CROP RESPONSE BASED ASSESSMENT OF NUTRIENT DEFICIENCIES IN VERTISOL AND INSEPTISOL OF BEMETARA DISTRICT OF CG.

M. Sc. (Ag) Thesis

by

Neha Sahu

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE
INDIRA GANDHI KRISHI VISHWAVIDYALAYA
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Thesis

Submitted to the

Indira Gandhi Krishi Vishwavidyalaya, Raipur

by

Neha Sahu

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Science

in

Soil Science and Agricultural Chemistry

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CERTIFICATE – I

This is to certify that the thesis entitled **"Crop response based assessment of nutrient deficiencies in *Vertisol* and *Inceptisol* of bemetara district of C.G."** submitted in partial fulfillment of the requirements for the degree of **Master of Science in Agriculture** of the Indira Gandhi Krishi Vishwavidyalaya, Raipur, is a record of the bonafide research work carried out by **Neha Sahu** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma (Certificate awarded etc.) or has been published/published part has been fully acknowledged. All the assistance and help received during the course of the investigations have been duly acknowledged by her.

Date: 22/7/2016

Chairman
Advisor committee

THESIS APPROVED BY THE STUDENT'S ADVISORY COMMITTEE

Chairman:	(Dr. V. N. Mishra)	22/7/2016
Member:	(Dr. L. K. Srivastava)	
Member:	(Dr. G. S. Tomar)	
Member:	(Dr. R. R. Saxena)	22/7/16

CERTIFICATE - II

This is to certify that the thesis entitled **"Crop response based assessment of nutrient deficiencies in *Vertisol* and *Inceptisol* of bemetara district of C.G."** submitted by **Neha Sahu** to the Indira Gandhi Krishi Vishwavidyalaya, Raipur, in partial fulfillment of the requirements for the degree of **Master of Science in** Agriculture in the Department of Soil Science and Agricultural Chemistry has been approved by the external examiner and Student's Advisory Committee after oral examination.

Date: 30.07.2016

Signature External Examiner
(Name. Dr. S. S. Tomar)

Major Advisor ______________________

Head of the Department ______________________ 11/08/2016

Dean / Dean Faculty ______________________

Approved/Not approved

Director of Instructions ______________________

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"Education plays important role in personal and social development and teacher plays a fundamental role in imparting education. Teachers have crucial role in preparing young people not only to face the future with confidence but also to build up it with purpose and responsibility..

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Department of Soil Science and Agril. Chemistry, **(Neha Sahu)**

College of Agriculture,

I.G.K.V., Raipur (C.G)

Date:

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NOTATIONS / SYMBOLS		DESCRIPTIONS
%	-	Per cent
@	-	At the rate of
^{0}C	-	Degree Celsius
>	-	Greater than
<	-	Smaller than

LIST OF ABBREVIATIONS

Abbreviation	Description
B	Boron
c	Clayey
Ca	Calcium
CEC	Cation exchange capacity
CG	Chhattisgarh
cl	clay loam
Cu	Copper
E.C.	Electrical conductivity
et al.	and co-worker/and others
Fe	Iron
Fig.	Figure
g	Gram
ha^{-1}	Per hectare
i.e.	That is
K	Potassium
kg	Kilogram
Mg	Magnesium
mg	Milligram
Mn	Manganese
Mo	Molybdenum
MSL	Mean sea level
N	Nitrogen
Na	Sodium
P	Phosphorus
ppm	Part per million
S	Sulphur
S. No.	Serial number
SSNM	Site specific nutrient management
viz	That is to say / in other words
Zn	Zinc

THESIS ABSTRACT

a) Title of the Thesis	:	Crop response based assessment of nutrient deficiencies in *Vertisol* and *Inceptisol* of Bemetara district in CG.
b) Full name of the Student	:	Neha Sahu
c) Major Subject	:	Soil Science and Agricultural Chemistry
d) Name and Address of the Major Advisor	:	Dr. V. N. Mishra, Principal Scientist, Department of Soil Science and Agricultural Chemistry, IGKV, Raipur (C.G.)
e) Degree to be Awarded	:	Master of Science in Agriculture (Soil Science & Agricultural Chemistry)

Signature of the Student

Signature of Major Advisor

Date: _____________

Signature of Head of the Department

ABSTRACT

A pot culture experiment was conducted in the green house of the Department of Soil Science and Agricultural Chemistry, College of Agriculture, IGKV, Raipur during kharif season 2015 to study the **“crop response based assessment of nutrient deficiencies in *Vertisol* and *Inceptisol* of Bemetara district of Chhattisgarh"** using two representative soils (*Vertisol* and *Inceptisol)* collected from village Bargaon (*Vertisol)* and Deori (*Inceptisol)* of the Berala block. The objectives of the study were to identify the specific nutrients which limit the crop yield through rice -response using nutrient omission technique during *kharif* season, 2015 and to demonstrate the optimum use of identified limiting nutrients and it’s comparison with farmer’s fertilizer practice with wheat crop during *rabi* season. 2015-16. The treatments constituted with application of

all nutrients applied at optimum level known as SSNM dose while in others, one of the nutrient elements from all the nutrient treatments was omitted. Total 11 treatments were tested with rice (MTU-1010) as a test crop, laid out in CRD (Completely Randomized Block Design) with three replications. The experimental soils under study were texturally classed under clayey (*Vertisol*) and clay loam (*Inceptisol)*. The soil reaction (pH) of the *Vertisol* was at 7.6 and that of *Inceptisol* exhibited 6.6. Both the soils had low in organic C, available N and S, low to medium in available P, high status in available K, exchangeable Ca and Mg. The micronutrient status of the soils were above critical level specially high status in Fe, Mn, Ca, and Mg level except B and Cu in *Vertisol. The* S status in both the soils were near marginal.

Grain and straw yields of rice in both the soils were significantly reduced with the omission of N P, and S in comparison to the treatment receiving all the nutrients. The yield reductions were more pronounced with N and P omission as 54.76 and 44.73 %, respectively in *Vertisol* and 42.10 and 29.97 %, respectively in *Inceptisol* . The per cent reduction in rice yields were also recorded in *Vertisol* for S -11.63 %, Zn - 8.99 % and B - 6.51% whereas, in case of *Inceptisol,* S omitted treatments caused grain yield reductions by 13.60 % from the treatment that received all nutrients (SSNM). Straw yields of rice in both the soils performed identically with those of grain yields performance. Grain and straw yields were also supported with the similar growth performance with respect to effective tillers, number of filled grains per panicle in both the soil type under study.

With respect to N, P, K uptake by rice in both the soils under study, indicated an identical performance with dry matter production (grain and straw yields) as the nutrient uptake is the multiple of content and grain and straw yields. Like grain yield performance, N, P and K uptake also affected severely with N, followed by P and S omission treatments. The effect on other treatments, no remarkable variations were observed except Zn and B omitted treatments in case of *Vertisol.* Ca, Mg and S uptake by rice in both the soils, were also found in the similar trends. Highest Ca Mg and S uptake in *Vertisol* were recorded in the treatment receiving all nutrients as 280, 169 and 76 mg/pot, respectively and that in *Inceptisol* as 296, 170 and 85 mg/pot, respectively and statistically at par with those of other treatments except N, P and S omitted treatments.

Like other major and secondary nutrients, similar trends in micronutrients uptake were also recorded. Significantly lower uptakes were recorded in the treatments associated with N, P and S omitted treatments. The highest Fe, Mn, Zn, Cu and B uptake by rice in *Vertisol* were recorded in the treatment associated with Mn omitted treatment which were statistically at par with those of all other treatments except N, P and S omitted treatments. The highest Fe, Mn, Zn, Cu and

B uptake by rice in *Vertisol* were recorded as 8.25, 11.58, 1.81, 0.36 and 0.51 mg/pot, respectively. Similarly, in case of *Inceptisol*, highest Fe, Mn, Zn, Cu and B uptake by rice were as 9.60, 13.49, 2.05, 0.42, and 0.52 mg/pot respectively in the treatment associated with B omitted pot except N P and S omitted treatments.

Based on the performance of rice crop during *Kharif* season, the yield limiting nutrients in *Vertisol* were identified in the order of N > P > S > Zn > B whereas that in *Inceptisol*, the limiting nutrients were in the order of N > P > S. These limiting nutrients were tested on farmer's fields with wheat crop during *rabi* season, 2015-16, where bulk soil samples were collected for pot culture study. The limiting nutrients applied in optimum doses (SSNM) in *Vertisol* as N - 150, P_2O_5 - 100, K_2O - 80, S - 45, B - 3 and Zn – 7.5 kg/ha. and that in *Inceptisol* as N - 150, P_2O_5 - 100, K_2O - 80, S - 45 kg/ha. Yields performance of wheat were compared with farmer's practice dose (FPD) applied at the rate of 80:58:38 ($N:P_2O_5:K_2O$) kg/ha. The wheat grain yields were higher in SSNM dose applied based on the yield limiting nutrients in both the soil (*Vertisol* and *Inceptisol*) as compared to that of farmer's practice dose. The percent yield increased with the application of SSNM dose over FPD in both the soils were in the range of 27-29 %. This result confirms that application of identified limiting nutrients as N, P, S, Zn and B in *Vertisols* and N, P and S nutrients in *Inceptisols* should be applied as per the recommended dose for optimum crop production of the target district under study.

