DYNAMICS OF ZINC IN TYPIC KANDIUSTULTS WITH SPECIAL REFERENCE TO NUTRITION IN FODDER MAIZE (*Zea mays* L.)

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DECLARATION

I hereby declare that this thesis entitled **"Dynamics of Zinc in Typic Kandiustults with special reference to nutrition in fodder maize (Zea *mays* L.)"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associate ship, fellowship or other similar title, of any other university or society.

Vellayani,
03.02.10

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CERTIFICATE

Certified that this thesis entitled **"Dynamics of Zinc in Typic Kandiustults with special reference to nutrition in fodder maize (Zea *mays* L.)"** is a record of research work done independently by Ms. THANKAMONY, K. (2006-21-115) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associate ship to her.

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LIST OF ABBREVIATIONS

Am.FeOZn-Amorphous iron oxide bound Zn

Av.-Available

Ca-Calcium

CF-Crude Fibre

cm-centimeters

cmol-centimolper kilograms

CP-Crude Protein

CPY-Crude Protein Yield

Cu-Copper

Cv.-Cultivar

DAS-Days after sowing

DFY- Dry Fodder Yield

dSm^{-1}-desi Siemens per meter

DTPA-Diethylene Triamine Penta Acetic acid

EC-Electrical Conductivity

Fe-Iron

FAO-Food and Agricultural Organization

FYM-Farmyard manure

GFY- Green Fodder Yield

kg ha^{-1}- Kilo grams per hactare

K-Potassium

LAI-Leaf Area Index

LSR- Leaf Stem Ratio

mg kg^{-1}-milligram per kilogram

Mg m^3-mega gram per meter cube

Mg-Magnesium

Mn-Manganese

LIST OF ABBREVIATIONS CONTINUED

MnO.Zn-Manganese oxide bound Zn

MOP-Muriate of Potash

N-Nitrogen

OB Zn-Organically bound Zn

PDGFY-Per Day Green Fodder Yield

POP-Package of Practice Recommendation

P-Phosphorus

ppm- parts per million

Res-Zn- Residual Zn

S-Sulfur

Ws+Ex.Zn-Water soluble +Exchangeable Zn

$ZnSO_4.7H_2O$-Zinc sulfate heptahydrate

Zn-Zinc

1. INTRODUCTION

Zinc is an essential trace element necessary for plants (Sommer and Lipman, 1926) and animals (Prasad, 2008). Zinc is found in nearly 100 specific enzymes and is the second most abundant transition metal in organisms after iron and it is the only metal which appears in all enzyme classes (Broadley *et al*. 2007). Zn is essential for the normal healthy growth and reproduction of plants and animals and when the supply of plant available Zn is inadequate crop yields are reduced and the quality of crop products is frequently impaired.

In plants Zn plays a key role as a structural constituent or regulatory co-factor of a wide range of enzymes. It is also involved in many biochemical pathways and these are mainly concerned with carbohydrate metabolism, both in photosynthesis and in the conversion of sugars to starch, protein metabolism, auxin metabolism, pollen formation etc. When the supply of Zn to the plant is inadequate, one or more of the many important physiological functions of Zn is unable to operate normally and the growth of the plant is adversely affected. Even a reduction in yield up to 40 per cent has been reported without obvious visible symptom. Losses of yield of 40 per cent or more in many zinc deficient soils have a major economic impact on the farmer due to the reduced income as a result of yield loss (Alloway, 2004). Zn is believed to promote RNA synthesis and its role in gene expression and regulation were also reported (Das, 2007).

The Food and Agricultural Organization has estimated that 50 per cent of the world's agricultural lands are deficient in Zn (Mikko Sillanpaa, 1990). Further the WHO attributes eight lakhs deaths world wide each year to zinc deficiency and highlights that zinc deficiency in human is largely related to inadequate intake or absorption of Zn in the diet (Hambridge and Krebs, 2007)

Among the micronutrients, deficiency of Zn is more predominant in soils of India with highest rate of 57 per cent in acid soils of Kerala and Meghalaya followed by Jharkhand, Orissa and West Bengal (23-54 per cent) (Sarkar and Singh, 2003). The depletion of micronutrients from the soil is increasing due to the adoption of modern technologies in crop production such as the use of high analysis fertilizers and cultivation of newer and nutrient exploitative high yielding crop varieties. Occurrence of micronutrient deficiencies in Indian soil to an extent of 46, 9, 5 and 4 per cent Zn, Fe, Cu and Mn respectively. In another report, 49 per cent of samples were found to be Zn deficient in India. (Tiwari, 2008). Majority of the Kerala soils recorded a low content of available Zn (Mathew, 2006).

The use of Zn fertilizers in Zn deficient soils can increase crop productivity as well as the Zn nutritional status of crops. Proper understanding of micronutrient availability in soils and extent of their deficiencies is the pre-requisite for efficient management of micronutrient fertilizers to sustain crop productivity. The magnitude of response to micronutrient application varies widely from crop to crop and on different soils for the same crop. Since the difference between deficiency and toxicity levels is narrow, in many situations, location specific recommendation is necessary. Not only there is inherent variability in the behaviour of soils with respect to nutrient availability but also the crops grown influence the transformation of nutrients and their availability in soils.

Maize crop was found to be responsive to Zn. Fodder crops respond to micronutrients by increasing the drymatter yields and by improving their quality as a food for animal nutrition (Mikko Sillanpaa, 1990). Among the cultivated cereal forages, maize (*Zea mays* L.) is one of the most important crops grown all round the year under irrigated conditions. African tall variety of fodder maize is a quick growing, succulent, palatable, high yielding, and nutritious variety without any antinutritional qualities that increase the milk production.

Live stock is an integral component agriculture that plays a vital role in rural economy. Balanced nutrition and adequate feeding of animals are the major factors for improved animal production on sustainable basis. The demand for milk and meat is linked to demand for fodder. Shortage of fodder is a major problem in livestock production. Since there is only limited scope for extending the acreage under forage production, increasing forage productivity is the alternate way out for meeting the demand for fodder.

The deficit in green fodder and dry fodder in the country was estimated at 61.96 and 22.08 percent respectively during 2005 and it will increase to 62.76 and 23.46 percent during 2010. With the shift in cropping pattern of Kerala, the area under rice has come down by 50 per cent over the last two decades leading to drastic reduction in the availability of straw for feeding cattle in Kerala. One of the main constraints for increasing milk production is the shortage of quality fodder. The trend over the last five years period from 2001-02 to 2005-06 showed a continuous decline in total area brought under fodder cultivation in Kerala i.e. from 4315 ha to 1600 ha (Anon., 2008). This also necessitates the increased productivity of the fodder crop. The per capita land is decreasing every year due to unabated increase in human population, so there is little scope for horizontal expansion of area under plough and the future requirement of fodder has to be met through intensification of cropping.

Nutrient content in various parts of plant varies and logging it can assist in evaluating the nutrient status of crops. The knowledge of the plant parts which accumulate the highest concentration could prove to be useful in delineating the deficiency level of nutrients from sufficiency and toxicity levels (Sharma and Bapat, 2000). Tandon (1989) reported that middle season deficiencies in crops can easily be corrected through foliar spray. Keeping all these points in view, the present study was undertaken with the following objectives:

- ❖ To elucidate the role of Zinc in nutrition of fodder maize as evidenced by its growth, yield and quality attributes when supplied to soil as well as foliar application.

- To record the pattern of periodic release of Zn by its carriers on incubation with soil and its interaction with the major soil nutrients will also be studied.
- To select of the index plant part for foliar diagnosis for fixing up the critical nutrient level in that part for maximum crop yield.

2. REVIEW OF LITERATURE

Among the micronutrient disorders Zn deficiency in field crops constitutes a major soil fertility problem in many parts of the World. The critical value of Zn as determined by DTPA extraction varies from soil to soil and from crop to crop (Katyal, 1973). Zn is essential for several enzyme systems that regulate various metabolic activities in plants. Zn occurs in soils in different chemical pools which differ in their solubility and availability to plants (Mandal and Mandal, 1996 and Das, 2003). The different aspects of Zn nutrition in crops and Zn dynamics in soil are reviewed here.

2.1 Role of Zinc in the nutrition of crops

The essentiality of Zn for higher plants was established by Sommer and Lipman (1926). Tsui $_a$ (1948) reported that Zn has an active role in the production of auxins for a range of plant species and first suggested the role of Zn in the water relations and osmotic pressure of tomato plants.

According to Kessler (1961), Zn was required for the activity of various enzymes such as dehydrogenases, aldolases, isomerases, transphosphorylases, and RNA and DNA polymerases.

Jyung *et al*. (1975) have reported that Zn was involved in the carbohydrate and protein metabolism.

Carbonic anhydrase, alcohol dehydrogenase, Cu – Zn Super oxide dismutase and RNA polymerase contain bound Zn (Marschner, 1986).

Suge *et al*. (1986) studied that the giberellic acid metabolism was impaired by Zn deficiency in plants.

Cakmak *et al*. (1989) stated that Zn was required for the synthesis of tryptophan, a precursor for the synthesis of IAA.

Cakmak and Marschner (1990) have reported that Zn appears to be involved in all membrane proteins probably due to Zn preferential binding with –SH groups and the loss of membrane integrity in Zn deficient plants.

Graham and Reed (1991) established the relationship between carbonic anhydrase and the regulation of photosynthesis suggesting Zn involvement in the photosynthesis reaction of the plant.

Miller *et al*. (1991) and Frageria *et al*. (2002) reviewed Zn as an essential micronutrient for humans, animals and plants.

The role of Zn in higher plants was, as a divalent cation (Zn^{++}) which acts either as a functional, structural or a regulatory co-factor of a large number of enzymes (Brown *et al*. 1993).

Kochaian (1993) reported that in grasses the non-protein amino acids called phytosiderophores can complex Zn^{2+} in the rhizophere and transport Zn into the root cell.

Norvell and Welch (1993) investigated the role of Zn in regulating the uptake of nutrients, as Zn treatments produced an increase of P and Mn concentrations in barley shoots.

Welch and Norwell (1993) suggested that Zn had a protective role in preventing the oxidation of sulfi hydryl groups to disulfides in the root cell membrane.

Shuman *et al*. (1995) indicated the involvement of Zn in stomatal opening, possibly as a constituent of carbonic anhydrase needed to maintain adequate bicarbonate in the guard cell and also Zn affected the influx of K^+ uptake into guard cells.

Cakmak (2000) proved that Zn has a role in protecting cells by both controlling regeneration as well as detoxification of reactive oxygen species.

Zn has been identified as a yield limiting factor for maize in Ludhiyana (Anon, 2000).

Jyolsna (2005) reported that Zn influenced the growth, yield and quality of tomato.

Takkar (2006) reported, Zn as a constituent of carbonic anhydrase, alcoholic dehydrogenase, Super Oxide Dismutase, lactate dehydrogenase, aldolase, phosphatase, DNA -RNA polymerase etc.

The Zn plays a key role in auxin and protein synthesis, seed production, rate of maturity and membrane integrity. Zn is believed to promote RNA synthesis and recently its role has been reported in gene expression and regulation (Das, 2007).

Singh (2009) opined phytosiderophores in cereal crops increased Zn mobility in rhizosphere and uptake and also translocation of Zn from root to shoot. This may be involved in affecting Zn uptake efficiency of graminaceous species under Zn deficiency.

2.2. Micronutrient status of Kerala soil

The status of available Fe for rice soils was high and reaches toxic limits (Pisharody, 1965). Jacob (1989) reported that the values of available Fe ranged from 1.6-200 mg kg^{-1} in Kozhikode and 9.2 to 5066 mg kg^{-1} in Palakkad. This study also revealed that the mean values of available Fe in soils of lateritic alluvium, Karappadom, Kayal and coastal sandy alluvium were 307, 393, 282 and 127 mg kg^{-1} respectively.

Rajagopalan (1969) observed that the level of total Mn was the highest in black soil (950 mg kg^{-1}) and the lowest in sandy soil. (104 mg kg^{-1}).

Praseedom (1970) noticed that the available Zn status of Kerala soils varied between 0.25-8.0 ppm and that available Zn status in soils decreased with depth.

Singh (1998) observed the low Cu status in Kerala soils.

Rajendran (1981) found that all rice soils of Kerala except the coastal sandy alluvium and the lateritic alluvium were well supplied with available Mn.

Sharma *et al* (1986) reported a critical limit of 0.5 mg kg^{-1} in the soils of Kerala

According to Usha (1995), the available Fe content of wetland soils ranged from 89-455 mg kg^{-1}. The lowest value was observed for soils of Wayanad and the highest for Pokkali soils.

Sheeja *et al*. (1996) reported that available Zn content in sandy soil ranged from 0.09-2.90 mg kg^{-1} and in laterite soil the range was from 0.2-7.08 mg kg^{-1}.

Thampatty (1997) observed that the total Fe content of plough layer of Kuttanadu soils ranged from 1.62 to 7.1 per cent.

Sathyanarayanan (1997) reported that the available and total Zn in major land resources of Southern districts of Kerala was in the range of 0.3 to 6.3 mg kg^{-1} respectively.

Thampatty (1997) reported that Cu content ranged from 1.5 – 10.9 mg kg^{-1} in Kuttanadu soils. Sathyanarayanan (1997) found out that available Cu status ranged from 0.6 – 5.8 mg kg^{-1} in Southern districts.

Mathew (2000) reported that available Cu ranged from 0.7 – 2.5 mg kg^{-1} in wet land and 1.11 -3.60 mg kg^{-1} in garden land soils of Kerala.

The mean status of total Zn in the wet land soils and garden soils of Kerala were in the range of 24.1 to 78.9 and 11.5 to 43.5 mg kg^{-1} respectively (Mathew, 1999). The available Zn ranged from 1.4 to 2.9 and 0.9 to 3.2 mg kg^{-1} in the above soils. The available content of Zn in the surface samples of laterite soils in Kerala was found to be low (Mathew, 2006).

Nair *et al*. (2007) reported acute Zn deficiency in low land rice soils of Palakkad

According to Koshy *et al*. (1990) the available B content of Vellayani Series and Neyyattinkara Series was 1.52 and 1.26 ppm respectively

Jyolsna (2005) reported that the available B content of Vellayani Soil was was 0.35 mg kg^{-1}

The available Mo status of Vellayani Series was 0.04 mg kg^{-1} while that of Neyyattinkara Series was 0.06 mg kg^{-1} (Koshy *et al*., 1990).

2.3 Physico-chemical properties of soil in relation to the availability of Zn

Brawn *et al*. (1962) revealed that the acidification of soils increased the concentration of available Zn to plants.

Yoshida *et al*. (1973) observed that presence of excess organic matter tends to influence soil Zn and Zn uptake by plants.

Reddy and Perkins (1974) studied the absorption of Zn by kaolinite at different pH values and found that Zn was precipitated in clay lattice surfaces or adsorbed at surface exchange sites.

Saeed and Fox (1977) showed that Zn solubility at high soil pH was due to organic matter dispersion which can either release complexed Zn or supply ligands for metal complexion and decrease precipitation.

Kalbasi et al (1978) reported that the absorption of Zn by Al oxide was pH dependent and increased markedly with increasing pH. At equivalent pH values FeO absorbed more Zn than Al oxides.

The rate of absorption of Zn in goethite was slow at low pH but increased rapidly with increasing pH due to the high point of zero charge of goethite (Padmanabhan, 1983).

According to Barber (1984) and Morgan (1984) the Zn concentration in plants may decrease by 3-4 times for each one unit increase in soil pH.

Jahiruddin *et al*. (1986) revealed that at high soil pH, Zn is more strongly adsorbed on to the surface of silicate clays and oxides and hence the availability of Zn to plants is diminished. An increase in soil pH, decreased Zn availability for plant uptake. Moisture status in soil was found to have significant effect on Zn availability and it was more in air dry soil than in soil at field capacity and full saturation (Jyolsna, 2005).

Brummer *et al*. (1988) postulated that the diffusion of Zn into goethite is one possible reason for declining availability of Zn with time. The internal binding sites of goethite increased with time, temperature and Zn concentration.

Mortvedt and Kellose (1988) noticed that placing Zn with acid forming fertilizer increased the availability of applied Zn to plants.

Rattan *et al*. (1999) reported the pH determined the availability of Zn in the soils.

Clemente *et al*. (2003) suggested that soil acidification due to oxidation of metallic sulfides in the soil increases bioavailability of Zn.

Vasegi *et al*. (2003) reported that Zn concentration in maize tissues increased with decrease in pH.

Studies conducted by Lombanes and Singh (2004) revealed that Manganese deficient soil conditions induced elevated concentration of Zn in the shoots of barley plants.

Reactions of applied Zn with soil constituents appear to be the major cause of the reduction of the Zn availability with time, since capacity of soils to absorb Zn greatly exceeds the usual amount of Zn applied (Brennan, 2005).

2.4 Influence of organic matter on Zn

According to Himes and Barber (1957) Zn complexed with insoluble humus complexes is a significant component of the specifically absorbed Zn while additional Zn is non-specifically absorbed on exchange sites of organic matter.

The interactions between humic substances and Zn, fulvic acids form chelates with Zn ions over a wide pH range on increasing the solubility and mobility of Zn (Mortenson, 1963: Mc Bride, 1989: and Norvell, 1991).

It was observed that 60 to 75 per cent of soluble Zinc was present as soluble organic complexes [Hodgsen *et al* (1966) : Geering and Hodgson (1969)].

Schnitzer and Skinner (1966) and Stevenson and Adrakani (1972) determined the stability constant (log K) and Zn fulvate as 1.7 at pH 3.5 and 2.3 at pH 5.0.

A range of organic compounds such as humic substances, carbohydrates, proteins, peptides, amino acids, lipids, waxes, polycyclic aromatic hydrocarbons and lignin fragments were contributed by soil organic matter (Stevenson, 1991).

Stevenson and Adrakani (1972) divided the organic compounds that form stable complexes in soil into 2 groups first, simple compounds such as organic acid, polyphenols, amino acids, peptides, proteins and poly saccharides and second complex polymers formed by secondary synthesis reactions such as humic and fulvic acids. This study also revealed that soluble Zn complexes are mostly from group 1 and these maintain Zn in solution at soil pH values and resulted in insoluble precipitation of Zn compounds while, reactions of Zn with second group tend to form insoluble complexes that are unavailable to plants, although humic and fulvic acid may also form soluble complexes. They have also reported the relative significance of these compounds was difficult to determine because of analytical problems in measuring the small quantities involved, their dynamic nature due to balance between synthesis and degradation and also their heterogenous distribution throughout the soil.

. However, Schnitzer and Khan (1978) reported log values as 2.3 at pH 3 and 3.6 at pH 5.0. Thus the Zn complex stability increases with increasing pH value in the acid range. Many of these compounds of soil organic matter have a strong affinity to bind Zn.

Humic acids are insoluble in acid conditions and dissolved gradually as pH increases. Humic acids are completely soluble in alkaline media and behave as colloidal system, which means that they can be flocculated by Mg and Ca. Soil organic matter is an important factor affecting the behaviour of Zn in soils. The fulvic acids and low molecular weight organic acids mainly form soluble complexes and chelates with Zn, thus increasing its mobility in the soil (Alloway, 1990).

Stevenson (1991) reported that both humic and fulvic acid substances contained a large number of functional groups (OH, COOH, SH, C-O) that have a strong affinity for Zn and other micronutrient ions, Cu and Mn.
Application of FYM along with nutrients had an additive effect on increasing the DTPA – Zinc (Jagtap, *et al,* 2007).

2.5 Interaction of Zn with other nutrients

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Hulagur and Dangarwala (1983) recorded the increased uptake of N, Ca, Mg and S in maize due to the application of Zn.

Application of higher dozes or presence of higher levels of either Zn or P in soil may reduce or enhance the availability of the other nutrients (Orabi, 1985).

Zn and P were reported to interact either antagonistically or synergistically depending upon a number of physicochemical characters of the soil (Barrow, 1987).

Devarajan *et al*. (1988) observed the antagonistic effect of P and Zn where high levels of Zn recorded generally lower P content and uptake in pulse crops.

Loneragan and Webb (1993) reported negative relationship between Zn and P.

Nitrogen contents in grain and straw were increased significantly while P content decreased with increase in level of Zn. The low concentration of P might be due to antagonistic effect of Zn (Singh *et al* .1993).

Takkar and Walker (1993) investigated that Zn deficiency in plants was associated with calcareous high pH soils, because of their low total Zn content.

Krishna (1995) reported significant positive effects of Zn treatment on dry matter, seed and straw yield of mung bean as well as crude protein percentage in the seeds.

Mishra and Singh (1996) reported that the interactive effect of N and Zn significantly influenced the Zn accumulation.

Geethakumari *et al*. (2005) reported Zn exhibit positive interaction with N and K, while negative with P. High concentration of Ca, Mg and Na inhibited the absorption and translocation of Zn. They also reported the interaction between Fe, Mn and Cu with Zn are also negative in nature.

Das *et al*. (2007) noticed synergistic interaction between Ca and Zn

Fe and Mn are reported to be antagonistic in the absorption of Zn by roots (Varshney *et al*, 2008).

2.6. Critical level of Zn in soil and crops

Cate and Nelson (1965) indicated that 1.2 mg kg^{-1} in soil and 35.95 mg kg^{-1} in rice plants as the critical limits for Zn.

Cate and Nelson (1971) noticed that the critical level of DTPA Zn in soil was 0.5 mg kg^{-1}.

The critical level for DTPA extractable Zn for red and laterite and specifically for the laterite soils of Kerala were fixed as 0.6 and 1.2 mg kg^{-1} respectively (Valsaji, 1972).

Aiyer *et al*. (1975) observed the critical limit of available Zn in the acid rice soils of Kuttanad as 0.5 mg kg^{-1}.

Brennan and Gartrell (1981) reported the critical value for Zn in soil for subterranean clover as 0.25 mg kg^{-1}.

According to Sakal *et al*. (1981), the critical Zn concentration in 52 days old rice and wheat were 37 and 29 ppm respectively.

The work done by Dudde (1986) revealed the critical levels for DTPA Zn in soil and plants respectively were 0.74 and 23.35 mg kg^{-1} for wheat and 0.72 and 21.90 mg kg^{-1} respectively for gram. The critical values were 0.75 and 29 mg kg^{-1} in mungbean and 0.60 and 25.70 mg kg^{-1} in groundnut.

Available Zn in the range of 0.72 to 2.4 mg kg^{-1} was suggested as the medium range of availability to crops (Miko Sillanappaa, 1990).

Maleswar and Dudde (1995) have developed the critical concentration for DTPA Zn in cotton (NHH – 44) and sorghum (CSH – 5) as 0.86 and 0.85 mg kg^{-1} in soil, while it was 28.40 and 27.50 mg kg^{-1} respectively for plants.

Gupta and Vyas (1999) found that that the critical limit of DTPA extractable Zn for soyabean in vertisols as 0.5 mg kg^{-1}.

Singh *et al*. (1999) observed that in the wetland rice soils of Meghalaya, DTPA extractable Zn was less than 1.2 mg kg^{-1} and Zn concentration below 35.90 mg kg^{-1} in rice plants, as the critical limit.

Karche *et al*. (2003) established the critical levels of DTPA Zn in soil and plants as 0.41 and 117.0 mg kg^{-1} for Sorghum (CSH – 5); 0.88 and 40 mg kg^{-1} for wheat (HD 2189); 0.72 and 21.90 mg kg^{-1} in Grams (Vijay). This study also developed the critical values for DTPA Zn using groundnut (JL – 24) and Tomato (Roopali). For soil it was 0.62 and 0.72 mg kg^{-1}, where as the values for plant was 25.70 and 20.50 mg kg^{-1} respectively.

Pattil and Bharambe (2003) reported that the critical limits of DTPA Zn in rice and cotton growing soils was 0.62 to 0.64 mg kg^{-1} respectively while that of plants was 32 and 21 mg kg^{-1} dry matter.

Available Zn in clay bean soils of Kandiustults of Jammu region ranged from 0.28 – 2.4 ppm (Deepak *et al.* 2004).

Mehra *et al.* (2005) established a ranged value of critical limits for DTPA Zn for maize growing soil and the same varied from 0.30 to 4.12 mg kg^{-1}, while for plant, it ranged between 10.21 to 47.64 mg kg^{-1}.

According to Mehra *et al.* (2005), the critical limit for DTPA Zn was 0.95 mg kg^{-1} in soil and 32.7 mg kg^{-1} in plant.

John (2006) reported that the critical limit for Zn in Vellayani Soils was 0.60 mg $kg^{-1.}$

Chaudhary and Raina (2008) reported the critical range of Zn in apple plants as 16.0 – 20.0 ppm.

The critical Zn concentration in cereal crops below which Zn deficiency is likely to occur varied from 12 to 24 mg kg^{-1} The leaf blade 3 from the top is the most sensitive in relating relative yields of maize shoots to Zn concentration in the tissue (Singh, 2009)

The critical limit of 2.10-3.74 mg kg^{-1} for DTPA Zn in soil and 27.0-53.8 mg kg^{-1} Zn for leaf for maximum yield of ginger in an Ustic Humitropept (Sreenivasan *et al*. 2009).

2.7 Availability of Zinc to crop plants

Halvorson and Lindsay (1977) studied the availability of Zn to maize plants and stated that the availability depended on its form in solution and speciation of Zn as an important factor controlling Zn reactions in soil and its uptake by plants.

Singh and Sekhon (1977) opined that the speciation of Zn and other micronutrients was controlled by the reactions that occur in soil solution while the concentration of Zn in solution is controlled by adsorption to soil phases.

Bould *et al*. (1983) stated that concentration of Zn in wheat and barley for sufficiency was 40 and 35 ppm respectively.

Shuman (1985) reported that the availability of Zn to plants depended on several soil factors such as the concentration of Zn in solution, ion speciation and the interaction of Zn with other macro and micronutrient elements.

2.8. Effect of Zinc on the yield and quality of crops

Usage of $ZnSO_4$ in tea plantations during high cropping season increased the bush ability to utilize major nutrients (Anon, 1975).

Das (1986) reported that application of $ZnSO_4$. H_2O at 20 kg ha^{-1} gave the highest average yield of 4.12 t ha^{-1} for rice on an acid lateritic soil.

Application of $ZnSO_4$ @ 5-10 kg ha^{-1} or foliar application of $ZnSO_4$ @ 1.25 per cent increased tuber yield and decreased HCN content in cassava in laterite soils of Kerala(Nair and Abrol.1989).

Maize was found to be responsive to Zn. Fodder crops respond to micronutrients by increasing the dry matter yields and by changing their quality as a food or animal nutrition (Mikko Sillanpaa, 1990).

Singh *et al*. (1992) revealed that mean grain and straw yield in barley increased significantly up to Zn 5 $kgha^{-1}$. The significant response of barley to Zn upto $ZnSO_4$ 5 $kgha^{-1}$ was attributed to the low status of Zn availability in the soil and fulfilled by optimum requirement.

The increase in crude protein content with Zn addition was due to the involvement of Zn in the nitrogen metabolism (Frescenko and Lozek, 1998).

Channakesava *et al*. (1999) inferred that soil application of Zn SO_4 @ 10 kg ha^{-1} resulted in increased seed yield and yield components in African Tall fodder maize.

The favourable influence of $ZnSO_4$ on the higher yield of fodder maize may be attributed to its role in various enzymatic reactions, growth processes, hormone, production and protein synthesis (Mehla, 1999).

Singh *et al*. (1999) observed that the use of Zn fertilizer increased the yield of rice in wetland soils of Meghalaya.

Meerabai (2001) reported increase in ginger yield by the application of Zn @4 kg ha^{-1} increase in turmeric yield , oil content and curcumin content by applying 10 kg ha^{-1}.

Reddy and Ahlawat (2002) reported that application of Zn along with P increased grain yield in lentil.

The optimum level of Zn in different crops ranged between 5-10 kg ha^{-1} and response of crops to Zn application varied widely because of the differences in soil characteristics, available Zn status of soil and crop varietal characteristics (Sakal, 2001).

Singh et al. (2001) observed that the use of Zn fertilizer increased the yield of rice in wetland soils of Meghalaya.

Umamaheswarai and Singh (2002) showed that application of $ZnSO_4$ @ 5 kg ha^{-1} increased significantly the yield and yield attributes such as number of pods $plant^{-1}$, number of seeds pod $^{-1}$and 100 seed weight of rajmash.

The application of Zn 10 kg ha^{-1} significantly increased plant height and green fodder yield in pearl millet (Dadwhich and Gupta, 2003).

Devi and Rani (2003) reported that application of 25 kg ha^{-1} of $ZnSO_4$ improved significantly the grain yield by increasing the number of panicles $hill^{-1}$, number of spikelets $panicle^{-1}$, number of filled grains $panicles^{-1}$ and test weight in various rice hybrids. The increased yield was found to be 48.2 per cent higher than that of control.

Dewal and Pareek (2004) indicated that Zn fertilization @ 10 $kgha^{-1}$ significantly enhanced all the yield attributes and grain, straw and biological yields in wheat.

According to Ravikiran and Reddy (2004), foliar spray of $ZnSO_4$ (0.5per cent) increased the total number of tillers per hill, number of productive tillers per hill, number of filled grains per panicle, 1000 grain weight and grain yield in the rice cv MT4 100.

Verma *et al*. (2004) reported that foliar application of Zn (0.5per cent $ZnSO_4$) increased plant height, number of leaves and branches per plant in pigeon pea.

The application of Zn 5.0 kg ha^{-1} significantly increased growth of wheat plants which was on par with 6.25 and 7.25 kg ha^{-1} (Singh, 2004).

Jyolsna (2005) reported that application of Zn as $ZnSO_4$ @ 5 kg ha^{-1} was ideal for economic yield in tomato.

Application Zn 5 $kgha^{-1}$ along with NPK fertilizers were found suitable for achieving greater productivity in plants (Shivoy and Kumar, 2005).

When Zn was applied @ 4.4 kg ha^{-1} along with N, P, K and S, gave the highest number of nodules per plant, nodule N, leghaemoglobin contents, pod yield and highest protein content in groundnut (Tiwari *et al*., 2006).

Maximum Zn uptake was obtained for maize when Zn chelates were used @ 10 mg kg^{-1} (Alvarez, 2007).

Application of $ZnSO_4$,10 $kgha^{-1}$ resulted in increased stem diameter, more number of seed rows , and increased seed yield in maize (Channakesava *et al*. 2007).

Chaube *et al*. (2007) recorded that application of 1 per cent $ZnSO_4$ significantly increased the plant height, number of leaves, leaf area and yield in pearl millet.

Haris *et al*. (2007) application of 2.75 kg Zn ha^{-1} significantly increased mean maize grain yield by 720 kg ha^{-1} (25 per cent) total dry matter, number of cobs and cob weight.

2.9. Total Zinc and Fractions of Zinc in soil

The behaviour of Zn ions in soils and their uptake cannot be explained by the total concentration of Zn in the soil. Total Zn concentration of soils largely dependent on the composition of the parent rock material (Graham, 1953; Swaine, 1955 ;Swaine and Mitechell, 1960; Tiller, 1963. Mikko Sillanappa, 1972; Kabata Pendias and Pendias, 1984). Total Zn concentration was seldom used as a test for evaluating plant availability of Zn as the total Zn soil often incorporate Zn in unweathered minerals that is unavailable for plant growth.

The total concentration of Zn for soils ranged from 10-300 $mgkg^{-1}$ (Goldschmidt, 1954).

Soils with a low total Zn concentration are often Zn deficient for crop production. Since quartz contains negligible Zn, sandy soils are inherently low in total Zn concentration and frequently deficient in available Zn. Zn deficiencies of plants grown on acid soils are generally associated with low total soil Zn concentration (Lucas and Davis, 1961).

Viets (1962) and Hodgson (1963) reported that the successive pools of Zn form ions in the solution to Zn in crystal lattices and they are considered to represent pools of decreasing availability for plant uptake.

Total Zn concentration in calcareous soils are often similar to or higher than those of non-calcareous soils ,but Zn deficiency was repored for calcareous soils (Yoshida and Tanaka,1969). Though the total soil concentration of Zn in calcareous was reported to be higher, but it was not available to plants due to the effects of soil pH.

The mean Zn concentration ranged from 40 mg kg^{-1} in acid rocks (granites) to 100 mg kg^{-1} in basaltic rock (Krauskopf, 1972).

Lindsay (1972) reported that distribution of total Zn down the soil profile reported to be uniform, while extractable Zn decreased with depth.

The average concentration of Zn in basaltic rock was usually higher than the Zn concentration in granitic rocks. Wedepohl (1973) investigated and found magnetite as the most important Zn carrier in basaltic rocks, while biotite was the main source of Zn in granitic rocks.

Norrish (1975) reported that in igneous rock, low concentration of Zn was present in sulfides, but higher concentration of Zn in the more abundant silicates.

According to Takkar (1982) the total Zn content of Indian soils was in the range of 0 -1019 $mgkg^{-1}$.

Kabata Pendias and Pendias (1984) investigated that in the sedimentary rocks, the highest Zn concentrations were found in shales and clayey sediments (80-120 mg kg^{-1}) while sand stones, lime stones and dolomites generally have lower concentration (10-30 mg kg^{-1}).

Shuman (1985) reported the different Zn solutions as water soluble and exchangeable, organically bound, MnO bound, Amorphous Fe O bound, Crystalline FeO bound, Residual and total. Most procedure of chemical fractionation showed that the residual Zn is the greatest component of Soil Zn.

Barrow (1986) opined that the concentration of Zn OH^+ explained Zn adsorption on soil surfaces better than the total concentration.

It was inferred that total Zn content is an unsatisfactory measure of Zn availability to crops (Katyal and Rattan, 1993; Sureshkumar *et al.*, 2004).

