INFLUENCE OF PHOSPHORUS SUPPLEMENTATION THROUGH FISH BONE MEAL ON SOIL CHEMICAL PROPERTIES AND YIELD OF TOMATO

SUHANI
MA1TAI0364

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE, SHIVAMOGGA
KELADI SHIVAPPA NAYAKA
UNIVERSITY OF AGRICULTURAL AND HORTICULTURAL SCIENCES, SHIVAMOGGA

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Thesis submitted to the

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In partial fulfillment of the requirements
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DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE, SHIVAMOGGA
KELADI SHIVAPPA NAYAKA
UNIVERSITY OF AGRICULTURAL AND HORTICULTURAL SCIENCES, SHIVAMOGGA

CERTIFICATE

This is to certify that the thesis entitled **'INFLUENCE OF PHOSPHORUS SUPPLEMENTATION THROUGH FISH BONE MEAL ON SOIL CHEMICAL PROPERTIES AND YIELD OF TOMATO'** submitted in partial fulfillment of the requirements for the award of the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **SOIL SCIENCE AND AGRICULTURAL CHEMISTRY** to the College of Agriculture, Shivamogga, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga is a bonafide record of research work carried out by **SUHANI, ID. No. MA1TAI0364** (sbsuhani3@gmail.com) during the period of study in this university under my guidance and supervision and no part of this thesis has previously formed the basis for the award of any other degree, diploma, associateship, fellowship or any other similar titles.

Shivamogga
December, 2021

MAJOR ADVISOR

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(M. S. NANDISH)

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With regardful memories….

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INFLUENCE OF PHOSPHORUS SUPPLEMENTATION THROUGH FISH BONE MEAL ON SOIL CHEMICAL PROPERTIES AND YIELD OF TOMATO

(SUHANI)

ABSTRACT

A pot experiment was conducted at College of Agriculture, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences (KSNUAHS), Shivamogga, during *Rabi* season, 2021 to study the influence of phosphorus supplementation through fish bone meal on soil chemical properties and yield of tomato. Acidulation of fish bone meal (FBM) with sulphuric acid at 0, 2.50, 5.0, 7.50, 10, 15, 20, 30, 40 and 50 per cent (w/v) was conducted and water-soluble- P was estimated for a week in these acidulated levels. The 15 per cent acid-treated FBM recorded the highest WSP and was used for the experiment. The recommended dose of P through mineral fertilizer and FBM (raw and acidulated) at 100, 75 and 50 per cent levels plus recommended N and K along with FYM (except control), PSF and VAM were imposed in a completely randomized design with eleven treatment combinations and three replications. Application of P through mineral fertilizer and acidulated FBM in 75:25 ratio increased the biometric parameters, quality and yield attributing characters of tomato. The highest fruit yield of tomato (5.48 kg ha^{-1}) was observed in the treatment receiving 75 per cent of recommended P through mineral fertilizer and 25 per cent through AFBM. The nutrient content and uptake of N, P, K, Ca, Mg, S and micronutrients (Fe, Zn, Cu and Mn) by tomato and highest available N, P_2O_5, Ca and S nutrient status in the soil at 30 and 60 DAP and after final harvest were recorded with the application of 75 per cent recommended P through mineral fertilizer plus 25 per cent through acidulated FBM compared to other treatments.

Department of Soil Science and Agricultural Chemistry
College of Agriculture, Shivamogga
KSNUAHS, Shivamogga
December, 2021

Suhani
(sbsuhani3@gmail.com)

B. C. Dhananjaya
(bcdhananjaya@uahs.edu.in)

ಮೀನಿನ ಮೂಳೆ ಗೊಬ್ಬರದ ಮೂಲಕ ರಂಜಕ ಪೂರೈಕೆಯಿಂದ ಮಣ್ಣಿನ ರಾಸಾಯನಿಕ ಗುಣಲಕ್ಷಣಗಳು ಹಾಗೂ ಟೊಮ್ಯಾಟೊ ಇಳುವರಿಯ ಮೇಲಾಗುವ ಪ್ರಭಾವ

(ಸುಹಾನಿ)

ಸಾರಾಂಶ

ಮೀನಿನ ಮೂಳೆ ಗೊಬ್ಬರದ ಮೂಲಕ ರಂಜಕ ಪೂರೈಕೆಯಿಂದ ಮಣ್ಣಿನ ರಾಸಾಯನಿಕ ಗುಣಲಕ್ಷಣಗಳು ಹಾಗೂ ಟೊಮ್ಯಾಟೊ ಇಳುವರಿಯ ಮೇಲಾಗುವ ಪ್ರಭಾವದ ಬಗ್ಗೆ ಅಧ್ಯಯನ ಮಾಡಲು ಮಡಿಕೆ ಪ್ರಯೋಗವನ್ನು ೨೦೨೧ ರ ಹಿಂಗಾರಿನಲ್ಲಿ ಕೃಷಿ ಮಹಾವಿದ್ಯಾಲಯ, ಕೆಳದಿ ಶಿವಪ್ಪ ನಾಯಕ ಕೃಷಿ ಮತ್ತು ತೋಟಗಾರಿಕೆ ವಿಜ್ಞಾನಗಳ ವಿಶ್ವವಿದ್ಯಾಲಯ, ಶಿವಮೊಗ್ಗದಲ್ಲಿ ನಡೆಸಲಾಯಿತು. ಮೀನಿನ ಮೂಳೆ ಗೊಬ್ಬರವನ್ನು ವಿವಿಧ ಗಂಧಕಾಮ್ಲೀಕೃತ ಮಟ್ಟಗಳಲ್ಲಿ (ಶೇ. ೦, ೨.೫, ೫.೦, ೭.೫, ೧೦, ೧೫, ೨೦, ೩೦, ೪೦ ಮತ್ತು ೫೦) ಆಮ್ಲೀಕರಣ ನಡೆಸಲಾಯಿತು. ನೀರಿನಲ್ಲಿ ಕರಗುವ ರಂಜಕವನ್ನು ವಿವಿಧ ಆಮ್ಲೀಕೃತ ಮೀನಿನ ಮೊಳೆ ಗೂಬ್ಬರದಲ್ಲಿ ಅಂದಾಜಿಸಿದಾಗ, ಶೇ. ೧೫ ಗಂಧಕಾಮ್ಲೀಕೃತ ಉಪಚಾರದಲ್ಲಿ ಹೆಚ್ಚು ಕಂಡುಬಂದಿದ್ದು ಬಳಸಲು ಸುಲಭವಾಗಿದ್ದು ಪ್ರಯೋಗದಲ್ಲಿ ಉಪಯೋಗಿಸಲಾಯಿತು. ಶಿಫಾರಸು ಮಾಡಲಾದ ಸಾರಜನಕ ಮತ್ತು ಪೊಟ್ಯಾಷಿಯಂಗಳೊಂದಿಗೆ, ಶೇ. ೧೦೦, ೭೫ ಮತ್ತು ೫೦ ಮಟ್ಟಗಳಲ್ಲಿ ರಾಸಾಯನಿಕ ಗೊಬ್ಬರ ಮತ್ತು ಮೀನಿನ ಮೂಳೆ ಗೊಬ್ಬರದ (ಕಚ್ಚಾ ಮತ್ತು ಆಮ್ಲೀಕೃತ) ಮೂಲಕ ಶಿಫಾರಸು ಮಾಡಿದ ರಂಜಕದ ಜೊತೆಗೆ ಕೊಟ್ಟಿಗೆ ಗೊಬ್ಬರ (ನಿಯಂತ್ರಣ ಉಪಚಾರ ಹೊರತುಪಡಿಸಿ), ರಂಜಕ ಕರಗಿಸುವ ಶಿಲೀಂಧ್ರ ಮತ್ತು ವೆಸಿಕ್ಯುಲರ್ ಆರ್ಬಸ್ಕುಲರ್ ಮೈಕೋರೈಜಾದ ವಿವಿಧ ಸಂಯೋಗಗಳನ್ನು ಒಳಗೊಂಡ ಹನ್ನೊಂದು ಉಪಚಾರಗಳನ್ನು ಸಂಪೂರ್ಣ ಯಾದೃಚ್ಛಿಕ ವಿನ್ಯಾಸದೊಂದಿಗೆ ತ್ರಿಪತಿಯಲ್ಲಿ ಅಳವಡಿಸಲಾಗಿತ್ತು. ಅಧ್ಯಯನದ ಪ್ರಕಾರ ಶೇ. ೭೫:೨೫ ರ ಅನುಪಾತದಲ್ಲಿ ರಾಸಾಯನಿಕ ಗೊಬ್ಬರ ಮತ್ತು ಆಮ್ಲೀಕೃತ ಮೀನಿನ ಮೂಳೆ ಗೊಬ್ಬರದ ಮೂಲಕ ರಂಜಕವನ್ನು ಅನ್ವಯಿಸಿದ ಉಪಚಾರವು ಟೊಮ್ಯಾಟೊ ಬೆಳವಣಿಗೆ, ಗುಣಮಟ್ಟ ಮತ್ತು ಇಳುವರಿಯ ಗುಣಲಕ್ಷಣಗಳನ್ನು ಅಧಿಕವಾಗಿ ಹೆಚ್ಚಿಸಿದೆ. ಹೆಚ್ಚು ಹಣ್ಣಿನ ಇಳುವರಿಯು (೫.೪೮ ಕೆ. ಜಿ. / ಹೆ.) ಇದೇ ಉಪಚಾರದಲ್ಲಿ ದಾಖಲಾಗಿದೆ. ಟೊಮ್ಯಾಟೊದಲ್ಲಿ ಸಾರಜನಕ, ರಂಜಕ, ಪೊಟ್ಯಾಷಿಯಂ, ಕ್ಯಾಲ್ಸಿಯಂ, ಮೆಗ್ನೀಸಿಯಂ, ಗಂಧಕ ಹಾಗೂ ಲಘು ಪೋಷಕಾಂಶಗಳ ಪ್ರಮಾಣ ಮತ್ತು ಹೀರಲ್ಪಡುವಿಕೆಯು ಗಣನೀಯವಾಗಿ ಹೆಚ್ಚಾಗಿರುವುದು ಕಂಡುಬಂದಿದೆ. ಬೆಳೆ ನಾಟಿ ಮಾಡಿದ ೩೦ ಮತ್ತು ೬೦ ದಿನಗಳಲ್ಲಿ ಹಾಗೂ ಅಂತಿಮ ಕೊಯ್ಲಿನ ನಂತರ ಮಣ್ಣಿನಲ್ಲಿ ಲಭ್ಯವಿರುವ ಸಾರಜನಕ, ರಂಜಕ, ಕ್ಯಾಲ್ಸಿಯಂ ಮತ್ತು ಗಂಧಕ ಪೋಷಕಾಂಶಗಳ ಸ್ಥಿತಿಯ ಶಿಫಾರಸು ಮಾಡಿದ ರಂಜಕವನ್ನು ಶೇ. ೭೫:೨೫ ಅನುಪಾತದಲ್ಲಿ ರಾಸಾಯನಿಕ ಗೊಬ್ಬರ ಮತ್ತು ಅಮ್ಲೀಕರಣಗೊಳಿಸಿದ ಮೀನಿನ ಮೂಳೆ ಗೊಬ್ಬರ ಬಳಸಿದ ಉಪಚಾರದಲ್ಲಿ ಹೆಚ್ಚಿನ ಮೌಲ್ಯಗಳಲ್ಲಿ ದಾಖಲಾಗಿದೆ.

Suhani

ಸುಹಾನಿ
(sbsuhani3@gmail.com)

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ಡಿಸೆಂಬರ್, ೨೦೨೧

BCDhananjay

ಬಿ. ಸಿ. ಧನಂಜಯ
(bcdhananjaya@uahs.edu.in)

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INTRODUCTION

I INTRODUCTION

Now a days, there has been increase in the demand for use of chemical fertilizers to get more yields from hybrids and improved varieties. Usage of these chemical fertilizers alone increased the crop yield in the initial years but adversely it affected the sustainability over subsequent years (Singh *et al*., 2015). Application of organic manures to soil such as bone meals, fish bone meals, farm yard manure, vermi-compost and biodynamic manures has been found to have beneficial effects on horticultural crops' production.

Phosphorus is an important input for successful crop production in agriculture. Being a vital element for plant growth and development, it plays a dominant role in plant structure, metabolism and energy transformation. Hence, it stimulates root development, hastens flowering, crops maturity and increases the strength of straw thus helps to increase seed formation. Its role in increasing the yield and improving the quality of crops is very well known. Low Phosphorus Use Efficiency (PUE) (10 to 30 %) of from applied fertilizer due to high fixation characteristics in the acid soil along with the recent steep hike in prices of phosphate fertilizers have further complicated the problems of its use by the farmers.

India is second largest producer of tomato in the world with production of 21 metric tonnes from an area of 0.83 million hectares and productivity is 25.24 t ha^{-1} (Horticulture statistics division, 2019-2020). Karnataka has an area of 0.06 million hectares meter tomato with annual production of 2.16 metric tonnes and productivity is 33.66 t ha^{-1} (Horticulture statistics division, 2019-2020).

India is home to variety of climatic regions, ranging from temperate and alpine in the Himalayan North to tropical in the south. Environment is the most determinate factor in the growth and development of vegetables crops. Due to the influence of changing levels of temperature, humidity, wind flow etc., crop productivity is adversely affected. There is an urgent need to improve strategies to overcome high temperature in tropical climate or low temperature in the countries having temperate climate.

Tomato (*Solanum lycopersicon* Mill.) is self-pollinated crop with chromosome number (2n=24) and is one of the most popular and widely grown vegetable crop all over the India. It belongs to the family Solanaceae. Tomato is the origin of Peru, Ecuador and Bolivia based on the availability of numerous cultivated and wild relatives in these areas (Taylor, 1986). Tomatoes are cultivated in subtropics to tropics of the India. It is being cultivated in open fields, kitchen gardens and grown as 'forced crop' under protected cultivation in polyhouse and greenhouses conditions. It is rich in proteins, vitamins, antioxidants and minerals which are essential for human well-being.

In the present scenario, mankind is addicted to rock phosphate. It should be noted that phosphate rock is a non-renewable resource and the depletion of current economically exploitable deposits can be estimated at somewhere from 70 to 140 years. Further, it is expected that the growing population, change in lifestyle and diets bring about 50 to 100 per cent higher demand for phosphorus by 2050 (FAO, 2006).

Fish bone meal (FBM) is a commercially available product, which is made from the bones and leftover meat of fish by commercial fisheries. FBM is obtained by fish trimmings or drying the fish followed by grinding and it making it powder or cake. Fish bone meal consists of about 45 to 50 per cent protein, 32 to 35 per cent ash, 8 to 12 per cent of fat and 5 to 7 per cent moisture. It contains approximately 6 per cent N, 7 per cent P, 0.2 per cent K, 11 to 16 per cent of Ca, 0.18 to 0.26 per cent of Mg and 0.3 to 0.4 per cent of S. The organic matter content in FBM ranges from 20 to 24 per cent. The phosphorus content of FBM varies from 6 to 9 per cent, is majorly influenced by the bone content of raw material. Most of the P-FBM is present as calcium phosphate [$Ca_5(PO_4)_3OH$] in the bone fraction and as organic form in the meat fraction. However, because of its chemical nature, Phosphorus in FBM is classified as sparingly soluble (readily plant available content 18-42 %) (Lee *et al.,* 2010).

Phosphorus solubilizing biofertilizers are carrier-based preparations containing living or dormant cells of micro-organisms like bacteria, fungi and actinomycetes. These micro-organisms helps in increasing crop production by solubilization of insoluble phosphorus and increase plant growth by providing nutrients, vitamins and other growth factors (Gaur and Sunita, 1999). Fish bone meal in the presence of biofertilizers and soil micro-flora in the soil is acted upon by certain organic acids. It releases phosphorus in the form of available monocalcium phosphate.

Acidulation of phosphate rocks with acids helps to improve the nutrient availability with increasing water-soluble phosphorus. Treating phosphate rock with acid slowed down the immobilization of water-soluble P by reacting with some of the acidity produced during monocalcium phosphate hydrolysis, thus reducing the amount of acid available to solubilize soil Al and Fe. Reaction of acid with phosphate rock could release additional P to the water-soluble pool (Mokwunye, 1980). So, the acidulation of FBM could be done to improve the nutrient utilization by the crops.

Tomato requires phosphorus, calcium and sulphur for root growth, early flowering, growth and development. Slow release phosphatic fertilizer like FBM, is a cheap source of phosphorus to plants can be exploited with the mineral fertilizers along with PSF and VAM to increase phosphorus use efficiency, soil health and crop yield. Hence, the present study titled “Influence of phosphorus supplementation through fish bone meal on soil chemical properties and yield of tomato” is undertaken with the following objectives:

1. To study the effect of fish bone meal on growth, yield and quality of tomato
2. To study the effect of fish bone meal on nutrient content and uptake by tomato
3. To study the effect of fish bone meal on soil chemical properties

REVIEW OF LITERATURE

II REVIEW OF LITERATURE

The present experiment was conducted to study ‘Influence of Phosphorus supplementation through fish bone meal on soil chemical properties and yield of tomato’. Phosphorus (P) has been the subject to intensive research because of its peculiar behavior in soil. As such, P status is not poor in soils, but its availability to plants from the soil as meagre as it is present mostly in unavailable or fixed forms and applied soluble P fertilizers are also fixed immediately by various constituents of soil. Building up of soil P is anticipated at many places where intensive agriculture is practiced due to its regular application, quicker fixation and relatively slower movement in the soil. Therefore, efforts need to be made to utilize the organic sources of P for slow solubilisation to suit the crop demand. The phosphorus content of the organic fish bone meal (FBM) varies from 5 to 20 per cent, is mostly influenced by the bone content of raw material. Most of the FBM-P is present as calcium phosphate [$Ca_5(PO_4)_3OH$] in the bone fraction and organic form in the meat fraction. Knowledge of various forms of P in the soil and the priorities under which these forms become available to plants is a prerequisite in assessing its availability to plants, since different forms have different solubility with the use of solubilizers and mobilizers.

The available review of literature related to the present investigation is given under the following headings.

2.1 Characterization of fish bone meal

2.2 Characterization of acidulated phosphorus products

2.3 Effect of fish bone meal on soil chemical properties

2.4 Effect of fish bone meal on growth, yield and quality parameters of crops

2.5 Effect of fish bone meal on nutrient content and uptake by crops

2.6 Effect of acidulation on soil properties

2.1 Characterization of fish bone meal

Nash and Mathews (1971) studied the composition of meat bone meal (MBM) and found that MBM contains 54 to 59 per cent protein, 10 to12 per cent crude fat, 28 to 29 per cent ash and 3 to 6 per cent moisture. Amino acid composition studies indicated that glutamic acid and glycine were the most abundant amino acids. The least abundant amino acids were the sulphur-containing amino acids such as cysteine and methionine.

Jeng *et al*. (2004) reported the characterization of Norwegian meat bone meal. They found MBM having pH 6.5, 29.00 per cent total organic carbon, 7.89 per cent total nitrogen and C/N ratio of 3.7. It also contains 5.58, 0.36, 11.1 and 0.21 per cent of total P, total K, total Ca and total Mg, respectively.

Meat and bone meal (MBM) is a product of the rendering industry. It has about 50 percent protein, 35 per cent ash, 8-12 per cent fat and 4-7 per cent moisture and contains a big amount of nutrients, including about 8 per cent nitrogen, 5 per cent phosphorus, 10 per cent calcium (Jeng *et al*., 2006). Chemical properties of MBM vary a lot from different raw materials. On average, the pH tends to be acidic, about 6.5 and organic matter content is about 50 per cent.

Coutand *et al*. (2008) presented the ways to utilize ash after burning of MBM as a raw material for industrial phosphoric acid production, based on which P fertilizers can be produced.

Ylivainio and Turtola (2007) found that 90 per cent of P in MBM was soluble only in 1 M HCl. The phosphorus in MBM has a residual effect as it remains in the soil for at least three to five years in acid soils and even longer if the pH is more than 6.5.

Coutand *et al.* (2008) investigated the characterization of four different meat and bone meal (MBM) ashes obtained from specific incineration (laboratory) and co-incineration (industrial process). Three out of the four MBM ashes were mainly composed of calcium phosphates (hydroxyapatite and whitlockite) and their compositions (major and trace) were comparable with natural phosphate rocks.

Garcia and Rosentrater (2008) studied the concentration of critical elements in North American meat and bone meal. They reported that meat and bone meal contains 10.30 per cent calcium, 8.06 per cent nitrogen, 5.10 per cent phosphorus, 1.02 per cent of magnesium and other trace elements.

