Status of cationic micronutrients and their availabilities as influenced by application of lime sources in acid soil

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BANARAS HINDU UNIVERSITY

THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
Master of Science (Agriculture)
in
Soil Science and Agricultural Chemistry

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Submitted by
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CERTIFICATE

To,
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Through: The Head,
Department of Soil Science and Agricultural Chemistry,
Institute of Agricultural Sciences, Banaras Hindu University,
Varanasi-221005 (India)

Dear Sir,

I have great pleasure in forwarding the thesis **"Status of cationic micronutrients and their availabilities as influenced by application of lime sources in acid soil"** submitted by ***Miss Subhalaxmi Sahu*** **(I.D. No. 19412SAC016),** in partial fulfilment of the requirements for the degree of **Master of Science (Agriculture) in Soil Science and Agricultural Chemistry**, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi.

I certify that the entire scheme of investigation presented herein was planned and carried out solely by the candidate under my guidance and supervision. The data presented in the thesis, to the best of my knowledge and belief, are genuine and original. No part of the work has been submitted for any other degree or distinction.

Thanking you,

Forwarded by

(Prof. Surendra Singh)
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(Head)

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ACKNOWLEDGEMENT

Before I start inking let me truly admit that, it is practically impossible to mention all the worthy support, kind cooperation and directional guidance stretched out by my honorable teachers, supportive friends and loving relatives and all of my well-wishers in just two pages. However, I am trying to document all worth-mentioning hereunder.

With a deep sense of devotion, I bow and pray to the feet of ***Lord Viswanath and Lord Jagannath*** *who provided me choicest, everlasting blessing to get an opportunity to satisfy in Banaras Hindu University, Varanasi.*

At the outset, being the student of this great institution, I bow my head with great reverence to lotus feet of ***Bharat Ratna Mahamana Pandit Madan Mohan Malviyaji****, the founder of this great temple of* ***Goddess SARASWATI*** *for students like us to worship and nurture our lives.*

With immense pleasure and profound sense of gratitude, I take this opportunity to express my heartfelt and sincere thanks to my esteemed supervisor ***Prof. Surendra Singh,*** *Professor, Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, for his meticulous guidance, indelible inspiration, persistent encouragement, ingenious suggestions, mellifluous nature and indefatigable attitude. I will ever cherish the elderly affection that he bestowed upon me throughout my tenure as a student under him which helped me to cope with many a trying situation.*

I sincerely express my gratitude and warmest regard to ***Prof. Nirmal De,*** *Head, Department of Soil Science and Agricultural Chemistry for providing the necessary research facilities, critical suggestions and help during the course of investigation.*

I owe my sincere thanks to the members of my advisory committee, ***Prof. Janardan Yadav****, Professor, Department of Soil Science and Agricultural Chemistry, and* ***Prof. J.P. Singh,*** *Professor, Department of Agronomy, Institute of Agricultural Sciences, Banaras Hindu University, for their critical suggestions, impeccable and directional guidance.*

I extend my indebtedness to ***Prof. A. P. Singh, Prof. Priyankar Raha, Prof. S. K. Singh, , Prof. B.R. Maurya, Prof. Janardan Yadav, Prof. A.K. Ghosh, Prof. P.K. Sharma, Dr. A. Rakshit, Dr. Y. V. Singh*** *and* ***Dr. R. Meena****, and I am thankful to all staff members of Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University for all kinds of help and cooperation to me during my study period.*

With profound regards in a more personal sense, I owe deepest debts to my revered parents ***Sri Nilakantha Sahu*** *and* ***Smt. Suryakanti Bagh*** *who taught me the value of wisdom based on erudition but without being enslaved by it and their persistent inspiration, selfless sacrifice, continuous encouragement and blessing gave untiring help and have enabled me to be what I am, today. I will also like to acknowledge my affection towards my sister* ***Rajalaxmi*** *who was always with me during my ups and downs. I thank them once again for their kind cooperation.*

I would like to express my warm deep appreciation to my roommates ***Bijayalakshmi Thakur , Sarmistha Hada*** and ***Swetaleena Mahana*** *for their immense love and affection which always animated me to rise against all odds and face them with smiles.*

Without the help of seniors none can learn the lesson of life and cannot teach the same to loving juniors . So, my heartfelt and special thanks to my seniors Sachin sir, Saroj maam, Bharti maam, Arvind sir, Ayush sir, Satya Prakash sir, Satish sir for their kind co-operation during the study and investigation. A special thanks to Sudipta bhai, Tusar bhai, Brahma bhai,Dibyajyoti Bhai,Biswajeet bhai, Shyam Bhai ,Santrupta Bhai, Jyoti Bhai, Chandni didi,Ipsita didi,Manaswinee Didi, Madhu Didi, Manju didi,Prajna didi,Sravani didi,Shibani Didi, Sonali Didi who were always a great support in all my struggles and frustrations in my life and studies.

It is a pleasure for me to offer thanks to my friends, ***Ashutosh, Gopika, Govind, Kajal, Neeraj, Soumya, Anuj, Anuraj, Anshuman, Indushree, Prabhakar, Rohit*** *and BHU friends.*

I wish to place on record my appreciation and sincere thanks to ***Anil sir, Shishir sir, Agraj sir, H.N. sir, K.K. sir and Amarendra sir*** *non-teaching Staff members of Department of Soil Science and Agricultural Chemistry for extending their kind cooperation and motivation during the entire course of this study.*

Before I conclude, I confess that I do not know how to acknowledge the help and co-operation of my supervisor, members of advisory committee, family members and relatives, seniors, juniors, colleagues but above feelings come from the core of my heart in the shape of words and as gospel truth.

Date:
Place: *Varanasi* **(Subhalaxmi Sahu)**

Contents

LIST OF SYMBOLS AND ABBREVIATIONS

% : Per cent

˚F : Degree Fahrenheit

$\mu g\ L^{-1}$: Micro gram per liter

μgg^{-1} : Micro gram per gram

^{0}C : Degree centigrade

BC : Before Christ

bdl : Below detection limit

$CaCO_3$: Calcium carbonate

CEC : Cation exchange capacity

$cmol(p+)\ kg^{-1}$: Centimole (proton) per kilogram

dSm^{-1} : Desi Siemen per meter

e.g. : For example,

EC : Electrical conductivity

et al. : And others

Fig. : Figure

g : Gram

gcm^{-3} : Gram per cubic centimeter

$gmol^{-1}$: Gram per mole

hrs : Hours

i.e. : Which is to say, in other words

kg : Kilogram(s)

Km^2 : Square kilometer

m : Metre

M	:	Molarity
meq l^{-1}	:	Milli equivalent per liter
mL	:	Milliliter
MLD	:	Million liter per day
mm	:	millimeter
MT $year^{-1}$	:	Million tonne per year
N	:	Normality
ng L^{-1}	:	Nano gram per liter
No.	:	Number
OC	:	Organic carbon
pH	:	Puissance de hydrogen
ppm	:	Parts per million
v/v	:	Volume by volume
viz	:	That is to say
WHO	:	World Health Organization

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Chapter I

INTRODUCTION

Soil reaction is one of the physiological characteristics of the soil solution expressed in terms of pH indicating the soil is acid, alkaline or neutral. It exercises significant influence on many soil properties including nutrient availability, biological activity and soil physical condition. A soil which is in acid reaction throughout the root zone is called an acid soil. Acid soils occupy a considerable area in county, they are found to occur in the Himalayan region, the eastern and north- eastern plains, peninsular region and the coastal plains under varying environmental conditions of landscape, geology, climate and vegetation.

pH scale ranges from 1 to 14, but most of the agricultural crops thrive well between 5.5 and 7.5. Some crops, however, thrive at soil pH levels that are higher than the optimal range. The United States Department of Agricultural National Resources Conservation Service categorizes soil pH values as follows: ultra-acidic (3.5), extremely acidic (3.5–4.4), very strongly acidic (4.5–5.0), strongly acidic (5.1–5.5), moderately acidic (5.6–6.0), slightly acidic (6.1–6.5), neutral (6.6–7.3), and slightly alkaline (7.4–7.8), moderately alkaline (7.9–8.4), strongly alkaline (8.5–9.0) and very strongly alkaline (>9.0).

Soil acidity is a potentially serious issue in terms of land degradation. When soil becomes too acidic, it reduces the availability of essential nutrients, increases the impact of toxic elements, reduces plant production and water use, interferes with vital soil biological functions and makes soil more vulnerable to soil structure decline and erosion. Many essential plant micronutrients like iron (Fe), manganese (Mn), and boron (B) can benefit from an acidic pH but these advantages, however, may be outweighed by increased bioavailability of potentially phytotoxic elements such as Aluminum (Al^{3+}).

Micronutrients are essential for maintaining soil health and increasing crop productivity just like macronutrients. Micronutrient deficiency or excess can have both synergistic and antagonistic effects in plants as a result crop productivity suffered a lot. Micronutrients (Fe, Mn, Zn, Cu, and B) are soil elements that have been shown to influence plant fitness and soil quality. Because the solubility of soil chemical compounds is related to soil pH, soil acidity reduces the availability of macro and micro nutrients. In these soils, nutrient deficiency frequently coexists with Al^{3+} toxicity. Acidification can also reach the subsoil layers, posing serious problems for plant root development and remediation. Efforts to mitigate the negative effects of soil acidity must therefore be accompanied by measures to increase soil nutrient availability. In such cases, there is a lack of some essential nutrients and toxicity of some of them. As a result, crops grown on such problematic soils do not yield a remunerative return, but rather reduce yield to a greater extent. As a result, one of the most important and practically feasible management practices is the application of liming materials to reduce soil acidity. Nowadays cereals are grown intensively with acidic fertilizer that accelerates leaching of base elements. In addition, intensive irrigated farming of high-yielding cultivars with injudicious fertilizer management has resulted in a negative balance of base elements and a gradual increase in soil acidity, which has resulted in yield declines. Improving soil nutrient supply necessitates soil sampling and analysis, interpretation of analysis results, formulation of a recommendation, and implementation of that recommendation. The tests must be able to predict soil and plant responses to an ameliorant or ameliorating practice with high accuracy.

When a chemist thinks of 'lime', he usually refers to calcium oxide (CaO), but from the agricultural point of view a more general meaning is implied by the term. Agricultural lime may be defined as any component of calcium or magnesium, capable of counteracting the harmful effects of an acid soil. It may points arrow to the oxide, the hydroxide or the carbonate of calcium and/or magnesium. There is no accepted word for a material that neutralize soil acidity which must not include only the aforesaid compounds but also some slags and other forms of calcium silicate. It might be more appropriate to use the term 'liming material '.

Carbonate forms of lime i.e., Lime stone makes up to 95 % of the liming material applied to soil. Calcium carbonate, often occurring as a mixed compound with magnesium is the most common liming source and has a neutralizing value of

100 %, oxide forms of lime are the only material to which the term lime may be correctly applied. Calcium oxide (CaO) is produced under several commercial name such as burnt lime or quick lime. Hydroxide forms of lime [$Ca(OH)_2$] is frequently referred to as slaked lime or hydrated lime. Chemically pure calcium hydroxide has a neutralizing value of 136 making it second most efficient of the commonly used liming materials on weight basis.

Liming is an age-old practice followed to lower down the pH of acid soil increases availability of essential nutrients and decreases aluminum and manganese toxicity. Liming is done by using liming materials that contains calcium or magnesium or both. Types, amount methods of liming depend on crops and varieties to be grown, its management practices, quality of liming material, status of soil fertility and economic considerations. Crops that respond well to lime application are mostly legumes, followed by cotton, maize, and sorghum.

It must be emphasized again that lime, if widely used when needed, is indispensable to permanent agriculture in acid soil regions. It is important that soils are tested for their lime needs. The general need of soils for lime may be made by observations with in certain limits, but amounts that to be applied are not so indicated.

Incubation study is useful to understand how lime requirements with various liming material affect the physical and chemical properties of soil in the long run. Lime is added to a fixed amount of soil and kept in a defined moist state similar to field conditions in a laboratory setting for several weeks or months. The present experiment was carried out to attain following objectives:

- To characterize acid soils for their physico-chemical properties.
- To study the effect of liming materials on the availability of cationic micronutrients in acid soil at constant moisture regime.

* * *

Chapter II

REVIEW OF LITERATURE

2.1 SOIL ACIDITY

A substance that gives protons (hydrogen ions) to other compounds is known as an acid. Soil acidity is a natural and induced chemical condition of soil that can reduce the availability of essential nutrients, increase the number of toxic elements, reduce crop production and affect essential soil biological functions and make soil more vulnerable to erosion (Hollier *et al*., 2005).

Soil acidity has both an intensity and a quantity component. The quantity aspect is measured, directly or indirectly, by the quantity of an alkali necessary to titrate soil to an arbitrarily established endpoint. The intensity aspect is universally characterized by the measurement of ion activity, given as pH. Acidity in the soil is a big issue in terms of plant growth and, as a result, hence acid soils are called a problem soil.

In many parts of Ethiopia, soil acidity is a serious environmental and economic concern, resulting in large agricultural losses. Soil acidity is caused by a combination of variables including plant nutrient deficits and toxicities, low helpful microbial activity, and reduced plant root growth, all of which limit nutrient and water uptake. (Fageria, Zimmermann, Baligar, 1995)

Aluminum (Al^{3+}) toxicity, diminished nodulation or mycorrhizal infections, and low phosphorus (P) availability have long been linked to poor crop productivity on acidic soil. (Kochian *et al*., 2004; Wang *et al*., 2006). The excess of soluble aluminum and manganese ions (Al^{3+} and $Mn^{2+)}$ in acid soils is a severe issue caused by mineral dissolution. (Poolpipatana, Hue, 1994)

Acid soils have nutritional deficit as well as toxicity, limiting plant growth. (Behera and Shukla, 2015; Fageria and Baligar, 2008). Soil acidity has an impact on the resources, goods, and services that soils provide to humans as a result, the sustainability is reduced, which must be remedied through effective management decisions. Soil pH influences the growth and reproduction of microorganisms in the soil biosphere, which can have an impact on plants (Uchida and Hue, 2000).

Acidity is predicted to affect around 3950 million hectares of land area, accounting for nearly 30% of the worldwide land surface and near about 50% of the global arable land area. One of the most yield-limiting elements affecting agricultural output is soil acidity. This is mostly due to the fact that acidified soil diminishes the availability of many essential nutrients (e.g., phosphorus, P) while worsening the toxicity of others (e.g., aluminum, Al) via modifying a variety of chemical and biological processes in the soil (Sumner and Noble, 2003).

Acid soils cover 30% of the country's farmed land, with 12 percent severely acidic (pH 5.0), 48 percent moderately acidic (pH 5.1-5.5), and 40 percent softly acidic (pH 5.6-6.5) soils (Panda, 2009).

2.2 CAUSES OF SOIL ACIDITY

High rainfall, crop growth, fertilizer use, acid rain, and oxidative weathering are all factors that contribute to soil acidity.

- In the tropics, large amounts of rainfall cause soils to become acidic. Because of an interaction with CO_2 in the atmosphere that produces carbonic acid, rainfall is slightly acidic (around 5.7). Rainwater leaches basic cations and salt from the soil as it travels through the pores, increasing the fraction of stable minerals rich in iron and aluminum oxides relative to the rest of the cations in soil.

  During respiration, roots, microorganisms, and other living organisms produce CO_2, soluble organic acids, and acidic organic acids, which contribute to soil acidification. CO_2 from the atmosphere dissolves in water to generate carbonic acid, which reacts with the parent material and soil. (FSSA Fertilizer Handbook, 2003).

- Crop roots absorb soil nutrients in ionic forms (NO_3, $NH_4^{+,}$ Ca^{2+} and H_2PO_4). Cations are generally taken up by crop roots in greater quantities than anions. However, for normal physiological processes to occur, crops must establish a neutral charge near their roots. Crops generate protons to counteract for the excess positive charges caused by acid soils. Plant matter is removed during harvesting, limiting the return of bases taken up by plants from the soil. This can result in permanent soil acidity if there are no external sources of bases, such as fertilizer. (FSSA Fertilizer Handbook, 2003). The exudation of acidity exceeds the formation of alkalinity by plants because cation intake generally surpasses anion intake in plants. (Essington, 2003).

- Some fertilizers, like ammonium (NH_4^+), undergo nitrification to generate nitrate (NO_3), and H^+ ions are liberated during this process, resulting in acid soils.

