5 | 23.2 | 24.5 | 22.1 |
| $S_3$ | 0.545 | 0.552 | 0.553 | 0.550 | 19.8 | 25.5 | 25.8 | 23.7 |
| $S_4$ | 0.569 | 0.575 | 0.575 | 0.573 | 20.8 | 26.5 | 27.0 | 24.8 |
| $S_5$ | 0.598 | 0.605 | 0.607 | 0.603 | 21.9 | 27.8 | 28.0 | 25.9 |
| $S_6$ | 0.530 | 0.532 | 0.533 | 0.532 | 18.8 | 23.5 | 24.5 | 22.3 |
| $S_7$ | 0.532 | 0.537 | 0.538 | 0.536 | 19.0 | 23.8 | 25.0 | 22.6 |
| $S_8$ | 0.532 | 0.539 | 0.540 | 0.537 | 19.2 | 24.0 | 25.5 | 22.9 |
| Mean | 0.542 | 0.548 | 0.549 | 0.547 | 19.3 | 24.2 | 25.0 | 22.8 |
| CD (p=0.05) | | | | | | | | |
| M | 0.008 | | | | 2.9 | | | |
| S | 0.020 | | | | 1.5 | | | |
| M at S | 0.011 | | | | 3.2 | | | |
| S at M | 0.048 | | | | 2.2 | | | |

$M_2S_5$ (27.8 cmol (p+) kg$^{-1}$), $M_3S_4$ (27.0 cmol (p+) kg$^{-1}$), $M_2S_4$ (26.5 cmol (p+) kg$^{-1}$) and $M_3S_3$ (25.8 cmol (p+) kg$^{-1}$).

#### 4.7.1.3. Available nutrients

The available nutrients N, P and K were analyzed in the soil samples collected at tillering, flowering and post harvest stages of rice crop. The secondary (Ca and Mg) nutrients, micronutrients (Fe, Zn, Mn and Cu), organic carbon and CEC were also estimated at the harvest stage of rice crop. The results of the analysis are presented below.

##### 4.7.1.3.1. Available nitrogen [$KMnO_4$-N]

The data pertaining to $KMnO_4$-N at different growth stages are given in Table 36. At tillering stage, the application of NPK fertiliser significantly increased the $KMnO_4$-N. The $M_3$ treatment recorded higher $KMnO_4$-N of 245 kg ha$^{-1}$ than $M_2$ (229 kg ha$^{-1}$). The treatment $M_1$ recorded only 221 kg ha$^{-1}$ of $KMnO_4$-N.

In the HA treatments, $S_5$ recorded highest $KMnO_4$-N content of 245 kg ha$^{-1}$ and it was followed by $S_4$ (237 kg ha$^{-1}$) and $S_3$ (231 kg ha$^{-1}$). The $S_8$ recorded the highest $KMnO_4$-N content of 240 kg ha$^{-1}$, which was on par with $S_7$ (234 kg ha$^{-1}$) and $S_6$ (231 kg ha$^{-1}$). The treatments $S_5$ and $S_8$ were comparable. The per cent increase recorded by $S_5$ over $S_8$ was 2.0.

The application of NPK fertiliser combined with HA recorded higher $KMnO_4$-N content (232 to 255 kg ha$^{-1}$) than NPK fertiliser (219 to 229 kg ha$^{-1}$) did. Among the treatment combinations, the $M_3S_5$ (255 kg ha$^{-1}$), $M_3S_8$ (255 kg ha$^{-1}$), $M_3S_4$ (252 kg ha$^{-1}$), $M_3S_7$ (250 kg ha$^{-1}$), $M_2S_5$ (250 kg ha$^{-1}$), $M_2S_8$ (248 kg ha$^{-1}$) and $M_3S_3$ (245 kg ha$^{-1}$) were comparable with each other.

**Table 36. Effect of humic acid and fertilisers on $KMnO_4$-N content (kg $ha^{-1}$) in Inceptisol**

| Treatments | Tillering | | | | Flowering | | | | Post harvest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 195 | 219 | 229 | 212 | 181 | 207 | 216 | 201 | 183 | 198 | 208 | 196 |
| $S_2$ | 213 | 232 | 237 | 224 | 193 | 217 | 222 | 211 | 190 | 214 | 218 | 207 |
| $S_3$ | 221 | 239 | 245 | 231 | 206 | 227 | 235 | 223 | 200 | 220 | 227 | 216 |
| $S_4$ | 225 | 243 | 252 | 237 | 217 | 232 | 240 | 230 | 203 | 226 | 233 | 221 |
| $S_5$ | 236 | 250 | 255 | 245 | 222 | 238 | 246 | 235 | 207 | 228 | 235 | 223 |
| $S_6$ | 221 | 238 | 245 | 231 | 199 | 226 | 233 | 219 | 195 | 218 | 223 | 212 |
| $S_7$ | 224 | 240 | 250 | 234 | 208 | 230 | 240 | 226 | 198 | 223 | 225 | 215 |
| $S_8$ | 227 | 248 | 255 | 240 | 215 | 233 | 246 | 231 | 208 | 224 | 227 | 220 |
| Mean | 221 | 229 | 245 | 232 | 205 | 226 | 235 | 222 | 198 | 219 | 225 | 214 |
| CD(p=0.05) | | | | | | | | | | | | |
| M | 10.8 | | | | 10.2 | | | | 9.5 | | | |
| S | 5.8 | | | | 7.6 | | | | 5.2 | | | |
| M at S | 9.5 | | | | 9.5 | | | | 9.1 | | | |
| S at M | 7.1 | | | | 8.5 | | | | 7.2 | | | |

At flowering stage, the content of $KMnO_4$-N had declined. The treatments $M_3$ and $M_2$ recorded 235 and 226 kg $ha^{-1}$ of $KMnO_4$-N and they were statistically on par with each other. The $M_1$ recorded lower $KMnO_4$-N content of 205 kg $ha^{-1}$ than $M_2$ and $M_3$. In HA treatments, $S_5$ recorded higher $KMnO_4$-N content of 235 kg $ha^{-1}$ and it was followed by $S_4$ (230 kg $ha^{-1}$) and $S_3$ (223 kg $ha^{-1}$). The $S_8$ recorded 231 kg $ha^{-1}$ of $KMnO_4$-N, which was followed by $S_7$ (226 kg $ha^{-1}$) and $S_6$ (219 kg $ha^{-1}$). The $S_5$, $S_8$ and $S_4$ were statistically comparable. The per cent increase recorded by $S_5$ over $S_4$ and $S_8$ were 1.7 and 2.1.

The NPK fertiliser combined with HA registered higher $KMnO_4$-N of 217 to 246 kg $ha^{-1}$ than NPK fertiliser (207 to 216 kg $ha^{-1}$). Among the treatment combination, $M_3S_5$ and $M_3S_8$ recorded similar $KMnO_4$-N content of 246 kg $ha^{-1}$. The treatments $M_2S_5$ (238 kg $ha^{-1}$) $M_2S_8$ (233 kg $ha^{-1}$), $M_3S_6$ (233 kg $ha^{-1}$), $M_2S_4$ (232 kg $ha^{-1}$) and $M_2S_3$ (227 kg $ha^{-1}$) were comparable.

At the post harvest, the $KMnO_4$-N showed a significant increase due to application of fertiliser. The $M_3$ (225 kg $ha^{-1}$) and $M_2$ (219 kg $ha^{-1}$) recorded significantly higher $KMnO_4$-N content than $M_1$ (198 kg $ha^{-1}$). In the HA treatments, $S_5$ recorded the highest content of $KMnO_4$-N of 223 kg $ha^{-1}$ and it was on par with $S_4$ (221 kg $ha^{-1}$). Among $S_6$, $S_7$ and $S_8$, the treatment $S_8$ recorded 220 kg $ha^{-1}$ of $KMnO_4$-N and it was on par with $S_7$ (215 kg $ha^{-1}$) and the $S_7$ was followed by $S_6$ (212 kg $ha^{-1}$). The treatments $S_4$, $S_5$ and $S_8$ were comparable. The per cent increase recorded by $S_5$ over $S_4$ and $S_8$ were 0.9 and 1.3.

The application of NPK recorded lower $KMnO_4$-N content of 198 to 208 kg $ha^{-1}$ than NPK fertiliser with HA (214 to 235 kg $ha^{-1}$). In interaction, the treatments, $M_3S_5$ (235 kg $ha^{-1}$) and $M_3S_4$ (233 kg $ha^{-1}$) were on par with each other. The treatments $M_3S_3$, $M_3S_6$ were comparable. The $M_2S_5$ (228 kg $ha^{-1}$), $M_2S_4$ (226 kg $ha^{-1}$),

$M_2S_8$ (224 kg $ha^{-1}$) and $M_2S_7$ (223 kg $ha^{-1}$) were statistically on par with each other. The treatment $M_2S_8$ (224 kg $ha^{-1}$) and $M_3S_8$ (227 kg $ha^{-1}$) were on par with each other.

### 4.7.1.3.2. Available phosphorus (Olsen P)

A perusal of the data in the Table 37 revealed that the Olsen-P status of the soil during the tillering stage of the crop was high and declined thereafter. The fertiliser treatment $M_3$ registered the highest Olsen-P content of 25.3 kg $ha^{-1}$, which was on par with $M_2$ (24.8 kg $ha^{-1}$). The $M_1$ recorded 22.8 kg $ha^{-1}$ of Olsen-P content. In HA treatments, $S_5$ recorded the maximum Olsen-P content of 25.0 kg $ha^{-1}$and it was on par with $S_4$ (24.9 kg $ha^{-1}$) and followed by $S_3$ (24.1 kg $ha^{-1}$). Among the $S_6$, $S_7$ and $S_8$, the $S_8$ (24.7 kg $ha^{-1}$), $S_7$ (24.4 kg $ha^{-1}$) and $S_6$ (24.3 kg $ha^{-1}$) were recorded comparable Olsen-P content. The treatments $S_3$ (24.1 kg $ha^{-}$) and $S_2$ (23.8 kg $ha^{-}$) also were on par with each other. The treatments $S_5$, $S_4$, $S_6$, $S_7$ and $S_8$ were comparable.

The Olsen-P recorded in NPK fertiliser treatment were ( 24.0 to 24.5 kg $ha^{-1}$) lower than NPK fertiliser combined with HA (24.2 to 26.0 kg $ha^{-1}$). Among the interaction treatments, $M_3S_5$ recorded the highest Olsen-P content of 26.0 kg $ha^{-1}$. This was on par with $M_3S_8$ (25.8 kg $ha^{-1}$), $M_3S_4$ (25.7 kg $ha^{-1}$), $M_2S_4$ (25.7 kg $ha^{-1}$), $M_3S_6$ (25.5 kg $ha^{-1}$) and $M_3S_7$ (25.4 kg $ha^{-1}$).

At flowering stage, the $M_3$ (19.8 kg $ha^{-1}$) and $M_2$ (19.4 kg $ha^{-1}$) treatments recorded significantly higher Olsen-P content than $M_1$ (16.0 kg $ha^{-1}$). In HA treatments, $S_5$ recorded higher Olsen-P content of 19.1 and it was followed by $S_4$ (18.6 kg $ha^{-1}$) and $S_3$ (18.2 kg $ha^{-1}$). The $S_8$ registered 19.0 kg $ha^{-1}$of Olsen-P content, which was followed by $S_7$ (18.6 kg $ha^{-1}$) and $S_6$ (18.5 kg $ha^{-1}$).

**Table 37. Effect of humic acid and fertilisers on Olsen -P content (kg ha$^{-1}$) in Inceptisol**

| Treatments | Tillering | | | | Flowering | | | | Post harvest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 21.7 | 24.0 | 24.5 | 23.4 | 14.5 | 18.5 | 19.0 | 17.3 | 10.5 | 14.5 | 14.7 | 13.2 |
| $S_2$ | 22.4 | 24.2 | 24.8 | 23.8 | 15.1 | 18.7 | 19.2 | 17.7 | 11.3 | 15.2 | 15.2 | 13.9 |
| $S_3$ | 22.8 | 24.4 | 25.0 | 24.1 | 15.8 | 19.1 | 19.8 | 18.2 | 11.7 | 15.9 | 16.2 | 14.3 |
| $S_4$ | 23.4 | 25.7 | 25.7 | 24.9 | 16.3 | 19.7 | 19.8 | 18.6 | 12.5 | 16.5 | 16.7 | 15.2 |
| $S_5$ | 23.5 | 25.6 | 26.0 | 25.0 | 17.1 | 20.2 | 20.0 | 19.1 | 12.8 | 16.8 | 16.9 | 15.5 |
| $S_6$ | 22.7 | 24.8 | 25.5 | 24.3 | 16.0 | 19.3 | 20.1 | 18.5 | 11.3 | 15.5 | 16.0 | 14.3 |
| $S_7$ | 23.0 | 24.8 | 25.4 | 24.4 | 16.1 | 19.6 | 20.2 | 18.6 | 11.7 | 15.9 | 16.5 | 14.7 |
| $S_8$ | 23.1 | 25.1 | 25.8 | 24.7 | 16.7 | 19.9 | 20.3 | 19.0 | 11.9 | 16.1 | 16.7 | 14.9 |
| Mean | 22.8 | 24.8 | 25.3 | 24.3 | 16.0 | 19.4 | 19.8 | 18.4 | 11.7 | 15.8 | 16.1 | 14.5 |
| CD(p=0.05) | | | | | | | | | | | | |
| M | 0.9 | | | | 0.8 | | | | 0.7 | | | |
| S | 0.7 | | | | 0.4 | | | | 0.4 | | | |
| M at S | 1.1 | | | | 0.7 | | | | 0.9 | | | |
| S at M | 0.8 | | | | 0.5 | | | | 0.4 | | | |

The application of HA combined with NPK fertilisers registered higher Olsen-P content of 18.7 to 20.3 kg ha$^{-1}$ than NPK fertiliser (18.5 to 19.0 kg ha$^{-1}$). The interaction between fertilisers and HA were found to record significant differences. The treatment $M_3S_8$ recorded 20.3 kg ha$^{-1}$ of Olsen-P content. This was on par with $M_3S_7$ (20.2 kg ha$^{-1}$), $M_3S_6$ (20.1 kg ha$^{-1}$), $M_3S_5$ (20.0 kg ha$^{-1}$), $M_2S_8$ (19.9 kg ha$^{-1}$) and $M_2S_5$ (20.2 kg ha$^{-1}$).

At post harvest, the treatment $M_3$ (16.1kg ha$^{-1}$) and $M_2$ (15.8 kg ha$^{-1}$) were statistically on par with each other. In humic acid treatments, $S_5$ (15.5 kg ha$^{-1}$) registered maximum Olsen-P content of 15.5 kg $^{1}$. This was on par with $S_4$ (15.2 kg ha$^{-1}$) and the $S_8$ was followed by $S_3$ (14.3 kg ha$^{-1}$) and $S_2$ (13.9 kg ha$^{-1}$). The treatments $S_8$ and $S_7$ recorded 14.9 and 14.7 kg ha$^{-1}$ of Olsen-P content, which were on par with each other and followed by $S_6$ (14.3 kg ha$^{-1}$). The $S_5$ and $S_4$ were comparable.

The NPK fertiliser combined with HA recorded higher Olsen-P content of 15.2 to 16.9 kg ha$^{-1}$ than NPK fertiliser (14.5 to 14.7 kg ha$^{-1}$). In interaction, $M_3S_5$ (16.9 kg ha$^{-1}$), $M_2S_5$ (16.8 kg ha$^{-1}$), $M_3S_8$ (16.7 kg ha$^{-1}$), $M_3S_4$ (16.7 kg ha$^{-1}$), $M_3S_7$ (16.5 kg ha$^{-1}$) and $M_2S_4$ (16.5 kg ha$^{-1}$) were on par with each other. The treatments, $M_3S_3$ (16.2 kg ha$^{-1}$), $M_2S_8$ (16.1 kg ha$^{-1}$), $M_3S_6$ (16.0 kg ha$^{-1}$), $M_2S_3$ (16.3 kg ha$^{-1}$) and $M_2S_7$ (15.9 kg ha$^{-1}$) were comparable Olsen-P content.

#### 4.7.1.3.3. Available potassium [$NH_4OAc$-K]

The $NH_4OAc$-K content of the soil was estimated at tillering, flowering and post harvest stage of rice and presented in Table 38. At tillering stage, the $NH_4OAc$-K was significantly increased for the application of NPK fertiliser as compared to no fertiliser. The content of $NH_4OAc$-K recorded by $M_3$ was 317 kg ha$^{-1}$, which was significantly higher than that obtained in $M_2$ (290 kg ha$^{-1}$) and $M_1$ (227 kg ha$^{-1}$).

**Table 38. Effect of humic acid and fertilisers on $NH_4OAc$-K content (kg $ha^{-1}$) in Inceptisol**

| Treatments | Tillering | | | | Flowering | | | | Post harvest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 207 | 277 | 290 | 258 | 185 | 247 | 255 | 229 | 153 | 215 | 223 | 197 |
| $S_2$ | 223 | 280 | 307 | 270 | 210 | 255 | 263 | 243 | 163 | 225 | 232 | 207 |
| $S_3$ | 230 | 289 | 317 | 279 | 215 | 262 | 270 | 249 | 190 | 230 | 240 | 220 |
| $S_4$ | 237 | 299 | 326 | 287 | 229 | 260 | 277 | 255 | 197 | 240 | 245 | 227 |
| $S_5$ | 239 | 311 | 335 | 295 | 233 | 270 | 285 | 263 | 203 | 247 | 249 | 233 |
| $S_6$ | 223 | 282 | 319 | 275 | 212 | 257 | 272 | 247 | 180 | 227 | 243 | 217 |
| $S_7$ | 230 | 289 | 322 | 280 | 217 | 265 | 283 | 255 | 183 | 230 | 245 | 219 |
| $S_8$ | 230 | 290 | 323 | 281 | 220 | 270 | 285 | 258 | 180 | 232 | 245 | 219 |
| Mean | 227 | 290 | 317 | 278 | 215 | 261 | 274 | 250 | 181 | 231 | 240 | 217 |
| CD(p=0.05) | | | | | | | | | | | | |
| M | 21 | | | | 20 | | | | 14 | | | |
| S | 17 | | | | 15 | | | | 14 | | | |
| M at S | 22 | | | | 22 | | | | 18 | | | |
| S at M | 23 | | | | 19 | | | | 17 | | | |

In HA treatments, $S_5$ recorded the highest $NH_4OAc$-K content of 295 kg $ha^{-1}$, which was on par with $S_4$ (287 kg $ha^{-1}$) and $S_3$ (279 kg $ha^{-1}$). The $S_8$, $S_7$ and $S_6$ recorded 281, 280 and 275 kg $ha^{-1}$ of $NH_4OAc$-K content, which were comparable with each other. The $S_5$, $S_4$, $S_7$ and $S_8$ were found to be on par with each other. The per cent increase recorded by $S_5$ over $S_4$, $S_7$ and $S_8$ were 2.7, 5.1 and 4.7.

The application of NPK fertiliser combined with HA was recorded higher $NH_4OAc$-K content of 280 to 335 kg $ha^{-1}$ than NPK fertiliser (277 to 290 kg $ha^{-1}$). In the treatment combination, $M_3S_5$ recorded the highest $NH_4OAc$-K content 335 kg $ha^{-1}$. This was on par with $M_3S_8$ (323 kg $ha^{-1}$), $M_3S_7$ (322 kg $ha^{-1}$), $M_3S_4$ (326 kg $ha^{-1}$) and $M_3S_3$ (317 kg $ha^{-1}$). The treatments $M_2S_5$ (311 kg $ha^{-1}$) $M_3S_2$ (307 kg $ha^{-1}$), $M_2S_4$ (299 kg $ha^{-1}$) $M_2S_8$ (290kg $ha^{-1}$) and $M_2S_7$ (289 kg $ha^{-1}$) were on par with each other.

At flowering stage, the $NH_4OAc$-K content recorded by $M_3$ (271 kg $ha^{-1}$) and $M_2$ (261 kg $ha^{-1}$) were on par with each other. The $M_1$ recorded only 215 kg $ha^{-1}$ of $NH_4OAc$-K. In HA treatments, the $S_5$ (263 kg $ha^{-1}$), $S_4$ (255 kg $ha^{-1}$) and $S_3$ (249 kg $ha^{-1}$) recorded comparable $NH_4OAc$-K content. The treatments $S_8$ (258 kg $ha^{-1}$) and $S_7$ (255 kg $ha^{-1}$) were on par with each other and it was followed by $S_6$ (247 kg $ha^{-1}$). The treatments $S_5$, $S_4$, $S_3$, $S_7$ and $S_8$ were found to be comparable. The per cent increase recorded by $S_5$ over $S_4$, $S_3$, $S_7$ and $S_8$ were 3.0, 5.3, 3.0 and 1.9.

In the treatment combination, $M_3S_5$ and $M_3S_8$ recorded the highest $NH_4OAc$-K content of 285 kg $ha^{-1}$. This was on par with $M_3S_7$ (283 kg $ha^{-1}$), $M_3S_4$ (277 kg $ha^{-1}$), $M_3S_6$ (272 kg $ha^{-1}$) $M_3S_3$ (270 kg $ha^{-1}$), $M_2S_5$ (270 kg $ha^{-1}$) and $M_2S_8$ (270 kg $ha^{-1}$).

At post harvest, the treatment $M_3$ and $M_2$ recorded 240 and 231 kg $ha^{-1}$ of $NH_4OAc$-K content .The $M_1$ recorded only 181 kg $ha^{-1}$. The per cent increase recorded by $M_2$ and $M_3$ over $M_1$ were 21.6 and 24.6. In the HA treatment $S_5$ recorded the highest

$NH_4OAc$-K content of 233 kg ha$^{-1}$, which was on par with $S_4$ (227 kg ha$^{-1}$) and $S_3$ (220 kg ha$^{-1}$) .The $S_5$ was followed by $S_2$ (207 kg ha$^{-1}$). The treatment $S_6$ (217 kg ha$^{-1}$) $S_7$ (219 kg ha$^{-1}$) and $S_8$ (219 kg ha$^{-1}$) were comparable. The $S_5$ and $S_4$ recorded significantly higher content $NH_4OAc$-K than $S_6$, $S_7$ and $S_8$.

The HA combined with NPK fertilisers recorded higher $NH_4OAc$-K content of 225 to 249 kg ha$^{-1}$ than NPK fertiliser (215 to 223 kg ha$^{-1}$). The interaction effects were found to be significant. The treatment $M_3S_5$ recorded the highest $NH_4OAc$-K content 249 kg ha$^{-1}$. This was on par with $M_3S_7$ (245 kg ha$^{-1}$), $M_3S_8$ (245 kg ha$^{-1}$), $M_3S_4$ (245 kg ha$^{-1}$), $M_3S_6$ (243 kg ha$^{-1}$), $M_2S_5$ (247 kg ha$^{-1}$), $M_2S_4$ (240 kg ha$^{-1}$) and $M_2S_8$ (232 kg ha$^{-1}$).

### 4.7.1.4. DTPA extractable micronutrients

At harvest, the soil samples were collected and analysed for their DTPA extractable micronutrients and are presented in Table 39.

**Iron**

The DTPA Fe content in $M_1$, $M_2$ and $M_3$ were 49.63, 50.3 and 50.3 ppm respectively. The treatments $M_2$ and $M_3$ were on par but superior over $M_1$. Among the HA treatments, significantly the highest Fe content of 51.9 ppm was recorded in $S_4$, which was on par with $S_3$ (51.0 ppm). The $S_8$ (51.0 ppm) and $S_7$ (50.81 ppm) were comparable. Again the $S_4$ was comparable with $S_7$ and $S_8$. The NPK fertiliser combined with HA recorded higher Fe content of 49.5 to 51.5 ppm than NPK fertiliser (47.5 to 47.6 ppm). Regarding interaction, the treatment $M_2S_4$ (51.5 ppm), $M_3S_4$ (51.5 ppm), $M_3S_3$ (51.4 ppm) and $M_2S_3$ (51.2 ppm) recorded DTPA Fe content. However the interaction did not attain the level of significance.

**Table 39. Effect of humic acid and fertilisers on soil micro nutrients (ppm) at post harvest in Inceptisol**

| Treatments | Iron | | | | Zinc | | | | Manganese | | | | Copper | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 44.3 | 47.5 | 47.6 | 46.5 | 4.62 | 4.82 | 4.92 | 4.79 | 10.52 | 12.52 | 13.75 | 12.26 | 5.50 | 5.90 | 5.95 | 5.78 |
| $S_2$ | 48.0 | 49.5 | 49.5 | 49.0 | 4.73 | 4.91 | 5.08 | 4.91 | 10.72 | 12.77 | 13.89 | 12.46 | 5.61 | 6.02 | 6.01 | 5.88 |
| $S_3$ | 50.3 | 51.2 | 51.4 | 51.0 | 4.82 | 4.98 | 5.18 | 4.99 | 11.05 | 13.15 | 14.17 | 12.79 | 5.67 | 6.08 | 6.13 | 5.96 |
| $S_4$ | 52.6 | 51.5 | 51.5 | 51.9 | 4.92 | 5.09 | 5.26 | 5.09 | 11.16 | 13.42 | 14.31 | 12.96 | 5.73 | 6.14 | 6.19 | 6.02 |
| $S_5$ | 49.5 | 49.9 | 50.0 | 49.8 | 4.78 | 5.00 | 5.05 | 4.94 | 10.94 | 13.02 | 14.03 | 12.66 | 5.56 | 5.96 | 6.06 | 5.86 |
| $S_6$ | 50.8 | 50.5 | 50.6 | 50.6 | 4.76 | 4.90 | 5.08 | 4.91 | 10.83 | 12.89 | 14.03 | 12.58 | 5.60 | 6.01 | 6.07 | 5.89 |
| $S_7$ | 50.6 | 50.9 | 51.0 | 50.8 | 4.80 | 4.95 | 5.12 | 4.96 | 10.94 | 13.03 | 14.17 | 12.71 | 5.60 | 6.00 | 6.07 | 5.89 |
| $S_8$ | 50.9 | 51.0 | 51.1 | 51.0 | 4.80 | 5.00 | 5.15 | 4.98 | 10.90 | 13.09 | 14.25 | 12.75 | 5.69 | 6.02 | 6.13 | 5.95 |
| Mean | 49.6 | 50.3 | 50.3 | 50.1 | 4.78 | 4.96 | 5.11 | 4.95 | 10.88 | 12.99 | 14.08 | 12.65 | 5.62 | 6.02 | 6.08 | 5.90 |
| CD(P=0.05) | | | | | | | | | | | | | | | | |
| M | 0.58 | | | | 0.30 | | | | 2.1 | | | | NS | | | |
| S | 1.09 | | | | 0.14 | | | | 0.25 | | | | 0.08 | | | |
| M at S<br>S at M | NS | | | | NS | | | | NS | | | | NS | | | |

### Zinc

The zinc content recorded by $M_3$ (5.11 ppm) was the highest as compared to $M_2$ (4.96 ppm) and $M_1$ (4.78 ppm). In the HA treatments, $S_4$ recorded the highest Zn content of 5.09 ppm which was on par with $S_3$ (4.99 ppm). The $S_8$ (4.98 ppm), $S_7$ (4.96 ppm) and $S_6$ (4.91 ppm) were comparable. The interaction was found to be nonsignificant. The $S_4$, $S_3$, $S_7$ and $S_8$ were on par with each other. In the interaction $M_3S_4$ recorded 5.26 ppm of Zn content. However the interaction of treatments did not attain the level of significance.

### Manganese

In fertiliser treatment, the highest DTPA Mn content was recorded in $M_3$ (14.08 ppm), which was on par with $M_2$ (12.99 ppm) and followed by $M_1$ (10.88 ppm). Among the HA treatments, $S_4$ recorded 12.96 ppm of DTPA Mn content and it was on par with $S_3$ (12.79 ppm). The $S_8$ (12.75 ppm), $S_7$ (12.71 ppm) and $S_6$ (12.58 ppm) recorded comparable DTPA Mn content. The highest Mn content was registered in $M_3S_4$ (14.31 ppm) also in $M_3S_8$ (14.25 ppm). However the interaction of treatments did not attain the level of significance.

### Copper

The effect of NPK fertiliser on DTPA Cu was nonsignificant. The effect produced by HA treatments same as that of other micronutrients i.e. the $S_4$ registered the higher DTPA Cu content of 6.02 ppm, which was on par with $S_3$ (5.96 ppm). The $S_6$ (5.89 ppm), $S_7$ (5.89 ppm) and $S_8$ (5.95 ppm) were recorded comparable DTPA Cu content .The $S_4$,$S_3$ and $S_8$ were comparable. In the interaction the DTPA Cu content recorded by $M_3S_4$, $M_2S_4$,

$M_3S_3$ and $M_3S_8$ were 6.19, 6.14, and 6.13 ppm respectively. However the treatment combination did not attain the level of significance

### 4.7.2. Effect of humic acid on nutrient uptake

The N, P and K were estimated at tillering, flowering and at harvest stages of the rice crop. The uptake of secondary nutrients (Ca and Mg) and micronutrients (Fe, Zn, Mn and Cu) were determined in grain and straw.

#### 4.7.2.1. Nitrogen uptake

The data regarding the N uptake are given in Table 40. At tillering stage, N uptake was found to be higher in NPK fertiliser applied treatment than no fertiliser. The treatment $M_3$ recorded significantly higher N uptake of 27.4 kg $ha^{-1}$ than $M_2$ (24.1 kg $ha^{-1}$) and $M_1$ (12.3 kg $ha^{-1}$). In HA treatments, the N uptake recorded in $S_5$ (23.0 kg $ha^{-1}$) and $S_4$ (22.3 kg $ha^{-1}$) were statistically on par with each other and followed by $S_3$ (21.5 kg $ha^{-1}$) and $S_2$ (20.4 kg $ha^{-1}$). The treatments $S_8$ (21.7 kg $ha^{-1}$), $S_6$ (21.3 kg $ha^{-1}$) and $S_7$ (21.0 kg $ha^{-1}$) were comparable. In the interaction, the $M_3S_5$ recorded the highest N uptake of 29.4 kg $ha^{-1}$ and it was on par with $M_3S_4$ (28.5 kg $ha^{-1}$) and $M_3S_8$ (27.9 kg $ha^{-1}$).

At flowering stage, the NPK fertiliser treatment $M_3$ recorded significantly the highest N uptake of 73.8 kg $ha^{-1}$ and it was followed by $M_2$ and $M_1$ which recorded 72.7 and 29.8 kg $ha^{-1}$ respectively. In HA treatments, the $S_5$ recorded the highest N uptake of 63.3 kg $ha^{-1}$ and it was on par with $S_4$ (61.1 kg $ha^{-1}$) and followed by $S_3$ (59.0 kg $ha^{-1}$). The $S_8$ recorded highest N uptake 60.7 kg $ha^{-1}$ than $S_6$ (59.2 kg $ha^{-1}$) and $S_7$ (57.6 kg $ha^{-1}$) which were on par with each other. In the interaction, the highest N uptake was recorded in $M_3S_5$ (79.0 kg $ha^{-1}$) and it was on par with $M_3S_8$ (75.7 kg $ha^{-1}$), $M_3S_6$ (74.3 kg $ha^{-1}$) and

**Table 40. Effect of humic acid and fertilisers on N uptake (kg ha$^{-1}$) by rice in Inceptisol**

| Treatments | Tillering | | | | Flowering | | | | Grain | | | | Straw | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 10.8 | 21.5 | 25.0 | 19.1 | 26.8 | 64.7 | 67.6 | 53.0 | 22.0 | 57.1 | 62.7 | 47.3 | 15.7 | 48.9 | 51.8 | 38.8 |
| $S_2$ | 11.7 | 23.1 | 26.3 | 20.4 | 28.6 | 69.0 | 70.5 | 56.0 | 24.0 | 62.5 | 67.9 | 51.5 | 19.0 | 55.5 | 60.0 | 44.8 |
| $S_3$ | 12.4 | 24.4 | 27.6 | 21.5 | 29.8 | 73.5 | 73.7 | 59.0 | 25.9 | 67.3 | 71.7 | 54.9 | 21.6 | 62.2 | 62.6 | 48.8 |
| $S_4$ | 13.0 | 25.3 | 28.5 | 22.3 | 30.9 | 76.1 | 76.3 | 61.1 | 27.7 | 71.5 | 74.0 | 57.7 | 23.9 | 68.2 | 70.2 | 54.1 |
| $S_5$ | 13.4 | 26.1 | 29.4 | 23.0 | 32.1 | 78.7 | 79.0 | 63.3 | 29.0 | 73.9 | 77.3 | 60.1 | 25.8 | 73.9 | 73.5 | 57.7 |
| $S_6$ | 12.2 | 24.2 | 27.4 | 21.3 | 30.0 | 73.4 | 74.3 | 59.2 | 26.3 | 67.6 | 72.3 | 55.4 | 22.4 | 62.7 | 65.3 | 50.1 |
| $S_7$ | 12.3 | 23.8 | 26.8 | 21.0 | 29.1 | 70.8 | 72.9 | 57.6 | 26.6 | 64.4 | 69.2 | 53.4 | 21.4 | 60.5 | 62.1 | 48.0 |
| $S_8$ | 12.5 | 24.7 | 27.9 | 21.7 | 30.7 | 75.5 | 75.7 | 60.7 | 27.5 | 69.0 | 73.4 | 56.6 | 23.1 | 65.7 | 68.6 | 52.5 |
| Mean | 12.3 | 24.1 | 27.4 | 21.3 | 29.8 | 72.7 | 73.8 | 58.7 | 26.1 | 66.7 | 71.1 | 54.6 | 21.6 | 62.2 | 64.3 | 49.4 |
| CD(p=0.05) | | | | | | | | | | | | | | | | |
| M | 1.2 | | | | 1.0 | | | | 3.0 | | | | 3.28 | | | |
| S | 0.9 | | | | 2.8 | | | | 2.1 | | | | 2.88 | | | |
| M at S | 1.9 | | | | 4.6 | | | | 3.4 | | | | 4.42 | | | |
| S at M | 1.7 | | | | 5.4 | | | | 2.9 | | | | 3.26 | | | |

$M_3S_3$ (73.7 kg $ha^{-1}$). The $M_2S_5$ (78.7 kg $ha^{-1}$), $M_2S_4$ (76.1 kg $ha^{-1}$) and $M_2S_8$ (75.5 kg $ha^{-1}$) were comparable. The treatments $M_2S_8$ and $M_3S_8$ were also comparable.

At harvest stage, the N uptake of grain and straw samples were determined. In the grain, $M_3$ recorded 71.1 kg $ha^{-1}$ of N uptake and that was significantly higher than that obtained in $M_2$ (66.7 kg $ha^{-1}$) and $M_1$ (26.1 kg $ha^{-1}$). In HA treatments, $S_5$ recorded the highest N uptake 60.1 kg $ha^{-1}$ and it was followed by $S_4$ (57.7 kg $ha^{-1}$). The $S_8$ recorded the highest N uptake of 56.6 kg $ha^{-1}$ which was followed by $S_6$ (55.4 kg $ha^{-1}$) and $S_7$ (53.4 kg $ha^{-1}$). The $S_4$ and $S_8$ were on par with each other. The application of NPK fertiliser with HA recorded higher N uptake in grain (62.5 to 77.3 kg $ha^{-1}$) than NPK fertiliser treatments (57.1 to 62.7 kg $ha^{-1}$). In the interaction, $M_3S_5$ recorded the highest N uptake (77.3 kg $ha^{-1}$) and it was followed by the treatments $M_3S_4$ (74.0 kg $ha^{-1}$), $M_3S_8$ (73.4 kg $ha^{-1}$), $M_3S_6$ (72.3 kg $ha^{-1}$), $M_2S_5$ (73.9 kg $ha^{-1}$), $M_3S_3$ (71.7 kg $ha^{-1}$) and $M_2S_4$ (71.5 kg $ha^{-1}$).

In the straw, the fertiliser treatments $M_3$ and $M_2$ recorded 64.3 and 62.2 kg $ha^{-1}$ of N uptake, and they were on par with each other. The $M_1$ registered 21.6 kg $ha^{-1}$ of N uptake. The HA treatments $S_5$ recorded the higher N uptake of 57.7 kg $ha^{-1}$ and it was followed by $S_4$ (54.1 kg $ha^{-1}$). Among $S_6$, $S_7$ and $S_8$, the $S_8$ recorded 52.5 kg $ha^{-1}$ of N uptake and it was on par with $S_6$ (50.1 kg $ha^{-1}$) and the $S_6$ was followed by $S_7$ (48.0 kg $ha^{-1}$). The NPK fertiliser integrated with HA recorded higher N uptake in straw (55.5 to 73.9 kg $ha^{-1}$) than NPK fertiliser treatments (48.9 to 51.8 kg $ha^{-1}$). In the interaction, $M_2S_5$ recorded highest N uptake of 73.9 kg $ha^{-1}$ which was on par with $M_3S_5$ (73.5 kg $ha^{-1}$) and $M_3S_4$ (70.2 kg $ha^{-1}$). The treatments $M_3S_8$ (68.6 kg $ha^{-1}$), $M_2S_4$ (68.2 kg $ha^{-1}$) and $M_2S_8$ (65.7 kg $ha^{-1}$) were comparable with each other.

### 4.7.2.2. Phosphorus uptake

The statistical scrutiny of the data showed that the uptake of P increased from tillering to flowering stage (Table 41). At tillering stage, P uptake was significantly increased by addition of fertiliser. The treatments $M_3$ and $M_2$ registered 3.89 and 3.42 kg $ha^{-1}$ of P uptake and they were on par with each other, while the $M_1$ recorded only 76 kg $ha^{-1}$ of P uptake. In the HA treatments, the $S_5$ recorded 3.26 kg $ha^{-1}$ of P uptake, which was on par with $S_4$ (3.17 kg $ha^{-1}$) and the $S_5$ followed by $S_3$ (3.06 kg $ha^{-1}$) and $S_2$ (2.94 kg $ha^{-1}$). The treatment $S_8$ (3.04 kg $ha^{-1}$), $S_7$ (3.00 kg $ha^{-1}$), $S_6$ (2.96 kg $ha^{-1}$) and $S_2$ (2.94 kg $ha^{-1}$) were comparable. The NPK fertiliser with HA recorded higher P uptake (3.31 to 4.19 kg $ha^{-1}$) than NPK fertiliser treatments (3.12 to 3.64 kg $ha^{-1}$). In the interaction, the $M_3S_5$ recorded higher P uptake of 4.19 kg $ha^{-1}$ and it was comparable with $M_3S_4$ (4.05 kg $ha^{-1}$), $M_3S_3$(3.92kg $ha^{-1}$) and $M_3S_8$ (3.89 kg $ha^{-1}$). The $M_2S_5$ (3.68 kg $ha^{-1}$) and $M_3S_8$ (3.89 kg $ha^{-1}$) were comparable.