'kks/k& lkjka'k

v-शोधग्रंथ का शीर्षक : NRrhlx< d cerjk fty dh oVÊlksYk ,o bUlsIVhlksYk e Qly vufd;k vk/kkfjr पोषक तत्वों की कमीं का आंकलन

c- Nk=k dk uke : ugk lkg

l- प्रमुख विषय : मृदा विज्ञान एवं कृषि रसायन

n- प्रमुख मार्गदशd dk uke : Mk-0gh-,u-feJk] ¼ie[k oKkfud½

,o irk : enk foKku एवं कृषि रसायन विभाग कृषि egkfo|ky;]

इंदिरा गांधी कृषि विश्वfo|ky;] कृषक uxj]

jk;ij 492012 ¼NRrhlx<½

b- mikfèk : मृदा विज्ञान एवं कृषि jlk;u e LukRrdksRrj

Nk=k d gLrk{kj

प्रमुख मार्गदर्शक के हस्ताक्षर

fnukd% foÒkxkè;{k d gLrk{kj

'kks/k lkjka'k

मृदा विज्ञान एवं कृषि रसायन विभाग इंदिरा गांधी कृषि विश्वविद्यkky;] jk;ij fLFkr gfjr&गृह में वर्ष 2015 dh [kjhQ _r d njE;ku NRrhlx< d cerjk fty dh वर्टीसोल्स एवं इन्सेप्टीसोल्स में फसल अनुक्रिया आधारित पोषक तत्वों की कमीं का आंकलन gr ,d पात्र खेती शोध fd;k x;k ftle fodkl[k.M cjyk d xke ckjxko dh oVÊlksYl ,o nojh dh bUlsVhlksYl fefVV;ks d n ifrfufèk ueu ldfyr fd; x;A bl प्रयोग के प्रमुख उद्देश्य में पोषd rRo foyksfir rduhd d ekè;e l pkoy अनुक्रिया आधारित फसल उपज को सीमित करने वाले विशेष पोषक तत्वों की [kjhQ&2015 e igpku djr g, आगामी रबी ऋतु 2015–16 में गेंहू फसल पर चिन्हित पोषक तत्वों की ईष्टतम मात्रा dk कृषd }kjk bLreky mojd l तुलनात्मक प्रदर्शन किया जाना इस प्रयोग का प्रमुख उद्देश्य था। प्रयोग में एसएसएनएम आधारित सभी पोषक तत्वों की ईष्टतम दर

का प्रयोग तथा अन्य उपचारों के तहत सभी पोषक तत्वों में से एक तत्व छोड़ा गया था। èkku Qly ¼,eVh;&1010½ ij dy 11 mipkj¨ d¨ l i.k ;knfPNd [k.M ifjdYiuk e संयोजित कर तीन पुनरावृतियों में प्रदर्शित किया गया। प्रयोगित मृदा को मृतिका (वर्टीसोल्स) ,o n¨eV efRrdk ¼bUlIVhl¨Yl½ ox Z lcfèkr FkhA oVÊl¨Yl ,o bUlIVhl¨Yl dh मृदा अभिक्रिया क्रमशः7-6 ,o 6-6 Fkh] tcfd bu n¨u¨ fefVV;¨ e dkcfud dkcu] उपलब्ध नत्रजन, सल्फर का स्तर न्यूनतम, फॉस्फोरस न्यून से मध्यम, पोटेशियम, विनिमय कैल्शियम एवं मैग्नीशियम की अधिक मात्रा दर्ज की गई। इन मिट्टियों में सूक्ष्म पोषक तत्वों की मात्रा इनके क्रांतिक स्तर से ऊपर थी, विशेष रूप से वर्टीसोल्स में बोरॉन और काij d अतिरिक्त आयरन एवं मैग्नीशियम का स्तर अधिक पाया गया। दोनों मृदाओं में सल्फर का स्तर हाशिये पर था।

धान की फसल में सभी पोषक तत्वों से उपचार की तुलना में दोनों मिट्टियों में u=tu] LQj ,o lYQj rRo foy¨fir djus l nkuk ,o Òlk mit e lkFkd deh nt की गई। उपचार में नत्रजन एवं स्फुर विलोपित करने से उपज में स्पष्ट गिरावट दर्ज की गई। वर्टीसोल्स तथा इन्सेप्टीसोल्स में नत्रजन एवं स्फुर विलोपन से उपज में क्रमशः 54-76 v©j 44-73 प्रतिशत तथा 42-10 v©j 29-97 प्रतिशत की कमीं देखी गई। इसी प्रकार oVÊl¨Yl e lYQj] ftd ,o c¨रान तत्व विलोपित करने से धान की उपज में क्रमशः 11-63] 8-99 ,o 6-51 प्रतिशत जबकि इन्सेप्टीसोल्स में सल्फर विलोपित करने से सभी तत्वों के i;¨x dh vi{kk nkuk mit e 13-60 प्रतिशत की कमीं अंकित की गई। सभी उपचारों का Òlk mit ij nkuk mit d leku iÒko n[kk x;kA èkku d of) ,o mit vfÒy{k.k¨ के बेहतर प्रदर्शन की वजह से दाना एवं भूसा उपज में सार्थक बढ़त दर्ज की गई। धान द्वारा नत्रजन, स्फुर एवं पोटाश तत्वों की उदग्रहण दर दाना–भूसा उपज के समानां्तर पाई गई क्योंकि तत्व उदग्रहण दाना भूसा में उपस्थित पोषक तत्व प्रतिशत एवं उपt d x.kd होते है।उपज की भांति नत्रजन, स्फुर एवं पोटाश उदग्रहण की मात्रा में गिरावट नत्रजन, स्फुर एवं पोटाश उर्वरक विलोपित करने से हुई। जबकि वर्टीसोल्स में जिंक एवं बोरान के अलावा अन्य सूक्ष्म पोषक तत्वों के विलोपित करने से पोषक तत्वों के उदग्रहण पर सार्थक vrj ugÈ n[kk गया। वर्टीसोल्स में कैल्सियम, मैग्नीशियम एवं सल्फर का अधिकतम अवशोषण क्रमशः 280,169 एवं 76 मिग्रा- प्रति पात्र तथा इन्सेप्टीसोल्स में क्रमशः 296,170 ,o 85 fexk- प्रति पात्र दर्ज किया गया जोकि नत्रजन, स्फुर एवं पोटाश विलोपित उपचार d vykok vU; mipkj¨ d leku irhr हुआ। सभी प्रमुख एवं द्वितियक पोषक तत्वों की भांति सूक्ष्म पोषक तत्वों के उदग्रहण का प्रदर्शन भी समान था। वर्टीसोल्स में मैग्जीन foy¨fir mipkj l vk;ju] eXuht]ftd]dkij v©j c¨jku rRo¨ dk vfèkdre mnxg.k nt fd;k x;kA c¨jku foy¨fir mipkj d rgr oVÊl¨Yl e bu rRवों का अवशोषण क्रमशः 8-25]11-58]1-81]0-36 v©j 0-51 fexk- ifr i¨V rFkk bUlIVhl¨Yl e 9-60]13-49]2-05] 0-42 ,o 0-52 fexk- ifr ik= vfdr fd;k x;kA

खरीफ ऋतु में धान फसल के प्रदर्शन की विवेचना से ज्ञात हुआ कि वर्टीसोल्स में u=tu LQj] lYQj ftd ,o c¨jku rFkk bUlIVhl¨Yl e u=tu] LQj ,o lYQj पोषक तत्व उपज प्रभावित करने वाले पोषक तत्वों के रूप में चिन्हित किये गये । इन पोषक तत्वों का कृषक प्रक्षेत्र से संकलित मृदा नमूनों से रबी ऋतु में गेंहू फसल पर विधिवत

परीक्षण किये गये जिसके तहत वर्टीसोल्स में सीमित पोषक तत्वों की ईष्टतम मात्रा (एसएसएनएम) अर्थात नत्रजन, स्फुर, पोटाश, सल्फर, बोरान, जिंक कमशः 150, 100, 80, 45] 3-0 ,o 7-5 fdxk- प्रति हेक्टर तथा इन्सेप्टीसोल्स में नत्रजन, स्फुर, पोटाश एवं सल्फर कमशः 150, 100, 80 एवं 45 किग्रा- ifr gDVj i;¨x dh xÃA i;¨x l ikIr mit v®j कृषक व्यवहारित उर्वरक (80:58:38 किग्रा- नत्रजनःस्फुरःपोटाश प्रति हे-½ l ikIr mit dk तुलनात्मक अध्ययन किया गया। प्राप्त आंकड़ों से ज्ञात हुआ कि कृषक व्यवहारित उर्वरक फलस्वरूप दर्ज उपज की तुलना में एसएसएनएम अनुरूप उपज सीमित पोषक तत्वों की ईष्टतम दर के इस्तेमाल से दोनों gh enkv¨ e mxk; x; xg dh mit e veeu 27&29 प्रतिशत का सार्थक इजाफा दर्ज हुआ। अतः बेमेतर जिले में अधिकतम फसल उत्पादन हेतु वर्टीसोल्स में चिन्हित उपज कारक पोषक तत्वों यथा नत्रजन, स्फुर, सल्फर, जिंक और c¨jku rFkk bUlIVhl¨Yl e u=tu] LQj ,o lYQj dh vनुशंसित दर के प्रयोग की flQkfjl dh tk ldrh gA

CHAPTER-I

INTRODUCTION

Rice is the most important and extensively cultivated food crop, which provides half of the daily food for one of every three persons on the earth. In our country, more than 40 million hectares area is covered under rice cultivation and total production has crossed 100 million tones. Rice production in India is an important factor for food security. However, little is known about the sustainability of the current production systems, particularly systems with triple cropping under minimum practice. Among the various cropping systems, rice based cropping systems are the predominant systems in India. Managing the variability in soil nutrient supply that has resulted from intensive rice cropping is one of the challenges for sustaining and increasing rice yield in India.