Chen *et al.* (2011) reported that MBM, a potential organic fertiliser for agricultural crops contains about 8 per cent N, 5 per cent P, 1 per cent K and 10 per cent Ca, varying according to the rendering process and to the origin of the offal. The total amount of N from animal meals could be estimated at 120 million kg N and 155 million kg P or about 360 million kg P_2O_5.

Krupa-Zuczek *et al.* (2012) studied on physicochemical properties of the meat and bone meal. They reported that MBM contains 2.43 per cent of water, calcium of 7.7 per cent and phosphorus content was in the range of 15 to 17 per cent that was comparable with the level of phosphorus content in typical rock phosphate and also found that main crystalline component of MBM was hydroxyapatite.

Staron *et al.* (2016) reported that meat and bone meal and poultry litter incineration have high content of macronutrients (P, Ca, K, Mg and Na) as well as micronutrients (Zn, Cu, Mn and Fe) and they were used to improve the physicochemical properties of soil. They help to significantly reduce the problem of the disposal of such wastes.

Christiansen *et al.* (2020) measured the extractable inorganic P in waste products using different extraction methods. Out of total P content in meat and bone meal, only 0 to 12 per cent of the water-extractable P (H_2O-P), 67 per cent of citric acid extractable P, 75 per cent of oxalic acid extractable P and 92 per cent of HCl extractable P were found.

2.2 Characterization of acidulated phosphorus products

Mhalla *et al.* (2017) investigated that with the increase in the degree of acidulation both total and citrate insoluble P fractions deceased while water soluble P and citrate soluble P as a percentage of total P increased. The release of P increased significantly when the soil was treated with different partially acidulated phosphate rocks (PAPRs), as evident by higher available P (19.0 to 23.5 mg P kg^{-1} soil) over no P (control) treatment (11.5 mg P kg^{-1} soil) during 90 days of incubation irrespective of P sources.

Harrison and Hedley (1987) have examined the effect of acid type on the quality of PAPRs produced from ground NCPR and Jordan PR (JPR). At the same level of acidulation (30 %) the water-soluble P contents of the PAPRs produced from each PR varied with the type of acid used.

Bolan *et al.* (1990) found that phosphoric acid acidulation yields higher P analysis fertilizers, with a higher water-soluble P content per unit of residue P for the same level of nominal acidulation. The solubility characteristics of the directly acidulated PAPRs are affected by the type, composition and concentration of the acid used for acidulation, degree of acidulation, nature and fineness of PR and the method of manufacture. The agronomic value of partially acidulated phosphate fertilizers is affected by the amount of water soluble P and the solubility of residual PR. None of the single extraction tests such as 2 percent citric acid, 2 per cent formic acid and neutral ammonium citrate appear to be appropriate as indicators of 'plant available P' in these fertilizers.

Menon *et al.* (1990) studied the effectiveness of two phosphate rocks (moderately reactive PR and slightly reactive PR) compacted with triple superphosphate (TSP) materials as phosphorus sources was compared with that of partially acidulated phosphate rocks (PAPR) at 50 per cent acidulation with sulphuric acid and TSP in silt loam (pH 4.5) with maize as the test crop. Moderately reactive

PAPR and its PR compacted with TSP were as effective as TSP as phosphorus sources. The slightly reactive PR with 8.8 per cent Al_2O_3 + Fe_2O_3 content was not suited for direct application and its PAPR was only half as effective as TSP. slightly reactive PR compacted with TSP, however, was as effective as TSP. PR compacted with TSP, urea and KCl was no more effective as phosphorus source than PR compacted with TSP alone.

Biswas *et al.* (1995) reported the total phosphate content of acidulated rock phosphate decreases with increasing degree of acidulation with H_2SO_4 as compared to raw rock phosphate but increased when acidulated with H_3PO_4. Both water soluble and citrate soluble P increased and insoluble P decreased with successive levels of acidulation, irrespective of the source of rock, acid and curing temperature. Also, the water soluble as well as citrate soluble P decreased with increases in curing temperature from 35 to 55 °C.

McLean *et al.* (1964) studied the percentage concentrations of phosphorus in the various solubility categories at the different degrees of acidulation of the rock It was noted that the addition of 10 per cent of the H_3PO_4 required to completely convert the rock phosphate to triple super phosphate increased the water-soluble P from an almost negligible amount to 25.70 per cent of the total phosphorus. 20 per cent acidulation increased the water-soluble P to 43.30 per cent of the total amount, while 50 and 100 per cent acidulation increased the water-soluble P to 64.00 and 82.80 per cent of the total, respectively. The citrate-soluble P increased only slightly with 10 and 20 per cent acidulation, but increased considerably with 50 and 100 per cent acidulation. The commercial triple super phosphate was similar in solubility characteristics to the 100 per cent acidulated materials.

2.3 Effect of fish bone meal on soil chemical properties

Salomonsson *et al*. (1995) studied the effectiveness of MBM as a source of nitrogen fertilizer to wheat. They found the better release of nitrogen from the MBM than from pig slurry in the soil and the fertilizer was as effective as urea – N during the early growing phase of the wheat crop.

Bone meal has been found to give sufficient nitrogen supply for the good baking performance of organically grown wheat due to slow mineralization rate of the fertilizer than faster mineralizable fertilizer types (Fredriksson *et al*., 1997).

Lazarovits *et al*. (1999) revealed that mixing bone meal to soil had increased potato quality due to reduced incidence of potato scab (*Verticillinm dahliae*) and reduced populations of parasitic nematodes. There was an initial elevation of soil pH from 6.0 to 8.5 and a corresponding increase in ammonia levels 2 weeks after incorporation. Nitrite and nitrate levels were also higher than those of the control treatments after 4 weeks.

Sadanandan *et al.* (2002) reported that the adoption of IPNM (FYM at 5 t ha^{-1} + NPK at 100:40:140 kg ha^{-1} + agricultural lime, neem cake and bone meal each at 500 kg ha^{-1}) in black pepper increased organic matter status by 50 per cent, while P and K status increased by 88 and 43 per cent, respectively compared to check (farmer's practice).

Chaves *et al.* (2005) studied the dynamics of N-mineralization of five meat and bone meals. They evaluated the meat and bone meals in three differently textured soils during 20-week aerobic incubation. The amounts of mineralized N ranged from 253 to 338 mg N kg^{-1} soil (from 42.60 to 63.90 % of the organic N applied). Values of potentially mineralizable N varied from 232 to 302 mg N kg^{-1} soil and mineralization rate constants (k) ranged from 0.179 to 0.796 $week^{-1}$.

According to Jeng *et al.* (2006), the efficiency of added P depends mostly on the quantity of residual P in soils. Application of MBM as a phosphate fertilizer brings along a significant increase in the labile pool of available P and consequently, the capacity of soils to adsorb additional phosphate can be expected to decrease. They showed that the relative P efficiency of MBM was 40 to 50 per cent compared with superphosphate in experiments with cereals and rye grass.

Kricka *et al.* (2007) studied the application of MBM in combinations with mineral fertilizer applied and in combinations with half dosage of mineral fertilizer and different shares of organic manure. It was noticed that plants were larger and had a larger number of leaves when treated with half-dosage mineral fertilizer in combination with varying dosages of organic manure compared to mineral fertilizer only.

Ylivainio and Turtola (2007) reported that pH is an essential factor influencing P release from MBM. They proved that MBM might be a more effective P fertilizer in acid soils than in soils with pH more than 6. They observed that only about 3 per cent P is directly soluble in MBM and 90 per cent of the P in MBM was soluble only in 1 M HCl.

Mondini *et al.* (2008) reported that the addition of MBM enhanced microbial content and activity. Microbial biomass increased as a function of the rate of application and was higher for non-defatted (ND) MBM compared to defatted (D) MBM. The increase in numbers of aerobic and anaerobic bacteria and fungi caused by MBM addition was more pronounced with ND-MBM. Enzymatic activity in amended soils showed an enhancement in nutrient availability and element cycling.

Ylivainio *et al.* (2008) compared the P availability of MBM, superphosphate (SP) and fox and dairy manure in a 3-year pot experiment with ryegrass. They found that MBM-P was not immediately available to plants and contributed only 19 per cent of the availability. Of the P in MBM and fox and dairy manures, 90 and 65 to 89 per cent, respectively, was soluble only in 1 M HCl. Most of the P was inorganic; dairy manure contained the highest share (14 %) of organic P. For the three years with ten ryegrass cuts, the P availability of MBM increased to 63 per cent. Additions of the sparingly soluble P sources MBM and fox and dairy manure increased the acid-soluble P concentrations in the experimental soil, with MBM having the strongest effect, however, the acid-soluble P fraction decreased with time.

Ylivainio and Turtola (2009) conducted the field trials following the greenhouse experiment supported the conclusion of a longer effect of MBM-P, especially in case of perennial plants. Even though the phosphorus availability of MBM was merely 18 per cent of the P availability of SP-P during the year of application, the P of MBM was equal to SP in the following years. Altogether, the availability of MBM-P in 3 to 4 experimental years reached 32 per cent of SP-P. Furthermore, the highest availability of MBM-P (up to 100 % of SP-P) was found in the case of grassland 3 to 4 years after application.

Jeng and Vagstad (2009) studied environmental effects of MBM-P; the P leaching is reported to be minor even from soils without vegetation cover. The annual rates of orthophosphate (PO_4-P) losses were small for all treatments, rarely exceeding 0.3 kg ha^{-1} or 0.5 per cent of the total P applied. Naturally, the losses may be expected to increase considerably when MBM is used as N fertilizer. The highest application rate of MBM (2280 kg ha^{-1} or 180 kg N ha^{-1}) showed significantly higher PO_4-P losses relative to the other treatments.

Fernandes *et al.* (2010) found that an increased level of total N and available P with MBM application compared to the initial P status in Eutric Vertisol. The N/P ratio of MBM is rather narrow providing more P relative to N than the normal uptake by crops the use of MBM applications can increase available P in the soils. They showed that the application of higher doses of MBM (6 t ha^{-1}), especially for acid soils is not recommended because it leaves great quantity of residual P which can contribute to the contamination of ground waters by leaching and can induce eutrophication of surface waters.

Nogalska and Zalewska (2013) reported that application of meat and bone meal increased the available phosphorus in the soil as compared to mineral fertilization. The application of increasing MBM doses in slightly acidic soil insignificantly decreased the pH of the soil.

Stepien and Wojtkowiak (2015) compared the effect of MBM fertilizer applied at doses of 1.0, 1.5, 2.0 and 2.5 t ha^{-1} with mineral fertilization or no fertilization on winter and spring wheat grain and winter oilseed rape seeds. The experiment was conducted from 2007 to 2009 and did not show any effect of increasing MBM doses on the concentration of micronutrients in the soil. As a result of using higher doses of MBM (1.5, 2.0 t ha^{-1}), the content of Cu in 2009 and of Zn in 2007 considerably decreased (2.0 and 2.5 t ha^{-1}) and fertilization with MBM at 2.5 t ha^{-1} improved the quality of winter wheat grain by increasing the content of Cu, Fe, Mn and Zn.

Shi *et al.* (2016) showed that the combined application of biomass ash (BA), bone meal (BM) and alkaline slag (AS) increased the pH by 0.63 to 1.37 for five Ultisols. The most significant decrease of exchangeable soil acidity was also observed in the treatments of BA + BM + AS by 80.1 to 96.9 per cent and combined application of the amendments significantly increased the exchangeable potassium, calcium and magnesium of the five soils, respectively, by 0.4 to 3.8, 1.9 to 10 and 1.7 to 9.7 times. The contents of available phosphorus of the five soils were also increased significantly by 0.6 to 184 times due to the application of BA + HBM + AS.

Nogalska *et al.* (2017) conducted a field experiment in 2011 – 2013 to determine the effect of increasing doses of meat and bone meal (MBM) on the soil pH. The soil pH decreased with increasing MBM doses. Changes in the content of NH_4^+-N, NO_3^--N and available P in soil were affected by the MBM dose, weather conditions and crop species. MBM had no influence on the accumulation of mineralizable N in the soil, whereas the concentration of available P in soil increased significantly throughout the experiment. After the application of the highest MBM doses, soil pH classification was changed from neutral to slightly acidic.

Szymczyk and Stepien (2018) studied the changes in the chemical properties of groundwater in soils under meat and bone meal, natural and mineral fertilization regimes. They reported that the application of meat and bone meal at the rate of 1 to 2 t ha^{-1} with supplemental potassium fertilization does not lead to higher contamination of groundwater than mineral (NPK) fertilization. The use of meat and bone meal fertilizers at a rate of 2.5 t ha^{-1} significantly increased mineral nitrogen and phosphate concentrations in groundwater samples. The results suggest that meat and bone meal can be successfully used at a rate of 2.0 t ha^{-1} to fertilize. The application of higher doses of meat and bone meal intensifies the flow of biogenic elements into groundwater.

Da Silva *et al*. (2019) investigate the effects of phosphate fertilization with bone meal and single superphosphate on the concentration of phosphorus (P) in the plant tissue, total soluble solids and yield aspects of forage sugarcane. Sugarcane plants fertilized with the addition of bone meal showed an increase in height and number of nodes (13 and 15 %, respectively) when compared to the mineral fertilization with single superphosphate. The sugarcane attributes, in response to the P_2O_5 doses, were described by quadratic functions. The dose of 95.80 kg ha^{-1} of P_2O_5 in the bone meal led to the highest concentration of P in the plant tissue (3.60 g kg^{-1}). The comparison between the sources of P at the doses of 100 kg ha-1 and 150 kg ha^{-1} of P_2O_5 showed that the total soluble solids content was 8.62 and 13.84 per cent higher, respectively, in plants fertilized with bone meal.

Cheluvaraj *et al.* (2020) reported the highest available N, P_2O_5, K_2O and secondary nutrient status of soil at critical growth stages in the treatment receiving 25 per cent of recommended P through FBM and 75 per cent through mineral fertilizer with PSB seed treatment.

2.4 Effect of fish bone meal on growth, yield and quality parameters of crops

Aung and Flick (1980) showed that fish soluble nutrients (FSN), by products of the seafood industry applied at weekly or biweekly intervals gave comparable growth and yield of a sand culture grown tomatoes cv. Fireball, to those of plants given full strength Hoagland's nutrient solution. However, FSN delayed flowering and fruit ripening by 5 to 8 days, depending on the concentration and frequency of application.

Aoi (1988) observed that the application of normal fertilizers at 50 kg: 150 kg: 90 kg NPK with 3 tons poultry manure and 800 kg bone meal per ha resulted in highest total rhizome yield in Curcuma longa (Turmeric).

Salomonsson *et al*. (1995) noticed the effects of organic fertilizers (slurry manure and MBM) and urea on winter wheat. They reported that there were no consistent differences in protein content and yield level between the treatments with organic fertilizers and the urea treatments.

Supratik *et al.* (1998) studied the *Withania somnifera* seedling growth and alkaloid content with the application of cow dung, bone meal and neem seed cake at the rate of 28:28:28 g per 1.3 m^2 and found better root yield and alkaloid content compared to the recommended dose of fertilizers and other treatments.

Valenzuela *et al.* (2000) reported that chicken manure and bone meal combinations resulted in the most significant yields and most extensive root sizes in jicama (*Pachyrhizus erosus*). Yields from the low bone meal applications treatments were similar to those obtained with synthetic fertilizers, which were in turn, similar or numerically greater than those observed in controls.

In a pot experiment, Jeng *et al.* (2004) reported that increasing amounts of MBM gave significantly increased yields of cereals and this effect was significant in both without extra N fertilizer and with increasing amounts of mineral N. Application of mineral N-fertilizer resulted in larger yield response for the largest MBM application compared to treatments without added mineral N. Whereas, in the field experiment the treatments without N-fertilizer gave small yields. The yield obtained by the smallest amount of MBM (630 kg ha^{-1}) was not significantly different from treatment which had received the same amount of MBM and N 50 kg ha^{-1} in mineral fertilizer.

Saraf *et al.* (2004) investigated the growth of pomegranate. They concluded that application of poultry manure (5 kg) and bone meal (1 kg) per plant with N, P and K was an effective treatment to boost up the overall growth of pomegranate plants.

Jeng *et al.* (2006) conducted a greenhouse experiment, where fertilizing effects of MBM and mineral NPK fertilizer were compared in the case of barley and ryegrass. Barley and ryegrass yields with equal N supply did not differ significantly between the NPK and MBM treatments.

The fur animal manure is an important resource of P, which can be used by organic farms that lack of their own P sources and thus increase P recycling. Ylivainio (2007) found that although P in MBM and fur animal manure was mainly acid-soluble at the beginning, P eventually converted to a plant available form and achieved similar yield in ryegrass as obtained by dairy manure and super phosphorus application. Mixing the organic and mineral fertilizer got a better result than the application of only fur animal manure.

Chen (2008) reported that MBM application resulted in as high grain yields as did mineral fertilizer in case of barley and oat crops.

Kundu *et al.* (2010) evaluated the growth, productivity and economics of rice under fish meal application. The growth parameters, yield components and seed yield of rice were maximum when well-decomposed fish meal manure was applied along with inorganic fertilizer at 75 per cent of the recommended dose and showed that fish meal has a better result over FYM and vermicompost.

Pal *et al.* (2010) investigated the effects of partial substitution of chemical fertilizers with different organic sources on rice-rapeseed-black gram cropping sequence in coastal saline belts of West Bengal during 2005-06 and 2006-07. The growth parameters, yield components and productivity of all the crops in the sequence were maximum when organic manure was applied along with inorganic fertilizer at 75 per cent of the recommended dose. The effect of well-decomposed fishmeal on rice and its residual effect on succeeding crops of rapeseed and black gram were as good as farmyard manure. The highest rice equivalent yield (9.62 t ha^{-1}), net returns (Rs. 43728 ha^{-1}) and net production value (1.86) were recorded when 75 per cent recommended dose of NPK + 2 t ha^{-1} well-decomposed fishmeal was applied to rice.

Sempiterno *et al.* (2010) studied the effect of different level (2, 4 and 6 t ha^{-1}) of MBM application on yield of ryegrass in Eutric Vertisol and Humic Cambisol. They found that the dry matter yield increased with an increased level of MBM.

Chen *et al.* (2011) reported that the grain yield per hectare significantly improved in barley and oat when treated with bone meal and mineral fertilizers in comparison to chemically treated ones. A similar trend was demonstrated by grain quality parameters as well.

Haraldsen *et al.* (2011) conducted pot experiment by using bottom wood ash (BWA) (contains high concentrations of Ca, Mg, K and P) and meat and bone meal (MBM), a good N and P fertilizer. The effects of a mixture of MBM and BWA were compared with those of mineral NPK (21-4-10), MBM, MBM plus K and Mg mineral fertilizer and MBM with different types of crushed K or Mg-rich rock. The mixture of MBM and BWA gave the highest yield of barley at the same level of mineral NPK and significantly higher than for MBM alone and also than other treatments.

Stepien and Wojtkowiak (2011) studied the effect of applied fertilization with NPK as well as with manure and meat and bone meal in doses from 1.0 to 2.5 t ha^{-1} for five-year (2005-2009) with crop rotation of spring wheat cv. Nowra and Tybalt. It was observed that the increase in MBM significantly increased the protein content in grain.

Wojtkowiak and Stepien (2011) reported that application of manure and meat and bone meal, especially at a rate of 2.5 t ha^{-1} with the addition of effective microorganisms leads to increase in the protein of wheat grain by an increase in the proportion of protein fractions, albumins and globulins.

Nogalska *et al.* (2012) reported that increasing MBM doses contributed to an increase in maize grain yield and 1000 grain weight and treatment of 2.5 t ha^{-1} MBM met the fertilizer requirements for nitrogen and phosphorus and led to a significant increase in maize grain yield.

Alotaibi *et al.* (2013) showed that application of meat and bone meal ash had a limited effect on measured crop variables, suggesting that a significant portion of this ash P is present in an insoluble form and is not as readily available for plant uptake. This was also indicated by its lesser effect on enhancing extractable available P remaining in the soil after harvest in comparison to monocalcium phosphate.

Boen and Haraldsen (2013) used meat and bone meal and bio-solids as slow release phosphorus fertilizers in ryegrass. They found that compared with annual NPK fertilization, biosolids fertilized and MBM fertilized treatments had lower yield in early season and this slow start was compensated by higher yields later in the season.

Tammeorg *et al.* (2014) noticed that MBM treatments increased the easily soluble P content over chemical fertilizer treatments and unfertilized controls in two year application experiment. In contrast, the amounts of easily soluble Ca and S were significantly increased only during the first season of application. In both years, both the fertilizers increased the soil NO_3^--N and mineral N contents over the control, but there were no differences between these fertilizers.