At flowering stage, the higher P uptake of 14.54 kg $ha^{-1}$ was recorded in $M_3$ than $M_2$ (13.80 kg $ha^{-1}$) and $M_1$ (5.85 kg $ha^{-1}$). In the HA treatments, the $S_5$ (11.94 kg $ha^{-1}$), $S_4$ (11.72 kg $ha^{-1}$) and $S_3$ (11.44 kg $ha^{-1}$) were comparable. The $S_8$ (11.58 kg $ha^{-1}$), $S_6$ (11.43 kg $ha^{-1}$) and $S_7$ (11.29 kg $ha^{-1}$) were on par with each other. The treatments $S_5$, $S_4$, $S_3$, $S_6$ and $S_8$ were found to be comparable. In the interaction, the $M_3S_5$ (15.18 kg $ha^{-1}$), $M_3S_8$ (14.83 kg $ha^{-1}$), $M_3S_4$ (14.87 kg $ha^{-1}$), $M_3S_6$, (14.63 kg $ha^{-1}$) and $M_3S_3$ (14.56 kg $ha^{-1}$) were on par with each other.

At harvest stage, the P uptake of grain and straw samples were determined. The P uptake was higher in grain than straw. In grain, the $M_3$ and $M_2$ recorded 14.39 and 14.07 kg $ha^{-1}$ of P uptake and they were statistically on par with each other. Among the HA treatments, the $S_5$ recorded 11.96 kg $ha^{-1}$ of P uptake and it was on par with

Table 41. Effect of humic acid and fertilisers on P uptake (kg ha$^{-1}$) by rice in Inceptisol

| Treatments | Tillering | | | | Flowering | | | | Grain | | | | Straw | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 1.58 | 3.12 | 3.64 | 2.78 | 5.40 | 12.98 | 13.69 | 10.69 | 5.03 | 12.94 | 13.43 | 10.46 | 3.05 | 8.86 | 9.34 | 7.08 |
| $S_2$ | 1.70 | 3.31 | 3.80 | 2.94 | 5.68 | 13.43 | 14.19 | 11.10 | 5.32 | 13.74 | 14.04 | 11.03 | 3.36 | 9.71 | 10.24 | 7.77 |
| $S_3$ | 1.79 | 3.46 | 3.92 | 3.06 | 5.87 | 13.90 | 14.56 | 11.44 | 5.57 | 14.22 | 14.51 | 11.43 | 3.72 | 10.37 | 10.86 | 8.32 |
| $S_4$ | 1.87 | 3.58 | 4.05 | 3.17 | 6.05 | 14.23 | 14.87 | 11.72 | 5.77 | 14.54 | 14.91 | 11.74 | 4.06 | 11.05 | 11.47 | 8.86 |
| $S_5$ | 1.92 | 3.68 | 4.19 | 3.26 | 6.17 | 14.46 | 15.18 | 11.94 | 5.94 | 14.81 | 15.14 | 11.96 | 4.34 | 11.72 | 11.83 | 9.30 |
| $S_6$ | 1.71 | 3.35 | 3.81 | 2.96 | 5.90 | 13.78 | 14.63 | 11.43 | 5.49 | 14.02 | 14.27 | 11.26 | 3.64 | 10.02 | 10.85 | 8.17 |
| $S_7$ | 1.76 | 3.40 | 3.84 | 3.00 | 5.81 | 13.67 | 14.40 | 11.29 | 5.75 | 14.00 | 14.20 | 11.32 | 3.62 | 9.99 | 10.63 | 8.08 |
| $S_8$ | 1.78 | 3.44 | 3.89 | 3.04 | 5.94 | 13.98 | 14.83 | 11.58 | 5.70 | 14.31 | 14.61 | 11.54 | 3.88 | 10.56 | 11.20 | 8.55 |
| Mean | 1.76 | 3.42 | 3.89 | 3.03 | 5.85 | 13.80 | 14.54 | 11.40 | 5.57 | 14.07 | 14.39 | 11.34 | 3.71 | 10.28 | 10.80 | 8.27 |
| CD (p=0.05) | | | | | | | | | | | | | | | | |
| M | 0.49 | | | | 0.11 | | | | 0.71 | | | | 0.54 | | | |
| S | 0.14 | | | | 0.51 | | | | 0.32 | | | | 0.36 | | | |
| M at S | 0.47 | | | | 0.60 | | | | 0.73 | | | | 0.59 | | | |
| S at M | 0.29 | | | | 0.63 | | | | 0.40 | | | | 0.48 | | | |

$S_4$ (11.74 kg ha$^{-1}$) and followed by $S_3$ (11.43 kg ha$^{-1}$). The treatments $S_8$ (11.54 kg ha$^{-1}$), $S_7$ (11.32 kg ha$^{-1}$) and $S_6$ (11.26 kg ha$^{-1}$) were on par with each other. The $S_5$ and $S_4$ were found to be comparable. The application of NPK integrated with HA recorded higher P uptake of 13.74 to 15.14 kg ha$^{-1}$ than NPK fertiliser treatments (12.94 to 13.43 kg ha$^{-1}$). In the interaction of fertiliser and humic acid, the $M_3S_5$ recorded higher P uptake of 15.14 kg ha$^{-1}$, which was on par with $M_3S_4$ (14.91 kg ha$^{-1}$) and $M_2S_5$ (14.81 kg ha$^{-1}$). The treatments $M_3S_8$ (14.61 kg ha$^{-1}$), $M_2S_4$ (14.54 kg ha$^{-1}$), $M_3S_3$ (14.51 kg ha$^{-1}$), $M_2$ $S_8$ (14.31 kg ha$^{-1}$), $M_3S_6$ (14.27 kg ha$^{-1}$) and $M_2S_3$ (14.22 kg ha$^{-1}$) were comparable with each other.

In the straw, among the fertiliser treatments the $M_3$ and $M_2$ recorded of 10.80 and 10.28 kg ha$^{-1}$ of P uptake, which were comparable. In the HA treatments, $S_5$ recorded higher P uptake of 9.30 kg ha$^{-1}$ and it was followed by $S_4$ (8.86 kg ha$^{-1}$) and $S_3$ (8.32 kg ha$^{-1}$). The $S_8$ recorded 8.55 kg ha$^{-1}$of P uptake and it was followed by $S_6$ (8.17 kg ha$^{-1}$) and $S_7$ (8.08 kg ha$^{-1}$). The $S_5$ and $S_8$ were found to be comparable. The NPK fertiliser integrated with HA recorded higher P uptake of 9.71 to 11.83 kg ha$^{-1}$ than NPK fertiliser (8.86 to 9.34 kg ha$^{-1}$). In the interaction $M_3S_5$ recorded the highest P uptake of 11.83 kg ha$^{-1}$ and it was on par with $M_3S_4$ (11.47 kg ha$^{-1}$) and $M_2S_5$ (11.72 kg ha$^{-1}$).

### 4.7.2.3. Potassium uptake

The K uptake for different growth stages of paddy is given in Table 42. At tillering stage, the $M_3$ registered significantly the highest K uptake of 19.76 kg ha$^{-1}$ and it was followed by $M_2$ (17.58 kg ha$^{-}$) and $M_1$ (9.66 kg ha$^{-1}$). In the HA treatments, the $S_5$ (16.39 kg ha$^{-1}$), $S_4$ (16.12 kg ha$^{-1}$) and $S_3$ (15.77 kg ha$^{-1}$) were on par with each other and $S_3$ was followed by $S_2$ (15.36 kg ha$^{-1}$). Among $S_6$, $S_7$, and $S_8$, the $S_8$ recorded 15.78 kg ha$^{-1}$ of K uptake and it was followed by $S_7$ (15.68 kg ha$^{-1}$) and $S_6$ (15.47 kg ha$^{-}$). The treatments $S_3$, $S_4$, $S_5$ and $S_8$ were found to be comparable. The application of NPK with HA recorded

**Table 42. Effect of humic acid and fertilisers on K uptake (kg ha$^{-1}$) by rice in Inceptisol**

| Treatments | Tillering | | | | Flowering | | | | Grain | | | | Straw | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | M$_1$ | M$_2$ | M$_3$ | Mean | M$_1$ | M$_2$ | M$_3$ | Mean | M$_1$ | M$_2$ | M$_3$ | Mean | M$_1$ | M$_2$ | M$_3$ | Mean |
| S$_1$ | 8.91 | 16.52 | 18.93 | 14.79 | 19.84 | 45.94 | 46.76 | 37.51 | 4.73 | 12.32 | 12.81 | 9.95 | 31.49 | 77.02 | 78.41 | 62.31 |
| S$_2$ | 9.40 | 17.19 | 19.47 | 15.36 | 20.51 | 47.01 | 47.82 | 38.45 | 5.02 | 13.07 | 13.50 | 10.53 | 32.34 | 79.91 | 81.35 | 64.53 |
| S$_3$ | 9.75 | 17.72 | 19.85 | 15.77 | 20.95 | 47.93 | 48.49 | 39.12 | 5.26 | 13.46 | 13.84 | 10.85 | 33.27 | 81.29 | 82.59 | 65.72 |
| S$_4$ | 10.01 | 18.10 | 20.26 | 16.12 | 21.26 | 48.45 | 49.03 | 39.58 | 5.48 | 13.77 | 14.17 | 11.14 | 34.31 | 82.86 | 84.40 | 67.19 |
| S$_5$ | 10.22 | 18.40 | 20.54 | 16.39 | 21.59 | 48.95 | 49.19 | 39.91 | 5.59 | 14.06 | 14.45 | 11.37 | 34.91 | 84.81 | 85.25 | 68.32 |
| S$_6$ | 9.48 | 17.34 | 19.58 | 15.47 | 20.79 | 47.85 | 48.38 | 39.01 | 5.21 | 13.47 | 13.78 | 10.82 | 33.52 | 80.74 | 83.32 | 65.86 |
| S$_7$ | 9.73 | 17.64 | 19.68 | 15.68 | 20.80 | 47.96 | 48.21 | 38.99 | 5.27 | 13.45 | 13.63 | 10.78 | 34.10 | 81.36 | 82.58 | 66.01 |
| S$_8$ | 9.80 | 17.73 | 19.80 | 15.78 | 21.06 | 48.44 | 48.62 | 39.37 | 5.44 | 13.67 | 13.93 | 11.01 | 34.46 | 83.14 | 84.44 | 67.35 |
| Mean | 9.66 | 17.58 | 19.76 | 15.67 | 20.85 | 47.82 | 48.31 | 38.99 | 5.25 | 13.41 | 13.76 | 10.81 | 33.55 | 81.39 | 82.79 | 65.91 |
| CD(p=0.05) | | | | | | | | | | | | | | | | |
| M | 0.86 | | | | 0.46 | | | | 0.72 | | | | 1.52 | | | |
| S | 0.66 | | | | 0.68 | | | | 0.38 | | | | 0.98 | | | |
| M at S | 0.75 | | | | 0.70 | | | | 0.74 | | | | 1.60 | | | |
| S at M | 0.78 | | | | 0.78 | | | | 0.38 | | | | 0.90 | | | |

higher K uptake of 17.19 to 20.54 kg ha$^{-1}$ than NPK fertiliser treatments (16.52 to 18.93 kg ha$^{-1}$). In the interaction, $M_3S_5$ recorded 20.54 kg ha$^{-1}$ of K uptake, which was on par with $M_3S_4$ (20.26 kg ha$^{-1}$), $M_3S_3$ (19.85 kg ha$^{-1}$) and $M_3S_8$ (19.80 kg ha$^{-1}$).

At flowering stage, the uptake of K registered in $M_3$ was significantly highest (48.31 kg ha$^{-1}$ ) as against $M_2$ (47.82 kg ha$^{-}$) and $M_1$ (20.85 kg ha$^{-1}$). In the HA treatments, the highest K uptake was recorded in $S_5$ (39.91 kg ha$^{-1}$), which was on par with $S_4$ (39.58 kg ha$^{-1}$) and followed by $S_3$ (39.12 kg ha$^{-1}$). The treatments $S_8$ (39.37 kg ha$^{-}$), $S_7$ (38.99 kg ha$^{-}$) and $S_6$ (39.01 kg ha$^{-}$) were on par with each other. The $S_5$, $S_4$ and $S_8$ were found to be comparable. In the interaction, the $M_3S_5$ recorded 49.19 kg ha$^{-1}$ of K uptake and it was on par with $M_3S_4$ (49.03 kg ha$^{-1}$), $M_3S_3$ (48.49 kg ha$^{-1}$) and $M_3S_8$ (48.62 kg ha$^{-1}$).

In the grain, uptake of K recorded in $M_3$ and $M_2$ were 13.76 and 13.41 kg ha$^{-1}$and they were on par with each other. The $M_1$ recorded only 5.25 kg ha$^{-1}$ of K uptake. In the HA treatments, $S_5$ and $S_4$ recorded 11.37 and 11.14 kg ha$^{-1}$ of K uptake and the $S_4$ was followed by $S_3$ (10.85 kg ha$^{-1}$) and $S_2$ (10.53). The treatments $S_8$ (11.01 kg ha$^{-1}$), $S_7$ (10.78 kg ha$^{-1}$) and $S_6$ (10.82 kg ha$^{-1}$) were on par with each other. The $S_4$, $S_5$ and $S_8$ were comparable. The application of NPK fertiliser combined with HA recorded higher K uptake (13.07 to 14.45 kg ha$^{-1}$) than NPK fertiliser treatments (12.32 to 12.81 kg ha$^{-1}$). Among the treatment combination, $M_3S_5$ (14.45 kg ha$^{-1}$), $M_3S_4$ (14.17 kg ha$^{-1}$) and $M_2S_5$ (14.06 kg ha$^{-1}$) were comparable. The treatments $M_3S_8$ (13.93 kg ha$^{-1}$), $M_3S_3$ (13.84 kg ha$^{-1}$), $M_3S_6$ (13.78 kg ha$^{-1}$) and $M_2S_8$ (13.67 kg ha$^{-1}$) were comparable.

In the straw, the uptake of K recorded in $M_3$ (82.79 kg ha$^{-1}$) and $M_2$ (81.39 kg ha$^{-1}$) were on par with each other. The $M_3$ was followed by $M_1$ (33.55 kg ha$^{-1}$) .The $S_5$ (68.32 kg ha$^{-1}$) recorded the highest K uptake in straw followed by $S_8$ (67.35 kg ha$^{-1}$) and $S_4$ (67.19 kg ha$^{-1}$). The K uptake recorded in $S_8$ was 67.35 kg ha$^{-1}$ and it was on par with

$S_7$ (66.01 kg $ha^{-1}$) and $S_6$ (65.86 kg $ha^{-1}$). The $S_5$ and $S_8$ were found to be comparable .The NPK fertiliser combined with HA registered higher K uptake of 79.91 to 85.25 kg $ha^{-1}$ than NPK fertiliser (77.02 to 78.41 kg $ha^{-1}$). Among the interaction treatments $M_3S_5$ (85.25 kg $ha^{-1}$), $M_2S_5$ (84.81 kg $ha^{-1}$), $M_3S_8$ (84.44 kg $ha^{-1}$), $M_3S_4$ (84.40 kg $ha^{-1}$) were comparable.

### 4.7.2.4. Uptake of secondary nutrients

The calcium and magnesium uptake by rice grain and straw samples were calculated and presented in the Table 43

#### 4.7.2.4.1.Calcium uptake

Among the fertiliser treatments, $M_3$ and $M_2$ recorded 26.13 and 25.90 kg $ha^{-1}$ of Ca uptake in grain and followed by $M_1$ (11.12 kg $ha^{-1}$) . In the HA treatments, $S_5$ recorded the highest Ca uptake of 21.79 kg $ha^{-1}$, which was on par with $S_4$ (21.48 kg $ha^{-1}$) and the $S_4$ was followed by $S_3$ (21.06 kg $ha^{-1}$) and $S_2$ (20.57 kg $ha^{-1}$). The treatment $S_8$ recorded 21.52 kg $ha^{-1}$ of Ca uptake and it was on par with $S_7$ (21.11 kg $ha^{-1}$) and $S_6$ (21.13 kg $ha^{-1}$). The treatments $S_4$, $S_5$ and $S_8$ were found to be comparable. The application of NPK fertiliser with HA recorded higher Ca uptake of 25.31 to 26.90 kg $ha^{-1}$ than NPK fertiliser treatments (24.16 to 24.77 kg $ha^{-1}$). In the interaction treatments, $M_3S_5$ (26.90 kg $ha^{-1}$), $M_2S_5$ (26.90 kg $ha^{-1}$) $M_3S_4$ (26.61 kg $ha^{-1}$), $M_3S_8$ (26.55 kg $ha^{-1}$), $M_2S_4$ (26.48 kg $ha^{-1}$) and $M_2S_8$ (26.42 kg $ha^{-1}$) recorded comparable Ca uptake.

In the straw, the maximum Ca uptake of 32.63 kg $ha^{-1}$ was recorded in $M_3$, which was statistically on par with $M_2$ (32.07 kg $ha^{-1}$). The treatment $M_1$ recorded only 13.94 kg $ha^{-1}$. Among the HA treatments, $S_5$ recorded the highest Ca uptake of 27.65 kg $ha^{-1}$ and it was followed by $S_4$ (26.92 kg $ha^{-1}$), $S_8$ (26.92 kg $ha^{-1}$) and $S_7$ (26.23 kg $ha^{-1}$) and the $S_7$ was followed by $S_3$ (26.11 kg $ha^{-1}$) . In treatment combination, $M_3S_5$ (34.20 kg $ha^{-1}$) and $M_3S_4$

**Table 43. Effect of humic acid and fertilisers on Ca and Mg uptake (kg ha$^{-1}$) by rice in Inceptisol**

| Treatments | Ca (Grain) | | | | Ca (Straw) | | | | Mg (Grain) | | | | Mg (Straw) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 10.31 | 24.16 | 24.77 | 19.75 | 12.85 | 29.68 | 30.35 | 24.29 | 3.62 | 9.77 | 10.19 | 7.86 | 5.94 | 15.46 | 15.95 | 12.45 |
| $S_2$ | 10.73 | 25.31 | 25.68 | 20.57 | 13.32 | 31.17 | 31.80 | 25.43 | 3.88 | 10.45 | 10.56 | 8.30 | 6.30 | 16.41 | 16.84 | 13.18 |
| $S_3$ | 11.02 | 25.98 | 26.17 | 21.06 | 13.81 | 31.97 | 32.56 | 26.11 | 4.12 | 10.83 | 11.00 | 8.65 | 6.60 | 17.01 | 17.36 | 13.66 |
| $S_4$ | 11.36 | 26.48 | 26.61 | 21.48 | 14.40 | 32.86 | 33.50 | 26.92 | 4.31 | 11.07 | 11.27 | 8.88 | 6.90 | 17.72 | 17.99 | 14.20 |
| $S_5$ | 11.56 | 26.90 | 26.90 | 21.79 | 14.70 | 34.03 | 34.20 | 27.65 | 4.40 | 11.28 | 11.48 | 9.05 | 7.16 | 18.31 | 18.06 | 14.51 |
| $S_6$ | 11.07 | 26.04 | 26.27 | 21.13 | 13.92 | 31.86 | 32.70 | 26.16 | 4.11 | 10.74 | 10.81 | 8.55 | 6.72 | 16.75 | 17.64 | 13.71 |
| $S_7$ | 11.30 | 25.93 | 26.10 | 21.11 | 14.19 | 31.97 | 32.51 | 26.23 | 4.12 | 10.64 | 10.80 | 8.52 | 6.81 | 16.82 | 17.28 | 13.64 |
| $S_8$ | 11.60 | 26.42 | 26.55 | 21.52 | 14.34 | 33.01 | 33.41 | 26.92 | 4.33 | 10.98 | 11.02 | 8.78 | 6.93 | 17.49 | 17.77 | 14.06 |
| Mean | 11.12 | 25.90 | 26.13 | 21.05 | 13.94 | 32.07 | 32.63 | 26.21 | 4.11 | 10.72 | 10.89 | 8.57 | 6.67 | 17.00 | 17.36 | 13.68 |
| CD(p=0.05) | | | | | | | | | | | | | | | | |
| M | 1.27 | | | | 1.23 | | | | 0.68 | | | | 0.63 | | | |
| S | 0.32 | | | | 0.24 | | | | 0.27 | | | | 0.38 | | | |
| M at S | 1.28 | | | | NS | | | | 0.70 | | | | NS | | | |
| S at M | 0.40 | | | | | | | | 0.28 | | | | | | | |

(33.50 kg ha$^{-1}$) recorded highest Ca uptake. However the interaction did not attain the level of significance.

#### 4.7.2.4.2. Magnesium

The Mg uptake recorded in the NPK fertiliser treatments $M_3$ and $M_2$ were 10.89 and 10.72 kg ha$^{-1}$ and they were on par with each other. The $M_1$ recorded 4.11 kg ha$^{-1}$. The HA treatments $S_5$ (9.05 kg ha$^{-1}$) and $S_4$ (8.88) were on par with each other and the $S_4$ was followed by $S_3$ (8.65 kg ha$^{-1}$). The treatments $S_8$ (8.78 kg ha$^{-1}$), $S_6$ (8.55 kg ha$^{-1}$) and $S_7$ (8.52 kg ha$^{-1}$) were comparable. The $S_5$, $S_4$ and $S_8$ were found to be comparable.

The NPK fertiliser integrated with HA recorded higher Mg uptake of 10.45 to 11.48 kg ha$^{-1}$ than NPK fertiliser (9.77 to 10.19 kg ha$^{-1}$). In the interaction, the treatments $M_3S_5$ (11.48 kg ha$^{-1}$) $M_2S_5$ (11.28 kg ha$^{-1}$) and $M_3S_4$ (11.27 kg ha$^{-1}$) were on par with each other. The $M_2S_4$ (11.07 kg ha$^{-1}$), $M_3S_8$ (11.02 kg ha$^{-1}$) $M_3S_3$ (11.00 kg ha$^{-1}$), $M_2S_8$ (10.98 kg ha$^{-1}$), $M_2S_3$ (10.83 kg ha$^{-1}$), $M_3S_6$ (10.81 kg ha$^{-1}$) and $M_3S_7$ (10.80 kg ha$^{-1}$) were statistically on par with each other.

The fertiliser treatment $M_3$ recorded significantly the highest Mg uptake of 17.36 kg ha$^{-1}$, which was on par with $M_2$ (17.00 kg ha$^{-1}$). The $M_1$ registered only 6.67 kg ha$^{-1}$. In the HA treatments, $S_5$ (14.51 kg ha$^{-1}$) and $S_4$ (14.20 kg ha$^{-1}$) recorded comparable Mg uptake. The treatments $S_8$ (14.06 kg ha$^{-1}$) and $S_6$ (13.71 kg ha$^{-1}$) were on par with each other and followed by $S_3$ (13.66 kg ha$^{-1}$) and $S_7$ (13.64 kg ha$^{-1}$). The $M_3S_5$ and $M_2S_5$ recorded the highest Mg uptake of 18.31 and 18.06 kg ha$^{-1}$. However the interaction did not attain the level of significance.

### 4.7.2.5. Micronutrients uptake

The uptake of micronutrients (Fe, Mn, Zn and Cu) in grain and straw samples were estimated at harvest.

#### 4.7.2.5.1. Uptake of micronutrients in grain (Table 44)

**Uptake of iron**

Among the fertiliser treatments, $M_3$ recorded significantly higher Fe uptake of 1034 g ha$^{-1}$ than $M_2$ (997 g ha$^{-1}$) and $M_1$ (417 g ha$^{-1}$). In HA treatments, $S_5$ recorded the highest Fe uptake of 869 g ha$^{-1}$, which was on par with $S_4$ (852 g ha$^{-1}$) and the $S_5$ followed by $S_3$ (825 g ha$^{-1}$). The treatments $S_8$ (834 g ha$^{-1}$), $S_6$ (816 g ha$^{-1}$) and $S_7$ (814 g ha$^{-1}$) were on par with each other. The NPK fertiliser combined with HA recorded higher Fe uptake of 986 to 1112 g ha$^{-1}$ than NPK fertiliser treatments (886 to 917 g ha$^{-1}$). In the interaction, the treatment $M_3S_5$ (1112 g ha$^{-1}$) recorded higher Fe uptake and it was on par with $M_3S_4$ (1088 g ha$^{-1}$). The $M_2S_5$ (1052 g ha$^{-1}$), $M_3S_3$ (1050 g ha$^{-1}$), $M_3S_8$ (1043 g ha$^{-1}$), $M_2$ $S_4$ (1036 g ha$^{-1}$), $M_3S_6$ (1031 g ha$^{-1}$), $M_3S_7$ (1028 g ha$^{-1}$) and $M_2S_8$ (1019 g ha$^{-1}$) were on par with each other.

**Uptake of zinc**

The zinc uptake in grain for different treatments is furnished in Table 44. The data indicated that, the treatment $M_3$ recorded 334 g ha$^{-1}$ of zinc uptake and it was on par with $M_2$ (308 g ha$^{-1}$). The $M_1$ recorded only 118 g ha$^{-1}$ of Zinc uptake. The zinc uptake increased with increasing levels of HA applied to soil. The HA treatments $S_2$, $S_3$, $S_4$ and $S_5$ recorded 221, 255, 283 and 295 g ha$^{-1}$ respectively. The treatments $S_5$, $S_4$ and $S_8$ were on par. The $S_8$ recorded 292 g ha$^{-1}$ of zinc uptake and it was followed by $S_7$ (258 g ha$^{-1}$) and $S_3$ (255 g ha$^{-1}$). The application of NPK fertiliser combined with HA recorded higher Zn

Table 44. Effect of humic acid and fertilisers on micro nutrients uptake ( g ha$^{-1}$) by rice grain in Inceptisol

| Treatments | Iron | | | | Zinc | | | | Manganese | | | | Copper | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 369 | 886 | 917 | 724 | 81 | 217 | 252 | 183 | 54 | 145 | 158 | 119 | 27 | 72 | 74 | 58 |
| $S_2$ | 398 | 986 | 1003 | 795 | 106 | 266 | 290 | 221 | 69 | 192 | 204 | 155 | 32 | 96 | 97 | 75 |
| $S_3$ | 418 | 1008 | 1050 | 825 | 127 | 312 | 325 | 255 | 80 | 205 | 227 | 171 | 38 | 118 | 130 | 95 |
| $S_4$ | 432 | 1036 | 1088 | 852 | 143 | 347 | 359 | 283 | 90 | 228 | 239 | 186 | 43 | 130 | 131 | 101 |
| $S_5$ | 444 | 1052 | 1112 | 869 | 153 | 360 | 371 | 295 | 96 | 240 | 240 | 192 | 43 | 142 | 142 | 109 |
| $S_6$ | 418 | 998 | 1031 | 816 | 57 | 312 | 357 | 242 | 85 | 226 | 238 | 183 | 31 | 118 | 130 | 93 |
| $S_7$ | 420 | 995 | 1028 | 814 | 135 | 303 | 336 | 258 | 84 | 217 | 228 | 176 | 38 | 108 | 119 | 89 |
| $S_8$ | 440 | 1019 | 1043 | 834 | 147 | 348 | 382 | 292 | 73 | 261 | 262 | 198 | 44 | 119 | 131 | 98 |
| Mean | 417 | 997 | 1034 | 816 | 118 | 308 | 334 | 253 | 79 | 214 | 224 | 172 | 37 | 113 | 119 | 90 |
| CD(p=0.05) | | | | | | | | | | | | | | | | |
| M | 75 | | | | 27 | | | | 18.9 | | | | 10.5 | | | |
| S | 32 | | | | 13 | | | | 12.1 | | | | 10.8 | | | |
| M at S | 75 | | | | 28 | | | | 19.1 | | | | 10.8 | | | |
| S at M | 37 | | | | 14 | | | | 14.8 | | | | 13.0 | | | |

uptake of 266 to 382 g ha$^{-1}$ than NPK fertiliser treatments (217 to 252 g ha$^{-1}$). The interaction treatment showed that, the $M_3S_8$ (382 g ha$^{-1}$) and $M_3S_5$ (371 g ha$^{-1}$) were comparable. The treatments $M_2S_5$ (360 g ha$^{-1}$), $M_3S_6$ (357 g ha$^{-1}$), $M_3S_4$ (359 g ha$^{-1}$), $M_2S_4$ (347 g ha$^{-1}$) and $M_2S_8$ (348 g ha$^{-1}$) were on par with each other.

**Uptake of manganese**

The Mn uptake recorded in $M_3$ (224 g ha$^{-1}$) and $M_2$ (214 g ha$^{-1}$) were statistically comparable and followed by $M_1$ (79 g ha$^{-1}$). Among the HA treatments, the $S_5$ and $S_4$ recorded 192 and 186 g ha$^{-1}$ of Mn uptake and the $S_4$ was followed by $S_3$ (171 g ha$^{-1}$) and $S_2$ (155 g ha$^{-1}$). Among $S_6$, $S_7$ and $S_8$, the $S_8$ recorded the highest Mn uptake of 198 g ha$^{-1}$ and it was followed by $S_6$ (183 g ha$^{-1}$) and $S_7$ (176 g ha$^{-1}$) .The treatments $S_8$, $S_4$ and $S_5$ were found to be comparable.

The application of NPK fertiliser combined with HA recorded 192 to 262 g ha$^{-1}$ than NPK fertiliser (145 to 158 g ha$^{-1}$). Among the treatment combination, the $M_3S_8$ (262 g ha$^{-1}$) and $M_2S_8$ (261 g ha$^{-1}$) were on par. The treatments $M_3S_5$ (240 g ha$^{-1}$), $M_2S_5$ (240 g ha$^{-1}$), $M_3S_6$ (238 g ha$^{-1}$), $M_3S_4$ (239 g ha$^{-1}$), $M_3S_7$, $M_2S_4$ (228 g ha$^{-1}$) and $M_3S_3$ (227 g ha$^{-1}$) were on par with each other.

**Uptake of copper**

Among the fertiliser treatments, $M_3$ and $M_2$ recorded 119 and 113 g ha$^{-1}$ of Cu uptake and they were on par with each other and followed by $M_1$ (37 g ha$^{-1}$). In the HA treatments, $S_5$ recorded highest Cu uptake of 109 g ha$^{-1}$. This was on par with $S_4$ (101 g ha$^{-1}$) and $S_8$ (98 g ha$^{-1}$). The Cu uptake of rice grain recorded in NPK fertiliser integrated with HA was higher (96 to 142 g ha$^{-1}$) than NPK fertiliser (72 to 74 g ha$^{-1}$). Among the treatment combination, $M_3S_5$ (142 g ha$^{-1}$), $M_2S_5$ (142 g ha$^{-1}$) were on par. The

$M_3S_8$ (131 g ha$^{-1}$), $M_3S_3$ (130 g ha$^{-1}$), $M_3S_4$ (130 g ha$^{-1}$) and $M_3S_6$ (130 g ha$^{-1}$) were on par with each other.

### 4.7.2.5.2. Uptake of micronutrients by straw (Table 45)

**Iron**

The NPK fertiliser treatment $M_3$ registered highest Fe uptake of 3693 g ha$^{-1}$, which was on par with $M_2$ (3610 g ha$^{-1}$). The $M_1$ recorded significantly lower Fe uptake of 1545 g ha$^{-1}$ than $M_2$ and $M_3$. In the HA treatment, $S_5$ recorded the highest Fe uptake 3107 g ha$^{-1}$and it was followed by $S_4$ (3051 g ha$^{-1}$) and $S_3$ (2943 g ha$^{-1}$). The treatments $S_8$ recorded 3030 g ha$^{-1}$ of Fe uptake and it was followed by $S_6$ (2952 g ha$^{-1}$) and $S_7$ (2946 g ha$^{-1}$). The NPK fertiliser combined with HA recorded higher Fe uptake of 3512 to 3871 g ha$^{-1}$ than NPK fertiliser (3288 to 3375 g ha$^{-1}$). The treatment combination $M_2S_5$ recorded the highest Fe uptake of 3871 g ha$^{-1}$ and it was on par with $M_3S_5$ (3829 g ha$^{-1}$). The treatments $M_3S_8$ (3827 g ha$^{-1}$) and $M_3S_4$ (3808 g ha$^{-1}$) were comparable. The $M_2S_4$ (3752 g ha$^{-1}$), $M_3$ $S_6$ (3746 g ha$^{-1}$), $M_3S_7$ (3699 g ha$^{-1}$) and $M_2S_8$ (3678 g ha$^{-1}$) were comparable.

**Zinc**

The treatment $M_3$ recorded significantly higher Zn uptake of 296 g ha$^{-1}$ than $M_2$ (263 g ha$^{-1}$) and $M_1$ (86 g ha$^{-1}$). The treatment $S_8$ registered the maximum Zn uptake of 245 kg ha$^{-1}$ and it was on par with $S_5$ (240 g ha$^{-1}$) and followed by $S_4$ (225 g ha$^{-1}$). The treatment $S_8$ recorded the highest Zn uptake of 245 g ha$^{-1}$ and it was on par with $S_6$ (229 g ha$^{-1}$) and $S_7$ (222 g ha$^{-1}$) . The application of NPK fertiliser with HA recorded higher Zn uptake of 232 to 327 g ha$^{-1}$ than NPK fertiliser treatments (193 to 228 g ha$^{-1}$). In the interaction, the treatments $M_3S_5$ (327 g ha$^{-1}$), $M_3S_8$ (327 g ha$^{-1}$) and $M_3S_6$ (324 g ha$^{-1}$) were

**Table 45. Effect of humic acid and fertilisers on plant micro nutrients uptake (g ha$^{-1}$) by rice straw in Inceptisol**

| Treatments | Iron | | | | Zinc | | | | Manganese | | | | Copper | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 1422 | 3288 | 3375 | 2695 | 64 | 193 | 228 | 161 | 537 | 1333 | 1381 | 1084 | 64 | 161 | 163 | 129 |
| $S_2$ | 1486 | 3512 | 3615 | 2871 | 72 | 232 | 267 | 190 | 583 | 1425 | 1471 | 1160 | 79 | 232 | 251 | 187 |
| $S_3$ | 1540 | 3645 | 3643 | 2943 | 85 | 251 | 286 | 207 | 625 | 1508 | 1516 | 1216 | 88 | 251 | 270 | 203 |
| $S_4$ | 1594 | 3752 | 3808 | 3051 | 94 | 271 | 308 | 225 | 655 | 1578 | 1609 | 1281 | 105 | 288 | 291 | 228 |
| $S_5$ | 1620 | 3871 | 3829 | 3107 | 99 | 294 | 327 | 240 | 670 | 1628 | 1635 | 1311 | 107 | 312 | 310 | 243 |
| $S_6$ | 1546 | 3563 | 3746 | 2952 | 82 | 283 | 324 | 229 | 630 | 1512 | 1567 | 1236 | 89 | 266 | 289 | 215 |
| $S_7$ | 1568 | 3572 | 3699 | 2946 | 91 | 269 | 305 | 222 | 645 | 1512 | 1524 | 1227 | 99 | 252 | 271 | 207 |
| $S_8$ | 1586 | 3678 | 3827 | 3030 | 99 | 309 | 327 | 245 | 669 | 1594 | 1600 | 1288 | 106 | 291 | 292 | 230 |
| Mean | 1545 | 3610 | 3693 | 2949 | 86 | 263 | 296 | 215 | 627 | 1511 | 1538 | 1225 | 92 | 257 | 267 | 205 |
| CD ($p=0.05$) | | | | | | | | | | | | | | | | |
| M | 102 | | | | 19.5 | | | | 89 | | | | 27 | | | |
| S | 87 | | | | 12.0 | | | | 57 | | | | 28 | | | |
| M at S | 103 | | | | 19.8 | | | | 80 | | | | 27 | | | |
| S at M | 96 | | | | 13.0 | | | | 68 | | | | 30 | | | |

on par with each other. The $M_3S_4$ (308 g ha$^{-1}$), $M_2S_8$ (309 g ha$^{-1}$) and $M_3S_7$ (305 g ha$^{-1}$) were comparable.

**Manganese**

Among the fertiliser treatments, $M_3$ recorded the highest Mn uptake of 1538 g ha$^{-1}$, which was on par with $M_2$ (1511 g ha$^{-1}$) while the $M_1$ recorded only 627 g ha$^{-1}$. In the HA treatments, the $S_5$ (1311 g ha$^{-1}$), and $S_4$ (1281 g ha$^{-1}$) were on par and the $S_4$ was followed by $S_3$ (1216 g ha$^{-1}$) and $S_2$ (1160 g ha$^{-1}$). The $S_8$ (1288 g ha$^{-1}$), $S_6$ (1236 g ha$^{-1}$) and $S_7$ (1227 g ha$^{-1}$) were comparable.

The NPK fertiliser combined with HA recorded higher Mn uptake of 1425 to 1635 g ha$^{-1}$ than NPK fertiliser (1333 to 1381 g ha$^{-1}$). In the interaction, the Mn uptake recorded in the $M_3S_5$ was 1635 g ha$^{-1}$. This was on par with $M_2S_5$ (1628 g ha$^{-1}$), $M_3S_4$ (1609 g ha$^{-1}$), $M_3S_8$ (1600 g ha$^{-1}$), $M_2S_8$ (1594 g ha$^{-1}$), $M_2S_4$ (1578 g ha$^{-1}$) and $M_3S_6$ (1567 g ha$^{-1}$).