The use of plant nutrients in a balanced manner is the prime factor for efficient fertilizer program. Balanced nutrient use ensures high production level and helps to maintain the soil health and ensures sustainable agriculture. No developed or developing country in the world has been able to increase agricultural production without expanding the use of balanced fertilization. In fact, in countries where consumption of plant nutrients is low and imbalanced, agricultural production is also low, and yields are stagnant or declining. Hence, balanced fertilization programs must be developed to remove all yield-limiting factors using various research techniques.

Chhattisgarh State has four major soils type i.e. *Entisols, Inceptisols, Alfisols* and *Vertisols*. Almost all soils are deficient in nitrogen and phosphorus and medium to high in potassium. Zinc deficiency is also reported in some patches of *Alfisols* and *Vertisols* of this region. In view of continuous use of sulfur free complex fertilizers, chances of increase in S deficiency are likely. Continuous use of high analysis fertilizer, multiple nutrient deficiencies are likely. High crop yields can only be achieved when high yielding crop varieties are properly nutritioned in a correct amount and proper ratios. In addition to this limitation, low fertilizer efficiency, inadequacy of current fertilizer recommendations and the ignorance of nutrients other than N, P, and K may limit crop production.

Rice requires adequate supply of nutrients to achieve the high yields necessary to feed growing populations. Many of these nutrients come from soil and organic inputs, such as crop residues and manures; but high yields still require supplemental nutrients from fertilizer. Existing fertilizer recommendations for rice often advise fixed rates and timings of N, P and K for vast areas of rice production. Such recommendations assume the need of a rice crop for nutrients is constant among years and over large areas. But crop-growth and crop-need for supplemental nutrients can be strongly influenced by crop-growing conditions, crop and soil management, and climate - which can vary greatly among fields, villages, seasons, and years.

Deficiency of some micro- and secondary nutrients is one of the major causes for stagnation in crop productivity. Exploitive nature of modern agriculture involving use of high analysis N, P and K fertilizers, free from micronutrients as impurities, limited use of organic manures and restricted recycling of crop residues are some important factors having contributed towards accelerated exhaustion of secondary and micronutrients from soil. At several places, normal yield of crops could not be achieved despite balanced use of NPK due to micronutrient deficiency in soils. Sakal (2001)

Adequate supply of plant nutrients decides optimum productivity of any cropping system. Even if, all other factors of crop production are in the optimum, the fertility of a soil largely determines the ultimate yield (Sekhon and Velayutham 2002). Application of supplemental nutrients is required if the soil does not supply sufficient nutrients for normal plant development and optimum productivity. Fertilizer is one of the most important sources to meet this requirement. Indiscriminate use of fertilizers, however, may cause adverse effect on soils and crops both regarding nutrient toxicity and deficiency either by over use or inadequate use (Ray *et al*., 2000). Diagnostic techniques including identification of deficiency symptoms, soil and plant analysis and biological tests are helpful in determining specific nutrient stresses and quantity of nutrients needed to optimize the yield (Havlin *et al*., 2007). Soil fertility evaluation, thus, is the key for adequate and balanced fertilization in crop production.

It is necessary to obtain adequate information about the soil prior to establishing field trials which is an expensive task. This can be achieved through laboratory and green houses studies using pot culture experiments. Such information about the soil provides for clear interpretation of all the field trials, prevents loss of trials due to a 'surprise' nutrient deficiency and assures that adequate amounts of deficient nutrients are applied to satisfy both, soils complexing capabilities and the plant needs. Fertilizing soils to bring all the deficient elements at high levels as to provide sufficient ionic activity in soil solution for crop uptake is one of the most important considerations to achieve the maximum crop yield.

In view of this, pot culture experiment was carried out to evaluate the crop response based assessment of nutrient deficiencies in *Vertisol* and *Inceptisol* of Bemetara district of Chhattisgarh of with following objectives:

1. To identify the specific nutrients which limit the crop yield through crop-response using nutrient omission technique
2. To demonstrate the optimum use of identified limiting nutrients and it’s comparison with farmer’s fertilizer practice with wheat crop.

Chapter – II
REVIEW LITERATURE

In this chapter, crop response studies based on various researches conducted in nutrient omission trials for evaluation of fertility status of soils in the country and abroad have been extensively reviewed in the following heads

2.1 Status of plant nutrients in soil

2.1.1 Status of major nutrients (N, P and K) in soil

2.1.2 Status of Secondary Nutrients (Ca, Mg and S) in soil

2.1.3 Status of micronutrients in soil

2.2 Nutrient Omission Trials

2.3 Crop Response to Applied Nutrient in Omission Trial.

2.1 Status of plant nutrients in soil

2.1.1 Status of major nutrients (N, P and K) in soil

Nitrogen is an integral part of all proteins and is one of the main chemical elements required for plant growth and photosynthesis. It is one of the most yield limiting major nutrients among N, P and K required for optimum crop production. In most agricultural conditions, availability of usable Nitrogen is the most limiting factor of high growth. Plant absorbs nitrogen by absorbing either ammonium or nitrate through it’s root system. The plant will then utilize Nitrogen as a building block to produce protein in the form of enzymes. It is forth plant nutrient taken up by plants in greatest quantity next to carbon, oxygen and hydrogen, but it is one of the most deficient elements in the tropics for crop production (Sanchez, 1976; Mengel and Kirkby, 1987; Mesfin, 1998). Usually fine textured (heavy) soils contain more N than the coarse textured (light) soils. Indian soils are found to be low in available N content. The N content is lower in continuously and intensively cultivated and highly weathered soils of the humid and sub humid tropics due to leaching and in highly saline and sodic soils of semi arid and arid regions due to low OM content (Tisdale *et al*., 1995).

Ramesh *et al.* (1994) analyzed the soils of Guntur district of Andhra Pradesh and found the variation in available N from 85 to 282 kg ha^{-1}. Similarly, Kumar *et al.* (1995) reported the available N in the range from 203.8 to 407.2 kg ha^{-1} in soils of Soan river valley of lower Shiwaliks. Subba Rao *et al*. (2001) reported the status of available N in soils of Chhattisgarh as low level (< 250 kg ha^{-1} $KMnO_4$ - N) in all the districts except Bastar where it was medium. Motsara (2002) concluded that 63% of soil samples analyzed in different Indian laboratories have been found to be under low category. Similar results were also reported by many workers like Verma *et al.* (2005) in soils of arid tract of Punjab. The available N level of Tonk district of Rajasthan was reported by Meena *et al.* (2006) in the range of 125 to 555 kg ha^{-1} with an average value of 309 kg ha^{-1}.

Wakene (2001) reported that there was a 30% and 76% depletion of total N from agricultural fields cultivated for 40 years and abandoned land, respectively, compared to the virgin land in Bako area, Ethiopia. Average total N increased from cultivated to grazing and forest land soils, which again declined with increasing depth from surface to subsurface soils (Nega, 2006). The considerable reduction of total N in the continuously cultivated fields could be attributed to the rapid turnover (mineralization) of the organic substrates derived from crop residue (root biomass) whenever added following intensive cultivation (Mc Donagh et al., 2001). Moreover, the decline in soil organic carbon and total N, although commonly expected following deforestation and conversion to farm fields, might have been exacerbated by the insufficient inputs of organic substrates from the farming system (Mulugeta, 2004). The same author also stated that the levels of soil organic carbon and total N in the surface soil (0-10 cm) were significantly lower, and declined increasingly with cultivation time in the farm fields, compared to the soil under the natural forest.

Meena *et al.* (2006) analyzed the light textured soils of Tonk district of Rajasthan and reported that the available nitrogen content varied from 125 to 555 kg ha-1 with an average value of 309 kg $ha\text{-}^{1}$. On the basis of the rating suggested by Subbiah and Asija (1956), 32 % samples were low (< 250 kg ha-1 N), 61% medium (250 to 500 kg ha-1 N) and only 7 % samples were high (> 500 kg ha-1 N) in available nitrogen. Similarly, Kumar *et al.* (2009) observed that an available nitrogen content of Dumka and Lachimpur series varied from 125 to 310 kg ha^{-1} with a mean of 216 kg $ha-^{1}$ and 210 to 545 kg $ha-^{1}$ with a mean of 401 kg $ha-^{1}$ in soils of Santhal Paraganas Region of Jharkhand. About 40 to 50 % soil samples in light texture soils of Dumka series were rated as low in available nitrogen.

Awan *et al.,* (2011) studied the effect of different nitrogen levels (110,133 & 156 kg ha-1) at Rice Research Institute Kala Shah Kuku and concluded that application of 156 kg N ha^{-1} had maximum values of plant height (79.07 cm), tillers m^{-2} (594), panicle length (25.40cm), No of grains panicle-1 (132.97), grain yield (5461.03 kg ha^{-1}), straw yield (9662.03 kg ha^{-1}) and least value of sterility (5.7 per cent).