- When fossil fuels are burned, Sulphur and nitrogen oxides are emitted to the atmosphere, resulting in acid rain. Tetraoxosulphate (vi) acid and trioxonitrate (v) acid are formed when released oxides combine with rainfall in the atmosphere. During the oxidation reaction, sulphides and other compounds carrying Fe^{2+} generates acidity.

Soil acidification can be caused by a variety of factors, including natural processes, industrial pollution, and agricultural development (Fageria and Nascente, 2014; Holland *et al*., 2018). More than half of the world's agricultural land has been acidified solely as a result of agricultural intensification, primarily through monoculture farming and increased use of synthetic fertilizers. (Von Uexküll and Mutert, 1995). In response to the ever-increasing population and rising energy costs, the demand for alternative management practices that can effectively help mitigate soil acidification while maintaining crop productivity in the long run is essential to achieving agricultural sustainability.

2.3 STATUS OF MICRO NUTRIENTS IN ACID SOIL

Although micronutrients are required in minute quantities, they are equally important in terms of agronomy, as micronutrients play an important role in plant growth. When a micronutrient is deficient in a plant, it causes abnormal growth, which can lead to crop plant failure. In severe deficiency, grain and flower formation do not occur. These micronutrients are primarily found in parent material, sewage sludge, municipal waste, farmyard manure (FYM), organic matter and soils in small quantities ranging from a few mg kg^{-1} to several thousand mg kg^{-1}. Micronutrient availability is especially responsive to fluctuations in soil environment. Organic matter, soil pH, lime content, sand, silt, and clay content are all factors that influence the content of such micronutrients. There is also a link between the micronutrient content and the above-mentioned properties.

Micronutrient deficiency is now being manifested and reported, but it is more area, soil, crop, and situation specific. Micronutrients, like macronutrients, are important. According to Rattan *et al*. (2009), more than 2.5 lakh soil samples from 20 states of the country were analyzed as part of the All India Coordinated Research Project on Micronutrients, zinc, boron, iron, and molybdenum deficiencies were discovered in 49, 33, 13, and 7% of the samples, respectively. Soils depleted of available nutrients, particularly secondary and micronutrients, are being intensively cultivated. As a result, an assessment of the fertility status of soils vigorously cultivated with high-yielding crops was required. The assessment and delineation of micronutrients is critical in preventing a long-term agro-ecosystem's productivity.

2.3.1 Iron

Iron, which is one of the most crucial essential minerals for plant growth, can sometimes be present in high concentrations in acid soils, causing plant growth to be severely affected. The pH of the soil, the oxidation-reduction potential, and the presence of a soluble complexing agent all influence iron availability. Liming is the most widely used method for lowering concentration of toxicity of iron.

Iron exists in Fe^0 (metallic), Fe^{2+} (ferrous), and Fe^{3+} (ferric) forms. Under acidic conditions, Fe^0 readily oxidizes to Fe^{2+}, and Fe^{2+} oxidizes to Fe^{3+} as the pH increases above 5. Ferric iron (Fe^{3+}) is reduced to Fe^{2+} and is readily available to plants in acidic soils, but precipitates in alkaline soils. Iron oxides are dominant in governing Fe solubility in soils. Minimum Fe solubility occurs between pH 7.5 and 8.5, which is the pH range of many calcareous soils (Lindsay, 1991).

The redox potential (i.e., oxidizing or reducing circumstances) and pH are the general rules that control Fe's behavior. The precipitation of weakly organized Fe minerals (ferrihydrite) is favored by neutral pH circumstances, whereas the mobilization of Fe minerals is favored by reducing and acid pH conditions. In the most common Eh–pH soil, goethite and hematite have a high stability (reduced solubility). At a specific value of pH, Fe oxides (hematites) and hydroxides (goethite) produce the same Fe concentration in a solution, while ferrihydrite only at a much lower Eh. Despite their decreased stability, metastable forms such as lepidocrocite and ferrihydrite are common in many soils, especially in younger soils with non-equilibrium pedo-environments such as cold climates and acidic soils (Schwertmann 1988). In reducing conditions in acid soil, such as pyrite (FeS_2), or in alkaline soil, such as pyrite (FeS_2), small amounts of Fe minerals can be detected (Colombo *et al*., 2014).

The increases in soil pH or Eh shift Fe from exchangeable organic forms to water-soluble and Fe oxide forms. The solubility of Fe in well-aerated soils is controlled by dissolution and precipitation of Fe^{3+} (Moraghan and Mascagni, 1991). Iron deficiency has also been closely related to Ca carbonate equivalency and soluble salts in soil (Franzen and Richardson, 2000). Kang and Osiname (1985) also reported Fe toxicity on plants grown in the acid soil belt of equatorial Africa, which includes Senegal, Gambia, Liberia, and Sierra Leone.

2.3.2 Manganese

The presence of manganese in various forms is determined by a number of factors, the most vital of these is pH. Soils with a pH lesser than 5.5 may have a high concentration of Mn in the water-soluble and exchangeable form. According to Biswas (1953), acid soils (pH 4.3 to 6.9) contained 2.8 to 15.6 percent of total Mn in water-soluble and exchangeable form. Manganese has been discovered in soils as water soluble, exchangeable, and higher manganese oxides. These Mn forms are said to exist in soil in equilibrium (Mitchell, 1955).

Total manganese levels in Indian soils have been reported to range between 92 and 11500 ppm (Biswas, 1953; Biswas and Gawande, 1964). However, the majority of Indian soils have been reported to contain between 300 and 1600 ppm total.

Higher levels of manganese were only found in soils that were acidic in reaction and contained significant amounts of organic substances. Soils with a higher humus content also had a higher content of exchangeable Mn. The boron and manganese content of some Indian soils was investigated and the findings revealed that these soils contain an adequate amount of boron and manganese, as well as agricultural problems in these areas.

Evidence suggests that Al toxicity inhibits microbial organic matter decomposition in some highly acidic soils. When both were kept at pH 4.0, it was discovered that CO_2 production was larger in a Ca muck than in a Ca-AI muck. CO_2 production was dramatically reduced in a Latosol and in combinations of Ca^- and AI^- saturated mucks with increasing levels of Al during incubation at pH 4.0 or below.

Low nitrification rates in a Bladen soil (Typic Albaquults) at pH 4.6 were attributed to acidity and the associated low populations of nitrifiers, according to Brar and Giddens (1968). They also speculated that Al was a likely contributor to the nitrifier population's decline. Many soil variables, notably the critical soil pH at which Al becomes soluble or exchangeable at dangerous proportions, influence the critical soil pH. the predominant clay minerals, organic matter levels, concentrations of other cations, anions and total salts, and particularly, the plant species or cultivar (Foy, 1984; Kamprath & Foy, 1975).

Soil Mn appears in primary and secondary minerals, is sorbed onto mineral and OM surfaces, and incorporated into soil organisms and in soil solution. Soils derived from crystalline shales and acid igneous rocks have low reducible Mn, and soils derived from basalt, limestone, and shale commonly have high Mn (Glinski and Thai, 1971). High extractable Mn has been reported for Inceptisols and Vertisols and low extractable Mn has been reported for Ultisols and Oxisols (Lombin, 1983). Soil pH affects solubility, adsorption, desorption, oxidation of Mn, and reduction of Mn oxides in soil. As the pH decreases, Mn is mobilized from various fractions and increases Mn soil solution concentrations and availability. Exchangeable Mn (plant available form) was high at low soil pH.

2.3.3 Copper

Copper is an essential constituent of three important enzymes that regulate plant metabolism, controlling oxidation, reduction reactions. Copper is required for protein metabolism in plants. The average copper content of the lithosphere is about 100 ppm while that in the soils in reported to range between 2 and 100 ppm. The total amount of native copper in the soils, however, depends on the amount of copper present in the parent material.

The survey conducted by the Maharashtra State Agri-cultural Department showed that the total copper in 550 soil samples ranged from 33.6 to 1560.0 ppm. The highest total copper was found in non-lateritic soils, neutral in Chalcopyrite, Bornite, Chalcocite, Covellite, Cuprite, Tenosite, Malachite and Azurite have been listed by as copper minerals. Neutral insoluble salts include silicates, phosphates, hydroxides and basic carbonates. The exchangeable copper, in general, is considered as that which occurs as metallo-organic complexes and some of that adsorbed by clay minerals in soils. Water soluble and exchange-able forms of copper are probably available to plants.

Copper in soils may occur as metallic copper, copper minerals, neutral insoluble salts, water soluble compounds, copper adsorbed by clay minerals and organic copper compounds. Principally, copper in soils is found as the Cu^{+2} ion adsorbed by clay minerals. Copper availability to plants is influenced by a number of factors i.e., pH, organic carbon, clay, calcium carbonate and phosphate contents and soil microorganisms.

According to Holmes (1943), the copper content of soil is determined by the fine fraction of the soil. The total soil Cu availability also depends on the functional groups of the soil reactive particles and their sorption capacity, which is a result of diverse factors. The sorption capacity increases in accordance with the clay mineral content, iron (Fe) oxides, hydroxides of Fe, aluminum (Al) and manganese (Mn), carbonates, and organic matter (OM) (Bradl 2004; McBride 1994).

Soil pH (Chaignon *et al*. 2003), cation exchange capacity (CEC), and OM quality are important factors that regulate metal sorption and, therefore, Cu availability (Arias *et al*. 2005; Brun *et al*. 2001). Soil with neutral to alkaline pH values may generally have lower Cu availability relative to acid soils, which is explained by the presence of carbonates that favor Cu precipitation and adsorption (Bradl 2004).

2.3.4 Zinc

Zinc availability is influenced by a variety of factors including pH, organic carbon, clay, bases, and microorganisms. According to Berg (1947), zinc levels below 1.0 ppm cause deficiency symptoms, whereas levels above 100 ppm cause hazardous effects. The pH, organic matter, clay, and phosphate content are all important factors in the fixation and availability of Zn applied to soils, according to Schroo (1959).

Gall (1936) discovered that significant levels of lime stone lowered zinc availability, indicating that as lime concentration rises, zinc availability falls. Zinc availability reduced as pH increased, according to Camp (1945).

The significant correlation coefficient value of r = 0.402 between pH and 0.1 (N) HCl soluble zinc content in Gujrat soils was reported by Nair and Mehta (1959). However, Chatterjee and Das (1964) discovered that soils with pH below 6.0 had more ammonium acetate extractable zinc, while soils with pH over 7.0 had less.

Because of adsorption, hydroxylation, and coprecipitation, higher soil pH lowers Zn extractability (Cox and Kamprath 1972). However, reports on the impact of lime application on phytoavailable Zn and Zn content in crops are mixed. Higher lime application rates resulted in lower Zn availability in Brazil's Red Latosol (Gupta, Kening, and Siyuan 2008) and Ethiopia's Nitisols, as well as lower Zn absorption by the crops.

Proper assessment of available micronutrient status in soil is very important as their deficiency and toxicity range in soil is quite narrow. Deficiency of micronutrient may be due to low total content of elements caused by soil factors reducing their availability to plants. Soil pH influences solubility, concentration in soil solution, ionic form, and mobility of micronutrients in soil, and consequently acquisition of these elements by plants (Fageria, Baligar and Edwards, 1990). As a rule, the availability of B, Cu, Fe, Mn, and Zn usually decreases, and Mo increases as soil pH increases. These nutrients are usually adsorbed onto sesquioxide soil surfaces.

Zinc deficiency is a worldwide nutritional constraint for crop production. About 50% of soils used for cereal production in the world contain low levels of plant available Zn, which reduces not only grain yield but also nutritional grain quality (Graham and Welch, 1996). Zinc-deficient soils occur in both tropical and temperate regions, but are widespread in Mediterranean countries. (Cakmak *et al*., 1997).

2.4 STATUS OF MICRONUTRIENTS IN ACID SOILS OF UTTAR PRADESH AND ODISHA

The soil samples collected for the incubation study were from Uttar Pradesh state and Odisha state.

Soil types in Odisha range from fertile alluvial deltaic soils in the coastal plains to mixed red and black soils in the Central Tableland, low fertility red and yellow soils in the Northern Plateau, and red, black, and brown forest soils in the Eastern Ghat region. They range in pH from highly acidic to slightly alkaline, and in texture from light sandy to stiff clay. The majority of soils are acidic, with varying degrees of acidity. Here poverty and soil acidity are synonymous. Low crop production in such soils is caused by low water holding capacity, high bulk density, and soil crusting, as well as chemical restrictions such as low pH, low CEC, low base saturation (16 to 67 percent), high Al, Fe, and Mn saturation, and high P fixing capacity (80 to 91 percent).

Inorganic lime enhances pH, base saturation, and CEC while lowering Al, Fe, and Mn availability, acidity, and P fixation (Panda and Koshy, 1982; Sahu and Patnaik, 1990; Mishra and Pattanayak, 2011). Organic acids produced by organic ameliorants form complexes with Al and Fe, lowering their availability and minimizing their detrimental effects. Soil acidity is controlled, Al and Fe toxicity is reduced, and nutrient availability is increased (Mohanty and Pattanayak, 2000), resulting in better crop growth conditions in these soils (Mohanty and Pattanayak, 2000).

A study was taken up to identify the micronutrients status in soils of Angul, Cuttack, Deogarh, Dhenkanal, Khurdha, Puri and Sambalpur districts of Odisha and the soil samples were found to be adequate in Fe content. 66.42 per cent soils were sufficient and 33.57 per cent soils were deficient in Zn. The mean value for Mn and Cu ranged from 27.65 to 65.64 and 1.10 to 2.69 mg kg^{-1} respectively. (Mohanta *et al*., 2020)

250 GPS-based rhizosphere soil samples were collected from Cuttack, Khordha, Balasore, Mayurbhanj, and Keonjhar districts in Odisha, with 106 samples having a pH of less than 5.5. It was observed that soils were mostly deficient in Zn (33.57%) and B (80%). (Pradhan *et al*., 2018)

Based on the diethylenetriaminepentaacaeticacid (DTPA) extractable Zn and 0.1 M hydrochloric acid (HCl) extractable Zn, Zn deficiency was found in 7 to 82 percent of soils and 2 to 57 percent of soils, respectively. The pH of the majority of soils was less than 5.50. The EC values of the soils show that they were all non-saline in nature. The mean levels of soil OC were 0.29, while the mean values of DTPA-Zn (mg kg^{-1}) were 0.52, pH 4.90, EC (dS m^{-1}) 0.05 OC (%) 0.12–1.07 at Hariharpur of Odisha. (Behera *et al*., 2011)

The soil in Sonepur district, Odisha, is a mixture of red and black soil, with pockets of black soil among the prevalent red soil. Red soils are found in upper ridges, while black soils are found in lower ridges, due to the intermixing of red and black soils. The presence of excessive levels of iron oxides in the Odisha soil gives it a red colour. The soil of the Sonepur district is light textured soil. The soil has angular or sub angular blocky structure. The clay fraction of the soil is dominated by kaolinites and illites. The soil is acidic, with low to medium organic matter quality and weak water retentive capability. The soil is nitrogen and phosphorus deficient. These soils have a poor cation exchange capacity, a high phosphate and Sulphur absorption capacity, and are calcium and magnesium deficient. Zinc deficiency exists in rice-growing lowland soils. Application of lime neutralizes acidity in the soil. (Sahu, & Mishra, 2005)

The morphology and other properties of six typical pedons developed on sandstone, shale, granite, and colluvium representing various landforms in Uttar Pradesh's Banda area were investigated. The soils range from deep to very deep, are excessively to well drained, reddish brown to crimson, moderately acidic, low to medium in CEC, medium to high in organic carbon, and have a wide range of textural differences depending on the parent material and physiograplly. High molar ratios are seen in the soils, and differences in SiO_2/R_2O_3 are attributed to parent material. The stabilization of silica content in a mildly acidic pedochemical environment is indicated by the depth wise distribution of SiO_2. The Bt horizon develops on flat-topped hills and monadnocks, while the Bw horizon develops in other landforms' soils. The soils are divided into two groups: Inceptisols and Alfisols. (Walia & Rao,1996)

The available Zn concentration in Varanasi's black and alluvial soils, as well as Mirzapur's upland red soils, ranged from 0.14 to 0.76 mg kg^{-1}, 0.08 to 0.54 mg kg^{-1}, and 0.40 to 0.76 mg kg^{-1}, respectively. Zn deficiency was observed to be higher in vegetable-growing black and alluvial soils (31.0 and 36.0 percent, respectively) than in pulse-growing highland red soils (9.0 percent). Zn deficiency has also been recorded in more than 20% of Varanasi soils. All soils had sufficient levels of DTPA extractable Cu, Fe and Mn. (Singh & Kumar, 2012).