**Copper**

In the fertiliser treatment $M_3$ (267 g ha$^{-1}$) and $M_2$ (257 g ha$^{-1}$) recorded higher Cu uptake than $M_1$ (92 g ha$^{-1}$). Among the HA treatments, $S_5$ recorded 243 g ha$^{-1}$ of Cu uptake, which was on par with $S_8$ (230 g ha$^{-1}$), $S_4$ (228 g ha$^{-1}$) and $S_6$ (215 g ha$^{-1}$). The application of NPK fertiliser with HA recorded higher Cu uptake (232 to 312 g ha$^{-1}$) than NPK fertiliser treatments (161 to 163 g ha$^{-1}$). In the interaction treatments, $M_2S_5$ recorded 312 g ha$^{-1}$ of Cu uptake. This was on par with $M_3S_5$ (310 g ha$^{-1}$), $M_3S_8$ (292 g ha$^{-1}$), $M_3S_4$, $M_2S_8$ (291 g ha$^{-1}$) $M_3S_6$ (289 g ha$^{-1}$) and $M_2S_4$ (288 g ha$^{-1}$).

### 4.7.3. Yield and yield attributes of rice

#### 4.7.3.1. Number of productive tillers per hill

The effect of treatments on the number of productive tillers per hill is presented in Table 46. The treatments $M_3$ and $M_2$ recorded 8.55 and 8.35 tillers per hill and they were statistically on par with each other. The per cent increase recorded by $M_3$ and $M_2$ over $M_1$ were 22.5 and 20.6. Among the HA treatments, the $S_5$ recorded 8.14 tillers per hill and it was followed by the treatments $S_4$ , $S_3$ and $S_2$ ,which recorded 8.03, 7.78 and 7.53 tillers per hill respectively. The $S_8$ recorded 8.21 tillers per hill and it was on par with $S_7$ (8.10 tillers per hill) and the $S_8$ was followed by $S_6$ (7.74 tillers per hill). Again the $S_5$, $S_4$, $S_7$ and $S_8$ were comparable. The per cent increase recorded by $S_8$ over $S_4$, $S_5$, $S_6$ and $S_7$ were 2.2, 0.9, 5.7 and 1.3.

The application of NPK fertiliser recorded less number of productive tillers per hill (7.56 to 7.78 tillers per hill) than NPK fertilisers with HA (7.89 to 8.97 tillers per hill). In interaction, the treatment receiving $M_3S_8$ registered 8.97 tillers per hill, which was on par with $M_3S_7$ (8.86 tillers per hill), $M_3S_5$ (8.75 tillers per hill), $M_3S_4$ (8.75 tillers per hill), $M_2S_7$, $M_2S_5$ (8.75 tillers per hill) and $M_3S_3$, $M_2S_4$ (8.53 tillers per hill) and $M_2S_8$ (8.86 tillers per hill).

#### 4.7.3.2. Panicle length (Table46)

From the data it could be seen that the panicle length recorded by $M_3$ (22.1 cm) and $M_2$ (21.7 cm) were statistically on par with each other. The $M_1$ recorded only 18.9 cm. Among the HA treatments, $S_4$ recorded long panicle length of 21.6 cm, which was on par with $S_5$ (21.5 cm). Among $S_6$, $S_7$ and $S_8$, the $S_7$ and $S_8$ recorded 21.4 and 21.5 cm long panicles and they were on par with each other and while the $S_6$ recorded only of 21.3 cm

**Table 46. Effect of humic acid and fertilisers on yield attributes of rice in Inceptisol**

| Treatments | No. of productive tillers hill$^{-1}$ | | | | Panicle length(cm) | | | | No. of filled grains per panicle | | | | No. illfilled grains per panicle | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 6.27 | 7.56 | 7.78 | 7.20 | 18.3 | 21.1 | 21.5 | 20.7 | 63.00 | 90.30 | 93.45 | 82.25 | 21.0 | 17.4 | 12.9 | 17.1 |
| $S_2$ | 6.37 | 7.89 | 8.32 | 7.53 | 18.5 | 21.5 | 21.9 | 21.0 | 66.15 | 95.55 | 97.65 | 86.45 | 18.0 | 14.1 | 11.4 | 14.5 |
| $S_3$ | 6.59 | 8.21 | 8.53 | 7.78 | 18.7 | 21.8 | 22.2 | 21.3 | 68.25 | 97.65 | 99.75 | 88.55 | 16.8 | 11.9 | 9.9 | 12.9 |
| $S_4$ | 6.81 | 8.53 | 8.75 | 8.03 | 19.2 | 22.1 | 22.4 | 21.6 | 70.35 | 99.75 | 100.8 | 90.30 | 14.7 | 11.8 | 9.9 | 12.1 |
| $S_5$ | 6.91 | 8.75 | 8.75 | 8.14 | 19.0 | 22.1 | 22.3 | 21.5 | 71.40 | 100.8 | 102.9 | 91.70 | 14.2 | 13.8 | 14.7 | 12.0 |
| $S_6$ | 6.59 | 8.21 | 8.43 | 7.74 | 19.0 | 21.6 | 22.0 | 21.3 | 67.20 | 97.65 | 97.65 | 87.50 | 15.0 | 10.2 | 8.7 | 11.3 |
| $S_7$ | 6.70 | 8.75 | 8.86 | 8.10 | 19.2 | 21.8 | 22.1 | 21.4 | 68.25 | 99.75 | 99.75 | 89.25 | 19.2 | 11.1 | 6.3 | 12.2 |
| $S_8$ | 6.81 | 8.86 | 8.97 | 8.21 | 19.3 | 21.8 | 22.3 | 21.5 | 72.45 | 100.8 | 103.9 | 92.40 | 14.7 | 10.2 | 5.1 | 10.0 |
| Mean | 6.63 | 8.35 | 8.55 | 7.84 | 18.9 | 21.7 | 22.1 | 21.3 | 68.38 | 97.78 | 99.49 | 88.55 | 16.7 | 12.5 | 9.9 | 13.2 |
| CD (p=0.05) | | | | | | | | | | | | | | | | |
| M | 0.65 | | | | 0.81 | | | | 3.80 | | | | 3.4 | | | |
| S | 0.30 | | | | 0.20 | | | | 2.88 | | | | 2.5 | | | |
| M at S | 0.55 | | | | NS | | | | 4.30 | | | | 3.8 | | | |
| S at M | 0.48 | | | | | | | | 3.38 | | | | 2.9 | | | |

long panicle length. The $S_5$, $S_4$, $S_7$ and $S_8$ were comparable. The combined application of NPK fertiliser and HA recorded longer panicle length of 21.5 to 22.4 cm than NPK fertiliser (21.1 to 21.5 cm). In the treatment combination, the longest panicle length was recorded in $M_3S_5$ and $M_3S_8$ (22.3 cm). However, the interactions of treatment did not attain the level of significance.

### 4.7.3.3. Number of filled grains per panicle (Table 46)

The NPK fertiliser treatments, $M_3$ (99.49) and $M_2$ (97.78) recorded significantly higher number of filled grains per panicle than $M_1$ (68.38). With regard to HA treatments, the $S_5$ and $S_4$ recorded 91.7 and 90.3 grains per panicle and they were comparable. The $S_4$ followed by $S_3$ (88.55) and $S_2$ (86.45). The $S_8$ recorded maximum number of grains of 92.4 per panicle and $S_7$ (89.25) and $S_6$ (87.5) followed it. The treatments $S_5$, $S_4$ and $S_8$ recorded comparable number of grains per panicle. The per cent increase recorded by $S_8$ over $S_5$ and $S_4$ were 0.8 and 2.6.

The application of NPK fertiliser combined with HA recorded more number of filled grains per panicle (95.55 to 103.9) than NPK fertiliser (90.3 to 93.45). In the interaction, $M_3S_8$ (103.9 grains) treatment registered 103.9 number of grains per panicle and it was comparable with $M_3S_5$ (102.9) and $M_3S_4$, $M_2S_5$, $M_2S_8$ (100.8). The $M_2S_8$ treatment combination followed by $M_3S_3$ (99.75), $M_3S_7$ (99.75), $M_2S_4$ (99.75) and $M_3S_2$ (97.65), $M_2S_3$ (97.65), $M_2S_6$ (97.65) and $M_3S_6$ (97.65).

### 4.7.3.4. Number of chaffy grains per panicle

The treatments $M_3$ and $M_2$ recorded less number of chaffy grains of 9.9 and 12.5 than $M_1$, which had 16.7. The $M_2$ and $M_3$ were on par with each other. Among the HA treatments, the $S_4$ (12.1) recorded less number of chaffy grains than $S_3$ (12.9) and $S_2$ (14.5).

The $S_8$ recorded 10.0 chaffy grains per panicle and it was on par with $S_6$ (11.3) and $S_7$ (12.2). The treatments $S_8$, $S_6$, $S_7$, $S_5$ and $S_4$ were comparable. The application of NPK fertiliser combined with HA recorded less number of chaffy grains (14.1 to 5.1) than NPK fertiliser (17.4 to 12.9). In the interaction, the treatment $M_3S_8$ (5.1) and $M_3S_7$ (6.3) were on par with each other and the $M_3S_8$ followed by the $M_3S_6$ (8.7), $M_3S_3$ (9.9), $M_3S_4$ (9.9), $M_2S_6$ (9.9), $M_2S_8$ (10.2) and $M_2S_7$ (11.1).

### 4.7.3.5. Thousand grain weight (Table 47)

The thousand grain weight recorded by fertiliser treatments $M_3$ and $M_2$ were 21.28 and 20.99 g and they were statistically on par with each other. The $M_1$ treatment recorded only 20.17 g. Among the HA treatments, $S_5$ recorded 21.23 g of thousand grain weight and it was on par with $S_4$ (21.05 g) and the $S_5$ was followed by $S_3$ (20.8 g). Among $S_6$, $S_7$ and $S_8$, the $S_8$ recorded the highest grain weight of 21.03 g, which was followed by the treatment $S_7$ (20.88 g) and $S_6$ (20.73 g). The NPK fertiliser combined with HA registered 20.71 to 21.61 g of thousand grain weight, whereas the NPK fertiliser recorded only 20.48 to 20.79 g. In the interaction, the $M_3S_5$ recorded the highest grain weight of 21.61 g. The other combinations *viz.*, $M_3S_8$ (21.53 g) $M_3S_4$ (21.5 g) and $M_2S_5$ (21.37g) recorded higher grain weight than $M_3S_1$ (20.48 g). However the interaction of treatments did not attain the level of significance.

### 4.7.3.6. Grain yield (Table 47)

The grain yield recorded by $M_2$ and $M_3$ were 5739 and 5773 kg $ha^{-1}$ respectively. The $M_2$ and $M_3$ recorded significantly higher grain yield than $M_1$, which recorded only 2521 kg $ha^{-1}$. Among the HA treatments, $S_5$ recorded 4738 kg $ha^{-1}$ of grain yield which was on par with $S_4$ (4716 kgha$^{-1}$), $S_3$ (4682 kg $ha^{-1}$) and $S_2$ (4631 kg $ha^{-1}$). The $S_8$ recorded higher grain yield of 4746 kg $ha^{-1}$, which was statistically on par with $S_7$ (4716 kg $ha^{-1}$) and

**Table 47. Effect of humic acid and fertilisers on yield of rice in Inceptisol**

| Treatments | Grain yield(kg ha$^{-1}$) | | | | Straw yield(kg ha$^{-1}$) | | | | 1000 grain weight(g) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean | $M_1$ | $M_2$ | $M_3$ | Mean |
| $S_1$ | 2397 | 5518 | 5620 | 4512 | 3520 | 8000 | 8093 | 6538 | 19.43 | 20.48 | 20.79 | 20.23 |
| $S_2$ | 2458 | 5692 | 5743 | 4631 | 3586 | 8250 | 8324 | 6720 | 19.87 | 20.71 | 21.08 | 20.55 |
| $S_3$ | 2509 | 5753 | 5783 | 4682 | 3660 | 8341 | 8390 | 6797 | 20.16 | 20.98 | 21.26 | 20.80 |
| $S_4$ | 2540 | 5794 | 5814 | 4716 | 3750 | 8449 | 8522 | 6907 | 20.51 | 21.13 | 21.50 | 21.05 |
| $S_5$ | 2560 | 5824 | 5829 | 4738 | 3790 | 8622 | 8571 | 6994 | 20.73 | 21.37 | 21.61 | 21.23 |
| $S_6$ | 2519 | 5743 | 5773 | 4678 | 3693 | 8275 | 8479 | 6816 | 20.06 | 20.95 | 21.19 | 20.73 |
| $S_7$ | 2570 | 5783 | 5794 | 4716 | 3777 | 8368 | 8430 | 6858 | 20.29 | 21.11 | 21.26 | 20.88 |
| $S_8$ | 2611 | 5804 | 5824 | 4746 | 3786 | 8536 | 8566 | 6963 | 20.37 | 21.19 | 21.53 | 21.03 |
| Mean | 2521 | 5739 | 5773 | 4677 | 3695 | 8355 | 8422 | 6824 | 20.17 | 20.99 | 21.28 | 20.81 |
| CD(p=0.05) | | | | | | | | | | | | |
| M | 105 | | | | 130 | | | | 0.44 | | | |
| S | 47 | | | | 87 | | | | 0.32 | | | |
| M at S | 90 | | | | 132 | | | | NS | | | |
| S at M | 65 | | | | 95 | | | | | | | |

the $S_8$ was followed by $S_6$ (4678 kg $ha^{-1}$). The treatments $S_4$, $S_5$, $S_7$ and $S_8$ were comparable. The per cent increase recorded by $S_5$ over $S_4$, $S_3$, $S_2$, $S_6$ and $S_7$ were 0.5, 1.2, 2.3, 1.3 and 0.5.

The application of NPK fertiliser with HA recorded 5692 to 5829 kg $ha^{-1}$ of grain yield than NPK fertiliser (5518 to 5620 kg $ha^{-1}$). In the interaction, $M_3S_5$ (5829 kg $ha^{-1}$), $M_3S_8$ (5824 kg $ha^{-1}$), $M_3S_4$ (5814 kg $ha^{-1}$), $M_3S_7$ (5794 kg $ha^{-1}$) and $M_3S_3$ (5783 kg $ha^{-1}$) were comparable. The $M_2S_5$ (5824 kg $ha^{-1}$), $M_2S_8$ (5804 kg $ha^{-1}$), $M_2S_4$ (5794 kg $ha^{-1}$), $M_2S_7$ (5783 kg $ha^{-1}$) and $M_2S_6$ (5743 kg $ha^{-1}$) were on par with each other.

### 4.7.3.7. Straw yield (Table 47)

The straw yield recorded in $M_3$ was 8422 kg $ha^{-1}$, which was on par with $M_2$ (8355 kg $ha^{-1}$). The straw yield recorded by $M_1$ was only 3695 kg $ha^{-1}$. The per cent increase recorded by $M_3$ and $M_2$ over $M_1$ were 56.1 and 55.8. With regard to HA application, $S_5$ recorded the higher straw yield of 6994 kg $ha^{-1}$ and it was on par with $S_4$ (6907 kg $ha^{-1}$) .The $S_4$ was followed by $S_3$ (6797 kg $ha^{-1}$). The treatments $S_8$ recorded higher straw yield of 6963 kg $ha^{-1}$, which was followed by $S_7$ (6858 kg $ha^{-1}$) and $S_6$ (6816 kg $ha^{-1}$). The treatments $S_5$, $S_4$ and $S_8$ were comparable. The per cent increase recorded by $S_5$ over $S_4$ and $S_8$ were 1.2 and 0.5.

The application of NPK fertiliser combined with HA registered higher straw yield (8250 to 8622 kg $ha^{-1}$) than NPK fertiliser treatments (8000 to 8093 kg $ha^{-1}$). The highest straw yield was recorded in $M_2S_5$ (8622 kg $ha^{-1}$), which was on par with $M_3S_5$ (8571 kg $ha^{-1}$) $M_2S_8$ (8536 kg $ha^{-1}$), and $M_3S_8$ (8566 kg $ha^{-1}$). The treatments $M_3S_4$ (8522 kg $ha^{-1}$), $M_3S_6$ (8479 kg $ha^{-1}$) and $M_3S_7$ (8430 kg $ha^{-1}$) were also comparable.

## 4.8. Effect of humic acid with fertilisers on grain yield of rice during *kharif* 2001

Based on the observations recorded in the previous experiments, the $M_1$ main plot treatment was deleted, since the effect of humic acid in the presence of NPK was better expressed. The results recorded in the two experiments with 100 and 75 per cent of recommended dose of NPK showed that, the soil application of humic acid @ 20 kg $ha^{-1}$ recorded an increased grain yield over no humic acid. It was comparable with soil application (SA) of 10 kg $ha^{-1}$ + root dipping (RD) and 10 kg $ha^{-1}$+ RD + FS.

Hence, in order to test the best combination of modes of application of humic acid the present experiments were conducted in Noyyal and Irugur soil series during *kharif* season. The treatments consisted of two main plot treatments *viz.*, $M_1$-75 per cent of recommended dose of NPK fertiliser, $M_2$-100 per cent of recommended dose of NPK fertiliser and eleven sub plot treatments *viz.*, $S_1$-no humic acid (HA), $S_2$-0.1 per cent foliar spray (FS), $S_3$-0.3 per cent root dipping (RD), $S_4$-10 kg HA $ha^{-1}$, $S_5$-10 kg HA $ha^{-1}$+ FS, $S_6$-10 kg HA $ha^{-1}$+ RD, $S_7$-10 kg HA $ha^{-1}$+FS+RD, $S_8$-20 kg HA $ha^{-1}$, $S_9$-20 kg HA $ha^{-1}$+ FS, $S_{10}$-20 kg HA $ha^{-1}$+ RD, $S_{11}$-20 kg HA $ha^{-1}$+ FS+ RD. The grain yield recorded during harvest is given below:

### 4.8.1. Noyyal soil series- Alfisol (Table 48)

The highest grain yield was recorded in the $M_2$ (4630 kg $ha^{-1}$), which was statistically on par with $M_1$ (4495 kg $ha^{-1}$). In the HA treatments, the grain yield recorded by $S_8$ was 4771 kg ha¯1 and it was on par with $S_7$ (4725 kg $ha^{-1}$), $S_6$ (4658 kg $ha^{-1}$) and $S_5$ (4609 kg $ha^{-1}$). The $S_{11}$ recorded 4612 kg $ha^{-1}$ of grain yield was on par with $S_{10}$ (4633 kg $ha^{-1}$), $S_9$ (4671 kg $ha^{-1}$) and $S_8$ .Compared to control (4253), the foliar spray (4320 kg $ha^{-1}$) and root dipping (4355 kg $ha^{-1}$) recorded higher grain yield . The grain yield recorded by soil application of HA was superior to FS or RD.

**Table 48. Effect of humic acid and fertilisers on grain yield (kg ha$^{-1}$) of rice-Kharif**

| Treat ments | Alfisol | | | Inceptisol | | |
|---|---|---|---|---|---|---|
| | $M_1$ | $M_2$ | Mean | $M_1$ | $M_2$ | Mean |
| $S_1$ | 4142 | 4363 | 4253 | 4093 | 4212 | 4153 |
| $S_2$ | 4201 | 4439 | 4320 | 4158 | 4277 | 4217 |
| $S_3$ | 4244 | 4466 | 4355 | 4201 | 4298 | 4250 |
| $S_4$ | 4536 | 4628 | 4582 | 4352 | 4622 | 4487 |
| $S_5$ | 4558 | 4660 | 4609 | 4401 | 4590 | 4496 |
| $S_6$ | 4606 | 4709 | 4658 | 4455 | 4655 | 4555 |
| $S_7$ | 4655 | 4795 | 4725 | 4493 | 4752 | 4622 |
| $S_8$ | 4730 | 4811 | 4771 | 4590 | 4860 | 4725 |
| $S_9$ | 4612 | 4730 | 4671 | 4504 | 4795 | 4649 |
| $S_{10}$ | 4590 | 4676 | 4633 | 4471 | 4806 | 4639 |
| $S_{11}$ | 4568 | 4655 | 4612 | 4406 | 4806 | 4606 |
| Mean | 4495 | 4630 | 4563 | 4375 | 4607 | 4491 |
| CD ($p=0.05$) | | | | | | |
| M | | 197 | | | 240 | |
| S | | 168 | | | 197 | |
| M at S | | 241 | | | 292 | |
| S at M | | 238 | | | 279 | |

Regarding interaction, $M_2S_8$ recorded higher grain yield of 4811 kg $ha^{-1}$, it was comparable with $M_2S_7$ (4795 kg $ha^{-1}$) and $M_1S_8$ (4730 kg $ha^{-1}$). The $M_1S_8$ was on par with $M_2S_9$ (4730 kg $ha^{-1}$), $M_2S_6$ (4709 kg $ha^{-1}$) and $M_2S_5$ (4660 kg $ha^{-1}$). The application of NPK fertiliser combined with HA recorded higher grain yield of 4201 to 4811 kg $ha^{-1}$ than NPK fertiliser (4142 to 4363 kg $ha^{-1}$).

### 4.8.2. Irugur soil series- Inceptisol (Table 48)

The fertiliser and humic acid treatments on grain yield was significant. The fertiliser treatment $M_2$ recorded the higher grain yield of 4607 kg $ha^{-1}$ which was on par with $M_1$ (4375 kg $ha^{-1}$). Among the HA treatments, soil application of HA showed a significant increase in grain yield than root dipping or foliar application of HA . The $S_2$ and $S_3$ recorded 4217 and 4250 kg $ha^{-1}$ respectively. The higher grain yield was registered in $S_8$ receiving 20 HA kg $ha^{-1}$ (4725 kg $ha^{-1}$). This was on par with $S_9$ (4649 kg $ha^{-1}$), $S_{10}$ (4639 kg $ha^{-1}$), $S_7$ (4622 kg $ha^{-1}$) and $S_{11}$(4606 kg $ha^{-1}$). The application of NPK fertiliser combined with HA recorded higher grain yield of 4158 to 4860 kg $ha^{-1}$ than NPK fertiliser alone (4093 to 4212 kg $ha^{-1}$).In the interaction, $M_2S_8$ recorded higher grain yield of 4860 kg $ha^{-1}$ .This was on par with $M_2S_9$ (4795 kg $ha^{-1}$), $M_2S_{10}$, $M_2S_{11}$ (4806 kg $ha^{-1}$), $M_2S_7$ (4752 kg $ha^{-1}$), $M_2S_6$ (4655 kg $ha^{-1}$), $M_2S_5$ (4590 kg $ha^{-1}$),$M_2S_4$ (4622 kg $ha^{-1}$) and $M_1S_8$ (4590 kg $ha^{-1}$).

### 4.9. Test verification trial - Noyyal series (Table 49)

A field experiment was conducted with the best treatments selected from the previous experiments based on the response to HA. The treatments consisted of control ($T_1$), 75 per cent NPK ($T_2$), 100 per cent NPK ($T_3$), 10 kg HA $ha^{-1}$+FS of 0.1 per cent HA+RD of 0.3 per cent HA ($T_4$), 20 kg HA $ha^{-1}$+FS of 0.1 per cent HA+RD of 0.3 per cent HA ($T_5$), 10 kg HA $ha^{-1}$+FS of 0.1 per cent HA+RD of 0.3 per cent HA combined with 75 ($T_6$) and

**Table 49. Effect of treatments on the grain yield of rice (CO 43) -**
**- Test verification trial**

| Treatments | Grain yield (kg $ha^{-1}$) |
|---|---|
| $T_1$ | 3725 |
| $T_2$ | 4850 |
| $T_3$ | 5010 |
| $T_4$ | 4050 |
| $T_5$ | 4010 |
| $T_6$ | 5185 |
| $T_7$ | 5420 |
| $T_8$ | 5310 |
| $T_9$ | 5280 |
| CD | 131 |

**Table 50. Effect of soil application of humic acid on the paddy grain yield**

| Treatments | Grain yield (kg $ha^{-1}$ ) | Per cent increase |
|---|---|---|
| $T_1$ | 3865 | - |
| $T_2$ | 4199 | 8.6 |
| $T_3$ | 4298 | 11.2 |
| $T_4$ | 4356 | 12.7 |
| $T_5$ | 3985 | 3.1 |
| $T_6$ | 3880 | 0.38 |

100 per NPK ($T_7$), 20 kg HA ha$^{-1}$+FS of 0.1 per cent HA+ RD of 0.3 per cent HA combined with 75 ($T_8$) and 100 per cent NPK ($T_9$). The grain yield recorded showed that, among the treatments tried, the highest grain yield was recorded in $T_7$ (5420). This was on par with $T_8$ (5310), $T_9$ (5280 kg ha$^{-1}$) and $T_6$ (5185 kg ha$^{-1}$). The application of 100 per cent NPK was comparable with 75 per cent NPK+FS+RD (5185 kg ha$^{-1}$).

### 4.10. Optimization of humic acid for rice

In order to optimise the dose of humic acid for rice, an experiment was conducted in Inceptisol alluvium (Alfisol) during *kharif* 2001 at agricultural research station, Bhavanisagar. The treatments constituted are different levels of humic acid from 0 to 50 kg ha$^{-1}$. The yield data recorded for different levels of humic acid is given in Table 50. The yield data recorded for different levels were fitted in quadratic equation for the optimisation of HA for grain yield. From the regression equation obtained ($Y = 3891 + 34.93x - 0.7277x^2$), the dose of humic acid with fertiliser for maximum and economic yields of rice were computed. The result showed that the dose of humic acid for getting maximum yield was 24 kg ha$^{-1}$ and for economic yield it was 18.5 kg ha$^{-1}$ for rice in Inceptisol alluvium of Tamil Nadu.

### 4.11. Regression and correlation analysis

The regression analysis was carried out for yield with yield attributes, soil available nutrients and nutrient uptake for both Alfisol and Inceptisol (Annexure II). The correlation also worked out between yield, yield attributes, available nutrients and nutrient uptake (Annexure III).

# DISCUSSION

# CHAPTER V

# DISCUSSION

Humic acid products are being used extensively for its ability to release nutrients slowly to the plants, holding water to safeguard the plants, resist the changes in pH values and improve the soil condition. Humate concentrates provide many of the advantages of conventional organic matter sources over a long period with less handling problems, especially in situations where there is no feasible alternative in purchasing additional supplies of humus. The effect of these products depends on the source and characteristics of that material used on the crop. In the present investigation, laboratory studies were conducted to characterize the lignite humic acid used as potassium humate as well as its adsorption characteristics on Alfisol. Incubation experiment was carried out with soils collected from Alfisol to find out its effect on the nutrient release pattern. The pot and field experiments were conducted on two different soil types namely Noyyal series (Alfisol) and Irugur series (Inceptisol). The rice varieties used were ADT36 (short duration), ADT39 and ADT38 (medium duration), to study the influence of humic acid with and without NPK fertilisers on yield, yield attributes, nutrient uptake and soil fertility. The results obtained from the above studies are discussed hereunder.

## 5.1. Characterisation of humic acid

Coal and lignite are rich in humic substances. Between these two, lignite (brown coal) is richer in humic substances than coal. In Neyveli Lignite Corporation, humic acid is extracted from lignite adopting the classical fractionation procedure of Stevenson (1982), where the properties of differential solubility in alkali and acid are made use off. The extracted HA are then converted into solid granules by treating it with potassium hydroxide. The humic acid thus obtained is dark brown to black in color, which might be due to elemental configurations (Kumuda, 1987). It was also stated that, the dark colour of HA is principally due to the existence of various kinds of conjugated double bonds, which are primarily distributed randomly in the HA molecules and these conjugated double bond system should be regarded as the nature of humic substances (Kumuda, 1965). The pH of the potassium humate was neutral to alkaline. It ranged from 7.4 to 8.0. The alkaline pH was attributed to the treatment of humic acid with potassium hydroxide solution. The humic acid in general is not soluble in water. It was made water soluble by converting it into potassium humate. Govindasamy (2002) reported that, to convert the insoluble humic acid into water soluble product, the HAs are usually brought into solution as Na or K salts.

The organic carbon content of the potassium humate ranged from 22.8 to 65.0 percent and was found to be very high as compared to normal cultivable soil. Orlov (1995) reported 58.4 per cent of carbon content in peat samples. Chandrasekaran (1992) also reported 39.5 per cent of carbon content in the lignite humic acid, which lent support to the observation on organic carbon content of the test material in the present study.

Regarding cation exchange property, the potassium humate was found to have as high as 125 cmol (p+) kg$^{-1}$ as compared to 10 - 40 cmol (p+) kg$^{-1}$ in normal soils. Normally the humic substance is found to possess CEC nearly 3 to 4 times higher than a normal soil. According to Schnitzer (2000), humic substances contain relatively high concentration of oxygen containing functional groups per unit weight. This might have contributed towards the high CEC of humic acid obtained from lignite. Among the exchangeable cations, the K occupies the predominant position. Probably the exchange sites of HA molecule are filled predominantly with hydrogen ions. When these hydrogen ions are replaced with KOH treatment, the humate of monovalent alkali metal namely K was obtained and it is soluble in water. The analytical results of exchangeable cations clearly indicated the preponderance of K ions in exchange complex of HA and the comparatively negligible contribution of other cations towards cation exchange capacity.

### 5.1.1. Functional Group analysis of humic acid

The total acidity of humic acid as potassium humate ranged from 820 to 890 cmol p(+)kg$^{-1}$. The carboxyl and total phenolics contributed to total acidity ranged from 40 to 45 and 780 to 845 cmol (p+) kg$^{-1}$ respectively. Ushashree *et al.* (1989) found that, the total acidity, carboxyl and phenolic OH groups in lignite humic acid were 544, 243 and 301 cmol (p+) kg$^{-1}$ respectively. Saha and Sanyal (1988) reported that the contents of carboxyl and phenolic groups in synthetic humic acid ranged from 71 to 140 and 148 to 246 cmol (p+) kg $^{-1}$ respectively. The predominance of phenolic-OH in the present study was accompanied by high exchange capacity of humic acid. It is evident from the present study that the carboxyl and phenolic hydroxyl groups were always present in varying quantities and as indicated by Prasad and Sinha (1981), the variations in molecular weight would have been responsible for the differences in the quantities of functional groups. Schnitzer and Khan (1978) also reported that though the humic material are chemically similar, they differ in molecular weight, ultimate analysis and functional groups as found in the present study.

### 5.1.2. Elemental composition of humic acid

The humate was analysed in CHN analyzer and C, H, N and O contents were estimated and atomic ratios of these elements were calculated from the elemental composition. The contents of C, H, N and O ranged from 53.9 to 49.1, 4.1 to 4.2, 1.2 to 1.5 and 40.7 to 45.3 per cent respectively. The atomic ratios of carbon to hydrogen (C:H), carbon to nitrogen (C:N), oxygen to carbon (O:C), and oxygen to hydrogen

(O:H) ranged from 12.0 to 12.7, 32.4 to 44.7, 0.76 to 0.92 and 9.6 to 11.0 respectively in the present study. The presence of C, H and O in humic acid is accounted in the form of carboxyl, methoxyl and carbonyl groups (Govindasamy *et al.*, 1989). The value of H/C and O/C would give an idea to how the processes of extracting humic acids affect the variation in the composition of HA. These values are highly helpful in judging the extent of the role of dehydrogenation as well as removal of alkyl or carboxyl groups during the operational process of extracting humic acids. The differences in ratios studied could be attributed to the dissimilar splitting of the peripheral aliphatic chains as well as to an increase in the number and length of aliphatic chains (Govindasamy *et al.*,1989 ; Kononova ,1966).

### 5.1.3. Spectroscopic Studies of humic acid

#### 5.1.3.1. Ultra violet/visible Spectroscopic Studies- $E_4/E_6$ ratio

The $E_4/E_6$ ratio of humic acid ranged from 1.95 to 2.20. The ratio gives an idea about the degree of aromatization and condensation of aromatic rings in the molecules of humic acids. In the present study, though the two samples differed widely for their HA content, their $E_4/E_6$ ratios were found to have a very narrow difference indicating that, the ratio would be independent of the concentration of humic substances, but varies with difference in the genesis of the soil organic matter in ambient soil environment. Besides, it also indicated the morphological similarity of the samples (Stevenson, 1982).

#### 5.1.3.2. Fourier transform infrared spectroscopic (FTIR) studies

The humic acid used for the present investigation was subjected to FTIR spectroscopic analysis and the FTIR spectra are given in the Figure 1a and 1b. The spectra in the 1a showed that, the main bands were in the region of 3443, 2920, 2360, 1557, 1456 and 1030 $cm^{-1}$. In the spectra shown in 1b, the absorption bands were

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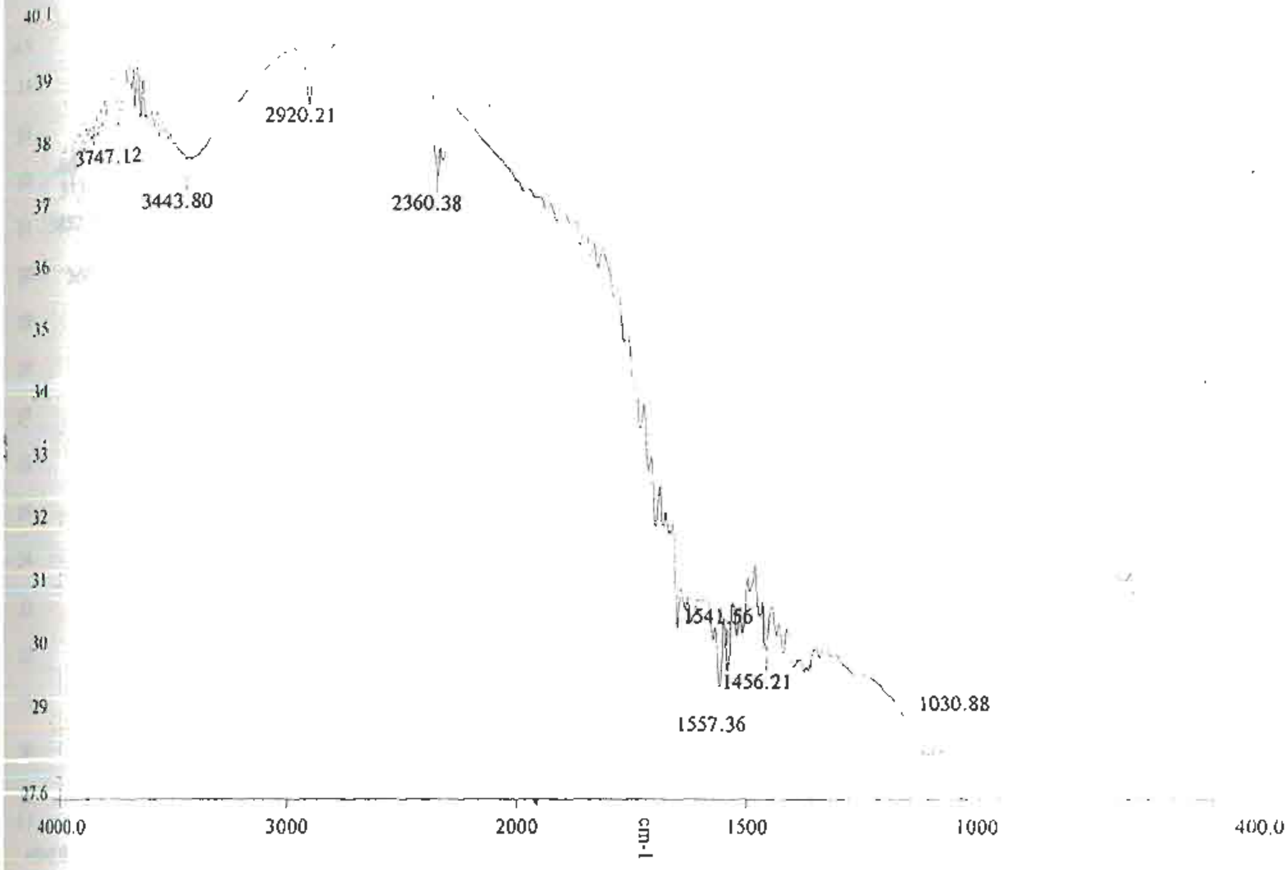

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33.PK

33.SP  1801  4000.00  400.00  27.64  40.06  4.00  %T  16  2.00
33/27
REF 4000 37.92 2000 37.37 600
3747.12  38.26  3443.80  37.72  2920.21  38.65  2360.38  37.46  1557.36  29.41
1541.56  29.66  1456.21  29.99  1030.88  27.64
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Fig 1a. Fourier Transform Infrared Spectra of humic acid sample-I

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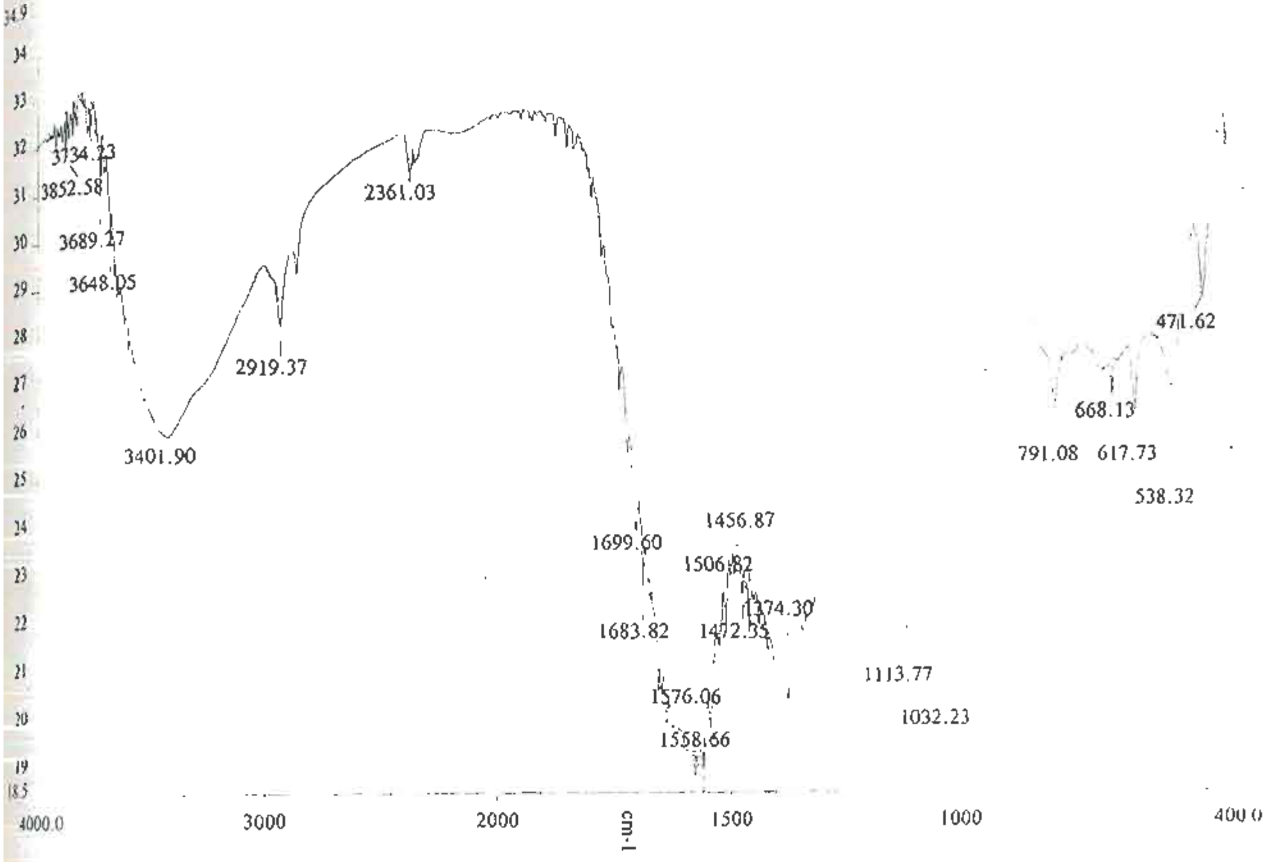

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60.PK

60.sp 1801 4000.00 400.00 18.48 34.86 4.00 %T 16 2.00
60%
REF 4000 32.04 2000 32.49 600
3852.58 31.70 3734.23 32.15 3689.27 31.29 3648.05 29.91 3401.90 25.84
2919.37 28.11 2361.03 31.28 1699.60 23.96 1683.82 22.93 1576.06 18.82
1558.66 18.42 1506.82 21.79 1472.35 22.57 1456.87 21.79 1374.30 20.40
1113.77 21.89 1032.23 21.94 791.08  26.56 668.13  26.73 617.73  26.55
538.32  26.87 471.62  28.70
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**Fig 1b. Fourier Transform Infrared Spectra of humic acid sample-II**

observed in the region of 3401, 2919, 2361, 1558, 1030 , 1113, 791, 617, 538 and 471 cm$^{-1}$. The bands at 3443 and 3401cm$^{-1}$ were attributed to the presence of unbound hydroxyl groups. This was in accordance with Orlov (1995) findings that, an absorption band at 3600-3300 cm$^{-1}$ was due to valance vibrations of unbound hydroxyl groups mostly bound with intermolecular hydrogen bonds. The band of IR spectra at 2920 cm$^{-1}$ indicated the aliphatic valance groups (Orlov, 1995) i.e. C-H stretching vibrations. Absorption bands at 2920 cm$^{-1}$ and the weak bands near 2840 cm$^{-1}$ suggested the presence of methyl or methylene groups. (Orlov, 1995 ; Kononova, 1966 ; Ushashree *et al.*, 1989). The peak at 2360 cm$^{-1}$ showed unidentified compound in the material. Orlov (1995) found that, weak absorption band at 2600-2500 cm$^{-1}$ was considered due to carboxylic acid. Small bands at 1683 and 1699 cm$^{-1}$ represents C=O stretching of carboxylic acid.