Neilson *et al*. (1986) determined the distribution of Zn in soil fractions. The total Zn was measured as 51.5-226.3 mg kg^{-1} with an average of 89.7 $mgkg^{-1}$. The exchangeable Zn consisted of 0.3-23.2 per cent, 0.5-29.7 per cent associated with organic matter, 1.3-15 per cent was in Fe and Al oxides. The MnO bound fraction ranged from 6.4-24 per cent while the residual Zn varied from 45.6-92 percent

Yaduvanshi and Sharma (1988) studied the transformation of Zn on an acid soil (Mollisol). The fractions of Zn for surface soil (0-15-cm) was found as 1.0 – 3.8ppm, 26.4 – 400ppm, 18.0 – 34.0 ppm, 10.9 – 18.0 ppm and 56.0 – 68.0 ppm for water soluble + exchangeable, specifically sorbed at inorganic sites, organically bound Zn, free oxides bound Zn and residual Zn respectively.

Hazra *et al*. (1993) studied the distribution of Zn fractions in red and lateritic soils of Birbhum (West Bengal). The total Zn in the surface layer varied from 24 - 85 mg kg^{-1}. The water soluble + Exch. Zn (0.40 - 3.30 mg kg^{-1}), organically bound Zn (3.8 per cent), MnO-Zn (1.7 per cent), AmFeO-Zn (23 per cent), CryFeO-Zn (0.84 per cent). For the subsurface (0.15 – 0.3 cm) layer, the various fractions ranged from 20 – 53 mg kg^{-1} for total Zn, 0.2 – 2.2 mg kg^{-1} for Ws + Ex – Zn and 0.2 – 3.5 mg kg^{-1} for organically bound Zn. The MnO-Zn, AmFeO-Zn and CryFeO-Zn were in the range of 0.3 – 1.8, 8.5 – 13.7 and 2.3 – 12.3 $mgkg^{-1}$ respectively.

Randhawa and Singh (1995) reported that exchangeable Zn contributed to the pool of available Zn and thus played a significant role in the Zn nutrition of maize.

Prasad *et al*. (1996) have studied the transformation of applied Zn in the rice growing OH alluvial soils of Bihar plain under submerged condition. The amount of Zn recovered in Ws + Ex, OB and CryFeO-Zn forms recorded a progressive decrease with increase in residual forms on submergence. But the complexed and amorphous Zn was not influenced by the submergence.

According to Sahu *et al*. (1996) the relative amount of different fractions of Zn were in the order of residual (22.1 mgkg-1) > complexed (6.68 mgkg-1)> organically bound (4.5 mgkg-1) > CBD extractable (3.03 mgkg-1) > water soluble + exchangeable (2.03 mgkg-1) > HCl soluble Zn (0.59 mgkg-1).

Sharma *et al*. (1996) reported that water soluble, exchangeable, complexed, organically bound, occluded and residual fractions constituted on an average of 0.10, 0.18, 0.55, 1.53, 2.06 and 90.7 per cent of the total Zn content of the soil respectively. This study also reported that complexed, occluded and residual Zn were the principal forms contributing to the pools of available Zn in Vertisols.

Deb (1997) has reported a wide variation in the total Zn content of Indian soils and that it might be due to the varied pedological conditions on the formation of soils. This study also reported that the total Zn content varied between 7.0 to 1000 $mgkg^{-1}$

The different forms of Zn were usually measured as water soluble, carbonate bound, organic matter bound, Fe and Al oxide bound and residual fractions (Ma and Uran (1997). This study also found that wetting, drying and elevated soil temperature enhanced the transformation of recently added Zn to Fe, Al and Mn oxide fractions.

Nayyar (1999) reported wide variations in the total micronutrient content in Indian soils due to the dominant influence of pedological conditions on soil development.

Singh *et al*. (1999) reported the distribution of various fractions of Zn in soil. Total Zn ranged from 66.5 – 72.9 $mgkg^{-1}$. The highest fraction of 65.6 – 76.6

percent of total Zn was remained as residual, while 1.12 – 2.73, 2.17 – 3.93, 3.08 – 5.31, 4.07 – 6.64, 12.30 – 19.5 per cent remained in Ws + Ex-Zn., OB, MnO-Zn, AmFeO-Zn and CryFeO-Zn form respectively.

Novillo *et al*. (2002) reported that The percentage of Zn in labile or exchangeable form is small, but it would appear that roots of plants obtain Zn from these pools and no Zn was detectable in the water soluble plus exchangeable fractions in a calcareous soil, while some Zn remained in the labile fractions of acidic and neutral soils.

According to Suresh Kumar *et al*. (2004) the Zn fractions were in the order of residual > amorphous FeO>, crystalline FeO and water soluble.

Chaudhary and Raina (2008) have reported that the amount of various fractions of Zn followed the order of WS+exch (4.0 per cent) < CBD extractable (7.7 per cent) < complexed (9.2 per cent) < organically bound (11.4 per cent) < acid soluble (13.4 per cent).

Mishra *et al*. (2009) reported that the total Zn ranged from 78.1 to 107.4 $mgkg^{-1}$ the ammonium acetate extractable Zn ranged from 0.02 – 0.84 mgkg-1 and copper acetate extractable Zn from 0.34 – 0.55 $mgkg^{-1}$. The pyrophosphate extractable, HCl extractable, CBD extractable were in the range of 2.22 – 3.06, 0.72 – 1.59 and 13.2 – 15.3 $mgkg^{-1}$ respectively.

2.10 Profile characteristics of Ultisol

Bhattacharya *et al*. (1994) classified the soils of Meghalaya as acidic, low base status, rich in organic matter and the surface horizons with less than 35 percent base saturation and revealed the presence of argillic/kandic horizons. These soils were included in Ultisols in Soil Taxonomy.

Sen *et al*. (1994) studied the Kandi soils of Manipur. Based on the physico-chemical and morphological properties, the soils were classified as Ultisol as they contain Kandic horizon with the base saturation less than 35 percent.

Krishnan *et al*. (2000) studied the morphological characteristics and classification of low activity clay soils of Kerala. The soils are very deep, well drained, fairly rich in organic matter, acidic, poor in bases and have low CEC with kandic or argillic horizon and the soils are classified under the order Ultisol.

Sathisha *et al*. (2002) reported the characteristics and limitations of rubber growing soils of Northern Mizoram as very deep soils, well drained, fine loamy texture with rich organic carbon, low CEC and low base saturation, acidic and included under the Ultisols.

Anon. (2007), classified Vellayani soils as a member of clayey, kaolinitic, isohyperthermic, Typic Kandiustults. The soils were identified as dark reddish grey to yellowish red, slightly acidic, sandy clay loam to sandy clay A horizon and reddish brown to brown, very strongly acidic to extremely acidic, sandy clay loam to clay B horizon.

2.11 Foliar diagnosis in crops

Velesco and Nevero (1951) suggested the recently matured first two blades from the top at the time of flowering (when heads are almost completely emerged)as the index part in rice.

Riceman and Jones (1958) reported the highest content of Zn was observed in the uppermost leaf in clover.

Shorrocks (1962) reported the four basal leaves from each whorl (for trees older than 4 years) to be the index part in rubber.

Romney *et al*. (1965) reported that the 11^{th} and 15^{th} leaf of coconut to be the index part of coconut

According to Johnson (1978), 5^{th} to 12^{th} leaves when the plants are 3-4 month old as the index tissue in ginger.

The first fully mature leaf from fruit bearing laterals proved to be the index part in pepper (Sushama, 1980).

According to Asher *et al*. (1980), youngest fully expanded leaf ,petiole or leaf blade at 3-4 month stage turned out to be the best indicator of nutritional status in cassava.

Saifudeen (1981) reported that the 3^{rd} leaf of tillers when the plants are 3-4 months old could be selected as the index tissue in turmeric.

Gopi (1983) reported that the middle leaflets of 10^{th} frond proved to be the best indicator of nutritional status of coconut.

Gnanadas (1989) standardized the leaves of 3^{rd} whorl of bottom region as the index leaf in clove for Zn status.

George (1994) reported that petiole of the third leaf of banana, (Musa, AAB, Nendran) upto shooting stage, flag leaf thereafter as the index part for K status.

In sugarcane crop tillering phase is identified as the best stage of leaf sampling for nutrient analysis. Regarding the leaf position, the 5th leaf from top without sheath is ideal for diagnostic purpose in relation to N while, the above leaf with sheath is ideal for P and K (Ramesh, 1994).

According to Singh and Nayar (1997), youngest fully expanded leaf was selected as the diagnostic tissue in soyabean and green gram. The critical deficiency level in youngest fully expanded leaf associated with a 10 percent reduction in the yields of soyabean and green gram and the critical level had been established as Zn 22.1 and 22.3 mg kg^{-1} respectively.

Nutrient content in various parts of plant can assist in evaluating the nutrient status of crops. The knowledge of the plant parts which accumulate the highest concentration should prove to be useful criterion in delineating the sufficiency and toxicity levels (Sharma and Bapat, 2000)

Jose (2005) reported that petiole from the middle 1/3rd of the total leaves could be selected as the index part in tapioca at four and a half month after planting

Application of Zn significantly increased its concentration in index tissue of rice and wheat. The flag leaf was selected as the index tissue and the zinc concentration ranged from 15.6 – 19.2 $mgkg^{-1}$ and 23.4 to 25.1 $mgkg^{-1}$ respectively for rice and wheat (Varshney *et al*, 2008).

3. MATERIALS AND METHODS

The study entitled 'Dynamics of Zinc in Typic Kandiustults with special reference to nutrition in fodder maize (*Zea mays* L.) was conducted at College of Agriculture, Vellayani during 2006-09. The research work consisted of two parts; a laboratory incubation study and a field study.

3.1 Incubation Study

The incubation study was conducted to determine the release pattern of Zn from soil, treated with $ZnSO_4 .7H_2O$ and incubated with and without FYM for a period of 75 days.

3.1.1 Materials

The soil for the incubation study was collected from the experimental site, at the Instructional Farm, College of Agriculture, Vellayani. The soil belonged to Typic Kandiustults (Red Soil) under Vellayani Series. One kilogram each of surface soil was taken in plastic containers of uniform size and incubated with $ZnSO_4$. $7H_2O$ as per treatments for 75 days by maintaining the moisture level at field capacity. The $ZnSO_4$. $7H_2O$ used contained 21% of Zn. The moisture level in each treatment was maintained at field capacity throughout the period of study replenishing the moisture lost by evaporation. The details of experiment carried out are presented below.

3.1.2 Design and Layout of the experiment

Design : Completely Randomized Design
Treatments : 10
Replications : 3

3.1.3 Treatments

T_1 : Soil alone
T_2 : Soil + Zn @ 0 kg ha^{-1}+ FYM @10t ha^{-1}
T_3 : Soil + Zn @5 kg ha^{-1}
T_4 : Soil + Zn @5 kg ha^{-1} + FYM @10 t ha^{-1}
T_5 : Soil + Zn @10 kg ha^{-1}
T_6 : Soil + Zn @10 kg ha^{-1} + FYM 10 t ha^{-1}
T_7 : Soil +Zn @15 kg ha^{-1}
T_8 : Soil + Zn @15 kg ha^{-1} + FYM @ 10 t ha^{-1}
T_9 : Soil + Zn @20 kg ha^{-1}
T_{10} : Soil + Zn @20 kg ha^{-1} + FYM@10 t ha^{-1}

Fig. 1 Layout of the incubation study

The soil samples were collected at an interval of 15 days for a period of 75 days and analyzed for available Zn by DTPA method. (Lindsay and Norvel, 1978) using Atomic Absorption Spectrophotometer. View of Incubation study is given in the Plate. 1.

3.2 Field Study

3.2.1

A field experiment was conducted to study the effect of Zn on the growth and yield of fodder maize (*Zea mays* L.) and the crop period extends from October, 2007 to September, 2008. Two experimental crops and two residual crops after each experimental crop were raised.

3.2.2 Experimental Site

The experiment was carried out at the Instructional Farm, College of Agriculture, Vellayani which is located at 8 º 30′ N latitude and 76 º 54′ E longitudes and at an altitude of 29 m above mean sea level.

3.2.3 Weather parameters

The major weather parameters during the crop period were monitored. The maximum temperature, relative humidity and total rainfall during the period ranged

Replications

$R1$	R_2	R_3
T_4	T_1	T_{10}
T_9	T_7	T_5
T_6	T_4	T_8
T_{10}	T9	T_3
T_2	T_8	T_7
T_5	T_2	T_1
T_1	T_6	T_4
T_8	T_3	T_2
T_3	T_{10}	T_6
T_7	T_5	T_9

Fig. 1. Layout of the incubation study

Plate 1. Incubation Experiment

from 30.55°C to 31.45°C, 86.59% to 91.12%, 0.0 to 186.2 mm respectively. The graphical representation of the data is presented in Fig.2.

3.2.4 Soil

The soil of the experimental site was Clayey, Kaolinitic, Isohyperthermic Typic Kandiustults belonging to Vellayani Series.

Table.1 Initial soil analysis of the experimental site

Physico-chemical properties	Surface (0-15 cm)	Subsurface (15-30cm)
Sand (%)	73.90	69.50
Silt (%)	10 .00	12
Clay (%)	15.10	18.30
Particle density (Mg m^{-3})	2.36	2.38
Bulk (density) (Mg m^{-3})	1.28	1.30
WHC (%)	38	40.20
Texture	sandy loam	Sandy loam
Chemical properties		
P^H	5.10	5.20
EC (dS m^{-1})	0.12	0.16
CEC (c mol (P+) $kg^{-1)}$	3.59	2.43
Organic carbon (%)	0.71	0.69
Available Nitrogen (kg ha^{-1})	271.00	227.50
Available Phosphorous (kg ha^{-1})	22.64	24.3
Available Potassium ($kgha^{-1}$)	88.92	102.7
Exch. Ca (c mol kg^{-1})	1.42	1.01
Exch. Mg (c mol kg^{-1})	0.45	0.32
Available S ($kgha^{-1}$)	12.21	10.64
DTPA Fe (mg kg^{-1})	22.60	16.59
DTPA Mn (mg kg^{-1})	8.64	6.80
DTPA Zn (mg kg^{-1})	0.48	0.42
DTPA Cu (mg kg^{-1})	0.84	0.80
Fractions of Zn (mg kg^{-1})		
Ws+Ex-Zn	0.31	0.30
OB-Zn	1.82	0.60
MnO-Zn	0.80	1.01
Am-FeO-Zn	14.10	12.69
CryFeO-Zn	28.94	24.99
Res-Zn	43.63	43.18
Total Zn	89.60	82.50

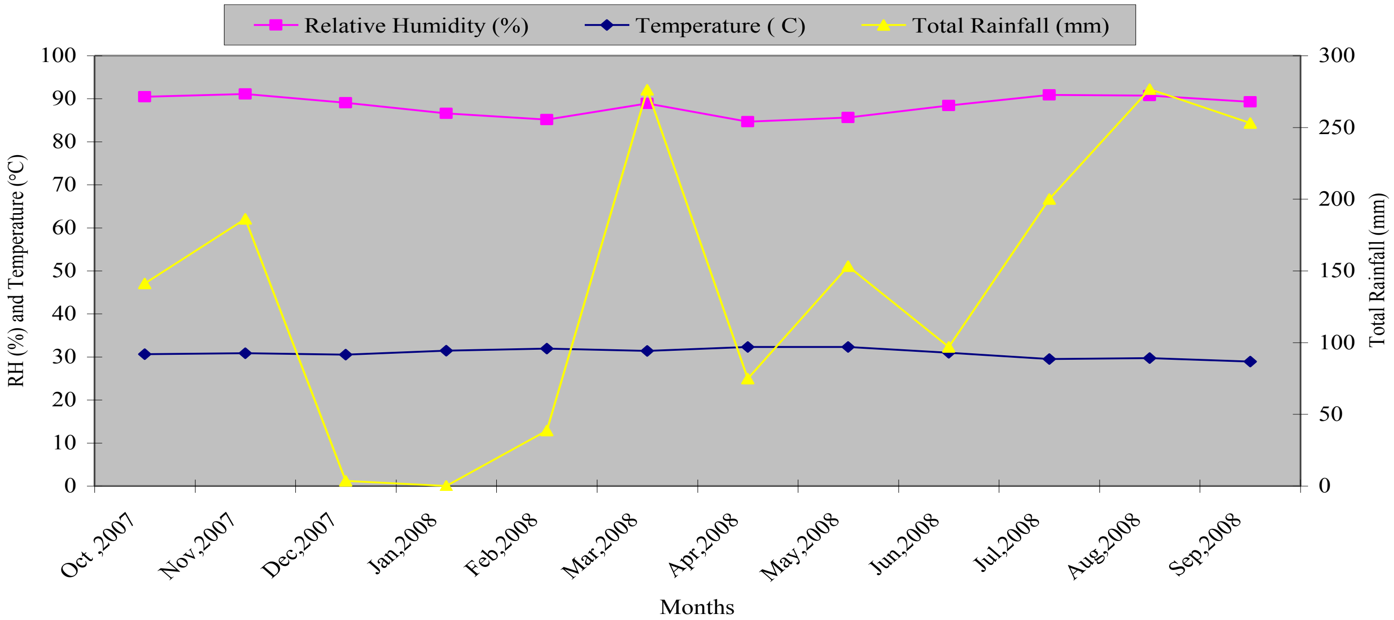

Fig. 2 Weather data during the cropping period (October,2007 to September ,2008)

3.2.5. Soil Profile Study

A vertical section of the soil adjacent to the experimental site has been taken upto a depth of 2m and studied the morphological characteristics and physico-chemical properties of the soil (Plate. 2).

3.2.6. Soil sample collection for initial analysis of soil

Composite samples of Surface soil (0-15 cm) and sub surface soil (15-30 cm) were collected from the experimental field before the layout of the crop and analyzed for various physico – chemical parameters and nutrient elements.

3.2.7. Design and Layout of the experiment

Design : Randomized Block Design
Plot size : 2.1 m x 2.1 m
Spacing : 30 x 15 cm
Treatments : 10
Variety : African Tall variety of fodder maize
Replications : 3

3.2.8. Treatments

T1	:	NPK @ 120:60:40 kg ha^{-1}without FYM
T2	:	NPK@120:60:40kg ha^{-1} +FYM @ 10 t ha^{-1}(POP recommendation)
T3	:	POP + 5 kg Zn ha^{-1} as Zn SO_4 (Soil application)
T4	:	POP + 10 kg Zn ha^{-1} as Zn SO_4 (Soil application)
T5	:	POP + 15 kg Zn ha^{-1} as Zn SO_4 (Soil application)
T6	:	POP + 20 kg Zn ha^{-1} as Zn SO_4 (Soil application)
T7	:	POP + 0.25% Zn as Zn SO_4 (Foliar application)
T8	:	POP + 0.5% Zn as Zn SO_4 (Foliar application)
T9	:	POP + 0.75% Zn as Zn SO_4 (Foliar application)
T10	:	Control

Fig.3. Layout of the field study

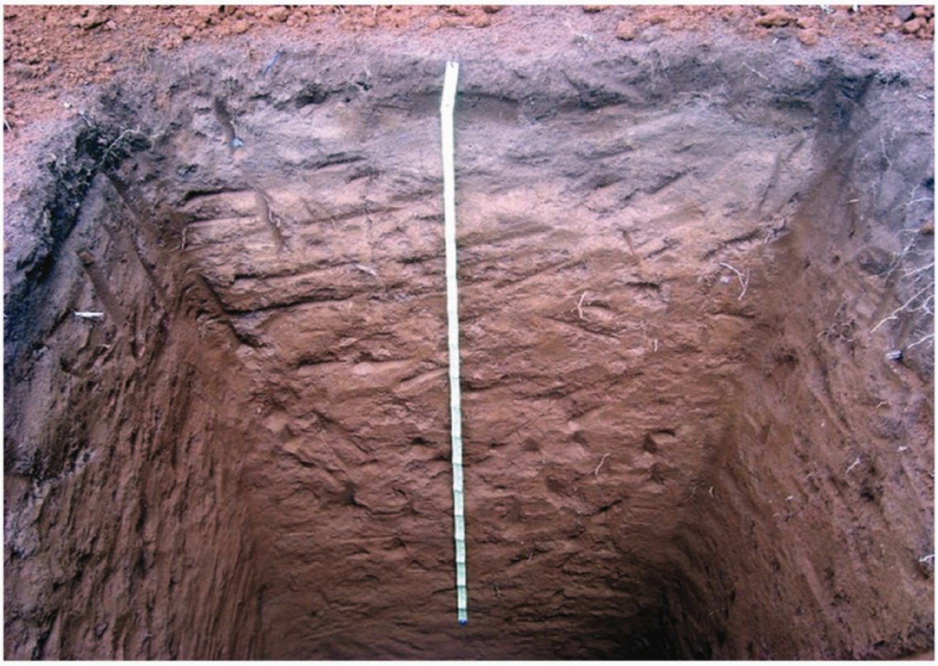

Plate 2. Soil profile

View of Experimental and residual crops given in Plate 3 & 4.

3.2.9. After cultivation practices

3.2.9.1. Irrigation

During summer months the field was irrigated twice a week and good drainage was provided to prevent water logging during rainy days.

3.2.9.2 Weed control

Before sowing, the entire field was cleared and made weed free using spade. During the crop growth period, hand weeding was resorted to as and when required.

3.2.9.3 Fertilizer application

FYM@ 10t ha^{-1} was applied to the plots as per the treatments. Urea, rock phosphate and MOP were given @ 120:60:40 NPK kg ha^{-1} ten days after the application of FYM. Soil application of $ZnSO_4 .7H_2O$ was given as per the treatments. Foliar spray of $ZnSO_4 .7H_2O$ was given to the treatment plots of T_7, T_8 and T_9 on the 4^{th} leaf stage.

3.2.9.4 Sampling details of foliar diagnosis

The 3^{rd}, 4^{th} and 5^{th} leaf and petiole from the tip were collected on the 15^{th}, 25^{th}, 35^{th} and 45^{th} day after sowing and analyzed for Zn content for indexing of plant part.

3.2.10. Growth characters

Five plants were selected from the middle row, recorded the growth parameters and the mean values were taken and tabulated.

Replications

R_1	R_2	R_3
T_7	T_5	T_8
T_2	T_7	T_4
T_5	T_{10}	T_7
T_8	T_9	T_{10}
T_9	T_3	T_9
T_{10}	T_2	T_3
T_3	T_7	T_5
T_4	T_8	T_6
T_1	T_6	T_2
T_6	T_4	T_7

Fig.3 Layout of the field study

Plate 3. Field study-Experimental crop

Plate 4. Field study- residual crop

3.2.10.1 Plant Height (cm)

Height of the plant was measured from the base of the plant to the topmost leaf bud on the 15th, 25th, 35th and 45th day after sowing and at the time of harvest and recorded.

3.2.10.2 Number of leaves

Total numbers of leaves were recorded on the 15th, 25th, 35th and 45th day after sowing and at the time of harvest and mean number of leaves per plant were recorded.

3.2.10.3. Leaf Area Index (LAI)

Leaf Area Index was computed from the values of the total leaf area of a plant and the geographical area occupied by it using the formulae

$$\text{LAI} = \frac{\text{Total leaf area of a plant}}{\text{Geographical area occupied by it}}$$

3.2.10.4 Leaf Stem Ratio

Leaf of observational plants were cut at the base. The leaves and stem were separated and oven dried for three days till constant weight was obtained. The dry weight of leaves and stem of individual plants were recorded and the ratio computed by dividing leaf dry weight by stem dry weight.

3.2.11. Yield and Quality attributes

3.2.11.1. Green fodder yield

The green fodder yield of fodder maize was recorded per plot and calculated and presented as q ha^{-1}.

3.2.11.2. Dry matter yield (q ha^{-1})

Dry matter yield was calculated as qha^{-1}

3.2.11.3. NPK content (%)

NPK contents were determined according to standard procedures and calculated.

3.2.11.4. Crude protein (%) (CP)

CP was calculated by multiplying the percentage content of N by a factor 6.25 (Strepson et al, 1965).

3.2.11.5. Crude Protein Yield (kg ha^{-1})

CPY was calculated by multiplying CP content by ha^{-1} dry matter production and expressed in kg ha^{-1}.

3.2.11.6. Crude fibre content (%)

The dried plant samples collected at the time of harvest were utilized for the estimation of crude fibre by gravimetric method (Sadasivam and Manickam, 1992).

3.2.11.7. Per day green fodder yield (q ha^{-1})

Total green fodder yield divided by duration of the crop gave the Per day green fodder yield in q ha^{-1}.

3.3. Soil Sample, Collection after the crop growth and Processing of soil

The soil samples were collected from the individual plots at two depths viz, surface (0-15 cm) and subsurface (15-30cm). The samples were air dried, processed and passed through a 2mm sieve and stored in polythene bags for analysis. The soil samples were analyzed for various physico-chemical parameters following the standard analytical procedures as detailed below (Table-2).

Table.2. Standard analytical procedures followed in soil analysis

Sl. No.	Parameters	Methods	Reference:
I. Physical Analysis			
1.	Mechanical Analysis	International Pipette Method	Piper (1966)
2.	Bulk density	Core sampling Method	Gupta and Dakshinamurthy (1980)
3.	Particle density	Pycnometer method	Gupta and Dakshinamurthy (1980)
4.	Field capacity	Core sampling Method	Black (1965)
5.	Water holding capacity	Core sampling method	Black (1965)
II. Chemical Analysis			
1.	pH	Direct reading using pH meter in 1:2.5 soil : water suspension	Jackson (1973)
2.	EC	Direct reading using Conductivity meter	Jackson (1973)
3.	CEC	Ammonium saturation by IN Neutral Normal Ammonium Acetate	Jackson (1973)
4.	Organic Carbon	Walkley and Black rapid titration method	Walkley and Black (1934)
5.	Available N	Alkaline Permanganate method	Subbaiah and Asija (1956)
6.	Available P	Bray No.1 Extraction and Spectrophotometry	Jackson (1973)
7.	Available K	NN Ammonium acetate extraction and flame photometry	Jackson (1973)
8.	Exch. Ca and Mg	Versenate Titration method	Hesse (1971)
9.	Available S	Turbidimetry – Barium chloride method	Chesnin and Yien (1950)
10.	Available Micronutrients	DTPA extraction and AAS	Lindsay and Norvell (1978)
11.	Fractions of Zn	Extraction using appropriate reagents and AAS	Shuman (1985)

3.4. Plant sample collection and processing

Plant samples collected at harvest were washed free of soil and dust particles and were dried to constant weight at 60-70^0 C in hot air oven. The dried plant samples were powdered in a Willey mill and wrapped in clean butter paper cover and stored for analysis. The plant samples were analyzed for their nutrient contents. The methods employed in the analyses are given in the table-3.

Table.3.Standard analytical methods followed in plant analysis

Sl. No.	Parameters	Methods	Reference:
1.	N	Microkjeldahl digestion with H_2SO_4 and distillation	Jackson (1973)
2.	P	Diacid digestion using Nitric acid – Perchloric acid (9:4) and colorimetry using vanado molybdate yellow colour method	Jackson (1973)
3.	K	Diacid digestion using Nitric acid – Perchloric acid (9:4)and flame photometry	Jackson (1973)
4.	Ca and Mg	Diacid digestion using Nitric acid – Perchloric acid (9:4) and versenate titration	Piper (1966)
5.	S	Turbidimetry – Barium chloride method	Chesnin and Yien (1950)
6.	Fe,Mn,Zn and Cu	Diacid digestion and Atomic Absorption Spectrophotometry	Lindsay and Norvel (1978)

3.4.1. Nutrient uptake

Uptake of each nutrient by the crop was computed from the dry matter yield and the per cent plant nutrient content.

3.5 Foliar diagnosis

3.5.1. Indexing of plant part for fodder maize for zinc

For identifying the best part and stage for sampling for Zn content, destructive sampling was done on the 15th, 25th, 35th and 45th DAS. The leaf and petiole samples from the 3rd, 4th and 5th from the tip were sampled and separated. The samples were dried, powdered and analyzed for Zn content. Correlations were worked out between the Zn content in each part at each stage to yield. The part which showed the maximum correlation as evidenced by the highest coefficient of correlation was selected as the best part and its stage of sampling as the best stage for sampling in fodder maize.

3.5.2. Critical level of Zn in the fodder maize for maximum yield

The scatter diagram technique developed by Cate and Nelson (1965) was adopted to determine the critical Zn concentration graphically. Yield was plotted against Zn concentrations. The points were distributed into four quadrants. Parallel lines were drawn each to X and Y axis. The intersecting points of the line drawn parallel to Y-axis on X-axis were taken as the critical level of leaf Zn for maximum yield.

3.6. Economic analysis

The economics of fertilizer application has been worked out for fodder maize under various treatments, using the cost of cultivation and BC ratio calculated.

3.7. Statistical Analysis

The data from the experiments were subjected to various statistical analyses. The data collected from the incubation study and field experiments were analyzed using analysis of variance techniques (ANOVA) in CRD and RBD. Wherever significant differences between treatments were detected through ANOVA critical differences (CD) are provided for effective comparison of treatments. Correlations with different factors were also done. Path analysis was adopted to study the direct and indirect effects of different fractions of Zn on yield (Singh and Choudhary, 1985).

4. RESULTS

The increasing crop requirements and use of pure forms of high analysis fertilizers have brought micronutrients to the fore front of soil fertility management. Though the total reserve of micronutrients in Kerala soils are considered high, available nutrient status is often very low. Among the micronutrients, Zn deficiency is found widespread in Kerala Soils. Zn is essential for the normal healthy growth and reproduction of plants and animals and when the supply of plant available Zn is inadequate, crop yields are reduced and the quality of crop products is frequently impaired.

In this context, a research programme was initiated to find out the optimum requirement of Zn for fodder maize as evidenced by its yield and quality when supplied to soil as well as foliar application, to observe the pattern of periodic release of Zn from Zn SO_4 and to identify the index plant part for foliar diagnosis in fodder maize cv. African Tall. The results of the study are presented below.

4.1. Incubation study

The incubation experiment was conducted to study the nutrient release pattern of Zn from zinc sulphate under the laboratory conditions. The treatments involved 5 levels of Zn varying from 0-20 $kgha^{-1}$ with and without FYM. The level of FYM applied was 10 t ha^{-1}. The periodic release of DTPA extractable Zn from $ZnSO_4.7H_2O$ is given in Table-4.

Table. 4. Effect of treatments and incubation periods on the availability of Zn (mg kg^{-1})

Treatments	Days of incubation					
	1	15	30	45	60	75
T_1	0.55	0.77	0.32	0.70	0.64	0.41
T_2	0.64	0.89	0.52	0.90	0.87	0.79
T_3	0.79	1.02	0.93	1.00	0.70	0.80
T_4	1.27	1.73	1.79	0.96	1.29	0.86
T_5	1.74	1.17	0.58	1.27	1.56	1.28
T_6	1.33	1.24	1.59	1.76	2.00	0.81
T_7	1.41	1.44	0.65	1.37	1.74	0.85
T_8	1.44	1.43	1.24	1.11	1.03	1.94
T_9	1.06	1.26	1.12	1.13	1.95	2.68
T_{10}	1.47	1.07	1.80	1.37	1.78	1.75
CD	0.27	0.30	0.25	NS	0.17	0.29

On the first day of incubation the highest mean value of Zn 1.74mg kg^{-1} was recorded in T_5 (ie. application of Zn @ 10 kg ha^{-1}) and it was on par with T_{10} . T_1, the control plot released the lowest Zn content.

As the incubation completes 15 days, the highest mean value of Zn 1.73 mgkg^{-1} was released from T_4 (Zn 5 kg ha^{-1} + FYM) and it was on par with T_8, The lowest was from T_1.

The highest mean value of Zn (1.80 mg kg^{-1}) was recorded in T_{10} on the 30th day of incubation study. But this was closely followed by T_4 (Zn 5 kg ha^{-1} + FYM). While the lowest was still observed in the control plot.

On the 45^{th} day of incubation no significant variation in Zn release was observed among the different treatments.

As the incubation entered on the 60^{th} day, the treatment that received Zn@ 10 kg ha^{-1} + FYM (T_6) gave the highest value of 2.00 mg kg^{-1} Zn release and this was on par with T_9 ie, 20 kg Zn applied plot without FYM.

On the 75^{th} day of incubation, the highest value of 2.68 mg kg^{-1} was recorded in T_9 ie, application of Zn @ 20 kg ha^{-1} without FYM, while the lowest value was recorded in the control plot.

4.2. Soil Profile Study

A soil profile has been taken adjacent to the experimental site in Instructional Farm, College of Agriculture, Vellayani, to study the morphological as well as physico-chemical characteristics of the soil.

The representative soil profile was taken up to 2 m depth. Various horizons were identified for the morphological descriptions of the field. Soil samples were collected from the profile based on approved guide lines. Soil colour was recorded under the field moisture conditions using Munsell Soil Colour Chart (Soil survey Staff, USDA, 1998). Soils were tentatively classified in the field itself as per keys to Soil Taxonomy (Soil survey Staff, USDA, 1998)

The soil samples from the different horizons of the soil profile were collected in polythene bags and labelled. They were analysed for physico-chemical and chemical parameters according to standard procedures.

The general description of the soil profile site is given below.