2.5 LIMING

The reduction of acidity in the soil and subsoil is an important part of acidic soil management. To address soil acidity, lime and/or alternative liming materials, as well as other management practices, must be applied.

Liming is the application of calcium and magnesium rich materials of various forms like; limestone, burnt lime, hydrated lime, marl, chalk etc. These chemicals function as a base in acid soils, neutralizing the acidity. This frequently stimulates plant development and boosts soil bacterial activity. Apart from increasing yield, application of lime enhances the efficiency of applied fertilizers, improves the effectiveness of some herbicides, protects the environment and increases the net profit of farmers (Prochnow, 2014). Liming can also improve aggregate stability on clay soils.

Liming-induced changes in soil pH may have a significant impact on the availability of several elements up taken by crops. Liming raises soil pH, lowering Al^{3+} and Mn^{+2} toxicity while increasing NO_3-N, Ca, and P availability (Arshad and Gill, 1996; Caires *et al.*, 2005). Liming soils to reduce toxic levels of A1 and Mn is recognized as necessary for optimal crop production on acid soils (Dixit, 2006).

According to John *et al.*, 1972, soil acidity is a complex of several factors, the most important of which is the toxicity of aluminum and manganese. Liming raises Ca^{2+} concentrations and ionic strength in soil solutions, resulting in clay flocculation and an improvement in soil structure and hydraulic conductivity (Haynes and Naidu, 1998). Liming soils to a pH of 5.5 where exchangeable aluminum (Al^{3+}) is neutralized has been shown in studies to be an acceptable approach to achieving maximum crop yields, particularly in highly weathered soils (Evans & Kamprath, 1970; Kamprath, 1970; McLean, 1970; Reeve & Sumner, 1970; Webber et aI., 1982)

It has been discovered that a decrease in soil pH has a negative impact on the growth of many plants, and that at extremely low pH, plants do not grow. Rahman *et al*. (2002) reported that 1 t/ha lime application raised soil pH from 5.26 to 5.98. The additional increase in lime rate (2 t/ha) raised the soil pH from 5.98 to 6.26.

According to Rahman *et al*. (2005), nutrient treatments had no discernible effect on soil pH, but liming had a significant effect. After 6 months of liming, the pH of the surface soil (0-15 cm) in the plots treated with lime @ 1.2 t/ha increased from 5.2 to 5.7 at Dinajpur and from 4.9 to 5.4 at Rangpur. The further increased lime (@2.4 t/ha) gave the further increase in soil pH from 5.7 to 6.3 and from 5.4 to 5.8 at Dinajpur and Rangpur, respectively. Liming improved soil acidity and decreased aluminum toxicity up to a depth of 60 cm in 1993 when compared to the no lime (control) plot. Liming in the year 2000 on previously limed plots was later compared to liming in 1993, and it was discovered that it increased pH up to a depth of 10 cm about one year after application and to a depth of 60 cm three years after application, indicating that the surface-applied lime in 2000 moved deeper whereas the topsoil was only slightly acidic (Caires *et al*., 2008).

The residual effect of lime increased soil pH from 4.8 to 5.0. Liming increased the pH and exchangeable Ca^{2+} content while decreasing the exchangeable Al^{3+} level in the 5 cm soil. According to Nduwumuremyi (2013) lime application reduced Al and Mn toxicity and improved soil pH. According to Barbieri (2015), lime application significantly increased soil pH. According to Lestari *et al*. (2016), the application of dolomite increased soil electrical conductivity, its effect was more pronounced in higher rate. According to McCallum (2016), limed plots had higher soil pH than unlimed plots, and soil pH was positively associated with liming. Alemu *et al*. (2017) discovered that soil pH increased dramatically with liming, peaking at 5.9 and then gradually declining to 5.3 after five years. The exchangeable acidity decreased significantly as lime application increased. Brandon *et al*. (2017) also mentioned that lime increases pH.

Lime can help plants grow in acidic soils in a variety of ways. It lowers soil acidity, improves the physical condition of heavy soil, provides calcium to plants and soil microorganisms, and influences the availability of other plant nutrients in the soil. The current study sought to determine the effect of lime applications on the reaction, base saturation, and availability of plant nutrients in certain western Washington soils (Dunn, 1943).

Liming will not work unless the liming material is thoroughly mixed with the soil. If possible, apply it evenly and work it in to a depth of 6 inches (15 cm). Lime recommendations are frequently based on a 6-inch plough depth. As a result, if the soil is ploughed to different depths (e.g., 4 or 8 inches), the amount of liming material should be adjusted proportionately to reach the same pH (Uchida and Hue, 2000)

Correcting soil acidity with appropriate amendments and adding necessary nutrients is critical for increasing crop yield (Rautaray, Ghosh, and Mitra 2003). The addition of various amendments improves soil pH and thus nutrient availability (Moon *et al.*, 2014). The use of liming materials such as quick lime, limestone, slaked lime, and dolomite is a practical method for soil acidity. The addition of lime to acid soil reduces soil acidity while significantly improving the status of basic cations and crop yield (Goulding, 2016).

The initial effects of calcium carbonate application to an acid soil are to raise the soil solution concentrations of calcium and hydroxyl ions. These changes in turn affect the solubility of other ions, the activity of microorganisms, and various adsorption-desorption reactions involving both cations and anions (Jackson 1967). This paper describes effects of $CaCO_3$ and H_2SO_4 application to an acid soil on the soil solution concentrations and plant uptake of a number of cations and anions. Plant growth and nutrient uptake measurements were used to assess whether changes in the soil solution levels of the various nutrients were reflected as changes in nutrient availability to plants (Siman *et al.*, 1971)

A three years of field experiments was done at two locations to study the effects of three doses of lime (0, 1.2, and 2.4 t ha^{-1}) and six fertilizer combinations on soil pH, nutrient availability, and rice and wheat yields. Liming increased soil pH, accessible P, exchangeable Ca, and hot-water-extractable B. The amount of Fe and Al in the soil decreased with lime levels whereas the level of Zn was not affected by lime levels (Rahman *et al*., 2005).

The productivity of resources on acid soils, which cover one-fourth of India's total land area, is abysmally poor. The major goal of applying lime to such soils is to increase crop productivity by improving the availability of native and added plant nutrients. Farmers rarely follow conventional guidelines because of the varying lime requirements (LR) of different groupings of acid soils (Barman *et al*., 2014)

Long-term agricultural practices such as liming ($CaCO_3$) are commonly employed to improve soil quality by enhancing nutrient bioavailability, improving soil structure, and increasing infiltration rates. Furthermore, raising the negative charge on oxides, clays, organic matter has been shown to reduce the solubility of cationic trace elements in soils (Kirkham, 2006).

2.5.1 Liming material

Currently, a variety of liming materials are available to farmers. The materials differ in place of origin, amount of neutralizing power, and nutrients or other elements associated with the liming agent.

Commonly used liming materials are briefly described below.

- Calcitic aglime - a ground limestone composed mostly of calcium carbonate ($CaCO_3$).
- Dolomitic aglime - a ground limestone containing a mixture of calcium carbonate and magnesium carbonate ($CaCO_3$, $MgCO_3$).
- Hydrated or slaked lime - a liming material composed of calcium hydroxide [$Ca(OH_2)$] or a mixture of calcium and magnesium hydroxide.
- Quicklime or burnt lime - a liming material containing calcium oxide (CaO) or a mixture of calcium and magnesium oxide.

- Marl - a deposit of calcium carbonate ($CaCO_3$) derived from mollusk shells and mixed with silt and clay.
- Industrial by - products including slags, refuse sludges, and flue dusts, these materials commonly contain a high percentage of calcium carbonate ($CaCO_3$), although the slags are mostly calcium and magnesium silicates ($CaSiO_3$, $MgSiO_3$); flue dusts may contain a substantial quantity of oxides.

The cost of the liming material increases with the fineness of its particles, which determines its rate of reaction with the soil. The initial soil pH, the degree of mixing with the soil, and the chemical nature of the material itself also influence the reaction rate (Uchida and Hue, 2000).

According to Halls worth (1954), one ton of dolomite increased soil pH as much as four tons of calcium carbonate, but Tisdale and Nelson (1970) found that dolomite was less effective than calcium carbonate.

According to Upjohn *et al*. (2005), the only feasible way to negate soil acidity is to apply finely crushed limestone or other liming materials. Limestone is the most effective if an adequate amount is applied and well incorporated into the soil to raise the pH to 5.5.

The degree to which a given amount of lime per unit of soil volume will increase soil pH depends on the buffer capacity of the soil (this is generally related to soil cation exchange capacity or CEC). Soils with low CEC will usually show a more marked pH increase than soils with high CEC. But the low-CEC soils will witness more rapid leaching of the added bases, and so will see a quicker return to original acidity unless additional liming is done (Peters, 1996).

Calcitic limestone is made up of calcium carbonate, whereas, dolomitic limestone is a mixture of calcium and magnesium carbonate. Dolomitic limestone reacts some-what more slowly with acid soils than does calcite lime (Peters, 1996).

A study at Spooner, WI, compared the relative effectiveness of dolomitic and calcific aglime over a 2-year period. There is no significant difference in pH between the two liming materials at any given rate or year (Peters, 1996).

The Adams and Evans method detects extremely small differences in lime requirement values, which can cause relatively large changes in soil pH due to the soils' very low CEC (buffer capacity). It is most commonly used in the United States' Southeastern and Mid-Atlantic regions and is best suited for soils with a maximum soil H content of 8.00 cmol/kg (Adams, 1984). However, while the Adams-Evans lime requirement is well correlated with soil-lime incubation values, it has a tendency to overestimate lime requirement, possibly due to the initially high pH of the buffer (PH 8.0), which may include pH dependent acidity that does not need to be neutralized to achieve the desired pH (Alabi *et al.*, 1986; Fox, 1980; Tran & van Lierop, 1981). It should also be noted that the correction factor proposed in the original Adams-Evans calibration study to account for the efficacy of agricultural grade limestone in neutralizing soil acidity may have contributed to the overestimation of lime requirement observed in these studies. Several laboratories have also developed state or region-specific regression equations that use target pH, soil pH and Adams-Evans's buffer pH to more accurately quantify lime requirement recommendations (Donohue, 1992).

One of the most detrimental effects of over-liming is the alteration of the physical properties, rather than the chemical properties in tropical soils. Soil permeability is also known to be affected by over-liming. High infiltration rates and consequent rapid leaching of bases from tropical soils are attributed to highly unstable soil structure and increased binding tendency of ferrous and aluminum oxides in soil particles. Over-liming destabilizes the soil structure, which in turn causes soil aggregates to break apart resulting in reduced permeability and inadequate drainage. The addition of lime of either calcium or magnesium to soil increases the number of small aggregates at the expense of larger ones.

2.5.2 Effect of liming on physico-chemical properties of soil

Soil physico-chemical characteristics are crucial in determining the availability of nutrients in the soil and, as a result, crop output. The supply of vital nutrients can be supplemented by good soil management. Soil quality is largely determined by how soil reacts to various land use regimes and management approaches, which can alter soil attributes and thus production.

No matter what the environmental or experimental conditions were, lime administration always resulted in a considerable elevation in soil pH. The effect of liming on soil pH was 36 percent stronger in pot circumstances than in field conditions. $Ca(OH)_2$ had the best benefit for improving soil pH with pH 0.6 in field settings, but solely utilizing CaO had a considerably stronger effect than $CaMg(CO_3)_2$ in pot trials (Li *et al*., 2019).

The efficacy of limestone and pelletized lime for soil acidity reclamation was examined by comparing whether limestone was more cost-effective solution to pelletized lime (Mizel *et al*., 2015). Pelletized lime and limestone sand were applied at rates of 2170 kg ha^{-1} and 4335 kg ha^{-1}, respectively, to separate 400 m^2 plots within the sites. As a control, 2 extra 400 m^2 plots were used. These findings showed that applying limestone sand at twice the rate of pelletized lime resulted in similar changes in soil as well as soil solution chemistry at a lower cost.

According to Manoj Kumar *et al*. (2012), liming, in conjunction with integrated nutrient management practices, can give rise to a more than three-fold increase in maize productive output on acidic soils in Meghalaya and other north-eastern Indian states with analogous soils.

In the spring of 2006, Luka Andric *et al*. (2012) set up a field trial with three rates (0, 5., and 20 t ha^{-1}) of hydrated calcite (73 percent CaO + 2-3 percent MgO + 21 percent H_2O). Liming elevated maize yield by up to 33 percent and 35 percent in 2006 and 2007, respectively. Soybean responded with a significant higher yield of up to four percent in the third year of testing.

Marschner (1993) reported an increase in plant Zn concentration with a decrease in soil pH. Staton and Warncke (2006) investigated the effects of pelletized lime and agricultural lime on soil pH and corn yields. They discovered that pelletized lime did not react as quickly as agricultural lime. The alteration in soil pH two months after formulation was greater with regular agriculture lime than with pelletized lime (0.8-unit vs 0.3 unit with 1.25 t/a). The low rate of pelletized lime (1.25 t/a) was insufficient to neutralize acidity and deter a huge yield loss. Pelletized lime must be implemented at rates comparable to agricultural lime to achieve an equal pH adjustment and yield enhancement.

Melese *et al*. (2015) found that incubating the soil for 60 days prior to actually sowing at varying rates of lime, wood ash and manure with 7.0 tons of $CaCO_3$ ha^{-1} substantially increased the available Olsen P as well as pH while decreasing the exchangeable acidity and Aluminum compared to the control.

2.5.3 Effect of liming on availability of plant micronutrients

Cu solubility of Cu^{2+} is very soil pH dependent and decreases 100-fold for each unit increase in pH. Plant uptake also decreases. Ferric (Fe^{3+}) and ferrous (Fe^{2+}) activities in soil solution decrease 1000-fold and 100-fold, respectively, for each unit increase in soil pH. In most oxidized soils, uptake of Fe by crop plants decreases with increasing soil pH. The principal ionic Mn species in soil solution is $Mn^{2+,}$ and concentrations decrease 100-fold for each unit increase in soil pH. In extremely acid soils, Mn^{2+} solubility can be sufficiently high to induce toxicity problems in sensitive crop species. Zinc solubility is highly soil pH dependent and decreases 100-fold for each unit increase in pH, and uptake by plants decreases as a consequence.

In a pot experiment using a highly leached acid (pH 4.2) soil, the effects of increasing rates of lime and phosphorus addition on soil concentrations of available nutrients and P, AI, and Mn uptake by two pasture legumes, lotus and white clover, were investigated. Liming increased the amount of exchangeable Ca in the water, resulting in a higher percentage of base saturation with concomitant decreases in levels of exchangeable AI, Fe and Mn (Haynes *et al*., 1981).

An experiment was undertaken to determine effects of soil pH changes from three liming sources i.e., calcite limestone, dolomitic limestone, and an industrial by-product on the distribution of micronutrients among soil fractions and the amounts of micronutrients in the fractions extracted by the Mehlich I and DTPA extractants. This increase in Zn and Mn in the organic fraction as pH is increased shows that pH does not influence metals in some fractions in the same manner as it does plant availability. Iron decreased in the exchangeable and organic fractions as pH increased. The industrial by product lowered Mn compared to the other sources and dolomite increased Zn in the exchangeable fraction. The industrial by-product raised the soil to the highest pH levels and so decreased the extractability of Mn by the neutral salt more than for the other sources. Copper and Fe were not affected by sources and Cu was also not affected by rates (Shuman, 1986).

A research was conducted in Ethiopian highlands to identify the status of soil acidity and determine the amount of lime requirement for neutralization to increase plant nutrient availability in Welmera woreda, Oromia region. The soil had low concentration of plant nutrients and high in micronutrients contents. After 90 days incubation of liming acid soil, all limed soils attain the target pH 6.9 and decrease in exchangeable acidity and Al. (Dinkecha *et al*., 2017).