Kivela *et al.* (2015) conducted an experiment on the effects of meat bone meal as fertilizer on yield and quality of sugar beet and carrot. MBM fertilization of sugar beet grown on clay loam and sandy clay soil gave 11.4 per cent (2008) and 19.6 per cent (2009) lower yields than mineral fertilizers. The lower root yield in 2008 was compensated by higher extractable sugar content and lower amino-N, K and Na in the root but no such compensation in root quality was detected for 2009. Similarly, in carrot, the lower yield was compensated by improved quality, lower NO_3^- content and good storability. The N supply from MBM is not sufficient for achieving the same yields as with mineral fertilizers. The relative N efficiency of total N of MBM was 83 per cent that of mineral fertilizers.

Jastrzębska *et al.* (2016) proved that yield of wheat fertilized with the biofertilizers from ash and bones did not differ from the yield achieved with the commercial fertilizers, Phosphorus bio-fertilizers from ash and bones equalled commercial fertilizers in terms of crop-enhancing efficiency.

Nogalska (2016) used meat and bone meal as fertilizer for spring barley with MBM dose of 0, 1.0, 1.5, 2.0, 2.5 t ha^{-1} $year^{-1}$, which was compared to the mineral fertilization (NPK) for two seasons. MBM used in doses higher than 1.0 t ha^{-1} had a more beneficial influence on the grain yield of spring barley and grain plumpness than mineral fertilizers. The positive yield forming effect of MBM doses 2.0 t $ha^{-1}$and 2.5 t ha^{-1} was statistically significant. The nitrogen content of grain was similar in treatments with MBM and mineral fertilization. The optimal MBM dose was 1.5 t ha^{-1}, which allowed producing 5.1 t ha^{-1} of the plumpest grain and wheat N and P content was consistent.

Singh *et al.* (2018) found that the application of 50 per cent RDF + 0.4 t sewage sludge ha^{-1} + 0.25 t bone meal ha^{-1} showed a significant positive impact on plant height, leaf area per plant, number of grains per spike and grain yield of wheat.

Bhutia *et al.* (2019) found that the application of bone meal @ 5 t ha^{-1}, Rhizobium, PSB and wood ash @ 0.5 t ha^{-1} demonstrated significantly higher plant height, root length, fresh and dry shoot and root weight, number of pods per plant, pod length, pod weight per plant and pod yield ha^{-1}.

Cheluvaraj *et al.* (2020) reported that application of 25 per cent of recommended P through FBM and remaining through mineral fertilizer with PSB seed treatment significantly increased the growth, yield attributes and yield of soybean.

2.5 Effect of fish bone meal on nutrient content and uptake by crops

Blatt (1991) compared the combinations of fish bone meal, blood meal, meat meal and a seaweed concentrate with chemical fertilizer for the two cropping seasons. In the majority of comparisons, plants receiving the organic amendments produced crops of comparable yield and size to those from plants receiving the chemical fertilizer.

Fu *et al.* (1992) observed that bone meal and superphosphate were good sources of phosphorus compare to rock phosphate in *Antirrhinum majus*. Bone meal resulted in a linear increase in phosphorus uptake and produced bigger and more brightly coloured flowers.

Nimje and Potkile (1997) conducted a field trial in soybean cv. PKV-1 and reported that application of phosphorus (P_2O_5) in the form of bone meal at different concentrations at 0, 25, 50, 75, 100 and 125 kg ha^{-1} resulted in higher chlorophyll content, root nodule nitrogen, plant phosphorus and plant potassium contents. These contents increased with the applied rate of bone meal.

In the case of leek seedlings inoculated with arbuscular mycorrhiza, Kahiluoto and Vestberg (1998) reported a significantly more P uptake from the bone meal than from Kola apatite. Bone meal (P content 7.4 %) increased the acetate-extractable P contents of soil significantly, whereas Kola apatite did not influence soil acetate-extractable P contents. The inoculation of seedlings with arbuscular mycorrhiza increased P uptake only on conventionally managed soil monocropped with cereal. The effect was even negative on organically cultivated soil. From these results, it can be concluded that MBM-P uptake can be greatly amplified on the presence of arbuscular mycorrhiza in soil.

Patil *et al.* (2000) conducted a field study at Dapoli, Maharashtra in rice cv. Ratnagiri with different combinations of 0, 50 and 100 per cent of recommended NPK (100:50:50 kg ha^{-1}) and fish meal (0, 1, 2 and 3 t ha^{-1}) and noticed that grain and straw yield increased with increasing fertilizer rates, and the highest yield and nutrient uptake were given by 100 per cent NPK + 3 t fish meal ha^{-1}. This treatment also gave the highest grain protein content.

In the pot experiment, Jeng *et al.* (2004) reported increased N uptake with N application. The N uptake in cereals was higher for mineral N fertilization treatments than for fertilization treatments with MBM. Whereas, in the field experiment, increased

N uptake with increasing N fertilization was found both for mineral fertilizer and MBM.

Sempiterno *et al.* (2010) reported that higher levels of MBM led to higher N and P uptake in ryegrass and higher apparent N recovery in Eutric Vertisol and Humic Cambisol.

Nogalska *et al.* (2012) reported significantly higher N, P, K and Mg uptake by maize plants was observed in treatments with the highest MBM dose (2.5 t ha^{-1}) compared with the control treatment.

Simoes *et al.* (2012) studied the agronomical performance of tifton grass with the application of meat and bone meals. The production levels of dry matter generated by the meat and bones proved effective in relation to single super phosphate, ranging from 94 per cent, 66 per cent and 78 per cent compared with the doses 100, 200 and 300 kg ha^{-1}, respectively. The meat and bone meal produced satisfactory results in relation to dry matter production of tifton, compared to conventional fertilization.

Nogalska and Zalewska (2013) found that phosphorus uptake by winter wheat and maize was higher in treatments applied with meat and bone meal compared to control.

Li *et al.* (2013) reported the increase in P uptake with bone meal application in winter triticale, winter wheat and also the green matter of maize.

Nogalska (2016) found that the optimal MBM dose of 1.5 t ha^{-1} for wheat produced the plumpest grain of 5.1 t ha^{-1}. N and P content of wheat was consistent with the feeding standards for livestock and the N content of grain was similar in treatments with mineral fertilization.

2.6 Effect of acidulation on soil properties

A growth chamber study had been done by McLean *et al.* (1964) to know the effect of partially acidulated rock phosphate on yields and P contents of Alfalfa and German Millet. Rock phosphates were acidulated with H_3PO_4 at 0, 10, 20, 50 and 100 per cent of that required to convert the rock phosphate to triple superphosphate and compared with control (0 P). The phosphate treatments were applied both in bands and mixed with the soil. The yields of the alfalfa grown in soil treated with the 10 per cent acidulated material were as good as or better than those where the treatment was 100 per cent acidulated material. Compared to 50 per cent acidulation, 100 per cent acidulation caused decreased yields of millet both when the fertilizer was mixed and when it was banded with the soil.

McLean *et al.* (1965) studied partially acidulated rock phosphate (with H_3PO_4) using additional soils, application rates and preparation methods under growth chamber and field conditions. The yields and P contents of German millet and alfalfa in the growth chamber increased to a maximum at 66 ppm P application and 20 per cent acidulation on one group of soils and continued to increase with application rate and acidulation degree in another group. Average field corn yield on five soils was highest with 20 per cent acidulated material resulting in marked economic advantage of this material.

Shinde *et al.* (1978) conducted a pot experiment with acid P deficient soils reported the behaviour of the HCl or H_2SO_4 acidulated products in respect of P availability in soil, grain yield response and P uptake by rice was more or less similar. Partially acidulated rock phosphate to the extent of 50 per cent with either of the acids was found to be suitable for growing rice under flooded soil conditions.

Hagin *et al.* (1990) conducted a dissipation experiment single fertilizer granules of 4 mm diameter were implanted into soil, incubated for 1 and 4 weeks and inorganic P fractionation in the residual granules and the surrounding soil was performed. Five phosphate rocks varying in formic acid P solubility from 18.9 to 52.7 per cent, expressed as percentage of total P, were acidulated with phosphoric or sulphuric acids to 0, 20 per cent, per cent and 50 per cent of full acidulation and granulated. Dissipated P was greater than the water-soluble P content of the partly acidulated phosphate rock fertilizers indicating the dissolution of the non-acidulated phosphate rocks. The amount of P dissipated was related to the initial water-soluble P content and to the formic acid solubility of phosphate rocks used for manufacturing the fertilizers. The P dissipated increased with an increase in soil acidity.

MATERIAL AND METHODS

III MATERIAL AND METHODS

A pot experiment was conducted to study the "Influence of phosphorus supplementation through fish bone meal on soil chemical properties and yield of tomato" during summer 2021 at College of Agriculture, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences (KSNUAHS), Shivamogga. The particulars of the material used and the methods adopted in the experiment are presented in this chapter under appropriate headings.

3.1 Location of the experimental site

The location of the experimental station comes under the Southern Transitional Zone of Karnataka (Agro-climatic Zone - VII). It is situated between 13°42' N latitude and 75°51' E longitude with an altitude of 667.5 m above mean sea level (MSL).

3.2 Weather condition of the experimental location

The annual rainfall of College of Agriculture, Shivamogga was 1037.30 mm 2020-21. The maximum amount of rain was distributed from January to May and highest rainfall was received in January (59.80 mm) followed by May (43.20 mm). The mean monthly maximum temperature was highest during April (35.50 °C), while it was lowest in January (30.90 °C). Maximum relative humidity was observed in May (73.50 %) and minimum during March (58.50 %). Sunshine hours were higher in February (8.50 hrs.) (Appendix I).

3.3 Initial characterization of soil used for pot experiment

Composite soil samples from the experimental pots were collected, thoroughly mixed and kept for air drying. The soil sample was analyzed for different physical and chemical properties. The result of the analysis is given in Table 1. Initial characterization of soil used for pot experiment indicate that soil had a pH of 6.3, electrical conductivity (EC) of 0.21 dSm^{-1} @ 25 ºC and organic carbon content of 4.70 g kg^{-1}. Further, the soil in the pot was low in nitrogen (208.51 kg ha^{-1}), high in phosphorus (66.12 kg ha^{-1}) and medium in available potassium status (298.20 kg ha^{-1}).

Table 1. Initial properties of soil used for pot experiment

Physical Properties	**Value**
Coarse sand (%)	36.80
Fine sand (%)	33.70
Silt (%)	10.20
Clay (%)	17.40
Textural class	Sandy loam
Chemical properties	
pH (1:2.5)	6.30
Electrical conductivity (dSm^{-1} @ 25 ^{o}C) (1:2)	0.21
Organic carbon (g kg^{-1})	4.70
Available macro nutrient status	
Available N (kg ha^{-1})	208.51
Available P_2O_5 (kg ha^{-1})	66.12
Available K_2O (kg ha^{-1})	298.20
Exchangeable Ca [cmol (p^+) kg^{-1}]	3.00
Exchangeable Mg [cmol (p^+) kg^{-1}]	1.50
Available S (mg kg^{-1})	17.10
Micronutrient status (mg kg^{-1})	
Available Fe	21.58
Available Zn	0.98
Available Cu	0.96
Available Mn	2.52

3.4 Acidulation of fish bone meal

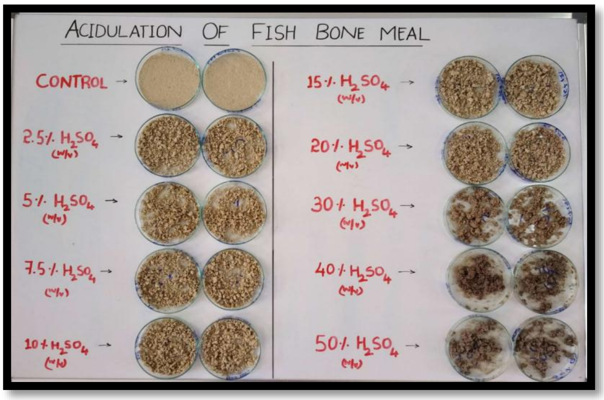
A lab study was conducted to study the dissolution of fish bone meal with the mineral acid (sulphuric acid) and to determine its effect in enhancing the phosphorus availability for the soil application. The fish bone meal sample was ground and passed through 0.2 mm sieve. 33 petri plates were taken and 50 grams of fish bone meal was placed in each of the petri plate. For acidulation of the fish bone meal, 0, 2.5, 5, 7.5, 10, 15, 20, 30, 40 and 50 per cent of H_2SO_4 solution was prepared with distilled water (v/v). Triplicate petri plates were added with 50 ml of each of prepared acid solutions in 1:1 ratio (w/v), respectively.

The acidulation process was carried out at room temperature and acidulated fish bone meal (AFBM) was analysed for water soluble phosphorus (WSP) for about a week following the methods described by Page *et al.* (1982). The WSP content was estimated after washing a known weight (0.2g) of the fish bone meal with distilled water. Sample was placed in funnel fitted with Whatman no. 1 filter paper and leached with distilled water till 50 ml of leachate was obtained. The 5 ml leachate was taken in a 100 ml capacity volumetric flask and volume was made up with distilled water. The aliquot of 5ml was pipetted and 5 ml of Barton's reagent was added and developed the vanadomolybdo-phosphoric yellow colour complex in a 25 ml volumetric flask. The volume was made up and absorbance was measured at 470 nm (Koenig and Johnson, 1942).

The result of the acidulation study to know the dissolution of fish bone meal for about a week is depicted in Table 2. The percent water soluble P_2O_5 in AFBM increased with the increase in the degree of acidulation. Among the different acidulation levels, 15 per cent (w/v) acidulation treatment recorded more WSP with increasing days. It was considered that though the WSP was more in 20, 30, 40 and 50 per cent (w/v) acidulation treatments, the acidulated material was less friable for practical application to the soils. Fifteen per cent acidulated FBM with was found more and was friable to be used and it was considered best for conducting experiment under acidulated fish bone meal.

Table 2. Water soluble phosphorus in fish bone meal after acidulation

Treatment with Sulphuric acid	WSP (P_2O_5) (%) after 5 days
No treatment with acid	1.41
2.50 %	8.90
5.00 %	9.68
7.50 %	11.09
10.00 %	14.21
15.00 %	19.05
20.00 %	11.24
30.00 %	7.34
40.00 %	6.71
50.00 %	6.25



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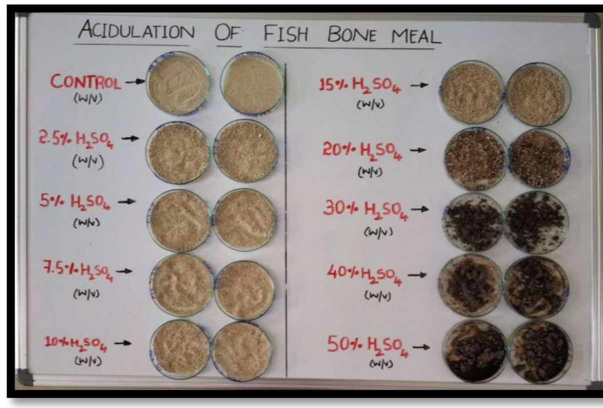

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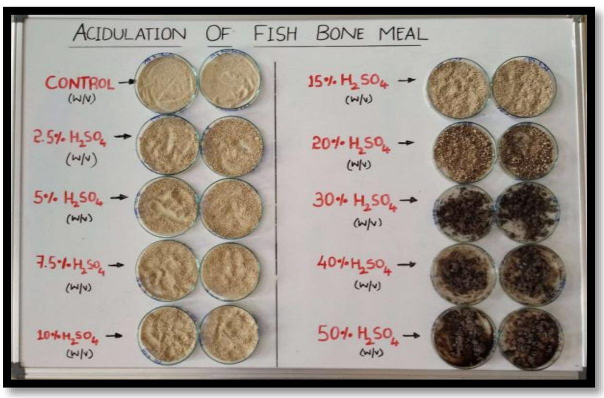

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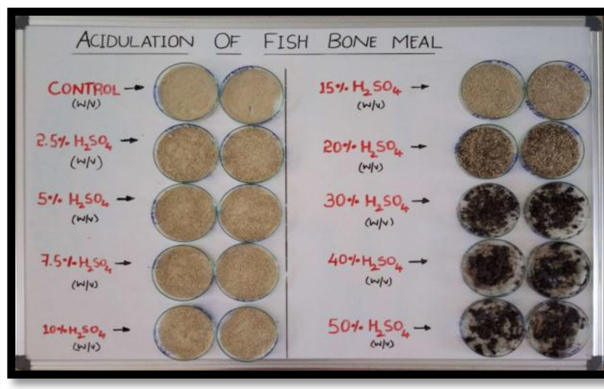

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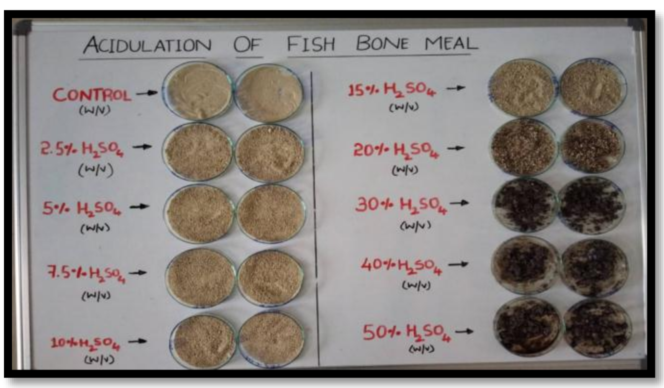

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(a), (b), (c), (d) and (e) are 1st , 2nd , 3rd , 4th and 5th day of acidulation

Plate 1. Acidulation of raw fish bone meal

3.5 Characterization of raw fish bone meal

Total elemental composition of fish bone meal estimated as per the procedures explained in section 3.13 is presented in Table 3. The pH of fish bone meal was 7.31 with electrical conductivity of 1.06 dSm^{-1} and the total C content was 21.20 per cent. The concentration of total nitrogen, phosphorus and potassium were 28.84, 7.20 and 0.26 per cent, respectively. FBM contains total calcium, magnesium and sulphur to the extent of 10.80, 6.12 and 0.34 per cent, respectively. The concentration of iron, manganese, zinc and copper were 233.27, 14.69, 121.38 and 4.24 mg kg^{-1}, respectively. The sodium content in fish bone meal was 0.19 per cent.

3.6 Characterization of acidulated fish bone meal

Total elemental composition of acidulated fish bone meal estimated as per the procedures explained in section 3.13 is presented in Table 3. The pH of acidulated fish bone meal was 5.31 with EC of 2.41 dSm^{-1} and the total C content was 22.90 per cent. The concentration of total nitrogen, phosphorus and potassium were 20.30, 9.05 and 0.29 per cent, respectively. AFBM contains total calcium, magnesium and sulphur to the extent of 11.20, 7.48 and 14.56 per cent, respectively. The concentration of iron, manganese, zinc and copper were 253.72, 15.18, 123.63 and 4.50 mg kg^{-1}, respectively. The sodium content in acidulated fish bone meal was 0.15 per cent.

3.7 Characterization of FYM

Total elemental composition of FYM estimated as per the procedures explained in section 3.13 is presented in Table 3. The pH of FYM was 8.11 with EC of 0.66 dSm^{-1} and the total C content was 14.25 per cent. The concentration of total nitrogen, phosphorus and potassium were 1.09, 0.80 and 1.10 per cent, respectively. FYM contains total calcium, magnesium and sulphur to the extent of 1.50, 0.60 and 0.18 per cent, respectively. The concentration of iron, manganese, zinc and copper were 598.89, 113.79, 84.42 and 1.24mg kg^{-1}, respectively. The sodium content in FYM was 0.04 per cent.

Table 3. Characterization of raw and acidulated fish bone meal and FYM

Parameter	Raw fish bone meal	Acidulated fish bone meal	FYM
pH (1:100 w/v)	7.31	5.31	8.11
EC (1:100 w/v) (dSm^{-1}@ 25 ^{o}C)	1.06	2.41	0.66
Total nutrient concentration			
Carbon (%)	21.20	22.90	14.25
Nitrogen (%)	28.84	20.30	1.09
Phosphorus (%)	7.20	9.05	0.80
Potassium (%)	0.26	0.29	1.10
Calcium (%)	10.80	11.20	1.50
Magnesium (%)	6.12	7.48	0.60
Sulphur (%)	0.34	14.56	0.18
Iron ($mg\ kg^{-1}$)	233.27	253.72	598.89
Zinc ($mg\ kg^{-1}$)	121.38	123.63	84.42
Manganese ($mg\ kg^{-1}$)	14.69	15.18	113.79
Copper ($mg\ kg^{-1}$)	4.24	4.50	1.24
Sodium (%)	0.19	0.15	0.04

3.8 Design and layout of the experiment

The experiment consisted of eleven treatment combinations and was replicated thrice. The detailed plan and layout of the experiment is presented in Fig 1.