Soil Profile – site descriptions

Location	:	Instructional Farm, College of Agriculture, Vellayani
Latitude	:	$8^0$35' N; Longitude : 70^0 59'E
Altitude	:	25 m above MSL
Village	:	Kalliyoor
Tehsil	:	Nemom
District	:	Thiruvananthapuram
State	:	Kerala
Local name	:	Red loam (Vellayani Series)
USDA	:	Clayey, Isohyperthermic, Typic Kandiustults)
Physiographic unit	:	Mid slope
Geology	:	Charnockite
Parent	:	Weathered charnockite
Topography	:	Slopy
Slope:East West	:	Gradient : 1-3%; Length:0-50 m
Erosion	:	Moderate
Drainage	:	Prominent
Ground water depth	:	>10.0 (m)
Flooding	:	Nil
Salt Alkali	:	Nil
P^H	:	4.5 – 5.5
EC	:	<2.0 d Sm $^{-1}$
Stone size	:	<2.5 cm
Stoniness	:	<3.0 %
Rockout crops	:	Nil
Natural vegetation	:	Cultivated
Crops	:	Fodder
Land use	:	Coconut based mixed farming

4.2.1. Morphological description of soil profile

The morphological characteristics of soil profile are presented in Table. 5

Table. 5 Morphological characteristics of soil profile

Horizon	Depth(cm)	Description
Ap	0-9.5	5 YR 3/4 , sandy loam, few (<1) non-sticky fine to very fine (0-1) non-plastic, crumb massive, Dry friable, many fine pores, Argillian cutans present, fine-medium nodules, fine-to coarse roots, abrupt wavy boundary.
Ac	9.5-25	5 YR 3/4Sandy loam, medium angular blocky, non-sticky, non-plastic medium nodules and gradual smooth boundary.
B_1	25-52	5 YR 4/8, sandy loam, fine to medium, granular, non-sticky, non-plastic friable few pores, gradual smooth boundary few fine roots.
B_2	52-98	5 YR 4/8, sandy loam, fine to medium, pores granular, non-sticky, non-plastic, friable fine to medium roots, sub angular blocky gradual smooth boundary.
Bt_2	98-123	5 YR 4/8, sandy clay, fine to medium pores, slightly sticky slightly plastic, friable, many roots, subangular blocky, gradual smooth boundary.
C_1	123-150+	5 YR 4/8, sandy clay, fine to medium, pores, granular, sub angular blocky, slightly sticky, slightly plastic fine to medium roots

Six horizons viz. Ap 0-9.5 cm; Ac 9.5-25 cm; B, 25-52 cm; B2 52-98 cm Bt2 98-123 cm; and C, 123-150 + cm were identified.

The upper most 2 horizons viz. Ap and Ac had a soil colour of 5 YR ¾, but as the depth increases the colour varied to 5 YR 4/8 till the C_1, layer. The morphological examination revealed the presence of clay at a depth of 98 cm and below. The presence of clay in these horizons made the consistency slightly sticky and slightly plastic in these horizons.

The view of the soil profile taken is presented in Fig.

4.2.2. Physico-chemical parameters of the soil profile

Soil samples were taken from each horizon and analyzed for various physico-chemical properties. The analytical Data is presented in Table-6

Table. 6. Physico- chemical parameters and nutrient content of the soil profile

Depth(cm)	Ap (0-95)	Ac (95-25)	B1 (25-52)	B2 (52-98)	Bt_2 (98-123)	C_1 (123-150 +)
Sand %	79.40	68.80	65.40	66.70	48.90	51.60
Silt %	11.5	16.20	15.90	14.50	10.70	9.01
Clay %	11.6	15.00	18.70	18.80	34.52	36.20
Particle density Mgm^{-3}	2.32	2.28	2.26	2.24	2.31	2.30
Bulk density Mg m^{-3}	1.26	1.24	1.3	1.26	1.27	1.35
Texture	SL	SL	SL	SL	SCL	SCL
pH	5.40	5.30	5.10	4.90	4.70	4.80
EC(d Sm^{-1})	0.12	0.15	0.13	0.12	0.12	0.12
Organic Carbon(%)	0.79	0.68	0.61	0.53	0.43	0.35
Avail. N (kg $ha^{-1)}$	297.11	257.32	261.5	228.4	196.5	164.67
Avail. P (kg ha^{-1})	22.40	18.65	15.33	11.47	9.65	5.34
Avail. K (kg ha^{-1})	84.50	76.70	73.21	76.5	82.85	56.44
Exch. Ca (c mol kg^{-1})	1.42	0.71	0.69	0.62	0.66	0.67
Exch.Mg (c mol kg^{-1})	0.42	0.36	0.32	0.30	0.30	0.28
Avail. S (kg ha^{-1})	11.25	9.42	6.78	6.13	6.03	5.48
DTPA Fe (mg kg^{-1})	20.34	22.36	18.34	27.64	21.59	20.76
DTPA Mn (mg kg^{-1})	9.70	10.20	11.30	14.50	16.80	18.94
DTPA Cu (mg kg^{-1})	0.89	0.92	0.93	0.85	0.88	0.90
DTPA Zn (mg kg^{-1})	0.56	0.52	0.46	0.34	0.57	0.55
Fractions of Zn in the Profile (mg kg^{-1})						
Ws+Ex.- Zn	0.47	0.32	0.05	0.15	0.07	0.01
OB-Zn	1.50	1.30	1.27	1.18	1.15	1.12
MnO-Zn	1.30	2.10	2.00	0.70	0.50	0.23
Am-Fe-O-Zn	23.50	17.40	13.40	13.50	11.90	10.60
Cry-Fe-O-Zn	34.20	24.00	23.10	16.95	14.20	19.60
Res-Zn	24.03	35.88	37.18	39.52	38.18	30.44
Total Zn	85.00	81.00	77.00	72.00	66.00	62.00

The sand percentage decreased from 79.40 in the Ap horizon to 51.60 percentage in the C_1 horizon. The silt content varied from 16.20 (Ac) per cent in the upper horizon to 9.01 per cent in the C_1. The clay content recorded a steady increase from 11.60 per cent in the Ap horizon to 36.20 per cent in the C_1 horizon and the textural class was sandy loam for the upper horizons and sandy clay loam for the lower horizons. The pH decreased as depth increased and the EC recorded a steady rate.

4.2.3. Nutrient content of soil profile

The data on the Table. 5 revealed that the Organic Carbon and other nutrients viz, Avail. N, P, K, Ca, Mg, and S decreased from Ap to C_1 horizon. But the available micronutrients showed a different pattern of distribution. The Mn content showed a steady increase of 9.7 to 18.94 mg kg^{-1} from the upper to lower horizon while Zn was decreased from Ap to B_2 horizon.

Various fractions of the Zn were estimated as Ws+Ex.-Zn, OB- Zn, MnO-Zn, AmFeO- Zn , Cry FeO-Zn , Res--Zn and Total Zn were estimated from different profile samples. All the fractions except MnO- Zn and Res-Zn showed a decrease from upper to lower horizons. The Ws+Ex.-Zn was maximum in the Ap horizon with 0.47 $mgkg^{-1}$ followed by Ac with 0.32 mg kg^{-1} The highest values for OB-Zn was 1.5 mg kg^{-1}. The highest values for FeO bound fractions were 23.50 mg kg^{-1} (AmFeO-Zn) and 34.20 mg kg^{-1}(Cry FeO-Zn) respectively. The RS-Zn was maximum in B1 horizon. The highest value for total Zn was recorded in Ap horizon. The MnO-Zn was 1.30 mg kg^{-1} in the Ap horizon and increased to 2.10 mg kg^{-1} in the Ac horizon, thereafter from B_1 to C_1 it showed a steady decrease in content and the C_1 horizon recorded only 0.23 mg kg^{-1}.

4.3. Initial soil analysis of the experimental site

Surface (0-15 cm) and subsurface (15-30cm) composite soil samples were collected from the experimental field before crop growth. Soil samples were collected and analysed for different physical and chemical parameters and the results are given in Table 6.

Surface and sub-surface samples showed that the experimental area comes under sandy loam texture. The different physico-chemical parameters were decreased in the subsurface soil, except for available P and K. The available P and K were higher in the subsurface soil with the values of 24.3 and 102.7 kg ha^{-1} respectively than that of 22.64 and 88.92 kg ha^{-1} of surface soil.

The various Zn fractions were analyzed as Ws+Ex-Zn, OB-Zn, MnO-Zn, AmFeO-Zn, Cry FeO-Zn, Res-Zn and Total Zn. All the fractions, except MnO bound Zn fraction, were recorded a higher value in the surface soil. But the MnO bound fraction of Zn showed a higher value in the subsurface soil (1.01 mg kg^{-1}) than that of the lower content of 0.80 mg kg^{-1} in the surface soil.

4.4. Field study

The results of the two experimental crops raised as per the treatments outlined in the earlier and the residual crops that have been taken after each experimental crop are presented below.

4.4.1. First field crop

4.4.1.1. Biometric observations

Different Biometric observations viz. Height of the plant, Number of leaves $plant^{-1}$ etc. were recorded, on the 15^{th}, 25^{th}, 35^{th}, 45^{th} Days after sowing and at harvest.

The height in (cm) of fodder maize at different stages of growth is given in Table. 7.

Table 7. Height (cm) of fodder maize at different stages of growth – first crop

Treatments	Stages of sampling				
	15DAS	25DAS	35DAS	45DAS	HVST
T1	13.70	33.37	54.33	78.70	163.73
T2	13.23	21.30	31.70	62.23	129.02
T3	14.00	27.63	46.73	67.86	138.69
T4	16.73	41.80	59.67	87.76	180.90
T5	15.53	32.53	49.60	90.55	152.17
T_6	13.53	27.28	46.37	62.70	158.48
T_7	12.47	30.73	47.00	63.76	149.42
T_8	13.97	35.37	51.37	72.66	151.97
T_9	13.90	29.53	47.56	67.36	156.50
T_{10}	9.53	17.97	24.56	33.46	56.13
CD	NS	3.486	10.588	16.836	22.994

The treatment means for height of the plants were not significant at 15DAS. At 25 DAS, the highest value of 41.80cm was noticed in T_4 and it was found superior to all other values. The lowest value was recorded in T_{10} (17.97cm). At 35DAS the highest value was again recorded in T_4 (59.67cm) and T_1,T_8 and T_5 were found to be on par with values of 54.33, 51.37 and 49.6cm respectively .T_{10} recorded the lowest value of 24.56 cm. In the case of 45DAS, the highest and lowest values were T_5 (90.55cm) and T_{10} (33.46cm). The treatment means of T_4 (87.76cm) and T_1 (78.7cm) were on par toT_5. At the time of harvest, the highest and lowest values were found to be 180.90 cm (T_4) and 56.13 cm for T_{10}. T_1 and T_6 were found on par with T_4.

The mean number of leaves recorded per plant on the 15^{th}, 25^{th}, 35^{th}, 45^{th} DAS and at the time of harvest are given in Table. 8.

Table 8 Mean number of leaves plant^{-1} of fodder maize at different stages of growth – first crop.

Treatments	Number of leaves				
	15DAS	25DAS	35DAS	45DAS	HVST
T_1	4.03	7.10	7.80	10.83	14.44
T_2	4.65	6.72	7.40	11.53	12.86
T_3	5.23	7.70	8.30	10.53	13.76
T_4	4.41	6.50	7.73	11.07	12.72
T_5	4.94	6.83	7.73	10.17	13.83
T_6	4.30	7.23	7.54	11.10	13.90
T_7	4.53	6.75	7.82	9.93	14.07
T_8	4.23	7.23	8.26	10.37	13.2
T_9	4.43	7.23	8.14	9.63	15.13
T_{10}	3.44	4.79	5.17	8.37	9.37
CD	0.705	0.673	0.847	NS	2.846

The highest and lowest mean values (Table. 8) for the number of leaves at 15DAS were recorded as 5.23 (T_3) and 3.44 (T_{10}). T_5, T_2 and T_7 were found on par with T_3. For 25 DAS, the maximum number of leaves were noticed inT_3 (7.70) and the treatments T_1, T_6, T_8 and T_9 were on par with T_3. The highest and lowest mean values obtained for 35DAS were 8.3 and 5.17 in T_3 and T_{10} respectively, while the other treatment means except T_2 and T_{10} were on par. At harvest, the maximum number of leaves was observed in T_9 (15.13) and the lowest in T_{10} (9.37), all other values were found to be on par with T_9.

4.4.1.2. Yield and growth attributes of fodder maize

The various yields and growth attributes viz. green fodder yield, dry fodder yield, dry matter percentage, per day green fodder yield, leaf area index, Leaf stem ratio etc. are recorded in Table. 9.

Table.9. Yield and growth attributes of fodder maize of first crop

Treatments	Green fodder (qha^{-1})	Dry fodder (qha^{-1})	DM (%)	PDGFY (qha^{-1})	LAI	LSR
T_1	408.10	83.02	20.33	6.79	10.63	2.54
T_2	318.30	65.15	20.40	5.30	9.73	1.58
T_3	457.10	89.76	19.63	7.62	11.62	2.61
T_4	512.50	103.92	20.30	8.54	12.97	2.63
T_5	418.40	81.81	19.57	6.97	11.09	2.58
T_6	301.40	59.71	19.83	5.02	9.69	1.58
T_7	366.10	72.86	19.90	6.10	7.51	2.40
T_8	389.30	77.02	19.77	6.48	9.33	*2.29*
T_9	395.10	77.77	19.63	6.58	10.09	2.48
T_{10}	66.40	12.61	19.00	1.10	7.17	1.48
CD	21.31	5.56	NS	0.37	NS	0.47

As seen from the Table.9, the yield and growth attributes were significant for various treatments. The highest GFY and DFY were recorded for T_4, i.e, application of Zn at 10 kg ha $^{-1}$ in addition to POP recommendation and was found superior to all other treatments. The yield T_4 treatment recorded a green fodder of (512.5 q ha $^{-1}$) and dry fodder yield of 103.92 q ha^{-1}. The lowest value was recorded in$T_{10}$with 66.4 q ha^{-1} and 12.61 q ha^{-1} respectively for GF and DF yield.

The per day green fodder yield (PDGFY) recorded the highest value of 8.54 q ha^{-1} and lowest value of 1.10 q ha^{-1} respectively for T_4 and T_{10}. T_4 was found superior to all. The treatment means for LAI was not found significant. Even though not significant, the maximum LAI of (12.97) obtained treatment ie., T_4 recorded the maximum green fodder yield.

The highest LSR was noted in T_4 (2.63) and the lowest value of (1.48) in T_{10}. T_4 was found superior to all other treatments. All other values except T_2, T_6 and T_{10} were found on par.

4.4.1.3. Quality attributes of fodder maize of first crop

The quality attributes viz. crude protein per cent, crude protein yield and crude fibre per cent are given below.

Table. 10. Quality parameters of fodder maize – first crop

Treatments	CP (%)	CPY (kg ha^{-1})	CF (%)
T_1	9.89	821	23.80
T_2	9.94	648	24.33
T_3	10.16	911	24.40
T_4	10.93	1136	23.70
T_5	10.19	833	23.76
T_6	9.23	551	26.63
T_7	8.78	639	25.96
T_8	9.00	693	25.63
T_9	9.16	712	23.10
T_{10}	6.57	216	29.40
CD	0.61	147	1.00

Regarding the quality aspects (Table.10), maximum CP content and CPY were recorded in T_4 with values of 10.93 percent and 1136 kg ha^{-1} and the lowest crude fibre was obtained in T_9 (23.1 percent). Even though T_9 showed the lowest crude fibre percentage of 23.1 per cent, it was on par with T_4. The lowest CP per cent CPY and maximum CF per cent were recorded in T_{10} with respective values of 6.57 per cent, 216 kg ha^{-1} and 29.4 per cent respectively.

The next higher values for CP was recorded for T_5 (10.19 percent), T_5 recorded a comparable crude fibre content with T_4 i.e., 23.76 per cent for T_5 and 23.70 per cent for T_4. This showed that T_4 (POP+Zn @10 kg ha^{-1}) was the best treatment followed by T_5 (POP+Zn @10 kg ha^{-1}).

4.4.1.4. Nutrient content in fodder maize.

After the harvest of the 1st crop the plant samples collected were processed and analyzed for the nutrient concentration and the results are given in Table. 11.

Table 11 Nutrient concentration in the fodder maize –first crop

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})
T_1	1.58	0.14	1.33	0.19	0.12	0.12	89.30	23.33	41.67	13.33
T_2	1.59	0.17	1.56	0.22	0.12	0.13	73.00	28.00	45.67	13.00
T_3	1.63	0.27	1.77	0.27	0.12	0.15	113.30	33.00	63.67	16.33
T_4	1.75	0.26	2.16	0.29	0.15	0.15	116.00	35.00	68.33	17.00
T_5	1.57	0.20	1.90	0.34	0.16	0.14	119.70	34.67	63.00	17.00
T_6	1.48	0.15	1.86	0.26	0.13	0.17	103.70	32.33	61.33	15.00
T_7	1.41	0.18	1.70	0.22	0.13	0.13	89.00	30.67	49.33	14.33
T_8	1.44	0.19	1.76	0.24	0.12	0.13	84.00	29.67	52.33	13.65
T_9	1.47	0.19	1.77	0.21	0.11	0.13	85.00	28.00	56.00	16.00
T_{10}	1.05	0.10	0.99	0.10	0.07	0.11	90.70	17..67	19.00	11.67
CD	0.064	0.031	0.99	0.024	0.02	0.01	9.68	3.748	4.006	1.805

Data presented in the Table .11 revealed that the nutrient concentrations in fodder maize for different treatments were found significant. The highest value for N was obtained in T_4 with 1.75 per cent and it was found superior to all other treatment mean values, while the lowest was recorded in T_{10} (1.05 per cent). For the P content, maximum mean value of 0.27 percent was observed in T_3 and T_4 (0.26 per cent) was found to be on par with T_3. The lowest was noted in T_{10} with a men value of 0.10 per cent. The highest value of 2.16 per cent K was observed in T_4 and all other values were on par except T_{10} (0.99 per cent) and T_1 (1.23 per cent).

Maximum content of Ca was 0.34 per cent in T_5 while the lowest value was observed in T_{10}. For Mg content, T_5 recorded the highest value of 0.16 per cent and T_4 (0.15 per cent) was on par while lowest value was noticed in T_{10} (0.07 per cent). The highest S concentration was 0.17 per cent in T_6 which was found to be the superior to all other treatment values. T_{10} recorded the lowest (0.11 per cent) value.

The Fe content was highest in T_5 (119.7 mg kg^{-1}) and T_4 (116.0 mg kg^{-1}) and T_3 (113.3 mg kg^{-1}) was found to be on par with T_5. The lowest value was recorded in T_2 (73 mg kg^{-1}). For Mn, T_4 (35 mg kg^{-1}) recorded the highest mean value and lowest value of (17.67 $mgkg^{-1}$) was observed in T_{10}. T_5, T_3 and T_6 were found to be on par with T_5 with values of 34.67, 33.00, 32.33 mg kg $^{-1}$ respectively.

The maximum content was observed in T_4 (68.33 mg kg^{-1}), and it was found significantly different from other mean values. The lowest value was recorded in T_{10} (19.00 mg kg^{-1}). The highest value for Cu was observed in T_4 and T_5 with a mean value of 17.00 $mgkg^{-1}$, but T_3 and T_9 were found to be on par with T_4 and the lowest value of 11.67 $mgkg^{-1}$ was given by T_{10}.

4.4.15. Nutrient uptake

Table.12. Nutrient uptake studies of the first crop ($kgha^{-1}$)

Treatments	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
T_1	131.50	11.37	113.4	15.75	9.94	9.81	0.73	0.19	0.35	0.11
T_2	103.70	10.91	103.8	14.06	7.60	8.34	0.48	0.18	0.30	0.09
T_3	146.00	23.80	142.2	24.26	11.05	13.88	1.02	0.28	0.57	0.14
T_4	181.80	24.91	224.7	31.15	15.61	14.64	1.20	0.36	0.71	0.18
T_5	128.40	16.36	155.5	30.14	13.09	11.8	0.98	0.28	0.52	0.13
T_6	88.20	12.54	111.2	10.21	8.23	9.91	0.70	0.19	0.37	0.10
T_7	102.40	13.09	123.6	16.26	9.71	10.89	0.65	0.21	0.36	0.10
T_8	77.50	14.34	135.7	18.23	9.25	10.14	0.67	0.23	0.40	0.10
T_9	114.00	14.78	137.3	15.99	8.80	10.44	0.66	0.22	0.44	0.12
T_{10}	13.20	1.26	12.5	1.26	0.92	1.35	0.11	0.02	0.02	0.01
CD	30.78	3.407	15.97	3.063	1.962	1.568	0.125	0.025	0.043	0.021

Data in the Table.12 revealed that the uptake of different nutrients were significant. For the uptake of N, maximum value was obtained in T_4 (181.80 kg ha^{-1}) which was found to be superior and the lowest value of 13.20 (kg ha^{-1}) was observed in T_{10} . For the P uptake, highest value was observed in T_4 24.91(kg ha^{-1}) and T_3 (23.80 kgha^{-1}) was found to be on par. The lowest value of 1.26 kg $ha^{-1}$was noted inT_{10}.Maximum value for K uptake was noticed in T_4 224.7(kg ha^{-1}) and found significantly superior to all other treatments, while the lowest value (12.5 kgha^{-1}) was noticed in T_{10}.

For the uptake of Ca, the highest value of 31.15 kg ha^{-1} was observed inT_4, while T_5 (30.14 kgha^{-1}) was found on par with T_4 and T_{10} recorded the lowest value (0.92 kgha^{-1}). For Mg uptake, T_4 recorded highest (15.61kgha^{-1}) and was superior when compared with other treatment means.T_{10} recorded the lowest value of (1.35 kgha^{-1}). The highest value for Mg uptake was found in T_4 (14.64 kgha^{-1}) and found superior to all other treatments. The lowest value was in T_{10} (1.35kgha^{-1}). For the S uptake, maximum value was recorded in T_4 (14.64 kgha^{-1}) and it was on par with T_3 with a value of 13.88 kgha^{-1} .The control plot recorded the lowest value.

The highest value of Fe uptake was noticed in T_4 (1.20 kgha^{-1}) while it was on par with T_3 (1.02 kgha^{-1}). For the uptake of Mn, there were significant differences among the treatments. T_4 recorded the highest value of 0.36 kg ha^{-1} and was found to be superior. Maximum uptake of Zn and Cu was obtained in T_4 with values of 0.71 kgha^{-1} and 0.18 kgha^{-1} respectively and found significantly different from all other mean values. T_{10} recorded the lowest value for all micronutrient uptake.

4.4.1.6. Physico-chemical properties and primary nutrient concentration in the surface soil after the first crop

Surface soil samples (0-15 cm) were collected from each plot after the 1st crop growth and analyzed for different physico-chemical parameters and primary nutrient elements and the data are presented in Table-13.

Table 13 Physico-chemical parameters and primary nutrients content of subsurface soil after the first crop

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Treatments	pH	EC (dSm^1)	Organic Carbon (%)	Av .N $kgha^{-1}$	Av. P $kgha^{-1}$	Av.K kg ha^{-1}
T_1	5.0	0.11	0.75	187.6	14.09	145.67
T_2	4.8	0.14	1.06	221	12.02	133
T_3	5.0	0.12	0.79	218.4	16.57	183.73
T_4	4.9	0.10	1.12	224.60	13.29	204.3
T_5	5.0	0.11	0.7	208.82	12.35	172.67
T_6	4.9	0.11	0.82	216.60	10.83	108.93
T_7	5.0	0.12	0.76	200.77	12.13	177.46
T_8	5.0	0.14	0.84	214.73	12.32	179.77
T_9	4.9	0.10	0.98	205.03	13.81	186.84
T_{10}	4.8	0.12	0.58	89.4	4.95	69.00
CD	NS	NS	NS	21.66	1.661	9.132

Data presented in the Table 13 showed that treatment effects were significant except for, P^H, EC and organic carbon. The highest value of available N was observed in T_4 with 224.60 kg ha^{-1} which was on par with T_2 (221.0 kg ha^{-1}), T_3 (218.4 $kgha^{-1}$) T_6 (216.60 kg ha^{-1}), T_8 (214.73 kg ha^{-1}), T_5 (208.82 kg ha^{-1}) and T_9 (205.03 kg ha-^{1}) respectively. The lowest value was noticed in T_{10} (89.4 kg ha^{-1}). For available P, maximum was noted in T_3 (16.57 $kgha^{-1}$) which was found to be superior and T_{10} recorded the lowest (4.95 $kgha^{-1}$). The highest value of available K was 204.3 $kgha^{-1}$ (T_4) and was found superior to all other treatments, while the lowest value of 69.00 $kgha^{-1}$ was recorded in T_{10}.

4.4.1.7. Secondary and micro nutrient content in the surface soil after the first crop

. The surface soil (0-15 cm) samples collected from each plot, after the harvest of the 1^{st} crop were analyzed for the secondary and micronutrient contents and the data is presented in Table 14.

Table -14 Secondary and micronutrient contents of subsurface soil after the first

Treatments	Ca (c mol kg^{-1})	Ex Mg (c mol kg^{-1})	Av. S ($kgha^{-1}$)	DTPA Fe ($mgkg^{-1}$)	DTPA Mn ($mgkg^{-1}$)	DTPA Zn ($mgkg^{-1}$)	DTPA Cu ($mgkg^{-1}$)
T_1	1.29	0.48	9.26	18.03	3.29	2.92	0.82
T_2	1.3	0.46	11.11	14.62	2.3	2.32	0.5
T_3	1.28	0.51	11.88	22.37	4.53	3.69	0.61
T_4	1.27	0.52	12.1	19.80	3.61	4.89	0.65
T_5	1.26	0.48	12.88	18.85	3.86	4.66	0.61
T_6	1.15	0.43	9.78	14	2.66	2.38	0.32
T_7	1.25	0.38	11.35	18	4.06	2.72	0.46
T_8	1.22	0.37	11.58	17.20	3.93	2.64	0.47
T_9	1.23	0.38	11.54	18.51	4.94	2.59	0.49
T_{10}	1.07	0.35	6.05	15.80	0.77	0.77	0.21
CD	0.070	0.034	2.106	5.03	0.544	0.194	0.08

The maximum and minimum value for Exch. Ca was in T_2 (1.30 c mol kg^{-1}) and T_{10} (1.07 c mol kg^{-1}). While T_1, T_3, T_4, T_5, T_7 and T_9 were on par with T_2. The value of 1.07 c mol kg^{-1} was noted as the lowest (T_{10}). The highest value of Exch. Mg was noted in T_4 (0.52 cmol kg^{-1}) followed by T_3 (0.51c mol kg^{-1}) and the lowest value of was recorded in T_{10} (0.35c mol kg^{-1}). The available S was maximum in T_5 (12.88 $kgha^{-1}$) and T_4 (12.1 $kgha^{-1}$), T_3 (11.88 $kgha^{-1}$), T_8(11.58 $kgha^{-1}$), T_9 (11.54 $kgha^{-1}$) T_7 (11.35 $kgha^{-1}$), T_2(11.11 $kgha^{-1}$) were found to be on par with T_5. But lowest was 6.05 $kgha^{-1}$ in T_{10}.

For the DTPA extractable Fe, the highest value of 22.37 mg kg^{-1} (T_3) was superior to all other treatments except T_{10} and T_2 and T_6. The highest value for DTPA extractable Mn was 4.94 mg kg^{-1}(T_9) and it was found on par with T_3. The highest and lowest for DTPA extractable Zn was in T_4 and T_{10} and the corresponding values were 4.89 mg kg^{-1} and 0.77 mg kg^{-1} respectively. The highest mean value of 0.82 mg kg^{-1} was noticed in T_1 for DTPA extractable Cu, while the lowest was found in T_{10} with 0.21 mg kg^{-1}. T_1 was found superior to all other values.

4.4.1.8.Zn fraction of surface soil after the first crop

The surface soil samples collected from each plot were analyzed for different fractions of Zn and the data is given in Table-15.

Table 15. Fraction of Zinc (mg kg^{-1}) in the surface soil after the first crop

Treatments	Ws+Ex.	OB Zn	Mn O Zn	Am FeOZn	Cry FeO Zn	Res Zn	Total
T_1	3.75 (3.34)	2.3 (2.05)	0.88 (0.78)	21.82 (19.48)	42.64 (38.07)	40.61 (36.28)	112
T_2	1.34 (1.14)	2.92 (2.50)	0.68 (0.58)	45.00 (38.46)	37.85 (32.40)	29.21 (24.92)	117
T_3	4.31 (2.89)	2.11 (1.42)	0.96 (0.64)	25.27 (16.95)	75.94 (50.96)	40.41 (27 .14)	149
T_4	4.36 (3.57)	2.41 (1.98)	1.01 (0.83)	27.01 (22.14)	55.61 (45.58)	31.35 (23.58)	122
T_5	5.43 (4.08)	2.21 (1.66)	0.61 (0.46)	23.40 (17.59)	70.00 (52.63)	31.35 (23.58)	133
T_6	1.54 (1.39)	3.84 (3.46)	1.14 (0.55)	26.14 (23.55)	24.51 (22.08)	53.83 (48.49))	111
T_7	2.76 (2.67)	2.52 (2.44)	0.43 (0.42)	27.00 (26.21)	21.54 (20.91)	48.75 (47.33)	103
T_8	2.87 (2.73)	2.14 (2.04)	0.44 (0.42)	40.91 (38.96)	35.38 (33.70)	23.26 (22.15)	105
T_9	5.91 (4.02)	2.01 (1.37)	0.36 (0.25)	36.75 (25.00)	90.33 (61.45)	11.64 (7.92)	147
T_{10}	0.30 (0.34)	3.38 (3.89)	0.10 (0.11)	16.64 (19.13)	43.91 (50.47)	22.67 (26.06)	87
CD	0.204	0.564	0.082	4.19	10.58	6.67	14.19

The values in parenthesis are the percentage content of the individual fractions to Total Zinc.

The Ws+Ex-Zn was maximum in T_9 (5.91mg kg^{-1}) and it was found significantly different from other values .The lowest value was obtained in the control (0.3 mg kg^{-1}). The highest value for OB fraction of Zn was in T_6 (3.84 mg kg^{-1}), but it was on par with T_{10} (3 ·38 mg kg^{-1}) and the lowest was recorded in T_9 (2.01 mg kg^{-1}). For the Am FeO bound fraction, the highest value was noted in

T_2(45 mg kg^{-1}) and it was on par with T_8(40.91 mg kg^{-1}) while the control recorded the lowest. The highest and lowest values for CryFeO content of Zn was T_9 and T_7 with mean values of 90.33 and 21.54 mg kg^{-1} respectively and also T_9 was found superior. The residual Zn was highest in T_6 (53.83 mg kg^{-1}) and was on par with T_7. With a mean value of 48.75 mg kg^{-1}. The highest value for total Zn was seen in T_3 (149 mgkg^{-1}) and T_9 (147 mg kg^{-1}) was on par with T_3. The control denoted the lowest value of 87 mg kg^{-1}.

4.4.1.9 . Physico-chemical properties and primary nutrient concentration in the subsurface soil after the crop growth in first crop

Soil surface soil samples (15-30 cm) were collected from each plot after the first crop period and analyzed for different physico-chemical parameters and primary nutrient elements and the data is presented in Table-16.

Table 16. Physico-chemical properties and nutrient content in the surface soil after the first crop

Treatments	P^H	EC (dSm^{-1})	Organic carbon (%)	Av. N kgha^{-1}	Av .P kgha^{-1}	Av . K kgha^{-1}
T_1	5.3	0.11	0.4	149.06	5.45	150.66
T_2	5.4	0.12	0.78	108.97	5.71	192.26
T_3	5.5	0.11	0.58	175.07	2.56	182.16
T_4	5.3	0.11	0.91	213.43	2.78	174.53
T_5	5.3	0.09	0.66	141.37	2.26	160.13
T_6	5.5	0.08	0.52	191.77	5.82	165.1
T_7	5.6	0.07	0.38	159.23	5.25	182.03
T_8	5.5	0.11	0.62	197.83	4.27	165.5
T_9	5.3	0.12	0.57	158.87	3.21	103.23
T_{10}	5.4	0.11	0.37	75.17	1.55	57.17
CD	0.305	NS	NS	48.565	2.510	18.802

The data (Table. 16) on pH, EC and OC per cent were found to be non-significant. .The highest and lowest value of available N was observed in T_4 (213.43 kg ha^{-1}) and T_{10} (75.17 kg ha^{-1}). The values of T_8 (197.83 kg ha^{-1}), T_6 (191.77 kg ha^{-1}) and T_3 (175.07 kg ha^{-1}) were found on par with T_4.The maximum value of available P was recorded in T_6 with 5.82 kg ha^{-1} and was found on par with T_2 (5.71 kg ha^{-1}), T_8 (4.27 kg ha^{-1}) and T_1. The lowest was found in T_{10} (1.55 kgha^{-1}). in T_3 and it was found to be superior to all other treatment means and the lowest was found in T_{10}. The highest value of 192.26 kg ha-1 for available K was found in T_2 and it was superior to all others.

4.4.1.10. Secondary and micronutrient contents in the subsurface soil after crop growth first crop

The sub-surface (15-30 cm) soil samples collected from each plot after the harvest of the first crop were analyzed for the secondary and micronutrient content and the data is presented in Table 17.

Table. 17 Secondary and micronutrient contents of subsurface soil after the first crop

Treatments	Ex. Ca (c mol kg^{-1})	Ex .Mg (c mol kg^{-1})	Avail. S (kgha^{-1})	DTPA Fe (mgkg^{-1})	DTPA Mn (mgkg^{-1})	DTPA Zn (mgkg^{-1})	DTPA Cu (mgkg^{-1})
T_1	0.97	0.38	11.22	15.50	2.17	2.35	0.71
T_2	0.92	0.41	7.43	14.47	2.79	2.27	0.71
T_3	1.07	0.35	11.52	12.30	3.24	3.22	0.56
T_4	1.02	0.42	11.61	15.83	2.44	3.88	0.71
T_5	1.01	0.46	11.98	15.40	3.01	3.28	0.76
T_6	0.70	0.43	10.26	13.13	2.82	2.18	0.41
T_7	0.89	0.39	10.33	12.60	2.71	2.33	0.39
T_8	0.77	0.35	10.42	5.00	2.87	2.14	0.48
T_9	0.77	0.38	11.07	8.37	3.58	2.26	0.47
T_{10}	0.64	0.33	3.72	12.37	3.01	0.61	0.44
CD	0.128	0.037	1.767	4.759	NS	0.252	0.139

The highest and lowest value of exchangeable Ca was noticed in T_3 with the values of 1.07 c mol kg $^{-1}$ and 0.640 c mol kg^{-1} in T_{10} and T_4 and T_5 were found to be on par with T_3. The highest mean value for exchangeable Mg was found to be in T_5 (0.46c mol kg^{-1}) while it was on par with T_6 and T_4 with the respective values of 0.43 and 0.42 c mol kg^{-1} respectively. T_{10} (0.33 c mol kg^{-1}) recorded the lowest. The maximum value for available S was noted in T_5 with a value of 11.98 kg ha^{-1} and T4, T_3, T_1, T_9, T_8, T_7 and T_6 were found on par with T_5.