Celi *et al.* (1997)) applied FTIR technique to the analysis of COOH (Carboxyl) groups in humic substances. The concentrations of COOH groups in HAs were determined directly from FTIR spectra by totaling absorbencies at 1720-1710 cm$^{-1}$ and 1620-1600 cm$^{-1}$. They found good correlation between carboxyl g9roups determined by FTIR and wet chemical method. In the present study, COOH groups estimated by chemical method were minimum compared to phenolic OH groups. In the FTIR method also prominent bands were not available in that COOH absorption band region (1720-1710 cm$^{-1}$ and 1600-1620 cm$^{-1}$) indicating minimum COOH groups. The bands at 1576, 1558, 1557, 1541 cm$^{-1}$ indicated the COO$^-$ symmetric stretching and N-H deformation (Stevenson, 1982). The absorption spectra of 1456 and 1472 cm$^{-1}$ showed the aliphatic C-H stretching.

Strong absorption band at 1113 cm$^{-1}$ indicated the secondary and tertiary alcohol (Jain and Sharma, 2000) and the absorption band at 1030 and 1032 cm$^{-1}$ were likely due to the presence of polysaccharides or primary alcoholic functions. The region between

900 to 650 $cm^{-1}$ would be aromatic region. From the published data, it is possible to assign the following absorption ranges to the corresponding groups for HA used for the study.

| **Absorption bands** | | |
|---|---|---|
| 3852, 3734 $cm^{-1}$ | - | Polymeric O-H stretching, H bonded OH, and N-H is stretching vibration. |
| 3401, 3420 $cm^{-1}$ | - | O-H stretching, N-H stretching |
| 2920, 2919 $cm^{-1}$ | - | Aliphatic $CH_2$ and $CH_3$ (C-H stretching) |
| 2361, 2360 $cm^{-1}$ | - | Unidentified compound |
| 1716, 1683, 1699 $cm^{-1}$ | - | Vibrations of carboxyl C=O in aromatic and aliphatic acids (C=O stretching of carboxyl and ketonic groups) |
| 1660, 1630 $cm^{-1}$ | - | C=O stretching of amide groups, quinine C=O. |
| 1620 -1600 $cm^{-1}$ | - | Aromatic C=O strongly H bonded C=O of conjugated ketones |
| 1590 -1517 $cm^{-1}$ | - | COO symmetric stretching |
| 1456 $cm^{-1}$ | - | Aliphatic C-H |
| 1113 $cm^{-1}$ | - | C-O of cyclic and aliphatic esters and alcohol |
| 1030 $cm^{-1}$ | - | Polysaccharides |
| 900-650 $cm^{-1}$ | - | Benzene rings (Aromatic band) |
| 538 $cm^{-1}$ | - | Alkyl halides (C-Br) |
| 471 $cm^{-1}$ | - | Alkyl halides (C-I) |

The region in the 600 to 470 $cm^{-1}$ might be due to impurities.

Thus, the IR spectra reflected the preponderance of oxygen containing functional groups ($CO_2H$, OH and C =O) in humic material. Also it provided worth while information on the distribution of various functional groups and the complexity of HA molecule. It also indirectly indicated its chemically reactive nature.

### 5.2. Assessment of organic carbon status of western zone

In general, the tropical soils are low in organic matter. The results on delineation of OC status of the soils of western zone of Tamil Nadu also revealed the low OC status. The knowledge on organic carbon content of soils could give an idea about the possible humic acid content. The humic acid fraction of soil organic matter ranged from 0.10 to 0.35 per cent (Ushashree *et al., 1989*). Sardessai (1989) reported that, of the organic matter, 40-69 per cent was found to be associated with humic substances. The HA is believed to be formed from diagenetic transformation of organic matter, the byproduct being resistant to biochemical degradation. The analysis of initial soil samples of Alfisol and Inceptisol showed that, higher the OC content higher was the HA content, thereby indicating the positive impact of OC on HA. The direct relationship of HA with organic carbon content also reported by Saikh (1999) and Gurunathan and Kaliyaperumal (1989). The results had thus highlighted the possibility of improving the HA content, through increasing the content of organic carbon. The build up of OC status in soil would be possible mainly through external application. The increased HA content in the treatments having high OC (Annexure V), found in the present study lent support that HA content of any soil could be augmented through externally applying any organic matter or any organic fertiliser material such as humate.

### 5.3. Laboratory experiments

#### 5.3.1. Humic acid and P sorption studies

It was reported that HA could prevent the adsorption of P on colloidal surfaces and making it more available either in the solution pool or in the exchangeable pool. Hence, the sorption studies were carried out with varied levels of P and HA. The regression analysis of the data indicated that, Langmuir equation gave the best fit of P sorption. The bonding energy coefficient (K), which is a measure of P sorption capacity of soil decreased with increasing rate of application of HA. It might be the sorptive interaction of humic acid with P on the sorption sites. The results obtained from P sorption studies showed the increased equilibrium P concentration and reduced sorption of P for increasing concentration of HA application (Fig 2).

### 5.3.2. Humic acid on nutrient release pattern

Humic acid, the main fraction of soil organic matter is a vital factor for maintenance of soil fertility. In the present investigation, an incubation experiment was conducted with different doses of HA in the form of potassium humate to find out its effect on N, P and K availability at definite intervals during incubation period and CEC and organic carbon at the end of incubation period.

#### 5.3.2.1. Nitrogen availability

The nitrogen availability was increased with increasing doses of HA (80 kg ha$^{-1}$) till 60 days after incubation (DAI) (Fig 3). The significant increase was observed at 20 kg HA ha$^{-1}$ and beyond that level, any further increase in HA exhibited a decrease in the increasing period. The decrease in the increment of available N at levels higher than 20 kg ha$^{-1}$ might be due to reduced microbial activity in the presence of some high content of phenolics produced by HA in the soil. The increase in available N might be attributed to the N contributed from the native N by the enhanced microbial activities induced by the humic acid (Deepa, 2001). Similar increase in N availability was reported by Govindasamy *et al.* (1989) for the application of HA @ 50 kg ha$^{-1}$ and by Prasad *et al.* (1991) by the released HA from the added tree leaves.

Fig 2. Effect of humic acid on P sorption characteristics

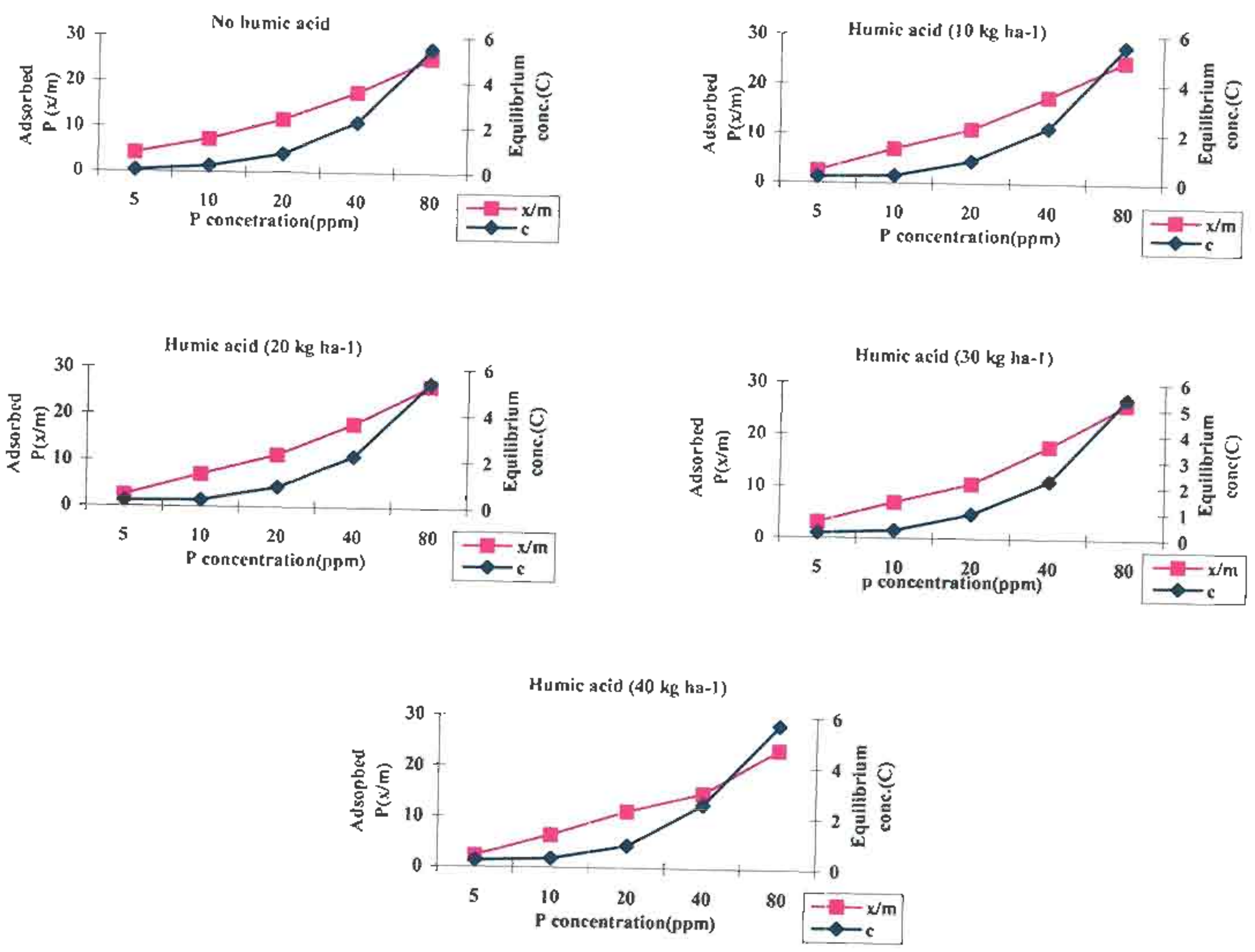
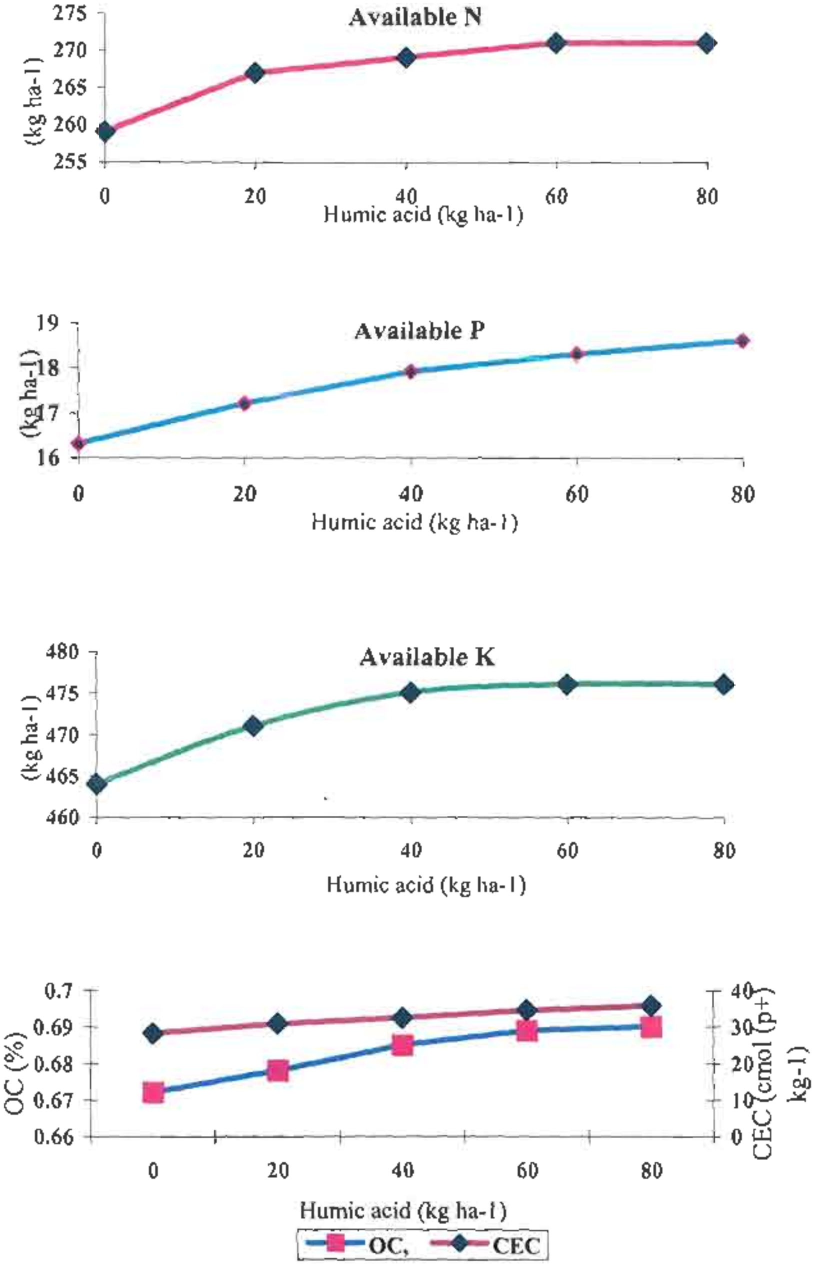


Fig 3. Effect of humic acid on available nutrients
of the soil - Incubation study



### 5.3.2.2. Phosphorus availability

A linear trend in P availability was observed for graded doses of HA till the end of incubation period. However the increase was marked for 40 kg ha$^{-1}$ and upto 60 DAI. Beyond that level, the magnitude of increase got reduced (Fig 3). The increase in the availability of P could be attributed to the chemical and biochemical processes involved. The humic acids might have helped in solubilizing P from insoluble to soluble form resulting on its increase. Similar increase was reported by Khan *et al.*(1997) for the application of metal humates up to 50 ppm . Fokin and Sinha (1969) proposed that, the derived benefits of the addition of organic matter to the soils might be due to the anion replacement or competition between humate from added OM and phosphate ions on adsorbing surfaces which in turn would have increased the P availability. Sinha (1972) indicated that fulvic acids and intermediate products of organic matter decomposition had played a significant role in mobilizing fairly soluble phosphates.Pal and Sengupta (1985) observed that when black soil was incubated with humic acid, the P availability increased. The reason attributed was phosphate ions were expected to interact with humic acid more through its phenolic and hydroxyl groups which might have changed the behavior of P. The presence of such functional groups as assessed by IR analysis in the present study would confirm similar action in the treated soil leading to increased P availability. David *et al.* (1994) found that, humus would form protective coating over sesquioxides and thereby reducing the fixation of any phosphate, which made them available in the soil. The increase in available P might also be due to the mineralisation of soil organic P (Sanchez, 1976 and Dusberg *et al.* 1989) as well as humic acid (Vaughan and Ord, 1985). Thangavelu and Manickam (1989) reported that, the P availability was increased with application of manure due to less fixation and release of P by humic substances released during mineralisation of organic matter. These results lent support to the finding of increased P availability due to HA noticed in the present study.

### 5.3.2.3. Potassium availability

The availability of K increased with increasing the level of HA from 0 to 80 kg $ha^{-1}$. But the significant increase was observed up to 40 kg $ha^{-1}$ and beyond that dose, as in N and P the magnitude of increase was reduced. With regard to incubation period, the significant increase was observed up to 45th DAI (Fig 3) and thereafter the increase in K availability started declining. The humic acids and fulvic acids are believed to play a definite role in liberating fixed K because of their high complexing power. In addition, the lower molecular weight fractions of humic compounds are capable of penetrating the intermicellar spaces of expanding types of clays and reach the specific sorption sites for K, where they might react or compete for sites with K and increase its availability in soil (Tan and McCreery, 1975; Schnitzer and Kodoma, 1972). The enhanced microbial activity due to humic acid application would also have paved way for the increased availability of K through reducing its fixation in the soil and dissolution of fixed K. Further, the K that contained in the potassium humate, which was applied as a source of humic acid in the present study, would also have contributed for the increase of soil K under submerged condition. With the increasing period of incubation, the K availability increased significantly. The probable exchange between hydronium ions and exchangeable K might be quoted as a reason for the increase in K availability. Tan (1978) reported that, at pH 7.0, humic and fulvic acids were capable of dissolving small amounts of K from the minerals by chelation, complex reactions or both. The amount released was reported to increase with time and reach a maximum at 800 to 8000 hours. A steady increase in the available K might be due to solubilising effect caused by humic acid coupled with the release from exchangeable sites by other cations (Khan *et al.*, 1997).

### 5.3.2.4. Organic carbon

The changes that occur in organic carbon (OC) would influence the soil fertility. Hence it is quite relevant to study the influence of HA on organic carbon content of soil. The result on present study clearly showed the profound effect of application of humic acid up to 80 kg $ha^{-1}$ on organic carbon, but the significant increase was noticed at 40 kg $ha^{-1}$(Fig 3). Beyond 40 kg $ha^{-1}$, there was a depressive influence of HA on OC content and it might be due to the reduced microbial population at higher level of HA (Deepa, 2001). The positive effect might be due to the high content of organic carbon in the potassium humate itself. The accentuated biotic activity (Deepa and Govindarajan, 2002) up to 30 kg HA $ha^{-1}$ and greater increase in soil microbial biomass might have paved way for concomitant increase in the organic carbon content.

### 5.3.2.5. Cation exchange capacity

The profound increase in CEC due to HA in the present study highlighted the beneficial effect of HA on CEC. There was a steady increase in CEC with increased levels of HA. However, significant increase was up to 60 kg of HA $ha^{-1}$(Fig 3). The HA was found to contain functional groups, that would form the source of negative charge. And they could have contributed towards the CEC of the soil. This charge might be due in part to the dissociation of hydrogen ions from carboxyl groups and also probably in part to their dissociation from phenolic hydroxyls and particularly from groups of the hydroxyls. Similar reports were reported earlier by Lax (1991), who observed that the incorporation of soil organic matter induced the exchange capacity due to the various functional groups namely carboxyl, phenolic etc., present in the humic substances of SOM. The oxidised groups present in HA used in the study might be responsible for the increase in CEC as reported by Roig *et al.*(1988). Cegarra *et al.* (1987) also established a direct relation with humification and consequent increase in the functional groups and

CEC. These findings lent support to the increase of CEC by HA application in the present study.

### 5.4. Pot and Field experiments

To find out the effect of HA with and without NPK fertilisers on soil properties, nutrition and yield of rice, pot and field experiments were conducted in two major soil series of western zone viz., Noyyal (Typic Haplustalf) and Irugur (Typic Ustropept). Soil samples were drawn at critical physiological stages of rice growth and analysed for available N, P and K content while the content of organic carbon, CEC and micronutrients were analysed at harvest stage. The plant samples were also collected at various growth stages of rice and analysed for major, secondary and micronutrients content and using the values and yield data, their uptake was calculated. The results of pot and field experiments are discussed below.

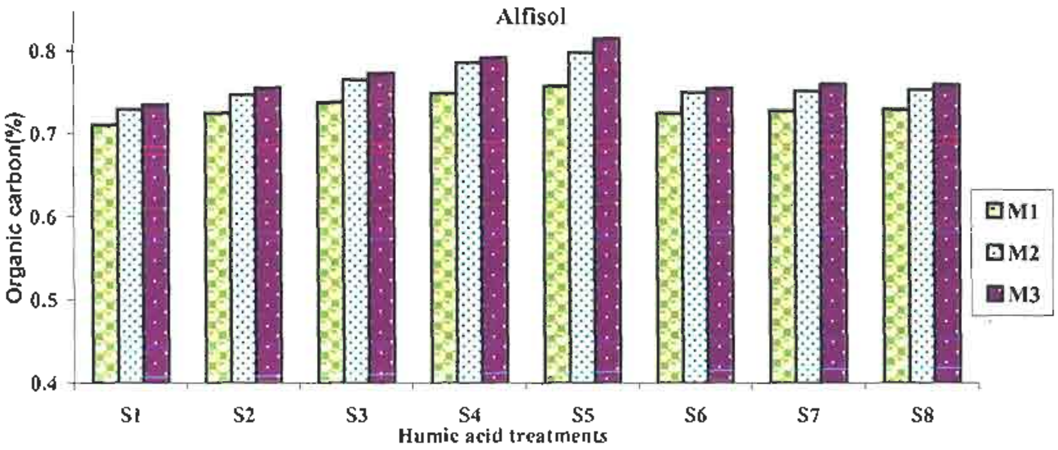
### 5.4.1. Soil fertility

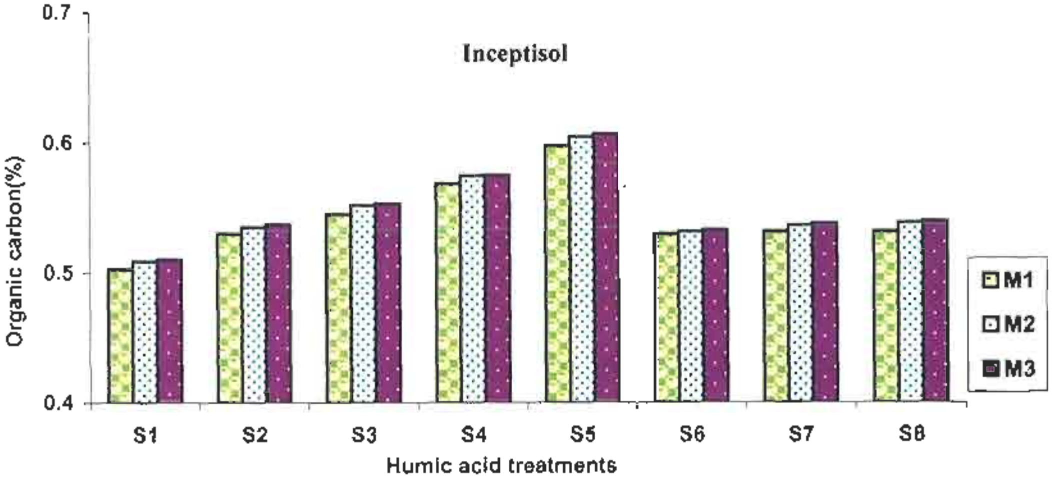
The maintenance of SOM in mineral soils is perhaps the most important challenge to modern agriculture. The carbon makes up a large definite proportion of the organic matter and also the humic acid molecules. The humic substances are important fraction of SOM and their transformation along with interactions are important because they provide useful information on the role of humic substances on nutrient availability in soil (Ghosh and Schnitzer, 1980). The effect of HA on soil fertility could be better expressed when there is a sufficiency of nutrients.

### 5.4.1.1. Organic carbon

The Alfisol and Inceptisol were enriched with OC content due to application of HA at graded doses. There was a steady increase up to 40 kg of HA $ha^{-1}$ in both the soils (Fig 4). The increase in OC was well pronounced in Alfisol as compared to Inceptisol.The enrichment of organic carbon content of the soils through HA application would have been direct or indirect or both. Since, HA itself contained large proportion of organic carbon, as ascertained by the present investigation, its application would have led to the increased organic carbon content in the soils. The indirect effect on increasing the organic carbon content might be due to microbial activities (Deepa, 2001). The HA in combination with either @100 per cent recommended dose of NPK or 75 per cent had an added effect on OC content of the soils. When HA was applied along with NPK fertiliser, the growth stimulating characteristics of added HA would have been better expressed, due to the presence of enough of readily available nutrients in the soil. Such situations would have been quite conducive for bringing about rapid decomposition of OM in the soil leading to the accumulation of organic carbon. The effect of HA alone as compared to its effect in combination with fertilisers was marked in Alfisol and not so in Inceptisol. Probably, the microbial activity might have been well expressed in Alfisol to cause such marked difference between fertilised and unfertilised treatments in it as compared to Inceptisol. Also variation in the magnitude of mineralisation rate would have caused such differences in OC status. When 100 per cent recommended dose of NPK was compared with 75 per cent NPK, there was not any marked difference in the build up of OC in both the soils and it could be ascribed to similar biotic activity and mineralisation rate in both the fertiliser treatments. The contribution towards OC from the added organic carbon rich potassium humate remained constant. Though the fertiliser treatments received the same quantity of HA, the non significant variation in the OC content of differently fertilised treatments indicated that the reduced level of NPK to an extent of 25 per cent might not bring about significant differences in OC content. With reference to application of HA through different means, the results have clearly highlighted that soil application of HA

Fig 4. Effect of humic acid and fertilisers on the organic carbon content of soil





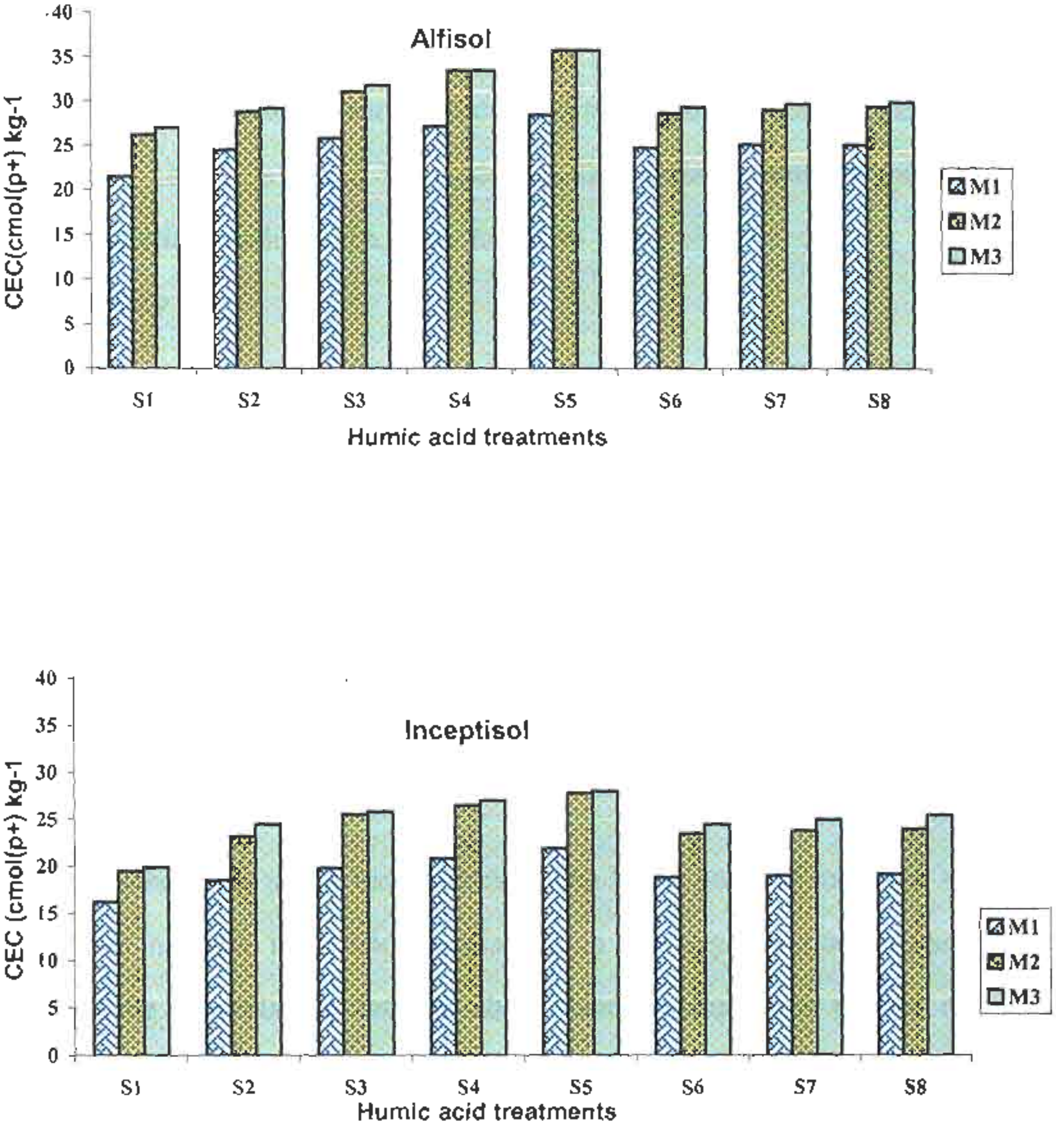
at high levels alone could enrich the soil with OC and not through root dipping and foliar spray.

### 5.4.1.2. Humic acid on exchange properties of soil

The inherent capacity of the soil to supply the essential cations for plant growth is made possible only by improved CEC. This was achieved by the application of HA at graded levels in Alfisol and Inceptisol. Though the CEC increased with increasing doses of HA, the significant effect was observed for 20 kg $ha^{-1}$ in both Alfisol and Inceptisol (Fig 5). The negative charges of humus or the high exchange capacity might be associated with partially dissociated enolic (-OH), carboxyl (-COOH) and phenolic groups (Brady, 1996; Lax, 1991). The characterisation studies of potassium humate confirmed the presence of functional groups in it and these groups might have been instrumental in conferring the high CEC of the humates obtained from lignite. When such substances with high exchange properties were added to soils, naturally there would be an increase in their exchange capacity.

The increased exchange capacity of soil due to the presence of humified leaf fall (Prasad *et al.*, 1991) and decomposition products of organic substances through microorganisms (Bear, 1976) are indicative of the improved ion exchange capacities when humic substances are available in the soil. This finding also supports the improved ion exchange capacity of the experimental soil due to application of humic acid. Regarding the methods of application of HA, soil application exerted profound effect on CEC than foliar spray and root dipping. It would be natural that the applied HA only when it reached the soil, it could act upon or interact with soil colloids to improve its capacity to hold on more cations. There was conspicuous variations brought out by HA between NPK applied and no NPK applied treatments and it could be ascribed to the marked increase in OC content of the soil. As in OC, in CEC also

Fig 5. Effect of humic acid and fertilisers on cation exchange capacity of soil



reduced level of NPK did not affect the possible impact of HA on CEC.

### 5.4.1.3. Nutrient availability

The high content of OC and CEC confer upon the soil, the capacity to hold the essential plant nutrients in sufficient amounts so as to provide the nutrient demanded by the crops. Such situations could be made possible through nutrient management. Inclusion of materials such as HA, was found to bring about conducive changes in nutrient availability.

Application of HA up to 40 kg ha$^{-1}$ increased the NPK availability. But the significant increase in N and K was observed up to 20 kg ha$^{-1}$ and for P up to 30 kg HA ha$^{-1}$. The NPK content of HA might be very little to bring about any significant increase in their availability in soil. Therefore, the pronounced increase in the content of available NPK by HA application in the soils during crop growth could be due to its indirect effect of stimulating microorganism and release of native nutrients or through other interactions of HA with soil particles.

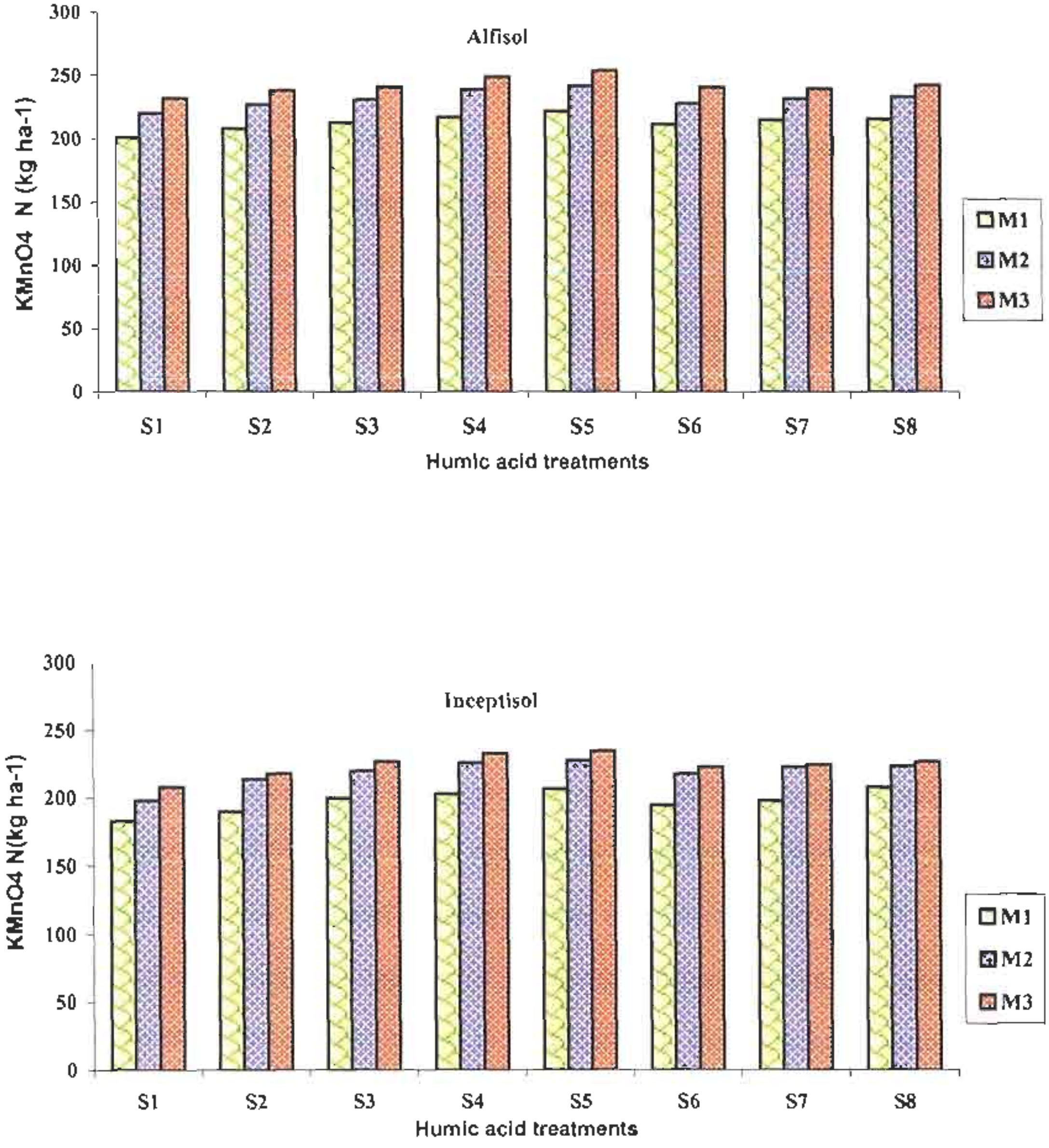
Humic substances might have enhanced the break down of minerals, which in turn would have increased the nutrient availability in two ways. First humic acids might have attacked the minerals and brought about their decomposition thereby releasing nutrients from a molecular state to an adsorbed state, which would have become more readily available to higher plants.The second mechanism for increasing the availability of some nutrients would be through the formation of stable organo mineral complexes of ions such as $Ca^{2+}$, $Fe^{3+}$, $Cu^{2+}$, $Zn^{2+}$ and $Mn^{2+}$ with organic ions. These cations are attracted from the minerals by the organic molecule and could be held in complex form. Later they might become plant available forms (Brady, 1996). Also the very high ion exchange capacities of humate might have transformed the unavailable form of nutrients to available form.