The long-term effect of organic manures, fertilizers and lime on secondary and micronutrient status of an acid soil is being studied in Ranchi. The results revealed that the pH of acid soil (5.5) increased by 0.9 units with lime and fertilizer use, while it decreased in unlimed plots. The DTPA-extractable micronutrients in acid soils increased in N, NP and NPK treated plots while a decrease was recorded in limed plots. it is concluded that the balanced fertilizer use in acidic soils should be preceded by lime application for better soil health and higher crop yields (Singh, Sarkar, Kumar and Singh, 2009)

Dhamija *et al*. (1956), Bhumbla *et al*. (1965), and Gupta *et al*. (1969) discovered a negative association between available iron and pH. Working with calcareous soils, Takkar *et al*. (1968) discovered that free iron content was unaffected by soil reaction, but that exchangeable and extractable iron had a significant relationship.

In most vineyard and seirozem soil profiles, scientists discovered a significantly negative association between reducible iron and $CaCO_3$ content. However, Takkar (1968) discovered a strong positive relationship between $CaCO_3$ and extractable iron. These connections suggest that the factors regulating $CaCO_3$ and iron solubility and precipitation are comparable.

However, according to Dubey (2003), liming a soil to a pH of 6.3 and up to 7.4 showed no negative consequences. Liming a soil to pH 6.3 and up to 7.4 had no negative impact on total extractable ferrous and ferric iron (96.1-99.7 ppm) or reducible iron (102-119 ppm). When the pH of a soil was elevated above 7.5 with the application of lime, however, there was a significant decrease in total extractable iron. Tewari *et al*. (1969) also found that liming acid soils significantly reduced available iron (from 732 to 367 ppm) while also reducing plant uptake.

According to Zende *et al*. (1961), the relationship between pH and exchangeable Mn was significant at the 1% level. Sharma and Motiramani (1964), Vinayak *et al*. (1964), Bhumbla and Dhingra (1964), Sherman and Harmer (1942), and Toth (1951) discovered that saline-alkali soils contained very low levels of sodium chloride. Exchangeable manganese reduced as soil pH increased, according to Chatterjee and Das found that exchangeable manganese decreased with increasing soil pH.

Mulder and Gerretsen (1952) discovered that manganese was fixed on the surface of the calcium carbonate particles through adsorption. Manganese cannot be released with neutral ammonium humate because the binding is too strong. Noncalcareous soils contained more exchangeable manganese than calcareous soils.

According to Piper (1942), the availability of copper decreases as the pH rises. Other scientists similarly found that when the amount of $CaCO_3$ in the soil increased, the amount of copper available decreased. Harmer (1946) found the opposite relationship in soils with high organic matter content. However, increasing $CaCO_3$ levels had little influence on copper availability, according to Pack *et al.* (1953). According to Kanwar (1954), copper availability declines with organic carbon content only when it is sufficiently high to form potential complexes, not at lower concentrations. Brown (1956) discovered that the high lime content in Florida soils was the source of the soils' low copper availability.

According to Reuther and Smith (1953), the positive impact of lime in reducing toxicity declines with substantial accumulation and water application. Agrawala *et al.* (1964) investigated the link between copper availability and soil pH and discovered that the two variables were adversely connected. Brown and Holmes (1956) observed decreased copper solubilities and plant availability when acid soils were limed.

In soils of Gujarat, Madhya Pradesh and Punjab, Neelkantan and Mehta (1961), Agarwal and Motiramani (1966) found a substantial negative association between pH and available copper. Agarwal *et al.* (1964), Kavimandan *et al.* (1964), and Eswarappa *et al.* (1969) found a positive, albeit statistically non-significant, correlation between pH and accessible copper concentration in Vidharbha and some tropical soils.

According to Hodgson (1963), the availability of naturally occurring forms of copper is influenced to a lesser extent than the availability of copper added by $CaCO_3$.Later workers found a high correlation between an increase in accessible copper and an increase in calcium carbonate, which contradicts most of the published data. With an increase in $CaCO_3$ content, Lal (1968), Mandal and Jha (1970) noticed a decrease in the amount of exchangeable copper.

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Chapter III

MATERIAL AND METHODS

To accomplish the objectives of the present investigation the methodology and material used in the laboratory during the experiments are:

3.1 COLLECTION OF BULK SOIL SAMPLE

Bulk soil samples were collected from red upland acid soils from three different locations of Chandauli district, Uttar Pradesh and one from Odisha. Soils are drawn from upper 0-15 cm soil depth from 15-20 well distributed spots moving in a zigzag manner from each individual sampling site after scrapping off the surface litter with the help of sampling tools.

3.2 PROCESSING OF SOIL SAMPLES

The collected bulk soil samples were air dried under shade, powdered with wooden pestle and mortar and passed through 2 mm sieve. For organic carbon analysis, a small quantity of soil was passed through 0.2 mm sieve. Samples were stored in labeled plastic bags for chemical analysis in the laboratory.

3.3 SOIL ANALYSIS

3.3.1 Soil pH

The pH of all the soil samples was measured in 1:2.5 (soil water suspension) with the help of Glass electrode pH meter (Jackson, 1967).

3.3.2 Mechanical composition

Particle size analysis of all the three acid soil samples were done by Bouyoucos Hydrometer Method (Bouyoucos, 1927) and the textural classes were determined by U.S.D.A textural triangle.

3.3.3 Bulk and particle density

The bulk and particle density were determined by using Pycnometer bottle in laboratory in disturbed soil samples (Black, 1965).

3.3.4 Water holding capacity (%)

The water holding capacity was measured in laboratory using Keen's box (Black, 1965).

3.3.5 Soil organic carbon

Organic carbon content of soil samples was determined by using finely ground soil samples with chromic acid wet digestion method followed by measurement of unreacted dichromate titrimetrically (Walkley and Black, 1934). In this method, 0.5 g soil (0.5 mm sieved) was taken in a conical flask. 1N potassium dichromate was added into the conical flask. 20 ml of concentrated sulphuric acid was then added to the conical flask. Swirled to mix and kept in dark for 30 minutes. Added 200 ml of distilled water. Added 10 ml of ortho phosphoric acid. Added 1 ml of di phenyl amine indicator and titrated the contents with 0.5 N ferrous ammonium sulphate, the end point was dirty green colour.

3.3.6 Lime requirement

Lime requirement of the soil samples was determined as outlined by Adams and Evans Buffer method (1962). In this method, 20 g of air-dried soil was weighed in a 50 ml beaker. 20 ml of distilled water was added and stirred to equilibrate for 1 hour and pH is read by a standardized pH meter and adjusted to 8.0. 20 ml of buffer was added and stirred thoroughly and after 10 minutes it was again stirred thoroughly and pH was read on a standardized pH meter and recorded the soil-buffer pH, this value was then compared with the table of Adams and Evans buffer as determining the lime requirement.

3.3 SOIL INCUBATION STUDY

In order to study the effect of liming on the availabilities of micro nutrients in four different acid soils, an incubation study was conducted with different liming material at constant moisture in the Soil Health and Plant Nutrition Laboratory, Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi.

Well processed 50g soil was taken in plastic containers. Lime [$CaCO_3$], burnt lime [CaO], Hydrated lime [$Ca(OH)_2$] was applied as three different liming agents to four soil samples. Four soil samples and three liming materials with control were replicated thrice in CRD design. Soil units were incubated at room temperature after amelioration. The moisture content of the samples was kept near field capacity throughout the entire period of incubation (up to 90 days) and maintained by distilled water as when required. The soil in each container was then irrigated to field capacity with deionized water and incubated for one week at ambient temperature. The samples were drawn at the interval of 15, 30, 60 and 90 days. These samples were processed and stored for chemical analysis and were determined with the help of commonly followed standard methods.

Table 1. Details of treatments for incubation study

Locations of collected acid soil samples	*Sample 1*	(S_1) Shivpur Mafi (Chandauli district, Uttar Pradesh)
	Sample 2	(S_2) Chandauli (Chandauli district, Uttar Pradesh)
	Sample 3	(S_3) Seledi (Subarnapur district, Odisha)
	Sample 4	(S_4) Jamsoti (Chandauli district, Uttar Pradesh)
Treatment	T_1 [control], T_2 [CaO], T_3[$Ca(OH)_2$],T_4 [$CaCO_3$]	
Replication	3	
Date of withdrawn of samples for analysis	0 DAY	28.03.2021
	90 DAY	24.06.2021
Experimental units	12 per soil	
Lime sources	Calcium Oxide[CaO], Calcium Hydroxide [$Ca(OH)_2$], Calcium Carbonate[$CaCO_3$]	

3.3 CATIONIC MICRONUTRIENT ANALYSIS

DTPA (0.005 M) extractable Fe, Mn, Zn and Cu was determined as the procedure outlined by Lindsay and Norvell (1978) using atomic absorption spectrophotometer Agilent FS 240.

3.4 STATISTICAL ANALYSIS

Data obtained from all the observations were statistically analyzed by Completely Randomized Design (CRD). Critical difference (CD at 5% level of significance) and Standard error of mean (SEM) of all the parameters were calculated (Gomez and Gomez, 1984).

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Chapter IV

RESULTS

The present study entitled "**Status of cationic micronutrients and their availabilities as influenced by application of lime sources in acid soil**" carried out at the Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. In this chapter, an attempt was made to characterize upland acidic soils, differing in physico-chemical properties. The main purpose of this study was to investigate availability of cationic micronutrients (zinc, iron, copper, manganese) in different acid soils at interval of time. The data recorded during the course of investigation were analysed statistically for drawing the valid conclusions. Results of the present study are described and discussed in this chapter.

4.1 PHYSICO-CHEMICAL PROPERTIES OF SOILS

The data pertaining to the physico-chemical properties of three different type of soils are presented in the table 2.

4.1.1 Physical properties of soil

4.1.1.1 Mechanical composition

The texture of red soils of Shivpur Mafi (Uttar Pradesh), Chandauli (Uttar Pradesh), Seledi (Odisha), Jamsoti (Uttar Pradesh) were all observed as sandy clay loam. Sands were mostly composed of quartz and micas. Silts are commonly composed of a mixture of quartz and small minerals particles viz., feldspars and micas. Clays are made up of secondary minerals. Texture in these soils may probably be due to content of primary and secondary minerals.

4.1.1.2 Bulk density

The bulk density of red soils of Shivpur Mafi (Uttar Pradesh), Chandauli (Uttar Pradesh), Seledi (Odisha), Jamsoti (Uttar Pradesh) were obtained 1.412, 1.406, 1.366 and 1.402 gcm^{-3}, respectively.

Table 2. **Physico-chemical properties of acidic soils of different locations used for incubation study**

Location / Properties	**Soil types**			
Location	Shivpur Mafi (Uttar Pradesh)	Chandauli (Uttar Pradesh)	Seledi (Odisha)	Jamsoti (Uttar Pradesh)
Coordinates	25.0929°N, 83.2595° E	24.8906° N, 83.2312° E	20.9559° N, 83.8009° E	24.9588° N, 83.1919° E
Mechanical composition				
Sand (%)	72.50	73.45	70.84	72.93
Silt (%)	6.03	5.48	7.22	6.92
Clay (%)	21.53	21.07	21.94	20.15
Textural class	Sandy clay loam	Sandy clay loam	Sandy clay loam	Sandy clay loam
Bulk density (g cc^{-3})	1.412	1.406	1.366	1.402
Particle density (g cc^{-3})	2.48	2.03	2.34	2.05
WHC (%)	37.62	38.66	39.15	37.48
pH	4.96	5.07	5.48	5.56
Organic carbon (g kg^{-1})	2.4	3.6	4.2	2.6
Lime requirement (t ha^{-1})	5.275	4.915	3.26	4.07
Available iron (mg kg^{-1})	370.78	268.62	302.38	309.23
Available manganese (mg kg^{-1})	26.90	48.44	57.19	50.27
Available copper (mg kg^{-1})	1.038	2.222	1.942	1.455
Available zinc (mg kg^{-1})	0.4030	0.2208	0.3900	0.3722

Fine textured soils tend to have lower bulk densities (higher porosities) than that of coarse textured soils due to lose packing of clay particle and presence of varying amount of sand and clay percentage this might be cause the difference in bulk density of soils.

4.1.1.3 Particle density

Particle density of red soils of were varied 2.48,2.03,2.34 and 2.05 g cm^{-3}, respectively. Particle density might be varied due to chemical composition and crystal structure of different soils.

4.1.1.4 Water holding capacity (%)

The value of WHC (%) in soils of Shivpur Mafi (Uttar Pradesh), Chandauli (Uttar Pradesh), Seledi T_2 (Odisha), Jamsoti (Uttar Pradesh) were obtained 37.62, 38.66, 39.15 and 37.48 respectively. These variations may probably be due to content of organic matter, soil particle as well as tillage practices for different cropping system.

4.1.2 Chemical properties of soil

4.1.2.1 Soil pH

The pH value of the Soils of Shivpur Mafi (Uttar Pradesh), Chandauli (Uttar Pradesh), Seledi (Odisha), Jamsoti (Uttar Pradesh) obtained 4.96, 5.07, 5.48 and 5.56 respectively. The pH values indicate that they were acidic in nature. This might be due to high rainfall causes leaching of bases in these upland red soils.

4.1.2.2 Soil organic carbon

Organic carbon content in these four soils were found to be 2.4, 3.6, 4.2 and 2.6 g kg^{-1} in the soils of Shivpur Mafi (Uttar Pradesh), Chandauli (Uttar Pradesh), Seledi (Odisha), Jamsoti (Uttar Pradesh), respectively.

In the acid soils of the above-mentioned locations are low content of organic carbon might be due to their upland situation and leaching loses of organic carbon with rainfall from surface soil.

4.1.2.3 Soil Available iron

Available iron content of soils was estimated 370.78, 268.62, 302.38 and 309.23 mg kg^{-1} in soils of Shivpur Mafi (Uttar Pradesh), Chandauli (Uttar Pradesh), Seledi (Odisha), Jamsoti (Uttar Pradesh), respectively.

4.1.2.4 Soil available manganese

Available manganese was recorded 27.83, 54.27, 57.51 and 48.53 mg kg^{-1}in Shivpur Mafi (Uttar Pradesh), Chandauli (Uttar Pradesh), Seledi (Odisha), Jamsoti (Uttar Pradesh), respectively.

4.1.2.5 Soil available zinc

Available zinc was recorded 0.4030, 0.2208, 0.3900 and 0.3722 mg kg^{-1}in Shivpur Mafi (Uttar Pradesh), Chandauli (Uttar Pradesh), Seledi (Odisha), Jamsoti (Uttar Pradesh), respectively.

4.1.2.6 Soil available copper

Available copper was recorded 1.038, 2.222 , 1.942 and 1.455 mg kg^{-1}in Shivpur Mafi (Uttar Pradesh), Chandauli (Uttar Pradesh), Seledi (Odisha), Jamsoti (Uttar Pradesh), respectively.

4.1.2.3.Soil Lime Requirement

Lime Requirement of these acidic soils of Shivpur Mafi (Uttar Pradesh), Chandauli (Uttar Pradesh), Seledi (Odisha), Jamsoti (Uttar Pradesh) were obtained to be 5.275, 4.915, 3.26 and 4.07 t ha^{-1} respectively.

Table 3. Lime requirement of acid soils based on Adams and Evans method

Soil type	Soil pH in water	Soil pH in buffered solution	Lime requirement (t ha $^{-1}$), target value = 6.5	Need of liming material		
				CaO (mg for 50 g soil)	$Ca(OH)_2$ (mg for 50 g soil)	$CaCO_3$ (mg for 50 g soil)
1	4.96	7.51	5.275	65.82	87.0	117.5
2	5.07	7.54	4.915	61.45	81.26	109.7
3	5.48	7.63	3.26	40.77	53.90	72.77
4	5.56	7.54	4.07	50.89	67.29	90.84

4.2 CHARACTERISTICS OF ACIDIC SOILS OF CHANDAULI DISTRICT OF UTTAR PRADESH

Altogether 21 surface (0-15 cm) soil samples were collected under two blocks i.e. Sahabganj and Chakia in Chandauli district. Samples were taken from different villages viz. Shivpur Mafi, Semara and Rasiya and from Hathera. The physiochemical properties of acidic soils of Chandauli district of Uttar Pradesh are depicted in table 5.