3.8.1 Details of the experiment

Crop : Tomato

Hybrid : SAKATA-914

Season : *Rabi*, 2021

Design : CRD

Treatments : 11

Replications : 3

RDF : 250:250:250 kg ha^{-1} and FYM 25 t ha^{-1}

3.8.2 Treatment details

T_1: Control

T_2: 250 kg P_2O_5 as DAP (Package of Practice)

T_3: 187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as RFBM

T_4: 125 kg P_2O_5 as DAP + 125 kg P_2O_5 as RFBM

T_5: 187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM

T_6: 125 kg P_2O_5 as DAP + 125 kg P_2O_5 as AFBM

T_7: 200kg P_2O_5 as DAP (80% recommended P_2O_5)

T_8: 150 kg P_2O_5 as DAP + 50 kg P_2O_5 as RFBM

T_9: 100 kg P_2O_5 as DAP + 100 kg P_2O_5 as RFBM

T_{10}: 150 kg P_2O_5 as DAP + 50 kg P_2O_5 as AFBM

T_{11}: 100 kg P_2O_5 as DAP + 100 kg P_2O_5 as AFBM

Note:

1. RDF-250:250:250 kg ha^{-1}
2. RD FYM- 25 t ha^{-1}
3. Recommended NK and FYM is common to all treatments except control (T_1).

4. PSF (*Aspergillus awamori*) and VAM (*Glomus fasciculatum*) is common to all the treatments

3. 9 Crop husbandry

3.9.1 Pot preparation

Pots are filled with soil obtained at a depth of about 0 to 15 cm. The pot experiment was laid out with eleven treatments and three replications. Individual pot capacity is of 10 kg soil. These pots were made ready for the crop production.

3.9.2 Application of fish bone meal and FYM

Calculated quantity of fish bone meal, acidulated fish bone meal and FYM were applied to each pot seven days before planting of crop as per the treatments.

3.9.3 Crop and hybrid

Tomato hybrid, *i.e.*, SAKATA-914 was used for the experimentation. It is a determinate type of hybrid that grows to a height of 3 to 4 feet. The crop period is from 110 to 120 days yielding attractive red color tomato berries.

3.9.4 Fertilizer application

The required recommended dose of nutrients for tomato used was 250 kg N, 250 kg P_2O_5 and 250 kg K_2O kg ha^{-1}. Nitrogen and phosphorus were applied through urea and DAP, while potash was applied using muriate of potash (MOP) as per calculation. Split application of nitrogen fertilizer was given half as basal dose and other half after four weeks of planting of crop. All the fertilizers were applied as basal and mixed with soil after planting the seedlings. The contribution of N and P from the fish bone meal and acidulated fish bone meal was taken into consideration during the application of fertilizers.

3.9.5 Application of bio-fertilizers

Phosphorus solubilising and mobilizing fungi such as *Aspergillus awamori* and *Glomus fasciculatum* (VAM) were applied to all the treatments.

3.9.6 Transplanting

One month-old tomato seedling were planted one all the pots.

3.9.7 Watering

Tomato is non-resistant to drought. Water deficient for short period would considerably affect crop yield.It is necessary to water the plants regularly, especially during flowering and fruit formation. Frequent irrigation was given to the crop.

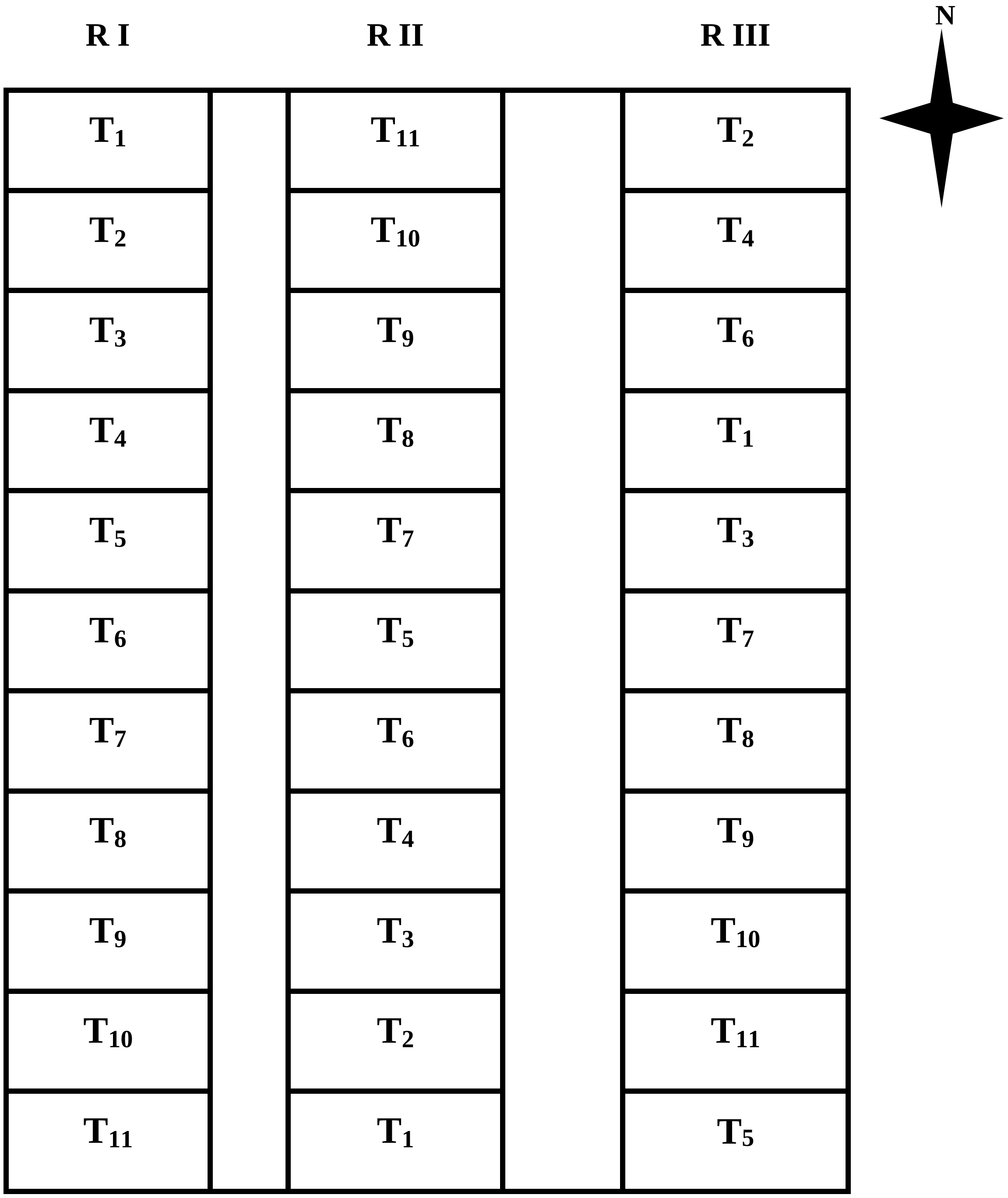

Fig. 1. Plan of layout of pot experiment

Plate 2. General view of the pot experiment

3.9.8 Weeding

Hand weeding was done thrice a week to keep the crop weed-free and maintain uniformity among treatments.

3.9.9 Staking

Staking tomato plants with jute thread and tied to a barbed wire 30 days after planting, as it provides support and keeps the fruit and foliage off the ground. Staking will increase fruit yield, size and reduce fruit rot and makes spraying and harvesting easy.

3.9.10 Plant protection

Plant protection sprays such as Emamectin benzoate 5 % SG @ 1.0 g L^{-1} was applied two times in the fifth and eighth week after planting to control leaf miner.

3.9.11 Harvesting

The fruits were harvested when it starts showing maturity *i.e.,* at breaker stage. Totally 6 to 7 (pickings) harvests were made at six days interval. The ripe tomatoes are picked with clean hands and twisted gently off a plant without squeezing the fruit.

3.9.12 Treatment evaluation

The effects of treatments were evaluated in terms of growth, yield attributes, yield, nutrient content and uptake by tomato crop.

3.10 Growth attributes

3.10.1 Plant height

The height of the plant from the bottom (cotyledonary node) to the tip of the plant was measured at 30, 60 DAP (days after planting) and after final harvest, expressed in centimeter (cm).

3.10.2 Number of branches plant^{-1}

The number of branches borne on the main stem were counted at 30, 60 DAP and final harvest, expressed as number.

3.11 Yield and yield attributes

3.11.1 Fruit diameter/width

The diameter/width of the fruit was recorded by selecting harvested fruits from each plant and measured at the highest bulged portion by using vernier calipers and average width of the fruit was computed and expressed in centimeter (cm).

3.11.2 Total number of fruits plant^{-1}

The fruits harvested in all the pickings from individual plant were added and the average was worked out and expressed in number.

3.11.3 Total yield plant^{-1}

The fruits harvested at different pickings from individual plant were weighed and pooled and the average yield per plant was worked out and expressed in kg plant^{-1}

3.11.4 Dry matter yield

Reliable estimates of vegetative dry matter yield by laboratory methods were reviewed by Pitt (1993). At harvest stage the entire plant was removed and places in oven dryer at 60-70 ^{o}C till constant weight was obtained. The percentage of dry matter was calculated based on moisture difference after drying the samples and expressed as kg plant $^{-1}$.

3.12 Quality parameters

3.12.1 Lycopene content

Lycopene is the pigment principally responsible for the characteristic deep-red color of ripe tomato fruits and tomato products. Lycopene is the most abundant carotenoid present in red tomatoes, comprising up to 90 per cent of the total carotenoids present. The fresh fruits were collected at the fruiting stage and lycopene content was estimated by spectrophotometric determination as described by Scott (2001) and Fish *et al*. (2002).

0.6 g of tomato fruit sample was taken

↓

Extracted with hexane: ethanol: acetone containing 0.05 % (w/v) BHT (Butylated Hydroxy Toluene) solvents in a ratio of 2:1:1 (10:5:5 ml)

↓

Samples were placed on orbital shaker to mix at 180 rpm for 15 minutes

↓

Added with 5ml of distilled water and samples were shaken for another 5 minutes

↓

After shaking placed at room temperature for 5 minutes to allow for phase separation

↓

Absorbance of hexane layer (supernatant) was measured spectrophotometrically at 503 nm against a blank of hexane solvent

$$\text{Lycopene}(\text{mg kg}^{-1}\text{ tissue}) = \frac{\text{A 503 } \times 31.2}{\text{Weight of sample (g)}}$$

Where,

A 503 = Absorbance of hexane layer measured at 503 nm

3.12.2 Ascorbic acid

The nutritive value of tomato juice depends largely on its ascorbic acid (Vitamin C) content and ascorbic acid determination was made as described by the AOAC (1999).

5 ml tomato juice was taken in a volumetric flask of 100 ml

↓

Volume made by adding 0.4 % oxalic acid

↓

10 ml filtered aliquot was taken

↓

Added some distilled water for making end point clear

↓

Titrated against standardized (0.04 %) 2, 6-Dichlorophenolindophenol Sodium salt hydrate dye, to light pink as end point which should persist for at least 15 seconds

Ascorbic acid content was expressed as mg per 100 g of fresh weight. The representative fruits were collected from each replication at the harvest stage and fruit juice was extracted and the extracted juice was subjected to analysis of ascorbic acid content (vitamin C) of tomato fruit.

Vitamin C content was calculated as ascorbic acid by using the following formula

$$\text{Ascorbic acid (mg 100g}^{-1}) = \frac{1 \times R_1 \times V \times 100}{R \times W \times V_1}$$

Where,

R= ml of dye used to titrate against 2.5 ml of reference solution(1 ml standard ascorbic acid + 1.5 ml 0.4 % oxalic acid)
R_1= ml of dye used to titrate against V_1 of aliquot
V= volume of aliquot made by 0.4 % oxalic acid
V_1= ml of aliquot taken for titration
W= ml of juice taken

3.12.3 Total soluble solids

Total soluble solids were measured as stated by Dong *et al.,* (2001). One to two drops of the tomato juice extract was prepared and placed on the prism of the hand refractometer and TSS was measured as Brix (noted in percentage).

3.12.4 Shelf life

Fruits of uniform size were randomly selected from each treatment per replication. These fruits were kept in petri dish under ambient storage temperature at 25 to 30 ºC for about 15 days.

3.13 Analysis of FYM, fish bone meal and plant samples

3.13.1 Preparation of FYM, raw and acidulated fish bone meal and plant samples

The FYM and raw and acidulated fish bone meal samples were powdered and dried at 60 ºC in hot air oven. The plant and root samples collected at the time of harvest were shade-dried and dried at 60 ºC in hot air oven. The dried samples were powdered using grinder fitted with stainless blades and preserved in polythene bags for further analysis. The representative fruits were collected from individual plants in each replication and were crushed, shade dried first, dried in hot air oven later at 60 ºC and stored for further analysis. They were characterized for nutrient composition as explained under section 3.13.3 and 3.13.4.

3.13.2 Total Nitrogen

Total nitrogen in FYM, raw and acidulated fish bone meal and plant samples was determined by Kjeldhal's method of nitrogen determination, as described by Jackson (1973). In this method, one gram ofpowdered sample was digested with concentrated H_2SO_4 in the presence of digestion mixture (K_2SO_4: $CuSO_4.5H_2O$: Se in the proportion of 100:20:1) and distilled under alkaline medium. The liberated $NH_3$was trapped in 4 per cent boric acid containing mixed indicator and titrated against standard H_2SO_4.

3.13.3 Digestion of FYM, raw and acidulated fish bone meal and plant samples

0.2 gram of powdered FYM, raw and acidulated fish bone meal and plant sample was pre-digested with 8 ml HNO_3 and 2 ml H_2O_2 then digested in microwave digestion (make Milestone and model Ethos easy). The volume of the digest was made up to 100 ml with distilled water and used for total elemental analysis.

3.13.3.1 Water soluble phosphorus in raw and acidulated fish bone meal

A known volume of the digested sample was taken for total phosphorus determination using the vanado-molybdo phosphoric yellow colour method in the nitric acid system as described by Jackson (1973).

3.13.4 Total phosphorus

A known volume of the digested sample was taken for total phosphorus determination using the vanado-molybdo phosphoric yellow colour method in the nitric acid system as described by Jackson (1973).

3.13.5 Total potassium

Total potassium content in sample was determined by the flame photometric method and per cent potassium in the plant sample was calculated (Jackson, 1973).

3.13.6 Total calcium and magnesium

In an aliquot of the digested extract, calcium and magnesium were estimated by titrating against standard versenate solution (Jackson, 1973).

3.13.7 Total sulphur

In an aliquot of digested extract sulphur content was determined by turbidimetric method. The light transmittance was read on a spectrophotometer at 420 nm (Black, 1965).

3.13.8 Micronutrients (Zn, Cu, Fe and Mn)

The digested samples were fed to the atomic absorption spectrophotometer using an appropriate hollow cathode lamp (Jackson, 1973).

3.13.9 Nutrient uptake

The uptake of nutrients was worked out by multiplying dry matter to the concentration of the crop by using the following equation.

$$\text{Nutrient uptake (kg plant}^{-1}) = \frac{\text{Wt. of dry matter (kg plant}^{-1}) \times \text{Nutrient concn. (\%)}}{100}$$

3.14 Tomato fruit analysis

The representative fruits were collected from each plant in each replication and were dried under shade and then oven dried at 60 °C. The dried fruits were powdered and used for analysis of different nutrient contents *viz*., N, P, K, Ca, Mg, S and micronutrients like Zn, Cu, Fe and Mn by following the same procedures as followed in plant analysis (3.13 section).

3.15 Soil analysis

3.15.1 Collection and preparation of soil sample

During the pot experiment, soil samples were collected from each pot at 30, 60 DAP and after the harvest of the tomato crop. The soil samples collected were dried under shade, powdered using wooden pestle and mortar, passed through 2 mm sieve and stored for further analysis.

3.15.2 Particle size distribution in soils

The relative proportion of sand, silt and clay particles present in the soil sample was determined by international pipette method using sodium hexametaphosphate as a dispersing agent (Piper, 1966). The soil texture was identified based on the relative proportion of sand, silt and clay present in soil using the textural diagram given by USDA.

3.15.3 Soil reaction

Soil pH was determined in 1:2.5 soil: water extract by a potentiometric method using pH meter (Jackson, 1973).

3.15.4 Electrical conductivity

The electrical conductivity of soil was determined in the supernatant solution of 1:2 soil: water extract using a conductivity meter (Jackson, 1973).

3.15.5 Soil organic carbon

Organic carbon was determined by following the Walkley and Black's wet oxidation method by oxidizing the organic matter in 0.2 mm sieved soil with chromic acid making use of the heat of dilution of sulphuric acid for the reaction as described by Jackson (1973).

3.15.6 Available nitrogen

Available nitrogen in the soil was determined by alkaline potassium permanganate method as described by Subbiah and Asija (1956).

3.15.7Available phosphorus

Available phosphorus was extracted from the soil using Bray's No.1 (0.03 N NH4F + 0.025 N HCl) and Olsen's (0.5 M $NaHCO_3$) extractant depending on soil pH. The concentration of phosphorus in the extract wasdetermined by chlorostannous reduced molybdo-phosphoric acid blue colour in HCl system using a spectrometer (Jackson, 1973).

3.15.8 Available potassium

Available potassium was extracted from the soil using neutral normal ammonium acetate in 1:5 soil to extractant ratio and the concentration of potassium present in the extract was determined by a flame photometer (Jackson, 1973).

3.15.9 Exchangeable calcium and magnesium

The exchangeable calcium and magnesium were determined by leaching the soil with neutral normal ammonium acetate solution, and calcium and magnesium in the leachate were determined by versenate titration method (Jackson, 1973).

3.15.10 Available sulphur

Available Sulphur was determined by the turbidimetric method. The light transmittance was read on spectro-photometer at 420 nm (Black, 1965).

3.15.11 DTPA- extractable micronutrients

The available micronutrients in soil were extracted with DTPA- extractant (0.005 M Diethylene Triamine Penta Acetic acid + 0.01 M $CaCl_2$ + 0.1 M Triethanol Amine) at 1:2 soil to extractant ratio as described by Lindsay and Norvell (1978). The concentration of micro nutrients in the extract was determined by Atomic Absorption Spectrophotometer (AAS) under suitable measuring conditions.

3.16 Statistical analysis

Fisher's method of analysis of variance was adopted for statistical analysis and interpretation of the data. The treatments were tested at five per cent levels of significance. The analysis was carried out by following the methodology described by Sundararaj *et al*. (1972).

EXPERIMENTAL RESULTS

IV EXPERIMENTAL RESULTS

Result of the pot experiment on “Influence of phosphorus supplementation through fish bone meal on soil chemical properties and yield of tomato” is presented under the following headings and subheadings.

4.1 Effect of fish bone meal on biometric parameters of tomato

4.2 Effect of fish bone meal on yield attributing characters, yield and quality parameter of tomato

4.3 Effect of fish bone meal on per cent N, P, K, Ca, Mg, S and micronutrient content and uptake at harvest of tomato

4.4 Effect of fish bone meal on available N, P, Ca and S status of soil at 30, 60 DAP and after final harvest of tomato

4.5 Effect of fish bone meal on selected physicochemical properties of soil at harvest of tomato

The data in respect of biometric parameters of tomato like plant height and number of branches as influenced by fish bone meal application is presented in Table 4.

4.1.1 Effect of fish bone meal on plant height and number of branches at different growth stages of tomato

Data recorded on plant height as influenced by fish bone meal application in tomato at different growth stages are given in Table 4. Scrutiny of data indicated that there was no significant variation in plant height of tomato at 30 DAP, whereas substantial influence was observed at remaining growth stages due to different treatments. Highest plant height (60.97 cm) at 30 DAP was recorded in treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) followed by T_6 (60.40 cm), T_2 (60.27 cm), T_4 (58.47 cm) and T_3 (58.00 cm). The lowest value of plant height at 30 DAP (53.90 cm) was recorded in T_1 followed by T_9 (54.33).

Application of fish bone meal along with acidulated fish bone meal and mineral fertilizers significantly influenced the plant height at 60 DAP. Treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) recorded highest plant height (82.53 cm) which was significantly superior over rest of the treatments. The recorded values for subsequent ttreatments T_6, T_2, T_4, T_3, T_{10}, T_{11}, T_7, T_9 and T_8 are 81.83, 81.10, 79.07, 77.50, 76.73, 75.90, 75.53, 71.10 and 70.70 cm, respectively, whereas lowest plant height of 69.90 cm was recorded with T_1.