The highest values of DTPA Fe was found in T_4 (15.83mg kg^{-1}) and T_1 (15.50 mg kg^{-1}), T_5(15.40mg kg^{-1}), T_2(14.47mg kg^{-1}), T_6(13.13mg kg^{-1}),T_7(12.60mg kg^{-1})and T_{10}(12.37mg kg^{-1}) were found on par with T_4. The lowest was obtained in T_8 (5.mg kg^{-1}).

For the DTPA extractable Zn, the highest and lowest values were 3.30 and 0.61mg kg^{-1} respectively for T_4 and T_{10}. However the values of 3.28 (T_5), 3.22(T_3) and 3.00 mg kg^{-1} in T_9 found to be on par. The highest value for Cu was recorded in T_5 (0.76 mg kg^{-1}) and it was found on par withT_1, T_2 and T_4 while the lowest was observed in T_7 (0.39 mgkg^{-1}).

4.4.1.11. Zn fractionation of subsurface soil after the first crop

The sub-surface soil samples collected from each plot were analyzed for different fractions of Zn and the data is presented in Table. 18. The values in parentheses are the percentage content of the individual fraction to Total Zn.

Table. 18 Different fractions of Zn in the sub surface soil after the first crop (mg kg^{-1})

Treatments	WS+EX.-Zn	OB-Zn	MnO-Zn	Am Fe-Zn	Cry Fe-Zn	Res-Zn	Total-Zn
T1	0.72 (2.23)	0.61 (2.25)	0.92 (0.98)	26.4 (13.58)	34. 21 (57.63)	35.14 (23.33)	98
T2	1.01 (1.35)	1.83 (2.36)	0.43 (0.98)	32.73 (17.81)	40.33 (25.51)	14.67 (52)	91
T3	0.85 (0.69)	1.44 (2.09)	1.01 (1.47)	14.52 (21.16)	36.56 (29.72)	68.62 (55.78)	123
T4	1.17 (0.83)	1.84 (1.16)	1.47 (1.02)	25.8 (20.69)	33.66 (37.50)	39.06 (38.79)	103
T5	2.1 (1.13)	0.79 (0.80)	1.18 (1.03)	20.5 (28.72)	69.63 (33.34)	32.8 (34.98)	127
T6	1.24 (2.59)	2.18 (1.39)	0.61 (1.43)	34.5 (24.34)	33.43 (45.95)	24.04 (24.39)	96
T7	1.83 (1.88)	1.35 (1.39)	0.87 (0.89)	21.43 (22.09)	43.65 (45.00)	27.87 (28.73)	97
T8	1.55 (2.30)	1.44 (1.86)	0.64 (1.70)	17.95 (19.50)	30.7 (58.69)	41.72 (19.19)	94
T9	1.73 (1.58)	1.22 (0.99)	0.43 (1.07)	16.17 (30.24)	35.36 (36.78)	57.09 (29.34)	112
T10	0.073 (0.11)	0.24 (0.36)	0.28 (0.42)	10.88 (16.49)	31.81 (48.19)	22.72 (34.40)	66
CD	0.134	0.161	0.112	5.106	2.454	4.75	20.3

The values in parenthesis are the percentage content of the individual fractions to Total Zinc.

The highest value obtained for the Ws+Ex. content of Zn, was in T_5 (2.1 mg kg^{-1}) and it was found superior to all other treatments, while the lowest mean was recorded in T_{10}.The highest value for OB fraction was noticed in T6 with a mean value of 2.18 mg kg^{-1} and the lowest was noted in the control(0.24 mg kg^{-1}). For the

Mn O bound Zn was highest in T_4(1.47 mg kg^{-1}) while the lowest was obtained in the control. The Am Feo was highest in T_6 and T_2 was found to be on par. The lowest value of 10.88 mg kg^{-1} was obtained in T_{10}. The highest mean value of Cry Feo-Zn was obtained T_5 (69.63 mg kg^{-1}) and it was found superior to all others. the control recorded the lowest .The Res-Zn content was found to be maximum in T3 (68.62 mg kg^{-1}) and it was significantly different from other treatment means, while T_2 (14.67 mg kg^{-1}) recorded the lowest mean value.T_5 recorded the highest value for total Zn (127 mg kg^{-1}) and T_3 and T_9 were on par to T_5 with the values of 123 and 112 mg kg^{-1} respectively. The lowest mean value was noted in T_{10} (66 mg kg^{-1})

4.4.2. First residual crop

A residual crop has been raised after the 1st experimental crop without adding any of the manures or fertilizers and harvested. The green fodder yield and dry fodder yield of the crop is given in Table.19.

Table 19. Green fodder and Dry fodder yield of the first residual crop

Treatments	GFY(q ha^{-1})	DFY(q ha^{-1})
T1	10.32	2.06
T2	14.96	2.89
T3	15.67	3.06
T4	10.32	2.05
T5	34.65	6.86
T6	13.21	2.59
T7	26.62	4.08
T8	20.68	4.24
T9	10.54	2.16
T10	7.61	1.78
CD	6.618	0.457

The residual crop was raised after the harvest of first crop without applying any manures or fertilizer to know the residual impact of nutrients supplied in the first crop season to the yield. The data showed that T_5 (Zn applied at 15 kgha^{-1}) along with POP recommendation of 120: 60:40 NPK kgha-1 and FYM 10tha^{-1} gave the maximum yield of 34.65 qha^{-1} of GFY, while the application of the highest doze of Zn(20 $kgha^{-1}$) along with POP recorded only a lower value for GFY (13.21qha^{-1}).

4.4.2..1 Total and DTPA extractable Zn after the crop growth first residual crop

Soil samples both surface and subsurface, were collected from each experimental plot after the harvest of the first residual crop and analyzed for Total and DTPH extractable Zn and presented in Table 20.

Table.20. Total and DTPA extractable Zn in the surface and sub surface soil after first residual crop (mg kg^{-1})

Treatments	DTPA Zn surface (mg kg^{-1})	DTPA Zn Subsurface (mg kg^{-1})	Total Zn Surface (mg kg^{-1})	Total Zn Subsurface (mg kg^{-1})
T1	1.03	0.69	41.29	31.9
T2	0.93	0.87	50.73	25.3
T3	1.33	0.79	54.2	27.93
T4	2.06	1.12	48.83	26.07
T5	1.71	1.31	48.13	33.78
T6	1.17	0.98	45.93	43.25
T7	0.97	0.63	37.33	31.07
T8	0.99	0.82	36.67	33.23
T9	1.07	0.84	33.57	28.00
T10	0.56	0.51	38.3	28.83
CD	0.13	0.109	13.07	NS

The treatment means were significantly differ among themselves except for total Zn in the subsurface soil. For the DTPA extractable Zn in the surface and subsurface soil .T_4 and T_5 recorded the highest value of 2.06 and 1.31 mg kg^{-1} respectively. In the surface soil the highest value for total Zn was in T_3 (54.2 mg kg^{-1}) while T_2, T_4, T_5 and T_6 were found to be on par. The highest and lowest value for total Zn was 43.25 (T_6) and 25.3 mgkg^{-1} (T_2) for subsurface soil.

4.4.3 Second field crop

4.4.3.1 Biometric observations

Different biometric observations viz. Height of the plant no. of leaves per plant etc. were recorded, on the 15th, 25th, 35th, 45th days after sowing and at harvest.

Table. 21 . Height (cm) of fodder maize at different stages of growth – second crop

Treatment	Height(cm)				
	15DAS	25DAS	35DAS	45DAS	HVST
T1	4.90	20.17	46.40	114.50	133.40
T2	5.34	19.57	41.50	104.90	119.00
T3	6.00	21.30	50.27	113.90	133.80
T4	5.53	17.40	33.60	123.70	139.20
T5	4.56	16.83	34.20	94.20	137.90
T6	5.47	16.73	36.20	119.70	136.30
T7	5.24	19.78	36.70	93.70	108.80
T8	4.18	15.10	32.90	104.70	117.80
T9	4.20	16.94	27.50	93.00	111.20
T10	1.90	9.00	18.20	26.20	37.40
CD	1.386	2.767	4.435	14.684	12.280

Data presented in Table.21 showed that the height of fodder maize at different stages of growth were significant. At 15 DAS, the highest mean value was observed in T_3 (6 cm) while T_4, T_2 and T_1 were on par. The lowest value was in T_{10}. At 25 DAS, maximum height was in T_3 (21.30 cm) while T_1 (20.17 cm) T_7 (19.78 cm) and T_2 (19.57 cm) were found to be on par with T_3. T_{10} recorded the lowest value of 9 cm at 25 DAS. At 35 DAS, highest mean value of 50.27 cm was found in T_3 and it was on par with T_1 (46.40 cm). However T_{10} recorded the lowest. In the case of 45 DAS, the highest mean value of 123.70 cm was noticed in T_4 and it was on par with T_6, T_1 and T_3. While the lowest was noted in T_{10} (26.20 cm). At the time of harvest, T_4 recorded the highest value of 139.20 cm, and T_5, T_6, T_3 and T_1 were found to be on par and lowest value was recorded in T_{10}.

The mean number of leaves recorded plant^{-1} on the 15th, 25th, 35th, 45th DAS and at the time of harvest are given in Table-22.

Table-22 Mean number of leaves plant $^{-1}$of fodder maize at different stages of growth

Treatments	Number of leaves				
	15DAS	25DAS	35DAS	45DAS	HVST
T1	4.50	8.15	8.80	10.86	11.30
T2	4.97	7.40	8.63	10.33	11.93
T3	4.93	7.20	8.47	11.60	12.63
T4	5.14	6.80	8.50	10.53	12.13
T5	4.59	6.70	8.43	10.76	11.87
T6	4.37	6.50	8.30	9.51	11.53
T7	4.73	7.20	7.90	10.70	11.36
T8	4.20	5.97	7.13	11.30	11.00
T9	4.04	7.07	8.20	11.30	10.63
T10	2.95	4.17	7.60	8.0	10.37
CD	0.742	1.124	NS	1.716	NS

The data presented in Table.22 showed that the number of leaves at different growth stages except 35 DAS and at harvest were found to be significant. At 15 DAS, the highest mean value of 5.14 was recorded inT_4 and T_2, T_3, T_7, T_6 and T_1 were found on par with T_4. The observation taken after 25 DAS showed T_1 as the maximum leaf produced treatment. The number of leaves 35 DAS and at harvest were found to be non significant. At 45 DAS T_8 and T_9 ie., the Zn foliar application received treatments on the 13th DAS, produced the maximum number of leaves, next to T_3.

3.4.3.2. Yield and yield attributes of fodder maize attributes viz. green fodder yield, dry fodder yield, dry matter percentage, per day green fodder yield, leaf area index, leaf stem ratio etc. were recorded in Table-23.

Table-23 Yield and yield attributes of fodder maize - second crop

Treatments	Green fodder (qha^{-1})	Dry Fodder (qha^{-1})	DM (%)	PDGF (qha^{-1})	LAI	LSR
T1	170.40	45.47	18.43	3.97	7.97	1.79
T2	374.10	74.45	19.87	6.79	8.03	1.86
T3	348.70	74.82	21.47	6.33	7.73	1.79
T4	416.70	83.78	20.80	7.57	8.21	1.94
T5	519.30	108.05	20.77	9.44	8.31	2.48
T6	465.40	93.67	20.10	8.46	8.23	2.31
T7	385.00	77.09	20.03	7.00	7.68	1.92
T8	418.70	82.61	19.70	7.61	7.71	1.90
T9	441.60	86.97	19.67	8.03	8.22	1.94
T10	142.50	22.59	15.87	2.59	5.01	1.49
CD	69.850	5.795	1.221	0.671	0.665	NS

Data presented in Table-23 revealed that the yield and yield attributes of second crop were significant except for LSR. The GFY was maximum in T_5 (soil application of Zn @ 15 $kgha^{-1}$ +POP) with a value of 519.3 qha^{-1} and T_6 was found on par with an yield of 465.4 $qha^{-1.}$ The lowest GFY was recorded in T_{10} with 142.5 q ha^{-1}. In the case of DFY, T_5 recorded the highest value of 108.05 and T_{10} observed the lowest (22.59 qha^{-1}). T_5 was found to be superior over other mean values.

T_3 recorded the maximum dry matter content which was on par with T_4 and T_5. The values were 21.47, 20.80 and 20.77 per cent respectively. While the lowest was recorded in T_{10} (15.87 per cent). For the PDGFY, T_5 recorded the highest (9.44 qha^{-1}) while T_{10} observed the lowest value of 2.59 qha^{-1}. T_5 found significantly superior to all other values. For LAI the highest value was found to be in T_5 (8.31) and all other treatment means except T_{10} were found to be on par. As in the case of

1st crop for the 2nd crop too, the maximum LAI recorded treatment had given the maximum green fodder yield. The leaf stem ratio was found to be non-significant among treatments.

4.4.3.3 Quality attributes of fodder maize of second crop

The quality attributes viz. crude protein per cent, crude protein yield and crude fibre per cent are given in Table-24

Table-24 Quality attributes of fodder maize of second crop

Treatments	CP (%)	CPY (kg ha^{-1})	CF (%)
T1	9.52	433	27.94
T2	10.06	749	23.43
T3	10.23	766	26.1
T4	9.78	818	25.46
T5	10.08	1090	24.23
T6	10.14	949	23.93
T7	9.46	730	25.6
T8	9.52	787	24.3
T9	9.67	841	24.1
T10	6.50	147	29.73
CD	0.452	826	0.846

The data in Table.24 revealed that the highest CP content was observed in T_3 (10.23 per cent) and T_6, T_5, T_2, and T_4 were found to be on par with values of 10.14, 10.08, 10.06 and 9.78 respectively. In the case of CPY, it was maximum in T_5 (1090 kg ha^{-1}) and it was found significantly different from all other mean values. The lowest CF was obtained in T_2 (23.43 per cent).

4.4.3.4. Nutrient content in fodder maize – Second crop

After the harvest of the 2nd crop the plant samples collected were processed and analyzed for the nutrient concentration and the results are given in Table-25.

Table.25. Nutrient concentration in the fodder maize – second crop

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe ($mgkg^{-1}$)	Mn ($mgkg^{-1}$)	Zn ($mgkg^{-1}$)	Cu ($mgkg^{-1}$)
T1	1.52	0.12	1.33	0.26	0.14	0.13	109.0	41.67	56.33	12.33
T2	1.61	0.21	1.6	0.32	0.19	0.17	128.3	45.67	61.67	15.00
T3	1.67	0.18	1.76	0.24	0.13	0.16	108.7	39.33	66.00	14.00
T4	1.56	0.25	1.83	0.31	0.21	0.16	96.0	36.00	75.00	13.00
T5	1.61	0.21	2.18	0.35	0.17	0.15	97.3	34.67	89.00	12.67
T6	1.62	0.20	1.50	0.41	0.18	0.14	98.0	32.67	84.00	12.67
T7	1.51	0.18	0.84	0.25	0.14	0.15	119.3	34.00	85.67	12.67
T8	1.52	0.19	0.87	0.28	0.16	0.15	116.0	32.67	86.33	13.00
T9	1.55	0.20	0.90	0.29	0.17	0.16	117.7	35.00	90.33	13.33
T10	1.04	0.08	0.76	0.10	0.09	0.11	102.7	28.67	29.33	10.33
CD	0.072	0.020	0.170	0.241	0.019	0.004	15.480	5.353	5.220	1.502

The data from the Table. 25 revealed that the nutrient concentration in fodder maize among the different treatments were significant. Maximum content of N was noticed in T_3 (1.67 per cent) and T_6 (1.62 per cent), T_5 and T_2 (1.61 percent each) were found to be on par with T_3. The lowest was noticed in T_{10} (1.04 per cent). The highest value for P was in T_4 (0.25 per cent) and was found superior to other treatments. The lowest was seen in T_{10} (0.08 per cent).The highest value for K (2.18 per cent) was showed in T_5 and this treatment was found to be superior, while the lowest was recorded by T_{10} (0.76 per cent).

The Ca content was maximum in T_6 (0.41 per cent). All other treatments were found on par with T_6 except T_{10} which recorded the lowest value of 0.1 per cent. The highest value for Mg was observed in T_4 (0.21 per cent) and T_2 was at par with T_4, while the lowest value was noted by T_{10} (0.09 per cent). In the case of S, T_2 recorded the maximum content of 0.17 per cent and was superior to all other mean values. But lowest was found in T_{10} (0.11 per cent).

In the case of Fe content, T_2 recorded the maximum value of 128.3 mg kg^{-1} which was on par with T_7, T_9 and T_8. The lowest value was noticed in T_4 (96.0 mg kg^{-1}). For the Mn concentration, T_2 recorded the highest value of 45.67 mg kg^{-1} and T_1 (41.67 mg kg^{-1}) was on par. The lowest value of 49 mg kg^{-1} was noted in T_{10}. The Zn concentration was highest (90.33 mg kg^{-1}) on T_9 and it was found on par with T_5, T_7 and T_8. T_{10} (29.33 mg kg^{-1}) recorded the lowest. Maximum Cu content was observed in T_2 and T_3 was found at par with T_2 and the values were 15 mg kg^{-1} and 14 mg kg^{-1} respectively. T_{10} recorded the lowest value of 10.33 mg kg^{-1}.

4.4.3.5.Nutrient uptake Table 26

Nutrient uptake studies are given in the Table.26

Table.26 Nutrient uptake studies of second crop in kg ha^{-1}

Treatments	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
T1	69.26	5.46	60.63	11.2	6.35	9.81	0.49	0.18	0.25	0.06
T2	119.91	15.37	119.29	23.83	13.92	8.34	0.95	0.34	0.46	0.11
T3	122.55	12.82	131.76	17.7	12.54	13.88	0.90	0.30	0.49	0.10
T4	130.95	20.94	153.97	25.96	17.60	14.64	0.80	0.30	0.59	0.13
T5	174.52	23.01	235.27	37.42	30.87	11.80	1.06	0.37	0.96	0.12
T6	151.90	18.50	157.76	38.43	17.78	9.91	0.90	0.31	0.79	0.12
T7	116.72	13.89	64.67	19.82	10.56	10.89	0.92	0.26	0.70	0.10
T8	125.86	15.42	71.85	23.10	13.24	10.14	0.95	0.27	0.71	0.11
T9	134.55	17.13	77.90	25.24	14.83	10.44	1.02	0.30	0.79	0.12
T10	23.54	1.89	17.12	2.23	2.19	1.35	0.23	0.06	0.07	0.07
CD	13.083	2.994	13.075	3.258	6.852	1.568	0.148	0.038	0.068	0.019

Uptake studies (Table 26) revealed that the different treatment means were significant. The highest N uptake was observed in T_5 and was found superior to 174.52 $kgha^{-1}$, while the lowest value of 23.54 $kgha^{-1}$ was noticed in T_{10}.The P up take was maximum in T_5 (23.01 $kgha^{-1}$) and T_4 (20.94 $kgha^{-1}$) was on par with T_5 and T_{10} (1.89 $kgha^{-1}$) recorded the lowest. The uptake of K was maximum in T_5 (235.27 $kgha^{-1}$) and was significantly superior. The lowest value of 17.21 $kgha^{-1}$ was observed in T_{10}.

For Ca uptake, T_6 (38.43 $kgha^{-1}$) recorded the highest and was superior to all treatment means and the lowest was observed in 2.23 $kgha^{-1}$. T_5 with a value of 37.42 $kgha^{-1}$ on par with T_6.For the uptake of Mg, the highest value was observed in T_5 (30.87) and significantly superior, but lowest value was obtained for T_{10} (2.19 $kgha^{-1}$).In the case of S, T_4 was noticed the highest uptake of 14.64 and T_3 (13.88 $kgha^{-1}$) found to be on par with T_4, while the value of 1.35 $kgha^{-1}$ observed as lowest (T_{10}).

For the highest uptake of Fe was in T_5 (1.06 $kgha^{-1}$), while T_9 (1.02 $kgha^{-1}$), T_8 and T_2 (0.95 $kgha^{-1}$) and T_7 (0.92 $kgha^{-1}$) were found to be on par with T_5. But T_{10} showed the lowest value of 0.23 $kgha^{-1}$. The highest value of Mn uptake (0.37 $kgha^{-1}$) was observed in T_5 and T_2 was found to be on par (0.34 kg ha-^{1}). T_{10} (0.04 $kgha^{-1}$) observed the lowest value. In the case of Zn, T_5 (0.96 kg ha^{-1}) was noticed the maximum uptake value and lowest was showed in T_{10} (0.069 kg ha^{-1}). But T_5 observed as significantly superior .Highest uptake value for Cu was noticed in T_4 (0.13 $kgha^{-1}$), but T_5 , T_6 and T_9 (0.12 $kgha^{-1}$), T_2 and T_8 (0.11 $kgha^{-1}$) was on par with T_4. T_1 recorded the lowest (0.06 $kgha^{-1}$).

4.4.3.6. Physico-chemical properties and primary nutrient concentration in the surface soil after the crop growth

Surface soil samples (0-15 cm) were collected from each plot after the second crop growth and analyzed for different physico-chemical parameters and primary nutrient elements and the data is presented in Table-27.

Table.27 Physico-chemical parameters and primary nutrient content of surface soil after the second crop

Treatments	pH	EC (dSm^{-1})	Organic Carbon (%)	Avail.N (kg ha^{-1})	Avail.P (kg ha^{-1})	Avail.K^{-} (kg ha^{-1})
T_1	5.1	0.13	0.79	178.2	12.13	109.9
T_2	5.2	0.13	0.99	215.9	12.32	188.2
T_3	5.1	0.13	0.73	185.9	13.81	156.7
T_4	5.1	0.15	0.80	211.1	14.12	144.0
T_5	5.4	0.14	0.70	254.2	13.32	86.2
T_6	5.3	0.12	0.80	207.5	12.88	104.2
T_7	5.3	0.13	1.11	189.7	9.56	150.2
T_8	5.2	0.16	0.97	205.4	10.81	115.3
T_9	5.2	0.13	1.01	223.5	11.84	140.8
T_{10}	5.3	0.12	0.78	73.0	4.95	75.8
CD	0.45	NS	NS	21.5	1.661	15.97

The treatment means were significant for the physico-chemical parameters and primary nutrient content of the surface soil after the second crop except for EC and organic carbon (Table 25). The pH was maximum in T_5. The highest content of available N was with T_5 (254.20 kg ha^{-1}) while the lowest value was recorded in T_{10} (73.0 kg ha^{-1}). Available P was highest in T_4 (14.12 kg ha^{-1}) and was on par with T_3 T_5 and T_6 while the lowest was recorded in T_{10} 2.85 kg ha^{-1}). The highest and lowest value of K was noticed in T_2 and T_{10} with values of 188.20 and 75.80 kg ha^{-1} respectively.

4.4.3.7 Secondary and micronutrient content in the surface soil after the second crop

The surface soil (0-15 cm) samples collected from each plot, after the harvest of the second crop were analyzed for the secondary and micronutrient content and the data is presented in Table-28

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Table 28 Secondary and micronutrient content of surface soil after crop growth – Second crop

Treatments	Exch. Ca (cmol kg^{-1})	Exch. Mg (cmol kg^{-1})	Avail.S (kg ha^{-1})	DTPA Fe (mg kg^{-1})	DTPA Mn (mg kg^{-1})	DTPA Zn (mg kg^{-1})	DTPA Cu (mg kg^{-1})
T_1	1.30	0.54	11.50	16.33	7.79	2.5	0.75
T_2	1.30	0.46	17.50	15.33	6.20	3.74	0.86
T_3	1.26	0.55	12.83	20.67	5.60	4.63	0.62
T_4	1.15	0.46	13.60	20.00	7.57	6.15	0.60
T_5	1.48	0.51	15.18	15.00	2.38	5.93	0.40
T_6	1.27	0.46	15.74	17.00	8.19	5.99	0.52
T_7	1.22	0.60	12.00	16.00	6.11	3.55	0.32
T_8	1.23	0.44	13.73	17.33	8.15	3.56	0.37
T_9	1.25	0.42	14.50	13.00	5.59	3.68	0.45
T_{10}	1.07	0.40	7.60	17.00	1.14	0.97	0.27
CD	0.068	0.102	1.158	2.932	1.317	0.229	0.28

The highest value for exch. Ca was 1.48 cmol kg^{-1} and it was found superior to all other treatments, while the lowest was observed in T_{10}(1.07 cmol kg^{-1}). For exch. Mg, the highest mean value of 0.55 c mol kg^{-1} was observed in T_3 while T_1 was found on par with a value of 0.54 cmol kg^{-1} and T_{10} recorded the lowest. Available S was highest in T_2 with a value of 17.50 kg ha^{-1} which was found superior and lowest value of 7.60 kg ha^{-1} was observed in T_{10}.

Maximum value for DTPA Fe was observed in T_3 (20.67 mg kg^{-1}) while T_4 and T_8 were found on par with values of 20 and 17.33 mg kg^{-1}. T_9 recorded the lowest value of 13 mg kg^{-1}. For DTPA Mn, maximum value of 8.19 mg kg^{-1} was observed in T_6 while T_8, T_4 and T_1 were found to be on par. T_{10} recorded the lowest of 1.14 $mgkg^{-1}$. The highest value of DTPA Zn was observed in T_4 (6.15 $mgkg^{-1}$), while T_6 (5.99 $mgkg^{-1}$) andT_5 (5.93 $mgkg^{-1}$) were found on par. The lowest value was 0.97 mg kg^{-1} in T_{10}.Maximum value for DTPA Cu was observed in T_2 (0.86 $mgkg^{-1}$) and was on par with T_1 (0.75 $mgkg^{-1}$), T_3 (0.62 $mgkg^{-1}$) and T4 (0.60 mg kg^{-1}). The lowest value was in recorded in T_{10} (0.27 $mgkg^{-1}$).

4.4.3.8. Zn fractionation of surface soil after the second crop

The surface soil samples collected from each plot were analyzed for different fractions of Zn and the data is given in Table-29.

Table 29 Fractions of Zn (mg kg^{-1}) in the surface soil after the second crop

Treatments	Ws+Ex-Zn	OB-Zn	MnO-Zn	AmFeO-Zn	Cry FeO-Zn	Res-Zn	Total Zn
T1	2.34 (1.97)	4.47 (3.76)	1.09 (1.12)	27.89 (43.56)	33.30 (27.91)	29.91 (25.13)	119.00
T2	1.65 (1.70)	1.92 (1.98)	0.61 (0.51)	30.53 (31.47)	43.00 (44.33)	19.29 (19.80)	97.00
T3	3.68 (3.07)	3.93 (3.28)	1.26 (1.05)	27.82 (23.18)	46.00 (38.33)	37.31 (31.09)	120.00
T4	4.66 (3.17)	3.22 (2.19)	1.46 (0.99)	27.65 (18.81)	86.00 (58.50)	24.01 (16.33)	147.00
T5	5.06 (3.89)	3.28 (2.19)	1.22 (0.94)	23.28 (17.91)	75.00 (57.69)	22.16 (17.04)	130.00
T6	4.74 (4.83)	3.16 (2.52)	0.84 (0.85)	26.95 (27.50)	39.00 (39.80)	23.31 (23.79)	98.00
T7	3.32 (2.20)	2.25 (3.22)	0.47 (0.31)	23.93 (15.85)	76.00 (50.33)	45.03 (29.82)	151.00
T8	2.28 (1.65)	2.76 (1.49)	0.66 (0.49)	13.82 (10.01)	91.00 (66.00)	27.48 (19.91)	138.00
T9	2.16 (1.38)	3.09 (2.00)	0.73 (0.46)	22.11 (14.08)	90.00 (57.32)	18.91 (12.00)	157.00
T10	0.59 (0.72)	0.91 (1.97)	0.31 (0.38)	22.00 (26.83)	33.00 (40.24)	25.19 (30.72)	82.00
CD	0.194	0.186	0.093	3.69	10.05	5.07	30.85

The values in parentheses are the percentage content of the individual fractions to total Zn.

The data from the Table. 29 indicated that the different fractions of Zn in the surface soil after the second crop was found significant among treatments. The highest content of Ws+Ex-Zn was of 5.06 mgkg^{-1} was in T_5 significantly superior and the lowest was in the control (0.59 mg kg^{-1}). The OB fraction, the highest and the lowest values were in T_I (4.47 mg kg^{-1}) and T_{10} (0.91mg kg^{-1}), For the Mn O bound content, the maximum value of 1.46 mg kg^{-1} was recorded in T_4 . Maximum value of AmFeO-Zn (30.53 mg kg^{-1}) was noticed in T_2 and the lowest value (13.82 mg kg^{-1}) was noted in T_8 The Cry FeO-Zn content was highest in T_8 (91 mg kg^{-1}) but it was closely followed by T_9 and T_4. with values of 90 and 86 mg kg^{-1}. The lowest was in the control. The Res- Zn was highest in T_7 (45.03 mg kg^{-1}) , The lowest value was in T_9 . For the total Zn, maximum value was found to be 157 mg kg^{-1} (T_9) while T_7 ,T_4, T_8 and T_5 were on par with mean values of 151 ,147,138 and 130mg kg^{-1} respectively and the lowest value was in T_{10} (82 mg kg^{-1}).

3.4.3.9 Physico-chemical properties and primary nutrient concentration in the subsurface soil after the crop growth

Subsurface soil samples (15-30cm) were collected from each plot after the second crop growth and analyzed for different physico-chemical parameters and primary nutrients and the data is presented in the Table .30

Table.30. Physico-chemical parameters of the subsurface soil after the second crop

Treatments	pH	EC (dSm^{-1})	Organic carbon (%)	Av N (kgha^{-1})	Av. P (kgha^{-1})	Av.K (kgha^{-1})
T_1	5.01	0.11	0.44	143.8	3.21	245.67
T_2	4.8	0.14	0.46	155.3	3.42	133.00
T_3	5.0	0.12	0.40	164.4	9.15	183.73
T_4	4.9	0.10	0.30	171.1	6.10	204.3
T_5	5.1	0.11	0.20	219.2	3.29	172.67
T_6	4.9	0.12	0.82	166.9	3.87	108.93
T_7	5.0	0.12	0.76	157.8	3.58	177.46
T_8	5.03	0.15	0.84	193.9	4.63	179.77
T_9	4.97	0.10	0.98	138.7	3.81	186.84
T_{10}	4.89	0.12	0.58	98.0	2.85	69.00
CD	NS	NS	NS	32.41	3.504	9.132

The pH, EC and OC contents were not significant among treatments. The maximum content of available N was observed in T_5, available P in T_3 and available K in T_1.

4.4.3.10. Secondary and micronutrient contents in the subsurface soil after the crop growth

The sub-surface (15-30 cm) soil samples collected from each plot after the harvest of the second crop were analysed for the secondary and micronutrient contents and the data is presented in Table-31.

Table 31. Secondary and micro nutrient contents of subsurface soil after the second crop

Treatments	Ex ca (c mol kg^{-1})	Ex Mg (c mol kg^{-1})	Avail.S ($kgha^{-1}$)	DTPA Fe ($mgkg^{-1}$)	DTPA Mn ($mgkg^{-1}$)	DTPA Zn ($mgkg^{-1}$)	DTPA Cu ($mgkg^{-1}$)
T_1	1.29	0.48	9.26	18.03	3.29	2.17	0.82
T_2	1.3	0.46	11.11	14.62	2.3	2.44	0.50
T_3	1.28	0.51	11.88	22.37	4.53	3.25	0.61
T_4	1.27	0.52	12.1	19.80	3.61	3.28	0.65
T_5	1.26	0.48	12.88	18.85	3.86	3.20	0.61
T_6	1.15	0.43	9.78	14	2.66	2.72	0.32
T_7	1.25	0.38	11.35	18	4.06	1.75	0.46
T_8	1.22	0.37	11.58	17.20	3.93	2.16	0.47
T_9	1.23	0.38	11.54	18.51	4.94	2.12	0.49
T_{10}	1.07	0.35	6.05	15.80	0.77	0.85	0.21
CD	0.070	0.034	2.106	5.03	0.544	0.35	0.08

The exch.Ca and DTPA C u were higher in T_1 and T_4 recorded the highest exch.Mg and DTPA Zn .The avail. S ,DTPA Fe and DTPA Mn recorded higher values in T_5, T_3 and T_9 respectively.

4.4.3.11 Zn fractionation of sub-surface soil after the Second crop

The sub-surface soil samples collected from each plot were analysed for different fractions of Zn and the data is presented in Table-32.