When the nutrient elements were added externally through materials such as fertilisers, their availability was also largely increased by HA as evidenced through higher NPK content of the fertilised treatments than in the unfertilised treatments. When HA was combined with NPK fertilisers, the increase in nutrient availability would be from both the sources. There would have been complementary effect of HA on NPK fertilisers so that, their combination was found to produce marked effect on NPK availability.

The increased N availability in the presence of HA as well as in its combination with NPK fertilisers (Fig 6), might be due to decreased number of nitrifying microorganisms (Quraishi and Cornfield, 1973). Flaig (1964) attributed the newly formed quinones from HA for the inhibition of nitrification and consequently increased the N availability.

The addition of N fertilisers (urea) might get lost through leaching or volatilisation. But the presence of HA, on account of its influence to slow down urease activity (Bundy and Bremner, 1973), to inhibit the nitrification processes (Govindasamy *et al.*, 1989) and reduce the loss of added N through regulation of N release at a relatively slow rate would have increased available N. Tyler *et al.* (1974) however reported the stimulating tendency of HA in the process of nitrification and an increase in the N availability. This would have been the cause for release of N from the native source in the absence of any added N. Govindasamy *et al.* (1989) also reported that, HA with urea retarded the release of N and thus reducing N loss. It was reported that there was higher sustained flow of $NH_4$-N mediated by HA was the cause for increased N availability due to HA application. These reports lent support for the increased N availability due to HA application in the present study. The increased N use

Fig 6.Effect of humic acid and fertilisers on KMnO4-N of soil



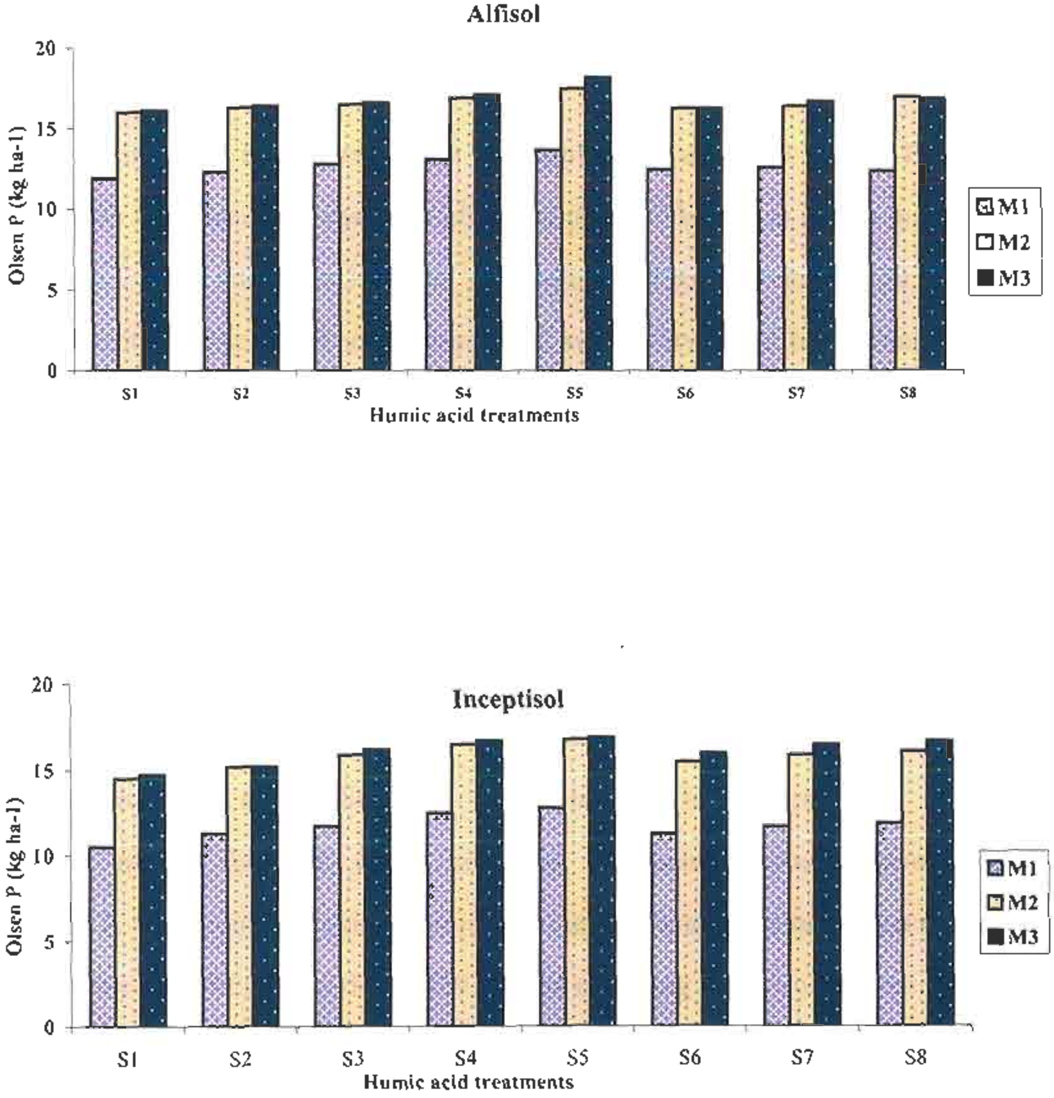
efficiency recorded in the present study would also support to this finding. In the other methods of application viz., root dipping and foliar spray was not found as effective as that of soil application of HA in augmenting the nutrient availability.

Similar to N, the P availability was also significantly increased during rice growth for the application of HA (Fig 7). The high available P content of HA applied soils was ascribed to the tendency of metal humate to extract more P from native sources leading to increased availability of P in the soil. (Heng, 1989; Mary *et al.*, 2002b). Martinez *et al.* (1984) also supported the increased P availability by HA addition through solubilisation reaction. Tan and Binger (1986) reported that, the increased P availability in the presence of humic acid might be due to chelation of HA with Al, rendering it inactive for reaction with P and this would have increased the P concentration in soil solution.

In both the soils, HA at 20 kg $ha^{-1}$ level influenced P availability mostly. The significant increase was observed up to 30 kg $ha^{-1}$ at tillering stage of rice in Alfisol and at maturity phase in Inceptisol. The magnitude of increase was more at lower level of HA than at higher level (40kg $ha^{-1}$) . As reported by Gray and Williams (1975) at lower level of metal humates, a rapid decomposition of organic matter with the native participation of soil microbes capable of releasing inorganic acids and gases would possibly be the main feature that helped in solubilising P from insoluble form resulting in its increase.

Lee and Bartlett. (1976) found that the formation of HA protective film on adsorbing surfaces in soil decreased the possibility of P retention and increased its solubility. From the adsorption study, it was inferred that, by the addition of HA, the solution P increased and the adsorbed P reduced. The adsorption reactions probably would protect the P from microbial attack through complexation of HA with Fe and Al

Fig 7.Effect of humic acid and fertilisers on Olsen P content of soil

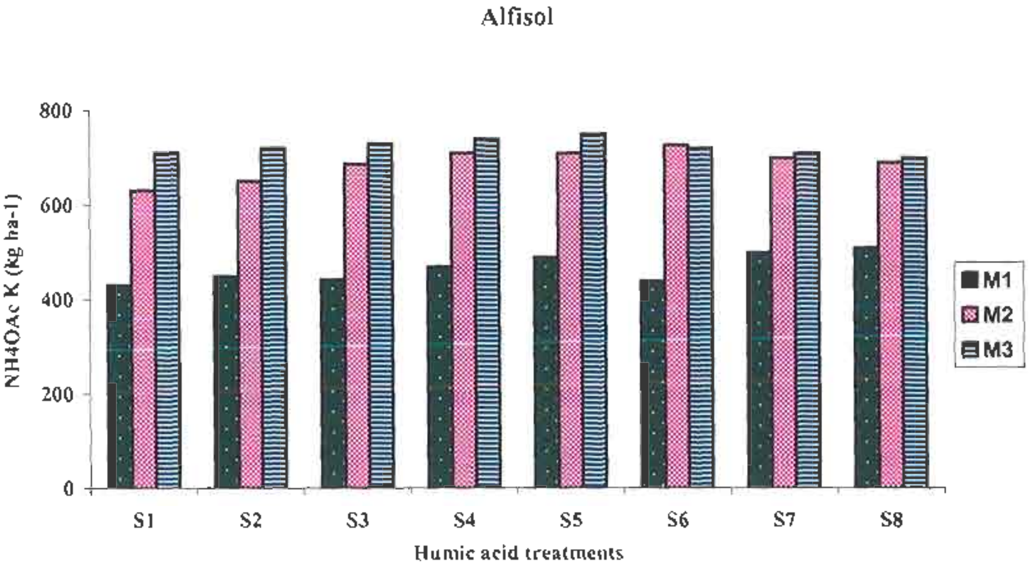


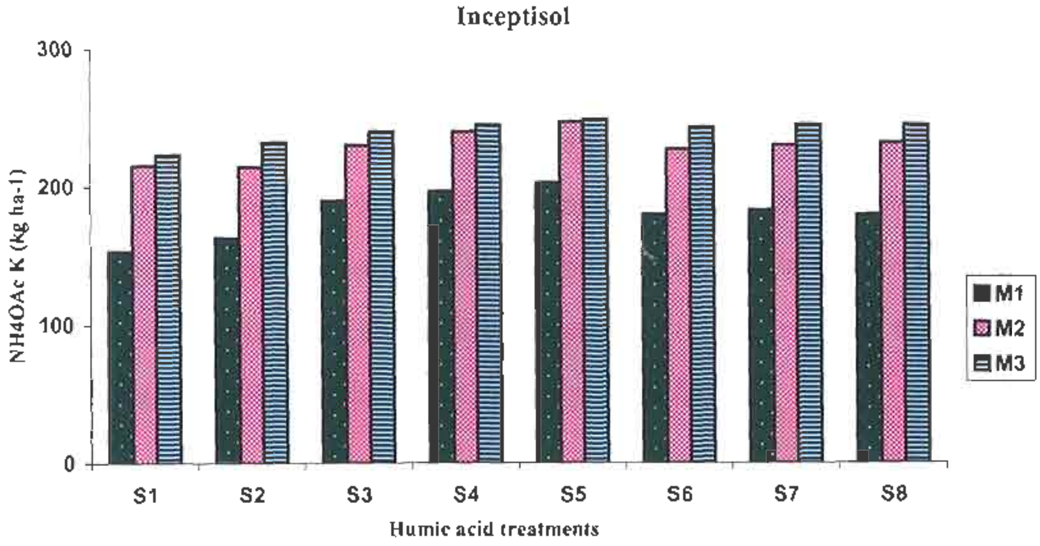
thereby preventing the P fixation. Tyler *et al.* (1974) reported that application of HA increased the availability of P and K in soil through stimulating tendencies on microbes. The above findings are in accordance with the present study.

The availability of K increased with HA application up to 40 kg ha$^{-1}$ linearly in both soils. But the significant increase was observed up to 20 kg ha$^{-1}$ at all the three stages of crop growth in Alfisol and up to 30 kg ha$^{-1}$ at tillering and post harvest and 20 kg ha$^{-1}$ at flowering in Inceptisol (Fig 8). The increase in K availability could be attributed to the release of K from the minerals as a result of reactions of soil particles with humic acid or complex reactions to the solubilising effect caused by acids produced during the biodegradation of SOM (mainly humic substances) and to the release from the exchange sites by other cations.

As in N and P, combining NPK fertilisers with HA resulted in larger availability of K and reduction of NPK dose from 100 to 75 per cent recommended dose did not produce any marked variations in K availability. The ammonium ions generated during mineratilisation of N fertiliser under reducing environment could have caused displacement of K ions from the lattice positions at clay surfaces by virtue of ion exchange as reported by Raju and Mukkhopadhyau (1976) and enriching the K concentration in soil solution.The beneficial effect of HA on the available K might also be due to reduction of K fixation and release of K by the interaction of HA with clay minerals besides its direct contribution to the pool of available K in soil. The high native K status coupled with more K released from the added fertiliser would have caused the higher K availability. Among the soil application, root dipping and foliar spray of HA, the later two methods were not as good as that of soil application in accentuating the availability of NPK.

Fig 8.Effect of humic acid and fertilisers on NH4OAc K content of soil





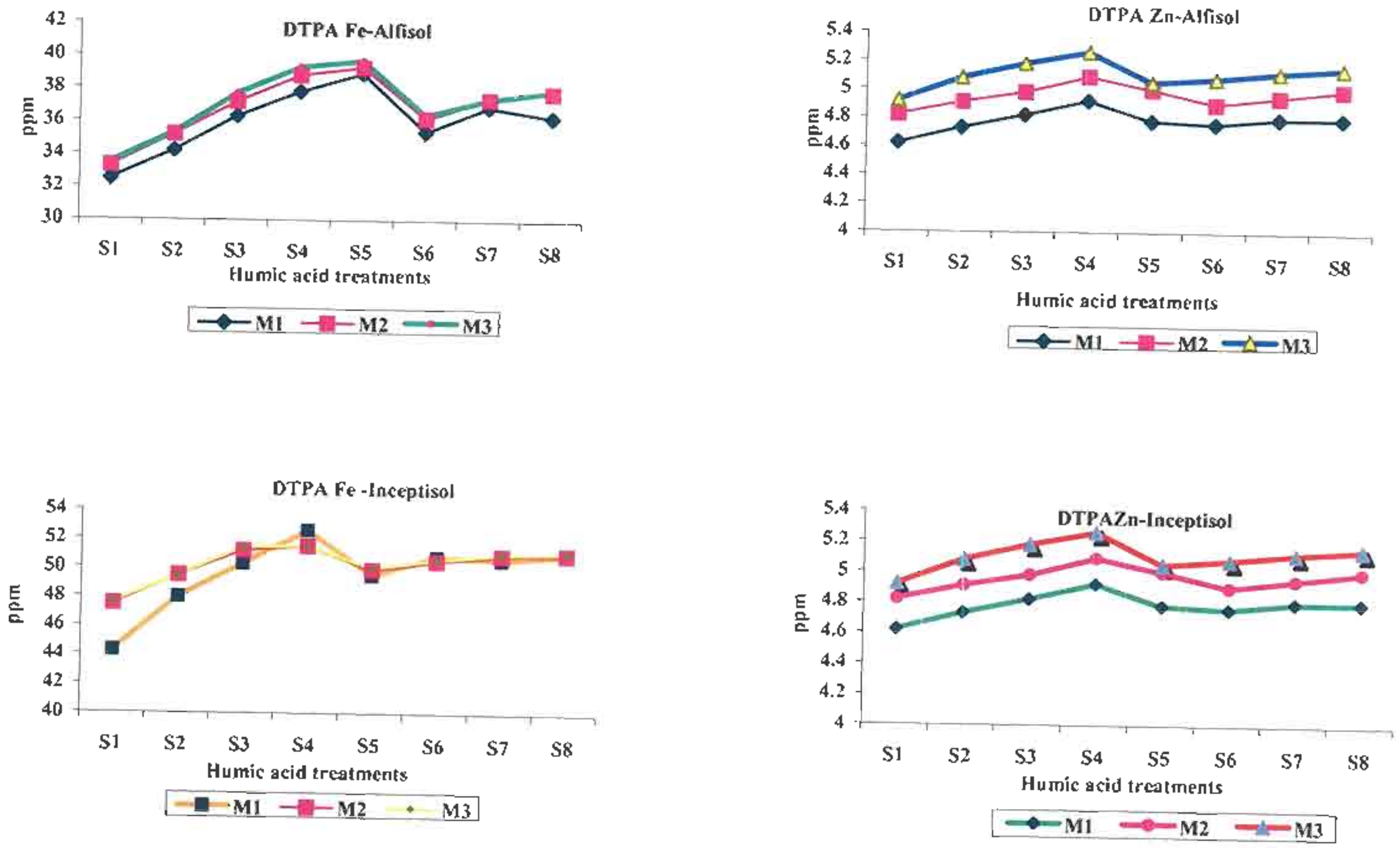
Thus, the combined application of NPK fertiliser with HA favourably influenced the available N, P and K status of soil. Tandon (1988) also reported that combined application of FYM and NPK fertiliser facilitated better nutrient availability in soil. Probably the humic substances of decomposed FYM in the soil would have stimulated in greater NPK availability. These reports are in accordance with the observations made in the present case.

The significant increase in micronutrient availability was observed for HA application up to 30 kg ha$^{-1}$ in Alfisol and 20 kg ha$^{-1}$ in Inceptisol (Fig 9). Humus had the ability to hold micronutrients for a considerable time and release them when needed to crops.The increased Fe availability in the HA applied treatments might be due to the complex formation of HA with metals particularly Fe and its further release on dissolution (Banerjee and Basak, 1978). Stumm and Morgan (1970) reported that, increased Zn availability under natural conditions by humic substances might be due to prevention of formation of insoluble and immobile hydroxides of Zn.

The chelating effect of HA with micronutrients and beneficial influence of HA in soil would prevent the formation of insoluble complexes (Fortun and Polo, 1982) and thereby increasing their availability in the soil. The increased availability of micronutrients with the addition of HA might be attributed to the ability of the humic substances to form chelating compounds (Elgala *et al.* (1978). Shanmugam *et al.* (1989) reported that chelates with micronutrients were not precipitated but in the available form.

The reduced redox potential by HA application would have increased the Mn, Cu, Fe and Zn availability in soils (Shuman, 1988). Further, humus could influence the solubility of soil minerals and facilitate the formation of compounds with elements such as Fe, Cu , Zn rendering them more easily available for plants (Waksman, 1936).

# Fig 9. Effect of humic acid and fertilisers on DTPA Fe and Zn content in soil



DTPA Fe-Alfisol

DTPA Zn-Alfisol

DTPA Fe -Inceptisol

DTPAZn-Inceptisol

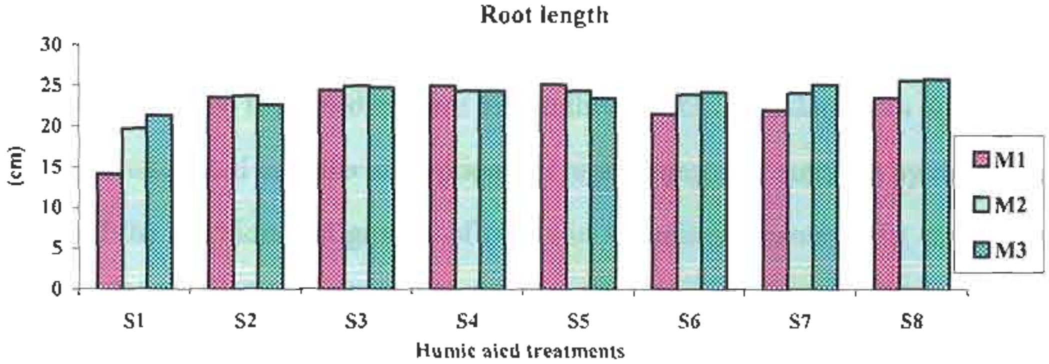
### 5.5. Humic acid on root characteristics

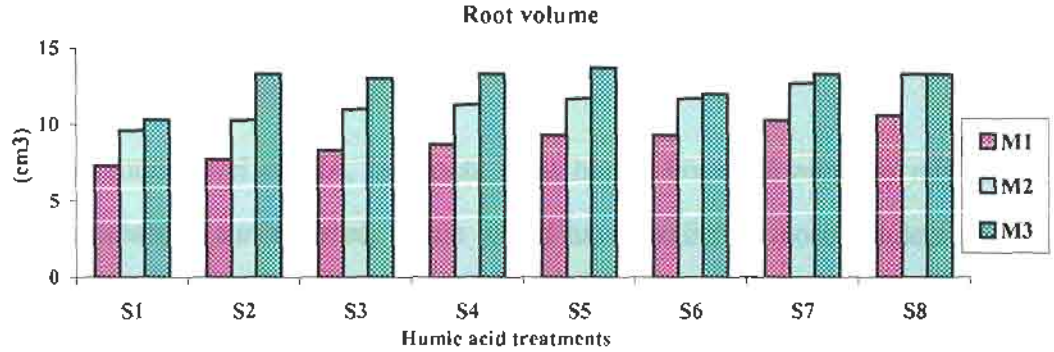
The profound effect of HA on root characteristics such as root volume, root CEC and root length was observed (Fig 10). Humic acids being an important fraction of soil organic matter had a direct and selective effect on biochemical mechanisms within the plant root (Vaughan *et al.*, 1978). The very high ion exchange capacity of HA as evident from the results of the present study might have increased the availability of nutrients in the root zone leading to enhanced root length. The beneficial effect of HA on root length has also been reported by Azam and Malik (1983) and Malik and Azam (1985).

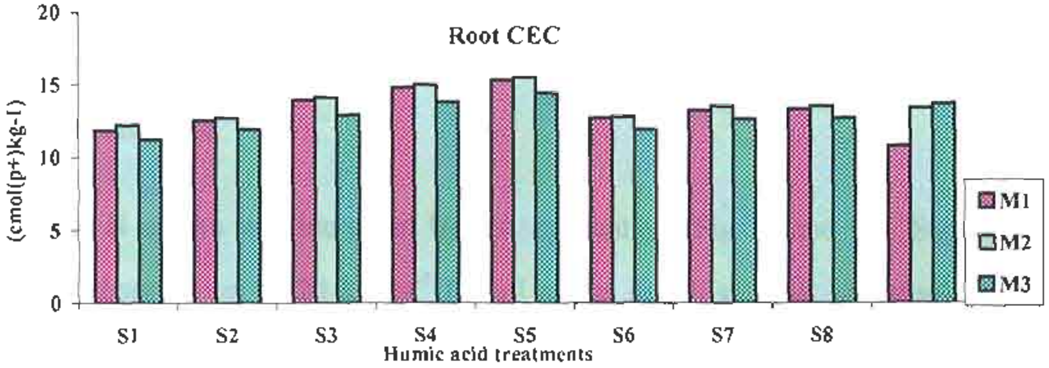
The root volume of rice was favourably increased up to 40 kg $ha^{-1}$. The increase was significant up to 10 kg of HA $ha^{-1}$ and beyond that level the increase in root volume was not marked. Humic substances by virtue of chelation reactions could retain soil nutrients in available forms and render them available for plant growth as well as increase in root proliferation and root volume (Stevenson and Ardakani, 1977). Anuratha (1994) and Sripriya (1993) also reported the increased root volume by HA application in rice.

The root CEC of plants increased with increasing levels of humic acid. The exchange properties of roots are attributed mainly to carboxyl groups, similar to the exchange sites on humus and account for 70 to 90 per cent of the exchange properties of roots (Tisdale *et al.*, 1997). The increased root volume and root length influenced by HA application recorded in the present study would have increased the root surface area and root CEC. The favourable effect of HA on improving the soil physical and biological properties in turn would have indirectly promoted the root growth and consequently increased the root volume and root CEC.

Fig 10. Effect of humic acid and fertilisers on root characteristics of rice







## 5.6. Humic acid on nutrition of rice

A large increase was recorded in the uptake of nutrients for the application of HA up to 40 kg $ha^{-1}$. The increased nutrient availability by HA as evident from the present study would have resulted in better absorption and higher uptake of nutrients by rice. Thus HA influenced the nutrition and growth of plants in an indirect manner. HA might also influence the plant growth directly either through its effects on ion uptake or by more direct effects on the growth regulation of the plant (Vaughan and Linehan, 1976). The increased nutrient uptake due to HA would be attributed to the enhanced microbial activity and reduced nutrient losses in the soil. With increasing dose of HA from 0 to 40 kg $ha^{-1}$, the uptake of N, P, K, Ca, Mg, Fe, Zn and Cu also increased except Mn which was reduced at 40 kg $ha^{-1}$.

At optimum level of HA, the roots were highly branched and this might have resulted an increase in surface area, which would have facilitated more efficient nutrient absorption. (Mallikarjuna rao *et al.*, 1987). Tan and Nopamornbodi (1979) also reported similar results. Increased root volume, surface area and CEC together would have led to more nutrient uptake by providing better means for greater absorption. The mechanisms of root interception with soil nutrients is one of the ways in which crop could take nutrients. It was made possible when there was profuse root growth (Tisdale *et al.*, 1997). The improved root growth of rice in the presence of HA observed would have induced the large uptake of nutrients.

The N uptake was increased by HA application (Fig 11 and 12). Significant increase was observed up to 20 kg $ha^{-1}$ for all stages in Alfisol. For Inceptisol, the N uptake was found to increase with increase in HA dose at each critical stage of the rice growth. The highest uptake of nutrients in grain and straw was found up to 40 kg $ha^{-1}$. The increased N uptake by the rice crop for HA application was attributed to better use

Fig 11. Effect of humic acid and fertilisers on N uptake by rice (ADT 36)-Alfisol

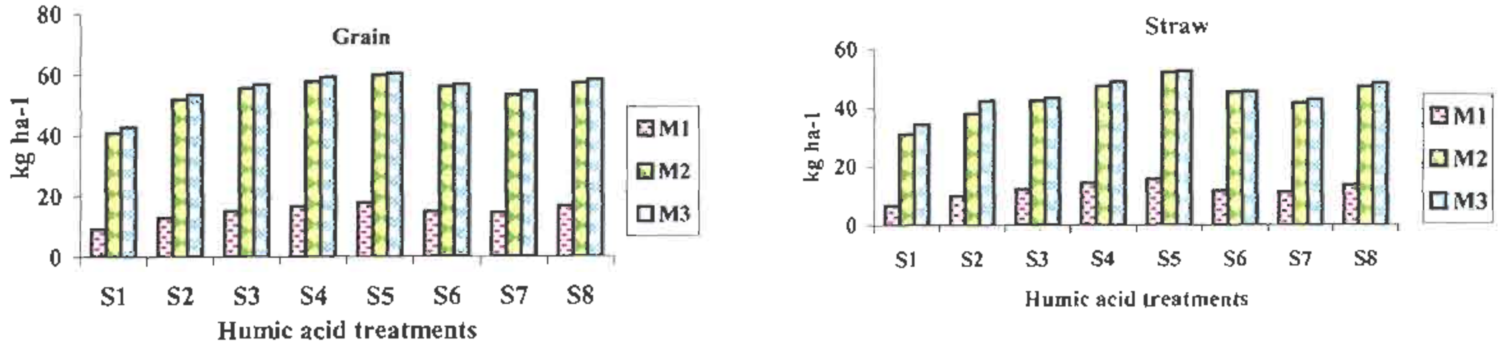
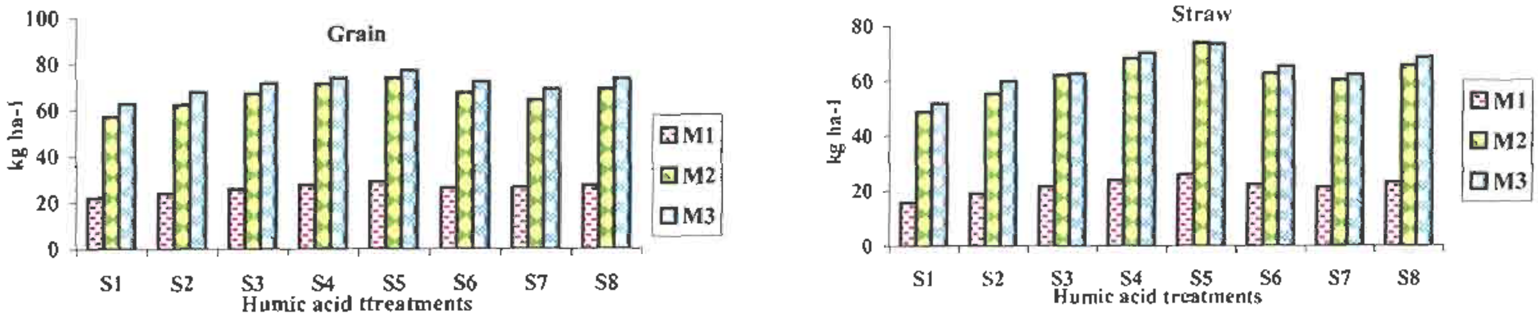


Fig 12. Effect of humic acid and fertilisers on N uptake by rice (ADT 39)-Inceptisol



efficiency of applied nitrogen fertilisers in the presence of HA (Guminski, 1968) as evident from the higher response ratio obtained in the present study (Annexure IV). HA application would have sustained the flow of ammoniacal nitrogen for longer period of time and it was clearly revealed by the higher available N content of soil in the present study. When such N availability was coupled with enhanced activation of roots, it would have led to the better utilisation of N by rice. This is in agreement with the findings of Govindasamy *et al.* (1989). According to Guminski (1968), HA application had a definite impact on the protein and nucleic acid synthesis, which indirectly indicated the increased uptake of various nutrient elements essentially N, K and Ca.

Humic acid application favourably influenced the P uptake of rice. The significant increase in P uptake was observed at 10 kg $ha^{-1}$ in all the growth stages of rice in Alfisol. But in Inceptisol, the trend was different. Significant increase in P uptake occurred at lower level of HA (10 kg HA $ha^{-1}$) at tillering. As the growth of rice advanced, the P uptake was significant at higher levels of HA (Fig 13 and 14). In Alfisol, 10 kg of HA $ha^{-1}$ itself would have mobilised enough of P to meet the crop need throughout its growth. Probably the rich native P would have contributed to P nutrition in the presence of 10 kg HA $ha^{-1}$. In contrast, in Inceptisol, more than 10 kg HA $ha^{-1}$ would have needed to meet the P requirement of rice. The variations in the levels of HA to bring about the significant effect on P nutrition of rice might be attributed to the native P and other chemistry of soil towards P release. The results have clearly showed that, the dose of HA would differ in different soil types to produce marked effect on nutrition of crops. The increased P uptake was ascribed to the action of forming humo phospho complexes, which could be easily assimilable by plants (Szymanski, 1962) and this explains the more of P uptake by rice in the present study. Vaughan and Ord (1985) reported that, the higher P uptake by rice could be due to development of P uptake capacity in plants through the stimulating effect of HA. In the presence of humates, the plants could use phosphate

Fig 13. Effect of humic acid and fertilisers on P uptake by rice (ADT 36)-Alfisol

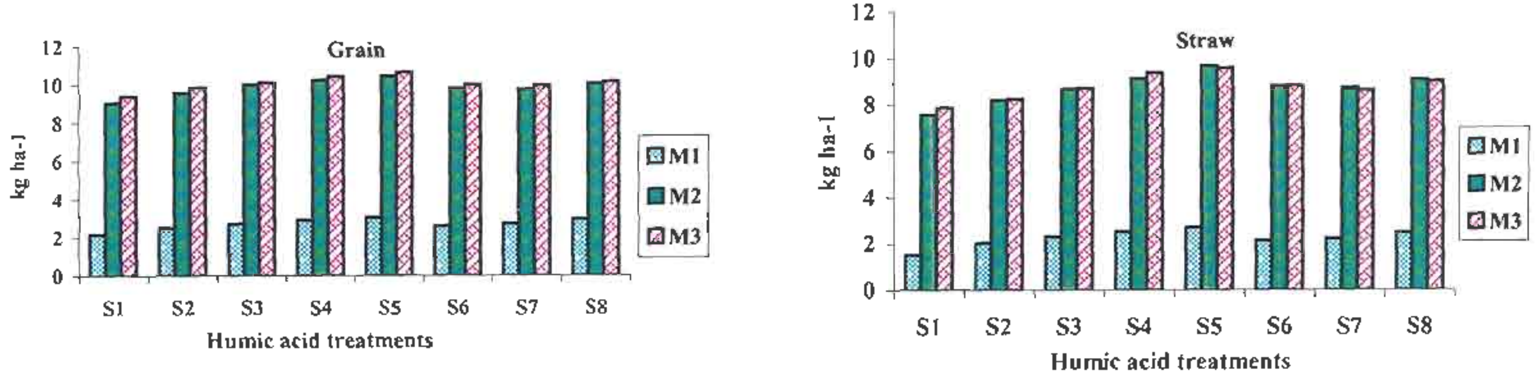
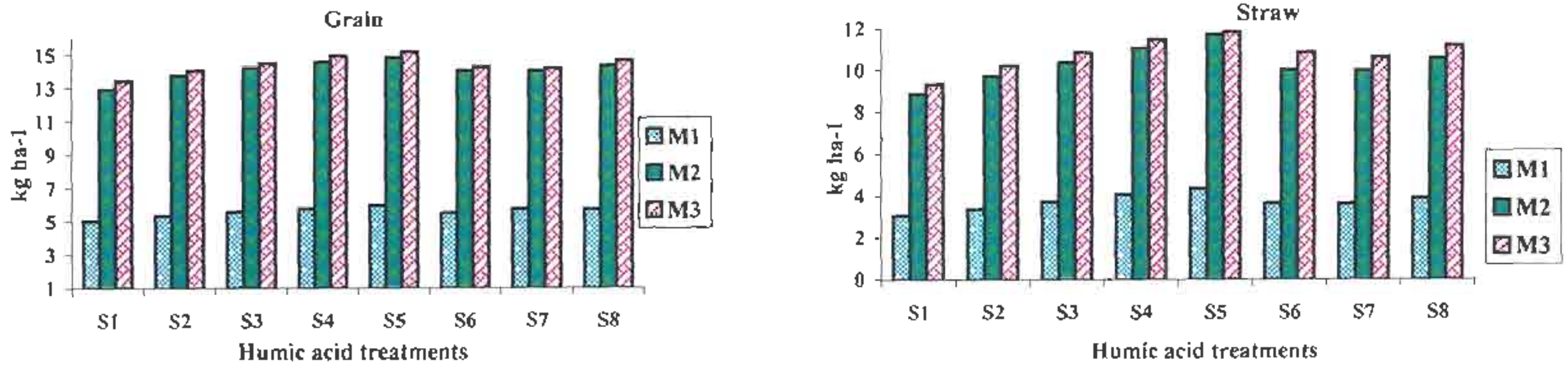


Fig 14. Effect of humic acid and fertilisers on P uptake by rice (ADT 39)-Inceptisol



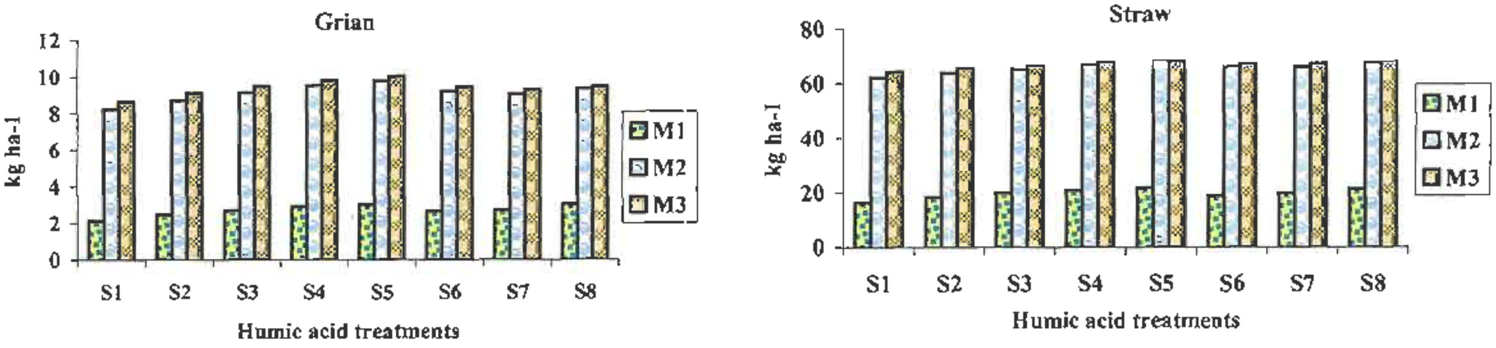
fertilisers fully as the humic molecules and the phosphate anion compete on an almost equal basis. Anion exchange phenomenon could be another reason for increasing P availability and higher P uptake by rice (Deb and Datta, 1967).

Potassium uptake by rice was also marked due to HA application. The K uptake significantly increased up to 10 kg $ha^{-1}$ in both Alfisol and Inceptisol (Fig 15 and 16). Rice being a monocot it could have taken up more amount of K by virtue of its high root CEC (Tisdale *et al.*, 1997), which was increased due to HA. The mobile nature of K and increase in the root volume would also have resulted in higher K uptake. The increased K content of the soil due to HA application as indicated in the present study would have led to more K absorption by rice.

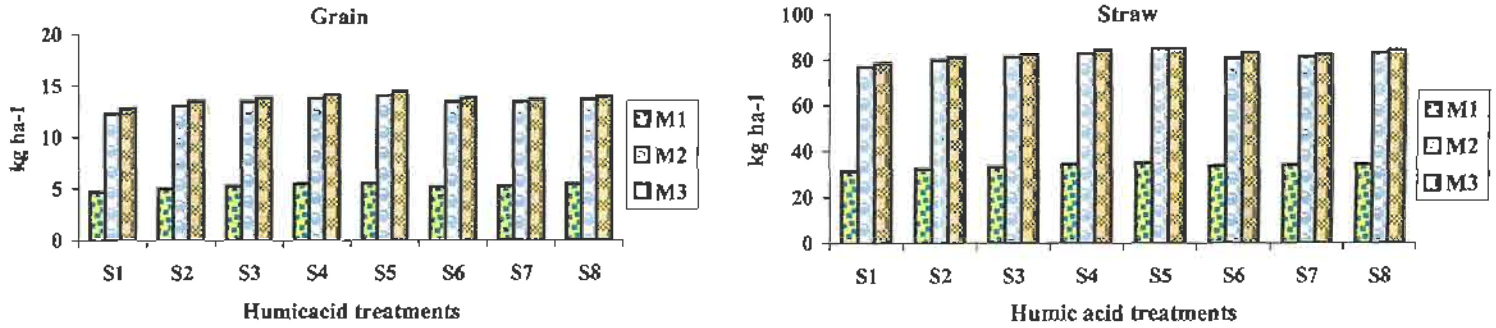
The uptake of Ca and Mg significantly increased up to 20 kg $ha^{-1}$ in Alfisol and 40 kg $ha^{-1}$ in Inceptisol. The increased Ca and Mg uptake could probably be because of their increased availability by the HA application in soil as evident from the observation made in the present study.The results of Mylonas and McCants (1980) are in corroboration with the above results. In addition to the increased availability, the increased root volume and length might have paved way for increased Ca absorption.