Table 4. Influence of P levels as DAP and fish bone meal on plant height and number of branches at different growth stages of tomato

Treatments		Plant height (cm)			No. of branches		
		30 DAP	60 DAP	Harvest	30 DAP	60 DAP	Harvest
T_1:	Control	53.90	69.90	83.20	13.00	19.33	19.67
T_2:	250 kg P_2O_5 as DAP (Package of Practice)	60.27	81.10	100.07	21.00	26.33	28.33
T_3:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as RFBM	58.00	77.50	95.83	19.33	24.33	26.33
T_4:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as RFBM	58.47	79.07	97.43	20.67	25.67	27.67
T_5:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM	60.97	82.53	101.97	22.00	28.33	30.67
T_6:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as AFBM	60.40	81.83	101.20	21.33	26.67	29.00
T_7:	200 kg P_2O_5 as DAP (80 % recommended P_2O_5)	56.63	75.53	91.80	16.33	22.67	23.33
T_8:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as RFBM	54.33	70.70	90.53	14.67	21.00	22.00
T_9:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as RFBM	55.83	71.10	91.93	16.33	21.67	23.67
T_{10}:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as AFBM	57.13	76.73	95.37	18.33	23.33	25.00
T_{11}:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as AFBM	56.80	75.90	93.10	17.00	23.00	24.33
	S. Em ±	**1.57**	**1.59**	**1.25**	**0.78**	**1.26**	**1.18**
	CD @ 0.05	**NS**	**4.66**	**3.68**	**2.30**	**3.68**	**3.45**

RFBM – Raw fish bone meal, AFBM – Acidulated fish bone meal, DAP – Days after planting, NS: Non –significant

The maximum plant height was recorded in T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) treatment at harvest (101.97 cm) which was significantly superior over almost all treatments. The treatments T_6 and T_2 were on par with each other The recorded values for subsequent treatments T_4, T_3, T_{10}, T_{11}, T_7, T_9 and T_8 are 97.43, 95.83, 95.37, 93.10, 91.80, 91.93 and 90.53 cm, respectively, whereas, treatment T_1 recorded lowest plant height (83.20 cm).

The data collected on the number of branches per plant as influenced by the application of fish bone meal in tomato at different growth stages are given in Table 4. There was significant difference found in the number of branches of tomato at 30 DAP. The maximum number of branches per plant of tomato recorded in treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) at all growth stages (22.00, 28.33 and 30.67 at 30, 60 DAP and harvest, respectively). The treatments T_6, T_2, T_4, T_3, T_{10}, T_{11}, T_7, T_9 and T_8 were found significantly different at 30, 60 DAP and harvest. At the same time, the lowest number of branches per plant was observed in T_1 treatment (13.00, 19.33 and 19.67 at 30, 60 DAP and harvest, respectively) at all the growth stages.

4.2 Effect of fish bone meal on yield attributing characters, yield and quality parameters of tomato

4.2.1 Fruit diameter of tomato

The maximum fruit diameter of (6.68) tomato was recorded in the treatment receiving 75 per cent P through mineral fertilizer (DAP) and remaining through AFBM treatment (T_5) followed by T_6 (6.23 cm), T_2 (6.12 cm), T_4 (6.10 cm), T_3 (6.01 cm), T_{10} (5.94 cm), T_{11} (5.93 cm), T_7 (5.89 cm), T_9 (5.83 cm) and T_8 (5.67 cm). The lowest fruit diameter (5.45 cm) was observed with T_1 treatment, as indicated in Table 5.

4.2.2 Total number of fruits plant $^{-1}$

Perusal of data indicates that the total number of fruits per plant of tomato was found significant as influenced by the application of FBM and mineral fertilizer (Table 5). The maximum number of fruits per plant of tomato was observed with treatment T_5 (42.00) followed by treatment T_6 (36.33), which were significantly superior over T_2, T_4, T_3, T_{10}, T_{11}, T_7, T_9 and T_8. Lowest total number of fruits per plant of tomato (20.33) were recorded in treatment T_1.

Table 5. Influence of P levels as DAP and fish bone meal on yield parameters and yield of tomato

	Treatments	Fruit diameter (cm)	Total no. of fruits $plant^{-1}$	Dry matter yield (g $plant^{-1}$)	Total yield (kg $plant^{-1}$)
T_1:	Control	5.45	20.33	23.99	1.52
T_2:	250 kg P_2O_5 as DAP (Package of Practice)	6.10	34.67	32.24	4.86
T_3:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as RFBM	6.01	31.33	27.96	4.05
T_4:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as RFBM	6.12	33.67	30.47	4.50
T_5:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM	6.68	42.00	37.69	5.48
T_6:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as AFBM	6.23	36.33	35.30	5.25
T_7:	200 kg P_2O_5 as DAP (80 % recommended P_2O_5)	5.89	27.33	26.73	3.26
T_8:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as RFBM	5.67	22.67	25.15	2.61
T_9:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as RFBM	5.83	26.33	25.73	2.96
T_{10}:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as AFBM	5.94	30.67	27.03	3.87
T_{11}:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as AFBM	5.93	27.67	26.69	3.71
	S. Em ±	**0.20**	**1.02**	**0.68**	**0.09**
	CD @ 0.05	**0.60**	**2.99**	**1.99**	**0.26**

RFBM – Raw fish bone meal, AFBM – Acidulated fish bone meal

4.2.3 Total yield plant $^{-1}$ (kg plant $^{-1}$)

The data revealed that the total yield per plant of tomato was significantly influenced by various treatments (Table 5). Treatments receiving 75 per cent of recommended P through mineral fertilizer and remaining through AFBM treatment (T_5) recorded higher fruit yield of 5.48 kg plant^{-1}. The treatment T_5 and T_6 was on par with each other. The treatments T_2, T_4, T_3, T_{10}, T_{11}, T_7, T_9 and T_8 were found significantly low to T_5, whereas T_1 treatment recorded lowest total fruit yield per plant (1.52 kg plant^{-1}).

4.2.4 Dry matter yield (kg plant $^{-1}$)

The effect of different treatments on dry matter yield is given in Table 5. The dry matter yield of tomato plant was significantly influenced by the application of FBM along with mineral fertilizer. Among different treatments, pot fertilized with 75 per cent of recommended P through mineral fertilizer and remaining through AFBM treatment (T_5) was found out to be significantly best treatment with dry matter yield of 37.69 g plant^{-1}. Among all the remaining treatments T_{11} (100 kg P_2O_5 as DAP + 100 kg P_2O_5 as AFBM), T_9 (100 kg P_2O_5 as DAP + 100 kg P_2O_5 as RFBM) and T_8 (150 kg P_2O_5 as DAP + 50 kg P_2O_5 as RFBM) remained on par with each other. Significantly lower dry matter yield was recorded in treatment T_1 (23.99 g plant^{-1}).

4.2.5 Lycopene content in tomato (mg 100g $^{-1}$)

Data presented in Table 6 showed that the lycopene content in tomato fruit was not significantly affected by various treatments even though the maximum lycopene content was recorded with treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) (5.76 mg 100g^{-1}), which was relatively higher than the rest of the treatments. The result further revealed that the lowest lycopene content to the tune of 3.50 mg 100g^{-1} in fruit was recorded with treatment T_1 (control).

4.2.6 Ascorbic acid content in tomato (mg 100g $^{-1}$)

The data recorded in Table 6 indicates that the ascorbic acid content in tomato fruit was not significantly affected by various treatments even though the highest ascorbic acid content was recorded in treatment T_5 (RDF 187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) (15.05 mg 100g^{-1}), which was comparatively higher than the rest of the other treatments. The result further expressed that the lowest ascorbic acid content to the tune of 12.01 mg 100g^{-1} in fruit was recorded in treatment T_1 (control).

Table 6. Influence of P levels as DAP and fish bone meal on quality parameters of tomato

Treatments		Lycopene (mg $100g^{-1}$)	Ascorbic acid (mg $100g^{-1}$)	Total soluble solids (°Brix)	Shelf life (days)
T_1:	Control	3.50	12.01	4.97	12.33
T_2:	250 kg P_2O_5 as DAP (Package of Practice)	5.48	14.93	5.63	14.33
T_3:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as RFBM	5.44	14.24	5.43	14.00
T_4:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as RFBM	5.45	14.50	5.57	14.00
T_5:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM	5.76	15.05	5.80	15.67
T_6:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as AFBM	5.65	14.95	5.73	15.00
T_7:	200 kg P_2O_5 as DAP (80 % recommended P_2O_5)	5.32	13.75	5.13	13.00
T_8:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as RFBM	5.15	13.26	5.07	15.00
T_9:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as RFBM	5.29	13.51	5.10	13.00
T_{10}:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as AFBM	5.35	14.05	5.30	12.67
T_{11}:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as AFBM	5.35	13.89	5.23	13.33
	S. Em ±	**0.43**	**0.52**	**0.20**	**0.77**
	CD @ 0.05	**NS**	**NS**	**NS**	**NS**

RFBM – Raw fish bone meal, AFBM – Acidulated fish bone meal, NS: Non –significant

2.7 Total soluble solids in tomato (°Brix)

The values presented in Table 6 represented that the total soluble solids in tomato fruit was not significantly affected by other treatments even though the highest TSS content was recorded in treatment T_5 (RDF 187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) which was relatively higher than the rest of the treatments. The result further revealed that the lowest TSS was obtained in treatment T_1 (control) to the tune of 4.97 ^{o}Brix).

4.2.8 Shelf life in tomato

The data represented in the Table 6 indicate that the shelf life of tomato fruit was not significantly affected by various treatments even though the maximum shelf life was recorded in the treatment T5 (RDF 187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) (15.67 days), which was relatively higher than the rest of the treatments. The result further revealed that the lowest shelf life to the tune of 12.33 in fruit was recorded with treatment T_1 (control).

4.3 Effect of fish bone meal on per cent N, P, K, Ca, Mg, S and micronutrient content and uptake at harvest of tomato

Results indicating the effect of fish bone meal application on nitrogen, phosphorus, potassium, calcium, magnesium and sulphur content in the tomato plant and fruit at final harvest are listed in Table 7 to 12.

4.3.1 Content and uptake of nitrogen

Results of the data indicating the effect of the application of fish bone meal on the concentration of nitrogen and uptake at final harvest of tomato are listed in Table 7 and 12.

The N content in tomato plant didn't influence significantly by fish bone meal application (Table 7). The higher N content in tomato was recorded in treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) (1.36% in plant and 1.78 % in fruit). The treatment T_8 (150 kg P_2O_5 as DAP + 50 kg P_2O_5 as RFBM) was found on par with T_1. The lowest N content in tomato was recorded in treatment T_1 (control) (1.19 % in plant and 1.58 % in fruit).

Table 7. Influence of P levels as DAP and fish bone meal on total N, P and K contents (%) in tomato

Treatments		Total N content			Total P content			Total K content		
		Plant	Fruit	Total	Plant	Fruit	Total	Plant	Fruit	Total
T_1:	Control	1.19	1.58	2.77	0.24	0.21	0.45	0.63	1.25	1.88
T_2:	250 kg P_2O_5 as DAP (Package of Practice)	1.33	1.73	3.06	0.39	0.31	0.70	0.83	1.32	2.15
T_3:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as RFBM	1.28	1.70	2.98	0.38	0.29	0.67	0.81	1.30	2.11
T_4:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as RFBM	1.32	1.71	3.03	0.38	0.30	0.68	0.82	1.31	2.13
T_5:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM	1.36	1.78	3.14	0.48	0.35	0.83	0.94	1.33	2.27
T_6:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as AFBM	1.35	1.75	3.1	0.42	0.32	0.74	0.89	1.32	2.21
T_7:	200 kg P_2O_5 as DAP (80 % recommended P_2O_5)	1.23	1.66	2.89	0.34	0.26	0.60	0.76	1.27	2.03
T_8:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as RFBM	1.20	1.63	2.83	0.31	0.25	0.56	0.72	1.26	1.98
T_9:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as RFBM	1.22	1.65	2.87	0.33	0.26	0.59	0.74	1.27	2.01
T_{10}:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as AFBM	1.25	1.69	2.94	0.37	0.28	0.65	0.78	1.28	2.06
T_{11}:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as AFBM	1.24	1.67	2.91	0.36	0.27	0.63	0.77	1.26	2.03
	S. Em ±	**0.01**	**0.02**	**0.02**	**0.04**	**0.03**	**0.03**	**0.11**	**0.03**	**0.05**
	CD @ 0.05	**NS**	**NS**	**NS**	**0.11**	**NS**	**0.04**	**NS**	**NS**	**NS**

RFBM – Raw fish bone meal, AFBM – Acidulated fish bone meal, NS: Non –significant

A similar trend was also depicted in nitrogen uptake by plant and fruit of tomato at harvest shown in Table 10, where treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) recorded the highest uptake in both plant and fruit (0.51 g pot^{-1} and 8.06 g pot^{-1}, respectively) followed by T_6 (0.48 g pot^{-1} and 7.52 g pot^{-1}), T_2 (0.43 g pot^{-1} and 7.43 g pot^{-1}) and T_4(0.40 g pot^{-1} and 7.27 g pot^{-1}). The lowest nitrogen uptake in plant and fruit (0.29 g pot^{-1} and 4.14 g pot^{-1}, respectively) was observed in treatment T_1. In case of the total N uptake by tomato, the highest total uptake (8.57 g pot^{-1}) was recorded with treatment T_5 followed by the treatment T_6 (8.00 g pot^{-1}) and these were significantly superior over other remaining treatments. In contrast, the lowest total uptake of N (4.43 g pot^{-1}) was recorded with T_1 treatment.

4.3.2 Content and uptake of phosphorus

Data recorded in Table 7 and 12 indicates the effect of the application of fish bone meal on the content of phosphorus and its uptake in plant and fruit of tomato at final harvest of the crop.

The P content in tomato was significantly influenced by fish bone meal (Table 7). Significantly higher P content observed with treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) (0.48 % in plant and 0.35 % in fruit). The treatment T_6 (125 kg P_2O_5 as DAP + 125 kg P_2O_5 as AFBM), T_2 (250 kg P_2O_5 as DAP (PoP), T_3 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as RFBM) and T_4 (125 kg P_2O_5as DAP + 125 kg P_2O_5as RFBM) were on par with each other. The lowest P content in tomato was recorded in treatment T_1 (control) (0.24 % in plant and 0.21 % in fruit). The P content in tomato fruit was not influenced significantly by the application of fish bone meal, although the higher P content in tomato fruit was recorded in the treatment T_5.

It was also observed from the results given in Table 10 that treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) recorded the highest uptake of P (0.18 g pot^{-1}) by plant and also found significantly superior over rest of the treatments. Treatment T_1 recorded lowest P uptake (0.06 g pot^{-1}) in plant. Data recorded for phosphorus uptake in fruit showed highest P uptake (1.59 g pot^{-1}) in treatment T_5 followed by treatment T_6 and T_2 (1.37 and 1.34 g pot^{-1}, respectively) and these treatments combination found significantly superior over remaining treatments. In contrast, treatment T_1 recorded the lowest uptake of P (0.56 g pot^{-1}) in fruit. In case of the total P uptake by tomato, the highest total uptake (1.77 g pot^{-1}) was recorded with treatment T_5 followed by the treatment T_6 (1.52 g pot^{-1}) and these were significantly superior over other remaining treatments. In contrast, the lowest total uptake of P (0.62 g pot^{-1}) was recorded with T_1 treatment.

4.3.3 Content and uptake of potassium

Based on observed data presented in Table 7 and 10, it can be inferred that the application of fish bone meal application did not significantly influence the content and uptake of K in plant and fruit of tomato.

A non-significant difference was observed in the K content of plant and fruit due to application of fish bone meal. Higher K content observed with treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) (0.94 % in plant and 1.33 % in fruit). The lowest K content in tomato was recorded in the treatment T_1 (control) (0.63 % in plant and 1.25 % in fruit). The K content in tomato fruits was not influenced significantly by the application of fish bone meal although the higher K content in tomato fruits was recorded under the treatment T_5.

It was also observed from the results that treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) recorded the highest uptake of K by plant and fruit of tomato (0.35 g pot^{-1} and 6.04 g pot^{-1}, respectively). The data presented concerning to K uptake in plant recorded highest K uptake in treatment T_5. The lowest K content and uptake in fruit (1.25 % and 3.30 g pot^{-1}, respectively) and plant (0.63 % and 0.15 g pot^{-1}, respectively) were observed in T_1 treatment. In case of the total K uptake by tomato, the highest total uptake (6.39 g pot^{-1}) was recorded with treatment T_5 followed by the treatment T_6 (6.29 g pot^{-1}) and these were significantly superior over other remaining treatments. In contrast, the lowest total uptake of K (3.45 g pot^{-1}) was recorded with T_1 treatment.

4.3.4 Content and uptake of calcium

Results of the data indicating the effect of the application of fish bone meal on the concentration of calcium and its uptake in tomato are presented in Table 8 and 11.

The Ca content in tomato plant was influenced significantly by fish bone meal application (Table 8). The higher Ca content in tomato was recorded in the treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) (0.77 % in plant and 0.58 % in fruit). The treatment T_6 (125 kg P_2O_5 as DAP + 125 kg P_2O_5 as AFBM) was

Table 8. Influence of P levels as DAP and fish bone meal on total Ca, Mg and S contents (%) in tomato

Treatments		Total Ca content			Total Mg content			Total S content		
		Plant	Fruit	Total	Plant	Fruit	Total	Plant	Fruit	Total
T_1:	Control	0.77	0.58	1.35	0.31	0.20	0.51	0.25	0.18	0.43
T_2:	250 kg P_2O_5 as DAP (Package of Practice)	0.98	0.75	1.73	0.68	0.34	1.02	0.37	0.21	0.58
T_3:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as RFBM	0.92	0.71	1.63	0.62	0.32	0.94	0.34	0.20	0.54
T_4:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as RFBM	0.95	0.74	1.69	0.64	0.33	0.97	0.35	0.21	0.56
T_5:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM	1.08	0.83	1.91	0.74	0.38	1.12	0.44	0.23	0.67
T_6:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as AFBM	1.03	0.77	1.80	0.72	0.37	1.09	0.38	0.21	0.59
T_7:	200 kg P_2O_5 as DAP (80 % recommended P_2O_5)	0.85	0.68	1.53	0.53	0.28	0.81	0.31	0.19	0.50
T_8:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as RFBM	0.81	0.66	1.47	0.48	0.25	0.73	0.29	0.19	0.48
T_9:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as RFBM	0.82	0.67	1.49	0.49	0.26	0.75	0.30	0.19	0.49
T_{10}:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as AFBM	0.91	0.70	1.61	0.61	0.30	0.91	0.33	0.20	0.53
T_{11}:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as AFBM	0.86	0.69	1.55	0.57	0.29	0.86	0.32	0.20	0.52
	S. Em ±	**0.02**	**0.04**	**0.04**	**0.01**	**0.04**	**0.02**	**0.04**	**0.01**	**0.01**
	CD @ 0.05	**0.06**	**0.12**	**0.11**	**0.04**	**0.10**	**0.06**	**NS**	**NS**	**NS**

RFBM – Raw fish bone meal, AFBM – Acidulated fish bone meal, NS: Non –significant

on par with T_5. The treatment T_2 (250 kg P_2O_5 as DAP (PoP), T_3 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as RFBM) and T_4 (125 kg P_2O_5 as DAP + 125 kg P_2O_5 as RFBM), were on par with each other. The lowest Ca content in tomato plant was recorded in the treatment T_1 (control) (0.77 % in plant and 0.58 % in fruit).

A similar trend was also depicted in calcium uptake by plant and fruit of tomato at harvest shown in Table 11, where treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) recorded the highest uptake in both fruit and plant (3.78 g pot^{-1} and 0.41 g pot^{-1}, respectively) followed by T_6 (3.30 g pot^{-1} and 0.36 g pot^{-1}), T_2 (3.22 g pot^{-1} and 0.32 g pot^{-1}) and T_4 (3.14 g pot^{-1} and 0.29 g pot^{-1}), respectively as compared to other treatments. The lowest calcium uptake in fruit and plant (1.52 g pot^{-1} and 0.19 g pot^{-1}, respectively) was observed in treatment T_1. In case of the total Ca uptake by tomato, the highest total uptake (4.25 g pot^{-1}) was recorded with treatment T_5 followed by the treatment T_6 (3.73 g pot^{-1}) and these were significantly superior over other remaining treatments. In contrast, the lowest total uptake of Ca (1.68 g pot^{-1}) was recorded with T_1 treatment.