Table. 32 Fractions of Zn in the subsurface soil ($mgkg^1$)

Treatments	WS+EX.	OB	Mn O	Am Fe	Cry Fe	Res	Total
T_1	1.46 (1.70)	1.18 (1.37)	1.56 (1.81)	20.65 (24.01)	33.5 (38.95)	27.65 (32.15)	86
T_2	1.28 (1.35)	2.24 (2.36)	0.93 (0.98)	16.92 (17.81)	39.33 (41.4)	34.3 (36.10)	95
T_3	2.63 (2.22)	2.65 (2.25)	1.16 (0.98)	16.03 (13.58)	68 (57.63)	27.53 (23.33)	118
T_4	1.57 (1.22)	2.08 (1.61)	1.53 (1.18)	48.97 (37.96)	52 (40.31)	22.85 (17.71)	129
T_5	1.21 (1.44)	0.86 (1.02)	1.1 (1.02)	30.73 (36.58)	35.67 (42.46)	14.43 (17.18)	84
T_6	2.2 (2.59)	1.18 (1.39)	1.18 (1.39)	20.69 (24.34)	39.06 (46.0)	20.69 (24.34)	85
T_7	0.7 (0.83)	0.98 (1.17)	0.86 (1.02)	17.38 (20.69)	31.5 (38)	32.5 (38.69)	84
T_8	3.01 (2.30)	1.34 (1.02)	2.2 (1.68)	25.54 (19.50)	76.89 (59)	22.02 (16.81)	131
T_9	1.8 (1.58)	1.13 (0.99)	1.22 (1.07)	34.37 (30.14)	41.93 (37)	33.55 (29.43)	114
T_{10}	0.15 (0.20)	0.66 (0.86)	0.74 (0.96)	21.24 (27.58)	27.54 (36)	26.67 (34.63)	77
CD	0.163	0.124	0.17	3.734	10.64	4.66	9.678

The values in parentheses are the percentage content of the individual fractions to Total Zn.

The data presented in the Table. 32 were significant for various treatment means of Zn fractions in the subsurface soil .The highest value of Ws+Ex, MnO bound , Cry Fe O and total Zn was observed in T_8 and these values were found significantly different when compared to other mean values. The highest and lowest values for Am FeO – Zn were recorded for T_4(48.97 mgkg^{-1}) and T_3(16.03 mgkg^{-1}) respectively. For residual content of Zn, though T_2 (34.3mgkg^{-1}) recorded maximum, T_9 and T_7 were found so par with T_2.

4.4. 4 Second Residual Crop after the second experimental crop

A second residual crop has been raised after the second experimental crop without adding any of the manures or fertilizers and harvested. The green fodder and dry fodder yield of the second residual crop are given in Table-33.

Table.33. Green fodder and Dry fodder yield of the second residual crop

Treatments	Green fodder Yield (qh a^{-1})	Dry fodder Yield (qha^{-1})
T_1	21.54	4.34
T_2	30.93	6.3
T_3	31.94	6.32
T_4	26.87	5.3
T_5	26.00	5.19
T_6	39.49	7.77
T_7	32.16	6.39
T_8	23.17	4.59
T_9	34.29	6.93
T_{10}	18.37	3.02
CD	3.381	0.964

The residual crop was raised after the harvest of the second crop without applying any manures or fertilizers to know the residual effect of nutrients applied earlier.

The data shown in the Table. 33 of the second residual crop were significant among treatments. The highest mean value for green fodder as well as dry fodder was observed in T_6 with the values of 39.49 qha^{-1} and 7.77 qha^{-1}) which was found superior while the lowest was noticed in the control.

4.4.4.1 Total and DTPA extractable Zn after the crop growth – Second residual crop

Soil samples both surface and sub surface were collected from each experimental plot after the harvest of the second residual crop and analysed for Total and DTPA extractable Zn and presented in Table-34.

Table 34 DTPA extractable and total Zn in the surface and sub surface soil after second residual crop (mg kg^{-1})

Treatments	DTPA Zn surface	DTPA Zn subsurface	Total Zn Surface	Total Zn subsurface
T_1	1.05	0.77	41.27	35.63
T_2	0.98	0.63	50.73	33.17
T_3	1.89	0.87	54.2	43.87
T_4	2.1	0.72	57.53	38.03
T_5	1.62	1.09	45.5	27.42
T_6	1.28	0.99	52.53	50.47
T_7	1.17	0.59	36.83	33.63
T_8	1.41	0.65	36.67	37.37
T_9	1.49	0.52	35.97	33.83
T_{10}	0.54	0.49	33.6	31.53
CD	0.076	0.11	13.81	5.084

The data presented in the Table. 34 revealed that the treatment means for the DTPA extractable and total Zn in the surface and subsurface soil for the second residual crop were significant . The highest mean value for the DTPA extractable Zn in the surface soil was observed in T_4 (2.1 $mgkg^{-1}$) and it was found superior to all other values. The lowest value of 0.54 ($mgkg^{-1}$) was noted in the control. For the subsurface, the highest was 1.09 mg kg^{-1} which was found on par withT_6. and lowest was noted in T_{10}. The maximum value for total Zn in the surface soil was noted in T_4 (57.53 $mgkg^{-1}$) while it was on par to T_3, T_6, T_2 and T_5 while the lowest value was in T_{10}. For the subsurface soil, T6 recorded the highest value (50.47 mg kg^{-1}) and it was found significantly differ from all other values. The lowest value was in the control plot.

4.4.5. Pooled analysis – Yield

The yield data generated out of the two field experiments were pooled and analysed statistically. The pooled data on yield is given in Table 35.

Table. 35 . Pooled analysis data on yield

Treatment	Green fodder yield ($q\ ha^{-1}$)	Dry fodder yield ($q\ ha^{-1}$)
T_1	327.60	64.20
T_2	346.10	69.70
T_3	402.80	82.20
T_4	464.50	93.80
T_5	468.80	94.90
T_6	383.30	76.60
T_7	375.50	74.90
T_8	403.90	79.80
T_9	418.30	82.30
T_{10}	104.30	17.60
CD	66.30	6.67

The data presented in the Table-35 revealed that the pooled analysis data for the yield was found significant. The highest yield was recorded for T_5 with a mean value of 468.8 q ha^{-1}, but it was on par with T_4, T_9 and T_8. The highest dry fodder yield was in T_5 which was on par to $T_4$with the values of 94.9 and 93.8 q ha^{-1} respectively.

4.4.6 Foliar diagnosis

To identify the best part and best stage of sampling the 3rd, 4th and 5th leaf lamina and petiole were analysed for Zn at different stages of crop growth viz, 15, 25,35 and 45 DAS.

4.4.6.1 Zinc concentration ($mgkg^{-1}$) of leaf and petiole of fodder maize at 15 DAS

Table. 36. Zinc concentration ($mgkg^{-1}$) of leaf lamina and petiole of fodder maize at 15 DAS

Treatments	Leaf lamina			Petiole		
	3rd	4th	5th	3rd	4th	5th
T_1	4.60	5.22	4.67	6.08	6.63	7.10
T_2	4.63	6.10	4.70	5.37	5.83	6.50
T_3	5.33	5.20	5.70	6.60	7.03	7.93
T_4	6.57	6.47	6.73	7.73	8.10	7.77
T_5	9.97	9.83	10.03	11.93	11.53	11.33
T_6	8.07	8.03	8.27	10.47	9.77	10.13
T_7	8.82	8.67	8.90	11.33	9.70	10.32
T_8	9.27	9.47	9.57	12.13	11.90	12.10
T_9	9.63	9.93	10.05	12.00	11.27	11.00
T_{10}	4.13	4.83	4.50	5.42	4.90	5.75
CD	0.794	1.495	0.713	1.664	1.691	1.490

Data presented in the Table. 36 showed that the treatment means were significant at 15 DAS. For the third leaf lamina, the highest mean value obtained for T_5 (9.97 $mgkg^{-1}$) and was found significantly superior. The lowest mean value 4.13 $mgkg^{-1}$for T_{10}. The treatments T_9 and T_8 were found to be on par with T_5. For the 4th leaf lamina the maximum value was recorded 9.93 $mgkg^{-1}$ forT_9 and it was on par with,T_5,T_8 and T_7 and the lowest value was recorded forT_{10} with 4.83 $mgkg^{-1}$ .While in the 5th leaf lamina highest mean value was noticed 10.05 $mgkg^{-1}$ for T_9 and it was on par with T_5, and T_8 and the lowest value was noticed in T_{10} with 4.50 $mgkg^{-1}$.

The concentration of Zn in the petiole was in the range of 4.90 mg kg^{-1} to 12.13 $mgkg^{-1}$. For the 3rd petiole, the highest value of 12.13 $mgkg^{-1}$ was recorded for T_8 and it was on par with T_9, T_5 T_7 and T_6 with the values 12.00 ,11.93, 11.33 and 10.47 $mgkg^{-1}$ respectively while the lowest value was observed for T_{10} (5.42 mg kg^{-1}). For the 4th petiole, the highest value obtained for T_8 (11.90 $mgkg^{-1}$) and it was on par to T_5(11.53 mg kg^{-1}), T_9(11.27 mg kg^{-1}) respectively and the lowest value of 4.90 mg kg^{-1} was recorded for T_{10}. In the case of 5th petiole, the highest value of 12.10 mg kg^{-1} was noticed in T_8 which was found to be on par with T_5 and T_9 with values of 11.33 and 11.00 $mgkg^{-1}$. The lowest value (5.75 mg kg^{-1}) was recorded for T_{10}.

4.4.6.2 Zinc concentration ($mgkg^{-1}$) of leaf and petiole of fodder maize at 25DAS

Table.37. Zinc concentration ($mgkg^{-1}$) of leaf lamina and petiole of fodder maize at 25DAS

Treatments	Leaf lamina			Petiole		
	3rd	4th	5th	3rd	4th	5th
T_1	12.23	13.38	13.00	10.45	16.10	9.73
T_2	15.83	11.70	15.67	11.80	17.60	11.21
T_3	18.22	21.03	18.90	16.15	22.20	17.57
T_4	19.83	21.80	19.70	20.09	26.20	17.00
T_5	23.00	25.26	15.67	24.64	14.20	23.42
T_6	20.85	18.93	19.47	15.26	21.40	17.85
T_7	15.67	18.91	15.47	18.99	17.00	19.13
T_8	17.17	19.99	17.30	19.06	18.60	20.32
T_9	17.93	18.88	17.17	20.07	28.80	22.13
T_{10}	8.45	8.96	10.64	8.61	10.64	8.67
CD	5.199	1.996	3.191	2.15	2.01	3.608

Zinc concentration (mg kg^{-1}) of leaf and petiole of fodder maize at 25DAS (Tab.35) showed that the different treatment means were found significant. For the 3rd leaf, T_5 recorded the highest value of 23.00 $mgkg^{-1}$ and was found to be on par with T_6 T_4, T_3 and T_9 with values of 20.85 , 19.83,18.22 and 17.93 $mgkg^{-1}$ respectively . The lowest value was 8.45 $mgkg^{-1}$ (T_{10}). For the 4th leaf, the highest value of 25.26 $mgkg^{-1}$ (T_5) was found significantly superior. T he lowest value was found in T_{10} (8.96 $mgkg^{-1}$). For the 5th petiole, T_4 recorded the highest value (19.70 $mgkg^{-1}$) . T_6, T_3, T_8 and T_9 were found to be on par while T_{10} (10.64 $mgkg^{-1}$) was found to be the lowest.

For the 3rd petiole, T_5 was recorded the highest and the T_{10} recorded the lowest values with corresponding values of 24.64 and 8.61 $mgkg^{-1}$ and T_5 was found to be superior. For the 4th petiole, highest value of 28.88 $mgkg^{-1}$ was noticed in T_9 and was found significant difference over other treatment means while T_{10}(10.64 $mgkg^{-1}$) recorded the lowest value. The maximum value recorded for the 5th petiole was in T_5 (23 . 42 $mgkg^{-1}$) while T_9 and T_8 were found on par with values of 22.13 and 20.32 $mgkg^{-1}$ respectively. T_{10} recorded the lowest value of 8.67 $mgkg^{-1}$.

4.4.6.3 Zinc concentration (mg kg^{-1}) of leaf lamina and petiole of fodder maize at 35DAS

Table.38. Zinc concentration ($mgkg^{-1}$) of leaf and petiole of fodder maize at 35DAS

Treatments	Leaf lamina			Petiole		
	3rd	4th	5th	3rd	4th	5th
T_1	17.17	17.90	20.07	19.40	19.91	16.38
T_2	19.89	20.20	23.67	41.40	21.86	17.46
T_3	22.50	29.80	32.16	24.30	33.20	17.20
T_4	28.53	37.25	40.25	32.00	31.90	23.81
T_5	33.33	38.20	41.51	44.30	41.50	32.00
T_6	29.33	31.60	33.27	35.70	34.65	26.83
T_7	28.04	26.00	31.00	21.00	24.80	16.48
T_8	25.00	26.50	33.83	14.70	33.67	17.45
T_9	28.40	35.00	35.77	46.20	28.08	18.21
T_{10}	16.94	14.52	13.70	14.90	15.85	12.57
CD	5.177	4.13	8.819	NS	7.846	1.202

As seen from the Table. 38 the treatment means were found significant at 35 DAS except for 3rd petiole. $T_5$and T_{10} recorded highest and lowest mean values in all cases. For the third leaf, T_5 with the maximum value of 33.33 $mgkg^{-1}$ and T_{10} recorded the lowest value (16.94 $mgkg^{-1}$) .While T_6, T_4 and T_9 were found to be on par with values of 29.33,28.53, and 28.40 $mgkg^{-1}$ respectively . In the 4th leaf, the highest value of 38.20 $mgkg^{-1}$ was noticed by T_5 while the lowest value was observed in T_{10} (14.52 $mgkg^{-1}$). T_4 and T_9 were found on par with T_5 .For the 5th leaf, T_5 with highest value of 41.51 $mgkg^{-1}$ and it was on par to T_4(40.25 $mgkg^{-1}$), T_9(35.77 $mgkg^{-1}$) and T_8(33.83 $mgkg^{-1}$)and the control plot recorded the lowest value (13.70 $mgkg^{-1}$). The Zn content of 3rd petiole was not significant for various mean values while the highest and lowest mean values were 46.20 $mgkg^{-1}$ (T_9)and 14.90 $mgkg^{-1}$ (T_{10}) respectively. The maximum value for Zn content in the 4th petiole was 41.50 $mgkg^{-1}$ which was on par with T_6 (34.65 mg kg^{-1}). T_{10} recorded the lowest value of 15.85 $mgkg^{-1}$.For the 5th petiole, T_5 was found to be significantly different with a value of 32.00 $mgkg^{-1}$ and control with the lowest value of 12.57 $mgkg^{-1}$.

4.4.6.4. Zinc concentration (mg kg^{-1}) of leaf lamina and petiole of fodder maize at 45DAS

Table.39. Zinc concentration ($mgkg^{-1}$) of leaf and petiole of fodder maize at 45DAS

Treatments	Leaf lamina			Petiole		
	3rd	4th	5th	3rd	4th	5th
T_1	28.50	27.10	29.33	32.57	25.70	24.80
T_2	31.20	29.27	32.27	28.90	29.00	25.30
T_3	41.00	35.00	43.76	35.24	34.59	39.20
T_4	45.50	38.50	45.46	41.60	47.20	39.90
T_5	46.54	43.67	49.54	39.00	39.76	40.10
T_6	45.30	36.64	43.87	40.80	45.70	36.20
T_7	42.50	32.40	44.33	36.00	32.54	35.60
T_8	41.76	34.25	45.57	38.50	42.74	33.20
T_9	47.40	32.63	47.00	45.90	42.30	34.30
T_{10}	15.78	17.93	21.53	15.20	18.80	16.10
CD	11.29	6.981	7.693	9.76	11.384	18.446

The data presented in the Table.39. The 3rd,4th and 5th leaf follows the same pattern for the Zn concentration . The highest and lowest values of 47.40 and15.78 $mgkg^{-1}$,43.67 and 17.93 $mgkg^{-1}$,49.54 and 21.53 $mgkg^{-1}$ respectively for 3rd ,4th and 5th petiole and all other mean values except T_1, T_2 and T_{10} respectively found on par with T_5.

The highest mean value of the 3rd petiole was recorded in T_9 (45.90 $mgkg^{-1}$) and it was on par with T_4(41.60 $mgkg^{-1}$) ,T_6(40.80 $mgkg^{-1}$) T_5(39.00 $mgkg^{-1}$) and T_8(38.50 $mgkg^{-1}$)while the lowest was recorded in T_{10}(15.20 $mgkg^{-1}$). T_4 and T_{10} recorded the highest and the lowest mean value o 47.20 and18.80 mg kg^{-1}respectively in the 4th petiole. But T_6, T_8 ,T_9 and T_5 were found to be on par with T_4 and values were 45.70, 42.74 ,42.30 and 39.76 $mgkg^{-1}$ respectively. For the 5th petiole, maximum value (40.10 $mgkg^{-1}$) has been observed in T_5 and all other treatment means except T_1, T_2 and , T_{10}. The lowest was in T_{10} (16.10 $mgkg^{-1}$).

5. DISCUSSION

A study has been undertaken on the dynamics of Zinc in Typic Kandiustults with special reference to nutrition in fodder maize (*Zea mays* L.). This comprised of an incubation study to determine the release pattern of Zn from $ZnSO_4$. $7H_2O$, a preliminary investigation on the Physico-chemical parameters especially Zn dynamics in soil profile and the surface and sub-surface soil of the experimental site, and a field study to find out the optimum requirement of Zn by the fodder maize cv. African Tall through soil and foliar application. The study also aimed to identify the index plant part of fodder maize for foliar diagnosis. The results of the experiments conducted are discussed below.

5.1. Study on the release pattern of Zn from $ZnSO_4$. $7H_2O$ on incubation with and without FYM

The medium range of available Zn proposed by FAO (Mikko Sillanpaa, 1990) was 0.7-2.4 mg kg^{-1}. Data given in Table. 3 ie. the release status of Zn from Zinc sulphate indicate that when Zn was applied @ 5, 10 and 15 kg ha^{-1}, the availability of Zn was in the medium range during the period of incubation and it has exceeded 2.4 mg kg^{-1} on the 75^{th} day of incubation only, when Zn was applied @ 20 kg ha^{-1}.

The release pattern of Zn from zinc sulphate is graphically presented in Fig. 4.

On examining the data on the Zn release status during incubation, the Zn release was more at 5 and 10 kg ha^{-1} of Zn application along with FYM. The chelation of inorganic sources of Zn with the organic compounds in farm yard manure might have increased the Zn availability. But as the levels of Zn application increased to 15 and 20 kg ha^{-1}, the effect of FYM could not be much evidenced on the Zn release. This showed that at a higher level of Zn application the complexing of Zn with organic matter is immaterial (Shover *et al*. 2007).

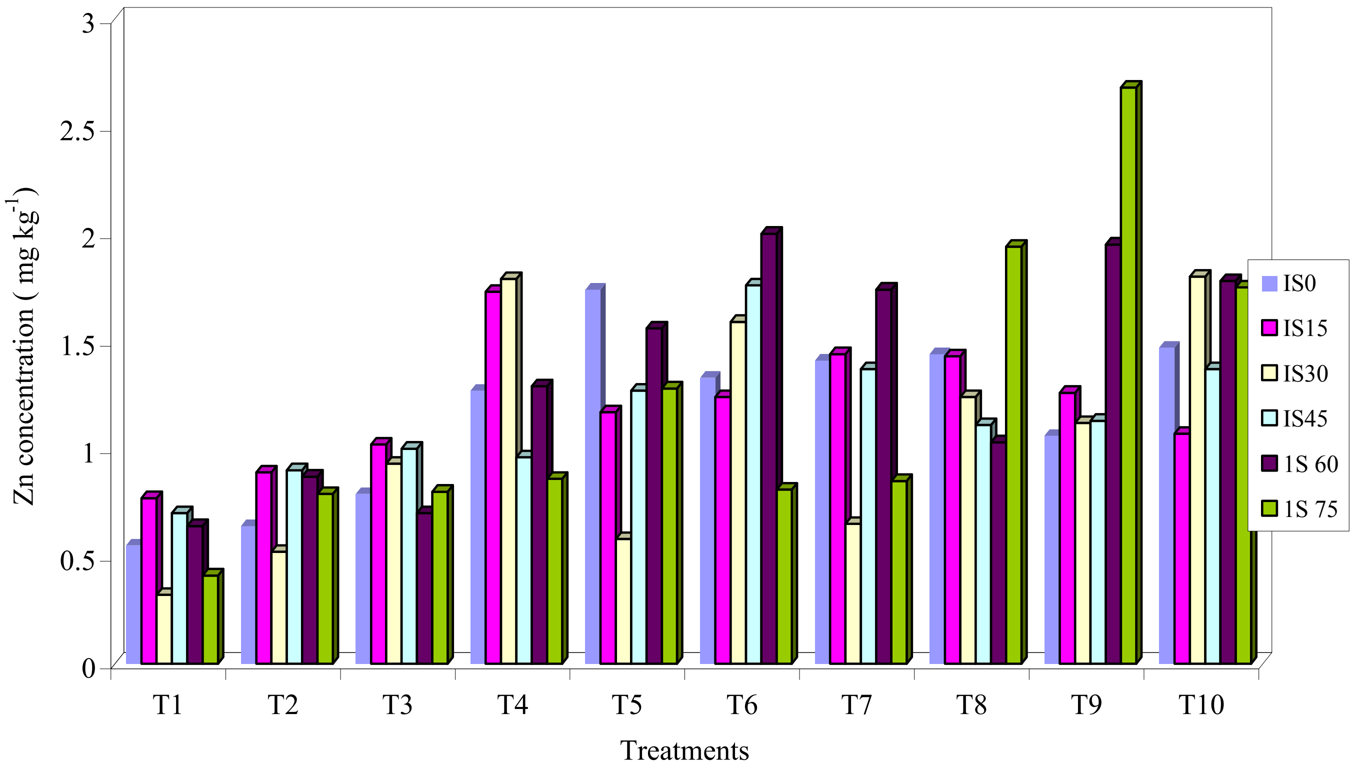

Fig. 4 Effect of different treatments with and without FYM on the availablity of Zn

The incorporation of organic manures in soil is quite effective to mitigate Zn deficiency in crops. Organic manures may serve as a source of Zn and their decomposition products give rise to natural complexing agents which mobilize the native Zn already present in soil through chelation (Sakal, 2001).

5.2. Study of the soil profile

The photograph of the soil profile examined is given in plate-1.

5.2.1. Morphological characteristics of the soil profile

The solum was very deep (10.123 cm). Five horizons from Ap to Bt_2 (Table-4) were identified in the solum. The soil colour varied from 5 YR ¾ in the Ap horizon to 5 YR 4/8 in the Bt_2 horizon. The soil colour appears to be the function of different chemical and mineralogical composition as well as textural make up of soil and conditioned by topography and moisture regime (Walia and Rao, 1997).

The texture varied vertically from sandy loam to sandy clay loam. The textural variation might be due to variation in the parent material, weathering and translocation of clay. The structure of the upper horizon was crumb and this might be due to continuous addition of organic matter through vegetation. The lower horizons had a subangular blocky structure and this was attributed to the presence of higher quantities of clay fraction (Sharma *et al*. 2004).

The consistence of the soil were dry, friable, non-sticky and non-plastic in the upper horizons and as the depth increases, at the B2t and C_1 horizons it was slightly sticky and slightly plastic. The consistence of the soils viz. non-sticky to slightly sticky and non-plastic to slightly plastic might be due to negligible or very small amount of expanding clay minerals (Thangasamy *et al*. 2004).

The horizon boundaries were abrupt wavy to gradual smooth in topography. The roots in different horizons of the pedons were fine to coarse in size and more in surface layer and decreased with depth.

5.2.2. Physico-chemical characteristics of soil profile

The detailed physico-chemical characteristics of the soil profile are presented in Table 5. Particle size analysis of the different horizons from Ap, Ac, B_1, B_2, Bt_2 and C_1 was carried out. In the Ap horizon the sand content was 79.4 per cent and silt and clay contents were 11.5 and 11.6 per cent respectively and classified as sandy loam. The Ac, B_1 and B_2 horizons also could be classified under sandy loam, as the sand content varied from 50-80, silt 0-50 and clay 0-20 per cent. For the Bt_2 silt and clay content estimated were 48.9, 10.7 and 34.52 per cent. The C_1 horizon was observed with a sand, silt and clay contents of 51.6, 9.01 and 36.2 per cent respectively and classified under the textural class sandy clay loam The Bt_2 and C_1 horizons contained 34.5 and 36.2 percentage of clay and the increase in clay content could be attributed to vertical migration or translocation of clay (Sarkar et al. 2002).

The bulk density of the C_1 horizon (1.35 Mgm^{-3}) was the highest, which might be due to more compaction, low organic matter and less aggregation. Similar findings were reported by Singh and Agrawal (2005).

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The pH of the soil varied from 5.4 in the upper horizon to 4.8 in the lower horizon and the EC did not varied much among horizons.

5.2.3. Nutrient content of soil profile (Table. 5)

The organic carbon percentage varied from 0.79 in the Ap horizon to 0.35 in the C_1 horizon. This decreased trend in organic carbon content with depth could be attributed to the addition of plant residues and farm yard manure to surface horizons.

The nutrient content of N, P, K, Ca, Mg and S steadily decreased from the Ap to $_1$ horizon.

The higher availability of Nitrogen and Phosphorus and Sulphur in the surface horizons and steady decrease with depth may be due to decreasing trend of organic carbon with depth, cultivation of crops which is mainly confined to the surface horizon only and also due to supplementation of depleted nitrogen and phosphorus content by the external addition of fertilizers during crop cultivation (Prasuna Rani *et al*. 1992).

The highest available potassium content in the surface horizon might be attributed to more intense weathering, release of labile K from organic residues, application of K fertilizers etc. Available K had a significant and positive correlation with organic carbon (Thangasamy et al 2005). But the micronutrients viz. Fe, Mn, Zn and Cu expressed a different pattern. The vertical distribution of Fe, Zn and Cu contents exhibited little variation from Ap to C_1 horizon. Distribution of total Zn with depth down the soil profile has been reported to be uniform (Lindsay, 1972).

The Mn content increased from 9.7 mg kg^{-1} in Ap horizon to 18.94 mg kg^{-1} in theeC_1 horizon.

The water soluble + exchangeable form of Zn was maximum ie, 0.41 mg kg-1 in the Ap horizon (0-9.5 cm) followed by 0.32 mg kg-1 in the Ac horizon (9.5 – 25 cm). According to Hazra and Mandal (1996), the availability of added zinc is directly related to the amount of water soluble +exchangeable fractions of Zn in soil. The added organic manures and fertilizers to the surface soil might have contributed to the highest content of the Ws+Ex-Zn.

5.3. Field study – Fodder maize cv. African Tall

5.3.1. Height (cm) and different stages of crop growth

The data presented in Table-7 , 20 and Fig. 5 revealed that at the different stages of observation viz. 25 and 35 DAS and at harvest the T4 (FYM 10 tha^{-1} 120:60:40 NPK kg ha^{-1} and 10 kg Zn ha^{-1} as $ZnSO_4$ $7H_2O$ recorded the maximum height of the plant. At 45 DAS, even though T_5 gave the maximum height which was on par with T_4. Tsui (b) (1948) investigated that Zn have an active role in the production of auxins for a plant species. The Zn plays a pivotal role in regulating the auxin concentration in plant and might have contributed to the increased height. Similar findings were reported by Dewal and Parek (2004) and Jain and Dahama (2006).

For the 2nd crop also, the T_4 treatment recorded the maximum height on the 45th DAS and at harvest. For the 1st crop 45 DAS and for the 2nd crop 35 DAS, a boost on height was noticed. The favourable climatic condition viz. rainfall at the active vegetative growth of the crop have influenced this enhanced height. The first experimental crop has been sown during the last week of October, 2007 and the total rainfall in mm recorded for the month of November, 2007 was 186.20. Like that the second experimental crop was raised during the first week of May, 2008 and the rainfall observed was 153.20 mm. This evidently established the impact of rainfall during the active vegetative growth of the crop and enhancement in height. The meteorological data is given in Fig.-2.

5.3.2. Mean number of leaves at different stages of crop growth

At the time of harvest the first crop recorded maximum production of leaves in T_9 (POP+0.75% Zn given as foliar) and it was on par with T_3. (Table-8). As zinc plays an important role in chlorophyll synthesis, the photosynthetic rate might have increased, resulted in the maximum production of leaves. Similar findings on foliar spray of mustard crop with 1% $ZnSO_4$ (Sushama *et al*. 2003) and on pigeon pea with

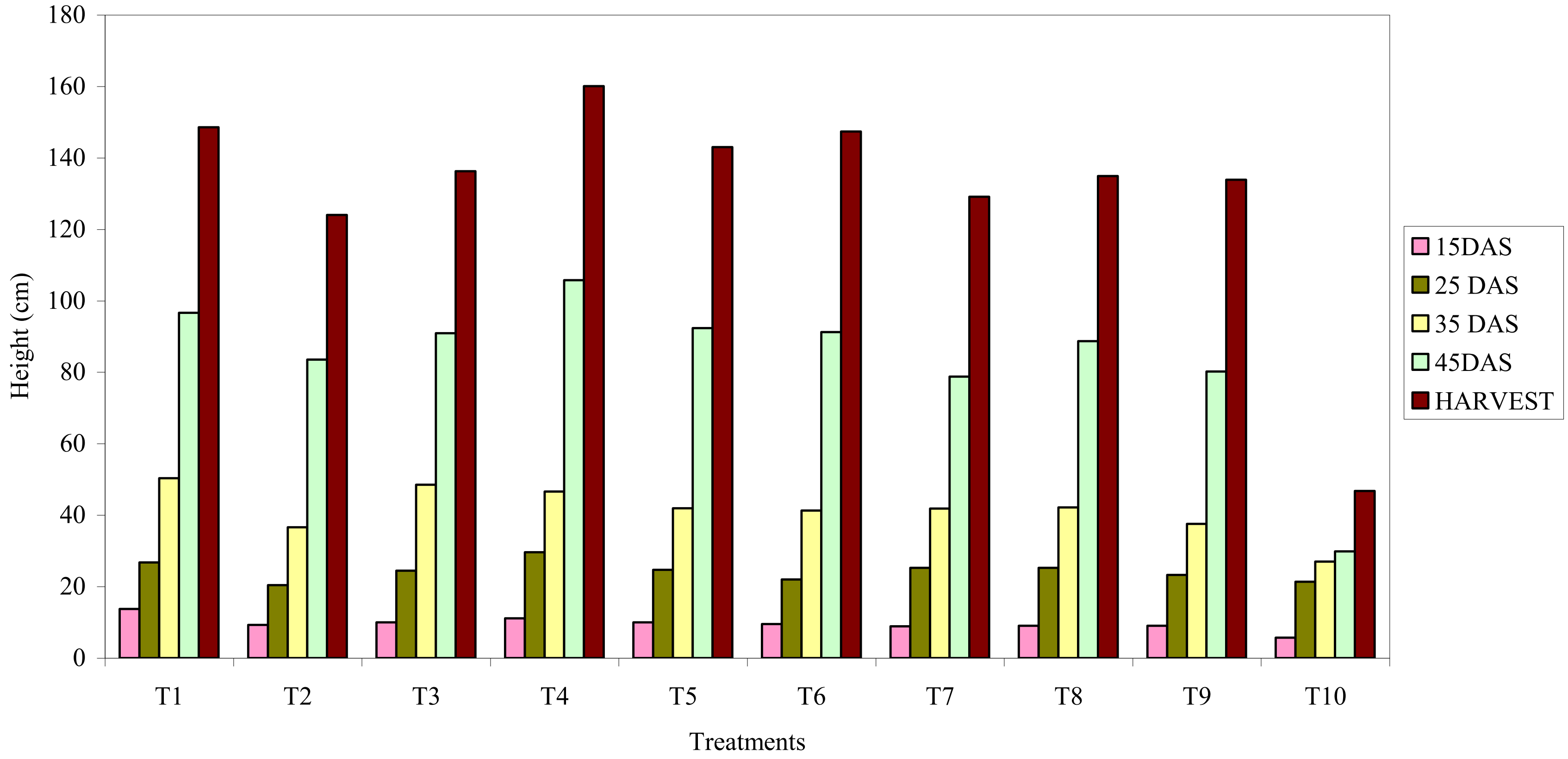


Fig. 5. Mean values of height (cm) at different stages

0.5% $ZnSO_4$ (Dube *et al*. 2001: Verma *et al*. 2004) were reported. At the time of harvest the number of leaves produced among treatments were not significant.for the 2nd crop. . At 45 DAS T_8 and T_9 ie, Zn foliar applied treatments on the 4th leaf stage produced the maximum number of leaves, next to T3, the maximum leaf produced treatment (Table-21).

5.3.3. Yield and yield attributes of fodder maize

The highest green fodder yield (512.5 qha^{-1}) was recorded in T_4 (POP + Zn@10 kg ha^{-1}) and was found superior to all other treatments. The per day green fodder yield and LAI were also highest in T_4. (Table-9 and Fig. 6&7). Not only there is inherent variability in the behaviour of soils with respect to nutrient availability but also the crops grown influence the transformation of nutrients and their availability. Sakal 2001 also reported that Zn application varied widely because of the differences in soil characteristics, available Zn status of soils and crop varietal characteristics. All these factors might have influenced the fodder production and the present study revealed that an application rate of organic and inorganic nutrients @10t FYM + 120:60:40 NPK kg ha^{-1} + 10 kg Zn ha^{-1} as soil application was the best treatment for fodder maize cv. African Tall. The optimum level of Zn for different crops ranged between 5-10 kg ha^{-1}. The favourable influence of $ZnSO_4$ on the higher yield of fodder may be attributed to its role in various enzymatic reactions, growth processes, hormone production and protein synthesis (Mehla, 1999). Data presented in Table-22 revealed that the yield and yield attributes of second crop were significant except for LSR. The green fodder yield was maximum in T5 (Soil application of Zn @ 15 kg ha^{-1} + POP) with a value of 519.3 q ha^{-1} and T6 was found on par with an yield of 465.4 q ha^{-1}. As in the case of first crop for the second crop too, the maximum LAI recorded treatment had given the maximum green fodder yield. For the first crop, the highest LSR was noted in T_4, but for the second crop, the leaf stem ratio was found to be non-significant among treatment.