The obtained pH of the soils of Sahabganj block ranges from 5.0 to 7.9 with a mean 6.16. The organic carbon content of the soils of this block is low to medium ranging from 3.3 to 6.5 mg kg^{-1} with a mean value of 4.615 g kg^{-1}. Micronutrient's status of these soils are above critical limits. Iron content of these soils vary from 120.7 to 358.5 mg with an average 245.14 mg kg^{-1}. Available manganese content varies from 9.0 to 34.6 mg kg^{-1}. Copper in soil is found in the range of 1.3 to 3.0 mg kg^{-1} with the mean value 2.067 mg kg^{-1}. Zinc varies in these soils from 0.2 to 1.0 mg kg^{-1} with 0.637 average value. Sand percent in soil of Sahabganj block varies from 70.3 to 74.2 % with a mean value of 72.83 % , silt content varies from 5.8 to 7.7% with a mean value 6.44 % and clay content varies from 20 to 22% with a mean value of 20.72% .

The obtained pH of the soils of Chakia block ranges from 5.3 to 7.6 with a mean same as Sahabganj block i.e., 6.16. The organic carbon content of the soils of this block is in medium to high range from 54.0 to 79.0 g kg^{-1} with a mean value of 68.83 g kg^{-1}. Micronutrient's status of these soils are above critical limits. Iron content of these soils vary from 129.9 to 332.7 mg kg^{-1} with an average 180.705 mg kg^{-1}. Available manganese content varies from 29.6 to 55.2 mg kg^{-1}. Copper in soil is found in the range of 2.3 to 4.0 mg kg^{-1} with the mean value 2.947 mg kg^{-1}. Zinc varies in these soils from 0.1 to 1.5 mg kg^{-1} with 0.728 mg kg^{-1} average value. Sand percent in soil of Chakia block varies from 70.1 to 74.3 % with a mean value of 72.2 % , silt content varies from 5.1 to 7.8 % with a mean value 6.6 % and clay content varies from 20.4 to 22.1 % with a mean value of 21.1 % .

Considering the samples, it may be concluded that Chandauli district has an average pH value of 6.1, medium range of organic carbon with a mean value of 52.633 g kg^{-1}. The obtained mean values of micronutrients are 226.733 mg kg^{-1}, 24.032 mg kg^{-1}, 2.318 mg kg^{-1} and 0.728 mg kg^{-1} for Iron, manganese, copper and zinc respectively. Availability status of all micronutrients are above critical limits. The obtained mean values of soil separates is 72.6, 6.4, 20.8 % respectively for sand, silt and clay.

Table 4 . Physico-chemical properties of acidic soils of Chandauli District of Uttar Pradesh

S.No.	Block / village	Co-ordinates	pH	OC ($g\ kg^{-1}$)	Texture			Cationic Micro-nutrients ($mg\ kg^{-1}$)			
					Sand (%)	Silt (%)	Clay (%)	Fe	Mn	Cu	Zn
	Sahabganj block										
1	Shivpur Mafi	25.09105 N 83.25809 E	6.6	6.5	72.6	6.2	21.2	305.72	13.356	2.980	0.880
2	Shivpur Mafi	25.09135 N 83.25914 E	6.8	4.0	73.1	6	20.9	188.96	26.240	2.240	0.184
3	Shivpur Mafi	25.09382 N 83.25920 E	7.8	3.8	72.8	6	21.2	148.86	18.930	2.570	0.660
4	Shivpur Mafi	25.09355 N 83.25923 E	7.5	5.3	70.3	7.7	22	301.50	33.580	2.642	0.550
5	Semara	25.09655 N 83.25897 E	5.1	5.7	72.1	6.7	21.2	287.73	9.032	2.516	0.740
6	Semara	25.09657 N 83.25964 E	5.6	4.6	72.8	6.4	20.8	315.32	21.232	1.438	0.248
7	Semara	25.09034N 83.25814 E	5.3	3.9	72.8	6.4	20.8	120.74	34.582	1.586	0.744
8	Semara	25.09004 N 83.25835 E	5.7	4.4	72.1	6.8	21.1	313.60	19.628	1.820	0.336
9	Rasiya	25.09038 N 83.25638 E	5.3	6.5	72.3	6.5	21.2	358.48	15.548	2.082	0.760
10	Rasiya	25.09037 N 83.25537 E	5.0	4.2	73.5	6.3	20.2	222.76	13.658	1.930	0.442
11	Rasiya	25.09982 N 83.25777 E	5.4	4.5	73.5	6.4	20.1	316.40	13.482	1.694	0.536
12	Rasiya	25.09977 N 83.25813 E	5.5	3.3	73.4	6.6	20	232.60	14.948	1.328	0.954

Table Contd…

S.No.	**Block / village**	**Co-ordinates**	**pH**	**OC (g kg $^{-1}$)**	**Texture**			**Cationic Micro-nutrients (mg kg $^{-1}$)**			
					Sand (%)	**Silt (%)**	**Clay (%)**	**Fe**	**Mn**	**Cu**	**Zn**
13	Rasiya	25.09928 N 83.25752 E	6.5	3.9	73.5	6.5	20	313.20	14.618	1.562	0.720
14	Rasiya	25.09931 N 83.25663 E	6.6	4.2	74.2	5.8	20	123.98	19.340	1.960	0.816
15	Rasiya	25.09934 N 83.25652 E	7.9	4.4	73.5	6.3	20.2	127.32	12.680	2.653	0.992
Range of Sahabganj block			5-7.9	3.3-6.5	70.3-74.2	5.8-7.7	20-22	120.74-358.48	9.032-34.582	1.328-2.98	0.184-0.992
Mean of Sahabganj block			6.17	4.61	72.83	6.44	20.72	245.145	18.724	2.067	0.637
Chakia block											
16	Hathera	25.49697 N 82.65750 E	5.4	5.4	73	6.6	20.4	136.87	55.204	2.985	0.824
17	Hathera	25.49731 N 82.65606 E	5.3	6.5	74.3	5.1	20.6	332.70	29.576	3.979	1.144
18	Hathera	25.49796 N 82.65684 E	5.4	7.9	72.3	6.4	21.3	129.89	30.508	3.021	0.084
19	Hathera	25.49769 N 82.66037 E	7.6	7.4	70.8	7.7	21.5	162.32	39.982	2.549	1.474
20	Hathera	25.49665 N 82.66065 E	7.3	6.9	70.1	7.8	22.1	146.20	35.098	2.857	1.164
21	Hathera	25.49811 N 82.66035 E	6.0	7.2	72.7	6.2	21.1	176.25	33.454	2.288	1.040
Range of Chakia block			5.3-7.6	5.4-7.9	70.1-74.3	5.1-7.8	20.4-22.1	129.89-332.7	29.576-55.204	2.288-3.979	0.084-1.474
Mean of Chakia block			6.1	6.8	72.2	6.6	21.1	180.705	37.304	2.947	0.955
Range			5-7.9	3.3-7.9	70.1-74.3	5.1-7.8	20-22.1	120.74-358.48	9.032-55.204	1.328-3.979	0.084-1.474
Mean			6.1	5.2	72.6	6.4	20.8	226.733	24.032	2.318	0.728

This analysis is for the question about the possible relationship between the variables pH, OC, texture and micronutrient content (Fe, Mn, Cu and Zn). The table 5 depicts there is a significant correlation between sand percentage and organic carbon content; sand percentage and silt content; available iron and manganese content at 0.05 level i.e., if the value of former factor goes up, then value of later goes down and vice versa (inverse correlation). There is a statistically significant relation between organic carbon content and clay; organic carbon and copper; sand percentage and clay percentage and silt and clay content at 0.01 level of significance. Rest relations are found non-significant.

4.3 AVAILABILITY OF CATIONIC MICRONUTRIENTS IN ACID UPLAND SOIL

4.3.1. Availability of zinc in acid soils of Shivpur Mafi

The data regarding release of available zinc with different liming material in acid soils of Shivpur Mafi (Uttar Pradesh) has been presented in table 6 and depicted in fig.1.

A critical perusal of the data revealed that release of available zinc attended a decreased value during 90 days of incubation. Highest decrease of available zinc was recorded in soil amended with T_2 [CaO] i.e., 0.2117 mg kg^{-1} which was significantly lower than T_3 [Ca $(OH)_2$] and T_4 [$CaCO_3$]. T_4 having 0.2586 mg kg^{-1} after 90 days was found significantly higher than T_3 having 0.2322 mg $kg^{-1.}$ The zinc status of T_1 i.e., control was recorded 0.2955 mg kg^{-1}, which was significantly higher than all other treatments.

4.3.2. Availability iron in acid soils of Shivpur Mafi

The data regarding the availability of Iron with different liming material in acid soil of Shivpur Mafi (Uttar Pradesh) has been presented in table 6 and depicted in Fig. 2.

Table 5. Correlation of relevant soil properties with cationic micronutrients of acid soils of Chandauli district

	pH	OC	sand	silt	clay	Fe	Mn	Cu	Zn
pH	1.000	-0.002NS	-0.381NS	0.338NS	0.340NS	-0.345NS	0.090NS	0.207NS	0.317NS
OC	-0.002NS	1.000	-0.475*	0.239NS	0.606**	-0.017NS	0.397NS	0.635**	0.318NS
sand	-0.381NS	-0.475*	1.000	-0.890**	-0.890**	0.035NS	-0.365NS	-0.161NS	-0.144NS
silt	0.338NS	0.239NS	-0.890**	1.000	0.585**	-0.062NS	0.300NS	-0.116NS	0.187NS
clay	0.340NS	0.606**	-0.890**	0.585**	1.000	-0.001NS	0.351NS	0.402NS	0.070NS
Fe	-0.345NS	-0.017NS	0.035NS	-0.062NS	-0.001NS	1.000	-0.453*	-0.119NS	-0.170NS
Mn	0.090NS	0.397NS	-0.365NS	0.300NS	0.351NS	-0.453*	1.000	0.385NS	0.234NS
Cu	0.207NS	0.635**	-0.161NS	-0.116NS	0.402NS	-0.119NS	0.385NS	1.000	0.314NS
Zn	0.317NS	0.318NS	-0.144NS	0.187NS	0.070NS	-0.170NS	0.234NS	0.314NS	1.000
SD	0.980	1.393	1.124	0.631	0.631	85.118	11.667	0.657	0.348

Application of different lime sources brought significant difference by the treatments in the availability of iron. The data clearly indicated that the release of available iron decreased after 90 days of incubation period. After 90 days of incubation highest iron (248.87 mg kg^{-1}) was recorded in T_1 i.e., soil not amended with any liming material and it was found to be significantly higher than other treatments. The maximum decrease was obtained with T_4 i.e., $CaCO_3$ as liming material. It was 102.80mg kg1. T_2 [CaO] and T_3 [Ca $(OH)_2$] were recorded 119.13 and 116.67 mg kg^{-1} respectively, which were significantly higher than T_4. T_2 is also found to be significantly higher than T_3 [Ca $(OH)_2$].

4.3.3. Availability of manganese in acid soils of Shivpur Mafi

The data regarding release of available Manganese with different liming material in acid soil of Shivpur Mafi (Uttar Pradesh) has been presented in table 6 and depicted in fig. 3.

The data clearly indicates that the release of available Mn showed decrease in the release pattern of available Mn 90 days after incubation. Minimum release of available Manganese was seen in T_4 [$CaCO_3$]. It was 5.52 mg kg^{-1} as compared to 27.90 mg kg in T_1 [control] which was highest among all treatments. Available Manganese of T_2 and T_3 were found 7.44 and 6.58 mg kg^{-1} respectively. All results were found to be significantly different from each other.

4.4.4. Availability of copper in acid soils of Shivpur Mafi

The data regarding release of available Copper with different liming material in acid soils of Shivpur Mafi (Uttar Pradesh) has been presented in table 6 and depicted in fig. 4.

Application of different lime sources brought significant difference by the treatments in the availability of copper. The data clearly indicated that the release of available Copper decreased after 90 days of incubation period. After 90 days of incubation highest Copper (1.411 mg kg^{-1}) was recorded in T_1 i.e., soil not amended with any liming material and it was found to be significantly higher than other treatments. The maximum decrease was obtained with T_4 i.e., soil having $CaCO_3$ as liming material. It was 0.739 mg kg1. T_2 [CaO] and T_3 [Ca $(OH)_2$] were recorded 0.764 and 0.958 mg kg^{-1} respectively, while T_2 was found at par with T_4.

Table 6. Availabilities of cationic micronutrients in acidic soil of Shivpur Mafi (Chandauli district, Uttar Pradesh) as influenced by different liming materials at constant moisture regime

Available cationic micronutrients (mg kg^{-1})								
Liming materials	Zinc		Iron		Manganese		Copper	
	Incubation period							
	0 day	90 day	0 day	90 day	0 day	90 day	0 day	90 day
T_1- control	0.4020	0.2955	370.87	248.87	26.11	27.90	1.040	1.411
T_2-calcium oxide	0.4032	0.2117	371.20	119.13	27.49	7.44	1.041	0.764
T_3-calcium hydroxide	0.4046	0.2322	370.53	116.67	27.16	6.58	1.038	0.958
T_4-calcium carbonate	0.4022	0.2586	370.53	102.80	26.83	5.52	1.032	0.739
Mean	0.4030	0.2495	370.78	146.87	26.90	11.86	1.038	0.968
SEM	0.00156	0.01454	3.65	0.60	1.77	0.03	0.010	0.083
C.D. (P=0.05)	0.00508	0.04742	11.90	1.97	5.77	0.10	0.034	0.272

4.4.5. Availability of zinc in acid soils of Chandauli

The data regarding release of available zinc with different liming material in acid soils of Chandauli (Uttar Pradesh) has been presented in table 7 and depicted in fig. 5.

A critical perusal of the data revealed that release of available zinc attended a decreased value during 90 days of incubation. Highest decrease of available zinc was recorded in soil amended with T_2 [CaO] i.e., 0.2351 mg kg^{-1} which was significantly lower than T_3 [Ca $(OH)_2$] and T_4 [$CaCO_3$]. T_4 having 0.3245 mg kg^{-1} after 90 days was found significantly higher than T_3 having 0.2823 mg $kg^{-1.\ The}$ zinc status of T_1 i.e., control was recorded 0.3907 mg $kg^{-1,\ which}$ was significantly higher than all other treatments.

4.4.6. Availability iron in acid soils of Chandauli

The data regarding the availability of Iron with different liming material in acid soil of Chandauli (Uttar Pradesh) has been presented in table 7 and depicted in Fig.6.

Application of different lime sources brought significant difference by the treatments in the availability of iron. The data clearly indicated that the release of available iron decreased after 90 days of incubation period. After 90 days of incubation highest iron (276.07 mg kg^{-1}) was recorded in T_1 i.e., soil not amended with any liming material and it was found to be significantly higher than other treatments. The maximum decrease was obtained with T_2 i.e., CaO as liming material. It was 82.37 mg kg1. T_3 [Ca $(OH)_2$] and T_4 [$CaCO_3$] were recorded 215.07 and 205.53 mg kg^{-1} respectively, which were significantly higher than T_2. T_4 is also found to be significantly higher than T_3.

4.4.7. Availability of manganese in acid soils of Chandauli

The data regarding release of available Manganese with different liming material in acid soil of Chandauli (Uttar Pradesh) has been presented in table 7 and depicted in fig. 7.

The data clearly indicates that the release of available Mn showed decrease in the release pattern of available Mn 90 days after incubation. Minimum release of available Manganese was seen in T_2 [CaO]. It was 7.22 mg kg^{-1} as compared to 30.60 mg kg in T_1 [control] which was highest among all treatments. Available Manganese of T_3 and T_4 were found 11.42 and 17.44mg kg^{-1} respectively. All results were found to be significantly different from each other's.

4.4.8. Availability of copper in acid soils of Chandauli

The data regarding release of available Copper with different liming material in acid soils of Chandauli (Uttar Pradesh) has been presented in table 7 and depicted in fig. 8.

Application of different lime sources brought significant difference by the treatments in the availability of copper. The data clearly indicated that the release of available Copper decreased after 90 days of incubation period. After 90 days of incubation highest Copper (2.166 mg kg-1) was recorded in T_1 i.e., soil not amended with any liming material and it was found to be significantly higher than other treatments. The maximum decrease was obtained with T_4 i.e., soil having $CaCO_3$ as liming material. It was 1.675 mg kg1 and was significantly different from T_2 and T_3. T_2 [CaO] and T_3 [Ca $(OH)_2$] were recorded 1.781 and 1.879 mg kg^{-1} respectively and were found at par with each other.