4.3.5 Content and uptake of magnesium

Based on observed data presented in Table 8 and 11, it indicates that the application of fish bone meal significantly influenced the content and uptake of Mg in plant and fruit of tomato.

A significant difference was observed in Mg content of both plant and fruit due to application of fish bone meal. Higher Mg concentration observed with treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) (0.74 % in plant and 0.38 % in fruit). The treatment T_2, T_6, T_{10} and T_{11} were on par with each other. The lowest Mg content in tomato was recorded in the treatment T_1 (control) at (0.31 % in plant and 0.20 % in fruit). The Mg content and concentration in tomato fruit was influenced significantly by the application of fish bone meal was recorded under the treatment T_5.

The results showed that treatments received 75 per cent of P through mineral fertilizer and remaining through AFBM treatment recorded the highest uptake of Mg by fruit and plant of tomato (1.80 g pot^{-1} and 0.28 g pot^{-1}, respectively). The lowest Mg uptake in fruit and plant (0.54 g pot^{-1} and 0.07 g pot^{-1}, respectively) were observed in T_1 treatment. In case of the total Mg uptake by tomato, the highest total uptake (2.08 g pot^{-1}) was recorded with treatment T_5 followed by the treatment T_6 (1.82 g pot^{-1}) and these were significantly superior over other remaining treatments. In contrast, the lowest total uptake of Mg (0.61 g pot^{-1}) was recorded with T_1 treatment.

4.3.6 Content and uptake of sulphur

Data recorded in Table 8 and 11 indicates the effect of the application of fish bone meal on the content of sulphur and its uptake in plant and fruit of tomato at final harvest of the crop. A non-significant difference was observed in the sulphur content of plant and fruit of tomato plant. Higher sulphur content observed with treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) (0.44 % in plant and 0.23 % in fruit). The treatment T_2, T_4, T_6 and T_3 were on par with each other. The lowest sulphur content in tomato was recorded in treatment T_1 (control) (0.25 % in plant and 0.18 % in fruit). The sulphur content in tomato fruits was not influenced significantly by the application of fish bone meal although the higher S concentration in tomato fruits was recorded under the treatment T_5.

It was also observed from the results that treatments receiving 75 per cent of P through mineral fertilizer and remaining through AFBM treatment recorded the highest uptake of S by fruit and plant of tomato (1.03 g pot^{-1} and 0.17 g pot^{-1}, respectively). The lowest S uptake in fruit and plant (0.49 g pot^{-1} and 0.06 g pot^{-1}, respectively) were observed in T_1 treatment. In case of the total S uptake by tomato, the highest total uptake (1.20 g pot^{-1}) was recorded with treatment T_5 followed by the treatment T_6 (1.03 g pot^{-1}) and these were significantly superior over other remaining treatments. In contrast, the lowest total uptake of S (0.55 g pot^{-1}) was recorded with T_1 treatment.

4.3.7 Content and uptake of micronutrients in tomato

4.3.7.1 Content and uptake of Fe in tomato

Data recorded in Table 9 and 12 indicates the effect of the application of fish bone meal on the content of iron and its uptake in plant and fruit of tomato at final harvest of the crop.

There was no significant difference observed in the iron content of plant and fruit of tomato plant. Higher iron content observed with treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) (510.15 mg kg^{-1} in plant and 282.41 mg kg^{-1} in fruit). The treatments T_6, T_2, T_4, T_3, T_{10}, T_{11}, T_7 and T_8 were on par with T_5. The

Table 9. Influence of P levels as DAP and fish bone meal on total micronutrients content (mg kg^{-1}) in tomato

Treatments		Total Fe			Total Zn			Total Cu			Total Mn		
		Plant	Fruit	Total	Plant	Fruit	Total	Plant	Fruit	Total	Plant	Fruit	Total
T_1:	Control	497.97	252.60	750.57	32.50	23.65	56.15	22.08	5.07	27.15	52.94	21.33	74.27
T_2:	250 kg P_2O_5 as DAP (Package of Practice)	507.17	280.48	787.65	38.06	34.55	72.61	24.15	6.60	30.75	54.29	31.33	85.62
T_3:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as RFBM	503.61	272.25	775.86	37.40	31.55	68.95	23.73	6.37	30.10	53.94	29.00	82.94
T_4:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as RFBM	504.34	273.21	777.55	37.73	32.50	70.23	23.92	6.57	30.49	54.14	29.67	83.81
T_5:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM	510.15	282.41	792.56	39.69	35.89	75.58	24.30	6.97	31.27	54.93	37.33	92.26
T_6:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as AFBM	508.48	282.25	790.73	38.55	35.58	74.13	24.18	6.87	31.05	54.48	31.67	86.15
T_7:	200 kg P_2O_5 as DAP (80 % recommended P_2O_5)	502.12	263.28	765.40	36.10	29.62	65.72	23.17	5.47	28.64	53.24	26.00	79.24
T_8:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as RFBM	498.25	258.12	756.37	35.28	29.29	64.57	22.45	5.23	27.68	53.01	25.00	78.01
T_9:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as RFBM	499.90	262.36	762.26	35.93	29.51	65.44	22.77	5.40	28.17	53.09	26.33	79.42
T_{10}:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as AFBM	502.57	266.04	768.61	36.91	30.32	67.23	23.52	5.90	29.42	53.80	27.67	81.47
T_{11}:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as AFBM	502.17	264.59	766.76	36.26	30.17	66.43	23.28	5.83	29.11	53.46	27.33	80.79
	S. Em ±	**10.40**	**7.03**	**16.67**	**1.81**	**2.86**	**1.48**	**0.52**	**0.64**	**0.64**	**0.57**	**2.83**	**1.79**
	CD @ 0.05	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

RFBM – Raw fish bone meal, AFBM – Acidulated fish bone meal, NS: Non –significant

lowest iron content in tomato was recorded in treatment T_1 (control) (497.97 mg kg^{-1} in plant and 252.60 mg kg^{-1} in fruit). The iron content in tomato fruits was not influenced significantly by the application of fish bone meal though the higher Fe concentration in tomato fruits was recorded under the treatment T_5.

It was also observed from the results that treatments 75 per cent of P through mineral fertilizer and remaining through AFBM treatment recorded the highest uptake of Fe by fruit and plant of tomato (128.17 mg pot^{-1} and 19.22 mg pot^{-1}, respectively). The lowest Fe uptake in fruit and plant (66.35 mg pot^{-1} and 11.94 mg pot^{-1}, respectively) were observed in T_1 treatment. In case of the total Fe uptake by tomato, the highest total uptake (147.39 mg pot^{-1}) was recorded with treatment T_5 followed by the treatment T_6 (139.20 mg pot^{-1}) and these were significantly superior over other remaining treatments. In contrast, the lowest total uptake of Fe (78.29 mg pot^{-1}) was recorded with T_1 treatment.

4.3.7.2 Content and uptake of Zn in tomato plant

Data recorded in Table 9 and 12 indicates the effect of the application of fish bone meal on the content of zinc and its uptake in plant and fruit of tomato at final harvest of the crop.

A non-significant difference was observed in the zinc content of plant and fruit of tomato plant. Higher zinc content observed with treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) (39.69 mg kg^{-1} in plant and 35.89 mg kg^{-1} in fruit). The treatments T_6 and T_2 were on par with T_5. The lowest zinc content in tomato was recorded in treatment T_1 (control) (32.50 mg kg^{-1} in plant and 23.65 mg kg^{-1} in fruit). The zinc content in tomato fruits was not influenced significantly by the application of fish bone meal though the higher Zn concentration in tomato fruits was recorded under the treatment T_5.

It was also observed from the results that treatments receiving 75 per cent of P through mineral fertilizer and remaining through AFBM treatment recorded the highest uptake of Zn by fruit and plant of tomato (16.29 mg pot^{-1} and 1.49 mg pot^{-1}, respectively). The lowest Zn uptake in fruit and plant (6.27 mg pot^{-1} and 0.78 mg pot^{-1}, respectively) were observed in T_1 treatment. In case of the total Zn uptake by tomato, the highest total uptake (17.78 mg pot^{-1}) was recorded with treatment T_5 followed by the treatment T_6 (16.63 mg pot^{-1}) and these were significantly superior over other remaining treatments. In contrast, the lowest total uptake of Zn (7.05 mg pot^{-1}) was recorded with T_1 treatment.

Table 10. Effect of raw and acidulated fish bone meal on total nitrogen, phosphorus and potassium uptake (g pot^{-1}) by tomato

Treatments		Total N uptake			Total P uptake			Total K uptake		
		Plant	Fruit	Total	Plant	Fruit	Total	Plant	Fruit	Total
T_1:	Control	0.29	4.14	4.43	0.06	0.56	0.62	0.15	3.30	3.45
T_2:	250 kg P_2O_5 as DAP (Package of Practice)	0.43	7.43	7.86	0.13	1.34	1.47	0.27	5.66	5.93
T_3:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as RFBM	0.36	6.66	7.02	0.11	1.14	1.25	0.23	5.08	5.31
T_4:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as RFBM	0.40	7.27	7.67	0.12	1.26	1.38	0.25	5.58	5.83
T_5:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM	0.51	8.06	8.57	0.18	1.59	1.77	0.35	6.04	6.39
T_6:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as AFBM	0.48	7.52	8.00	0.15	1.37	1.52	0.31	5.98	6.29
T_7:	200 kg P_2O_5 as DAP (80 % recommended P_2O_5)	0.33	5.62	5.95	0.09	0.87	0.96	0.20	4.30	4.50
T_8:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as RFBM	0.30	4.99	5.29	0.08	0.76	0.84	0.18	3.86	4.04
T_9:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as RFBM	0.31	5.11	5.42	0.08	0.81	0.89	0.19	3.94	4.13
T_{10}:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as AFBM	0.34	6.23	6.57	0.10	1.02	1.12	0.21	4.72	4.93
T_{11}:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as AFBM	0.33	6.14	6.47	0.10	1.00	1.10	0.21	4.62	4.83
	S. Em ±	**0.01**	**0.22**	**0.22**	**0.01**	**0.11**	**0.11**	**0.03**	**0.23**	**0.11**
	CD @ 0.05	**0.03**	**0.65**	**0.67**	**0.04**	**0.31**	**0.34**	**0.10**	**0.68**	**0.33**

RFBM – Raw fish bone meal, AFBM – Acidulated fish bone meal, NS: Non –significant

Table 11. Influence of P levels as DAP and fish bone meal on total Ca, Mg and S uptake (g pot^{-1}) by tomato

Treatments		Total Ca uptake			Total Mg uptake			Total S uptake		
		Plant	Fruit	Total	Plant	Fruit	Total	Plant	Fruit	Total
T_1:	Control	0.19	1.52	1.68	0.07	0.54	0.61	0.06	0.49	0.55
T_2:	250 kg P_2O_5 as DAP (Package of Practice)	0.32	3.22	3.61	0.22	1.44	1.66	0.12	0.90	1.02
T_3:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as RFBM	0.26	2.79	3.06	0.17	1.25	1.42	0.09	0.78	0.87
T_4:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as RFBM	0.29	3.14	3.46	0.20	1.40	1.60	0.11	0.88	0.99
T_5:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM	0.41	3.78	4.25	0.28	1.80	2.08	0.17	1.03	1.20
T_6:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as AFBM	0.36	3.30	3.73	0.25	1.57	1.82	0.14	0.89	1.03
T_7:	200 kg P_2O_5 as DAP (80 % recommended P_2O_5)	0.23	2.31	2.54	0.14	0.93	1.07	0.08	0.64	0.72
T_8:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as RFBM	0.20	2.03	2.22	0.12	0.74	0.86	0.07	0.58	0.65
T_9:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as RFBM	0.21	2.08	2.29	0.13	0.80	0.93	0.08	0.58	0.66
T_{10}:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as AFBM	0.25	2.57	2.82	0.16	1.11	1.27	0.09	0.74	0.83
T_{11}:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as AFBM	0.23	2.53	2.76	0.15	1.07	1.22	0.08	0.75	0.83
	S. Em ±	**0.01**	**0.17**	**0.07**	**0.01**	**0.11**	**0.03**	**0.01**	**0.04**	**0.02**
	CD @ 0.05	**0.03**	**0.51**	**0.20**	**0.02**	**0.34**	**0.09**	**0.03**	**0.12**	**0.06**

RFBM – Raw fish bone meal, AFBM – Acidulated fish bone meal

Table 12. Influence of P levels as DAP and fish bone meal on micronutrient uptake (mg pot^{-1}) by tomato

Treatments		Total Fe			Total Zn			Total Cu			Total Mn		
		Plant	Fruit	Total	Plant	Fruit	Total	Plant	Fruit	Total	Plant	Fruit	Total
T_1:	Control	11.94	66.35	78.29	0.78	6.27	7.05	0.53	1.33	1.86	1.27	5.60	6.87
T_2:	250 kg P_2O_5 as DAP (Package of Practice)	16.36	120.28	136.64	1.23	14.82	16.05	0.78	2.83	3.61	1.75	13.44	15.19
T_3:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as RFBM	14.09	106.39	120.48	1.05	12.32	13.37	0.66	2.49	3.15	1.51	11.36	12.87
T_4:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as RFBM	15.37	116.45	131.82	1.15	13.81	14.96	0.73	2.78	3.51	1.65	12.65	14.30
T_5:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM	19.22	128.17	147.39	1.49	16.29	17.78	0.92	3.16	4.08	2.07	16.98	19.05
T_6:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as AFBM	17.95	121.25	139.20	1.36	15.27	16.63	0.85	2.95	3.80	1.92	13.65	15.57
T_7:	200 kg P_2O_5 as DAP (80 % recommended P_2O_5)	13.41	88.99	102.40	0.97	9.99	10.96	0.62	1.84	2.46	1.42	8.70	10.12
T_8:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as RFBM	12.53	78.85	91.38	0.89	9.09	9.98	0.56	1.59	2.15	1.33	7.63	8.96
T_9:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as RFBM	12.86	81.47	94.33	0.92	9.14	10.06	0.59	1.67	2.26	1.37	8.13	9.50
T_{10}:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as AFBM	13.58	98.14	111.72	1.00	11.14	12.14	0.64	2.17	2.81	1.45	10.22	11.67
T_{11}:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as AFBM	13.40	97.20	110.60	0.97	11.08	12.05	0.62	2.14	2.76	1.43	10.05	11.48
	S. Em ±	**0.44**	**4.23**	**2.57**	**0.06**	**1.13**	**0.29**	**0.02**	**0.25**	**0.07**	**0.04**	**1.08**	**0.28**
	CD @ 0.05	**1.30**	**12.40**	**7.54**	**0.19**	**3.32**	**0.86**	**0.07**	**0.75**	**0.20**	**0.12**	**3.17**	**0.84**

RFBM – Raw fish bone meal, AFBM – Acidulated fish bone meal, NS: Non –significant

4.3.7.3 Content and uptake of Cu in tomato plant

Data recorded in Table 9 and 12 indicates the effect of the application of fish bone meal on the content of copper and it's uptake in plant and fruit of tomato at final harvest of the crop.

A non-significant difference was observed in the copper content of plant and fruit of tomato plant. Higher copper content observed with treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) (24.30 mg kg^{-1} in plant and 6.97 mg kg^{-1} in fruit). The treatment T_6, T_2 and T_4 were on par with T_5. The lowest copper content in tomato was recorded in treatment T_1 (control) (22.08 mg kg^{-1} in plant and 5.07 mg kg^{-1} in fruit). The copper content in tomato fruits was not influenced significantly by the application of fish bone meal though the higher Zn concentration in tomato fruits was recorded under the treatment T_5.

It was also observed from the results that treatments receiving 75 per cent of P through mineral fertilizer and remaining through AFBM treatment recorded the highest uptake of Cu by fruit and plant of tomato (3.16 mg pot^{-1} and 0.92 mg pot^{-1}, respectively). The lowest Cu uptake in fruit and plant (1.33 mg pot^{-1} and 0.53 mg pot^{-1}, respectively) were observed in T_1 treatment. In case of the total Cu uptake by tomato, the highest total uptake (4.08 mg pot^{-1}) was recorded with treatment T_5 followed by the treatment T_6 (3.80 mg pot^{-1}) and these were significantly superior over other remaining treatments. In contrast, the lowest total uptake of Cu (1.86 mg pot^{-1}) was recorded with T_1 treatment.

4.3.7.4 Content and uptake of Mn in tomato plant

Data recorded in Table 9 and 12 indicates the effect of the application of fish bone meal on the content of manganese and its uptake in plant and fruit of tomato at final harvest of the crop.

A non-significant difference was observed in the manganese content of plant and fruit of tomato plant. Higher manganese content observed with treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) (54.93 mg kg^{-1} in plant and 37.33 mg kg^{-1} in fruit). The treatment T_5 and T_6 were on par with each other. The lowest manganese content in tomato was recorded in treatment T_1 (control) (52.94 mg kg^{-1} in plant and 21.33 mg kg^{-1} in fruit). The manganese content in tomato fruits was not influenced significantly by the application of fish bone meal though the higher Mn concentration in tomato fruits was recorded under the treatment T_5.

It was also observed from the results that treatments receiving 75 per cent of P through mineral fertilizer and remaining through AFBM treatment recorded the highest uptake of Mn by fruit and plant of tomato (16.98 mg pot^{-1} and 2.07 mg pot^{-1}, respectively). The lowest Mn uptake in fruit and plant (5.60 mg pot^{-1} and 1.27 mg pot^{-1}, respectively) were observed in T_1 treatment. In case of the total Mn uptake by tomato, the highest total uptake (19.05 mg pot^{-1}) was recorded with treatment T_5 followed by the treatment T_6 (15.57 mg pot^{-1}) and these were significantly superior over other remaining treatments. In contrast, the lowest total uptake of Mn (6.87 mg pot^{-1}) was recorded with T_1 treatment.

4.4 Effect of fish bone meal on available N, P, Ca and S status in soil at 30, 60 DAP and after final harvest of tomato

4.4.1 Available nitrogen

The data depicted in Table 13 clearly showed that there is no significant variation in the available N status of soil at all the critical growth stages due to the application of fish bone meal and mineral fertilizer except 30 DAP. Among all the treatments T8 (150 kg P_2O_5 as DAP + 50 kg P_2O_5 as RFBM) have highest available N (287.45 kg ha^{-1}) at 30 DAP, followed by T_9 (286.34 kg ha^{-1}), T_7 (281.23 kg ha^{-1}), T_1 (277.82 kg ha^{-1}), T_{10} (275.67 kg ha^{-1}), T_3(269.75 kg ha^{-1}), T_4 (263.97 kg ha^{-1}), T_2 (261.45 kg ha^{-1}), T_6 (258.71kg ha^{-1}) and T_5 (253.45 kg ha^{-1}).

At 60 DAP, application of fish bone meal had no significant variation on the available nitrogen in the soil. The highest available nitrogen (264.17 kg ha^{-1}) recorded in the treatment T_8 (150 kg P_2O_5 as DAP + 50 kg P_2O_5 as RFBM) followed by T_9 treatment recorded (261.49 kg ha^{-1}), T_7 which recorded 258.73 kg ha^{-1} and T_{11} found higher available N compared to other treatments. The treatment T_1 recorded (140.46 kg ha^{-1}) recorded lower available N which was control.

Similarly, at harvest stage, combined application of fish bone meal with mineral fertilizer had no significant variation on the available nitrogen in the soil. The highest available nitrogen (227.18 kg ha^{-1}) in soil recorded in the treatment T_8, followed by treatment T_9 recorded (227.05 kg ha^{-1}) and treatment T_7 recorded (226.80 kg ha^{-1}), whereas treatment T_1 recorded (135.95 kg ha^{-1}) which was control.

Table 13. Influence of P levels as DAP and fish bone meal on available nitrogen and phosphorus in soil at different growth stages of tomato

	Treatments	Available nitrogen (kg ha^{-1})			Available phosphorus (kg ha^{-1})		
		30 DAP	60 DAP	Harvest	30 DAP	60 DAP	Harvest
T_1:	Control	150.52	140.46	135.95	58.04	52.14	48.30
T_2:	250 kg P_2O_5 as DAP (Package of Practice)	261.45	229.85	220.72	177.01	123.15	93.87
T_3:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as RFBM	269.75	244.19	222.00	173.97	118.56	85.86
T_4:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as RFBM	263.97	238.85	220.77	176.64	120.70	89.65
T_5:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM	253.45	228.77	218.45	178.64	131.40	95.36
T_6:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as AFBM	258.71	230.71	219.97	177.67	124.79	94.01
T_7:	200 kg P_2O_5 as DAP (80 % recommended P_2O_5)	281.23	258.73	226.80	140.79	107.23	76.30
T_8:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as RFBM	287.45	264.17	227.18	139.60	103.82	71.05
T_9:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as RFBM	286.34	261.49	227.05	139.75	104.39	73.96
T_{10}:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as AFBM	275.67	244.53	224.42	141.67	115.46	82.66
T_{11}:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as AFBM	277.82	245.24	226.14	141.30	113.16	80.63
	S. Em ±	**5.71**	**6.52**	**18.15**	**3.37**	**1.24**	**1.16**
	CD @ 0.05	**16.74**	**NS**	**NS**	**9.89**	**3.65**	**3.41**

RFBM – Raw fish bone meal, AFBM – Acidulated fish bone meal, NS: Non –significant

Initial available N is 208.51 kg ha^{-1}

Initial available P_2O_5 is 66.12 kg ha^{-1}

4.4.2 Available phosphorus

Result on the effect of fish bone meal application on available P status in the soil at different growth stages of tomato is presented in Table 13. Available P status in the soil at all the stages varied due to various levels of fish bone meal and mineral fertilizers treatment.