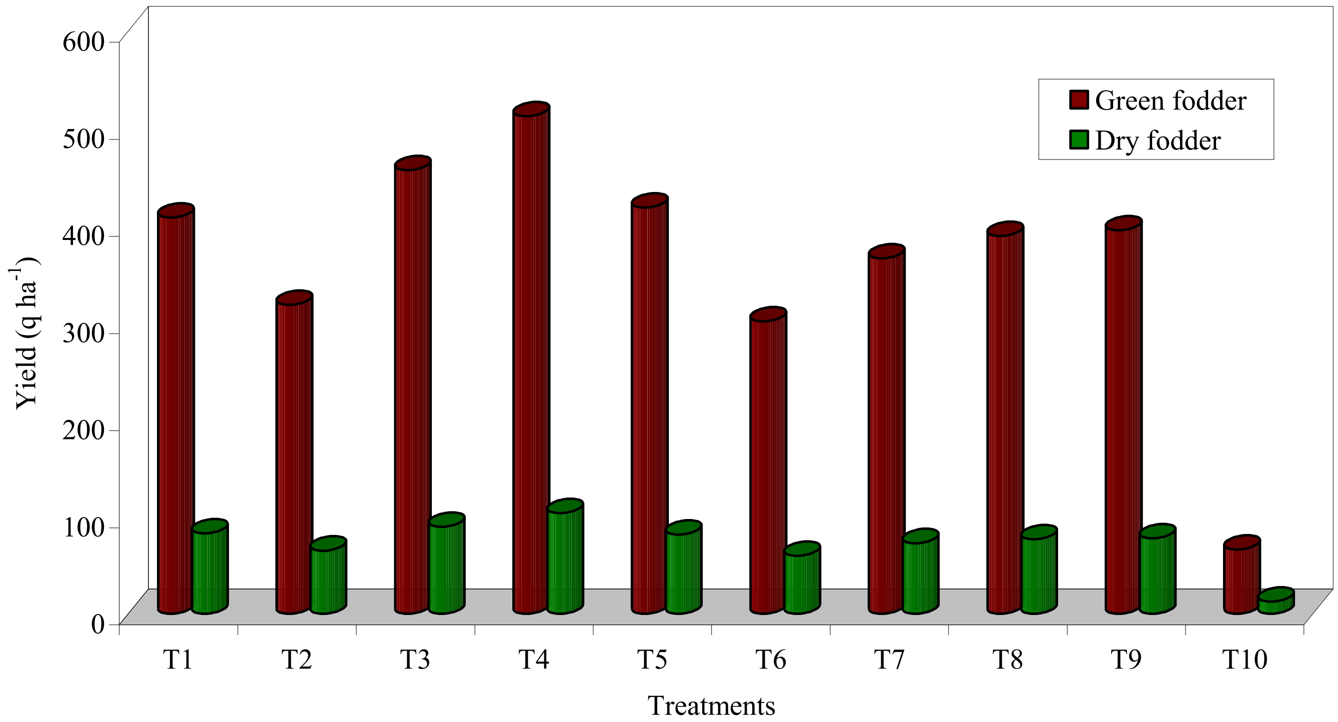


Fig.6 Green and dry fodder yield (q ha^{-1}) of fodder maize of first crop

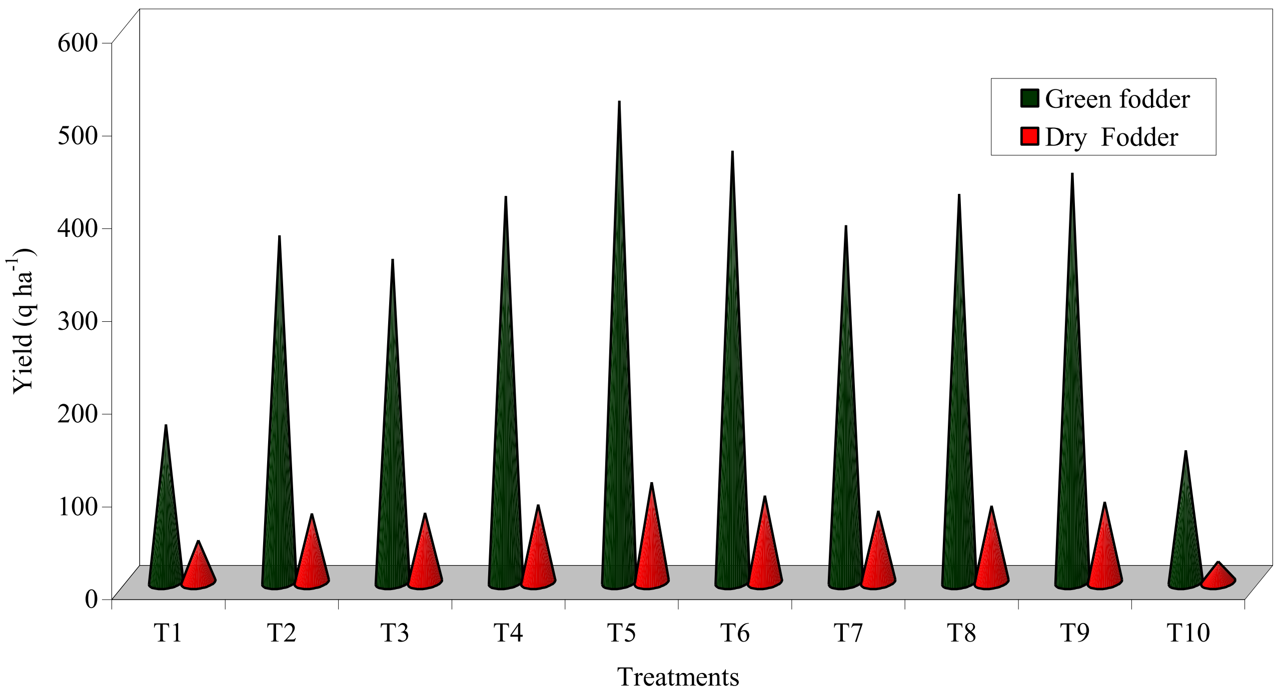


Fig. 7. Green and dry fodder yield (q ha^{-1}) of the second crop

5.3.4. Effect of Zn application on the yield of fodder maize

On examining the yield data of the 1st experimental crop, the T_4 treatment ie. POP+10 kg Zn ha^{-1} as soil application recorded the highest yield of 512.5 q ha^{-1} (Table-9). For the 1st residual crop the treatment that received Zn @ 15 kg Zn ha^{-1} showed the highest yield (Table-19).

In the case of 2nd experimental crop the T_5 treatment that received 15 kg Zn ha^{-1} recorded the highest yield (519.30 q ha^{-1}) and it was on par with T_6. The yield of the fodder maize due to the foliar application of Zn leaf at 4th leaf stage showed a steady increase from the lowest to highest level of foliar spray given and the trend was same for both the experimental crops raised (Table 9 and 23).

The yield data of the 1st and 2nd experimental crop were pooled and analyzed statistically (Fig. 8). The pooled analysis data for the yield was found significant for the Zn applied treatments. Katyal *et al*. (1999) emphasized the role of Zn in increasing yield of pearlmillet. For the pooled data, the T_5 with a mean value of 468.8 q ha^{-1} showed the highest yield and it was on par with T_4, T_8 and T_9 which recorded a yield of 465.5 q ha^{-1}, 403.90 ha^{-1} and 418.30 q ha^{-1} respectively. The T_8 and T_9 were the foliar applied plots. It is seen that the yield difference between T4 and T5 was only 4.3 q ha-1 a meager difference only (Table . 35).

For the of 1st residual crop, the plot that received 15 kg Zn ha^{-1} and for the 2nd residual crop, the plot that received 20 kg Zn ha^{-1} recorded the maximum yield (Fig. 9). But for the experimental crops the highest yields were at 10 kg Zn ha-1 and 15 kg Zn ha-1 for the 1st and 2nd crop respectively. From this it is presumed that the plants haven't utilized fully the added Zn fertilizer at these higher doses during the year the fertilizer was applied. This may be due to the tendency of the soil organic matter to chelate the added zinc or may be due to the slow rate of movement of this element to plant roots in the soil.

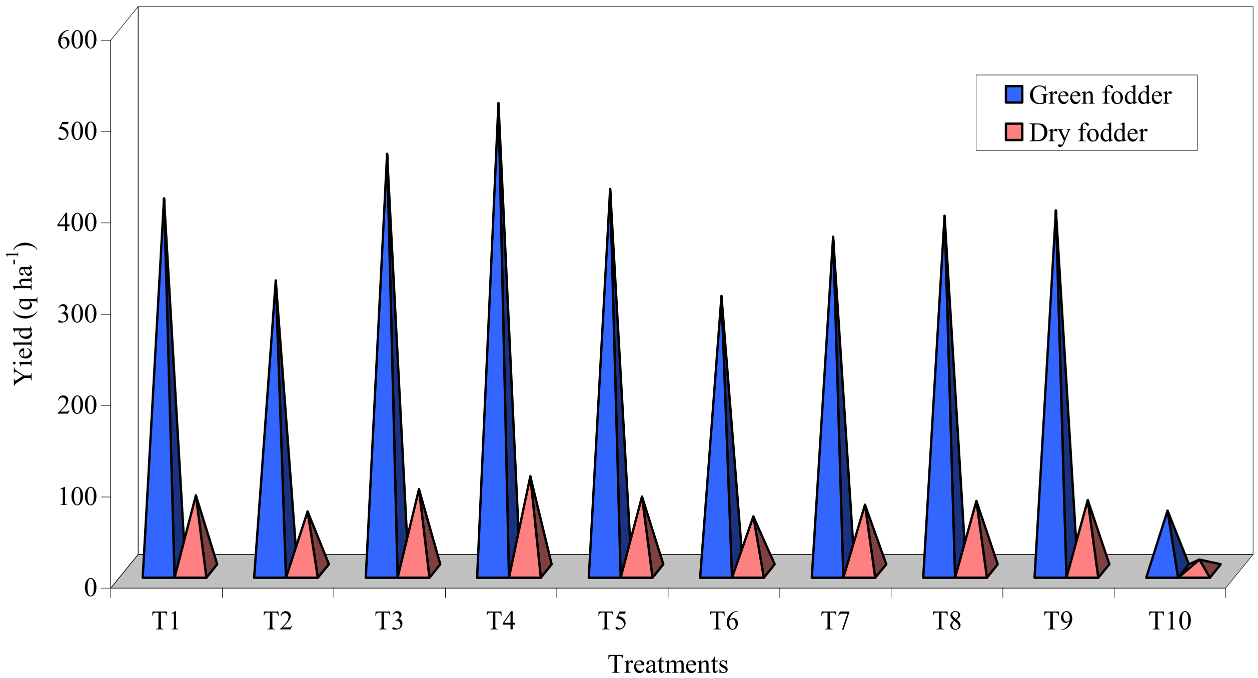


Fig. 8 Pooled analysis data on green and dry fodder yield (q ha^{-1})

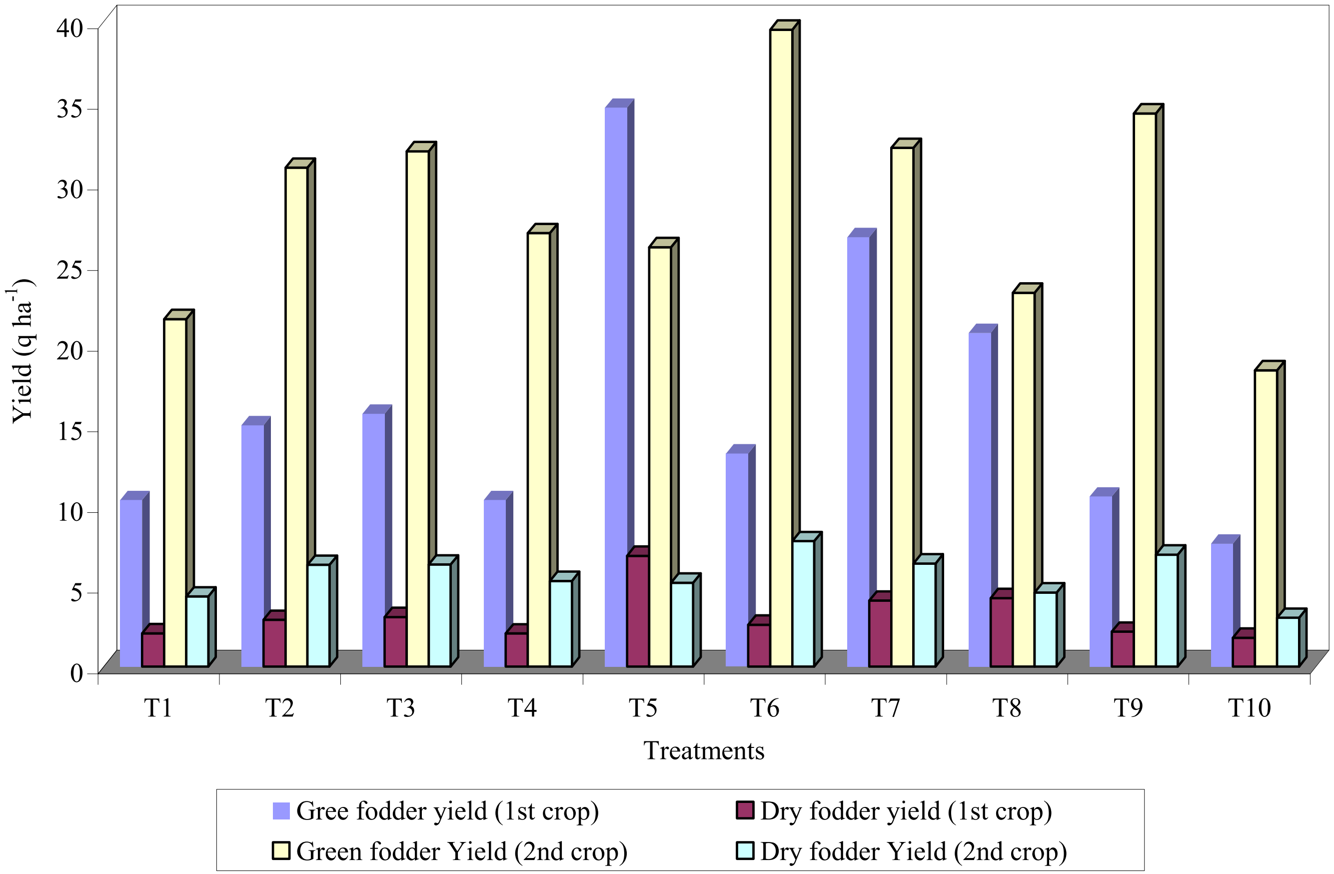


Fig.9 . Green and dry fodder yield (q ha^{-1}) of residual crops

Continuing application of Zn fertilizers in time tends to increase the level of this nutrient in the soil and particularly its level in the labile forms which can release Zn in the soil solution. Thus even though much of the Zn added in fertilizers was not used during the year of application it may provide an important source in future years.

From the above results the following conclusion could be drawn.

For raising a single crop of fodder maize var. African Tall, soil application of Zinc sulphate @10kg Znha^{-1} along with pop ie. 10t ha^{-1} FYM and NPK 120:60:40 kg ha^{-1}is being recommended. The increase in yield caused by FYM with Zn could be attributed partly to the presence of Zn in FYM itself and also to the chelation effect of organic acids formed during decomposition on both native and applied Zn. One common characteristic of all the micronutrients is that they are required in very small amounts. Also, they are all harmful when the available forms are present in the soil in larger amounts that can be tolerated by plants or by animals consuming the plants. Thus the range of concentration of these elements in which plants will grow satisfactorily must not be too great. Irrespective of the source, grain yield and zinc uptake significantly increased upto 10kg Zn ha^{-1} (Prasad and Umar,1993). Application of 15kg $ZnSo_4$ha^{-1} as soil application along with POP for the 1st crop will help to skip the Zn application of the succeeding crop. The profitability of Zn application in conjunction with FYM could be higher if the carry over benefits of a single application to succeeding crops are taken into account. Residual carry over of available zinc varies from slight to moderate, increasingly as soils become less alkaline.

The foliar application @0.75% $ZnSo_4$ is recommended at 15 DAS. The 0.75% $ZnSO_4$ as foliar spray at 15 DAS recorded the highest yield among foliar application treatments and it was on par with T_4. Foliar spray of zinc sulphate was an effective emergency method but in highly zinc deficient soils it did not compare well with soil application of zinc. (Katyal and Rattan, 2003)

5.3.5. Quality attributes of fodder maize

Regarding the quality aspects of first crop maximum crude protein percentage and crude protein yield was also recorded for T_4, where maximum fodder yield has been obtained. The lowest crude fibre was obtained in T9 (23.1%), but it was on par with T4 (23.7%) (Table-10 and Fig. 10). For the second crop (Table-23) the highest crude protein was for T_3 but it was on par with T_4. Considering the quality aspects viz. increased crude protein and reduced fibre, the T_4 treatment could be identified as the best treatment. Forage with less fibre and more protein was relished by the cattle. Crude fibre consists largely of cellulose and lignin (97%) plus some mineral matter. The crude fibre content is commonly used and measure of the nutritive value of livestock feeds. In addition to the nutrition of the crop, the genetic make up and potentiality of the African Tall variety also might have influenced the better performance of the variety. The increase in protein content due to zinc addition might be due to its involvement in the N metabolism of the plant (Frescenko and Lozek, 1998). Zn activates enzymes in protein synthesis. The higher crude protein was due to the high nitrogen content (Evans and Sagar, 1966).

5.3.6. Nutrient concentration in fodder maize

The N, P, K, Ca, Mg, S and other micronutrient contents showed significant variation among treatments. In the case of N,P,K, Fe, Mn, Zn and Cu, T_4 showed the highest or statistically on par with the highest, nutrient concentration in the plant (Table-11 and Fig.11 & 12). Increased uptake of nutrients due to the application of Zn to maize was reported earlier (Hulagur and Dangarwal, 1983). But Ca and Mg recorded the highest concentration in T5 but in the case of Mg it was on par with T_4. At the highest level of Zn application ie at 20 kg $Znha^{-1}$, the Cu content was found to be decreased. Plant roots appear to absorb Zn and Cu by the same mechanism. This might have caused interference in the uptake of Cu, when Zn was in excess.

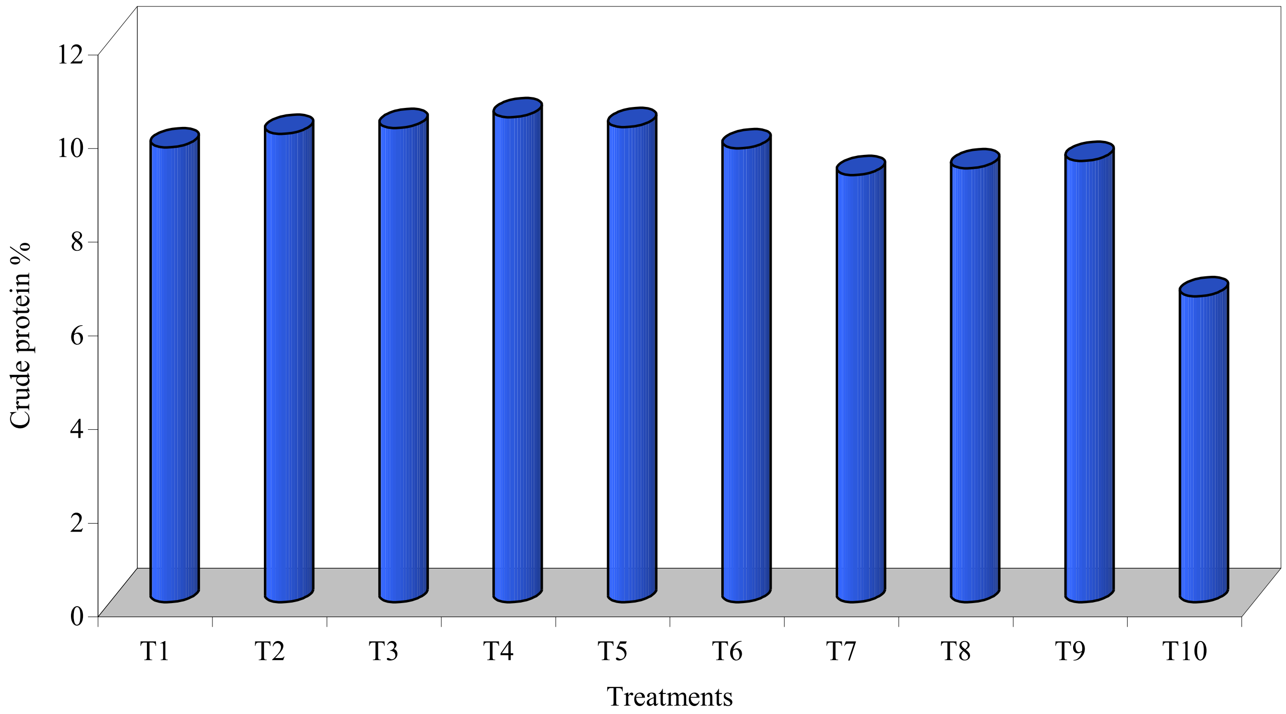
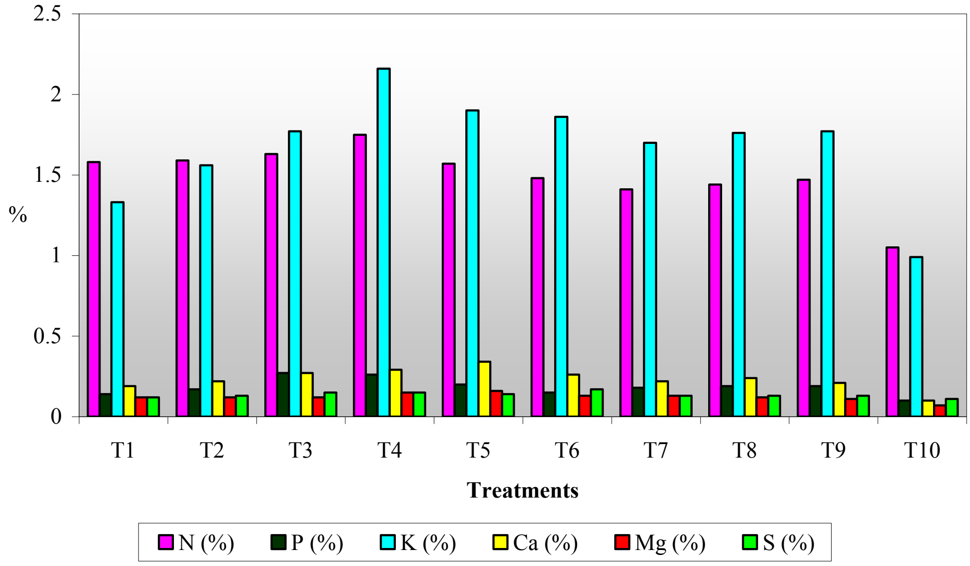


Fig. 10 Mean value of crude protein content of 1st and 2nd crop

First crop



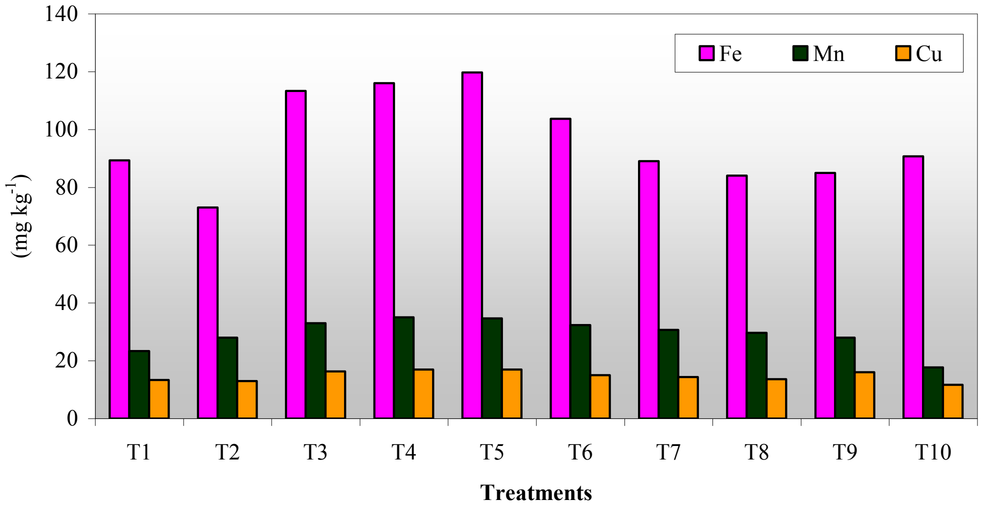
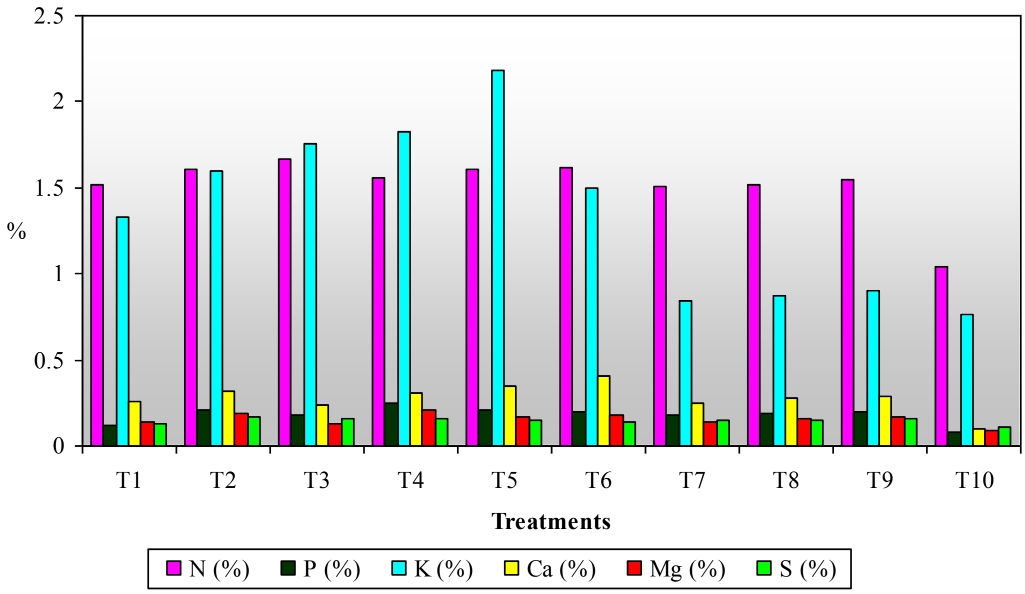
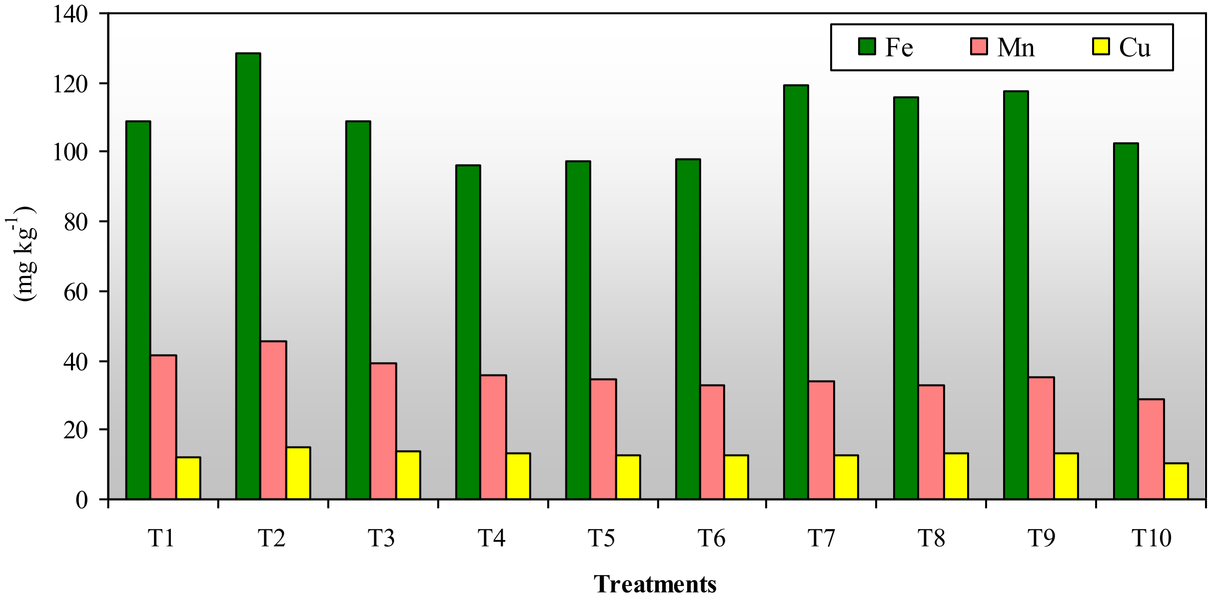


Fig. 11. Total nutrient concentration in the fodder maize


2.5
2
1.5
1
0.5
0
%
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
Treatments
N (%)
P (%)
K (%)
Ca (%)
Mg (%)
S (%)


140
120
100
80
60
40
20
0
(mg kg-1)
Fe
Mn
Cu
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
Treatments

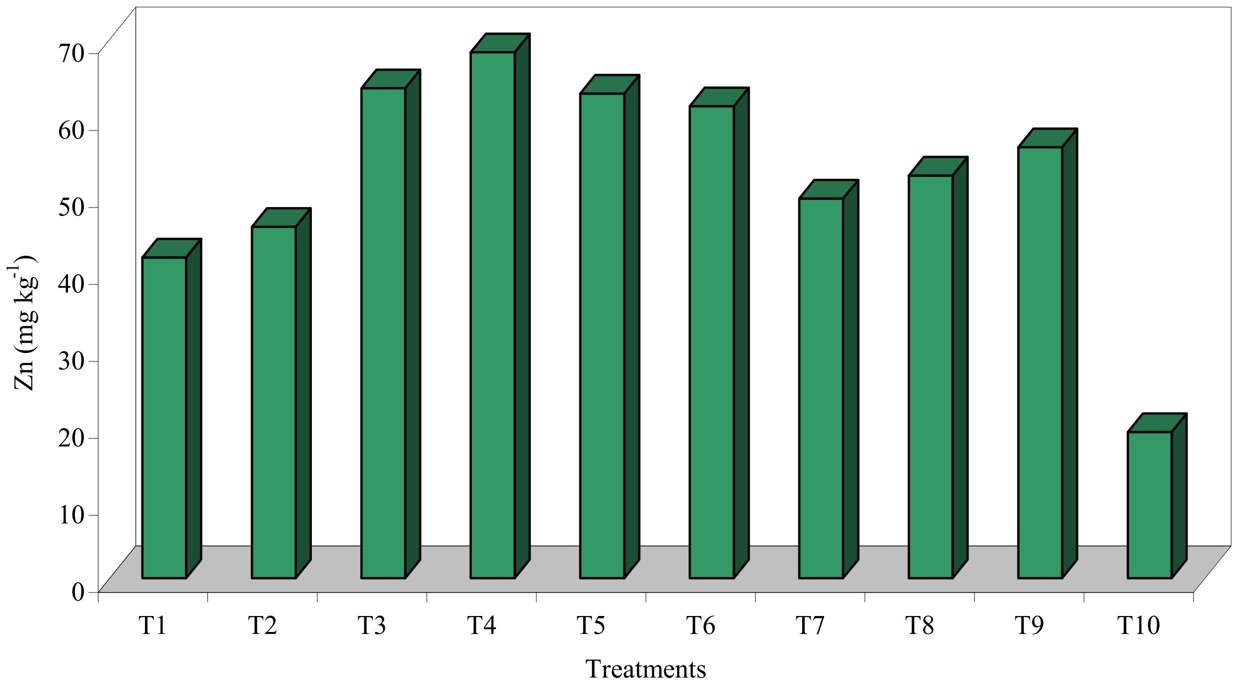


Fig. 12 Total Zn concentration in the plant

For the second crop also (Table-24) the Zn applied treatments (soil application) recorded the maximum and comparable N content in plants.

In the control plot, the concentration of nutrients in the plants, were minimum, the low N availability might have decreased the vigour of plants to an extent that it affects the uptake of other nutrients.

5.3.7. Physico-chemical properties and nutrient content of the soil after the crop growth

After the crop growth (Table-12 & 26, and Fig. 13 & 14), a reduction in the Nitrogen and phosphorus content was noticed in the soil. But the potassium content has been increased from the initial level. The release of non-exchangeable K might have contributed to this increased content. The crop requirements were partly met from the released K and both the applied K and released K caused available K build up in the soil. The differential release pattern of non-exchangeable K from the soil reserve besides variation in K uptake by the crop was also responsible for differences in the available K status in soil (Yaduvanshi et al. 1985). The experimental area represents more of coarse fractions of sand and that also might have influenced the K availability. Pasricha (2002) reported that coarse fractions of sand and soil in many soils can be an important source of K for crop plants. Studies on the release of K from sand fractions showed comparable or slightly higher release of K in soils.