Table 7. Availabilities of cationic micronutrients in acidic soil of Chandauli (Chandauli district,Uttar Pradesh) as influenced by different liming materials at constant moisture regime

Available cationic micronutrients (mg kg^{-1})								
Liming materials	Zinc		Iron		Manganese		Copper	
	Incubation period							
	0 day	90 day	0 day	90 day	0 day	90 day	0 day	90 day
T_1- control	0.2274	0.3907	265.20	276.07	54.27	30.60	2.241	2.166
T_2-calcium oxide	0.2141	0.2351	271.87	82.37	44.27	7.22	2.205	1.781
T_3-calcium hydroxide	0.2174	0.2823	266.20	215.07	50.94	11.42	2.221	1.879
T_4-calcium carbonate	0.2241	0.3245	271.20	205.53	44.27	17.44	2.219	1.675
Mean	0.2208	0.3082	268.62	194.76	48.44	16.67	2.222	1.875
SEM	0.02571	0.02717	4.85	5.29	5.02	0.16	0.051	0.101
C.D. (P=0.05)	0.08385	0.08861	15.80	17.24	16.36	0.53	0.165	0.330

4.4.9. Availability of zinc in acid soils of Seledi

The data regarding release of available zinc with different liming material in acid soils of Seledi (Subarnapur district, Odisha) has been presented in table 8 and depicted in fig.9.

A critical perusal of the data revealed that release of available zinc attended a decreased value during 90 days of incubation. Highest decrease of available zinc was recorded in soil amended with T_4 [$CaCO_3$] i.e., 0.2173 mg kg^{-1} which was at par with T_3 [$Ca(OH)_2$] and T_2 [CaO]. T_2 having 0.2367 mg kg^{-1} after 90 days was at par with T_3 having 0.2395 mg kg^{-1}. The zinc status of T_1 i.e., control was recorded 0.2955 mg kg^{-1}, which was significantly higher than T_4 and at par with other two treatments.

4.4.10. Availability iron in acid soils of Seledi

The data regarding the availability of Iron with different liming material in acid soil of Seledi (Subarnapur district, Odisha) has been presented in table 8 and depicted in Fig. 10.

Application of different lime sources brought significant difference by the treatments in the availability of iron. The data clearly indicated that the release of available iron decreased after 90 days of incubation period. After 90 days of incubation highest iron (284.33 mg kg^{-1}) was recorded in T_1 i.e., soil not amended with any liming material and it was found to be significantly higher than other treatments. The maximum decrease was obtained with T_2 i.e., CaO as liming material. It was 176.00 mg kg^{-1}. T_3 [Ca $(OH)_2$] and T_4 [$CaCO_3$] were recorded 243.87 and 194.67 mg kg^{-1} respectively, which were at par with T_2. T_4 is also found to at par with T_3.

4.4.11. Availability of manganese in acid soils of Seledi

The data regarding release of available Manganese with different liming material in acid soil of Seledi (Subarnapur district, Odisha) has been presented in table 8 and depicted in fig. 11.

The data clearly indicates that the release of available Mn showed decrease in the release pattern of available Mn 90 days after incubation. Minimum release of available Manganese was seen in T_2 [CaO]. It was 21.81 mg kg$^{-1.}$ Available manganese was found 33.61 mg kg in T_1 [control] which was found significant with T_2 and T_3 but at par with T_4. Available Manganese of T_3 and T_4 were found 22.43 and 27.75mg kg^{-1} respectively. All results were found to be at par with each other.

Table 8. Availabilities of cationic micronutrients in acidic soil of Seledi (Subarnapur district, Odisha) as influenced by different liming materials at constant moisture regime

Available cationic micronutrients (mg kg^{-1})								
Liming materials	Zinc		Iron		Manganese		Copper	
	Incubation period							
	0 day	90 day	0 day	90 day	0 day	90 day	0 day	90 day
T_1- control	0.4016	0.2955	302.73	284.33	56.85	33.61	1.942	1.157
T_2-calcium oxide	0.3917	0.2367	302.60	176.00	57.86	21.81	1.902	0.842
T_3-calcium hydroxide	0.3816	0.2395	306.07	243.87	57.52	22.43	1.610	1.119
T_4-calcium carbonate	0.3849	0.2173	298.13	194.67	56.53	27.75	1.633	0.887
Mean	0.3900	0.2472	302.38	224.72	57.19	26.40	1.772	1.001
SEM	0.01357	0.02226	9.69	17.01	0.72	2.70	0.02226	9.69
C.D. (P=0.05)	0.04425	0.07258	31.61	55.47	2.34	8.80	0.646	0.223

4.4.12. Availability of copper in acid soils of Seledi

The data regarding release of available Copper with different liming material in acid soils of Seledi (Subarnapur district, Odisha) has been presented in table 8 and depicted in fig. 12.

Application of different lime sources brought significant difference by the treatments in the availability of copper. The data clearly indicated that the release of available Copper decreased after 90 days of incubation period. After 90 days of incubation highest Copper (1.157 mg kg-1) was recorded in T_1 i.e., soil not amended with any liming material and it was found to be significantly higher than T_2 and T_4 and at par with T_3. The maximum decrease was obtained with T_2 i.e., soil having CaO as liming material. It was 0.842 mg kg1 and was significantly different from T_3 and at par with T_4. T_3 [Ca $(OH)_2$] and T_4 [CaCO3] were recorded 1.119 and 0.887mg kg^{-1} respectively and were found significantly different with each other.

4.4.13. Availability of zinc in acid soils of Jamsoti

The data regarding release of available zinc with different liming material in acid soils of Jamsoti (Chandauli district, Uttar Pradesh) has been presented in table 9 and depicted in fig.13

A critical perusal of the data revealed that release of available zinc attended a decreased value during 90 days of incubation. Highest decrease of available zinc was recorded in soil amended with T_2 [CaO] i.e., 0.2151 mg kg^{-1} which was significantly lower than T_3 [Ca $(OH)_2$] and T_4 [CaCO3]. T_4 having 0.1438 mg kg^{-1} after 90 days was at par with T_3 having 0.1587 mg $kg^{-1. The}$ zinc status of T_1 i.e., control was recorded 0.2294 mg kg^{-1}, which was significantly higher than T_3 and T_4 and at par with T_2 treatment.

4.4.14. Availability iron in acid soils of Jamsoti

The data regarding the availability of Iron with different liming material in acid soil of Jamsoti (Chandauli district, Uttar Pradesh) has been presented in table 9 and depicted in Fig.14

Application of different lime sources brought significant difference by the treatments in the availability of iron. The data clearly indicated that the release of available iron decreased after 90 days of incubation period. After 90 days of incubation highest iron (263.93 mg kg-1) was recorded in T_1 i.e., soil not amended with any liming material and it was found to be significantly higher than T2 and T_3. The maximum decrease was obtained with T_2 i.e., CaO as liming material. It was

113.80 mg kg1. T_3 [Ca $(OH)_2$] and T_4 [$CaCO_3$] were recorded 144.47 and 218.60 mg kg^{-1} respectively. $T_3$was at par with T_2. T_4 was found at par with T_3 and T_2.

Table 9. Availabilities of cationic micronutrients in acidic soil of Jamsoti (Chandauli district, Uttar Pradesh) as influenced by different liming materials at constant moisture regime

Available cationic micronutrients (mg kg^{-1})								
Liming materials	Zinc		Iron		Manganese		Copper	
	Incubation period							
	0 day	90 day	0 day	90 day	0 day	90 day	0 day	90 day
T_1- control	0.3377	0.2294	298.07	263.93	48.53	32.37	1.676	1.277
T_2-calcium oxide	0.4382	0.2151	317.47	113.80	49.29	9.63	1.662	0.821
T_3-calcium hydroxide	0.4048	0.1587	308.87	144.47	52.62	14.49	1.248	1.184
T_4-calcium carbonate	0.3080	0.1438	312.53	218.60	50.62	13.08	1.232	1.205
Mean	0.3722	0.1868	309.23	185.20	50.27	17.39	1.455	1.122
SEM	0.04547	0.01493	6.21	15.33	1.65	1.49	0.152	0.083
C.D. (P=0.05)	0.14830	0.04870	20.26	49.99	5.38	4.85	0.495	0.271

4.4.15. Availability of manganese in acid soils of Jamsoti

The data regarding release of available Manganese with different liming material in acid soil of Jamsoti (Chandauli district, Uttar Pradesh) has been presented in table 9 and depicted in fig. 15.

The data clearly indicates that the release of available Mn showed decrease in the release pattern of available Mn 90 days after incubation. Minimum release of available Manganese was seen in T_2 [CaO]. It was 9.63 mg kg$^{-1.}$ Available manganese was found 32.37 mg kg in T_1 [control] which was found significant with all treatments. Available Manganese of T_3 and T_4 were found 14.49 and 13.08 mg kg^{-1} respectively which were at par with each other. T_3 was significantly lower than T_2 but at par with T_4.

4.4.16. Availability of copper in acid soils of Jamsoti

The data regarding release of available Copper with different liming material in acid soils of Jamsoti (Chandauli district, Uttar Pradesh) has been presented in table 9 and depicted in fig. 16.

Application of different lime sources brought significant difference by the treatments in the availability of copper. The data clearly indicated that the release of available Copper decreased after 90 days of incubation period. After 90 days of incubation highest Copper (1.277 mg kg^{-1}) was recorded in T_1 i.e., soil not amended with any liming material and it was found to be significantly higher than T_2 and at par with T_3 and T_4. The maximum decrease was obtained with T_2 i.e., soil having CaO as liming material. It was 0.821 mg kg1 and was at par with T_3 and significantly different from T_4. T_3 [Ca $(OH)_2$] and T_4 [CaO] were recorded 1.184 and 1.205 mg kg^{-1} respectively and were found at par with each other.

Table 10. **Changes in pH of acidic soils as influenced by liming materials at constant moisture regime under incubation period**

Liming materials	**Incubation period**							
	S1- Shivpur mafi		**S2 - Chandauli**		**S3 - Seledi**		**S4 - Jamsoti**	
	0 day	90 day	0 day	90 day	0 day	90 day	0 day	90 day
T_1- control	4.96	5.01	5.07	5.09	5.48	5.53	5.56	5.50
T_2-calcium oxide	4.96	7.13	5.07	6.93	5.48	6.51	5.56	6.84
T_3-calcium hydroxide	4.96	6.56	5.07	6.48	5.48	6.43	5.56	6.43
T_4-calcium carbonate	4.96	7.36	5.07	7.26	5.48	7.08	5.56	7.54

It had been observed that all three liming materials i.e. CaO,$CaCO_3$,$Ca(OH)_2$ were effective in reclamation of acid soil having acidic pH by increasing the soil pH. All the lime treated units have increased the pH value than initial soil pH after 90 days . McCallum et al. (2016) also reported the similar result i.e. limed plots had higher soil pH than un-limed plot and soil pH was positively associated with liming.

T_1 which was not treated with liming material and its pH value might be increased or decreased slightly . T_2 [CaO] increased pH from 4.96 to 7.13,5.07 to 6.93,5.48 to 6.51 and 5.56 to 6.84 of soil 1,soil 2,soil 3 and soil 4 respectively. T_3 [$Ca(OH)_2$] increased pH from 4.96 to 6.56,5.07 to 6.48,5.48 to 6.43,5.56 to 6.43 of soil 1,soil2,soil3 and soil 4 respectively. T_4 [CaCO3] increased pH from 4.96 to 7.36,5.07 to 7.26,5.48 to 7.08, 5.56 to 7.54 of soil 1,soil 2,soil 3 and soil 4 respectively. From the Table 12 and Fig.17, it can be suggested that all liming material show its significant effect after 90 days. The effectiveness of all three liming materials in reclamation of soil acidity was found in order of T_4 ($CaCO_3$)> T_2 (CaO)> T_3 $Ca(OH)_2$

* * *

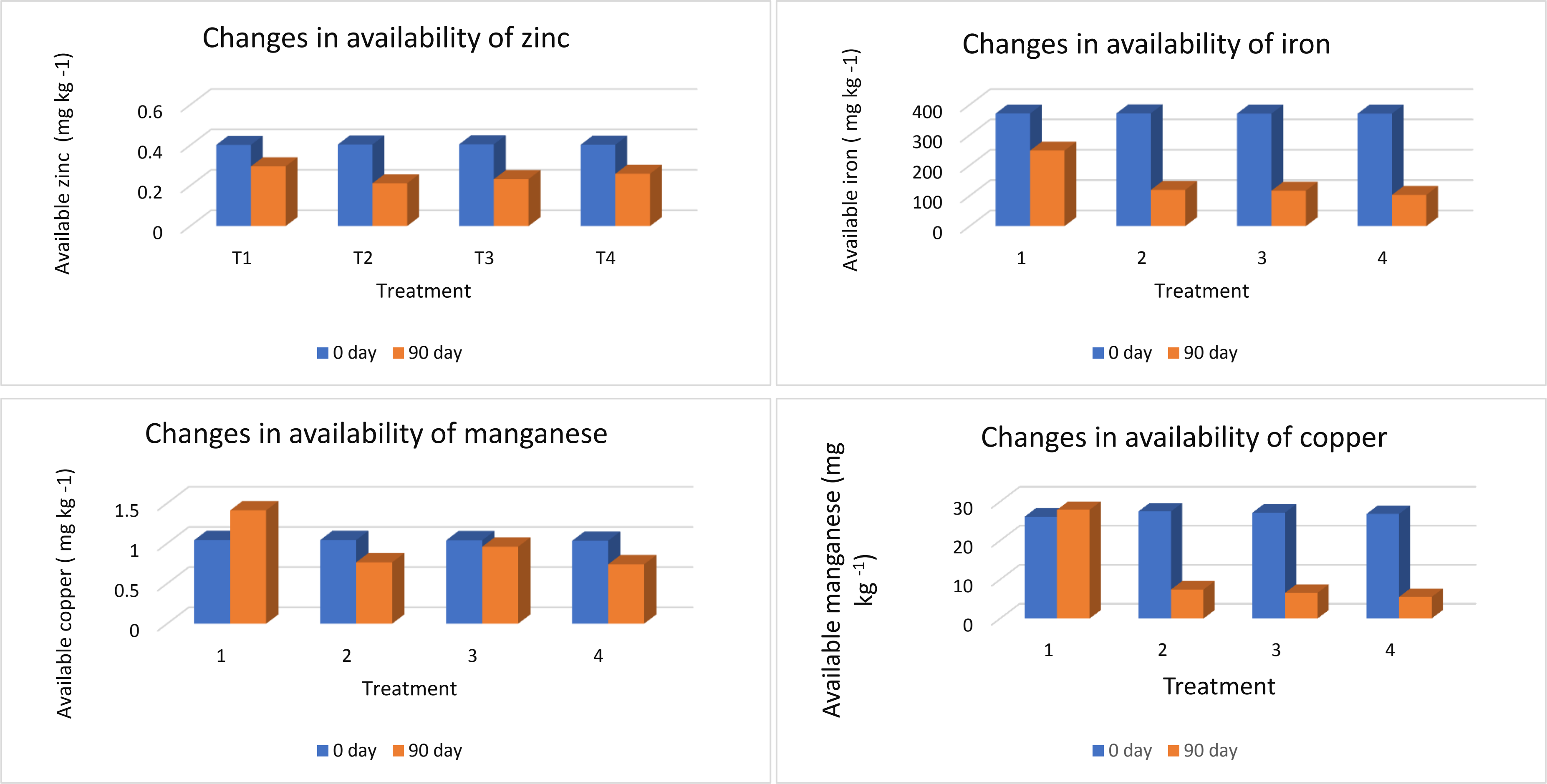
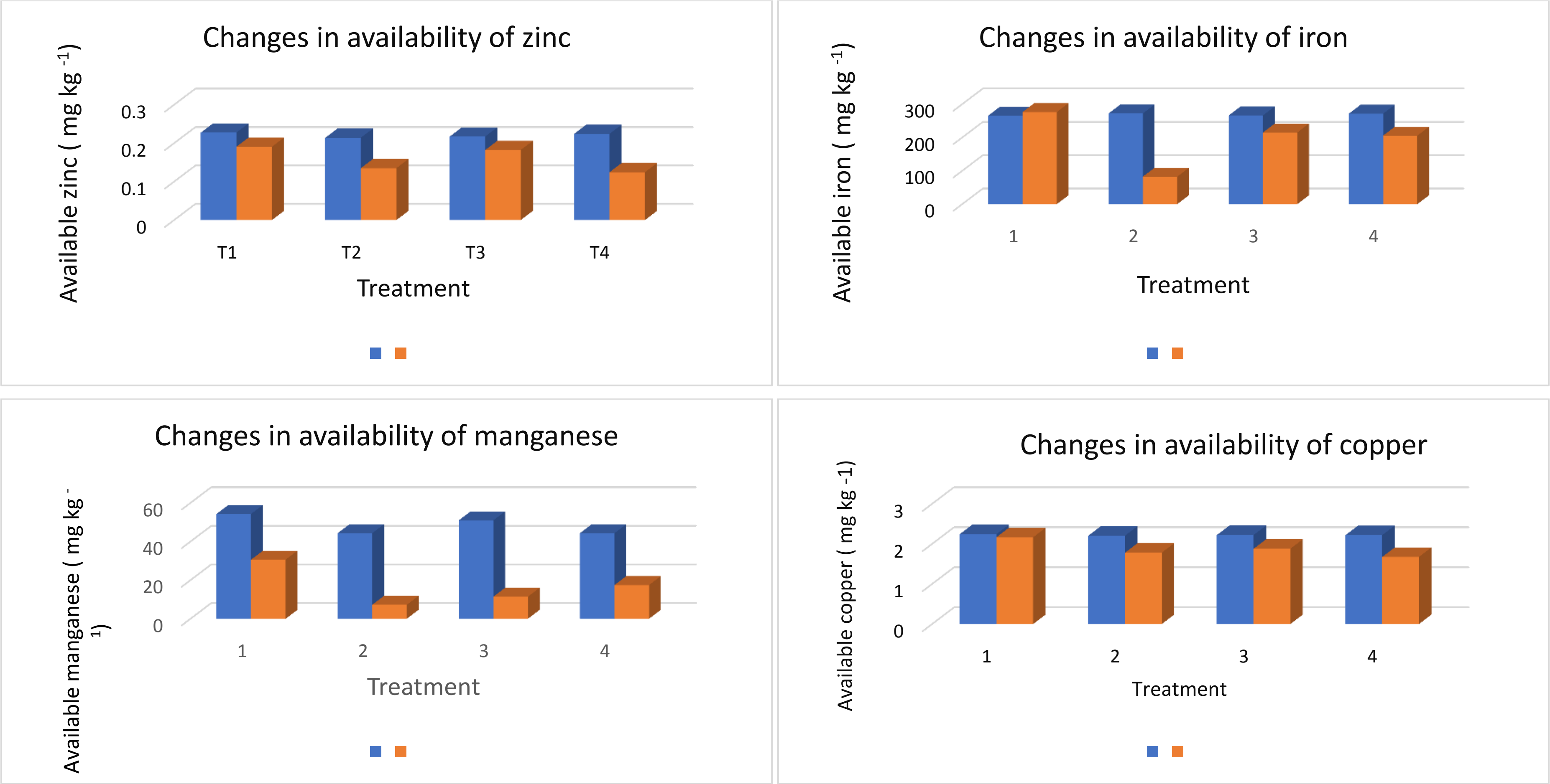