At 30 DAP, among the treatments, T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) recorded highest available P_2O_5 value of 178.64 kg ha^{-1} followed by T_6 (125 kg P_2O_5 as DAP + 125 kg P_2O_5 as AFBM), T_2 (250 kg P_2O_5 as DAP (PoP)), T_4 (125 kg P_2O_5 as DAP + 125 kg P_2O_5 as RFBM) and T_3 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as RFBM) recorded on par available P_2O_5 values of 177.67, 177.01, 176.64 and 173.97 kg ha^{-1}, respectively and were significantly higher compared rest of the other treatments. Lowest available P_2O_5 recorded in the treatment T_1 (58.04 kg ha^{-1}) which was control.

At 60 DAS, among the treatments, T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) recorded highest available P_2O_5 value of (131.40 kg ha^{-1}) followed by T_6 (125 kg P_2O_5 as DAP + 125 kg P_2O_5 as AFBM), T_2 (250 kg P_2O_5 as DAP (PoP)), T_4 (125 kg P_2O_5 as DAP + 125 kg P_2O_5 as RFBM) and T_3 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as RFBM) recorded higher available P_2O_5 values of 124.79, 123.15, 120.70 and 118.56 kg ha^{-1}, respectively and were significantly higher compared to rest of the treatments. Lowest available P_2O_5 recorded in the treatment T_1 (52.14 kg ha^{-1}) which was control.

At the harvest of crop, there was a significant variation in the available P_2O_5 status of the soil. Among the treatments, T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) recorded highest available P_2O_5 value of (95.36 kg ha^{-1}) followed by T_6 (95.01 kg ha^{-1}) and the lowest available P_2O_5 status of soil was recorded in T_1 (48.30 kg ha^{-1}).

4.4.3 Exchangeable calcium

The result on the effect of fish bone meal application on exchangeable Ca status in the soil at different growth stages of tomato is presented in Table 14. Exchangeable calcium status in the soil at all the stages varied due to various levels of fish bone meal and mineral fertilizers.

Table 14. Influence of P levels as DAP and fish bone meal on exchangeable Ca and available S in soil at different growth stages of tomato

Treatments		Exchangeable Ca [cmol (p^+) kg^{-1}]			Available S (mg kg^{-1})		
		30 DAP	60 DAP	Harvest	30 DAP	60 DAP	Harvest
T_1:	Control	2.46	2.12	1.99	15.25	11.17	10.06
T_2:	250 kg P_2O_5 as DAP (Package of Practice)	3.48	3.11	2.92	14.18	11.34	10.15
T_3:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as RFBM	8.90	8.74	7.85	33.72	31.74	29.41
T_4:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as RFBM	8.93	8.79	7.91	33.93	31.80	29.65
T_5:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM	9.38	9.30	8.53	37.71	35.24	32.74
T_6:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as AFBM	9.28	8.93	8.32	35.89	32.66	30.31
T_7:	200 kg P_2O_5 as DAP (80 % recommended P_2O_5)	7.74	7.49	6.98	32.69	29.76	27.13
T_8:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as RFBM	7.05	6.85	6.40	31.39	28.06	26.76
T_9:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as RFBM	7.15	7.01	6.71	32.38	29.08	26.75
T_{10}:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as AFBM	8.10	7.77	7.47	33.71	30.84	29.38
T_{11}:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as AFBM	8.09	7.99	7.09	32.82	30.73	28.46
	S. Em ±	**0.17**	**0.31**	**0.55**	1.39	1.54	1.52
	CD @ 0.05	**0.50**	**0.90**	**1.60**	**NS**	**NS**	**NS**

RFBM – Raw fish bone meal, AFBM – Acidulated fish bone meal, NS: Non –significant
Initial available Ca is 3.00[cmol (p^+) kg^{-1}]
Initial available S is 17.10 (mg kg^{-1})

At 30 DAP, among the treatments, T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) recorded highest exchangeable Ca value 9.38 cmol (p^+) kg^{-1} followed by T_6 (125 kg P_2O_5 as DAP + 125 kg P_2O_5 as AFBM) [9.28cmol (p^+) kg^{-1}] which was on par with T_5. The treatment T_4 (125 kg P_2O_5 as DAP + 125 kg P_2O_5 as RFBM) [8.93 cmol (p^+) kg^{-1}] and T_3 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as RFBM) [8.90 cmol (p^+) kg^{-1}] were on par with each other and were significantly higher compared to rest of the treatments. Lowest exchangeable Ca [2.46 cmol (p^+) kg^{-1}] recorded in the control treatment T_1.

At 60 DAP, among the treatments, T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) recorded highest exchangeable Ca value of 9.30 cmol (p^+) kg^{-1}. The treatment T_6 (125 kg P_2O_5 as DAP + 125 kg P_2O_5 as AFBM), T_4 (125 kg P_2O_5 as DAP + 125 kg P_2O_5 as RFBM) and T_3 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as RFBM), recorded on par exchangeable Ca values of 8.93, 8.79 and 8.74 cmol (p^+) kg^{-1}, respectively and were significantly higher compared to T_8, T_7 and T_{10}. Lowest exchangeable Ca recorded in the control treatment T_1 [2.12 cmol (p^+) kg^{-1}].

At harvest of crop, there is significant variation in the available Ca status of soil. Among the treatments, T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) recorded highest exchangeable Ca value of 8.53 cmol (p^+) kg^{-1} followed by T_6 [8.32 cmol (p^+) kg^{-1}] and T_4 [7.91 cmol (p^+) kg^{-1}] and lowest exchangeable Ca status of soil were recorded in treatment T_1 [1.99 cmol (p^+) kg^{-1}].

4.4.6 Available sulphur

The available S status in soil increased with fish bone meal application (Table 14). Higher values of S status in soil were recorded in treatments receiving 75 per cent of P through mineral fertilizer and remaining through AFBM treatment compared to the application of only fish bone meal and mineral fertilizer at all the growth stages (37.71, 35.24 and 32.74 mg kg^{-1} 30 and 60 DAP and after final harvest, respectively). The lowest available S found in treatment T_1 in all critical growth stages of tomato (15.25, 11.17 and 10.06 mg kg^{-1} at 30 and 60 DAS and at harvest, respectively).

4.5 Effect of fish bone meal on selected physicochemical properties of soil at harvest of tomato

4.5.1 Soil pH

The pH of the post-harvest soil showed no significant differences among the treatments. However, a slight increase in pH with treatments of FBM compared to before application of FBM was observed (Table 15).

4.5.3 Organic carbon

Organic carbon status in the soil at harvest stage of tomato did not vary due to various levels of fish bone meal and mineral fertilizers treatment. Data (Table 15) indicates that maximum organic carbon (4.85 g kg^{-1}) was recorded in treatment T_3. Lowest organic carbon recorded in the treatment T_1 (4.75 g kg^{-1}) which was control. A cursory look of the data (Table 15) reveals that the soil applied with fish bone meal has more organic carbon compared to only fertilizer applied treatment.

4.5.2 Soil EC

There was a non-significant difference in EC of soil among different treatments after harvesting of the tomato crop (Table 16). However, the highest EC (1.27 dSm^{-1}) was found in treatment (T_5) which received 75 per cent of P through mineral fertilizer and remaining through AFBM. The lowest of (0.31 dSm^{-1}) EC was found with T_1 (control) treatment.

4.5.4 Available potassium

The available K status in soil increased with fish bone meal application (Table 16). Higher values of K status in soil were recorded in T_8 at final harvest soil of tomato crop (407.87 kg ha^{-1}). The lowest available K found in treatment T_1 at final harvest soil of tomato (207.75 kg ha^{-1}).

4.5.5 Available magnesium

The available Mg status in soil increased with fish bone meal application (Table 16). Higher values of Mg status in soil were recorded in treatments receiving 75 per cent of P through mineral fertilizer and remaining through AFBM treatment compared to the application of only fish bone meal and mineral fertilizer at final harvest soil of tomato crop (3.23 [cmol (p^+) kg^{-1}]). The lowest available Mg found in treatment T_1 at final harvest soil of tomato (0.98 [cmol (p^+) kg^{-1}]).

Table 15. Influence of P levels as DAP and fish bone meal on pH of soil at different growth stages and organic carbon at harvest of tomato

Treatments		Soil pH			Organic carbon (g kg^{-1})
		30 DAP	60 DAP	Harvest	Harvest
T_1:	Control	6.30	6.32	6.40	4.75
T_2:	250 kg P_2O_5 as DAP (Package of Practice)	6.42	6.43	6.43	4.84
T_3:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as RFBM	6.48	6.52	6.53	4.85
T_4:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as RFBM	6.46	6.51	6.52	4.80
T_5:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM	6.28	6.00	5.98	4.82
T_6:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as AFBM	6.26	6.02	5.99	4.78
T_7:	200 kg P_2O_5 as DAP (80 % recommended P_2O_5)	6.43	6.44	6.45	4.83
T_8:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as RFBM	6.54	6.57	6.58	4.81
T_9:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as RFBM	6.52	6.56	6.58	4.76
T_{10}:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as AFBM	6.27	6.02	5.95	4.82
T_{11}:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as AFBM	6.28	5.97	5.96	4.83
	S. Em ±	**0.02**	**0.01**	**0.02**	**0.04**
	CD @ 0.05	**NS**	**NS**	**NS**	**NS**

RFBM – Raw fish bone meal, AFBM – Acidulated fish bone meal, NS: Non –significant

Initial pH of soil is 6.3; Initial OC is 4.70 g kg^{-1}

Table 16. Influence of P levels as DAP and fish bone meal on EC, available K and exchangeable Mg in soil at harvest of tomato

Treatments		EC(dS m^{-1})	Available K (kg ha^{-1})	Available Mg [cmol (p^+) kg^{-1}]
T_1:	Control	0.31	207.75	0.98
T_2:	250 kg P_2O_5 as DAP (Package of Practice)	0.53	398.12	1.52
T_3:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as RFBM	0.98	399.45	3.18
T_4:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as RFBM	1.01	399.08	3.19
T_5:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM	1.27	396.41	3.23
T_6:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as AFBM	1.06	397.15	3.21
T_7:	200 kg P_2O_5 as DAP (80 % recommended P_2O_5)	0.46	401.82	3.10
T_8:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as RFBM	1.13	407.87	2.92
T_9:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as RFBM	1.06	407.71	2.96
T_{10}:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as AFBM	1.26	399.97	3.16
T_{11}:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as AFBM	1.26	401.52	3.11
	S. Em ±	**0.04**	**6.01**	**0.10**
	CD @ 0.05	**NS**	**NS**	**NS**

RFBM – Raw fish bone meal, AFBM – Acidulated fish bone meal, NS: Non –significant

Initial available K_2O is 298.20 kg ha^{-1}, Initial exchangeable Mg is 1.50 [cmol (p^+) kg^{-1}]

4.5.6 DTPA- extractable micronutrients

No significant difference was found concerning DTPA extractable Zn, Cu, Fe and Mn in the soil after harvest of tomato crop due to different treatments imposed (Table 17).

A statistically non-significant difference was observed in available Fe content at harvest. Treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) recorded highest available Fe content in soil (14.87 mg kg^{-1}) followed by treatment T_6, T_2 and T_4 (13.50, 13.06 and 13.05 mg kg^{-1}, respectively) and treatment T_1 recorded the lowest available Fe (11.35 mg kg^{-1}) soils of tomato.

Based on the presented data, a non-significant difference was inferred in both available Mn and Cu content soil. Treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) recorded highest available Mn and Cu content at harvest (9.49 and 1.14 mg kg^{-1}) followed by treatment T6 (7.38 and 1.11 mg kg^{-1}) whereas T_1 treatment recorded the lowest available manganese and copper content (3.78 and 0.61 mg kg^{-1}).

Perusal of data illustrated in Table 16 indicated that there was no significant variation in available Zn content at harvest of tomato as influenced by FBM. Treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) recorded higher available Zn content (2.22 mg kg^{-1}) followed by treatments T_6, T_2 and T_4. Lowest available Zn (1.11 mg kg^{-1}) of tomato harvested soil was recorded with Treatment T_1.

Table 17. Influence of P levels as DAP and fish bone meal on soil available micronutrients at harvest of tomato

Treatments		Available Fe	Available Zn	Available Cu	Available Mn
		(mg kg^{-1})			
T_1:	Control	11.35	1.11	0.61	3.78
T_2:	250 kg P_2O_5 as DAP (Package of Practice)	13.06	1.51	1.05	7.24
T_3:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as RFBM	12.90	1.38	1.03	6.31
T_4:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as RFBM	13.05	1.47	1.04	6.92
T_5:	187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM	14.87	2.22	1.14	9.49
T_6:	125 kg P_2O_5 as DAP + 125 kg P_2O_5 as AFBM	13.50	1.54	1.11	7.38
T_7:	200 kg P_2O_5 as DAP (80 % recommended P_2O_5)	12.37	1.22	0.80	5.17
T_8:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as RFBM	12.10	1.16	0.66	4.64
T_9:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as RFBM	12.32	1.20	0.79	5.16
T_{10}:	150 kg P_2O_5 as DAP + 50 kg P_2O_5 as AFBM	12.74	1.36	0.98	5.67
T_{11}:	100 kg P_2O_5 as DAP + 100 kg P_2O_5 as AFBM	12.62	1.27	0.96	5.18
	S. Em ±	3.23	0.33	0.31	1.12
	CD @ 0.05	**NS**	**NS**	**NS**	**NS**

RFBM – Raw fish bone meal, AFBM – Acidulated fish bone meal, NS: Non –significant

Initial Available Fe is 21.58 (mg kg $^{-1}$), Zn is 0.98 (mg kg $^{-1}$), Cu is 0.96 (mg kg $^{-1}$) and Mn is 2.52 (mg kg $^{-1}$)

DISCUSSION

V DISCUSSION

Tomato is high calcium and phosphorus loving vegetable crop and to harvest the full potential, the application of phosphorus and calcium is essential. The water-soluble sources of phosphorus as single super phosphate are cost-effective and its use efficiency is also low in acidic soils developed under high rainfall conditions. Tomatoes can make use economical and sparingly soluble phosphorus sources such as a bone meal.

The results obtained from the present experiment entitled “Influence of phosphorus supplementation through fish bone meal on soil chemical properties and yield of tomato” are discussed under the following mentioned headings

5.1 Effect of fish bone meal on biometric parameters of tomato

5.2 Effect of fish bone meal on yield attributing characters, yield and quality parameter of tomato

5.3 Effect of fish bone meal on percent N, P, K, Ca, Mg, S and micronutrient content and uptake at harvest of tomato

5.4 Effect of fish bone meal on available N, P, Ca and S status of soil at 30, 60 DAP and after final harvest of tomato

5.5 Effect of fish bone meal on selected physicochemical properties of soil at harvest of tomato

5.1 Effect of fish bone meal on biometric parameters of tomato

Results presented in Table 4 indicate that plant height was significantly influenced by the imposed treatments at all the growth stages of tomato crop except at 30 DAP. Application of FBM with mineral P fertilizers significantly increased the plant height. The treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) recorded significantly higher plant height compared to other treatment and lowest plant height was recorded in control treatment (T_1). The increase in plant height might be due to continuous phosphorus availability from FBM-P and AFBM-P application with DAP fertilizer as it plays an essential role in growth, development and photosynthesis which might have reflected in higher values for plant height as reported by Salve *et al.* (2010), Singh *et al.* (2018). Increase in tomato plant height was due to increased availability of N, P and Ca and their beneficial effects on cell division and multiplication (Madhavi *et al.*, 1997). Mineralization of organic P and solubilization of precipitated P by the microorganisms enhance the P availability in soils as also reported by Chen *et al.* (2006).

Similarly, at 30, 60 DAS and after final harvest stage of the tomato crop showed a significant increase in number of branches per plant due to the application of fish bone meal with mineral fertilizers. However, treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) recorded significantly higher number of branches per plant compared to other treatments. The treatments T_6 (125 kg P_2O_5 as DAP + 125 kg P_2O_5 as AFBM) and T_2 (250 kg P_2O_5 as DAP (PoP)) were on par with each other. High and continuous availability of phosphorus and its role in growth, development and photosynthesis might have reflected in more numbers of branches per plant. These results are in line with findings of Pal *et al.* (2010), Kundu *et al.* (2010) and Patil *et al.* (2000).

5.2 Effect of fish bone meal on yield attributing characters, yield and quality parameters of tomato

It was evident from the results that the yield attributes *viz.*, fruit diameter, total number of fruits per plant, total yield per plant and dry matter yield was significantly influenced due to application of fish bone meal.

The fruit diameter and total number of fruits per plant were significantly increased by the application of fish bone meal and mineral fertilizer P (Table 5). Application of 75 per cent of P through mineral fertilizer and remaining through AFBM significantly increased the fruit diameter and total number of fruits per plant. Treatment (T_5) recorded considerably higher fruit diameter (6.68). The total number of fruits per plant (42.00) was higher in treatment T_5 as compared to other treatments and followed by the treatment which received 50 per cent of P through mineral fertilizer and remaining through FBM (T_6), treatment (T_2) and control (T_1). This may be imputed to increased P availability in soil due to fish bone meal application, which in turn influenced the physiological processes that are directly related to nitrogen fixation, photosynthesis and translocation of carbohydrates for fruit development. Increase in diameter of the fruit may be due to the involvement of nitrogen content of AFBM and RFBM fertilizer in chlorophyll formation. Apart from nitrogen calcium, might have also helped to favors cell division, meristematic activity in apical tissue, expansion of cell and formation of new cell wall which in turn enhances the width of the fruit. The number of fruits per plant depends on the number of flowers and the ability of the plant to provide the nutrients required for growth and development led to production of fruits in the plant. These findings are in accordance with previous studies of Paithankar *et al*. (2004) and Suganiya *et al*. (2015) in tomato.

Application of 75 per cent of P through mineral fertilizer and remaining through AFBM recorded higher yield per plant compared to other treatments. There was significant difference in total yield per plant was recorded due to the imposition of the treatments.

The data on the effect of fish bone meal on total yield per plant of tomato was enlisted in Table 5. It was evident from the results that the total yield of tomato was significantly influenced due to fish bone meal and mineral fertilizer application. The treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) recorded significantly higher fruit (5.48 kg $plant^{-1}$) yield than the T_6 and T_2 treatments. The minimum fruit yield (1.52 kg $plant^{-1}$) was recorded with treatment T_5. The greater availability of nutrients under the influence FBM resulted in better growth and development of plants. Ultimately it increased total yield per plant in tomato as reported by Salomonsson *et al.* (1995), Valenzuela *et al*. (2000) and Jeng *et al*. (2004). Fruit yield of tomato was significantly influenced due to fish bone meal and mineral fertilizer application. This may be ascribed to increased P availability in soil due to applied P content as mineral fertilizer in initial days and through AFBM-P, FBM-P in the later growth period. This intern influenced the physiological processes that are directly related to nitrogen fixation, photosynthesis and translocation of carbohydrates for fruit development. Phosphorus solubilizing bacteria species like Pseudomonas striata are also reported to be beneficial in increasing the P availability in soil and thereby grain and stover yield of pulses (Gupta, 2006). The availability of Ca from AFBM and RFBM could have increased fruit set and better fruit weight through better canopy development. This would also have increased efficiency of photosynthesis in plants. The Ca also have increased activity of enzymes like phospholipase, arginine kinase, amylase and Adenosine tri phosphatase (ATPase) enzymes which would have made them effective in better flowering, fruit set and in turn yield of crop. Similar findings are also reported by Muhammad (2012), Tamilselvi *et al.* (2002) and Alia *et al*. (2015) in tomato.