In the case of available P, maximum content of 16.57 kgha^{-1} after the 1st crop was noticed for the treatment where Zn @ 5 kg ha^{-1} has been applied. As the level of Zn application increased the P content was found to be decreased. The antagonistic relationship of P and Zn was reported by many scientists (Orabi *et al.*1985 :Barrow, 1987;Lonaragan and Webb ,1993). Much variation after the crop growth has not been showed for the nutrients viz. Ca, Mg, S,Fe and Cu (Table 14

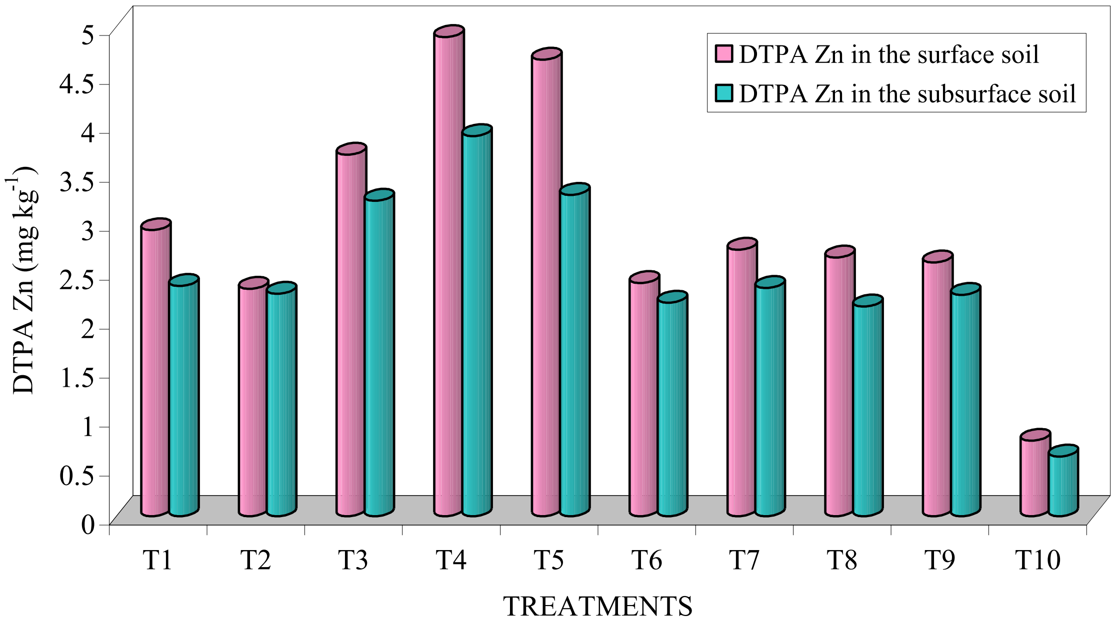


Fig.13 DTPA Zn in the surface and subsurface soil after the first crop

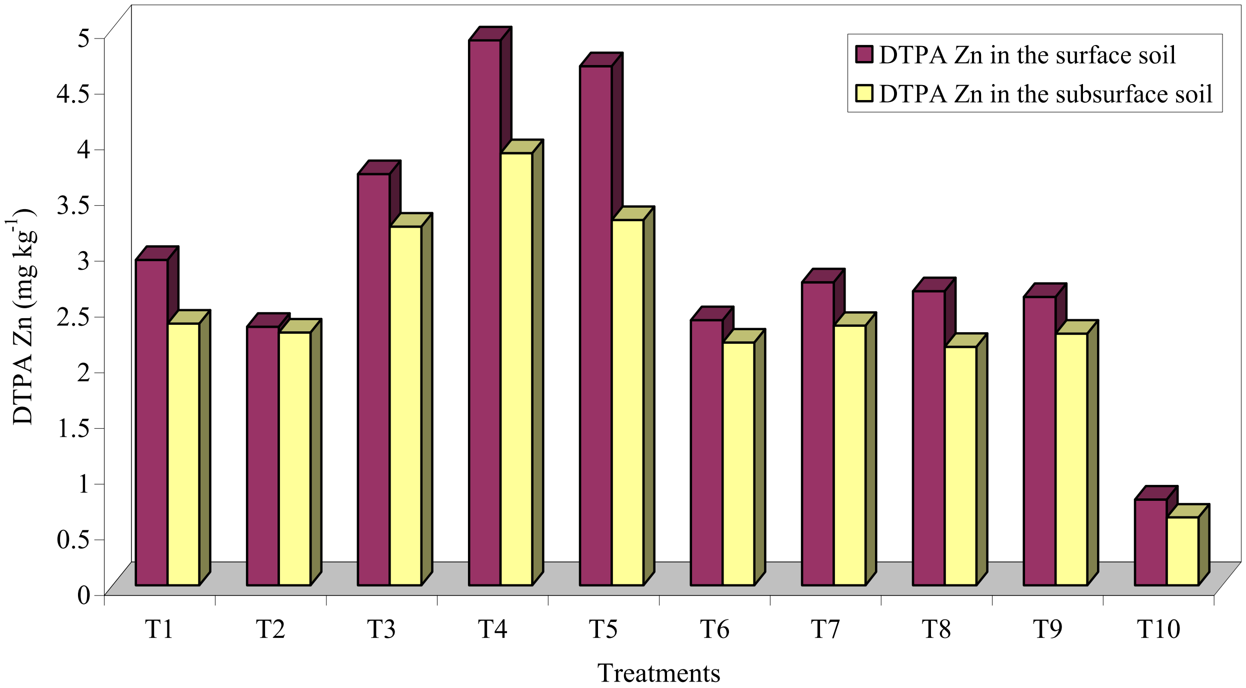


Fig.14. Concentraton of Zn in the surface and subsurface soil after the second crop (mg kg^{-1})

and 28). Zn content got increased in the Zinc applied as well as farm yard manure applied plots. The applied Zn nutrient as well as the chelated Zn in the organic matter might have contributed to this. A reduction in the Mn content was noticed after the crop growth. Similar findings were reported by Lombanaes and Singh (2004).

5.3.8. Zinc fractions of soil after the crop growth

The data on the different fractions of Zn in the surface soil (Table 15 & 29 and Fig. 15 &16) revealed that the Ws+Exch. Zn was maximum in T_9 and it was found significantly superior to other treatments. Actually these Ws+Exch-Zn. Fractions contributes to the available Zn and that might not have been utilized by the plant and reflected in the significantly lower yield. In T_4, where the highest yield (512.5 qha^{-1}) obtained plot recorded a significantly lower content of Ws + Exch. Fraction of Zn. Randhawa and Singh (1995) reported that exchangeable Zn contributed to the pool of available Zn and thus played a significant role in the Zn nutrition of maize.

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The percentage contribution of different fraction of Zn to the total Zn in the surface soil, after the growth of first crop varied from 0.34 to 4.08 Ws+Ex- Zn, 1.37 to 3.89 OB- Zn, 0.11 to 0.83 MnO-Zn, 16.95 to 38.96 Am FeO-Zn, 20.91 to 61.45 Cry Feo-Zn, 7.92 to 48.49 Res- Zn and for the subsurface soil, it varied from 0.11 to 2.59 Ws+Ex- Zn, 0.36 to 2.36 OB- Zn, 0.42 to 1.70 MnO-Zn, 13.58 to 30.24 Am FeO-Zn, 25.51 to 58.69 Cry Feo-Zn, 19.19 to 55.78 Res- Zn. The range values of different fractions showed that all the fractions, except Mn O-Zn were lower in the surface soil.

After the growth of the second crop also, the soil samples were collected from the surface and subsurface and analyzed the different Zn fractions. The percentage contribution of the different fractions to the total Zn varied from 0.72 to 4.83 Ws+Ex- Zn, 1.49 to 3.76 OB- Zn, 0.31 to 1.12 MnO-Zn, 10.01 to 43.56 Am

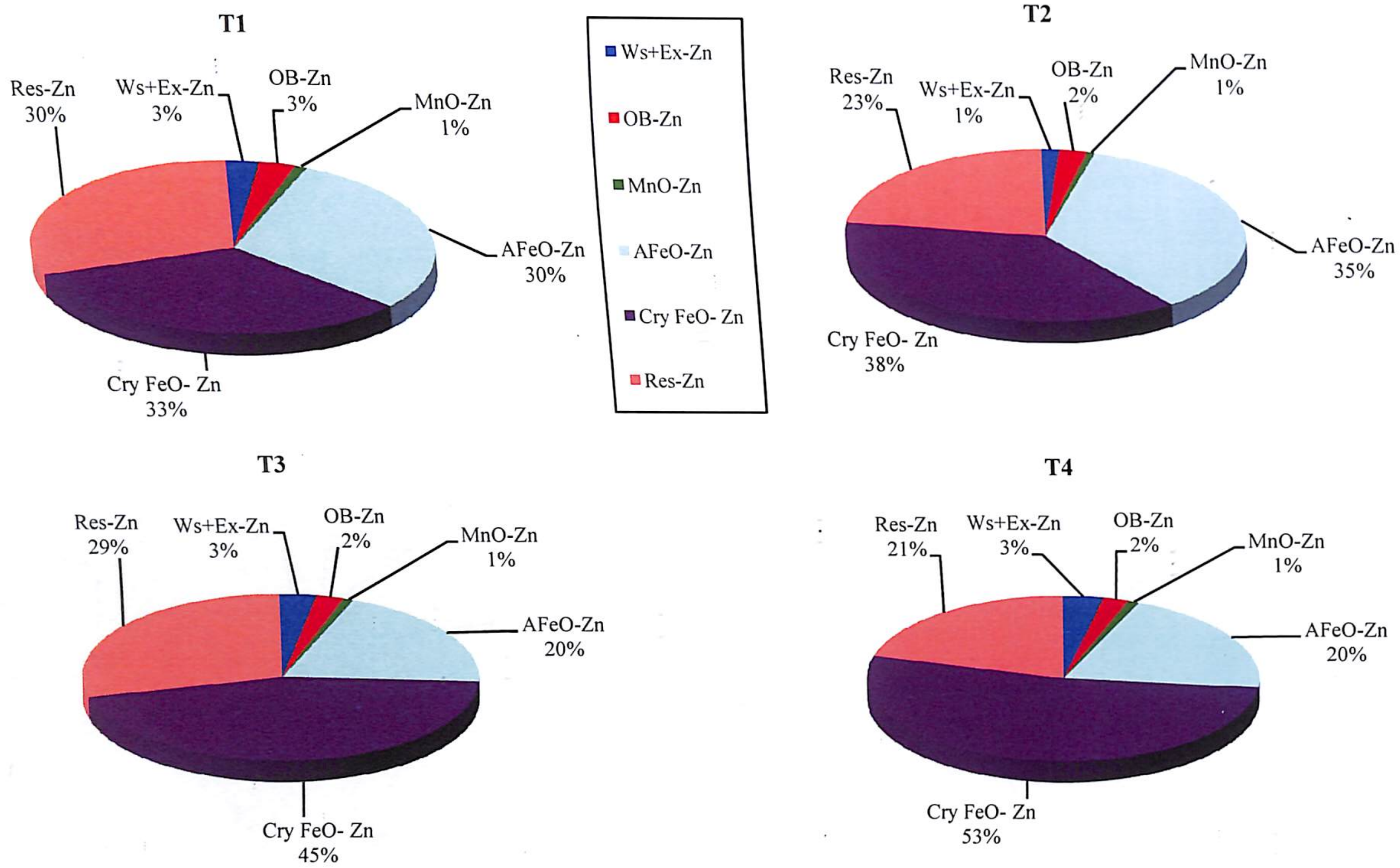


Fig. 9 Mean values of different fractions (%) of Zn to the total Zn in the surface soil

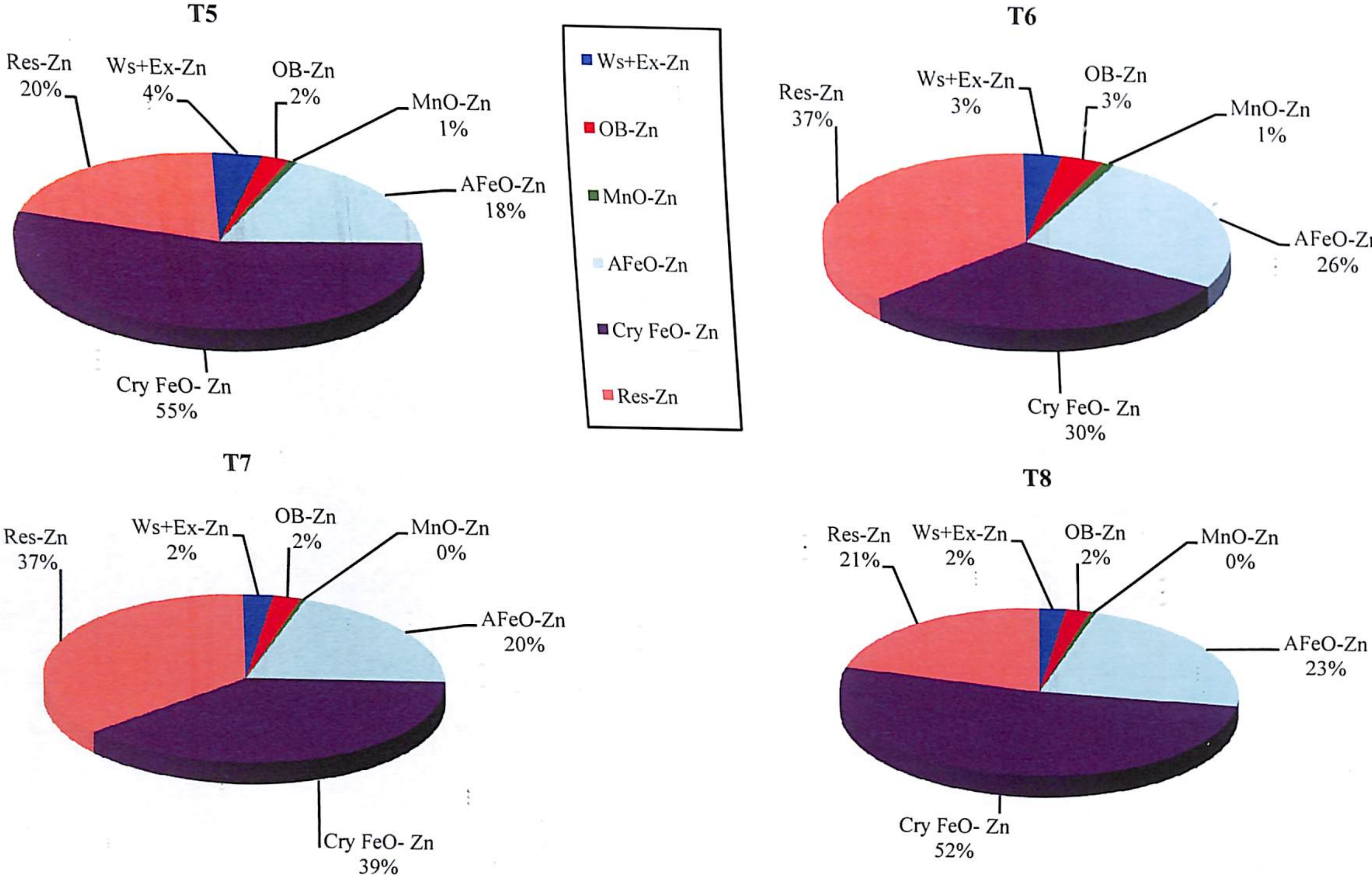
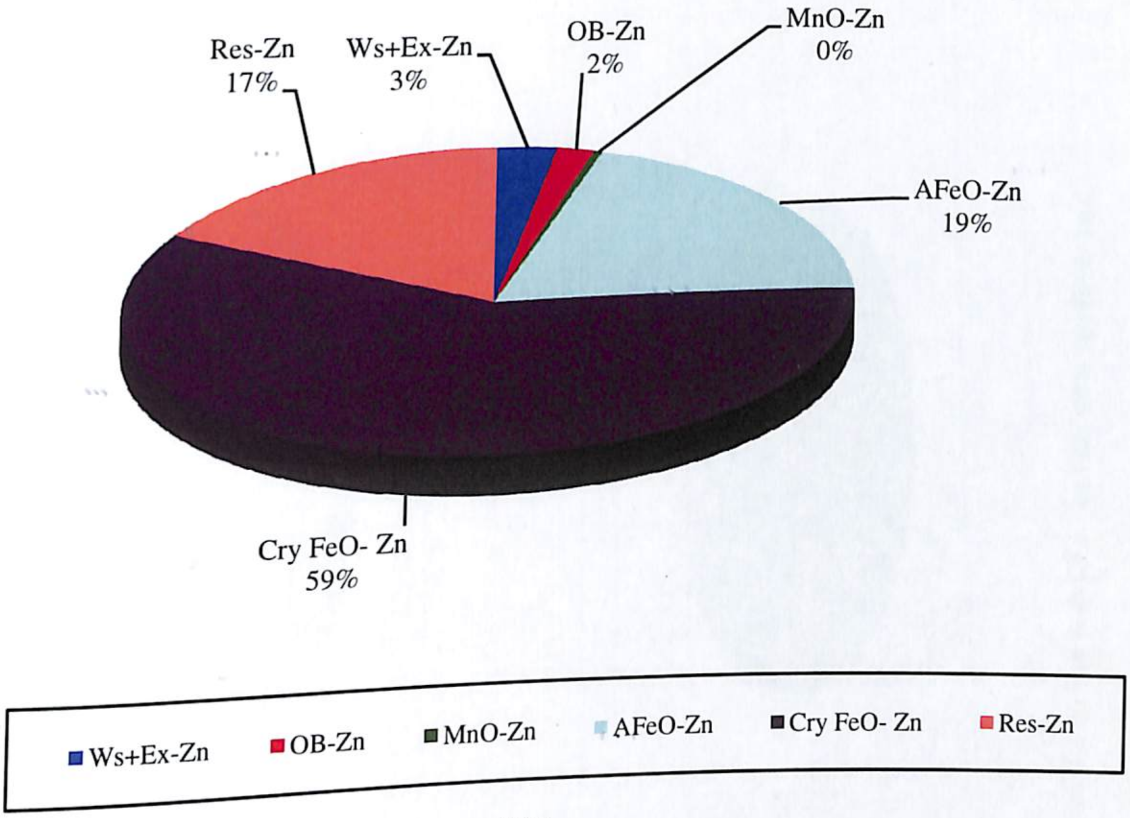


Fig. 9 Mean values of different fractions (%) of Zn to the total Zn in the surface soil (Continued)

T9



T10

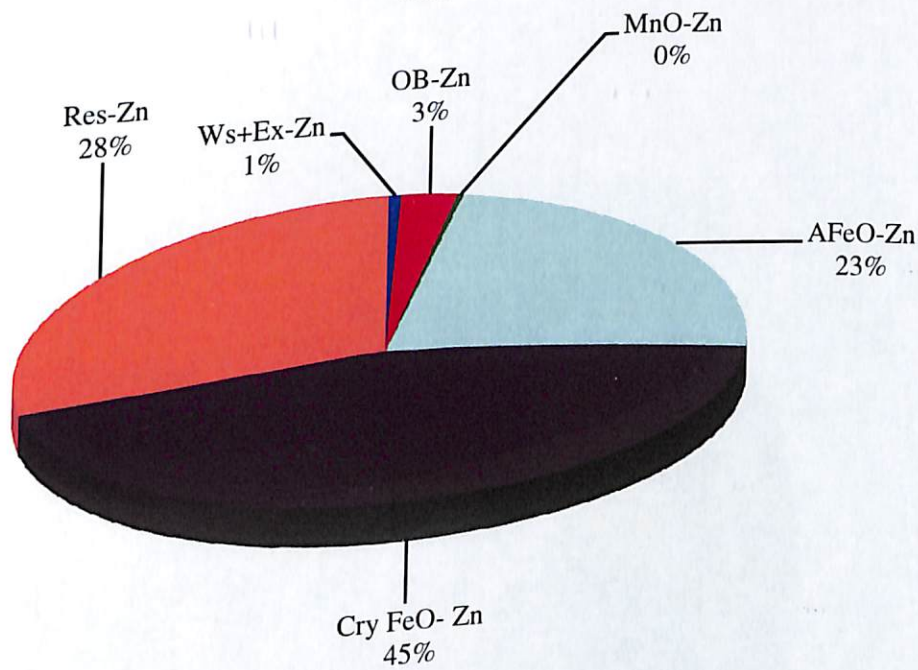


Fig. 9 Mean values of different fractions (%) of Zn to the total Zn in the surface soil (Continued)

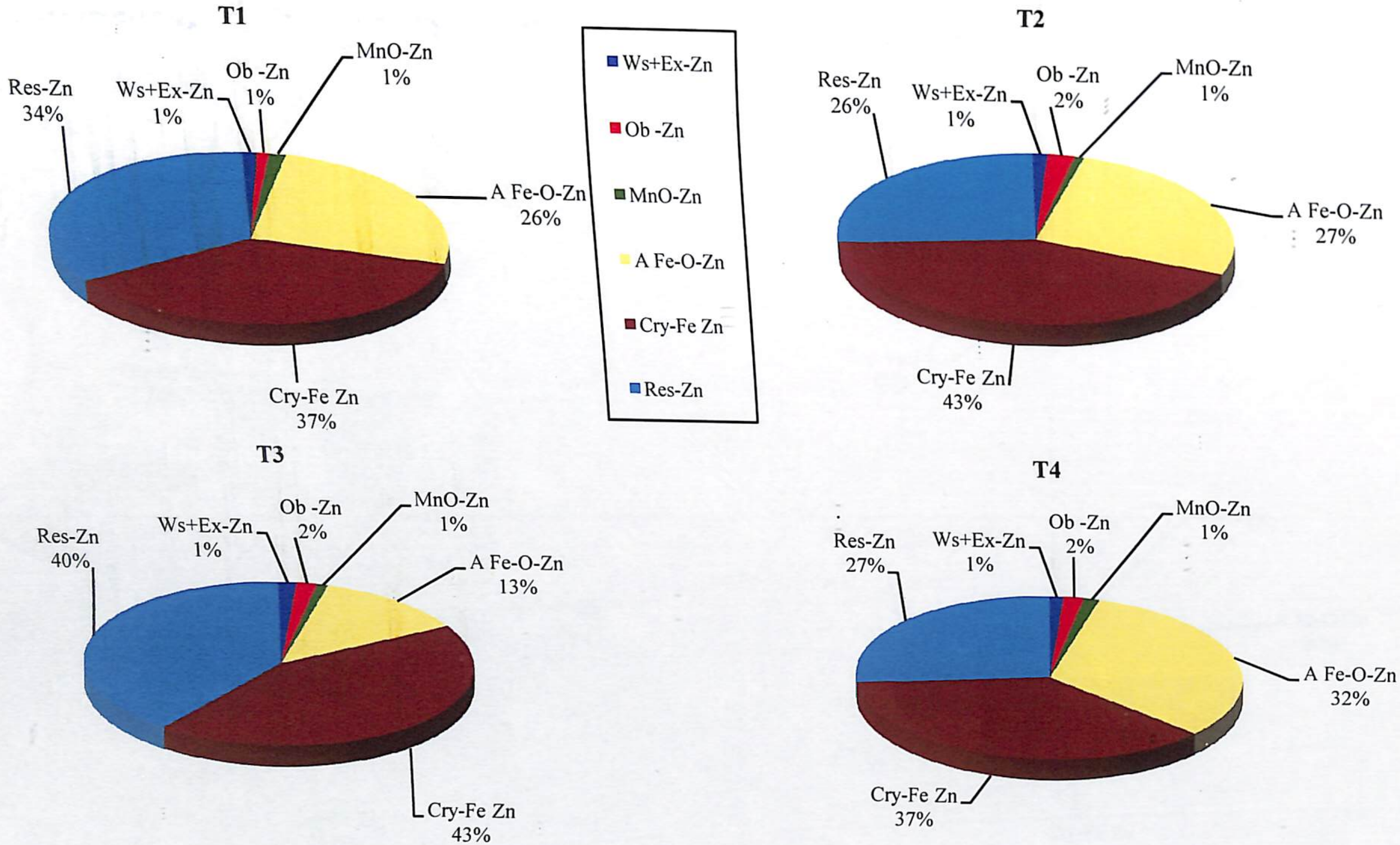


Fig. 10 Mean values of different fractions (%) of Zn to the total Zn in the sub surface soil

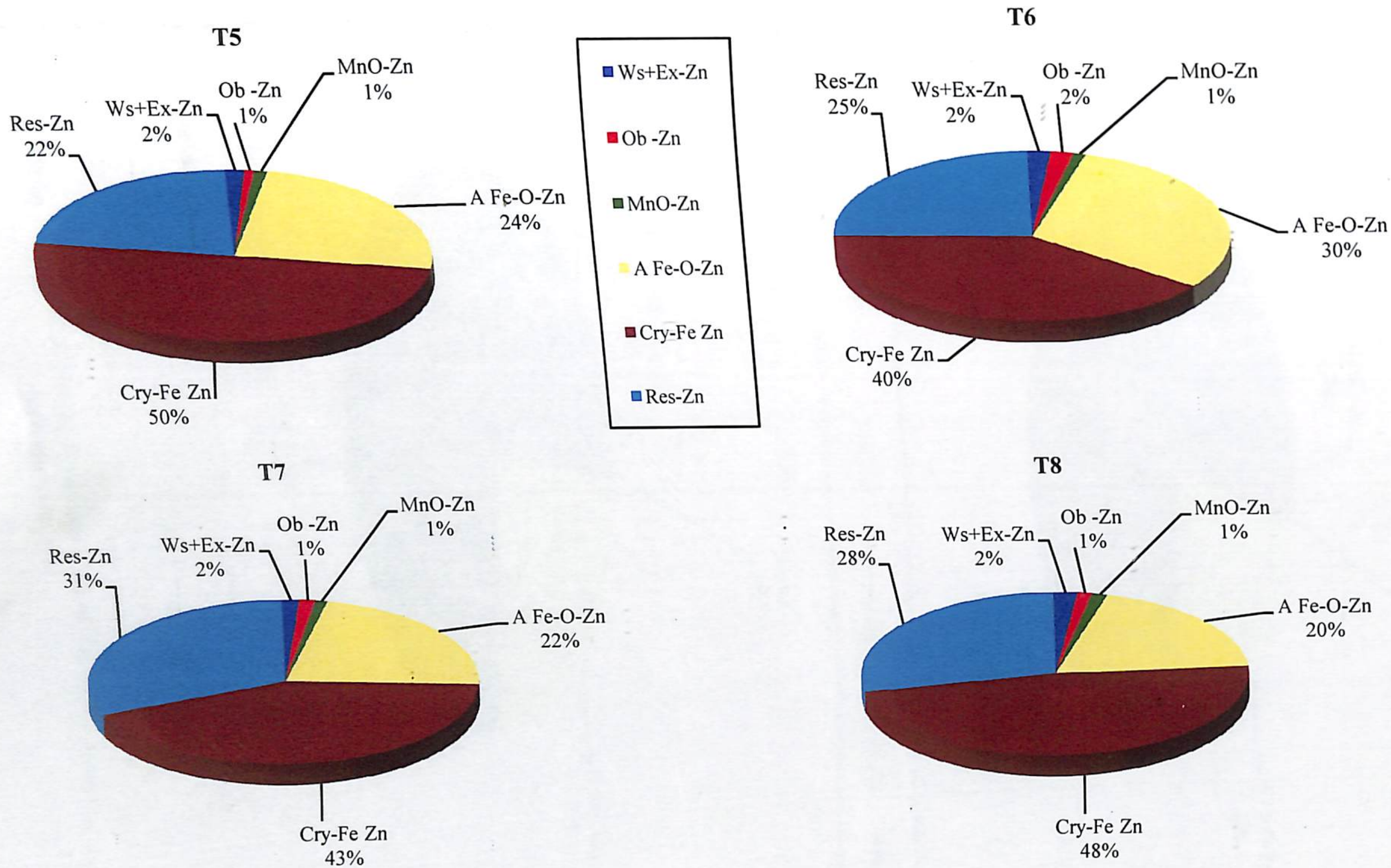


Fig. 10 Mean values of different fractions (%) of Zn to the total Zn in the sub surface soil

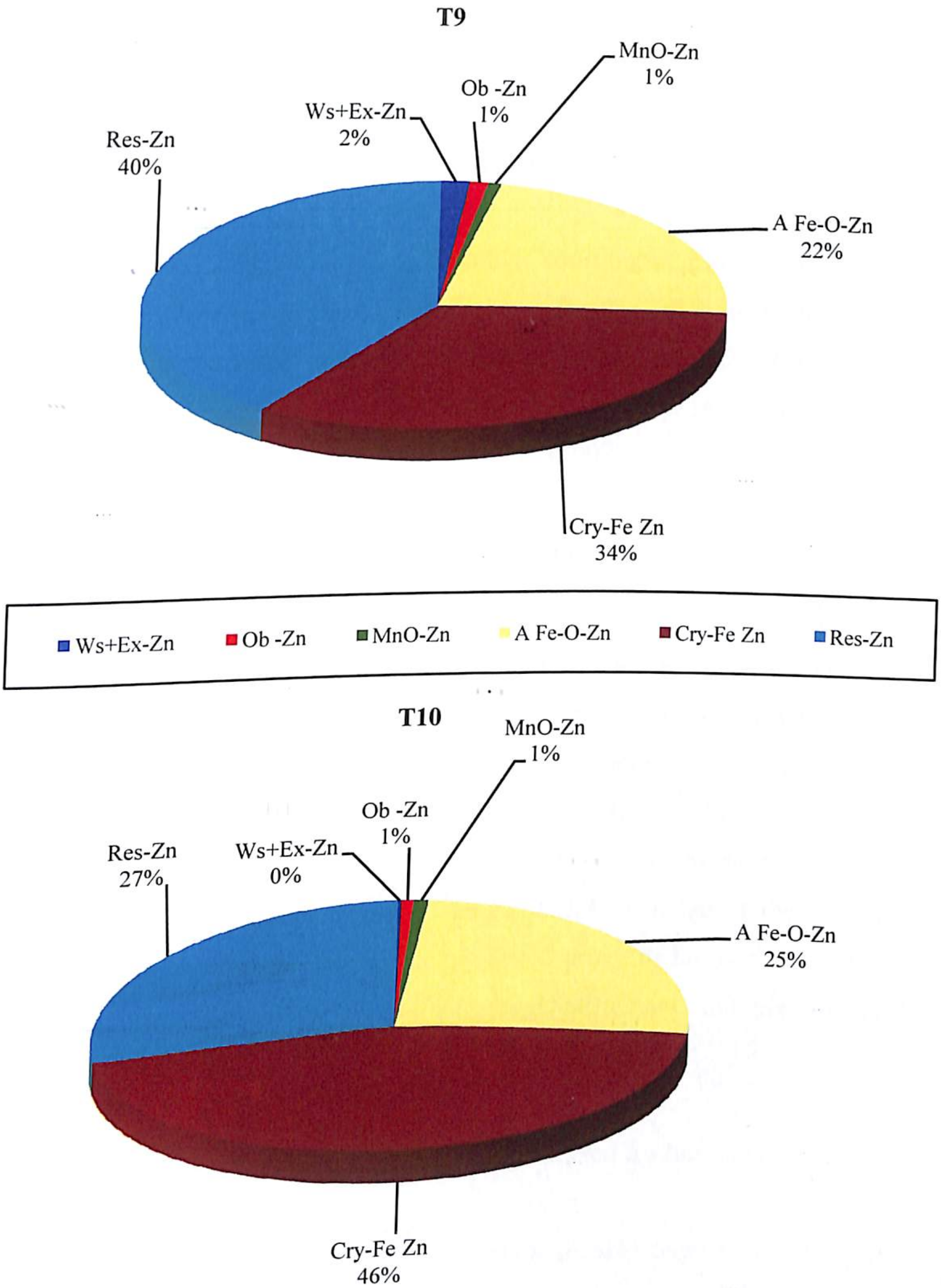


Fig. 10 Mean values of different fractions (%) of Zn to the total Zn in the sub surface soil

FeO-Zn, 27.91 to 66.0 Cry Feo-Zn, 16.33 to 31.09 Res- Zn for the surface soil and 0.20 to 2.59 Ws+Ex- Zn, 0.86 to 2.36 OB- Zn, 0.86 to 1.81 MnO-Zn, 13.58 to 37.96 Am FeO-Zn, 36 to 59 Cry Feo-Zn, 16.81 to 38.69 Res- Zn for the subsurface soil. As in the MnO-Zn fractions recorded a higher content in the sub-surface layer.

The perusal of the data on the percentage contribution of each fraction to the total Zn showed that the highest contribution was for the Am Feo-Zn and Cry Feo-Zn. In both the surface and subsurface soils after the crop growth. The crystalline iron oxides present in the soils of the experimental area might have influenced this.Similar results are reported by Arundino *et al*. (2007).

5.3.9 Indexing of leaf part in fodder maize for Zn status

Leaf analysis as a diagnostic tool was first recognized by Weinhold (1862) .Lundegardh (1935) defined index plant part as that part of a plant which gives the highest predictability on yield. This is based on the assumption that concentration of the nutrients in the leaf at the specific growth stage is related to the performance of the crop (Bould *et al*. 1984). Nutrient content of various plant parts of plant can assist in evaluating the nutrient status of crops. The knowledge of the plant part which accumulate the highest concentration should prove to be useful criterion in delineating the deficiency level of nutrients from sufficiency and toxicity levels (Sharma and Bapat,2000).

The leaf lamina and petiole samples were analysed for the Zn content.

The values of coefficient of correlation (r) obtained at each stage of the crop are given below.

Table .40 Coefficient of Correlation of Zn content and yield at different stages of sampling

Stages of sampling	3rd leaf lamina	3rd petiole	4th leaf lamina	4th petiole	5th leaf lamina	5th petiole
15	0.844*	0.839*	0.786*	0.806*	0.780*	0.751*
25	0.933*	0.804*	0.746*	0.848*	0.673*	0.868*
35	0.906*	0.847*	0.868*	0.660*	0.847*	0.743*
45	0.907*	0.884*	0.903*	0.788*	0.851*	0.722*

* Significant at 5% level

The 3rd leaf lamina at the 25th DAS recorded the maximum relationship with green fodder yield as evidenced by the highest value for coefficient of correlation (0.933) and it was selected as the best index part for foliar diagnosis as a close relationship exists between the concentration in that part and yield. Young leaves are particularly suitable for determining Zn status of the plants because symptoms of Zn deficiency usually develop in young leaves and also Zn content of the young leaves is usually more stable than that of older leaves (Rossel and Ulrich,1964).