Regar and Singh (2014) reported that the nutrient requirement (kg q^{-1}) for producing one quental rice yield, soil, fertilizer and organic manure efficiencies or the percent contribution from soil, fertilizer nitrogen, phosphorus, potassium and FYM have been calculated from each plot based on the data of whole field. The nutrient estimates of nutrient requirement (kg q^{-1}) values of fertilizer nitrogen, phosphorus and potassium based on whole field method were 2.56, 0.56 and 2.21, respectively. The percent nutrient contribution from soil, fertilizer and FYM in an *Inceptisols* were found to be 26.35, 51.17 and 26.14, 54.03, 36.35 and 75.68 and 18.59, 3.10 and 8.56 for nitrogen, phosphorus and potassium, respectively.

Sankalpa *et al.* (2014) conducted experiment with five nitrogen level N_1 :Control N_2: RDF + 20% additional N ,N_3: RDF + 40% additional N N_4 : RDF + 60% additional N N_6: RDF + 80% additional N and two variety V_1 : GGV-05-01 ,V_2 : BPT-5204. The contents and uptake of N, P and K in grain in N_5 was 1.63, 0.56, 0.62 per cent and 83.8, 30.7, 34.2 kg ha $^{-1}$ and in straw 0.58, 0.068, 1.57 per cent and 41.5, 4.93, 112.7 kg ha $^{-1}$, respectively. In comparison to control, N_4 had 30.6, 60.0 and 12.7 per cent more NPK content in grain and 36.7, 75.4, 23.0 per cent more N, P and K uptake respectively. The N, P and K contents and uptake were in accordance with the yield obtained with different levels of N applied where in increased grain and straw yields were associated with increased contents and uptake of these major nutrients. However, though there were significant differences in content and uptake of N, P and K in grain at 40, 60 and 80 per cent excess of RDN, this has not resulted in significant increase in grain yield among these levels Zinc and Fe uptake in grain increased significantly with increase in levels of N applied up to N4 only. The treatment N_4 (23.1 g ha $^{-1}$ and 1165 g ha $^{-1}$) had 10.6 (N_3) to 23.1 per cent (N_1) and 9.1 (N_3) to 44.5 per cent (N_1) higher Zn and Fe uptake in grain, respectively. Zinc uptake in straw also increased significantly with increase in levels of N applied up to N4 only which may be attributed to increase in dry matter and content of nutrient in grains. The treatment N_4 (341.4 g ha $^{-1}$) had 10.0 (N_3) to 30.8 per cent (N_1) higher Zn uptake in grain compare to control. Iron uptake in straw increased significantly only up to N_2 (2031 g ha $^{-1}$) which was 18.0 per cent more than N_1 (control). TheBPT-5204 (V_2) had significantly higher Zn (327.3 g ha $^{-1}$) and Fe (2198.2 g ha $^{-1}$) uptake in straw compared to GGV-05-01, respectively. No significant interaction effect was observed for Zn uptake in straw. The treatment N_1V_2 (2456.3 g ha^{-1}) had 15.1 (N_5V_2) to 50.4 per cent (N_1V_2) significantly higher Fe uptake in straw.

Hardev *et al.* (2014) conducted a experiment with combinations of genotypes ('PHB 71' and 'NDR 359') and spacings (25 cm × 25 cm and 30 cm × 30 cm). They reported that the hybrid 'PHB 71' recorded significantly higher N, P and K uptake in grain, straw and total uptake than 'NDR 359'. Since nutrient uptake is the outcome of the nutrient concentration and the crop output, the higher grain and straw yields of hybrid 'PHB 71' resulted in its higher values of NPK uptake. An increase of 8.5–9.8% in total nutrient uptake with 25 cm × 25 cm spacing compared to 30 cm × 30 cm spacing commensurate with similar increases in grain yield recorded under 25 cm × 25 cm plant spacing.

Parvin *et al.* (2014) conducted a field experiment to evaluate the effects of spacing on nutrient content and total uptake of phosphorus and zinc by grain and straw of traditional rice of Khulna region. The experiment was laid out in split-plot design with three replications assigning three varieties viz., Jotai, Bashfulbalam, Ranisalute and three spacings viz., 30 cm x 30 cm, 40 cm x 40 cm and 50 cm x 50 cm. The highest P and Zn content of grain was found from the variety Ranisalute at 50 cm x 50 cm but in straw from Ranisalute at 40 cm×40 cm and Bashfulbalam at 30 cm × 30cm, respectively. The total uptake of P and Zn was found the highest from Jotai variety at 30 cm x 30 cm spacing. From the interaction it showed that the highest P and Zn uptake (4.85, 0.273 kg ha^{-1})was found from Jotai at 30 cm × 30 cm and the lowest ((3.0,0.156 kg ha^{-1}) from Ranisalute with 50 cm x 50 cm .

Phosphorus (P) is the second most important nutrient after N among the three primary nutrients required in crop nutrition. Information on P fertility status of soils is of great importance, since it helps to determine the level of P fertilizer to be applied to crops. Indian soils have been found to be low in available P content. Phosphorus is vital for strong growth. Phosphorus, when combined with water, breaks in to separate ions that can be absorbed by the plant's root system. The plant uses phosphorus for photosynthesis and energy nutrient transport. The right amount of phosphorus can help crops yield more fruits and create healthier stocks and root systems, they may also mature much quicker than plants without phosphorus. Insufficient supply can cause stunted, spindly crops, green & purple discoloration, wilting, small fruits and flowers (if at all). When phosphorus is added to the crops when sowed, it establishes a strong root base and produces strong all through the growth season.

Maji *et al.* (1993) reported that available phosphorous content in soils of Sundarbans of West Bengal fluctuated from 14 to 85 kg ha^{-1}. Murthy and Shrivastava (1994) reported that in moderately acidic soils of Pantnagar University, Uttar Pradesh, the available 'P' content varied from 2.0 to 80.0 kg ha^{-1}. Similarly, Kumar *et al.* (1995) found that in soils of Soan river valley of Himachal Pradesh the available 'P' content varied from 2.0 to 29.0 kg ha^{-1}.

Subba Rao *et al.* (2001) observed low P (< 10 kg ha^{-1}) in the entire area of Chhattisgarh and stated that the P deficiency was more pronounced in *Vertisols*. Available phosphorus content of the soils varied from 1.8 to 59.6 kg ha^{-1} with a mean value of 18.46 kg ha^{-1} in soils of arid tract of Punjab (Verma *et al.,* 2005).

Meena *et al. (*2006) reported that status of available potassium (K_2O) in the soils ranged from 105 to 1059 kg ha^{-1} with an average of 377 kg ha^{-1} in the light texture soils of Tonk district of Rajasthan.

Kumar *et al.* (2009) observed that an available phosphorus content in soils ranged from 5.80 to 14.20 (Dumka series) and 7.00 to13.40 kg ha^{-1} (Lachimpur series) with a mean value of 10.0 and 9.0 kg ha^{-1} phosphorus in light texture soils of

Dumka and sandy loam soils of Lachimpur series, respectively. Both the series had 70 to 60% low level of available phosphorus in soils of Santhal Paraganas region of Jharkhand

Potassium (K) is the third most important primary nutrient after N and P required for proper growth and development of the plants. It aids in water absorption and retention, also encourages strong roots, sturdy stems, and healthy, full grown crops that have longer shelf life. Potassium is in the soil naturally in two forms, one of the forms is able to be absorbed into the plant, while the other is unavailable to the plant. Agricultural products that contain potassium are water soluble, allowing it to be absorbed by crops in through the nutrient rich soil. Available K content in Indian soils on an average is considered to be medium.

Ghosh and Mukhopadhyay (1996) reported that available K content varied from 62 to 262 and 52 to 386 kg ha^{-1}, respectively in soils of Jagannathpur and Barakonda of West Bengal. In soils of Chhattisgarh, thestatus of available K in medium to high (250- 400 kg ha^{-1}) and the supply of K is adequate to meet the crop demand at present level of crop production (Subba Rao *et al.,* 2001). Motsara (2002) reported that 37.0 % and 50.0 % of soil samples analyzed in different Indian laboratories have been found to be under medium to high category.

Arora and Chahal (2003) observed that the range of available K in soils series varied from 48.5 to 314.0 mg kg^{-1}in aridic, 32.0 to 134.0 mg kg^{-1} in ustic, and 36.0 to 62.5 mg kg^{-1} in udic moisture regime of Punjab.

Meena *et al.* (2006) reported that status of available potassium (K_2O) in the soils of Tonk district of Rajasthan, ranged from 105 to 1059 kg ha^{-1} with an average of 377 kg ha^{-1} Kumar *et al.* (2009) observed that the content of available potassium in soils of Dumka series varied from 111 to145 kg ha^{-1} with a mean value of 124 kg ha^{-1} and in Lachimpur series varied from 110 to 188 kg ha^{-1} with a mean of 134 kg ha^{-1}. The available potassium in both the series was medium in status in soils of Santhal Paraganas region of Jharkhand.

Rajeswar *et al.* (2009) reported that the available potassium in all the pedons varied from 110 to 389 kg ha^{-1}. The highest available potassium content was noticed in the surface horizons and distribution of available potassium showed decreasing trend with depth in soils of Garikapadu in Krishna district of Andhra Pradesh.