Fig. (1-4) Availabilities of cationic micronutrients in acidic soil of Shivpur Mafi(Chandauli district, Uttar Pradesh) as influenced by different liming materials at constant moisture regime


Changes in availability of zinc

Changes in availability of iron

Changes in availability of manganese

Changes in availability of copper

Fig. (5-8) **Availabilities of cationic micronutrients in acidic soil of Chandauli (Chandauli district ,Uttar Pradesh) as influenced by different liming materials at constant moisture regime**

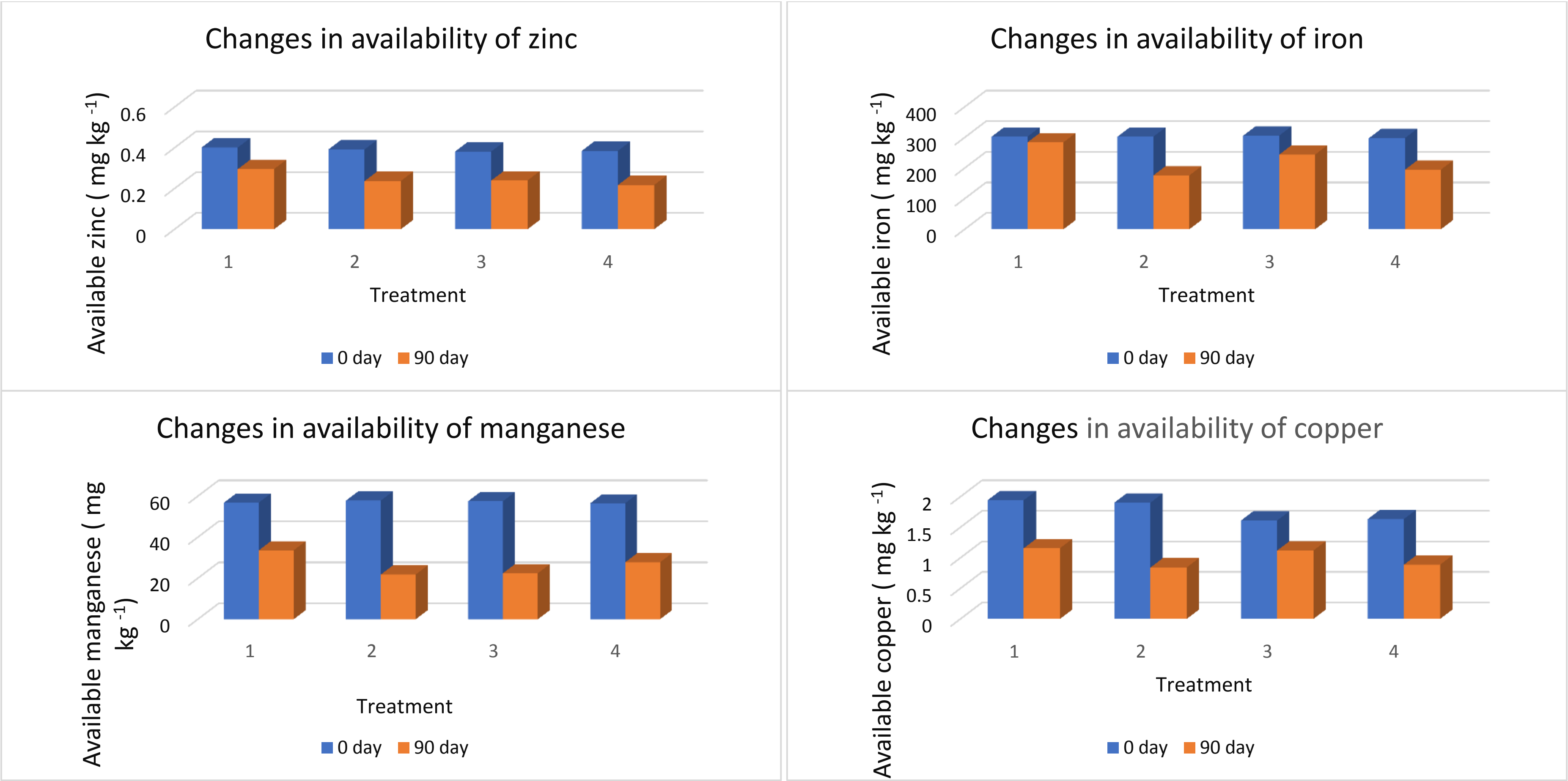


Fig. 9-12 **Availabilities of cationic micronutrients in acidic soil of Seledi (Subarnapur district ,Odisha) as influenced by different liming materials at constant moisture regime**

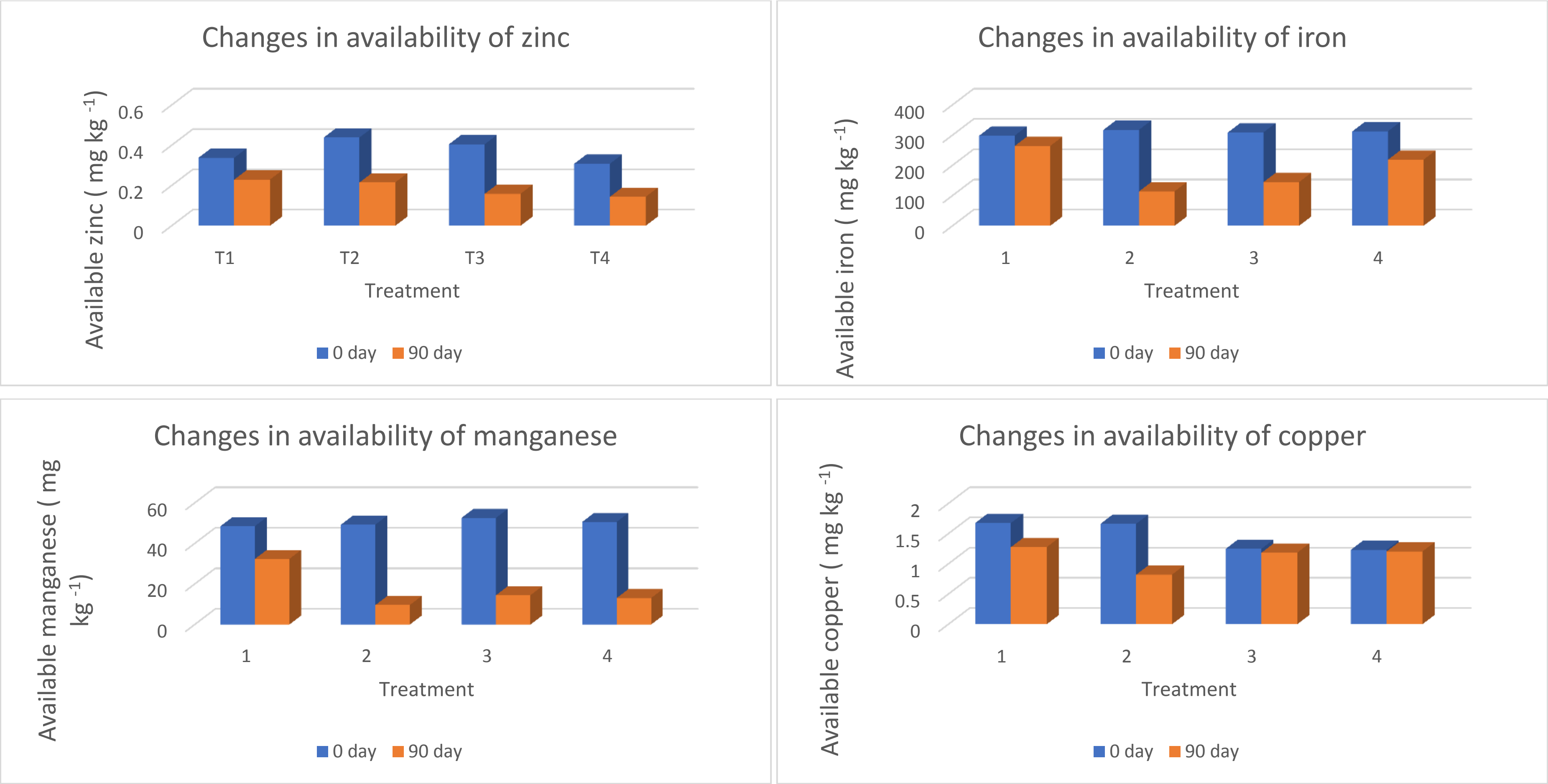


Fig. 13-16. **Availabilities of cationic micronutrients in acidic soil of Jamsoti (Chandauli district,Uttar Pradesh) as influenced by different liming materials at constant moisture regime**

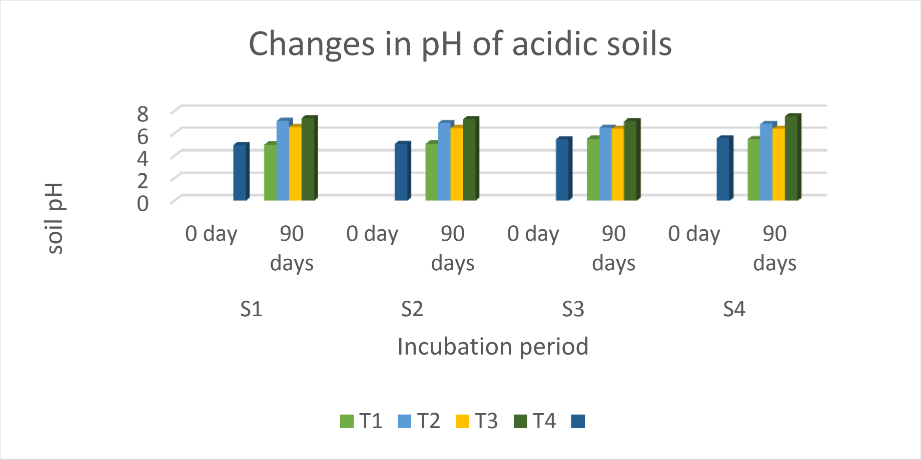


Figure 17 Changes in pH of acidic soils as influenced by liming materials at constant moisture regime of different locations

Chapter V

DISCUSSION

Impact of lime on soil pH

Liming has been one of the best ways of ameliorating an acid soil. In acid soils, plant growth is likely to be affected due to toxic concentrations of Fe, Al and Mn, precipitation and low availability of phosphorus, deficiency of nutrients such as calcium, magnesium, potassium, reduced microbial and biochemical activity etc. Although low soil pH by itself is not harmful to plants, its attendant factors such as the ones mentioned above limit crop growth. To reclaim acid soils, several liming materials are available. Application of any liming materials is meant to neutralize the soil acidity, but simultaneously this practice also increases the availability of P and Ca and other nutrients and suppresses the toxicity of Fe, Al and Mn.

The present study was intended to determine how lime affects soil properties and nutrient availabilities . With this objective a field experiment was conducted, whose results are furnished in chapter IV. In the succeeding paragraphs an attempt has been made to explain the variations noticed with their application in soil plant relationship in acid soils.

In all the soil samples, the application of $CaCO_3$ increased the soil pH to maximum value followed by CaO after 90 days of incubation and the lowest level of increase was seen by application of $Ca(OH)_2$. The relative increase in soil pH due to liming is more in case of Soil -1 (Shivpur mafi), which may be due to higher rate of lime requirement owing to low buffering capacity of the soil, the reason being lowest organic matter content among all the soils. The increase in soil pH due to liming as when liming material is applied the Ca^{2+} present in the liming material replace H^+ and Al^{3+} on the colloidal complex, precipitating $Al(OH)_3$. the adsorption of the calcium and magnesium ions lowers the percentage acid saturation of the colloidal complex, and the pH of the soil solution increases correspondingly (Brady and Weil, 2016). The lowest level in increase in pH was found in Seledi, Subarnapur soil Odisha, may be due to high organic matter content of the soil among all the soil, thereby high pH buffering capavcity (Briedis et al. 2012).

If the pH increases, the ionic forms of the micronutrient cations change first to the hydroxy ions and, finally, to the insoluble hydroxides or oxides of the elements. All of the hydroxides of the micronutrient cations are relatively insoluble, thereby reducing there extractability and ultimate availability to plants. T3 [$Ca(OH)_2$] had highest level of all the micronutrient, as it increased the soil pH to a lowest level among all the liming materials in all the soil. This showed a clear inverse correlation between pH and micronutrient availability of the soil. Shuman (1985) also observed similar kind of result. He found that by liming, the exchangeable Zn, Mn content decreases, increasing the organic fraction of these nutrients. However, in all the cases, micronutrient level is well above the critical value required for plant nutrient even after liming, which may be due to fact that, though the soil pH has been increased in all the cases, still it is in neutral range (6.5-7.5).

The pH of the acid soil was increased due to replacement of H+ ions by Ca2+ and Mg2+ions. The carbonate (CO3 2-) reacts with water to form bicarbonate (HCO3-). These react with H+ ions to form H2O and CO2. But all three liming materials showed different period of soil reaction may be due to their different neutralizing values, their different solubility nature and moisture content in the soil during liming. Jena (2008) revealed that application of lime @ 0.2 LR increased the pH from 5.1 to 6.9 and decreased exchangeable Al3+from 0.62 to 0 cmol (pi kg-' within seven days of incubation. The calcium ion present in the ameliorants can be readily adsorbed on soil particles and organic matter. Shazana et al. (2011) showed that increase in solution pH resulting from lime application was due to the production of hydroxyl ions that were hydrolyzed .