Application of HA increased the uptake of micronutrients by rice. In Alfisol marked increase was up to 40 kg HA $ha^{-1}$ while in Inceptisol, the maximum dose to get significant effect was 30 kg $ha^{-1}$. In straw, beyond 10 kg HA $ha^{-1}$, no marked change in micronutrient uptake could be noticed. The increase in the uptake of micronutrient might be due to increased root activity. In addition, the formation of soluble humus chelates in soil would have favoured the increased micronutrients uptake ( Fortun and Polo,1982).

## Fig 15. Effect of humic acid and fertilisers on K uptake by rice (ADT 36)-Alfisol



## Fig 16. Effect of humic acid and fertilisers on K uptake by rice (ADT 39)-Inceptisol



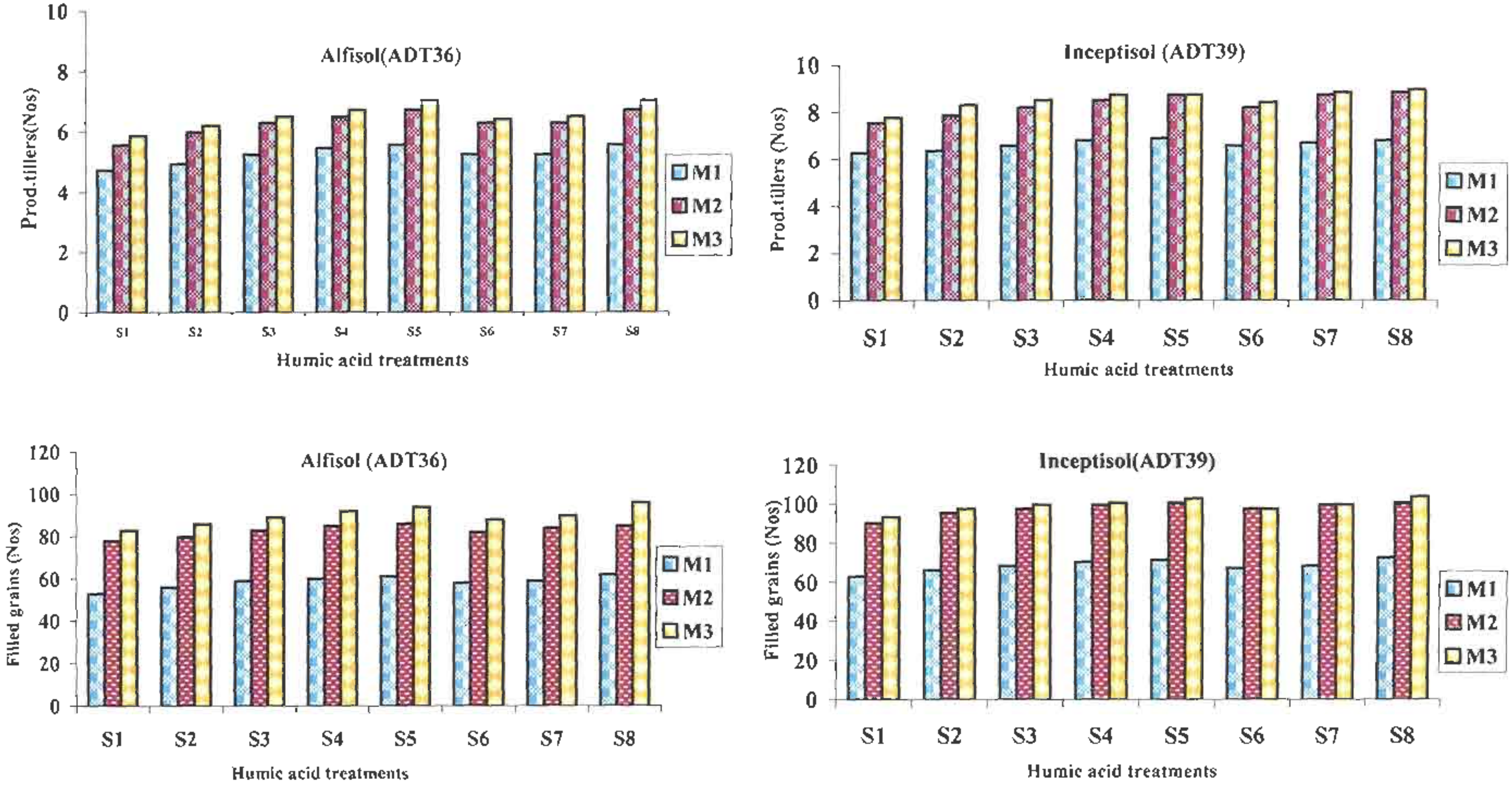
The results have clearly highlighted that HA levels to bring out pronounced effect on rice nutrition would depend largely on soil type, rice variety and yield. On Alfisol, the significant effect on nutrient uptake by a short duration variety of rice was observed up to 20 kg $ha^{-1}$ . In contrast, on Inceptisol, the medium duration variety of rice recorded significantly high amount of N, P and K for the application of HA at a level higher than 20 kg $ha^{-1}$ especially as growth advanced towards maturity.

## 5.7. Yield and yield attributes of rice

### 5.7.1. Yield attributes

In general, favourable effect of humic acid on yield attributes such as productive tillers, filled grains, panicle length and thousand grain weight was recorded in rice (Fig 17). Though the improvement was observed with graded dose of HA, the significant effect was observed for 20 kg $ha^{-1}$ in Alfisol and for 30 kg $ha^{-1}$ in Inceptisol. The HA was reported to augment the rate of respiration in roots, facilitating the release of greater energy that could be used for higher cell division and growth of plants. Further the rapid growth of plants was explained on account of rapid utilization of reserve materials, when respiration rate was accelerated leading to more synthesis and growth (Smidova, 1960). In addition to respiration of roots, cell permeability also reported to get increased due to HA application and favoured the growth of plants at cellular level also (Sanders *et al.*, 1993). The HA also found to have auxin like properties. The enhanced and prolonged activity of IAA in plants was reported due to increased ortho-dihydric phenols in the presence of HA resulting in better growth (Mato *et al.*, 1971). These factors lent support to the finding of the significant increase in number of productive tillers per hill in rice recorded in the present study. Ravindraprasad (1988) reported similar beneficial effect of application of HA on number of productive tillers in rice. Pandey and Sinha (1998) reported increased bud development in wheat due to HA application indicating its growth promoting effect.

Fig 17. Effect of humic acid and fertilisers on yield attributes of rice



The marked effect of HA on filling of paddy grain reported to be on account of enhanced activity of hydrolysing and oxidising enzymes and the resultant increase in mobilisation of reserve food materials to the sink for grain filling (Mato and Mendoz, 1970). The improved photosynethic activity in the presence of HA (Khristeva and Lokyanenka, 1962) could be quoted to be the cause for increased grain filling. It was also reported that a rise in the content of phenolics due to HA in rice (Balasubramanian *et al.,* 1989; Senthilkumar, 2001) and in groundnut (Arunash, 2001) would have led to increase in the number of filled grains (Datta and Nanda, 1985). Mandal *et al.*(1989) reported that the application of HA through soil and root dipping produced the highest number of productive tillers, filled grains and grain yield. These reports also support the observations recorded in the present study.

As stated by Ravindraprasad and Chandrasekaran (1988), the increased thousand grain weight and filled grains could be ascribed to the continuous supply of nutrients in the presence of HA during grain filling stage of rice and it might have suppressed the number of chaffy grains also. Seitz (1960) reported that, the very high ion exchange capacities of humate brought about better utilisation of fertilisers by making nutrients available in the root zone and this would also have produced the positive effect on yield and yield attributes of rice.

Mallikarjunarao *et al.* (1987) reported that, the application of HA facilitated highly branched roots and the resultant increase in surface area. Similar effects of HA on root system was observed in the present study for the HA application to soil as well in the combined methods of application viz., soil application with foliar spray and root dipping. Probably this would have promoted more efficient nutrient absorption, which could have improved the growth and yield attributes of rice.

Humic substances can regulate plant growth not only by promoting better physical environmental conditions and storing a higher concentration of ions in the soil, but also by interfering with plant metabolism (Agnola and Nardi, 1987), which improved the translocation of absorbed nutrients in the plant. Rauthan and Schnitzer (1981) reported that, by complexing with metal ions, the HA increased the solubility of nutrients and made them available to plant roots. The increased NPK availability in soil and improved nutrient supply would have increased the yield attributes of rice as evident from the observations made in the present study.

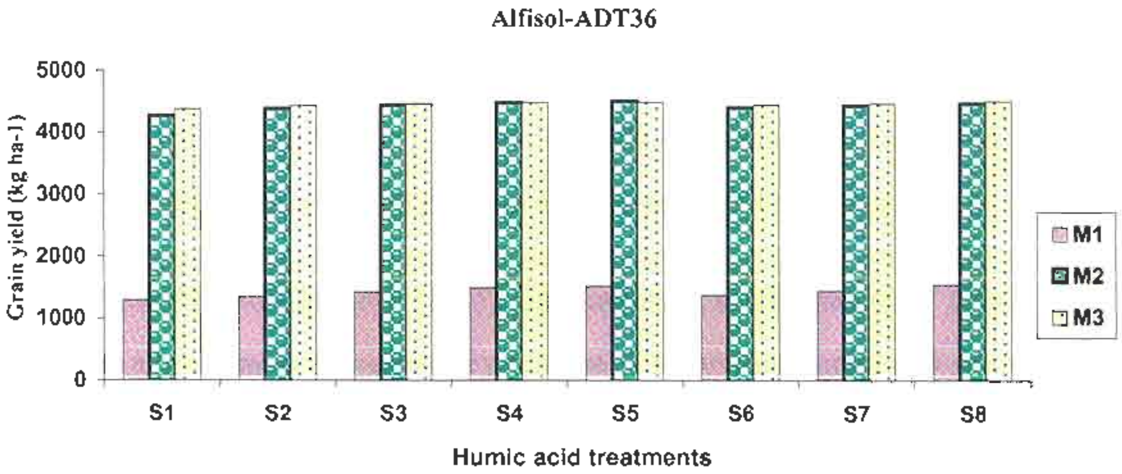
In all the experiments, presence of HA produced better effect on yield attributes than in its absence. The HA along with NPK fertiliser was found to have the best effect on yield attributes. In the presence of HA, the effect of 75 and 100 percent NPK fertilisers on yield attributes was comparable with each other. The positive effect of applied fertiliser combined with HA on growth and root production would have caused a greater uptake of nutrients. This would have resulted in impressive yield and yield attributes as observed in the improved yield attributes of the treatment where soil application of HA was coupled with RD.

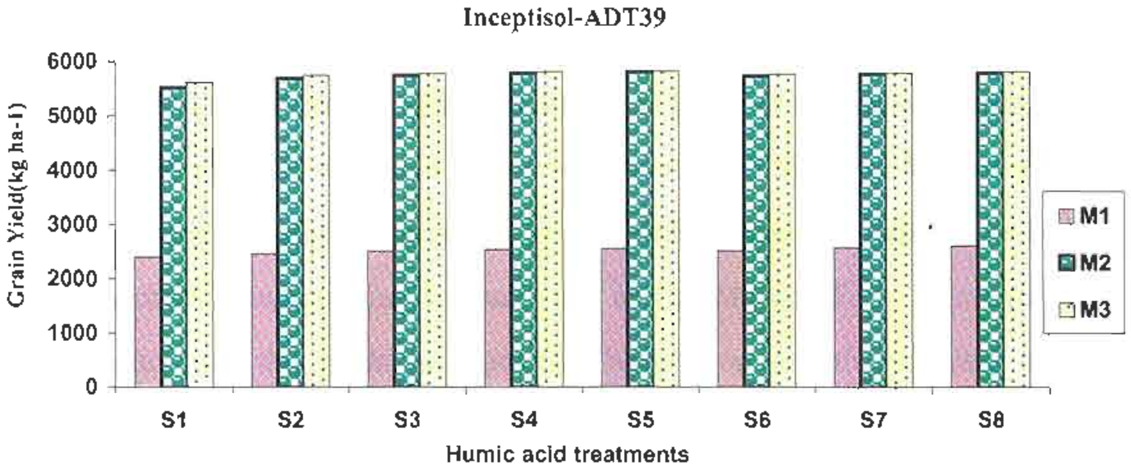
Alexsandrova (1978) reported similar beneficial impact of combined addition of mineral and organic fertilisers on yield and yield attributes. The result of the present investigation had clearly highlighted the fact that, the fullest benefit of humic acid could be realised only when the sufficient nutrients were present in the soil, which could be achieved by combining NPK fertilizer with HA.

### 5.7.2. Grain and straw yield

Application of HA at graded doses (0 to 40 kg $ha^{-1}$) increased the grain and straw yields markedly (Fig18) in both soil types. The increase was found to be

Fig18. Effect of humic acid and fertilisers on grain yield of rice-Rabi season





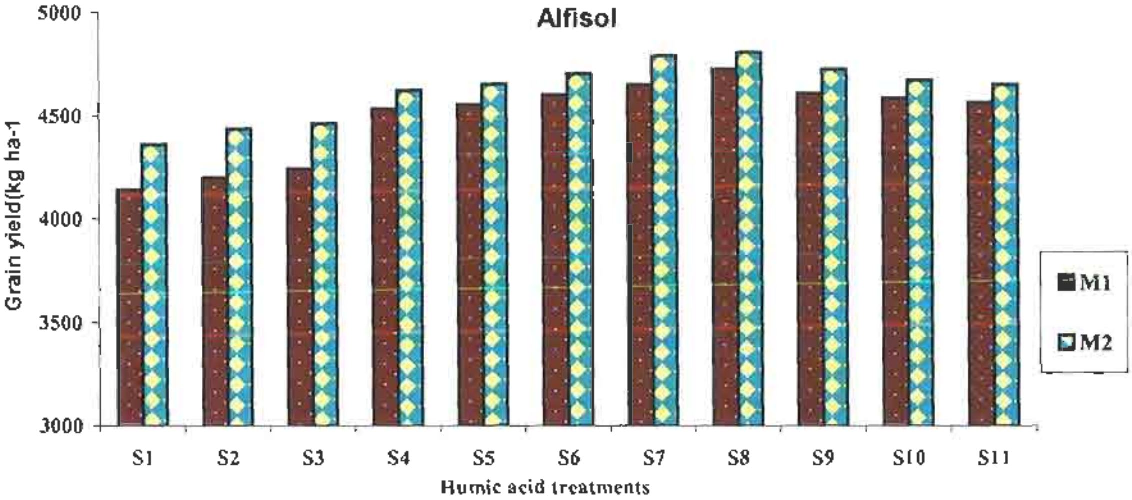
significant up to 20 kg HA ha$^{-1}$, there after there was a diminishing trend on the increase due to HA addition. When HA was applied @ 10 kg ha$^{-1}$ coupled with FS or RD or both, there was significant increase in the grain and straw yields than obtained in 10 kg HA ha$^{-1}$ alone. It was also shown that, the 20 kg HA ha$^{-1}$ was as good as 10 kg HA ha$^{-1}$ with FS and RD. (Fig 19). The test verification result showed that, the application of 100 per cent NPK +10 kg HA ha$^{-1}$ plus FS and RD of humic acid had given higher yield but it was comparable with 75 per cent with the same HA combination.

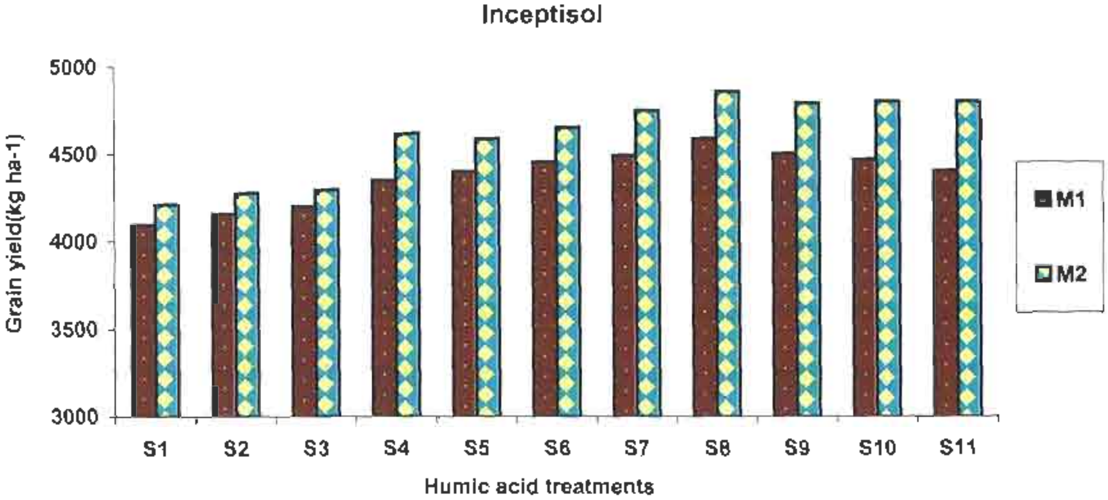
According to Khristeva (1953), application of small amount of humic acid would act as a hormone and a respiratory catalyst. The increased grain and straw yield with the application of humic acid could be explained on the fact that, enzyme systems are activated, cell division is accelerated and the root system shows greater development (Gaur and Mathur, 1966). The increased yield was reported for increasing concentration of humic acid (Babu *et al.*, 1989). The increased yield at graded doses of HA might be due to the efficient utilization of nutrients, improved aeration and water holding capacity observed in the humic acid applied treatments (Haripriya *et al.*, 2002).

Anuratha (1994) reported that grain and straw yields of rice were conspicuously increased by the application of urea coated with humic acid @ 30 kg ha$^{-1}$ along with green leaf manure. Soil application of HA as localized addition was found to be highly effective in contributing nutrient elements such as Ca, Mg and Fe to plants through chelation action and this might be promoting better crop growth and yield of rice (Andreu *et al.*, 1994).

The favorable effect of foliar spraying of HA on increasing yield (Nair.,1995) was attributed to increased levels of chlorophyll in leaves and consequently enhanced photosynthetic activity and to the higher uptake of nutrients like P (Xudan, 1986; Senthil Kumar, 2001).The yield increase due to root dipping could be attributed to the

Fig 19. Effect of humic acid and fertilisers on grain yield of rice-Kharif season





accelerated metabolic activities in the rice plant by HA absorbed through the roots directly from their surface and transported to other plant parts (Govindasamy and Chandrasekaran, 1989). Schnitzer and Khan (1972) also reported the enhanced metabolism in plants on account of direct uptake of humic substances through roots. Probably the HA were of low molecular weight substances and hence their absorption by roots might be made easy.

Addition of HA would have resulted in the increase of ortho dihydric phenols and subsequent increase in the IAA concentration of plant (Mato *et al.,* 1971). This increase in turn would have increased the growth activities of the rice crop leading to higher dry matter production and yield.The inhibitory effect caused by high concentration of HA could be due to growth inhibitory effect rather than the growth promoting effect. (Sanfilippo *et al.*, 1990). Kononova and Pankova (1950) also reported similar effect of decreased rice yield at higher concentration of HA.

Application of HA and NPK fertilisers produced pronounced effect on grain and straw yield of rice in all the experiments. In the presence of humic acid, the 75 per cent NPK fertiliser was found to be as effective as 100 per cent NPK fertiliser. The use efficiency of fertiliser nutrients at reduced level in the presence of humic acid would have been such that it could bring the yield level of 75 per cent NPK on par with 100 per cent NPK. Mathur and Gaur (1977) proved the greater use efficiency of nitrogenous fertilisers with humus. Guminski *et al.* (1965) also reported the better fertilising effect of lignite by virtue of its ability to complex ions and subsequently rendering the largely available nutrients for absorption by the crop. The results revealed the complimentary effect of HA on NPK use by rice. It was better expressed in reduced dose (75 per cent) of NPK and thus resulting in comparable response in rice as that of higher dose of NPK (100 per cent). The results of test verification trial also confirmed this finding (Fig 20).

Fig 20. Effect of humic acid and fertilisers on grain yield of rice

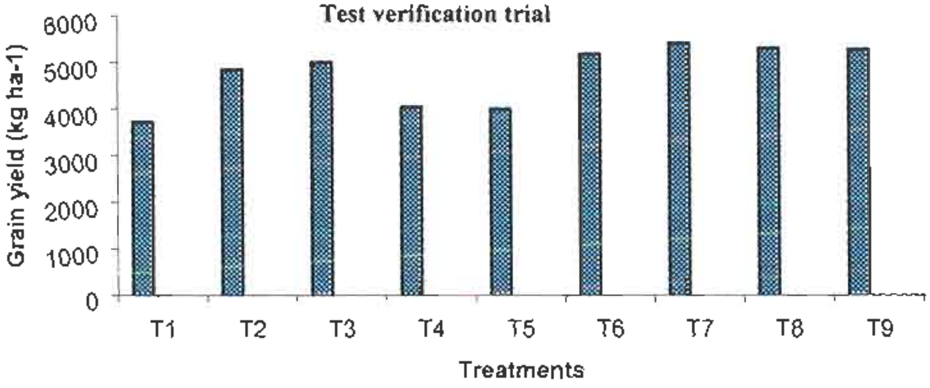
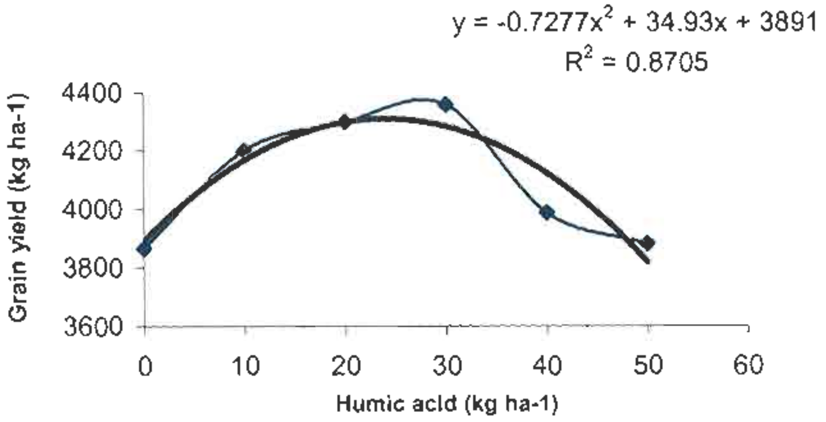


Fig 21. Optimisation of humic acid dose for rice



From the above results it is inferred that, rice yield was enhanced largely with the application of HA. In both the soils the response of rice to the HA application at graded levels was found to increase significantly up to 20 to 30 kg $ha^{-1}$ of HA and diminish with increase in the dose of HA. On Alfisol, the highest grain yield of 3517 kg $ha^{-1}$ was produced under 40 kg HA $ha^{-1}$, which was comparable with that produced by 20 kg $ha^{-1}$ (3450 kg $ha^{-1}$). On Inceptisol, the highest yield of 4738 kg $ha^{-1}$ was obtained with 40 kg HA $ha^{-1}$ and it was comparable with that obtained for 30 kg HA $ha^{-1}$ (4716 kg $ha^{-1}$) and significantly higher than that obtained at 20 kg $ha^{-1}$ (4682 kg $ha^{-1}$). The results of four experiments conducted in both the soils, had highlighted that, application of HA @ 10 kg $ha^{-1}$ along with FS and RD was as effective as application of HA @20 kg $ha^{-1}$ in augmenting the rice yields. It was also observed that the rice response to soil application of HA and RD was higher than that observed for soil application and FS.

### 5.8. Optimisation of humic acid for rice

The yield of rice grain exhibited diminishing trend in the yield increase with increasing levels of HA. Hence, the yield data recorded for the graded levels of HA were fitted in a quadratic function and the HA doses were optimised for different yield levels of rice. From the quadratic equation, the HA required for maximum yield of rice was found to be 24 kg $ha^{-1}$ and for economic yield it was 18.5 kg $ha^{-1}$ on Inceptisol of Tamil Nadu (Fig 21).

### 5.9. Economic analysis of yield data

The economics of application of humic acid with and without fertilisers were worked out using the yield data. The BCR, response ratio, relative agronomic effectiveness (RAE), relative economic effectiveness (REE) and price ratio were calculated (Annexure IV). From the economic analysis it could be inferred that the response for added HA was more in the presence of fertiliser especially at 75 per cent NPK combined with FS + RD than 100 per cent NPK with HA combination or HA alone. The recommended dose of 75 per cent NPK combined with RD or FS + RD recorded higher BCR, RR and price ratio, bring forth the better use efficiency of added NPK in the presence of HA in the soil as well as in the plant parts viz., leaves and roots. Bhuma (2001) observed similar improved efficiencies of added nutrients in pulse crop.

# SUMMARY AND CONCLUSION

# CHAPTER VI

# SUMMARY AND CONCLUSION

The dynamics of organic matter in tropical soils is characterised by very rapid turnover interms of degradation and synthesis. Sustained higher crop production can be achieved by the maintenance of soil fertility. It has long been recognised that soil organic matter is the key to soil fertility. Currently recycling of organic matter to soil by various sources is declined due to intensive crop cultivation. Humic substances is a product of organic matter decomposition, which have humic acid as one of its constituents known to promote growth and yield of the crops. The metal humates are commonly used as organic fertilisers. They contain humic acid in larger proportions. The HA which is extracted from lignite have manifold role on crop growth and soil fertility. The importance of organic matter for rice cultivation is very well brought forth by the earlier research. Hence, the present investigation was undertaken to study the influence of lignite humic acid with and without NPK fertilisers on rice response and soil fertility in Alfisol and Inceptisol. The salient findings of the investigation are summarised hereunder.

☛ Studies on the characterisation of HA as potassium humate carried out by Fourier Tansform Infrared Spectroscopy and Carbon Hydrogen and Nitrogen (CHN) analyser showed the presence of various quantities of functional groups like phenolic and carboxyls and elements like C, H, N and O, thereby indicating their reactiveness in ion exchange properties. The other characteristic properties of potassium humate were its dark brown colour, neutral to alkaline pH, high cation exchange capacity (103-125 cmol (p+) $kg^{-1}$) and the organic carbon content (29 to 34 per cent). The $E_4$ / $E_6$ ratio is the degree of aromatisation and condensation of aromatic rings ranged between 1.95 and 2.20.

☛ Delineation of soils of western zone for organic carbon indicated its low status in most of the soils studied highlighting the importance of its build up as well as that of humic substances in the soils through external addition of organic matter or any organic material so as to improve the soil fertility and productivity.

☛ Adsorption studies conducted using HA and P on Alfisol exhibited a reduction in the bonding energy coefficient of P, which had a negative influence on P sorption and that had resulted in an increase of the solution P concentration.

☛ Incubation experiment was conducted with graded levels of HA on Alfisol and the pattern of N, P and K release and the changes in OC and CEC were studied. The findings emanated from the above studies are as follows.

★ A linear trend in the release of N, P and K was observed for the application of HA. The release of N was significant up to 20 kg of HA ha$^{-1}$, whereas for P and K it extended up to 40 kg ha$^{-1}$. The N and P were released for a longer period of 60 days, while K release attained a plateau on 45 DAI. At the end of incubation period, there was a steep and significant increase of organic carbon and CEC up to 40 kg HA ha$^{-1}$.

☛ The research findings emanated from the pot and field experiments are as follows.

★ The Alfisol and Inceptisol were enriched with OC content due to application of HA at graded doses. With reference to application of HA through different means, the results have clearly highlighted that soil application of HA at high levels alone could enrich the soil with OC and not through root dipping and foliar spray. The HA in combination with either @100 per cent recommended dose of NPK or 75 per cent had an added effect on OC content of the soils. The reduced level of NPK to an extent of 25 per cent did not bring about significant difference in OC content.

★ The CEC increased with increasing doses of HA, but the significant effect was observed for 20 kg ha$^{-1}$ in both Alfisol and Inceptisol. Regarding the methods of application of HA, soil application exerted profound effect on CEC than foliar spray and root dipping. There was conspicuous variations brought out by HA between NPK applied and no NPK applied treatments. As in OC in CEC also reduced level of NPK did not affect the possible impact of HA on CEC.

★ Application of HA up to 40 kg ha$^{-1}$ increased the NPK availability. Profound effect of HA up to 20 kg ha$^{-1}$ was observed and beyond that there was a diminishing trend in the increase at all the three stages of rice growth. Among the soil application, root dipping and foliar spray of HA, the later two methods were not as good as that of soil application in accentuating the availability of NPK. The micronutrient availability showed increasing trend up to 20 kg ha$^{-1}$ in both the soils. The combined application of NPK fertilizer with HA favourably influenced the available N, P and K content of soil.

★ Application of HA produced pronounced effect on root characteristics such as root volume, root CEC and root length, which was further improved in the presence of NPK fertiliser applied either @ 100 or 75 per cent of recommended dose in both the soil types.

★ The HA levels to bring out pronounced effect on rice nutrition would depend largely on soil type, rice variety and yield. On Alfisol, the significant effect on nutrient uptake by a short duration variety of rice was observed up to 20 kg ha$^{-1}$. In contrast, on Inceptisol, the medium duration variety of rice recorded significantly high amount of N, P and K uptake for the application of HA at a level higher than 20 kg ha$^{-1}$ especially as growth advanced towards maturity. There was an enhanced nutrient uptake when HA accompanied the NPK fertilisers.

★ Appreciable improvement in the yield attributes such as productive tillers, filled grains, panicle length, thousand grain weight and reduction in chaffy grains was observed with graded dose of HA, but the significant effect was observed for 20 kg $ha^{-1}$ in Alfisol and for 30 kg $ha^{-1}$ Inceptisol. In the presence of HA, the effect of 75 and 100 percent NPK fertilizers on yield attributes was comparable with each other.

★ In both the soils, the response of rice to the HA application at graded levels was found to increase up to 40 kg HA $ha^{-1}$. On Alfisol, the significantly higher grain yield was produced at 20 kg $ha^{-1}$ whereas on Inceptisol, the highest yield was obtained at 30 kg HA $ha^{-1}$.

★ The results of four experiments conducted in both the soils had highlighted that, the soil application of HA @ 10 kg $ha^{-1}$ along with FS and RD was as effective as soil application of HA @ 20 kg $ha^{-1}$ in augmenting the rice yields. It was also observed that the rice response to soil application of HA and RD was higher than that observed for soil application and FS. The grain yield in the combined application of HA with NPK at 100 per cent recommended dose was as good as that of HA with 75 per cent NPK

★ The optimisation of humic acid dose was attempted and the result showed that 18.5 kg $ha^{-1}$ of HA as the dose for economical optimum and 24.0 kg $ha^{-1}$ for physical optimum for rice in Inceptisol of Tamil Nadu.

★ The response of rice to the application 75 per cent NPK fertilizer with HA @ 10 kg $ha^{-1}$+ FS+ RD or 75 per cent NPK + 20 kg HA $ha^{-1}$ was better performed than the same HA treatment combination with 100 per cent NPK as evident by the high RR, BCR and low PR.

The results of the present investigation clearly highlighted the fact that, the fullest benefit of humic acid could be realised only when the sufficient nutrients were present in the soil, which could be achieved by combined application of NPK fertiliser with HA. The results also revealed the complimentary effect of HA on NPK use by rice. It was better expressed in reduced dose of NPK (75 per cent NPK) and resulting in comparable response in rice as that of higher dose of NPK fertiliser (100 per cent NPK). From the economic point of view, applying 10 kg of HA ha$^{-1}$ with FS and RD was found to be better than 20 kg ha$^{-1}$ of soil application. However, from the fertility point of view, application of HA even up to 40 kg ha$^{-1}$ had produced beneficial effect such as building up of OC, increasing CEC, root proliferation and nutrient availability.

# REFERENCES

# REFERENCES

Abo-El-Fadl, M., N.A., Bayoumi and S.M.A.El. Barbary. 1992. Characteristics of humic acids extracted from some soils of the Nile Delta in Egypt. **Egypt. J. Soil Sci., 32**: 119-129.

Agnola, G.D. and S. Nardi. 1987. Hormone like effect and enhanced nitrogen uptake induced by depolycondensed humic fractions obtained from *Allolobophora rosea* and *A. caliginosa* faeces. **Biol. Fert. soils. 4**: 115-118.

Aleksandrova, T.V. 1978. Soil organic matter and the nitrogen nutrition of plants. **Soviet Soil Sci., 77**: 293-301.

Allison, F.E. 1973. Soil organic matter and its role in crop production. Elsevier, New York.

Andreu, S., J. Jovda and M. Jucreaz. 1994. Humic substances, Incidence on crop fertility. **Acta Hort.,** 357.

Anuratha, A. 1994. Studies on the interaction of humic acid treated urea and organic manure enriched rock phosphate in rice soil. M.Sc. (Ag.) thesis, Agrl. College and Research Institute, Madurai, Tamil Nadu

Arias, M., M.T. Barral and F.D. Fierros. 1996. Effect of associations between humic acids and iron or aluminium on the flocculation and aggregation of kaolin and quartz. **Eur. J. Soil Sci., 147**: 335-343.

Arunash, A.A.D. 2001. Effect of humic acid treatments on growth and development of ground nut under different fertilizer levels. M.Sc (Ag) Thesis, TNAU, Coimbatore.

Arya, R., B.R.Gupta and P.D. Bajpai. 1984. Distribution of organic phosphorus in humus fractions in some soils of Uttar Pradesh. **J. Indian Soc. Soil Sci., 32**: 42-51.

Aso, S and J. Sakai. 1963. Studies on the physiological effect of humic acid (Part 1). Uptake of humic acid by crop plants and its physiological effects. **Soil Sci. Pl. Nutr., 9:**1-5.

Azam, F.E. and K.A. Malik. 1983. Effect of humic acid soaking of seeds on seedling growth of wheat under different condition. **Pakistan. J. Bot., 15**: 31-38.

Babu, M., R. Govindasamy and S. Chandrasekaran. 1989. Effect of humic acids on the yield and composition of peanut in calcareous soil. In: **Proc. National Seminar on "Humus acids in agriculture"**, Annamalai University, Tamil Nadu. pp.131-138.

Balasubramanian, A., R. Siddaramappa and G. Rangaswami. 1972. Effect of organic manuring on the activities of the enzymes hydrolysing sucrose, urea and on soil aggregation. **Pl. Soil, 37:** 319-328.

Balasubramanian, P., R. Govindasamy and S. Chandrasekaran. 2002. Changes in content and uptake of mineral nutrients in soybean by the addition of lignite humic acid. **In: National seminar on recent trends on the use of humic substances for sustainable agriculture,** Annamalai University, Tamil Nadu. p.12

Balasubramanian, P., S. Chandrasekaran and R. Govindasamy. 1989. Effect of humic acid on the growth and changes in phenolics of rice seedlings (*Oryza sativa* L.)variety IR 50. **In: Proc. National seminar on "Humus acids in agriculture",** Annamalai University, Tamil Nadu. pp.201-207.

Bama, K.S and G. Selvakumari. 2001. Effect of humic acid on growth, yield and nutrition of amaranthus. **South Indian Hort., 49**: p.155-156

Bama, K.S and G. Selvakumari. 2002. Optimisation of humic acid for maximum and economic yield of rice (ADT 36) in an Inceptisol. **In: National seminar on recent trends on the use of humic substances for sustainable agriculture**, Annamalai University , Tamil Nadu.

Banerjee, S.K. and R.K. Basak. 1978. Studies on ammonia and urea treated humic substances and their interaction with some heavy metal ions. **J. Indian. Soc. Soil Sci., 26**: 347-351.

Bartoli, F. and R. Philippy. 1990. Al-Organic matter associations as cementing substances of ochreous brown soil aggregates, preliminary examination. **Soil Sci**., **150**: 745-751

Basak, V.K. and S.K. Ghosh. 1999. Adsorption of humic substances on synthetic amorphous aluminosilicates of varying Si / Al molar ratio. **J. Indian Soc. Soil Sci., 47**: 200-205.

Basu, A.N., D.C. Mukherjee and S.K. Mukherjee. 1968. Interaction between humic acid fraction of soil and trace element cations. **J. Indian Soc. Soil Sci., 12**: 315-318.

Bear, F.E. (Ed.) 1976. Chemistry of the soil, 2nd Edn. Oxford and IBH Publishing Co., New Delhi.

Beckwith, R.S. 1955. Metal complexes in soils. **Aust. J. Agrl. Res., 6**: 685-698.

Bhandari, G.S., M.S. Maskina and N.S. Randhawa. 1970. A study of humic and fulvic fractions of soil of different agroclimatic regions of the erstwhile Punjab. **Geoderma, 3**: 239.

Bhuma, 2001. Studies on the impact of humic acid on sustenance of soil fertility and productivity of green gram (VBNGG2). M.Sc(Ag) Thesis, TNAU, Coimbatore.

Blondeau, R. 1989. Biodegradation of natural and synthetic humic acids by the white rot fungi phanerochoaete *Chrysos porium*. **Appl. Environ. Microbiol., 55**: 1282-1285.

Bonmati, M., H. Pujola, J. Sana, Soliva, M. Felipo, M. Garau, B. Ceccanti and P. Nannipieri. 1985. Chemical properties, populations of nitrite oxidizers, urease and phosphatase activities in sewage sludge amended soil. **Pl. Soil. 84**: 79-91.

Boul, S.W., F.D.Hole and R.J.McCracken. 1980. Soil genesis and classification. Oxford & IBH Publishing Co. Pvt., Ltd., New Delhi.

Brady, N.C. 1996. The nature and properties of soils. 10th edition. Prentice Hall of India Pvt., ltd. New Delhi.