Pandey *et al.* (2009) reported that N uptake from 42.1 to 80.0 kg ha^{-1} , P uptake from 9.7 to 16.7 kg ha^{-1} and K uptake from 49.7 to 82.6 kg ha^{-1} by rice increased with increasing levels of N, P and K from 0 to 150%. Datta and singh (2010) reported that with the application of 10 t cattle manure ha^{-1} , nutrient uptake exhibited 1.38-2.36 and 1.76-2.60 times increase in rice green gram and rice field pea cropping systems , respectively.

Naidu *et al.* (2011) studied that Emerging deficiency of potassium in soils and crops of India and result found that High crop K removal than K addition by farmers and imbalanced use of N, P and K fertilizers are contributing to large-scale K mining leading to emergence of K deficiency in soils and crops. Red, lateritic and shallow black soils have under gone K fertility depletion. Deficiency of K is more sever in areas where intensive cropping systems are being followed. Widespread K deficiency was identified in rice-wheat system of IGP, horticultural, plantation, ornamental, aromatic and avenue plants. The current fertilizer recommendations based on agro-climatic zones are very much generalized not taking into consideration of the soil types. More than one soil types occur in each agro-climatic zone with dissimilar behavior and response to management and needs separate K recommendation. Further, fertilizer recommendations are being made based on available K status, but significant proportion of plant needs is met from non exchangeable fraction of K. Therefore, there is a need to consider both the fractions of K in soils for potash fertilizer recommendation to crops. Also, the present fertilizer recommendations which are being followed are four decades old and hence need revision and revalidation. Site-specific fertilizer recommendations, if followed can minimize the fertility K depletion and maintain productivity and sustainability and also economize the fertilizer cost. Awareness on K use by farmers in K deficient regions needs more emphasis.

Ujwalaranade Malvi (2011) studied that Interaction of micronutrients with major nutrients with special reference to potassium and reported that Synergistic and Antagonistic relationships between nutrients are responsible for efficient and inefficient uptake and utilization of potassium. This paper discusses the interrelationships between plant nutrients with a special reference to potassium and macronutrients like nitrogen and phosphorus, potassium and secondary nutrients like calcium, magnesium and sodium and finally potassium and micronutrients. The goal of this paper is to elucidate the complicated and still less understood relationships between essential nutrients so as to bridge the gap between potential yields and actual yields.

2.1.2 Status of Secondary Nutrients (Ca, Mg and S) in soil

Calcium, magnesium and sulphur are conventionally classified as secondary nutrients. Their requirements by plants are quantitatively less than those of primary nutrients (N, P and K). Calcium and magnesium are the most abundant cations occupying the exchange sites of soil colloids. Thus, most soils, with possible exception of highly weathered, leached acid soils, contain enough Ca and Mg for crop growth (Pasricha and Sarkar 2002). The importance of Ca and Mg as plant nutrients is more realized in acid and alkali soils than in neutral soils. In acid soils, lime- loving crops do not give high yields unless these are suitably fertilized with Ca and Mg. Similarly in alkali soils, crops suffer due to lack of Ca and excess of Na.

Mathur *et al*. (1983) reported that the exchangeable Ca and Mg in acidic red loam soil of Ranchi were 3.7 and 1.7 me/100g, respectively. $CaSO_4.2H_2O$ and $CaCO_3$ were used as sources of calcium as a nutrient for legume crops in this soil.

Tiwari (1990) generated systematic information on S status of soils of Central plain zone and Bundelkhand zone of Uttar Pradesh. Out of 501 samples tested in Farrukhabad district, 19 % samples were found to be deficient in available S. Available S in these soils ranged from 4 to 45 ppm with a mean value of 19 ppm. In Hamirpur district of the 500 samples tested, 24 % samples were deficient in S. Available S in these soils varied from 6 to 45 ppm with a mean value 17 ppm.

Mathan (1991) reported that the exchangeable Mg ranged from 0.2 to 2.4 cmol (p+) kg^{-1} in surface of acidic (lateritic) soils of Nilgiris. Singh (2001) reported that the S deficiency in soils of various Indian states varied from 5 to 83 % with an overall mean of 41 %.

Subba Rao *et al.* (2001) studied the sulphur status of soils of Chhattisgarh and stated that *Vertisols* of this region are deficient in sulphur. Considering 22.5 kg ha^{-1} S as the critical limit, soils of Rajnandgaon district were moderately deficient while soils of Raipur district were medium in available sulphur.

Chattopaddhyay and Ghosh *et al.* (2006) reported that available S content belonging to ten blocks of Birbhum district of West Bengal, varied from 2.1 to 68.2 mg kg^{-1} with a mean value of 23.4 mg kg^{-1} .

Das *et al*. (2006) studied the distribution of sulphur in selected soil series of *Inceptisols* in West Bengal. Available S varied from 7 to 15 mg kg^{-1} in the surface soils and 31 % of the analyzed samples were S deficient (containing less than 10 mg kg^{-1} S).

Eamel *et al. (*2010) reported that the predictability of any soil extractant with tomato plant tissue S or yield was low, thereby rendering a soil test based on these extractions unpractical. Hence, the current Florida recommendation for S using plant analysis should continue to be utilized.

Patel *et al.* (2011) studied that distribution of different forms of sulphur in soil of Banaskantha district of Gujarat and reported that the forms of sulphur followed the following trend: non-sulphate > organic > heat soluble > water soluble > sulphate sulphur. The highest fraction of non-sulphate sulphur (50.76 per cent) followed by organic sulphur (36.74 per cent) and sulphate sulphur (12.49 per cent) of the total sulphur were observed.

Patra *et al.* (2012) reported that the lowest mean available sulphur content was recorded in the surface soils of Birbhum district, and in the sub-surface soils of Burdwan district, whereas the highest was recorded in the surface and sub-surface soils of Purulia district. Birbhum district recorded to be the most deficient as 87 per cent of the surface soil samples and 67 per cent sub-surface soils of Burdwan district fall under low sulphur range.

2.1.3 Status of micronutrients in soil

Micronutrients play an important role in the plant metabolism process starting from cell wall development to respiration, photosynthesis, chlorophyll formation, enzyme activity, hormone synthesis, nitrogen fixation etc. Micronutrient requirements of crop are relatively small and ranges between their deficiencies and toxicities in plants and soils are rather narrow which needs special attention for their management's in increasing crop production**.**

The available boron and molybdenum in different states of India have been found to vary from traces to 12.2 mg kg^{-1} and from traces to 1.65 mg kg^{-1} , respectively. Boron deficiency is extensive in soils of several states of India where in oilseed crops are grown and is attributed for low crop yields. Out of 1715 and 227 samples analyzed in Gujarat and Madhya Pradesh respectively, 11 and 18 % of the samples respectively have been found to be deficient in available Mo (Tandon 1995).

Dhane and Shukla (1995) found that available Fe content varied from 2.6 to 8.3 mg kg^{-1} in *Entisols, Inceptisoils* and *Vertisols* of Maharashtra. Available Cu content varied from 0.9 to 2.1 mg kg^{-1} while Zn content fluctuated from 0.2 to 0.6 mg kg^{-1}.

Rathore *et al*. (1995) tested the soils of Madhya Pradesh and observed that the available iron content ranged from 0.30 to 42.0 mg kg^{-1} (mean-26.0 mg kg^{-1}). Out of 13800 surface soil samples, about 60.6 per cent were zinc deficient and amongst the soil groups, deficiency was the largest in alluvial soils (86%) followed by mixed red and black soils (68%), red and yellow (62%), medium black soils (61%), deep black soils (35%) and skelatal soils (31%) .

Kumar *et al.* (1996) reported that available iron content varied from 5.4 to 35.4 mg kg^{-1}, 4.8 to 23.8 mg kg^{-1} and 5.2 to 17.8 mg kg^{-1} in hill soils, piedmont plains and flood plain of Himachal Pradesh, respectively. Available Zn content varied from 0.3 to 0.5 mg kg^{-1} in hill soils, from 0.4 to 1.5 mg kg^{-1} in piedmont plains and from 0.4 to 8.6 mg kg^{-1} in flood plains of lower Shiwaliks of Himachal Pradesh.

Singh and Nayyar (1999) reported that considering 0.5 mg kg^{-1} as the critical limit for available B, in arid and semi-arid soils of Firozpur and Faridkot districts of Punjab, 13 and 50 %, 6 and 28 % samples respectively were found in the deficient and low range

Singh (2000) reported that among 39319 surface soil samples analyzed, 33 % soils were deficient in available boron considering 0.5 mg kg^{-1} as the critical limit in soil.

Sharma *et al.* (2001) tested the soils of Chhattisgarh plains and Northern hills zone of Chhattisgarh and found that the DTPA –extractable iron ranged from 15 to 300 mg kg^{-1} (Mean 49.8 mg kg^{-1}) in Chhattisgarh plains and from 4.8 to 420 mg kg^{-1} $^{(}$49.6 mg $kg^{-1)}$ in Northern hills zone of Chhhattisgarh. DTPA –extractable Mn was more in Northern hills zone (41.7 mg kg^{-1}) than the CG plains (25.8 mg kg^{-}). Available Cu in Northern hills zone ranged from 0.20 to 22.1 mg kg^{-1} (Mean -3.55 mg kg^{-1}) while in Chhattisgarh plains it ranged from 0.39 to 11.92 mg kg^{-1} (Mean 2.72 mg kg^{-1}). Zn content in Northern hills zone ranged from 0.04 to 5.94 mg kg^{-1} (mean 0.63 mg kg^{-1}) while in Chhattisgarh plains it ranged from 0.05 to 5.21 mg kg^{-1} (mean -0.50 mg kg^{-1}).