A statistically non-significant difference was observed for quality parameters of tomato due to application fish bone meal. The treatments T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) recorded comparably high lycopene content, ascorbic acid content, TSS and shelf life. The lowest quality parameter was observed in control treatment (T_1). The increases in ascorbic acid might be due to physiological influence of organic matter in combination with inorganic sources on the activity of a number of enzymes and also might be due to more energy and food material available in the fruit due to strong vegetative growth of plant. The increase in ascorbic acid content might be due to growth promoting substances which could have accelerated synthesis of carbohydrates resulting in increase in ascorbic acid contents. Similar observations were also reported by Gourkhede *et al.* (2015) and Kipkosgel *et al.* (2003). Tanwar and Shaktawat (2003) also found similar results. Singh *et al.* (2009) also reported the same trend of results.

5.3 Effect of fish bone meal on per cent N, P, K, Ca, Mg, S and micronutrient content and uptake at harvest of tomato

5.3.1 Content and uptake of nitrogen

To study the impact of different levels of fish bone meal, mineral fertilizer on nutrient content and uptake in tomato, plant samples were analyzed for N, P, K, Ca, Mg, S and micronutrients and result presented in table 7 and 12. The N content in tomato plant was influenced significantly by treatments (Table 7). The higher N content in tomato was recorded due to the treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM). This might be due to the fact that, VAM and PSF inoculation solubilized and mobilised the continues phosphorus availability, increased in growth and development, resulting in better absorption and utilization of all plant nutrients, thus led to more N and P content and uptake in shoot and fruits.

The total N uptake in tomato plant was significantly influenced by fish bone meal application. Significantly higher N uptake was observed with treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) (8.57 g pot^{-1}) over T_6 and T_3 treatments (Table 12). Significantly lower N uptake was recorded with treatment T_1 (4.43 g pot^{-1}). Jeng *et al*. (2004) also reported increased N uptake with increasing N fertilization for both for MBM and mineral fertilizer in field experiments. Sempiterno *et al*. (2010) also reported higher N and P uptake in ryegrass as result of application of MBM.

5.3.2 Content and uptake of phosphorus

The data on total P content in tomato as influenced by fish bone meal application are presented in Table 7. Phosphorus content of tomato was affected significantly due to application 75 per cent of P through mineral fertilizer and remaining through AFBM. Highest P content in tomato was recorded under the treatment T_5 at all the growth stages of the tomato crop.

The P uptake in tomato was significantly influenced by fish bone meal application. Significantly higher P uptake observed with T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) (1.77 g pot^{-1}) over T_6 and T_2 treatments (Table 10). Treatments T_{10} and T_{11} were at par with each other in both plant and fruit uptake of P by tomato. Significantly lower total P uptake was recorded with treatment T_1 (0.62 g pot^{-1}).

The higher concentration of phosphorus at all the stage of tomato in T_5 treatment is due to the continues availability of P initially from DAP fertilizer and in later stages of crop due to solubility of AFBM and RFBM. The ability of PSF to transform insoluble phosphate in the soil into soluble forms by secreting organic acids resulting in effective solubilization and utilization of phosphate. Inoculation with PSF increased the content of phosphorus in the plant. Dubey (1997) observed that phosphate solubilizing microorganisms play a significant role in the solubilization and uptake of native and applied soil phosphorus. Ylivainio *et al.* (2008), Nogalska et *al.* (2012) and Nogalska *et al.* (2014) also reported the beneficial influence of MBM on phosphorus content in different crops. Kahiluoto and Vestberg (1998) reported a significantly larger P uptake from bone meal than from kola apatite. Nogalska and Zalewska (2013) also found that phosphorus uptake by winter wheat and maize was higher in treatments applied with meat and bone meal, compared to control. Similar results were reported by Li *et al.* (2014) in winter triticale, winter wheat and the green matter of maize.

5.3.3 Content and uptake of potassium

The data regarding total K content in tomato as influenced by fish bone meal application are presented in Table 7. Potassium content in tomato plant and fruit was non-significantly due to different levels fish bone meal application. Still, the higher K content in tomato was recorded with the treatment T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as acidulated fish bone meal) at all the growth stages of the tomato crop (Table 10). Significantly higher K uptake was recorded with T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) treatment over $T_6$and T_2 treatments. Significantly lower K uptake was recorded with treatment T_1.

The increased content of K might be due to the application of N and P, which increased the K content in the plant. Phosphorus fertilization helps in promoting root growth which leads to increased content and uptake of K by the crop. It indicates the application of phosphorus through integrated sources seems to be beneficiary for the absorption of N, P and K by the plants. These results are in conformity with those of Dhage *et al*. (2014).

5.3.4 Content and uptake of calcium

The data on Calcium content in tomato as influenced by fish bone meal application are presented in Table 8. Calcium content of tomato was affected significantly due to 75 per cent of P through mineral fertilizer and remaining through AFBM. Highest Ca content in tomato was recorded under the treatment T_5 at all the growth stages of the tomato crop.

The Ca uptake in tomato was significantly influenced by fish bone meal. Significantly higher Ca uptake observed in T_5 (187.5 kg P_2O_5 as DAP + 62.5 kg P_2O_5 as AFBM) over T_6 and T_2 treatments (Table 11). Significantly lower Ca uptake recorded with treatment T_1 (1.68 g pot^{-1}). The higher content of Ca at all the stage of tomato in T_5 treatment is due to continues availability of Ca initially from DAP fertilizer and in later stages due to solubility of RFBM and AFBM. The ability of PSF to transform insoluble phosphate into soluble forms by secreting organic acids resulting in effective solubilization and utilization of Ca from fish bone meal. Lower uptake in T_1 attributed to lower availability of Ca in soils control treatments. Ibrahim (2009) also studied that calcium content in plants increased with application of bone meal. Babu and Seshaiah (2006) obtained a similar trend in their investigations, where an increase in content and uptake of the nutrients in stover and grain linearly with an increase in levels of P in combination with organic manure.

5.3.5 Content and uptake of magnesium

The magnesium content in tomato plant was significantly influenced by FBM at all the growth stages of tomato (Table 8). Significantly higher Mg uptake recorded in T_5 treatment (2.08 g pot^{-1}) over T_6 and T_2 treatments.The total Mg uptake by tomato was recorded significantly lower with treatment T_1. Increased uptake of Mg by tomato crop might be due to increased dry matter yield of the tomato crop. The higher content of Mg in fruit and shoot together with increased fruit yield might be the result of higher uptake of magnesium. Nogalska *et al.* (2012) also observed significantly high Mg uptake in treatments with the MBM treatment.

5.3.6 Content and uptake of sulphur

The sulphur content in tomato plant was not significantly influenced at all the growth stages of tomato (Table 8) and higher S uptake recorded with T_5 treatment (1.20 g pot^{-1}) over T_6 and T_2 treatments. Significantly lower S uptake was recorded with treatment T_1. Increased uptake of S by tomato crop might be due to increased dry matter yield of the tomato crop. The higher content of S in fruit and shoot together with increased fruit yield might be the result of higher uptake of sulphur. These results are in agreement with those of Tomar (2011). The results are in agreement with those of Sonal (2018) who recorded a similar content of sulphur in soybean.

5.3.7 Content and uptake of micronutrients

The Fe, Zn, Cu and Mn content in tomato fruit was not significantly influenced by FBM at all the growth stages of tomato (Table 9). Highest total Fe, Zn, Cu and Mn uptake (147.39, 17.78, 4.08 and 19.05 mg pot^{-1}, respectively) was recorded with T_5 treatment over T_6 and T_2 treatments. The total Fe uptake by tomato was recorded lower in treatment T_1. Increase in the uptake of Fe, Zn, Cu and Mn by tomato crop might be due to more nutrient content and dry matter, also the fact that as the growth of plant increases the nutrient uptake also increases.

5.4 Effect of fish bone meal on available N, P, Ca and S status of soil at 30, 60 DAP and after final harvest of tomato

5.4.1 Available nitrogen

No significant variation in available N status of soil was observed due to different treatments. The single primary factor predicting soil mineralization of the N added with organic residues is the C/N ratio of the material. Low C/N ratio residues are regarded as highly decomposable materials. N mineralization was higher when a lot of soluble N compounds with a low C/N ratio were present. The mineral N content (ammonium and nitrate) in FBM is only 8.52 per cent and in AFBM is 7.14, but the C/N ratio is 3 to 4, indicating a vast potential for N mineralization after its application to soil. These findings can be explained by the rapid, initial release of inorganic N from FBM, which had a relatively constant rate of mineralization after 3 to 6 weeks of application and making it available at initial days. Higher availability of N in treatment T_5 and T_6 is due to the higher application of N as FBM is applied in concern with recommended P application by FBM. Also with the use of VAM and PSF microorganisms the nutrient solubilization and release was throughout the crop period. These results are in line with the findings of Salomonsson *et al.* (1995), Jeng *et al.* (2004) and Chaves (2005). Mondini *et al*. (2008) also showed organic N of MBM was readily transformed into $NH4^+$ and further converted into nitrate, indicating the high potentiality of MBM as N fertilizer.

5.4.2 Available phosphorus

Available phosphorus in the soil at all the stages varied significantly due to fish bone meal treatment (Table 14). Higher values were recorded at all the stages due to application of 75 per cent of P through mineral fertilizer and remaining through AFBM (178.64, 131.40 and 95.36 kg ha^{-1} at 30, 60 DAP and harvest, respectively) followed by application of 50 per cent of P through mineral fertilizer and remaining through FBM (T_6). At all the stages, higher values were recorded in treatments with 75 per cent of P through mineral fertilizer and remaining through AFBM.

Increased availability of P_2O_5 due to application of 75 per cent of P through mineral fertilizer and remaining through AFBM might be due to availability of phosphorus in initial days from water-soluble DAP fertilizer and later by FBM. This, makes the nutrient availability throughout the cropping period for tomato by conjunctive application of FBM and water-soluble fertilizer. The rate of phosphorus mobilization in FBM is slower, compared to nitrogen. The rates of phosphorus solubility and release from the fish bone meal are relatively quiet. Such divergence can be explained by lower readily plant-available phosphorus content of FBM than mineral phosphate fertilizers. However, a significant amount of FBM-P is still available for crops in later stages and increase in available P_2O_5 shows that the phosphorus in FBM had the residual effect. The residual impact of FBM-P was evident as the phosphorus content in post-harvest soils is excellent in all application levels. The somewhat increased soil phosphorus level for all treatments can be explained by mobilization of phosphorus stocks from the fish bone meal as time proceeds in acid soil. Such a result is consistent with data of Ylivainio and Turtola (2009), where PUE of MBM was 13 per cent in the first year, in contrast, for mineral superphosphate, it was 23 per cent. Cerny *et al.* (2012) found that the combination of organic and mineral fertilizers increase productivity of crops. Ylivainio and Turtola (2007) also investigated that bone meal may be a more effective P fertilizer in acid soils than in soils with pH more than 6. Increase in P availability with bone meal application were also reported by Nogalska and Zalewska (2013), Nogalska *et al.* (2017), Brod *et al.* (2015), Stepien and Wojtkowiak (2015), Shi *et al.* (2016), Alotaibi *et al*. (2018), Da Silva *et al*. (2019) in different crops.

5.4.3 Exchangeable calcium

Table 15 and 17 represent the result on the effect of fish bone meal and mineral fertilizer levels on exchangeable calcium and magnesium in the soil at different growth stages of tomato. Exchangeable Ca status in the soil at all the stages varied significantly due to fish bone meal treatment except at harvest. At all critical stages, higher values were recorded due to application of 75 per cent of P through mineral fertilizer and remaining through AFBM followed by application of 50 per cent of P through mineral fertilizer and remaining through FBM (T_6) than the treatments T_2 and T_4.

Increased availability of Ca was recorded in treatment which 75 per cent of P through mineral fertilizer and remaining through AFBM. This might be due to solubility and availability of Ca in initial and in later stages by FBM. Making the nutrient availability throughout the cropping period for tomato by conjunctive application of FBM and water-soluble fertilizer. The rates of Ca solubility and release from the fish bone meal are relatively slow. The combined and individual application of fish bone meal and mineral fertilizer significantly increased soil effective CEC and availability of calcium and magnesium to plants. Ibrahim *et al.* (2009) also reported increase in the availability of Ca and Mg with application of bone meal.

5.4.4 Available sulphur

The available sulphur of soil did not vary significantly as a result of the application of phosphorus through diammonium phosphate or fish bone meal. But comparatively low available S was recorded treatment T_1. Increased S availability in treatment T_5 can be attributed to the presence of sulphur in AFBM and organic S present in fish bone meal which easily mineralizes and make available to plants. Diammonium phosphate and fish bone meal did not show any variation from the rest of the treatments concerning available sulphur content of the soil. This suggests that PSF does not have any direct influence on the available sulphur in the soil. The decrease in the available sulphur with the number of days of plant growth was due to the S uptake by the tomato plant.

5.5 Effect of fish bone meal on selected physicochemical properties of soil at harvest of tomato

5.5.1 Soil pH and EC

The pH of the post-harvest soil didn't vary significantly among the treatments. However, a slight increase in pH with treatments of FBM compared to treatments without FBM was observed. Highest EC were found in treatment T_5 (EC of 1.27 dS m^{-1}) treatment compared to others. It was assumed that due to high calcium content (10.80 % Ca) in fish bone meal, which acts as a liming agent and raise the pH and EC of soil. Increases in the pH of soil amended with MBM in the present studies are also reported by Valenzuela *et al.* (2000) and Deydier *et al.* (2003).

5.5.2 Organic carbon

Perusal of the data presented in table 13 revealed that there was no significant variation in organic carbon in the soil at harvest stage due to application of FBM. Treatments that received RFBM in combination with fertilizer showed a higher amount of organic carbon than only fertilizer applied treatment. This might be due to the high amount organic carbon in FBM. These results are in line with the findings of Salomonsson *et al*. (1995) and Jeng *et al*. (2004) where high OC content of MBM was recorded as compared to other organic amendments. Addition of FBM also increases microbial activity in the soil, which may increase the organic carbon content in the soil and the results are in agreement with those of Chaves (2005).

5.5.3 Available potassium

The potassium content of FBM is rather low (0.26 %) and in most agricultural soils the demand for additional potassium fertilizer exists. The recommended potassium was applied through muriate of potash to all the treatments. Among different treatments, no significant difference was concerning the available K_2O status of soil. A decrease in the available K_2O may be due to the uptake by the crop.

5.5.4 DTPA extractable micronutrients

It was observed that micronutrients such as Fe, Zn, Cu and Mn status of soil not varied due to application of fish bone meal. The higher micronutrient content of the soil was recorded in treatment T_5 due to the availability of all major nutrients, which increased the microbial activity and increased micronutrient availability through chelation. An increase in the status of available micronutrients in soil applied with fish bone meal and PSF may be attributed to enhancing native mineral solubilization. Application of biofertilizers with FBM converts insoluble form of nutrients to soluble form and makes them easily available, resulting in increased content of micronutrients. This might be attributed to increased root colonization with increase root surface area, resulting in adsorption and translocation of nutrients from a distant area (Sharma and Dixit, 1987).

Conclusions

1. Higher tomato fruit yield (5.48 %) and available major and secondary nutrient status in soil was noticed with the application of 75 per cent of recommended P through mineral fertilizer and remaining through AFBM (T_5) compared to other treatments.

2. Application of fish bone meal in combination with reduced mineral fertilizers can be used for sustainable nitrogen, phosphorus and calcium management in crop production under acidic soil conditions.

Future line of work

- Field response studies for the effect of raw and acidulated fish bone meal across the crops.

- Long term application studies for nutrient dynamics especially in acidic soil conditions.

SUMMARY

VI SUMMARY

A pot experiment was conducted at College of Agriculture, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences (KSNUAHS), Shivamogga during *Rabi* season 2021 to study the "Influence of phosphorus supplementation through fish bone meal on soil chemical properties and yield of tomato". The recommended dose of N, P and K were applied through mineral fertilizer at 100, 75 and 50 per cent along with raw and acidulated fish bone meal and FYM. Eleven treatment combinations were used in CRD with three replications. During experimentation, soil and plant samples collected were analysed for various parameters. Analysed soil and plant samples data were statistically analysed and interpreted. The results of the experiment are summarized in this chapter.

1. Application of fish bone meal in combination with mineral fertilizer significantly increased morphological characters like plant height and number of branches in all crop growth stages. Application of 75 per cent of recommended P through mineral fertilizer and remaining through AFBM (T_5) recorded significantly higher morphological characters than other treatments and the lowest was recorded in control treatment (T_1).

2. Yield parameters, *viz*., fruit diameter, total number of fruits per plant, dry matter yield, total yield per plant and quality parameters like lycopene content, ascorbic acid content, total soluble solids and shelf-life increased with the application of fish bone meal in combination with mineral fertilizer. The significantly more fruit diameter, total number of fruits per plant, dry matter yield and total yield per plant were recorded in the treatment received 75 per cent of recommended P through mineral fertilizer and remaining through AFBM (T_5). The lowest total number of fruits per plant, dry matter yield and total yield per plant were recorded in control treatment (T_1).

3. The content and uptake of N, P, K, Ca Mg and S in shoot and fruit of tomato was increased due to the application of fish bone meal in combination with mineral fertilizer. Treatment received 75 per cent of recommended P through mineral fertilizer and remaining through AFBM (T_5) recorded higher content and uptake of N, P and K than other treatments.

4. Application of fish bone meal in combination with mineral fertilizer significantly increased the Fe, Zn, Cu and Mn content and uptake in tomato fruit and shoot. These were considerably higher in the treatment, which received 75 per cent of recommended P through mineral fertilizer and remaining through AFBM (T_5) compared to others.

5. Available N, P, S and exchangeable Ca at critical growth stages of tomato increased with the application of fish bone meal combined with mineral fertilizer. The highest available N, P, S and exchangeable Ca status of soil at critical growth stages were recorded in the treatment received 75 per cent of recommended P through mineral fertilizer and remaining through AFBM (T_5) compared to other treatments. The lowest values of available P were recorded in the control treatment (T_1).

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APPENDICES

VIII APPENDICES

Appendix I: Monthly meteorological data for the experimental period against normal at ZAHRS, Navile, KSNUAHS, Shivamogga

	Rainfall (mm)			Maximum temperature (°C)			Minimum temperature (°C)			Sunshine hours			Relative humidity (%)		
	N	A	D	N	A	D	N	A	D	N	A	D	N	A	D
January	0.40	59.80	59.40	31.30	30.90	-0.40	16.90	16.30	-0.60	9.00	8.00	-1.00	59.00	65.50	6.50
February	0.30	28.20	27.90	33.40	31.50	-1.90	17.60	16.10	-1.50	9.00	8.50	-0.50	56.00	59.50	3.50
March	3.60	1.00	-2.60	35.80	35.00	-0.80	20.90	20.30	-0.60	7.00	6.70	-0.30	54.00	58.50	4.50
April	44.40	37.40	-7.00	36.40	35.50	-0.90	22.10	21.90	-0.20	8.00	8.20	0.20	60.00	61.00	1.00
May	73.10	43.20	-29.90	34.70	33.10	-1.60	22.70	22.50	-0.20	7.50	6.00	-1.50	66.00	73.50	7.50
Total	**121.80**	**169.60**	**---**	**34.32**	**33.20**	**---**	**20.04**	**19.42**	**---**	**8.10**	**7.48**	**---**	**59.00**	**63.60**	**---**

Note:

N- Normal meteorological data (mean of 1986-2020)

A - Actual meteorological data (2021)

D - Deviation from the normal (A-N)

Appendix II: Symbols and abbreviations used

%	:	Per cent
°C	:	Degree Centigrade
AFBM	:	Acidulated Fish bone meal
cmol (p^{+}) kg^{-1}	:	Centimole per kilogram
conc	:	Concentrated
dS m^{-1}	:	Deci Siemen per metre
DTPA	:	Diethylene triamine penta acetic acid
DAP	:	Days after planting
EC	:	Electrical conductivity
et al.	:	And others
etc.	:	Etcetera
Fig	:	Figure
FBM	:	Fish bone meal
g kg^{-1}	:	Gram per kilogram
ha	:	Hectare
i.e.	:	That is
kg ha^{-1}	:	Kilogram per hectare
MBM	:	Meat and bone meal
meq 100 g^{-1}	:	Milli equivalents per 100 gram
mg kg^{-1}	:	Milligram per kilogram
NH_4^+ -N	:	Ammonical nitrogen
NO_3^- - N	:	Nitrate nitrogen
NS	:	Non significant
ppm	:	Parts per million
PSF	:	Phosphorus Solubilizing Fungi
RDF	:	Recommended dose of fertilizer
VAM	:	Vesicular Arbuscular Mycorrhiza
viz.,	:	Namely