Brydon, J.E. and E.J. Sowden. 1959. **Can. J. Soil Sci., 39**: 136.

Bundy, L. G and J.M. Bremner. 1973. Effect of substituted P benzoquinones on urease activity in soils. **Soil Biol. Biochem., 5**: 847-853.

Cegarra, J., A. Vazquez, F. Costa, A. Lax and E. Morgan. 1987. Changes undergoes by some characteristics of organic wastes during the composting process. In: compost : production quality and use. M. Bertoldi, M.P. Ferranti, P.L. Hermite and F. Zuccoli (eds.), Elsevier, London, pp. 776-780.

Celi, L., M. Schnitzer and M. Neygre. 1997. Analysis of carboxyl groups in soil humic acids by a wet chemical method, fourier transform infrared spectrophotometry and solution state carbon nuclear magnetic resonance. A comparative study. **Soil Sci**., **162:** 189-197.

Chandrasekaran, S. 1989. Efficient use of fertilizers by crops with humic acid addition in soils.Dr. N.R. Dhar Memorial Lecture. 22nd Annual Meeting of the Indian Society of Agricultural Chemists held on 11th and 12th Dec at TNAU, Coimbatore.

Chandrasekaran, S. 1992. Efficient use of fertilizers by crops with humic acids addition in soils. **Indian J. Agrl. Chem., 25**: 129-141.

Chaney, K. and R.S. Swift. 1984. The influence of organic matter on aggregate stability in some British soils. **J. Soil Sci., 35**: 223-230.

*Chapman, H.D.1965. **Monog. Am. Soc. Agron., 9**: 891

Chen, Y. and F.J. Stevenson. 1986. In: The role of organic matter in Modern Agriculture. Moprtinus Nishoff, Dord recht, The Netherlands, p.73-116.

Chen, Y. and M. Schnitzer. 1976. Water adsorption on humic substances. **Can. J. Soil Sci., 56**: 521-524.

Chen, Y. and T. Aviad. 1985. Effects of humic substances on plant growth. In: Proc. Humic substances in soil and crop sciences: Selected Readings. Symposium co-sponsored by the Intl. humic substances society (ed). Maccorthy. **Abstrs. Soils. Fert.,** 1991, **54:** P. 350.

Chen, Y., A. Banin and M. Schnitzer. 1976. Use of the scanning electron microscope for structural studies on soils and soil components. **In: Proc. Intl. Symp. Scanning. Electron Microscopy** (O.Joharil ed.), pp.425-432. ITT Research Institute, Chicago.

*Chen, Z. and S. Pawluk. 1995. **Geoderma, 65**: 173.

Chen,Y. and M. Schnitzer.1978. The surface tension of soil humic substances. **Soil Sci., 125**: 17-15.

Concheri, G., S. Nardi, F. Reniero and G.D. Agnola. 1996. The effect of humic substances within the Ah horizon of a calcic luvisol on morphological changes related to invertase and peroxidase activities in wheat roots. **Pl. Soil, 179**: 65-72.

Czerney, P. and H.J. Fiedler. 1968. Rahmenwerte fur die chemischen eigenschaften von Fichten humus. **Wissenschaftl. Zeitschr. Tech. Univ., Dresden, 17**: 223.

Das, M., S.K. Khan and B.P. Singh. 2000. Characterisation of humic acid under different land use systems existing in the hills of Meghalaya. **Ann. Agric. Res., 21:** 216-222.

*Datta, A., S.K. Sanyal and S. Saha. 2001. **Pl. Soil, 235**: 115.

Datta, K.S. and K.K. Nanda. 1985. Effect of some phenolic compounds and gibberellic acid on growth and development of cheena millet. **Indian J. Plant Physiol., 28**: 298-302.

David ,P.P., V. Nelson and D.C.Sanders.1994.Humic acid improves growth of tomato seedling in solution culture. **J. Pl. Nutr.**,**17**:173-184.

Deb, D.L. and N.P. Datta. 1967. Effect of association of ions on phosphorus retention in soils. II. Under variable anion concentrations. **Pl. Soil, 26**: 432-444.

Deepa, M. 2001. Effect of lignite humic acid on soil microorganisms. M.Sc (Ag) Thesis, TNAU, Coimbatore.

Deepa, M. and K. Govindarajan. 2002. Effects of lignite humic acid on soil bacterial, fungal and actinomycetes population. **In: National seminar on recent trends on the use of humic substances for sustainable agriculture**, Annamalai University, Tamil Nadu.

Deiana, S., C. Gessa, B. Manunza, R. Rauza and R. Seeber. 1990. Analytical and spectroscopic characterization of humic acids extracted from sewage sludge, manure and worm compost. **Soil Sci., 150**: 419-424.

Dinel, H., G. R. Mehays and M. Levesque. 1991. Influence of humic and fulvic materials on the aggregation and aggregate stability of a lascutrine silty clay. **Soil Sci., 151**: 146-158.

Dubrova, S.N., R. Ch. Alyutdinova, E.N. Ekatrinisura and M.N. Zharova. 1984**. Chemical Abstrs, 102**: 415-475.

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

Duwayri, M.D., V.Tran and V.N. Nguyen.1999. Reflections on yield gaps in rice production. **Intl. Rice Comm. News lett., 48**:13-25.

Dyanand, S. and M.K. Sinha. 1979. Kinetics of Fe EDTA reactions in calcareous soils. **Soil Sci** ., **127**: 202-210

Edwards, A.P. and J.M. Bremner. 1967. Dispersion of soil particles by sonic vibrations. **J. Soil Sci., 18:** 47.

Elgala, A.M., A.I. Metwally and R.A. Khalil. 1978. The effect of humic acid and $Na_2$EDDHA on the uptake of Cu, Fe and Zn by barley in sand culture. **Pl. Soil, 49** : 41-48.

Felbeck, G.T. 1965. Structural chemistry of soil humic substances. **Adv. Agron**., **17**: 327-368.

Flaig, W. 1964. Effects of microorganisms on the transformation of lignin to humic substances. **Geollem. Cosmochim Acta., 28**: p.1523.

Flaig, W. 1984. In: "Organic Matter and Rice". Int. Rice Res. Inst., Manila, Philippines, pp. 73-92.

Flaig, W., Beutelspachor and B. Reiz. 1975. Chemical composition and physical properties of humic substances. In: Soil components. Vol.I. Organic compounds (J.E.Gieseking ed.) Sprigner-Verlag, Berlin, New York, pp.1-211.

*Fokin, A.D. and M.K. Sinha. 1969. Interaction of phosphate with soil humic substances. **Izveston Timiryazey Acad. Agric. Sci. 4**.

Fortun, A., C. Fortun and C. Ortega. 1989.Effect of farmyard manure and its humic fractions on the aggregate stability of a sandy-loam soil. **J. Soil Sci**., **40:** 293-298.

Fortun, C. and A. Polo. 1982. Effects of some types of humic compounds on the growth of roots of *Zea mays*. **Agrochemica., 26**: 44-54.

Frankenberger, W.T. and C.O. Nelson. 1983. Urease activity in sewage sludge amended soils. **Soil Biol. Biochem., 15**: 543-549.

Freundlich, H. 1926. Colloid and capillary. Translated from the third German edition by H.Stanford Hatfield.Methuen and Co. Ltd. Londan.

Gascho, G.F. and F.J. Stevenson. 1968. An improved method for extracting organic matter from soil. **Soil Sci. Soc. Am. Proc.**, **32**: 117-118.

Gaur, A.C. and K.K.R. Bhardwaj. 1971. Influence of sodium humate on the crop plants inoculated with bacteria of Agricultural importance. **Pl. Soil, 35**: 613-621.

*Gaur, A.C. and R.S. Mathur. 1966. **Proc. National. Academic. Sci. India, 36A**: 879.

*Ghosh, K. and M. Schnitzer, 1980. **Soil Sci**. 129-266.

Giesy, J.P. 1976. Stimulation of growth in *Scenedesmas obliquus*. (chlorophycaea) by humic acids under iron limited conditions. **J. Phycol., 12**: 172-179.

Gorovoya, A. I. and K.I. Solocha. 1971. Influence of physiologically active substances of the soil humus and fertilizers on the specific activity of meristematic cells of plant sprouts and the quality of seed grains. **In: Humus et Planta**, V: 557-566.

Govindasamy, R. and S. Chandrasekaran. 1989. Rice yields as influenced by seedlings root dipping in humic acid. **In: Proc. National Seminar on "Humus acids in agriculture"**, Annamalai University, Tamil Nadu PP.267-273.

Govindasamy, R. and S. Chandrsekaran 2002.Effect of graded levels of humic acid with and without N on the performance of lowland rice. **In: National seminar on recent trends on the use of humic substances for sustainable agriculture**, Annamalai University, Tamil Nadu. p.5

Govindasamy, R., S. Chandrasekaran and K. Natarajan. 1989. Influence of (lignite) humic acid on ammonia volatilization from urea. **In: Proc. National Seminar on "Humus acids in agriculture"**. Annamalai University, Tamil Nadu. Pp319 to 325.

Govindasamy, R., S. Chandrsekaran and C. Karunakaran. 2002. $^{13}C$ NMR spectra of lignite humic acids. **In: National seminar on recent trends on the use of humic substances for sustainable agriculture**, Annamalai University, Tamil Nadu. p 2

Govindasamy. 2002. Scope on the use of lignite derived humic substances for sustainable crop production. Lead paper. **In: National seminar on recent trends on the use of humic substances for sustainable agriculture,** Annamalai University, Tamil Nadu.

Gowrisankaran, S.B., V. Manoharan and J.N. Ravi. 1989. Application of humic acids for reclamation of dumped soil of Neyveli mines. A preliminary study. **Proc. National Seminar on "Humus acids in agriculture"**. Annamalai University, Tamil Nadu. pp.243 - 252.

Grace, D., B. Dkhar, B. Prasad and M.K. Sinha. 1986. Characterization of humic and fulvic acids of forest and cultivated soils. **J. Indian Soc. Soil Sci., 34**: 29-37.

Gray, T.R.G. and S.T. Williams. 1975. Soil Microorganisms (1st edn). London. Longman group Ltd.

Greenland, D.J. 1971. Interaction between humic and fulvic acids and clays. **Soil Sci., 111**: 34-41.

Griffith, S.M. and M. Schnitzer. 1975. Analytical characteristics of humic and fulvic acids extracted from tropic volcanic soils. **Soil Sci. Soc. Am. Proc., 39**: 861-867.

Guminski, S. 1968. Present day views on physiological effects induced in plant organisms by humic compounds. **Soviet Soil Sci., 9**: 1250-1256.

Guminski, S., Z. Guminski and J. Sulej. 1965. Effects of humate, agar-agar and EDTA on the development of tomato seedlings in aerated and non-aerated water cultures. **J. Exp. Bot., 16**: 151-162.

Gupta, R.D., K.K.R. Bhardwaj and A. Raina. 1989. Composition and Nature of humus in forest soils of Himachal Pradesh. **In: Proc. National Seminar on "Humus acids in agriculture"**, Annamalai University, Tamil Nadu. pp. 49-63.

Gupta, R.K., T.A. Singh and R.K. Sharma. 1991. Adsorption and desorption of P, Cu, Al, and Fe on humic acid. **J. Indian Soc. Soil Sci., 39**: 256-259.

Gurunathan, K. and S. Kaliyaperumal. 1989. Studies on the degradation of humic acids. **In:Proc. National Seminar on "Humus acids in agriculture"**, Annamalai University,Tamil Nadu pp. 219-223.

Haripriya, K., S. Kamalakannan, C.T. Sathappan, T. Umamaheswari and P. Poonkodi. 2002. Influence of humic acid on flower production in tuberose. **In: National seminar on recent trends on the use of humic substances for sustainable agriculture**, Annamalai University, Tamil Nadu.

Heng, L.C. 1989. Influence of humic substances on P-sorption in Malaysian soils under rubber. **J. Natural Rubber Res., 4**: 186-194.

*Hoffmann, F. 1966. Untersuchungen im Mecklenburgischen Kiistensuum' uber den einfluss der vegetation and der bodeneigenschaften auf die organische substanz des Bodens. **Albrecht-Thaer-Archiv., 10**: 1051.

Hue, N.V. 1992. Correcting soil acidity of a highly weathered Ultisol with chicken manure and sewage sludge. **Comm. Soil Sci. Pl. Anal., 23**: 241-264.

Humphries,E,S.1956. Mineral components and ash analysis. Modern methods of plants analysis,springer verlag.Berlin,1:468-502.

Jackson, M.L. 1973. Soil chemical analysis. Prentice Hall of India Pvt Ltd, New Delhi.

Jain, M.K. and S.C. Sharma. 2000. Organic Chemistry. Shoban Lal Nagin Chand & Co. Educational Publishers, Jalandhar. Punjab.

Jelanic, D.B., M. Hajdukovic and Z. Aleksic. 1966. The influence of humic substances on phosphate utilization from labelled super phosphoate. In: Report of FAO / IAEA proceedings. Pergamon Press. Oxford.

Jothimani, S., P.K.Shushma and A.I.Jose. 2002. Coir pith incorporated soil as a source of humic substances. **In: National seminar on recent trends on the use of humic substances for sustainable agriculture**, Annamalai University, Tamil Nadu.

Kadalli, G.G., L. Suseela Devi, R. Siddaramappa and E. John. 2000. Characterisation of humic fractions extracted from coir dust-based composts. **J. Indian Soc. Soil Sci.**, **48**: 51-55.

Kalidurai, M. 1988. Studies on nitrogen fixation and nitrogen contribution by stem nodulating legume *Sesbania rostrata* in rice soil ecosystem. M.Sc(Ag.) Thesis, TNAU, Coimbatore.

Kamprath, E.J. and C.D. Welch. 1962. Retention and cation exchange properties of organic matter in coastal plain soils. **Soil Sci. Soc. Am. Proc.,** 263-265.

*Kar, R. and S.K. Sanyal. 1988. **J. Indian Chem. Soc., 65**: 834.

Kar, S. 1998. Nature of humic substances of some soils from Eastern Himalayan region. **Indian Agric., 42:** 273-277.

Katyal, J.C. 2000. Organic matter maintenance: Main stay of soil quality. **J. Indian Soc. Soil Sci., 48**: 704-716.

Katyal, J.C. and B.D. Sharma. 1991. DTPA extractable and total Zn, Cu, Mn and Fe in Indian soils and their association with some soil properties. **Geoderma, 49**:165-179.

Khan, S., M.A. Qureshi, J. Singh and G. Prveen. 1997. Influence of Ni (ii) and Cr (iii), Humic acid (HA) complexes on major nutrients (NPK) status of the soil. **Indian J. Agric. Chem., 31**: 1-5.

Khan, S.U. 1969. Interaction between the humic acid fraction of soils and certain metallic cation. **Soil Sci. Soc. Am. Proc., 33:** 851-854.

Khandelwal, K.C. and A.C.Gaur.1980. Degradation of humic acids extracted from manure and soil by some streptomycetes and fungi. Zentralblatt-fur-Bakteriologie-parasitenkunde-infektions. **Kvanheiten-und-Hygiene. II. 135**: 119-122.

Khristeva, L.A. 1953. The participation of humic acids and other organic substances in the nutrition of higher plants. **Pochvovedonie , 10**: 46-59.

Khristeva, L.A. and N.V. Lukyanenka.1962. Role of physiologically active substances in the soil humic acids, bitumens and vitamins B,C and D in the life of plants and their replenishment. **Soviet Soil Sci.,** 1137-1141.

Khungar, S.C. and V. Manoharan. 2000. Humic acid: An innovative product rich in organic nutrient. **Fert. News, 45**: 23-25.

Kononova, M.M. 1966. Soil organic matter,its nature, its role in soil formation and soil fertility. 2nd Edn. Pergaman Press, Oxford, London.

Kononova, M.M. and N.A. Pankova. 1950. The action of humic substances on the development of plants. **Dokl. Akad. Nauk. SSSR, 73**: 1069-1071.

Krystanov, S.A. 1968. Kharakteristika. Organiches kogu Veshchestva Osnovykh tipov Pochv Severnoi Bulgarii (Description of organic matter of major types of soils of Bulgaria). Avtoref. Kand. diss., Moscow.

Kumuda, K. 1965. On the concepts of humic substances and humification-studies on the colour of humic acids. **J. Soil Sci. Pl. Nutr., 11**: 151-156.

Kumuda, K. 1987. Chemistry of soil organic matter. Japan Scientific Societies Press. Elsevier. Amsterdam-Oxford-New York – Tokyo. p.53-55.

Lakatus, B., T. Tibai and J. Meisel. 1977. ESR spectra of humic acids and their metal complexes. **Geoderma, 19**: 319-338.

Lal, J.K and B. Misra. 1999. Visible absorption spectroscopic investigation of soil humic substances. **J. Res., 11**: 135-140.

Langmuir,I.1916. Constitution and fundamental properties of solids and liquids. PartI.Solids.**J. Am. Chem. Soc**., **38**: 2221-2295.

Langmuir,I.1918. The adsorption of gases on plain surfaces of gases, mica and platinum. **J. Am. Chem. Soc**.,**40**:1361-1403.

Lax, A. 1991.Cation exchange capacity induced in calcareous soils by fertilization with manure. **Soil Sci., 15**: 174-178.

Lee, Y.S. and B.J. Bartlett. 1976. Stimulation of plant growth by humic substances. **Soil Sci. Soc. Am. Proc., 40**: 876-879.

Lindsay,W.L. and Norvell.1978. Development of DTPA soil test for zinc, iron, manganese and copper. **Soil Sci. Soc. Am. Proc., 42** : 421-428.

Lisiak, M.J. and J. Maria. 1984. Effect of sodium humate on the growth of tomatoes and accumulation of P and Fe in media at different pH. Acta Soc. Bot. Pol. 91984, 53: 377-383. **Chemical Abstrs**. 1984, 102, No.23585h.

Lobartini, J.C. and G.A.Orioli. 1988. Absorption of iron, Fe-humate in nutrient solutions by plants. **Pl. Soil, 106**: 153-157.

Malcolm, R.L. 1990. The uniqueness of humic substances in each of soil, stream and marine environments. **Anal. Chem. Acta., 232**: 19-30.

Malik, K.A. and F. Azam. 1985. Effect of humic acid on wheat (*Triticum aestivum* L.) seed ling growth. **Envt. and Expt. Botany. 25**: 249-252.

Mallikarjunarao, M.R. Govindasamy and S. Chandrasekran. 1987. Effect of humic acid on *Sorghum vulgare* var. CSH-9. **Curr. Sci., 56:** 1273-1276.

Mandal, B.K., P. Chatterjee and S.P. Bhattachanga. 1989. Effect of humic acid on wet season rice. **Intl. Rice. Res. Newsletter. 14**: 18-19.

Manjaiah, K.M. and S.K. Ghosh. 1995. Retention of humic acid by montmorillonite saturated with some divalent cations. **J. Indian Soc. Soil Sci., 43:** 334-338.

Martens, D.A., J.B. Johanson and W.T. Frankenbarger, J. 1992. Production and persistence of soil enzymes with repeated addition of organic residues. **Soil Sci., 153**: 53-61.

*Martin, D., P.C. Srivastava, D. Ghosh and W. Zech. 1998. **Geoderma, 84**: 345.

Martinez, M.T., C. Romero and J.M. Gavilan. 1984. Solubilization of phosphorus by humic acids from lignite. **Soil Sci., 138**: 257-261.

Mary, P.C.N., B. Raghupathy, R. Govindasamy and Jeyaramasoundari. 2002b. Effect of humic acid on the availability of some plant nutrients in lignite mine spoil. **In: National seminar on recent trends on the use of humic substances for sustainable Agriculture**, Annamalai University, Tamil Nadu.

Mary, P.C.N., B. Raghupathy, R. Govindasamy and R. Jeyaramasoundari. 2002a. Effect of lignite humic acid on the nutrition growth and yield of rice cv. ADT 38 in neyveli open cast minespoil. **In: National seminar on recent trends on the use of humic substances for sustainable agriculture,** Annamalai University, Tamil Nadu.

Mathur, R.S. and A.C. Gaur. 1977. Effect of humic acid on paddy. **Microbiologiya, 46**: 149-154.

Mato, M.C. and J. Mendoz. 1970. Effect of humic substances on some enzyme activities. **Geoderma, 3**: 255.

Mato, M.C., R. Fabregas and J. Mendoz. 1971. Inhibitory effect of soil humic acids on indoleacidic acid oxidase . **Soil Biol. Biochem., 3**: 285.

Mattson, S. 1931. The laws of soil colloidal behavior V Ion adsorption and exchange. **Soil Sci., 31**: 311-333.

McLean, E.O., D.C. Reicosky and C. Lakshmanan. 1965. Interrelationship of organic matter, liming and extractable Al with permanent charge (KCl) and pH dependent cation exchange capacity of surface soils. **Soil Sci. Soc. Am. Proc.,( ).** 374-378.

McLoughlin, A.J. and E. Kuster. 1972. The effect of humic substances on the respiration and growth of microorganisms. 1.Effects on the east. *Candida utilis*. **Pl. Soil., 37**: 17-25.

*Mei, Hui-Sheng, Jia., Li-Bin., Chen., Chen., De., Mao., Cao., Zong-Xun. 1980. Effect of sodium humate on the uptake of phosphorus by plants (Beisining University, Paking Peop. Pep. China), Tu Jan Hsuch. Pao. 17(3): 284-290(Ch.). **Chemical Abstrs.**, 191. 94-46082X.

Mendonca, E.S. and D.L. Rowell. 1996. Mineral and organic fractions of two Oxisols and their influence on effective cation exchange capacity. **Soil Sci. Soc. Am. J., 60**: 1888-1892.

Mishra, B. and L.L. Srivastava. 1988. Physiological properties of humic acids isolated from some major soil associations of Bihar. **J. Indian Soc. Soil Sci., 36**: 83-89.

Mishra, B. and L.L. Srivastava. 1990. Physico-chemical characteristics of humic substances of major soil associations of Bihar (India). **Pl. Soil, 122**: 185.

Mortenson, J.L. 1963. Complexing of metals by soil organic matter. **Soil Sci. Soc.Am. Proc., 27**: 179.

Mukherjee, D.C., A.N. Basu and M. Adhikari. 1975. Interactions of clay-humic acid complex with trace element cations in presence of magnesium as complementary ion. **Indian J. Agrl. Res., 9 :** 101-105.

Murphy, J and J.P. Riley.1962. A modified single solution methods for the determination of phosphate in natural water. **Analytical Chemica Acta**, **27**: 31.

Mylonas, V.A. and C.N. McCants. 1980. Effect of humic and fulvic acids on growth of tobacco. **Pl. Soil, 54**: 485-490.

Naidenova, O.A. 1968. Use of high frequency titration to determine functional groups in humic substances. In: Khimiya Genesis Kartografiya Pochv, p.26, Moscow.

Nair, M.R. 1995. Studies on the influence of foliar application of humic acid on soil fertility attributes and response of ADT36 rice in Periyar Vagai command area. M.Sc. (Ag.) Thesis, Agrl. College and Res. Inst., Madurai, TNAU,Tamil Nadu

Nannipieri, P., L. Muccini and C. Ciardi. 1983. Microbial biomass and enzyme activities – Production and Persistence. **Soil Biol. Biochem., 15**: 679-685.

Nannipieri, P., R.L. Johnson and E.A. Paul. 1978. Criteria for measurement of microbial growth and activity in soil. **Soil Biol. Biochem., 10**: 223-229.

Narayanan, K.A. 1989. Coal based fertilizers. **In: Proc. National Seminar on "Humus acids in agriculture"**. Annamalai University, Tamil Nadu. pp. 39-48.

Nayak, D.C., C. Varadachari and E.K. Ghosh. 1990. Influence of organic acidic functional groups of humic substances in complexation with clay minerals. **Soil Sci., 149**: 268-271.

Neto, L.M., O.R. Nascimento, T. Talamoni and N.R. Popp. 1991. EPR of micronutrients-Humic substances complexes extracted from A Brazilian soil. **Soil Sci.**, **151**: 369-376.

Newman, R.H. and K.R. Tate. 1991. $^{13}$C NMR characterisation of humic acids from soils of a development sequence. **J. Soil Sci.**, **42**: 39-46.

Oades, J.M. 1989. In: Minerals in Soil Environment. 2nd ed., Soil Sci. Soc. Am., Madison, Wisconsin, pp.89-159.

O'Donnel, R.W. 1973. The auxin like effects of humic preparation from leonardite. **Soil Sci., 115**: 106-112.

Olk, D.C., K.G. Cassman, E.W. Randall, P. Kin Chesh, L.J. Sanger and J.M. Anderson. 1996. Changes in chemical properties of organic matter with intensified rice cropping in tropical lowland soil. **Eur. J. Soil Sci., 47**: 293-303.

Olsen, S.R., C.V. Cole, F.F. Watanabe and A.L.Dean.1954.Estimation of available phosphorus in soil by extraction with sodium bicarbonate. USDA Circ.939.

Orlov, D.S. 1995. Humic substances of soils and general theory of humification. A.A.Balkema Publishers, Brookfield, VT 05036, USA.

*Orlov, D.S., I.A. Pivovarova and N.I. Gorbunov. 1973. **Agrokhomiya, 9**: 140.

Pal, S. 1992. Nature and properties of soil humic acid as influenced by incorporation of different plant materials. **Pl. Soil, 140**: 75-84.

Pal, S. and M.B. Sengupta. 1985. Nature and properties of humic acid prepared from different sources and its effect on nutrient availability. **Pl. Soil, 88**: 71-91.

Palaniappan, R. 1975. Studies on soil organic matter. Ph.D. Thesis, University of Agriculture, Tamil Nadu

Pandey, S.N. and B.K. Sinha. 1998. In: Plant Physiology, Vikas Publishing House Pvt. Ltd., pp.232-236.

Pandeya, S.B. and A.K. Singh. 1997. Kinetics of reaction of fulvic acid – Iron complexes in soils. **J. Indian Soc. Soil Sci., 45**: 713-719.

Panse, V.G and P.V. Sukhatme.1967. Statistical methods for agricultural workers. ICAR, New Delhi.

Pemberton, H.1945. Estimation of total phosphorus. **J.Amer.Chem.Soc**., **15**:382-395.

Perucci, P., L. Scarponi and M. Businelli. 1984. Enzyme activities in clay loam soil amended with various crop residues. **Pl. Soil, 81**: 345-351.

Piper, C.S. 1966. Soil and Plant analysis. Hans Publishers, Bombay.

Prasad, A., N.G. Totey, P.K. Khatri and A.K. Bhowmik. 1991. Effect of added tree leaves on the composition of humus and availability of nutrients in soil. **J. Indian Soc. Soil Sci., 39**: 429-434.

Prasad, B. and M. Kumar. 1989. Visible absorption spectroscopic investigation in relation to molecular characteristics of fulvic acids extracted from organic wastes. **J. Indian Soc. Soil Sci., 37:** 655.

Prasad, B. and M.K. Sinha. 1981. Properties of poultry litter humic acid fractions and their metal complexes. **Pl. Soil, 63**: 439-448.

Prasad, B. and M.K. Sinha. 1984. Structural characteristics of humic and fulvic acids isolated from soil and poultry litter. **J. Indian Soc. Soil Sci., 52**: 162-168.

Quraishi, M.S.I and A.H. Cornfield.1973. **Envt. Poll. 4**: 159.

Raina, J.N. and K.P. Goswami. 1988. Effect of fulvic acid and fulvates on the growth and nutrient uptake by maize plant. **J. Indian Soc. Soil Sci., 36**: 264-268.

Raju, R.A. and K. Mukkhopadhyay. 1976. Influence of adsorbed K on fixation of added ammonium in H soils. **Bull. Indian Soc. Soil Sci., 10**: 107-111.

Rashid, M.A. 1972. Quinone content of humic compounds isolated from the marine environment. **Soil Sci., 113**: 181-188.

Rauthan, B.S. and M. Schnitzer. 1981. Effects of a soil fulvic acid on the growth and nutrient content of cucumber plants. **Pl. Soil, 63**: 491-495.

Ravindraprasad, G. and S. Chandrasekaran. 1988. Effect of humic and nitro humic acids with and without urea on paddy. IR 20. **In. Proc. Intl. Symp. Paddy soil fertility**, Thailand, Dec, 9-13.

Ravindraprasad, G., P. Balasubramaniam, R. Govindasamy and S. Chandrasekaran. 1989. Effect of graded levels of lignite humic acids on the growth and phenolic contents of paddy IR 20 in a Tropaqualf soil. **Proc. National Seminar on "Humus acids in agriculture".** Annamalai University, Tamil Nadu pp.209-218.

Ravindraprasad. G. 1988. Influence of lignite humic acids on the growth, yield, nutrient content and uptake of paddy IR 20. M.Sc. (Ag.) Thesis, Annamalai University..

Reddy, K.S. and P.C. Rao. 2000. Characterization of humic metal ion interaction in Alfisols and Vertisols by potentiometric methods. **J. Indian Soc. Soil Sci., 48:** 596-598.

Relan, P.S., K.K. Girdhar and S.S. Khanna. 1984. Molecular configuration of compost's humic acid by viscometric studies. **Pl. Soil, 81**: 203-208.

Relan, P.S., S.S. Khanna, T. Chand and R. Kumari. 1986. Stability constants of Cu, Pb, Zn, Mn, Fe and Cd complexes with humic acid from farm yard manure. **J. Indian Soc. Soil Sci., 34**: 250-56.

Relan, P.S., V.K.Garg and S. Kumar. 1993. Infrared studies of the complexes of bivalent metal cations with humic materials. **Indian J. Trop. Agrl., 11**: 227-233.

*Rivero, C., N. Senesi, J. Paolini and V.D'Orazio. 1998. **Geoderma**, 81: 227.

Roig, A., A. Lax, J. Cegarra, F. Costa and M.L. Hernandez. 1988. Cation exchange capacity as a parameter for measuring the humification degree of manures. **Soil Sci., 146**: 311-316.

Saalbach, E. 1956. The influence of humic substances on the metabolism of plants. Sixth Congress International Dela Science de Sol. Paris, Rapports, pp.107-111.

Saha, K. and J. Shanker. 1981. Note on the effect of fertilizers and green manure on soil catalase activity. **Indian J. Agric. Sci., 51**: 654-686.

Saha, P.B. and S.K. Sanyal. 1988. Synthetic humic acids. Their constitution, shape and dimensions. **J. Indian. Soc. Soil Sci., 36**: 35-42.

Saikh, H. 1999. Characterisation of soil organic matter of some forest and cultivated soils of Simlipal National Park (Orissa). **J. Indian Soc. Soil Sci**., **47**: 542-544.

Saikh, H. and P.K. Chandra. 1999. Some characteristics of soil humic substances of Entisol, Alfisol and Vertisol. **J. Indian Soc. Soil Sci., 47:** 206-211.

Sanchez, P.A. 1976. Properties and Management of soils in the tropics. John Wiley and Sons. New York. USA.

Sanders, D.C., O.A. Bandele, C.H. Millar and A. Nash. 1993. Nitrogen uptake within sequential vegetable cropping system. **J. Pl. Nutr. 16**: 1119-1136.

Sanfilippo, C.D., E.J.A. Arguello, G. Abdulla and G.A. Orioli. 1990. Content of auxin inhibitor and gibberellin like substances in humic acids. **Biol. Plant., 32**: 346-351.

Santhy, P., P. Muthuvel and D. Selvi. 2001. Status and impact of organic matter fractions on yield, uptake and available nutrients in long term fertilizer experiment. **J. Indian Soc. Soil Sci**., **49**: 281-285.

Sanyal, S.K. 2001. Colloid chemical properties of soil humic substances: A Relook. **J. Indian Soc. Soil Sci., 49**: 537-569.

Sardessai, S. 1989. Humic and fulvic acids in sediments of the Hooghly estuary and some coastal areas in the northern bay of Bangal. **Indian J. Marine Sciences. 18:** 16-20.

Sarkar, A. 1987. Molecular weight distribution in humic and fulvic acids of some soils of Eastern himalayan regions. **J. Indian Soc. Soil Sci., 35**: 198-201.

Satishkumar, B. 1997. Extraction and characterization of humic acids and their effect on the performance of soybean, M.Sc.(Ag.) Thesis, Annamalai University..

Satishkumar, B., R. Govindasamy, K. Dhanasekaran and S.M. Hameed Sulaiman. 2002a. Infrared and Ultraviolet spectral characteristics of five different humic acids. **In: National seminar on recent trends on the use of humic substances for sustainable agriculture,** Annamalai University, Tamil Nadu

Satishkumar, B., R.Govindasamy, M. Ravichandran and K. Dhanasekaran. 2002b. Effect of humic acid extracted from various sources of soil fertility. **In: National seminar on recent trends on the use of humic substances for sustainable agriculture,** Annamalai University,Tamil Nadu

Schnitzer, M and S.U. Khan.1978. Soil organic matter. Elsevier, Amsterdam

Schnitzer, M. 2000. A life time perspective on the chemistry of soil organic matter. **Adv. Agron., 68**: 3-54.

Schnitzer, M. 1965. **Nature .207**: 667.

Schnitzer, M. 1991. Soil organic matter. The next 75 years. **Soil Sci., 151**: 41-58.

Schnitzer, M. and H. Kodama. 1969. **Israel J. Chem., 7**: 41.

Schnitzer, M. and H. Kodama. 1972. Differential thermal analysis of metal fulvic acid salts and complexes. **Geoderma, 7**: 93-103.

Schnitzer, M. and H.R. Schulten. 1995. Analysis of organic matter in soil extracts and whole soils by pyrolysis-mass spectrometry. **Adv. Agron.**, **55**: 168.

Schnitzer, M. and P.A. Poapst. 1967. Effects of a soil humic compound on root initiation. **Nature, 213**: 598-599.

Schnitzer, M. and S.I.M. Skinner. 1965. The carbonyl group in a soil organic matter preparation. **Soil Sci. Soc. Am. Proc., 29**: 400-405.

Schnitzer, M. and S.I.M. Skinner. 1966. Organo-metallic interactions in soils. Stability constants of $Cu^{2+}$, $Fe^{2+}$ and $Zn^{2+}$ - Fulvic acid complexes. **Soil Sci.**, **102**:361.

Schnitzer, M. and S.U. Khan. 1972. Humic substances in the environment. Marcel Dekket, Inc., New York. p. 327.

Schnitzer, M. and U.C. Gupta. 1964. Some chemical characteristics of the organic matter extracted from the O and $B_2$ horizons of a gray wooded soil. **Soil Sci. Soc. Am. Proc., 28**: 374.

*Schnitzer, M. and U.C. Gupta.1965. Determination of acidity in soil organic matter. **Soil Sci. Soc. Am. Proc.,.12:** 274-277.

Seitz, D.S. 1960. Ion Exchange resins from lignite coal. **Ind. Eng. Chem., 52**: 313-314.

*Sen, B.C. 1960. **Indian J. Appl. Chem., 23**: 145.

Senthilkumar, S. 2001. Physiological effects of humic acid on growth and yield of rice. M.Sc (Ag.) Thesis, TNAU, Coimbatore.

Shanmugam, T., M. Aruljothi and A.I. Johan. 1989. Preparation of micronutrients with lignite stocks, **Proc. National Seminar on "Humus acids in agriculture"**. Annamalai University, Tamil Nadu pp.303 to 307.

Shanmuganathan, R.T. and J.N. Oades. 1983. Influence of anions on dispersion and physical properties of the A horizon of a red brown earth. **Geoderma, 29**: 257-277.

Shuman, L.M. 1988. Effect of organic matter on the distribution of manganese, copper, iron and zinc in soil fractions. **Soil Sci., 146**: 192-198.

Singh, A. and S.K. De. 1990. Adsorption and release of metal ions $Cu^{2+}$, $Fe^{2+}$ and $Zn^{2+}$ from $\alpha$ and $\beta$ humic acids formed from soil treated with industrial wastes (basic slag, pressmud and molasses. **Indian J. Agrl. Chem., 23**: 213-222.

Singhal, R.M. and Pramod Kumar. 1992. Functional group characteristics of humic acids of forest soil. **J. Indian Soc. Soil Sci., 40**: 837-839.

Singhal, R.M. and S.D. Sharma.1983. Comparitive studies of infra red spectra of soil humic acids of doon valley forests. **J. Indian. Soc. Soil Sci., 31**: 182-186.

Sinha, M.K. 1972. Organo-metallic phosphates. The solvent action of fulvic acids on insoluble phosphates. **Pl. Soil, 37**: 457-467.

Skujins, J.J. 1976. Extracellular enzymes in soil. Critical reviews in microbiology. Pp. 383-421.

Smidova, M. 1960. The influence of humic acid on the respiration of plant roots. **Biol. Plant. 2**: 152-164.

Solaiappan, U., A. Muthusankaranarayanan and P. Muthusamy. 1995. Effect of humic acid on rainfed upland cotton. **Indian J. Agron., 40**: 156-157.

Sollins, P., P. Howmann and B.A. Caldwell. 1996. Stabilization and destabilization of soil organic mater. Mechanisms and controls. **Geoderma, 74**: 65-105.

*Spark, K.M., J.D. Wells and B.B. Johnson. 1997. **Aust. J. Soil Res., 35**: 89.

Sparling, G.P., B.G. Ord and D. Vaughan. 1981. Microbial biomass and activity in soils amended with glucose. **Soil biol. Biochem., 13**: 199-104.

Speir, T.W. 1977. Studies on a climosequence of soils in tussock grasslands. Urease, phosphatase and sulfatase activities of top soils and their relationships with other properties including plant available sulfur. **N.Z.J. Sci., 20**: 159-166.

Speir, T.W. and D.J. Ross. 1976. Studies on a climosequence of soils in tussock grassland. 9. Influence of age of *chionochloa rigida* leaves on enzyme activities. **N.Z.J. Sci., 19**: 389-396.