Sharma *et al.* (2001) reported that DTPA – extractable Fe content in the Rajgarh district of Madhya Pradesh ranged from 1.8 to 26.4 ppm (mean 8.5 ppm), Mn content ranged from 1.4 to 50.4 ppm (mean 12.6 ppm) and Cu content varied 0.18 to 6.20 (mean 1.52 ppm). Of the total samples studied, 13.3 % samples tested low in available iron.

Sharma *et al.* (2003) reported that the available boron in soils of Nagaur district of of Rajsthan varied from 0.2 to 2.0 mg kg^{-1} with a mean value of 0.68 mg kg^{-1} and available Molybdenum content ranged from 0.1 to 1.3 mg kg^{-1} with a mean value of 0.48 mg kg^{-1}

Meena *et al.* (2006) reported that available Fe, Mn, Cu, and Zn contents in the soils of Tonk district of Rajasthan ranged from 2.23 to 14.16 mg kg^{-1} (Mean 5.38 mg kg^{-1}), 6.85 to 45.25 (Mean 21.56 mg kg^{-1}), 21 to 1.87 (Mean 0.61 mg kg^{-1}) and 0.19 to 1.93 (Mean 0.83 mg kg^{-1}), respectively.

Sharma and Chaudhary (2007) studied the soils in lower Shiwaliks of Solan district in North–West Himalayas. They reported that available Fe contents in the soil profiles of different soil series ranged from 8.2 to 50.2 mg kg^{-1}, available Mn varied from 2.7 to 56.7 mg kg^{-1}, available copper ranged from 0.30 to 2.80 mg kg^{-1} and available Zn varied 0.31 to 4.7 mg kg^{-1}.

Arora and Chahal (2007) reported that hot water soluble boron in surface soils of Typic *Haplustalfs* of Punjab varied from 0.20 to 0.72 mg kg^{-1} with a mean value of 0.37 mg kg^{-1}.

Girish *et al.* (2007) found that the available boron in *Alfisols* collected from Bajaura and Junga was 0.30 mg kg^{-1} (in both soils) and were found to deficient.

Rajeswar *et al.* (2009) reported that the DTPA – Extractable zinc content varied from 0.13 to 2.79 mg kg^{-1} soil. Vertical distribution of zinc exhibited little variation with depth in soils of Garikapadu in Krishna district of Andhra Pradesh.

Singh *et al.* (2009) reported that the DTPA – Extractable zinc content in the surface and sub-surface soils varied between 0.3 to 2.1 mg kg^{-1}. About 24 % of the samples were deficient in available zinc micronutrients in the soils of district Ghazipur, Uttar Pradesh.

Yadav and Meena (2009) reported that available zinc in soil samples of Degana soil series of Rajasthan varied from 0.21 to 2.18 mg kg^{-1}.

Sharma and Chaudhary (2007) reported that available iron contents in the soil profiles of different soil series ranged from 8.2 to 50.2 mg kg-1 of lower Shiwaliks of Solan district in North – West Himalayas. Yadav *et al.* (2009) reported that available iron in soil samples of Degana soil series of Rajasthan varied from 0.20 to 18.73 mg kg^{-1}.

Kumar *et al.* (2009) observed that an available iron content of Dumka and Lachimpur series varied from 2.50 to 15.80 mg kg^{-1} with a mean of 7.66 mg kg^{-1} and 6.40 to 96.50 mg kg^{-1} with a mean of 19.41 mg kg^{-1} , respectively in soils of Santhal Paraganas region of Jharkhand

Rajeswar *et al.* (2009) reported that the DTPA – Extractable iron content varied from 0.4 to 40.2 mg kg^{-1} soil. All the surface soils were sufficient in availableiron content. Vertical distribution of iron exhibited little variation with depth in soils of Garikapadu in Krishna district of Andhra Pradesh.

Rajeswar *et al.* (2009) reported that the available DTPA -Extractable manganese content in these soils varied from 2.6 to 19.7 mg kg^{-1}. It was high in the surface horizons and gradually decreased with depth of soil. Vertical distribution of available manganese micronutrient was also observed in soils of Garikapadu of Krishna district of Andhra Pradesh.

Singh *et al.* (2009) reported that the DTPA - Extractable manganese content in the soils varied between 3.2 to 8.5 mg kg^{-1} in surface and subsurface soils. 16% percent of the samples contained DTPA- manganese between 3.3 and 4.0 mg kg^{-1} and 84 % had more than 4 mg kg^{-1} DTPA- Mn in the soils of district Ghazipur, Uttar Pradesh.

Yadav and Meena (2009) reported that available Mn in soil samples of Degana soil series of Rajasthan varied from 0.43 to 7.57 mg kg^{-1}.

Kumar *et al.* (2009) observed that an available Cu content of Dumka and Lachimpur series varied from 0.48 to 3.00 mg kg^{-1} with a mean of 1.59 mg kg^{-1} and 1.36 to 4.85 mg kg^{-1} with a mean of 3.04 mg kg^{-1}, respectively in soils of Santhal Paraganas region of Jharkhand.

Rajeswar *et al.* (2009) reported that all the pedons were found to be sufficient in the available Cu content in soils varied from 0.49 to 1.79 mg kg^{-1}. The available Cu content was more in surface layers and decreased with depth in soils of Garikapadu in Krishna district of Andhra Pradesh.

Singh *et al.* (2009) reported that the DTPA – Extractable Cu content in the soils varied between 1.0 to 3.5 mg kg^{-1} and none of the soils were deficient. A majority of the soil samples (83%) contained between 1.0 to 2.5 mg kg^{-1} whereas 17 % samples contained between 2.5 and 3.5 mg kg^{-1} in the soils of district Ghazipur, Uttar Pradesh.

Yadav and Meena (2009) reported that available Cu in soil samples of Degana soil series of Rajasthan varied from 0.09 to 3.05 mg kg^{-1} with a mean value of 0.50 mg kg^{-1}.

Meena *et al.* (2012) studied that distribution of available micronutrients as related to the soil characteristics in Malwa plateau region in southern Rajasthan and reported that the contents of available Fe, Mn, Zn and Cu were higher in surface horizons and decreased with depth in most of the pedons and ranged from 6.34 to 54.71, 2.42 to 57.64, 1.01 to 5.10 and 1.20 to 6.10 mg kg^{-1}, respectively.

All soils had adequate amounts of Fe, Mn, Zn and Cu. The available micronutrient content in these soils were in the order of Fe>Mn>Cu>Zn. DTPA extractable.

Sanwal *et al*. (2014) studied that available Zn and Mn status and their relationship with soil physico-chemical properties and its content in wheat crop of internal drainage dry zone of Rajasthan and reported that the majority of soils were found sandy in nature and their textural classes are sandy, loamy sand and sandy loam. Soils of the study area were found slightly calcareous in nature, low organic carbon and cation exchange capacity. Majority of soils under study were found deficient in Zn and adequate available in Mn.

Upadhyay and Sharma (2016) studied Soil characteristics and their nutritional status in Lucknowd District and reported that deficient levels of Zn were found at all the locations subjected to minimum level at Devricala (0.028 mg kg^{-1}). Iron was highest (23.14 mg kg^{-1}) at Mahipatpur and lowest at Tilsua (2.995 mg kg^{1}). Maximum and minimum level of Cu was found at Tilsua (0.352 mg kg^{-1}) and Bhavanipur (0.200 mg kg^{-1}), respectively. Mn was found maximum at Khalilabad (6.345 mg kg^{-1}) and minimum at Gosainganj (1.396 mg kg^{-1}).

2.2 Nutrient Omission Trials

Sekhon and Velayutham, (2002) stated that crop production broadly depends on the fertility of the soil where a crop is raised. The kind and quality of seed, climate of the region, soil moisture regime and plant protection measures adopted by a farmer are some other factors which affect the volume of production. But even if all these factors of crop production are in the optimum, the fertility of a soil largely determines the ultimate yield.

Site-specific nutrient management (SSNM) for rice is a plant-based approach for ‘feeding’ rice with nutrients as and when needed (IRRI, 2006 b). The SSNM approach provides the principles and guidelines that enable farmers to apply fertilizer to optimally match the needs of their rice crop in a specific field and season. The SSNM approach does not specifically aim to either reduce or increase fertilizer use. Instead, it aims to apply nutrients at optimal rates and times in order to achieve high rice yield and high efficiency of nutrient use by rice, leading to high cash value of the harvest per unit of fertilizer invested

Soil fertility refers to nutrient supplying capacity of a soil for crop growth. It describes available nutrients status of the soil and its ability to provide nutrients for optimum plant growth (Dev, 1997). When a nutrient element is deficient in soil, certain deficiency symptoms, which are more or less characteristics for the plant and the nutrient, may appear. In some cases, such symptoms may not be expressed due to ‘hidden hunger’. To a certain extent plant composition reflects the chemical composition of the soil. Since plant is an active entity, it exercises selectivity and discriminates in absorbing the soil-borne elements. Plant accumulates elements differentially; take up some elements in large quantities and some others in relatively smaller quantities. Indian soils are inherently low in nitrogen and phosphorus and medium in potassium content. Intensive cropping coupled with use of high analysis NPK fertilizers generally free from micronutrients and negligible or almost no application of bulky organic manures caused widespread deficiency of secondary and micronutrients in several areas (Shrivastava *et al*., 2006)

2.3 Crop Responses in Nutrients Omission Trials

When a nutrient is deficient in the soil then the growth of a crop plant and ultimately the yield is affected. A nutrients omission trial aims to find out the most limiting nutrients to the growth of a crop plant. If any element is omitted while other elements are applied at suitable rates and plants grow weakly, then the tested element is a limiting factor for crop growth. Conversely, if any element is omitted but plants are healthy, then that element is not a limiting factor for crop production. Literature pertaining to nutrient omission trials is meager.