For determining the critical Zn content in the selected index part (third leaf lamina at 25 DAS) for maximum yield the Scatter diagram technique outlined by Cate and Nelson (1965) was employed (Fig.17). Graph was plotted relating the Zn content in that part at 25 DAS (X- axis) to yield (Y-axis). The points were distributed into four quadrants using plastic overlays maximizing the points into the first and third quadrant. The intersecting point of the line on X-axis drawn parallel to

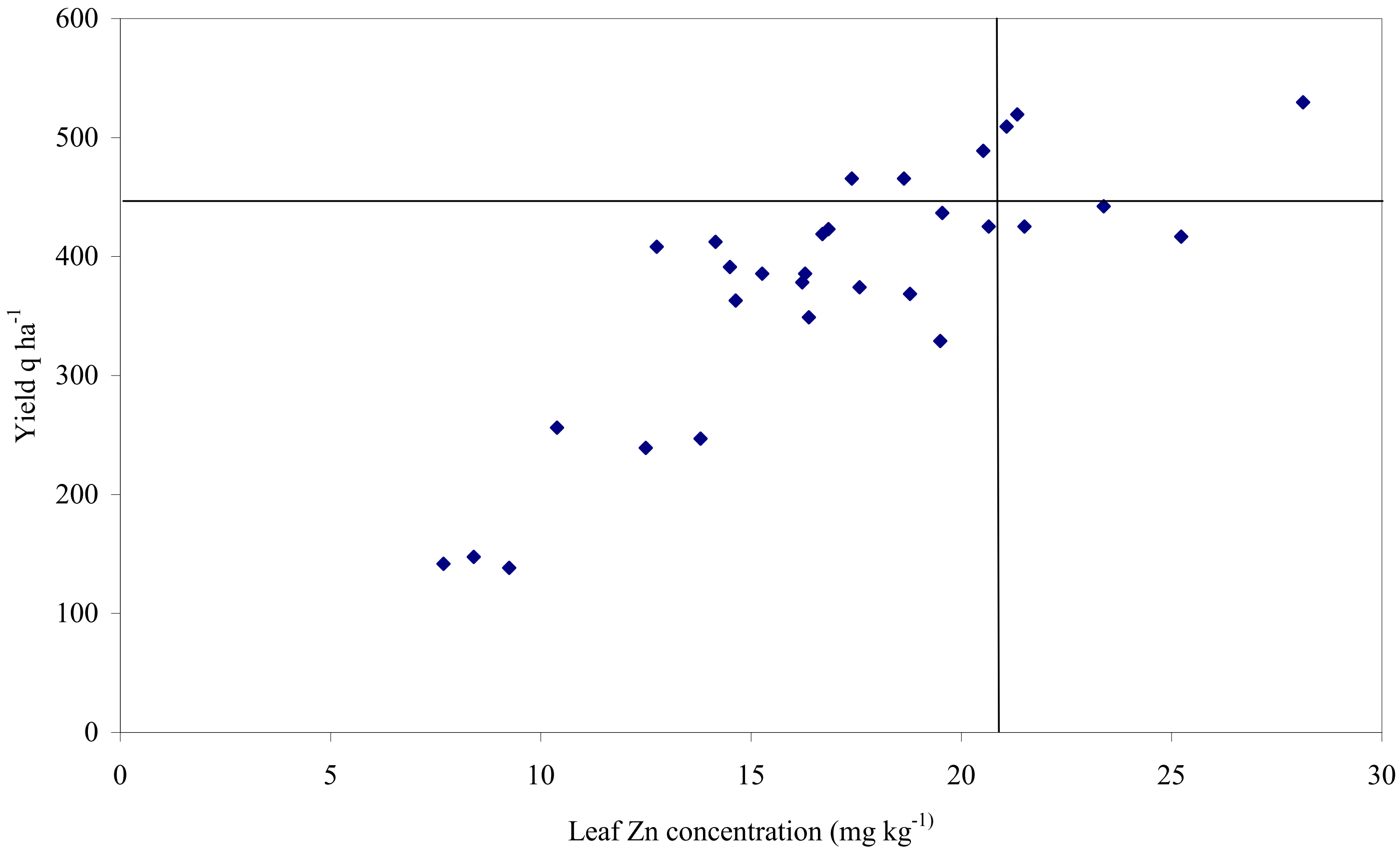


Fig. 17. Scatter diagram for crtical level of Zn for maximum yield

Y-axis was taken as the plant critical Zn level in the third leaf lamina at 25 DAS was computed as 21 mgkg^{-1} for maximum yield in fodder maize (Fig.17.). This is in accordance with the report by Alwarez *et al*. (1996).

5.3.10 Path Analysis of various fractions of Zn with Yield

Different fractions of Zn in the surface soil were selected for studying their direct and indirect effect on yield. The different fractions considered were Ws+Ex.-Zn(X_1), OB-Zn (X_2), MnO-Zn (X_3), Am FeO-Zn (X_4), Cry-FeO-Zn(X_5) and Total –Zn (X_6). Path coefficient analysis technique was employed to study the cause and effect relationship of these factors with yield. The results are presented in Table. 41 and illustrated in the Fig. 18

Table . 41 Coefficient of Correlation of Zn fractions with Yield

Parameters	Direct effect	Total indirect effect	Total correlation	Maximum indirect effect
Ws+Ex.-Zn(X_1)	1.1267	-0.4037	0.7230*	0.7327
OB-Zn (X_2)	-0.6706	0.9949	0.3243	-0.3582
MnO-Zn (X_3)	0.1860	0.3539	0.5399*	0.1210
Am FeO-Zn (X_4)	0.6559	0.6942	-0.0384	0.3169
Cry-FeO-Zn(X_5)	0.0815	0.4867	0.5682*	0.0374
Total –Zn (X_6)	-0.0776	-0.3313	0.4414	-0.0308

*Significant at 5% level

From the above it can be observed that the fraction X_1 (Ws+Ex.-Zn) had maximum direct effect on yield (1.1267). The influence of X_4 (Am FeO-Zn) was also positive and direct (0.6559). But the effect of OB-Zn (X_2), even though direct, was negatively significant (-0.6706).

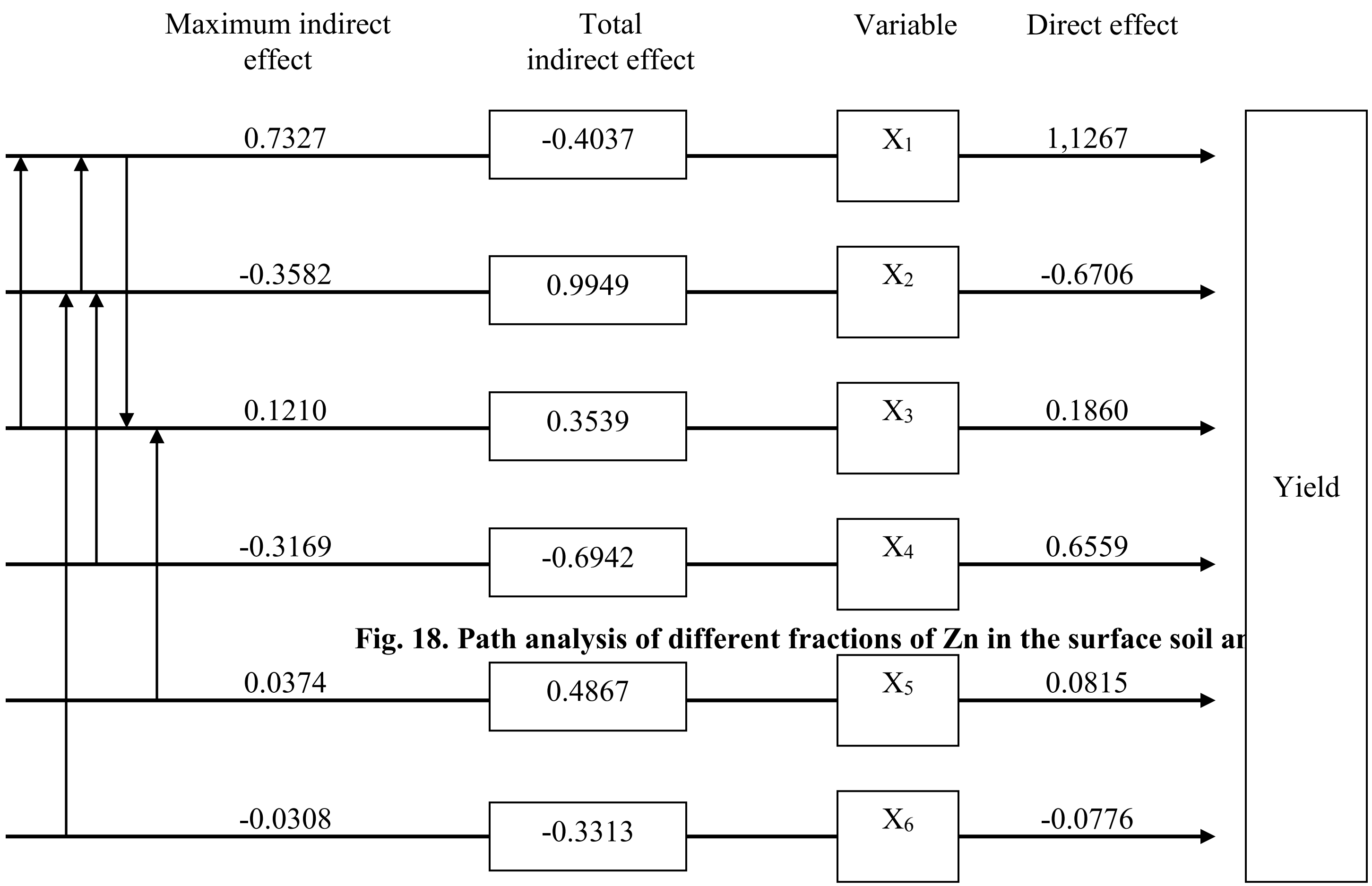


Fig. 18. Path analysis of different fractions of Zn in the surface soil ar

The indirect effect of X_1 was maximum (0.7327) through X_3 . The indirect effect of X_2 was through X_1 (-0. 3582). The indirect effect of X_3 was through X_1 (0.1210) even though it was not significant . The indirect effect of X_4 was through X_2 (-0.3169) while that of X_5 was through X_3(-0.0308) and X_6 through X_2 (-0.3582).

The results suggested that the depletion of Zn from fractions that are readily available to plants will be compensated by replenishment from other fractions of soil agreeing with reports by Viets (1962). The dominance of Ws+Ex.-Zn fraction through directly contributed to yield is quite evident .Hydrous oxides have a strong affinity for Zn, but they do not fix it in an available form (Mandal and Mandal, 1996). So the Ws+Ex-Zn fraction exert direct effect on yield. Similar findings were reported by Sharma *et al.* (1986) also.

The effect of total Zn is negative and significant. It indicates that the total Zn content is an unsatisfactory or unreliable measure of Zn availability to crops. Similar conclusions have been drawn by Katyal and Rattan, (1993) and Sureshkumar *et al* .(2004)

Table. 42 Economics of cultivation

Treatments	Yield (q ha^{-1})	Total returns (Rs.) x	Total cost of cultivation (Rs.) y	BC ratio (x/y)
T_1	408.10	12243	7805	1.56
T_2	318.30	9549	7990	1.15
T_3	457.10	13713	8755	1.57
T_4	512.50	15375	9505	1.61
T_5	418.40	12552	10255	1.22
T_6	301.40	9042	11005	0.82
T_7	366.10	7322	7998	0.91
T_8	389.30	7786	8006	0.97
T_9	395.10	7902	8014	0.99
T_{10}	66.40	1328	4375	0.30

Economics of fodder maize cultivation presented in the Table.42 showed that T_4 (NPK@120:60:40 kg ha^{-1} + FYM 10 t ha^{-1}+Zn@ 10 kg ha^{-1} as $ZnSO_4.7H_2O$ gave the maximum net returns (Rs.15375/-) and BC ratio of 1.61, followed by T_3 (NPK@120:60:40 kg ha^{-1} + FYM 10 t ha^{-1}+Zn@ 5 kg ha^{-1} as $ZnSO_4$) with a BC ratio of 1.57 and net returns of Rs.13713/- .Net returns and BC ratio were considerably lower for other treatments. So application of Zn @ 10 kg ha^{-1} as $ZnSO_4.7H_2O$ along with NPK @120:60:40 kg ha^{-1} + FYM 10 t ha^{-1} is more remunerative.

6. SUMMARY

Zinc is an essential micronutrient for plants and animals and when the supply of plant available Zn is inadequate, yield and quality of crop products get reduced. Evaluation of total micronutrient content in Indian soils revealed Zn as the most limiting nutrient. Maize is classified as a very sensitive crop to low levels of available Zn. In this context, the present study on the dynamics of Zn in soils and Zn nutrition of fodder maize was carried out and the salient findings of the study are summarized below.

- The results of the incubation study showed that the availability of Zn from the $ZnSO_4$. $7H_2O$ was in the medium range (0.4-2.4 $mgkg^{-1}$) on application of Zn @ 5, 10 and 15 $kgha^{-1}$, up to 60 days of incubation.

- On the 75th day of incubation the available Zn release exceeded the medium range of 2.4 $mgkg^{-1}$ at the highest level of Zn application ie, 20 kg Zn ha^{-1}.

- The soil profile study identified six horizons viz. Ap (0-9.5 cm), Ac (9.5-25 cm), B_1 (25-52 cm), B_2 (52-98 cm), Bt_2 (98-123 cm) and C_1 (123-150 cm).
- Regarding the soil morphological studies, the colour varied from 5YR 3/4 to 5YR4/8 , soil structure from crumb to subangular blocky ,and soil consistence from non sticky- non plastic to slightly sticky and slighly plastic , as the depth of soil profile increased.

- The particle size analysis of the soil samples from different horizons showed that the percentage of sand decreased from 79.4 in the Ap horizon to 51.60 in C_1 horizon. The silt content varied from 16.20 in the Ac to 9.01 percent in the C_1 horizon. The clay content recorded a steady increase from 11.60 percent (Ap horizon) to 36.20 percent in the C_1 horizon. The textural classes were sandy loam for the upper horizons and sandy clay loan for the lower ones.

- The availability of primary and secondary nutrients showed a gradual decrease with depth of soil profile, while available micronutrients followed an irregular pattern of distribution throughout the profile. The Mn content showed a steady increase from 9.7 to 18.94 mg kg-1 from the upper to lower horizon. Zn content decreased from Ap to B_2.

- Regarding the different fractions of Zn, Ws + Ex. – Zn, OB – Zn, Am FeO-Zn, CrY FeO-Zn deceased from upper to lower horizons.

- Initial analysis of surface (0-15 cm) and subsurface soil samples (15-30 cm) were carried out. Among the physico-chemical properties silt percent, Particle density, Bulk Density, WHC etc. showed a slight increase in the sub surface soil. The pH, Available P and K showed a slight increase in the sub surface soil, while all other nutrients recorded higher values in the surface soil.

- All the Zn fractions, except MnO-Zn recorded a higher value in the surface soil.

- At the time of harvest maximum height was observed for T_4, NPK @ 120:60:40 kg ha^{-1} + FYM 10 t ha^{-1} + Zn @ 10 $kgha^{-1}$ with a value of 180.90 cm while T_1 (NPK @ 120:60:40 $kgha^{-1}$) and T_6 (NPK @ 120:60:40 $kgha^{-1}$ + FYM 10 t ha^{-1} + Zn @ 20 $kgha^{-1}$) were found to be par with values of 163.73 and 158.48 cm respectively.

- The maximum number of leaves at the time of harvest for the first crop recorded for T_9(NPK @120:60:40 $kgha^{-1}$ + FYM 10 t ha^{-1} + foliar application of 0.75 percent $ZnSO_4\ 7H_2O$) with a mean value of 15.13.

- The T_4 (NPK @ 120:60:40 kgha^{-1} + FYM 10 t ha^{-1} ^{and} soil application of $ZnSO_4$. $7H_2O$ @ 10 kgha^{-1}) recorded the highest green fodder yield of 512.5 qha^{-1}, dry fodder yield of 103.92 qha^{-1} and these values were significantly superior to all others treatments in the first experimental crop. The PDGFY was also found to be maximum in T_4 (8.54 qha^{-1}).

- The highest mean value for LSR was recorded for T_4 (POP + Soil application of Zn 10 kgha^{-1}) found to be on par with T_3, T_5, T_1, T_9, T_7 and T_8.

- Regarding the quality aspects, T_4 recorded the highest value of CP and CPY with values of 10.93 and 1136 kgha^{-1} respectively. While the lowest value of 23.16 percent for CF was observed for POP + foliar application of 0.75 percent $ZnSO_4$. $7H_2O$. But T_4 also recorded a lower value of 23.70 percent of crude fibre and it was on par with T_9.

- The nutrient concentrations of the fodder maize, samples of the first experimental crop revealed the following. T_4 (POP + Soil application of Zn @ 10 kgha^{-1}) recorded the highest value of N, K, Mn, Zn and Cu while the highest value for P was obtained in T_3 (0.27 percent). The T_5 treatment recorded the maximum Ca $_{and}$ Mg context. S concentration (0.17 percent) was maximum for the highest doze of Zn with 20 kgha^{-1}. The highest value of Zn was obtained for soil application of Zn @ 10 kgha^{-1} with a mean value of 68.33 mgkg^{-1}.

- Physico-chemical parameters of surface soil showed that pH, EC and organic carbon were not significant. The available Nitrogen and Potassium were maximum in T_4 with values of 224.60 kgha^{-1} and 204.3 kgha^{-1}.

- The Ex-Ca and Mg were maximum in T_2 and T_4 with values of 1.30 and 0.52 c mol kg respectively. T_5 recorded the highest value of available S (12.88 kgha^{-1}). For the micronutrients, T_3 (POP + Zn @ 5 kgha^{-1}) recorded the highest value for DTPA Fe with (22.37 $mgkg^{-1}$) which was on par with T_4, T_5, T_9 and T_1. While DTPA Mn was maximum in T_9 (4.94 $mgkg^{-1}$). The highest content of DTPA Zn was in T_4 with a value of 4.89 $mgkg^{-1}$.

- For the first residual crop T_5 (POP + Zn @ 15 $kgha^{-1}$ as $ZnSO_4.7H_2O$) recorded the maximum green and dry fodder yield of 34.65 and 6.86 qha^{-1} respectively.

- The highest value for DTPA extractable Zn in the surface soil was observed in T_4 (POP + Zn @ 10 $kgha^{-1}$ as $ZnSO_4.7H_2O$) as 2.06 $mgkg^{-1}$ and lowest was in the control (0.56 $mgkg^{-1).}$

- For the second experimental crop the T_4 (POP+Zn@ 10 kg ha^{-1} as Zn SO_4) showed the maximum height at 45 DAS and at harvest with the values of 123.70 and 139.2 cm respectively.

- Considering the yield and yield attributes the highest yield as well as per day green fodder yield was obtained in T_5 (POP+Zn 15 kg ha^{-1}) with 519.3 q ha-1 and 9.44 q ha^{-1} respectively, for the 2nd experimental crop The highest value of crude protein was 10.23 per cent in $T_3$and T_6, T_5, T_2 and T_4 were found to be on par with this. The crude protein yield was maximum in T_5 with1090 kg ha^{-1}.

- After the crop growth, a reduction in the Nitrogen and phosphorus contents and enhancement of potassium was noticed. Among Zn applied plots maximum P content was noticed where minimum quantity of Zn has been applied.

- The highest yielded plot showed a significantly lower content of Ws+Ex-Zn fractions after the crop growth, revealing it's contribution to the available pool

- The Am Feo-Zn fractions contributed more to the total Zn in both surface and subsurface soil..

- For the second residual crop the highest green fodder yield of 39.49 q ha^{-1} and dry fodder yield 67.77 q ha^{-1} was obtained in T_6 and it was significantly different from other treatments.
- For raising a single crop of fodder maize Variety African Tall, soil application of Zinc Sulphate @Zn 10kg/ha along with FYM @10tha^{-1} and NPK 120:60:40 kgha^{-1} is recommended. T_4 treatment ie. (POP+Zn @ 10 kg ha^{-1} as Zn SO_4) showed the highest BC ratio of 1.61 and was found economical for maximum yield , Zn application could be skipped for the second crop of fodder maize, if . Zn @15 kg ha^{-1} for the first crop have been applied.
- The pooled analysis data on yield showed that the highest yield was observed in T_5 (468.80 q ha^{-1}), but T_4, T_9 and T_8 were found to be on par. The highest dry fodder yield was also in T_5 (94.90 q ha^{-1}) which was on par with T_4 (93.80 q ha^{-1}).

- The 3rd leaf lamina at 25th DAS recorded the maximum coefficient of correlation (r values 0.933) with yield and it was selected as the index part and stage for foliar diagnosis.

- For determining the critical level of Zn content in the index plant part (3rd leaf lamina at 25 DAS) for maximum yield, the scatter diagram technique of Caté and Nelson was employed and the critical Zn level was computed as 21 mg/kg for maximum yield in fodder maize.

- A path coefficient analysis of different fractions of Zn in the surface soil was selected for studying their direct and indirect effect on yield. The Ws+Ex-Zn fraction directly contributed to the yield while the total Zn is negative and significant.

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APPENDIX I

Weather data during the cropping period

(October, 2007 to September, 2008)

Months	Relative Humidity (%)	Temperature (^{o} C)	Total Rainfall (mm)
Oct ,2007	90.46	30.61	141.16
Nov,2007	91.12	30.84	186.20
Dec,2007	89.07	30.55	3.60
Jan,2008	86.59	31.45	0.00
Feb,2008	85.13	31.94	38.60
Mar,2008	88.88	31.37	276.21
Apr,2008	84.65	32.32	74.80
May,2008	85.62	32.31	153.20
Jun,2008	88.40	30.98	96.90
Jul,2008	90.90	29.50	200.00
Aug,2008	90.72	29.72	276.60
Sep,2008	89.25	28.91	253.00

APPENDIX II

Nutrient content of the manure and fertilizers used for the experiment

Manure/Fertilizer	Nutrient content
FYM	
N (%)	0.55
P (%)	0.24
K (%)	0.62
Ca (%)	0.65
Mg (%)	0.12
S	010
Fe (ppm)	138
Mn (ppm)	57
Zn(ppm)	60
Cu(ppm)	2.3
Urea	46 % (N) : 4% (Zn)
RP	18 % (P)
Muriate of Potash	60% (K)
$ZnSO_4.7H_2O$	21% (Zn),10% (S)

APPENDIX III

Mean values of different fractions of Zinc in the surface soil

Treatment	Ws+Ex-Zn	Ob - Zn	MnO-Zn	AFe –O-Zn	Cry Fe-O- Zn	Res- Zn	Total Zn
T1	3.05 (2.66)	3.39 (2.91)	0.99 (0.95)	34.86 (30.18)	37.97 (32.99)	35.24 (30.31)	115.50
T2	1.49 (1.39)	2.42 (2.26)	0.65 (0.61)	37.77 (35.30)	40.42 (37.78)	24.25 (22.66)	107
T3	3.99 (2.97)	3.02 (2.24)	1.11 (0.83)	26.54 (19.73)	60.97 (45.33)	38.87 (28.90)	134.50
T4	4.51 (3.35)	2.81 (2.09)	1.24 (0.92)	27.33 (20.32)	70.80 (52.64)	27.81 (20.68)	134.50
T5	5.25 (3.99)	2.75 (2.09)	0.92 (0.70)	23.34 (17.75)	72.50 (55.13)	26.74 (20.34)	131.50
T6	3.14 (3.00)	3.5 (3.34)	0.99 (0.95)	26.55 (25.40)	31.76 (30.40)	38.55 (36.91)	104.50
T7	3.04 (2.39)	2.89 (2.28)	0.45 (0.35)	25.47 (20.05)	48.77 (38.40)	46.38 (36.53)	127.00
T8	2.58 (2.12)	2.45 (2.02)	0.55 (0.45)	27.37 (22.52)	63.19 (52.01)	25.36 (20.88)	121.50
T9	4.04 (2.66)	2.55 (1.68)	0.55 (0.36)	29.43 (19.36)	90.17 (59.32)	25.26 (16.62)	152.00
T10	0.45 (0.53)	2.15 (2.54)	0.21 (0.25)	19.32 (22.86)	38.46 (45.51)	23.91 (28.31)	84.50

Values in the paranthesis shows the % share of individual fractions to total.

APPENDIX IV

Mean values of different fractions of Zinc in the sub surface soil.

Treatment	Ws+Ex-Zn	Ob- Zn	MnO-Zn	A Fe-O-Zn	Cry-Fe-O-Zn	Res- Zn	Total Zn
T1	1.09 (1.18)	0.90 (0.98)	1.24 (1.35)	23.53 (25.57)	33.86 (36.80)	31.40 (34.12)	92.00
T2	1.14 (1.22)	2.03 (2.18)	0.68 (0.73)	24.82 (26.69)	39.83 (42.83)	24.50 (26.35)	93.00
T3	1.74 (1.48)	2.04 (1.69)	1.09 (0.90)	15.20 (12.67)	52.28 (43.39)	48.15 (39.87)	12.50
T4	1.37 (1.18)	1.96 (1.69)	1.50 (1.29)	37.38 (32.22)	42.83 (36.92)	30.96 (26.68)	116.00
T5	1.66 (1.57)	0.83 (0.79)	1.14 (1.08)	25.61 (24.27)	52.65 (49.90)	23.61 (22.39)	105.50
T6	1.72 (1.90)	1.68 (1.86)	0.89 (0.98)	27.60 (30.49)	36.24 (40.04)	22.37 (24.73)	90.50
T7	1.26 (1.39)	1.16 (1.28)	0.86 (0.95)	19.40 (21.44)	37.58 (41.54)	30.19 (30. 24)	90.50
T8	2.28 (2.02)	1.39 (1.24)	1.42 (1.26)	21.75 (19.34)	53.80 (47.82)	31.86 (28.32)	112.5
T9	1.77 (1.57)	1.17 (1.04)	0.82 (0.72)	25.27 (22.30)	38.65 (34.30)	45.32 (40.07)	113
T10	0.11 (0.15)	0.45 (0.63)	0.51 (0.71)	16.06 (22.46)	29.67 (41.50)	24.69 (24.70)	71.5

Values in the paranthesis shows the % share of individual fractions to total.

APPENDIX V

Input Cost and market price of produce

1kg urea- Rs.5.50/-;

1 kg RP- Rs.5.50/-;

1kg MOP-Rs.5/-

1kg $ZnSO_4.7H_2O$ –Rs.30/- ;

1kg seed-Rs.15/-

1kg fodder-Rs.3/-;

Labour charge –Rs.175/-

DYNAMICS OF ZINC IN TYPIC KANDIUSTULTS WITH SPECIAL REFERENCE TO NUTRITION IN FODDER MAIZE (*Zea mays* L.)

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ABSTRACT OF THE THESIS
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for the degree

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ABSTRACT

Zinc is an essential mineral nutrient with exceptional biological significance in plant and animal nutrition. It is associated with several enzyme systems that regulate various metabolic activities in plants.

In Indian Scenario more than 45% of soils are Zn deficient. Majority of the Kerala soils also recorded a low content of available Zn. Proper understanding of micronutrient availability in soil and extent of their deficiencies is the pre-requisite for efficient management of micronutrient fertilizer to sustain crop productivity.

The response of Zn application varies widely from crop to crop and soil to soil. Maize crop was found to be responsive to Zn. Fodder crops respond to micronutrients by increasing the dry matter yields and by changing their quality as a feed for animal nutrition.

In this context the present study on the Dynamics of zinc in Typic Kandiustults with special reference to nutrition in fodder maize (*Zea mays*.L) was carried out to satisfy the objectives viz. understanding the release pattern of Zinc from Zinc sulphate with and without FYM under the laboratory conditions, to elucidate the role of Zn in the growth, yield and quality parameters of fodder maize. when applied to soil as well as foliar application. The selection of the index plant part for foliar diagnosis and fixing up of the critical nutrient level in that plant part was also included in the experiment.

The incubation study on the release pattern of Zn from zinc sulphate was conducted in complete randomized design with 10 treatments and three replications. The treatments are given below:

T_1 Soil alone: T_2 Soil + Zn @ 0 kg ha^{-1} + FYM @ 10 tha^{-1} : T_3 Soil + Zn @ 5 kg ha^{-1} : T_4 Soil + Zn @ 5 kg ha^{-1} + FYM @ 10 tha^{-1} : T_5 Soil + Zn @ 10 kg ha^{-1}: T_6 Soil + Zn @ 10 kg ha^{-1} + FYM @ 10 tha^{-1} : T_7 Soil + Zn @ 15 kg ha^{-1} : T_8 Soil + Zn @ 15 kg ha^{-1} + FYM @ 10 tha^{-1} : T_9 Soil + Zn @ 20 kg ha^{-1} T_{10} Soil + Zn @ 20 kg ha^{-1} + FYM @ 10 tha^{-1}

The soil samples were collected at an interval of 15 days for a period of 75 days and analyzed for available Zn by DTPA method.

The results of the incubation study showed that when Zn was applied at 5, 10, 15 kg ha^{-1}, the availability was in the medium range during the period of incubation and it has exceed 2.4mg kg^{-1} on the 75th day of incubation only, when Zn was applied @ 20 kg ha^{-1}.

Initial soil profile study and the initial analysis of the surface and subsurface soil samples of experimental site were also carried out.

The field study comprised of two experimental crops with fodder maize cv. African Tall, in the Instructional Farm, College of Agriculture, Vellayani in RBD with 10 treatments and 3 replications. The treatments are given below:

T_1 : NPK @ 120:60:40 kg ha^{-1} ; T_2 : NPK @ 120:60:40 kg ha^{-1} + FYM @ 10 t ha^{-1} (POP recommendation); T_3 : POP + Zn 5 kg ha^{-1} as $ZnSO_4$(Soil application); T_4 : POP + Zn 10 kg ha^{-1} as $ZnSO_4$(Soil application); T_5 : POP + Zn 15 kg ha^{-1} as $ZnSO_4$(Soil application); T_6 : POP + Zn 10 kg ha^{-1} as $ZnSO_4$(Soil application); T_7 : POP + 0.25% Zn as $ZnSO_4$(foliar application); T_8 : POP + 0.5% Zn as $ZnSO_4$ (foliar application); T_9 : POP + 0.75% Zn as $ZnSO_4$(foliar application); T_{10} : Control.

After each experimental crop, a residual crop was also raised without any fertilizers or manures to study the residual effect of applied zinc for the previous crop.

The yield data of the first experimental crop revealed that T_4 (POP + Zn 10 kg ha^{-1} as $ZnSO_4$ as soil application), recorded the highest yield of 512 q ha^{-1}. The higher dry fodder yield (103.92 q ha^{-1}) per day green fodder yield (8.54 q ha^{-1}) and leaf stem ratio (2.63) were also higher for the above treatment. The quality attributes viz. crude protein (10.93 per cent), crude protein yield were also showed for this treatment. For the first residual crop, T_5 (POP + Zn 15 kg ha^{-1}) recorded the maximum yield. In the second experimental crop, the T5 showed the maximum yield (519.3 q ha^{-1}). For the second residual crop, T_6 (POP + Zn 20 kg ha^{-1} as $ZnSO_4$) of soil applied Zn gave the maximum yield.

The yield data of the first and second experimental crops were pooled and analyzed statistically. The pooled analysis data for the yield was found significant among treatments. For the pooled data, the T_5 (POP + Zn 15 kg ha^{-1}) with a mean yield of 468.8 q ha^{-1}showed the highest yield and it was on par with T4, T8 and T9 which recorded and yield of 464.5 q ha^{-1} , 403.90 q ha^{-1}, 418.30 q ha^{-1}respectively. It is seen that the yield difference between T_4 and T_5 was only 4.3 q ha^{-1}. For raising a single crop of fodder maize (African Tall), soil application of zinc sulphate @ Zn 10 kg ha^{-1} along with 120:60:40 NPK kg ha^{-1} + FYM 10 t ha^{-1} is recommended. Foliar spray of zinc sulphate @ 0.75% Zn at the 4th leaf stage recorded the highest yield among foliar application treatments and it was on par with T_4.

Application of Zn @ 15 kg ha^{-1}as soil application along with 120:60:40 NPK kg ha^{-1} + FYM 10 t ha^{-1} for the first crop of fodder maize will help to skip the Zn application for the succeeding crop.

From the studies on foliar diagnosis to identify the index plant part of this crop, 3rd leaf lamina from the tip at 25 DAS was selected as the index plant part. The critical nutrient level of Zn for maximum response to yield in plant was standardized using the graphical method proposed by Cate and Nelson (1971). The content of Zinc in the 3rd leaf lamina was found to be 21 mg kg^{-1}. Foliar spray @ 0.75% Zn during the crop growth is recommended on identifying zinc deficiency to the crop. Zinc is an essential element for plant growth and metabolism, and exists in soil in different fractions such as Ws+Ex, OB, MnO, AmFeO, Cry FeO, and Res and all these forms are existed in a dynamic equilibrium. So the amount and rate of transformation of these forms determine the size of the labile pool of Zinc. The different fractions of Zn was also studied for the surface (0-15 cm) and subsurface soil (15-30 cm). The percentage share of different fractions in the surface soil to the total Zn was as follows i.e, Ws+exch.Zn (0.53-3.99%), 0B-Zn(2.15-3.34%), MnO-Zn (0.21-0.92%), Am. FeO-Zn (17.75-35.30%) and Cry-Fe-O Zn (30.40-59.32%) and RS-Zn (16.62-36.91%).

A path coefficient analysis was also carried out with the different fractions of Zinc on the yield of fodder maize and the results revealed that direct effect of water soluble + exchangeable fraction soil Zn on the yield of fodder maize.