Impact of lime on availabilities of cationic micronutrients

Significant variation in DTPA extractable micronutrients were observed (Mn, Cu, Zn) due to application of different liming material in Table 5 to 9. All the micronutrients significantly decreased in limed treatments compared to control both at 90 days after liming . Deceased in micronutrient availability upon liming was due to increases in soil pH. Ayodele and Shittu (2014) reported that there was a reduction in iron, manganese and aluminium upon liming and FYM addition due to increase the soil pH and exchangeable bases of acid soils.

Saha et al. (1999) reported that micronutrients were mobilized into 'gel' hydrous oxides (Zn, Cu, and Fe) and amorphous oxides fractions (except Cu) due to lime application. Lime decreased readily available water-soluble plus exchangeable forms of metals in both the soils. Decrease in micronutrient content upon liming were reported by many scientists Marschner (1995) and Fageria et al. (1995) .

The depression in available Cu content in soil due to liming (Figure) is related to decrease in the solubility of copper with increase in soil pH, because at high pH Cu is precipitated as hydroxides. Fine particles of calcium carbonate can also provide loci for the precipitation of Cu(OH)2 and Cu(OH)CO3 (Srivastava & Gupta, 1996). The elevation of soil pH above 5.0 was found to decrease the Cu concentration in soil solution (Sanders, 1982). Alloway (1990) reported that such negative effect of liming on Cu availability occurs, mainly, due to the increase in the soil cation exchange capacity which depends on the presence of pH dependent charge in the soil. Nascimento et al. (2003) studied the redistribution of Cu in different soil fractions as a result of addition of lime. They found that there was a reduction in exchangeable and organically bound Cu with concomitant increase in Fe and Mn oxide bound Cu.

Decrease in availability of Fe is ascribed to the fact that activity of Fe in solution decreases 1000-fold with a unit increase in pH (Lindsay, 1979). Katyal and Randhawa (1983) also reported the reduction in available Fe presumably due to raise in the value of soil pH. Significant reduction in available Fe content in soil with liming was reported by several workers (Lalljee & Facknath, 2001). Such effect of liming was related to elevation of soil pH. Total inorganic Fe in soil solution varies with pH and reaches a minimum in the pH range of 6.5 to 8.0. The activity of Fe in solution decreases 1000-fold for each unit increase in pH (Lindsay, 1978). Later on, Katyal and Randhawa (1983) also reported the reduction in available Fe presumably due to rise in the value of soil pH.

The significant decrease in available Mn content in soil with increase in pH may be explained by the fact that more Mn is present soil at low pH or high Al in soil because of total acidity as compared to higher soil pH (Curtin & Smilli, 1983; Tariq & Mott, 2006).Generally the solubility of Mn in soil decreases with liming. Geering et al. (1969) and Bohn (1970) reported that solubility of Mn varied with soil type and is highly dependent on soil reaction (pH). Lalljee and Facknath (2001) observed that acid-EDTA extractable Mn in some acid soils was substantially reduced as a result of liming. Similarity, Sanchez (1976) obtained a negative relationship between liming and Mn availability in acid soil. However, reports are also there in literature which indicates the positive effect of liming on the availability of Mn in soil (Tariq and Mott, 2006).

Soil pH has a profound influence on Zn retention and availability. Solubility of soil-Zn decreases 100-fold with a unit increase in soil pH (Lindsay, 1978). Based on this analogy, availability of Zn should be decreased due to increase in soil pH as a result of addition of calcium carbonate. It has also been reported that severity of Zn-deficiency was reduced due to Mg application, which may be related to replacement of Zn by Mg from specific sites on soil exhcnage complex (Srivastava & Gupta, 1996). Because Zn2+ and Mg2+ ions have similar charge and size and can substitute each other from specific sites on soil exchange complex. In the present investigation, addition of calcium carbonate might have increased the Mg concentration in soil solution through cation exchange, which, in turn, possibly increased the Zn concentration in soil solution.

Cationic micronutrients, Zn, Cu, Fe, Mn are more available for plant uptake under acidic soil conditions. Since the pH is increased due to lime application, the solubility of Zn, Cu, Fe and Mn decreases through a complex set of reactions. Kovacevic et al. (2006) reported that plant available Zn content increased considerably in the 0-30 cm soil layer due to increase in pH as result of lime addition. However, such effects of liming were more pronounced at higher rates as compared to that of lower rates of applied lime (Lalljee & Facknath, 2001).

Chapter VI

SUMMARY AND CONCLUSION

Soil acidity is a major reason for low productivity in most cultivated soils. To overcome this problem liming of acid soils is a common practice. In the present investigation, an attempt was made to evaluate efficacy of different liming material for its efficacy and micronutrient availability by ameliorating acid soil.

The Calcium Oxide [CaO], Calcium Hydroxide [$Ca(OH)_2$],Calcium Carbonate[$CaCO_3$] were analysed for their nutrient content and properties. Calcium Oxide[CaO] recorded pH of 7.13, 6.93, 6.51 and 6.84, Calcium Hydroxide [$Ca(OH)_2$] recorded pH of 6.56, 6.48, 6.43 and 6.43, Calcium Carbonate[$CaCO_3$] recorded 7.36, 7.26, 7.08 and 7.54 respectively indicating that $CaCO_3$ was more alkaline in nature. $CaCO_3$ was found more efficient than CaO and $Ca(OH)_2$ in increasing pH of the four soils.

These were laboratory tested to know the "Status of cationic micronutrients and their availabilities as influenced by applications of lime sources in acid soil" during 2020-21 at Soil Health and Plant Nutrition Laboratory, Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. Calcium Oxide, Calcium Hydroxide, Calcium Carbonate were provided to four different soils of Uttar Pradesh and Odisha in a CRD design with four treatments and three replications. During the experiment, the soil was sampled after 90 days.

The data obtained in respect to available primary, secondary, micro nutrient status in soil & soil acidity components initial & at harvest were analysed statistically. The results of the experiments are summarized in this chapter.

✓ The pH of the Sahab Ganj block soils ranges from 5.0 to 7.9, with an average of 6.16. The organic carbon content of this block's soils ranges from 33.0 to 65.0 g kg-1, with a mean of 46.15 g kg-1.

- ✓ The status of micronutrients in Sahab Ganj soils is above critical levels. These soils' iron content ranges from 120.7 to 358.5 mg kg^{-1}, with an average of 245.14 mg kg^{-1}. Manganese concentrations range from 9.0 to 34.6 mg kg^{-1}. Copper levels in soil range from 1.3 to 3.0 mg kg^{-1}, with a mean value of 2.067 mg kg^{-1}. Zinc levels in these soils range from 0.2 to 1.0 mg kg^{-1}, with an average value of 0.637 mg kg^{-1}.

- ✓ The pH of the soils of Chakia block ranges from 5.3 to 7.6, with a mean of 6.16, similar to that of Sahab Ganj block. The organic carbon content of this block's soils is in the medium to high range, ranging from 54.0 to 79.0 g kg-1, with a mean of 68.83 g kg-1.

- ✓ The status of micronutrients in Chakia soils is above essential levels. These soils' iron content ranges from 129.9 to 332.7 mg kg^{-1}, with an average of 180.705 mg kg^{-1}. Manganese concentrations range from 29.6 to 55.2 mg kg^{-1}. Copper levels in soil range from 2.3 to 4.0 v, with a mean value of 2.947 mg kg^{-1}. Zinc levels in these soils range from 0.1 to 1.5 mg kg^{-1}, with an average of 0.728 mg kg^{-1}.

- ✓ There is a significant correlation between sand percentage and organic carbon content; sand percentage and silt content; available iron and manganese content at 0.05 level.

- ✓ There is a statistically significant relation between organic carbon content and clay; organic carbon and copper; sand percentage and clay percentage and silt and clay content at 0.01 level of significance.

- ✓ After 90 days of incubation, the release of accessible iron in Shivpuri village soil declined, with the greatest iron (248.87 mg kg^{-1}) reported in T_1 and it was shown to be considerably greater than other treatments. T_4 [$CaCO_3$], was shown to be the most effective liming material with 102.80 mg kg^{-1}. T_2 [CaO] and T_3 [$Ca(OH)_2$] were recorded 119.13 and 116.67 mg kg^{-1} respectively.

- ✓ In Shivpuri village, the soil supplemented with T_2 [CaO] had the highest drop in available zinc, 0.2117 mg kg^{-1}, which was much lower than T_3 [$Ca(OH)_2$] and T_4 [$CaCO_3$]. After 90 days, T_4 with 0.2586 mg kg^{-1} was shown to be substantially greater than T_3 with 0.2322 mg kg-1. T_1 (control) had a zinc status of 0.2955 mg kg^{-1}, which was significantly higher than all other treatments.

- ✓ The release of accessible Mn in Shivpuri village soil decreased, with the lowest release of available Manganese in T_4 [$CaCO_3$]. It was 5.52 mg kg^{-1} against 27.90 mg kg in T_1 [control], which was the highest of all treatments. T_2 and T_3 manganese availability was determined to be 7.44 and 6.58 mg kg^{-1} mg kg^{-1}, respectively. All of the results were determined to be significantly different.

- ✓ After 90 days of incubation, the amount of available copper in Shivpuri village soil reduced. T_1 had the highest copper concentration (1.411 mg kg^{-1}). T_4 [$CaCO_3$] resulted in the greatest reduction. It was 0.739 mg kg^{-1}. The T_2 [CaO] and T_3 [$Ca(OH)_2$] concentrations were 0.764 and 0.958 mg kg^{-1}, respectively.

- ✓ After 90 days of incubation, the soil of Chandauli T_1, which had not been treated with any liming material, had the greatest iron (276.07 mg kg^{-1}) and was determined to be substantially higher than the other treatments. T_2, i.e., CaO as liming material, yielded the greatest reduction. It was 82.37 mg kg^{-1}. T_3 [$Ca(OH)_2$] and T_4 [$CaCO_3$] were found to be 215.07 mg kg^{-1} and 205.53 mg kg^{-1}, respectively.

- ✓ The greatest reduction in available zinc was observed in soil amended with T_2 [CaO], i.e., 0.2351 mg kg^{-1}, which was significantly lower than T_3 [$Ca(OH)_2$] and T_4 [$CaCO_3$]. After 90 days, T_4 with 0.3245 mg kg^{-1} was shown to be substantially greater than T_3 with 0.2823 mg kg^{-1}. The zinc status of T_1, i.e., the control, was 0.3907 mg kg^{-1}, which was significantly higher than the zinc status of all other treatments.

- ✓ The release pattern of available Mn showed a decrease 90 days after incubation. T_2 [CaO] showed the least amount of available Manganese release. It was 7.22 mg kg^{-1} compared to 30.60 mg kg in T_1 [control], which was the highest of any treatment. T_3 and T_4 manganese availability was found to be 11.42 and 17.44mg kg^{-1}, respectively.

- ✓ After 90 days of incubation, the release of available copper decreased. T_1 had the highest copper concentration (2.166 mg kg^{-1}) recorded. The greatest reduction was obtained with T_4, i.e., soil with $CaCO_3$ as liming material. It was 1.675 mg kg1 and markedly different from T_2 and T_3. T_2 [CaO] and T_3 [$Ca(OH)_2$] were measured to be 1.781 and 1.879 mg kg^{-1}, respectively.

- ✓ After 90 days of incubation, the available iron decreased. T_1 had the highest iron (284.33 mg kg^{-1}) after 90 days of incubation. The greatest reduction was obtained with T_2, i.e., CaO as liming material. The value was 176.00 mg kg1. T_3 [$Ca(OH)_2$] and T_4 [$CaCO_3$] were measured at 243.87 and 194.67 mg kg^{-1}, respectively, and were comparable to T_2. T_4 is also found to be comparable to T_3.

- ✓ During the 90-day incubation period, the amount of available zinc released decreased. The greatest reduction in available zinc was observed in soil amended with T_4 [$CaCO_3$], i.e., 0.2173 mg kg^{-1}, which was comparable to T_3 [$Ca(OH)_2$] and T_2 [CaO]. T_2 had 0.2367 mg kg^{-1} after 90 days, which was comparable to T_3's 0.2395 mg kg^{-1}. T_1's zinc status, i.e., control, was 0.2955 mg kg^{-1}.

- ✓ 90 days after incubation, the release pattern of available Mn showed a decrease in the release pattern of available Mn T_2 [CaO] showed the least amount of available Manganese release. The value was 21.81 mg kg^{-1}. Available manganese was found to be 33.61 mg kg in T_1 [control], which was significant when compared to T_2 and T_3, but not when compared to T_4. T_3 and

T_4 manganese availability was found to be 22.43 and 27.75 mg kg^{-1}, respectively.

- ✓ After 90 days of incubation, the release of available copper decreased. After 90 days of incubation, the highest Copper (1.157 mg kg^{-1}) was found in T_1, which was higher than T_2 and T_4 and comparable to T_3. The greatest reduction was obtained with T_2, i.e., soil containing CaO as liming material. It was 0.842 mg kg^{-1}, while T_3 [$Ca(OH)_2$] and T_4 [$CaCO_3$] were 1.119 and 0.887 mg kg^{-1}, respectively.

- ✓ The soil amended with T_2 [CaO] had the greatest decrease in available zinc, 0.2151 mg kg^{-1}, which was significantly lower than T_3 [$Ca(OH)_2$] and T_4 [$CaCO_3$]. T_4 had 0.1438 mg kg^{-1} after 90 days, which was comparable to T_3's 0.1587 mg kg^{-1}. T_1's zinc status, i.e., control, was 0.2294 mg kg^{-1}, which was significantly higher than T_3 and T_4 and comparable to T_2 treatment.

- ✓ The data clearly showed that after 90 days of incubation, the release of available iron decreased. After 90 days of incubation, the highest iron (263.93 mg kg^{-1}) was found in T_1, i.e., soil that had not been amended with any liming material, and it was significantly higher than T_2 and T_3. The greatest reduction was obtained with T_2, i.e., CaO as liming material. T_3 [$Ca(OH)_2$] was 113.80 mg kg1.

- ✓ T_2 [CaO] showed the least amount of available Manganese release. The value was 9.63 mg kg^{-1}. The available manganese was found to be 32.37 mg kg in T_1 [control], which was significant across all treatments. T_3 and T_4 manganese availability was found to be 14.49 and 13.08 mg kg^{-1}, respectively, which were comparable. T_3 was significantly lower than T_2, but comparable to T_4.

- ✓ T_1 had the highest Copper (1.277 mg kg^{-1}) after 90 days of incubation. The greatest reduction was obtained with T_2, i.e., soil containing CaO as liming material. It was 0.821 mg kg1 and was comparable to T_3 but significantly lower than T_4. T_3 [$Ca(OH)_2$] and T_4 [CaO] were measured at 1.184 and 1.205 mg kg^{-1}, respectively, and were found to be comparable.

- ✓ The pH of the soil increased as a result of the application of various liming sources. After 90 days of liming, soil sample 4 (Jamsoti, Uttar Pradesh) had a higher pH (5.56 - 7.54) in treatment T_4 ($CaCO_3$). T_4 ($CaCO_3$) was then detected in soil sample 1, which was collected in Shivpuri, Uttar Pradesh.

- ✓ It is suggested that after 90 days, all liming materials will show a significant effect. All three liming materials were found to be effective in reclaiming soil acidity in the following order: T_4 ($CaCO_3$)> T_2 (CaO)> T_3 $Ca(OH)_2$.

CONCLUSION

The acidity has to be measured and the lime requirement has to be assessed all on the basis of scientific and well recognised principles and methods. It is concluded from the present investigation that acidic soils of Chandauli are coarse textured, acidic to alkaline in reaction,low content of organic carbon and sufficient in cationic micronutrients. Further among the liming materials, calcium carbonate was found to be superior to neutralize the soil acidity. Results of incubation study revealed that availabilities of cationic micronutrients decreased at 90 days of incubation period with added liming materials in all acidic soils over control. Application of lime in such acidic soils can increase crop productivity and sustained soil health in years to come.

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