Aburu (1975) reported from a nutrient omission trial on a solodic soil that omission of N and P significantly decreased dry matter yields of maize tops to 6.92 and 6.75 g/pot, respectively, from 13.2 g in controls given all nutrients.

The response of *Stylosanthes guianensis* (Stylo) and *Brachiaria decumbens* (Signal grass) to N, P, K, S, Cu and Zn additions on a disturbed lateritic red earth replaced after bauxite mining was assessed in greenhouse nutrient omission trials (Grundy *et al*., 1981). The soil was shown to be severely deficient in P, N and K and deficient in Cu in all the horizons and deficient in A and A+ B horizons for signal grass. Growth of Stylo was severely restricted by the omission of P, K and Cu and to a lesser extent by the omission of Zn and S in all the horizons and by Ca in the B horizon. There were considerable differences in the yield in both species between the horizons. Yield tended in the direction A > A+ B > B for omission of N, K, Zn and Cu and in reverse direction with omission of S.

In a field trial conducted by Nebe (1982) on extremely poor quartzitic soils in East Germany, a missing element experiment included NPKCa, PKCa, NKCa, NPCa, NPK and no-fertilizer applications to young Norway spruce plantations. Potassium deficiency limited growth during the first years of crop development, ending at the pole stage (about 15 years after planting). N deficiency began at the sapling stage (about 8 years after planting) and increased with age. The results showed that on quartzitic and similar sites with a low cation-exchange capacity, appropriately phased applications of K and N markedly improve the site index and yield level of young spruce stands.

Bhuiyan *et al.* (1986) initiated a long-term field experiment using the missing element approach to identify the most limiting nutrients for high yield under intensive wetland rice culture in Bangladesh. N, P, K, S and Zn fertilizers were studied. It was conducted on a permanent layout at the Bangladesh Rice Research Institute farm, Joydebpur, during the 1985 *Boro* season. In the *Boro* season, the highest or nearly similar grain and straw yields were produced where all elements were present, or where only P or Zn was missing. The result was the same in the *Aman* season with the addition of the treatment missing K Yield reduction was significant in the *Boro* season when N, S and K were missing from the complete treatment. During the *Aman* season, only the absence of N and S treatments caused significant yield reduction. The level of nutrient contents and uptake by grain and straw at maturity generally were higher in treatments with N and S. N and S were considered to be the most limiting nutrients in achieving the high yield.

Spies *et al*. (1998) investigated in clay soils from Queensland on potential for the nutrients P, S, Zn and Mo to limit growth of *Desmanthus virgatus* using nutrient omission experiments in glasshouses located at Gatton and St Lucia. The effects of nutrient deficiencies were determined by measuring top growth 47 and 103 days after planting in the Gatton trial and 73 days after planting in the St Lucia trial, as well as by the observation of deficiency symptoms. In the first harvest of the Gatton trial, omission of P or Zn significantly reduced top dry weight of plants in three of the soils by 32 to 66% relative to plants given all nutrients. Responses to these nutrients decreased, and were not significant, at the second harvest. This was in contrast to the effect of S omission, which increased with time and was significant in four of the five soils at the second harvest, reducing top growth by 24 to 75% and drastically reducing pod production in three of the soils. A small reduction in growth in one soil also occurred due to the omission of Mo. In the St Lucia trial, omission of Mo and Zn, as well as S and P, caused significant reductions in plant growth in a slightly acid euchrozem soil.

Suriya Arunroj *et al*. (2000) conducted two experiments with rice seedlings in a glasshouse at Ubon Rice Research Center, Thailand, to identify the nutrients which limit rice growth in soils of Northeast Thailand, and to determine whether nutrient limitations are affected by water availability. In Experiment 1, rice was grown on two soils (Roi et and Ubon series) under well-watered and water-limiting conditions, and 15 nutrient treatments were imposed. In Experiment 2, six soils from Northeast Thailand were examined using the same 15 nutrient treatments. The nutrients which clearly limited the growth of rice plants in soils of Northeast Thailand were N and P. In some cases, K and S also limited growth, and in one soil Zn and B also limited growth. A shortage of N was the most important limitation for plant growth in all soils except one in which P was more important. Omission of P decreased plant height and leaf area development during early growth, low N supply had a greater effect later during growth. The omission of P had a larger detrimental effect on growth when water supply was limited. These studies show that the nutrients limiting rice growth depend on soil type and water availability in soils of Northeast Thailand.

Long-term permanent plot experiment was conducted by Gami *et al*. (2001) at the Regional Agricultural Research Station, Parwanipur, Nepal. Experiment consisted of two crops per year (rice and wheat) with 12 treatments. The application of P, K or both P and K along with N did not improve the yield of rice indicating that P and K were not limiting yields. Omission of P, K or both led to yields similar to those of N, P and K indicating that wheat did not respond to P and K.

Din *et al*. (2001) conducted a trial with missing element technique for determining the components of balanced nutrient management in rain fed chickpea and black gram. Omission of N and K in the fertilizer package did not affect production of either crop. However, missing of P and B reduced yield of both crops drastically and omission of Zn reduced yield of chickpea only. Concentrations of P, B and Zn in chickpea leaves were reduced appreciably where the respective nutrients were not applied.

Dobermann *et al*. (2003) conducted on-farm experiments at 155 locations in seven domains of Asia to quantify the variability of soil properties, grain yield of rice and nutrient uptake in N, P and K omission plots (0-N, 0-P, and 0-K, respectively). Soil properties showed little association with plant nutrient uptake or grain yield in nutrient omission plots. Mean grain yields in nutrient omission plots increased in the order 0-N (3.9 Mg ha^{-1}) < 0-K (5.1 Mg ha^{1}) < or = 0-P (5.2 Mg ha^{-1}), grain yield in fully fertilized plots being 5.2 Mg ha^{-1}. N, P and K accumulation in N, P, and K omitted plots were 54, 15 and 83 kg ha^{-1}, respectively.

Melteras *et al*. (2004) compared seven soils using nutrient omission trials in Vanuatu with maize as test plant. Relative top dry weight of maize was significantly affected by different treatments. Study revealed deficiencies of phosphorus in all soils tested, of N in four soils, of K in two soils and of S in two soils. No other nutrient deficiencies were detected.

Haefele and Wopereis (2005) reported that in nutrient omission trials, rice yield ranged from 2.2 to 6.0 Mg ha^{-1} in N omission plots, from 4.1 to 9.8 Mg ha^{-1}

in P omission plots and from 5.3 to 9.6 Mg ha^{-1} in K omission plots. The highest yield in the fully fertilized treatment was 11.6 Mg ha^{-1}

Segda *et al*. (2005) reported that in nutrient omission plot study, mean grain yields of rice in the N, P and K omitted plots were 2.6 , 6.1 and 6.3 t ha^{-1} respectively, during dry season. The same treatments yielded 2.5, 3.2 and 4.0 t ha^{-1} in the N, P and K omitted plots, respectively during the wet season. They stated that N and P were yield limiting nutrients while the indigenous potassium supply was considerable.

Mishra *et al*. (2007) conducted experiments in *Inceptisols* and *Vertisols* at IGAU, Research Farm, Raipur (CG), to study the effect of omission of nutrients from SSNM (site specific nutrient management) dose. The SSNM consisted of N-150; P_2O_5- 120; K_2O- 90; S- 30; Fe- 20; Zn- 10; and B- 0.8 kg ha^{-1}. Mean grain and straw yields of rice (variety Mahamaya) were significantly reduced in comparison to SSNM dose with omission of P only in both the soils. Significant reductions in P uptake were also observed with omission of P only. Omission of K, S, Fe, Zn and B did not cause any significant reductions in yields as well as uptake of nutrients, indicating that these elements were in sufficient amounts in the soils for rice crop. Similar experiments were also conducted in farmer's field in the same year and same soil types where SSNM dose consisted of N- 150; P_2O_5- 125; K_2O- 100; S-23; Fe- 10; Zn- 10; and B- 0.8 kg ha^{-1}. The mean grain and straw yields of rice (variety Swarna) as well as uptake of N and P were significantly affected with omission of N and P in both the soils. Omission of S resulted in significant reductions in yields and uptake of S in *Vertisols* only. Omission of K, S, Fe, Zn and B did not cause any significant reductions in yields as well as uptake of nutrients, indicating that these elements were not deficient in the soils under study

Hach et al. (2007) studied that site specific nutrient management (SSNM) for high yielding rice in Mekong delta and the results of study showed that: SSNM provided an increase in grain yield about 0.5 t ha^{-1} and gave higher benefit than FFP. Fertilizer rate as estimated by SSNM is almost met the requirement of crop, therefore it could save nutrients, especially nitrogen which was applied too high by farmers. SSNM is a simple technique that can be easily applied by the farmers.