Sripriya, S. 1993. Studies on the efficacy of humic acid on soil fertility, yield attributes and response of rice (ADT36). M.Sc.(Ag.) Thesis, Agrl. College and Res. Inst, Madurai, Tamil Nadu

Stanford ,S. and L. English.1949. Use of flame photometer in rapid soil tests of K and Ca. **Agron. J.,41** : 446-447

Stevenson, F.J. 1977. Nature of divalent transition metal complexes of humic acids as revealed by a modified potentiometric titration method. **Soil Sci., 123**: 10-17.

Stevenson, F.J. 1982. Humus chemistry: genesis composition reactions. A Wiley Inter Science Publication, John Wiley & Sons.

Stevenson, F.J. 1991. In: Micronutrients in Agriculture, 2nd ed, Soil Sci., Soc., Am., Madison, wisconsin, pp 145-186.

Stevenson, F.J. 1994. Humus chemistry: genesis, composition, reactions. 2nd ed. John Wiley & Sons, New York.

Stevenson, F.J. and M.S. Ardakani. 1972. Micronutrients in agriculture (JU.J.Mortvedt, P.M.Giordano and W.L.Lindsay eds.). American Soc.Agronomy, Maidson, Wisconsin.

Stevenson, F.J. and M.S. Ardakani. 1977. Organic matter reactions involving micronutrients in soil. Third Printing. Soil Sci Soc. Am., Inc.

Stumm, W. and J.J. Morgan. 1970. Aquatic chemistry. An introduction emphasising chemical equilibrium in natural waters. Wiley, Interscience, London.

Subbiah, B.V. and C.L. Asija.1956. A rapid procedure for estimation of available nitrogen in soils.**Curr. Sci., 25**: 259-260.

Subramani, S. and S. Kannaiyan. 1989. Effect of the waterfern Azolla on enzyme activity in soil under rice cultivation. **Microbiology, 58**: 101-104.

Swaby, R.J. and J.N. Ladd. 1966. Stability and origin of soil humus. In: The use of isotopes in soil organic matter studies. p.153-159. Pergamon Press Inc., New York.

*Szymanski, 1962.Trans. **Intl. Symp. Humus et planta**, p.165.

Tabatabai, M.A.1982. Soil enzymes. In: Methods of analysis. Part 2. 2nd Edn., A.L. Page et al.(eds.). pp. 903-947.

Tan, K.H. 1978. Effects of humic and fulvic acids on release of fixed potassium. **Geoderma, 21**: 67-74.

Tan, K.H. 1980. The release of silicon, aluminum and potassium during decomposition of soil minerals by humic acid. **Soil Sci., 129**: 5-11.

Tan, K.H. and A. Binger. 1986. Effect of humic acid on aluminum toxicity in corn plants. **Soil Sci., 141:** 20-25.

Tan, K.H. and R.A. McCreery. 1975. Humic acid complex formation and intermicellor adsorption by bentonite. **Proc. Intl. Clay Conf.**, Mexico City, pp.629-641.

Tan, K.H. and V. Nopamornbodi. 1979. Effect of different levels of humic acids on nutrients content and growth of corn (*Zea mays*). **Pl. Soil, 51**: 283-287.

Tandon, H.L.S. 1988. Potassium Research and Agricultural production in India FDCO. New Delhi.

Tarchitzky, J., Y. Chen and A. Banin. 1993. Humic substances and pH effects on Na and Ca montmorillonite flocculation and dispersion. **Soil Sci. Soc. Am. J., 57**: 367-372.

Thangavel, R. and R. Ramabadran. 1993. Quantitative changes in nitrogen content due to lignite humic acid application. **Madras Agric. J., 80:** 575-580.

Thangavelu, P. and T.S. Manickam. 1989. Studies on the effect of organic manure on fixation and release pattern of phosphorus and zinc under different moisture regimes. **In: Proc. National Seminar on "Humus acids in agriculture"**, Annamalai University, Tamil Nadu

Theng, B.K.G. 1979. Formation and properties of clay polymer complexes. Elsevier, Amsterdam.

Theng, B.K.G. and A.M. Posner. 1967. Nature of carboxyl groups in soil humic acids. **Soil Sci., 104**: 191-201.

Theng, B.K.G., G.G. Ristori, C.A. Santi and H.J. Percival. 1999. An improved method for determining the specific surface areas of top soils with varied organic matter content, texture and clay mineral composition. **Eur. J. Soil Sci., 50**: 304-316.

Thenmozhi, S., S. Natarajan and G. Selvakumari. 2002a . Effect of humic acid on growth, yield and quality of groundnut (var. VRI 2). **In: National seminar on recent trends on the use of humic substances for sustainable agriculture**, Annamalai University , Tamil Nadu.

Thenmozhi, S., S. Natarajan and G. Selvakumari. 2002b. Effect of humic acid on content and uptake of nutrients by groundnut (Var. VRI 2). **In: National seminar on recent trends on the use of humic substances for sustainable agriculture,** Annamalai University , Tamil Nadu.

Thiyagarajan, T.M. 1998. Distribution of organic carbon in some Alfisol and Vertisol profiles of Tamil Nadu uplands. **J. Indian Soc. Soil Sci., 46**: 446-448.

Tisdale, S.L., Nelson, W.L. Beaton, J.D. and J.L. Havlin. 1997. Soil fertility and fertilizers. (5th eds.) Prentice-Hall of India Pov. Ltd., New Delhi.

Tisdall, J.M. and J.M. Oades. 1982. Organic matter and water stable aggregates in soils. **J. Soil Sci., 33**: 141-163.

Titova, N.A. 1970. Iron humus complexes of some soils. **Pochvovedenie. 12**: 38.

Tollin, G., T. Reid and C. Steelink. 1963. Structure of humic acid, IV. Electron paramagnetic resonance studies. **Biochem. Biophys. Acta, 66**: 444-447.

Toth, S.J. and A.L. Prince.1949. Estimation of cation exchange capacity and exchangeable calcium, potassium and sodium contents of soils by flame photometer technique. **Soil Sci., 67**: 439-445.

Tyler, G, B. Mornsio and B. Nilsson.1974.Heavy metal pollution on soil available nutrients. **Pl. Soil, 40**: 237-159.

Udupa, S.G., N. Vasuki and H.T. Channel. 1990. Comparative studies on spectral properties and chemical behavior of humic acids. **J. India Soc. Soil Sci., 38**: 152-153.

Ushashree, N.N., R. Govindasamy, C. Karunakaran and S.Chandrasekharan. 1989. **In: Proc. National Seminar on "Humus acids in agriculture"**, Annamalai University, Tamil Nadu, pp.65-70.

Vaillancourt, N., L.E. Parent, P. Buteau, V. Parent and A. Karam. 1999. Sorption of ammonia and release of humic substances as related to selected peat properties. **Can. J. Soil. Sci., 79**: 311-315.

Van Dijk. H. 1971. Cation binding of humic acids. **Geoderma, 5**: 53.

Varadachari, C., A.H. Mondal and K. Ghosh. 1991. Some aspects of clay humus complexation. Effect of exchangeable cations and lattice charge. **Soil Sci., 151** : 220-227.

Varadachari, C., N.K. Biswas and K.Ghose.1984. Studies on decomposition of humus in clay-humus complex. **Pl. Soil .78**: 295-300.

Varshney, T.N. and A.C. Gaur. 1974. Effect of spraying sodium humate and hydroquinone of *Glycine max var. Bragg* and *Solanum lycopersicum* var. heiz, 1370. **Curr. Sci., 43**: 95-96.

Vaughan, D. 1974. A possible mechanism for humic acid action on cell elongation in root segments of *Pisum sativum* under aseptic conditions. **Soil Biol. Biochem., 6**: 241-247.

Vaughan, D. and B.G. Ord. 1983. Influence of humic acid on iron required for the formation of hydroxy proline in discs of *Beta vulgaris* L. storage tissue. **Pl. Soil, 73**: 27-34.

Vaughan, D. and B.G. Ord. 1985. Soil organic matter- a perspective on its nature, extraction, turn over and role in soil fertility. Soil organic matter and biological activity, pp4-18. Junk publishers, Werterland.

Vaughan, D. and D.J. Linehan. 1976. The growth of wheat plants in humic acid solutions under axenic conditions. **Pl. Soil. 44:** 445-499.

Vaughan, D. and I.R. McDonald. 1967. Effects of humic acid on protein synthesis and ion uptake in Beet Discs. **J. Expt. Bot., 18**: 578-586.

Vaughan, D., B.G. Ord and R.E. Malcolm. 1978. Effect of organic matter on some root surface enzymes and uptake into winter wheat. **J. Expt. Bot., 29**: 1337-1344.

Vedavyasa, K. and H.C. Parvathappa. 1989. Effect of continuous application of farmyard manure and fertilizer on organic matter in Alfisol of semi arid tropics. **In: Proc. National Seminar on "Humus acids in agriculture"**, Annamalai University, Tamil Nadu, pp.183-193.

Vinogradov, A.P. 1959. The geochemistry of rate and dispersed chemical elements in soil. 2nd Edn., Consultants Bureau, Inc., New York.

Visser, S.A. 1964. A physicochemical study of the properties of humic acids and their changes during humification. **J. Soil Sci., 15**: 202-219.

Visser, S.A. and M. Caillier. 1988. Observations on the dispersion and aggregation of clays by humic substances. I. Dispersive effects of humic acids. **Geoderma, 42**: 331-337.

Waksman, I.S.A.1936. Humus: Origin, chemical composition and importance in nature. Tindall Scox, London.

Walkley, A and C.A. Black. 1934. An examination of the Degtijareff method for determining soil organic matter and proposed modification of the chromic acid titration method. **Soil Sci., 37**: 233-244.

Xudan, X. 1986. The effect of foliar application of fulvic acid on water use, nutrient uptake and wheat yield. **Aust. J. Agric. Res., 37**: 343-350.

Yadav, K. 1989. Influence of different levels of humic acids on nutrient content and growth of maize. **In: Proc. National Seminar on "Humus acids in agriculture"**, Annamalai University, Tamil Nadu. pp.125-130.

* Originals not seen

# PLATES

Plate 1. General view of pot experiment with rice in Alfisol

Plate 2. General view of field experiment with rice in Alfisol – Rabi Season

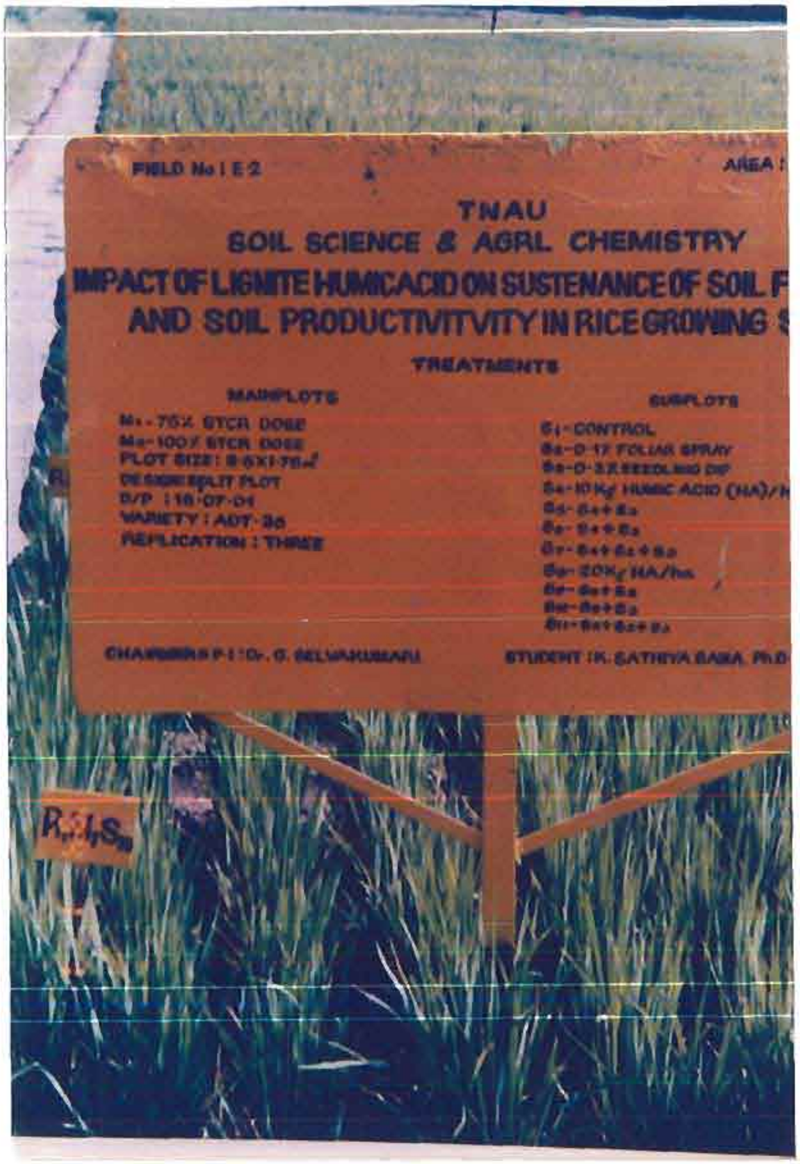


Plate 3. General View of field experiment with rice in Alfisol-Kharif Season

Plate 5. General view of field experiment with rice in Inceptisol-Rabi Season

Plate 6. General view of field experiment with rice in Inceptisol-Kharif Season

Plate 7. Field view of optimisation experiment - Inceptisol

Plate 8. Humic acid treatments on root growth of rice

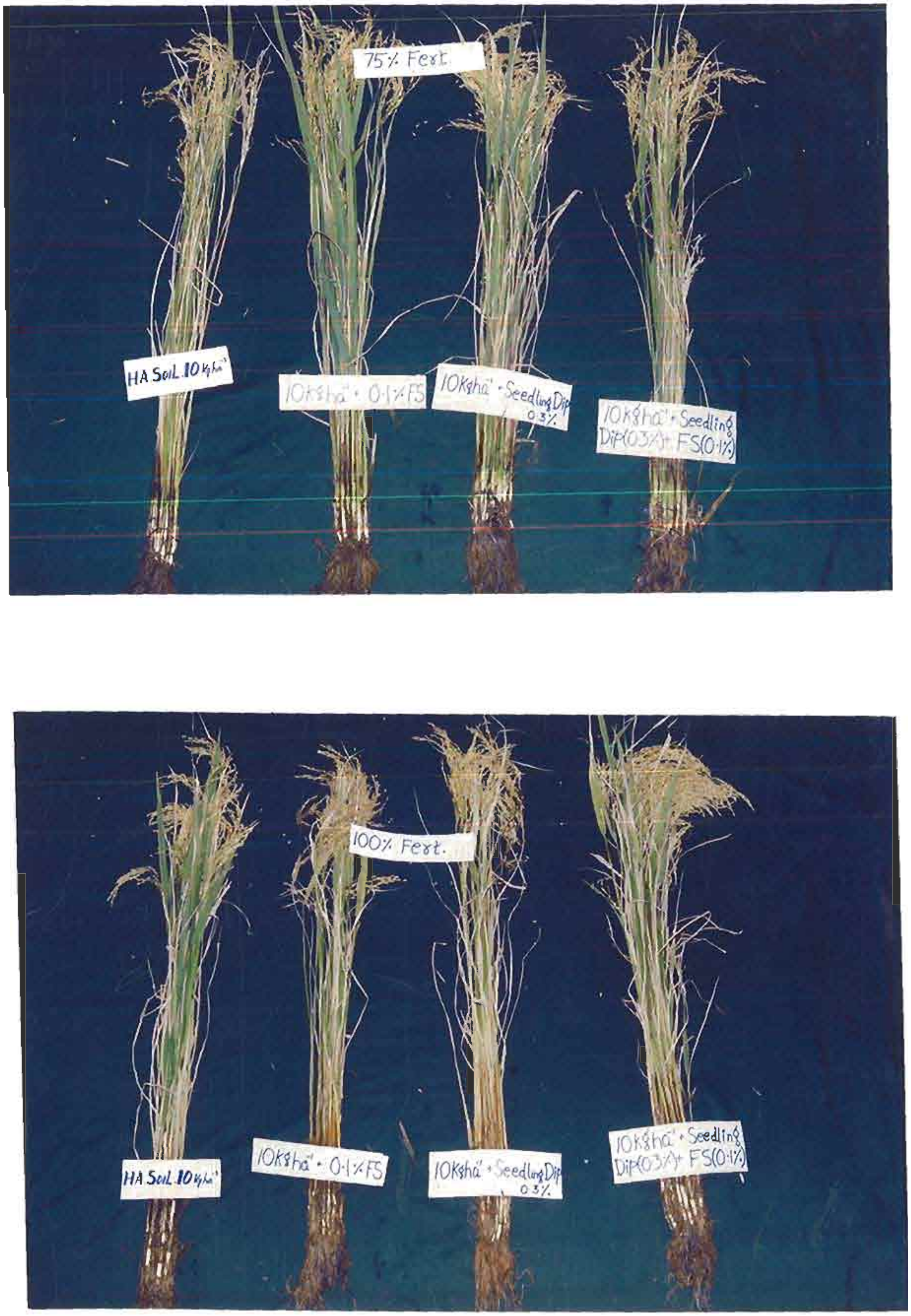


Plate 10. Humic acid and fertilisers on yield attributes of rice

# ANNEXURE

# Annexure I

## A. Delineation of organic carbon for western zone - Erode district

| Erode district (Bhavanisagar) | | |
|---|---|---|
| S. No. | Location | Organic carbon (%) |
| 1. | Pasur | 0.82 |
| 2. | Pasur | 0.56 |
| 3. | Panayampalli | 0.11 |
| 4. | Dasampalayam | 0.21 |
| 5. | Dasampalayam | 0.13 |
| 6. | Ponnampalayam | 1.43 |
| 7. | Neelipalayam | 0.15 |
| 8. | Neelipalayam | 0.74 |
| 9. | Neelipalayam | 0.16 |
| 10. | Panayampalli | 0.64 |
| 11. | Panayampalli | 0.27 |
| 12. | Panayampalli | 0.15 |
| 13. | Panayampalli | 0.53 |
| 14. | Pongalur | 0.45 |
| 15. | Pongalur | 0.18 |
| 16. | Pasakkuttai | 0.13 |
| 17. | A. Mettupalayam | 1.06 |
| 18. | Thoppampalayam | 0.80 |
| 19. | Sellappanpalayam | 0.29 |
| 20. | Puliampatti | 0.53 |
| | Status | No. of Samples |
| | Low | 11 |
| | Medium | 5 |
| | High | 4 |

**B. Delineation of organic carbon for western zone-Coimbatore district**

| Blocks | Location | Organic carbon (%) |
|---|---|---|
| Perianaiken palayam | Perianaiken palayam | 0.686 |
| S. S. Kulam | S.M.C.Palayam | 0.229 |
| | Vellamadai | 0.457 |
| | Vellakinaru | 0.629 |
| | Ideikarai | 0.543 |
| | Sarkarsamakulam | 0.514 |
| | P.G.Pudhur | 0.286 |
| | Udaiyam palayam | 0.514 |
| | S.S.Kulam | 1.400 |
| | Athipalayam | 0.143 |
| | Vaiyam palayam | 0.429 |
| Thondamuthur | Nadha gounden pudhur | 0.068 |
| | P.N.Pudhur | 0.512 |
| | Devarayapuram | 0.200 |
| | Pooluvampatti | 0.543 |
| | Pommanampalayam | 0.486 |
| | Alandhurai | 0.343 |
| | Semmedu | 0.457 |
| | Thondamuthur | 0.600 |
| Madukkarai block | Malumichampatti | 0.343 |
| | Mayilaripalayam | 0.429 |
| | CICR Agrl.station | 0.371 |
| | Pothanur | 0.257 |
| | Echanari | 0.229 |
| | Vellanur | 0.629 |

Contd.,

| | | |
|---|---|---|
| Perur | Sundakapudur | 0.629 |
| | Telungupalayam | 0.429 |
| | Perur | 0.571 |
| | Irugur | 0.657 |
| | Sankanur | 0.486 |
| Karamadai | Karamadai | 0.257 |
| | Illuppa palayam | |
| | Vivekanandapuram | 0.429 |
| | Kendipalayam | 0.057 |
| | Karamadai | 0.286 |
| | Nalroad,Sirumugai | 0.657 |
| | Mettupalayam | 0.486 |
| | Velliankadu | 0.200 |
| | Atthikadavu | 0.229 |
| | Kumarapalayam | 0.200 |
| | Nagegounden pudur | 0.714 |
| Avinasi | | |
| Annur | K.G.Palayam | 0.257 |
| | Kunnathur | |
| Avinasi | Nacchipalayam | 0.286 |
| | K.Pudhur | 0.657 |
| Thirrupur | Pongalur | 0.343 |
| | Pongalur | 0.257 |
| | K.Pongalur | 0.629 |
| | Ankearpalayam | 0.514 |
| | Vanjipalayam | 0.229 |
| | Katur | 0.229 |
| | Karuvampalayam | 0.086 |

Contd.,

| | | |
|---|---|---|
| Thirruppur | Mangalam | 0.171 |
| | Chinnakarai | 0.257 |
| | Palladam | 0.600 |
| Sulur | Semmandampalayam | 0.514 |
| | Kalangal | 0.457 |
| | Somanur | 0.257 |
| | | 0.100 |
| | Sulur | 0.286 |
| | Chinnaiyampalayam | 0.314 |
| Sultanpet | Puliamarathupalayam | 0.400 |
| | Chencheripudur | |
| | Sultanpet | 0.257 |
| | Periyakammalpatti | 0.229 |
| | Sultanpet | 0.143 |
| | Chencherrimalai | 0.657 |
| | Dasanayyakkan palayam | 0.286 |
| Pollachi | Mahalingapuram | 0.286 |
| | Pollachi | 0.143 |
| | Komangalam pudhur | 0.286 |
| | Ambarampalayam | 0.257 |
| | Anupperpalayam | 0.257 |
| | Palani pudhur | 0.600 |
| | Nallur | 0.542 |
| | Pollachi | 0.514 |
| | Veedampatti | 0.371 |
| | Maikinampatti | 0.971 |

Contd.,

| | | |
|---|---|---|
| Kinatthukadavu | Muthu goundanur | 0.257 |
| | Negamum | 0.229 |
| Udumalpet | Ganghinagar | 0.200 |
| | Guthuul kuttai | 0.886 |
| | Poolankinaru | 0.286 |
| | Udumalpet | 0.286 |
| | Podipatti | 1.000 |
| | Thirumurthinagar | 0.314 |
| | Udumalai | 0.571 |
| | Gandhinagar | 0.486 |
| Peddappampatti | Peddappampatti | 0.514 |
| | Udyampalayam | 0.429 |
| | Jallipatti | 0.457 |
| Madatthukulam | Krishnapuram | 0.488 |
| | Status | No. of Samples |
| | Low | 61 |
| | Medium | 24 |
| | High | 4 |

# Annexure II

## A. Regression co-efficient for grain yield with other parameters-Alfisol

| **Parameters** | **Equation** | **R$^2$** |
|---|---|---|
| Thousand grain weight | y=224.7x -1178 | 0.963 |
| Productive tillers | y=190.17x+2299 | 0.975 |
| Filled grains per panicle | y=21.027x+1826 | 0.989 |
| Root volume | y=58.55x+2798 | 0.781 |
| Root CEC | y=55.86x+2738 | 0.752 |
| Root length | y=28.11x+2789 | 0.776 |
| N uptake grain | y=13.39x+2891 | 0.857 |
| N uptake straw | y=13.16x+3007 | 0.875 |
| P uptake grain | y=180.2x+2084 | 0.889 |
| P uptake Straw | y=127.74x+2605 | 0.898 |
| K uptake grain | y=164.9x+2276 | 0.895 |
| K uptake straw | y=39.47x+1437 | 0.974 |
| Ca uptake grain | y=156.83x+1393 | 0.974 |
| Ca uptake straw | y=148.32x+2060 | 0.937 |
| Mg uptake grain | y=216.8x+1824 | 0.975 |
| Mg uptake straw | y=87.49x+2463 | 0.913 |
| Iron uptake grain | y=0.685x+2936 | 0.766 |
| Zinc uptake grain | y=2.194x+3040 | 0.885 |
| Manganese uptake grain | y=4.226x+2918 | 0.802 |
| Copper uptake grain | y=8.89x+3014 | 0.368 |
| Iron uptake straw | y=0.3379x+2474 | 0.880 |
| Zinc uptake straw | y=1.206x+3228 | 0.744 |
| Manganese uptake straw | y=1.318x+2141 | 0.898 |
| Copper uptake straw | y=4.539+3021 | 0.808 |
| KMnO$_4$ -N | y=9.686+1232 | 0.858 |
| Olsen-P | y=98.74x+1930 | 0.632 |
| NH$_4$OAc-K | y=2.883x+1639 | 0.809 |
| DTPA- Fe | y=32.19x+2264 | 0.886 |
| DTPA -Zn | y=650.9x+858 | 0.706 |
| DTPA -Mn | y=39.67x+3939 | 0.104 |
| DTPA -Cu | y=1018.3x-2726 | 0.606 |
| Organic carbon | y=1374x+2418.4 | 0.485 |
| CEC | y=20.76x+2833 | 0.734 |

## B. Regression co-efficient for yield versus other parameters-Inceptisol

| **Parameters** | **Equation** | **$R^2$** |
|---|---|---|
| Thousand grain weight | $y=229.9x-107.41$ | 0.902 |
| Productive tillers | $y=213x-3008.9$ | 0.941 |
| Filled grains per panicle | $y=22.97x+2643$ | 0.949 |
| N uptake grain | $y=17.42x+3726$ | 0.808 |
| N uptake straw | $y=11.85x+40.93$ | 0.814 |
| P uptake grain | $y=153.9x+2931$ | 0.852 |
| P uptake Straw | $y=99.08x+3858$ | 0.769 |
| K uptake grain | $y=167.3x+2869$ | 0.878 |
| K uptake straw | $y=39.16x+2097$ | 0.916 |
| Ca uptake grain | $y=115.6x+2243$ | 0.943 |
| Ca uptake straw | $y=70.02x+2842$ | 0.886 |
| Mg uptake grain | $y=192.2x+3030$ | 0.864 |
| Mg uptake straw | $y=112.03x+3145$ | 0.881 |
| Iron uptake grain | $y=1.639x+3339$ | 0.881 |
| Zinc uptake grain | $y=1.947x+4192$ | 0.919 |
| Manganese uptake grain | $y=2.94x+4170$ | 0.953 |
| Copper uptake grain | $y=4.427x+4280$ | 0.877 |
| Iron uptake straw | $y=0.5734x+2986$ | 0.905 |
| Zinc uptake straw | $y=2.611x+4116$ | 0.913 |
| Manganese uptake straw | $y=0.981x+3475$ | 0.914 |
| Copper uptake straw | $y=2.088x+4248$ | 0.939 |
| $KMnO_4N$ | $y=8.357x+2891$ | 0.935 |
| Olsen P | $y=95.45x+3293$ | 0.851 |
| $NH_4OAc$ K | $y=6.143x+3342$ | 0.805 |
| DTPA Fe | $y=39.84x+2683$ | 0.771 |
| DTPA Zn | $y=700.6x+1212$ | 0.612 |
| DTPA Mn | $y=296.8x+924.5$ | 0.694 |
| DTPA Cu | $y=7110.02x+479$ | 0.457 |
| Organic carbon | $y=1742x+3725$ | 0.448 |
| CEC | $y= 30.04x+3991$ | 0.743 |

# Annexure III

## Correlation coefficient of soil available nutirents, crop growth and yield parameters

| | Yield | Tillers | grains | Chaffy | Pan.len | Gr.Wt | OC | CEC | rt.vol | rt.CEC | rt.len | N.Till | N. flow | P.Till | P.flow | K.Till | K.Flow | Nup till | Nupfw. | Nupgr | Nupst | Puptill | Pupfw | Pupgr | Pupst | Kuptill | Kupfw. | Kupgr | Ku |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Yield | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Tillers | 0.865 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| filled rains | 0.962 | 0.946 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Chaffy | -0.833 | -0.914 | -0.899 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Pan.length | 0.932 | 0.913 | 0.935 | -0.860 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | |
| 1000Gr.Wt | 0.836 | 0.974 | 0.928 | -0.883 | 0.882 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | |
| OC | 0.149 | 0.447 | 0.256 | -0.127 | 0.290 | 0.514 | 1.000 | | | | | | | | | | | | | | | | | | | | | | |
| CEC | 0.812 | 0.938 | 0.873 | -0.763 | 0.866 | 0.942 | 0.670 | 1.000 | | | | | | | | | | | | | | | | | | | | | |
| RootVol | 0.798 | 0.919 | 0.892 | -0.937 | 0.805 | 0.913 | 0.257 | 0.807 | 1.000 | | | | | | | | | | | | | | | | | | | | |
| Root CEC | 0.804 | 0.927 | 0.866 | -0.746 | 0.854 | 0.935 | 0.670 | 0.992 | 0.803 | 1.000 | | | | | | | | | | | | | | | | | | | |
| Root Leng | 0.328 | 0.586 | 0.432 | -0.583 | 0.446 | 0.650 | 0.496 | 0.586 | 0.507 | 0.547 | 1.000 | | | | | | | | | | | | | | | | | | |
| Av.N.Till | 0.745 | 0.957 | 0.862 | -0.885 | 0.829 | 0.976 | 0.542 | 0.916 | 0.898 | 0.902 | 0.743 | 1.000 | | | | | | | | | | | | | | | | | |
| Av.N flow | 0.756 | 0.960 | 0.872 | -0.875 | 0.836 | 0.982 | 0.556 | 0.923 | 0.888 | 0.918 | 0.712 | 0.986 | 1.000 | | | | | | | | | | | | | | | | |
| Av.P.Till | 0.898 | 0.972 | 0.961 | -0.886 | 0.940 | 0.973 | 0.438 | 0.936 | 0.888 | 0.927 | 0.550 | 0.934 | 0.942 | 1.000 | | | | | | | | | | | | | | | |
| Av.P.flow | 0.953 | 0.952 | 0.976 | -0.909 | 0.941 | 0.948 | 0.306 | 0.892 | 0.889 | 0.884 | 0.512 | 0.897 | 0.904 | 0.972 | 1.000 | | | | | | | | | | | | | | |
| Av.K.Till | 0.928 | 0.939 | 0.986 | -0.867 | 0.909 | 0.940 | 0.342 | 0.896 | 0.886 | 0.887 | 0.449 | 0.878 | 0.888 | 0.967 | 0.961 | 1.000 | | | | | | | | | | | | | |
| Av.K.Flow | 0.916 | 0.961 | 0.974 | -0.913 | 0.926 | 0.972 | 0.363 | 0.906 | 0.902 | 0.892 | 0.587 | 0.931 | 0.937 | 0.973 | 0.978 | 0.974 | 1.000 | | | | | | | | | | | | |
| N up till | 0.972 | 0.925 | 0.993 | -0.863 | 0.927 | 0.907 | 0.261 | 0.871 | 0.865 | 0.862 | 0.388 | 0.831 | 0.839 | 0.950 | 0.967 | 0.985 | 0.958 | 1.000 | | | | | | | | | | | |
| N up flow. | 0.993 | 0.909 | 0.974 | -0.851 | 0.950 | 0.874 | 0.233 | 0.864 | 0.825 | 0.854 | 0.372 | 0.796 | 0.803 | 0.930 | 0.966 | 0.948 | 0.936 | 0.983 | 1.000 | | | | | | | | | | |
| N up grain | 0.985 | 0.927 | 0.985 | -0.864 | 0.946 | 0.898 | 0.263 | 0.881 | 0.851 | 0.871 | 0.391 | 0.824 | 0.831 | 0.948 | 0.973 | 0.967 | 0.950 | 0.993 | 0.997 | 1.000 | | | | | | | | | |
| N up straw | 0.968 | 0.948 | 0.976 | -0.868 | 0.960 | 0.915 | 0.330 | 0.914 | 0.857 | 0.902 | 0.430 | 0.854 | 0.857 | 0.961 | 0.973 | 0.960 | 0.951 | 0.980 | 0.991 | 0.994 | 1.000 | | | | | | | | |
| P up till | 0.972 | 0.913 | 0.990 | -0.848 | 0.922 | 0.900 | 0.256 | 0.865 | 0.857 | 0.858 | 0.370 | 0.818 | 0.827 | 0.942 | 0.961 | 0.984 | 0.954 | 0.999 | 0.980 | 0.990 | 0.974 | 1.000 | | | | | | | |
| P up flow | 0.996 | 0.893 | 0.980 | -0.847 | 0.938 | 0.866 | 0.194 | 0.841 | 0.825 | 0.831 | 0.347 | 0.780 | 0.789 | 0.923 | 0.963 | 0.955 | 0.936 | 0.989 | 0.996 | 0.995 | 0.981 | 0.988 | 1.000 | | | | | | |
| P up grain | 0.997 | 0.894 | 0.974 | -0.846 | 0.942 | 0.864 | 0.205 | 0.848 | 0.822 | 0.840 | 0.354 | 0.780 | 0.788 | 0.920 | 0.962 | 0.946 | 0.932 | 0.983 | 0.998 | 0.994 | 0.983 | 0.982 | 0.999 | 1.000 | | | | | |
| P up straw | 0.985 | 0.927 | 0.983 | -0.857 | 0.950 | 0.899 | 0.284 | 0.891 | 0.843 | 0.881 | 0.395 | 0.825 | 0.833 | 0.949 | 0.973 | 0.966 | 0.950 | 0.990 | 0.997 | 0.999 | 0.995 | 0.987 | 0.994 | 0.995 | 1.000 | | | | |
| K up till | 0.978 | 0.899 | 0.989 | -0.850 | 0.919 | 0.886 | 0.211 | 0.842 | 0.851 | 0.835 | 0.355 | 0.800 | 0.810 | 0.932 | 0.960 | 0.978 | 0.948 | 0.997 | 0.981 | 0.988 | 0.969 | 0.999 | 0.991 | 0.985 | 0.985 | 1.000 | | | |
| K up flow. | 1.000 | 0.870 | 0.965 | -0.833 | 0.934 | 0.840 | 0.161 | 0.820 | 0.802 | 0.811 | 0.329 | 0.750 | 0.760 | 0.902 | 0.953 | 0.933 | 0.919 | 0.975 | 0.995 | 0.988 | 0.973 | 0.975 | 0.997 | 0.998 | 0.988 | 0.980 | 1.000 | | |
| K up grain | 0.997 | 0.893 | 0.974 | -0.848 | 0.941 | 0.864 | 0.199 | 0.845 | 0.824 | 0.836 | 0.355 | 0.779 | 0.788 | 0.920 | 0.963 | 0.947 | 0.933 | 0.984 | 0.998 | 0.994 | 0.983 | 0.983 | 0.999 | 1.000 | 0.994 | 0.985 | 0.998 | 1.000 | |
| K up straw | 0.999 | 0.883 | 0.970 | -0.844 | 0.939 | 0.852 | 0.175 | 0.831 | 0.813 | 0.821 | 0.339 | 0.765 | 0.774 | 0.911 | 0.959 | 0.940 | 0.926 | 0.979 | 0.997 | 0.991 | 0.978 | 0.979 | 0.998 | 0.999 | 0.991 | 0.983 | 1.000 | 0.999 | 1. |

# Annexure IV

## Economic analysis

### A. Economic analysis –Field experiment kharif season

| Treatments | RR | BCR | PR |
|---|---|---|---|
| **75 per cent NPK fertiliser** | | | |
| M1S1 | - | 3.07 | 1.09 |
| M1S2 | - | 3.05 | 1.06 |
| M1S3 | - | 3.10 | 1.07 |
| M1S4 | 39.4 | 3.18 | 1.03 |
| M1S5 | 41.6 | 3.13 | 1.01 |
| M1S6 | 46.4 | 3.18 | 1.01 |
| M1S7 | 51.3 | 3.15 | 0.99 |
| M1S8 | 29.4 | 3.14 | 0.97 |
| M1S9 | 23.5 | 3.00 | 0.95 |
| M1S10 | 22.4 | 3.00 | 0.96 |
| M1S11 | 21.3 | 2.94 | 0.94 |
| **100 per cent NPK fertiliser** | | | |
| M2S1 | - | 2.98 | 1.00 |
| M2S2 | - | 2.97 | 0.98 |
| M2S3 | - | 3.01 | 0.99 |
| M2S4 | 26.5 | 3.00 | 0.95 |
| M2S5 | 29.7 | 2.96 | 0.93 |
| M2S6 | 34.6 | 3.01 | 0.94 |
| M2S7 | 43.2 | 3.01 | 0.92 |
| M2S8 | 22.4 | 2.96 | 0.90 |
| M2S9 | 18.35 | 2.86 | 0.89 |
| M2S10 | 15.65 | 2.84 | 0.89 |
| M2S11 | 14.6 | 2.78 | 0.88 |

**B. Economic analysis - test verification trial**

| Treatments | Parameters | | | | | |
|---|---|---|---|---|---|---|
| | Grain yield | BCR | Response ratio | RAE | REE | Price ratio |
| T1 | 3725 | 2.98 | - | 0 | - | 1.252 |
| $T_2$ | 4850 | 3.20 | - | 87.54 | 88.66 | 1.033 |
| $T_3$ | 5010 | 3.20 | - | 100.0 | 100.0 | 1.000 |
| $T_4$ | 4050 | 2.91 | 32.5 | 25.29 | 19.32 | 1.128 |
| $T_5$ | 4010 | 2.70 | 14.25 | 22.18 | 4.90 | 1.052 |
| $T_6$ | 5185 | 3.26 | 146.0 | 113.62 | 115.2 | 0.947 |
| $T_7$ | 5420 | 3.27 | 169.5 | 131.91 | 132.4 | 0.943 |
| $T_8$ | 5310 | 3.13 | 79.25 | 123.35 | 120.4 | 0.925 |
| $T_9$ | 5280 | 3.00 | 77.75 | 121.01 | 107.7 | 0.889 |

# Annexure V

## Effects of treatments on the humic acid build up in the Alfisol

| Treatments | Humic acid (%) |
|---|---|
| no HA | 0.261 |
| 10 kg $ha^{-1}$ | 0.266 |
| 20 kg $ha^{-1}$ | 0.297 |
| 30 kg $ha^{-1}$ | 0.320 |
| 40 kg $ha^{-1}$ | 0.324 |