Khan *et al.* (2007 a) revealed that Zn application significantly affected wheat and rice yield. Rice yield was also significantly affected by Zn levels ranged from 3.9 to5.9 t ha^{-1}. The highest yield was obtained from 10 kg Zn ha^{-1} each applied to both the crops (wheat and rice). Similarly, yield parameter of rice like the number of spikem-2, number of spike per plant, spike length, plant height and 1000 grain weight also affected by Zn application, significantly.

Habib (2009) studied the effect of foliar application of zinc and iron on wheat yield and quality at tillering and heading stage. The treatments were control (0, Zn and Fe), 150 g Zn.ha^{-1} as $ZnSO_4$, 150 g Fe.ha^{-1} as Fe_2O_3 and a combination of both Zn and Fe. In this study, parameters such as wheat grain yield, Zn and Fe contents in grain were evaluated. Results showed that foliar application of Zn and Fe increased seed yield and its quality as compared to control. Among treatments, application of (Fe + Zn) obtained highest seed yield and quality.

Satyanarayana *et al.* (2011) studied a new approaches and tools for site-specific nutrient management with reference to K and found that the farmer becomes the “sensor” for rapid, cost effective acquisition of location specific information, the tools/software (Nutrient Expert and Nutrient Manager) become the processors of this information, and the mobile phone becomes the vehicle for fast and effective transmission of the information to farmers. Moving ahead, GIS based fertility mapping assess variability in the distribution of native nutrients and other soil parameters limiting/building yield across a larger areas and thus aid in strategizing appropriate management of nutrients leading to better yield and environmental protection.

Khan *et al*.(2011) studied that residual ,direct and cumulative effect of boron application on wheat and rice yield under rice wheat cropping system and reported that Highest grain yield of wheat (4803 kg ha-1) was recorded with the application of 2 kg B ha^{-1} only to wheat crop (direct) while 4770 kg ha^{-1} recorded with the application of 2 kg B ha^{-1} both to wheat and rice (cumulative). The yield increased due to residual effect of B was statistically lower than the cumulative effect of B. In rice, maximum yield was recorded with the cumulative application of B followed by direct and residual applied B in rice-wheat system. Boron concentration in soils ranged from 0.1 to 0.58 mg kg^{-1} in wheat and 0.10 to 0.69 mg kg^{-1} in rice, while in straw, it ranged from 6-9.6 mg kg^{-1} in wheat and 8-16 mg kg^{-1} in rice. The yield attributes like 1000-grain weight, number of spikes, spike length and plant height were increased by the residual, direct and cumulative effect of B levels. Under B-deficient soil conditions, yield of wheat can be increased by direct application of B, while yield of rice can be maximized by the cumulative use of B fertilization.

Nath *et al.* (2012) studied that Farmers' participatory site specific nutrient management in ganges tidal floodplain soil for high yielding boro rice and result showed that nitrogen and phosphorus are the most vibrant factors to increase yield and omission of N and P has significant impact on yield during Boro season. To produce high yielding rice in Boro season, farmers can be recommended for using N, P, and K as 128.7 kg, 8.08 kg, and 12.78 kg, respectively. It can save P and K nutrient by 55.11% and 75.89% in compare to that of NPK treatment, respectively. Farmers' will be benefited from both economical and environmental aspects.

Rodriguez *et al.* (2012) evaluated the impacts of Site-Specific Nutrient Management in Irrigated Rice Farms in the Red River Delta, Northern Vietnam and found that the impact analysis identified several directions that can be pursued to improve further the adoption of SSNM.

Amin *et al*. (2013) studied on site specific nutrient management in ganges tidal floodplain soil of barisal for rice (oryza sativa). They observed that N and P are the most limiting factors to increase yield in South Pangsha of Babuganj while K omission plot had no significant impact. Thus to increase rice yield, significantly farmers could be emphasized on the use of nitrogen and phosphate fertilizers as well as would be advised to be cautious in the excessive use of Nitrogen fertilizer.

Timkhum *et al.* (2013) studied on nutrient assessment with omission pot trials for management of rubber growing Soil. The pot trial using maize and rubber showed that N, P and lime were limiting factors. However, order of limiting for maize was P > N > lime, whereas for the rubber was N > P > lime. Rubber in the experimental field responded to N and P fertilization, corresponded to the pot trial.

Wanyama *et al*. (2015) studied on optimization of major nutrients (N, P and K) for lowland rice production in Eastern Uganda using nutrient omission trial for estimating indigenous nutrient supply of the major nutrients and response function. Applications of nitrogen significantly increased yield components and consequently the grain yield of rice. The major limiting nutrient for lowland rice production is N and the soil N supplying potential can support yield target of 2.8 t ha^{-1}. Whereas, the indigenous P and K supply can support yield target of up to 9 t ha^{-1} and therefore, not limiting at achievable yield targets of 6 t ha^{-1}.

Dogbe *et al.* (2015) studied on Site-Specific Nutrient Management for lowland rice in the Northern Savannah Zones of Ghana and found that the impact of omitting N was different among the locations with the irrigated lowlands ecosystems in the Sudan Savannah that recorded the highest yield loss due to N omission and Guinea Savannah the least. Potash fertilizers have little effect on yield, especially in irrigated lowlands in the Sudan Savannah. Grain yield reductions due to nutrient deficiencies were more severe in the Upper West region than in Upper East region and Northern region. Higher levels of N in irrigated lowland ecosystems in the Sudan Savannah and higher P and K may be required in Upper West region in the Guinea Savannah than recommended for achieving higher yields on a sustainable basis.

CHAPTER – III

MATERIALS AND METHODS

This chapter deals with the description of materials used and technique adopted during the course of investigation for studying important soil characteristics of the profiles in different agro-climatic zones of Chhattisgarh and nutrient omission trials conducted thereafter.

3.1 Pot culture experiment using nutrient omission technique

The present study was under taken as nutrient omission trial to assess the fertility status of two representative soil group of Bemetara district. The details of the omission trials are presented in the following section.

3.1.1 Location of the study area

Two representative soil groups (*Vertisols a*nd *Inceptisols)* were taken in bulk from the farmer's fields of village Bargaon and Deori, block - Berla, district Bemetara, respectively to assess the fertility status. Pot culture nutrient omission experiment was carried out in the green house in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Indira Gandhi Krishi Vishwavidyala, Raipur, CG during *Kharif* season, 2015 with rice as test crop and based on the results of *Kharif* season, frontline demonstrations on farmer's field were taken during *Rabi* season, 2015-16 with wheat as a test crop.

3.1.2 Preparation of bulk soil samples for pot study

Bulk **s**oil samples of two group collected from the farmer's fields from a depth of 15 cm using spade, composited and brought to the green house in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Raipur. Soil samples were thoroughly mixed, made free from plant residues and filled in cemented pots as 10 kg/pot. The detail information on soil collected and used for pot experiment is presented in Table: 3.2.1

3.1.3 Test Crops

For evaluating the fertility status of soils, rice (MTU-1010) during *Kharif* season, 2015 was taken and based on the *Kharif* season's results frontline demonstration were taken on farmer's fields during *Rabi* season 2015-16 with wheat (GW-273) crops.

3.2 Soil information

The soil samples taken from the district belong to the order of *Vertisols* and *Inceptisols* collected from two different places of the Bemetara district. *Vertisols* group also known as *Kanhar* in local identification. It is clayey in texture dark brown to black in color, neutral to alkaline in reaction due to presence of lime concretion and profile depth is up to 1.5 meter. Due to clayey textured and good water holding capacity of this soil, double cropping can be planned with good production potential. This soil has very narrow workable. They have very narrow workable soil moisture regime and become massive when dry and sticky when wet making tillage operation extremely difficult with animal drawn implements normally available with farmers. Thus these soils remain mostly under-utilized due to difficulties in management problems. *Inceptisols* is also locally known as *Matasi* and are considered to be immature soil with poor soil profile features having lighter texture and shallow to moderate depth. It is used exclusive for growing early rice after bunding, puddling and leveling and also for pulses and maize without bunding. They are soft and non-sticky when wet, easily workable under wet cultivation for puddling and biasi operation and therefore, can easily be managed to improve surface water retention for rice cultivation.

3.3 Initial Characteristics of the experimental soils

The initial physico-chemical properties of the soils under study (Table 3.1) showed that the soils were texturally classed under clayey (*Vertisol*) and clay loam (*Inceptisol)*. The soil reaction (pH) of the *Vertisol* was at 7.6 and that of *Inceptisol* exhibited 6.6 . Both the soils had low organic C, available N and S, low to medium in available P, high status in available K, exchangeable Ca and Mg. The micronutrient status of the soils were above critical level specially high status in Fe and Mn level except B and Cu in *Vertisol*. Higher CEC (41.31 Cmol (p+) kg^{-1}) was estimated in *Vertisol* due to high clay content and around 18.55 Cmol (p+) kg^{-1} was estimated in *Inceptisol.*

Table 3.1 Physico-chemical properties of experimental soil

S.No.	Properties	*Vertisol*	*Inceptisol*
1	Mechanical analysis		
	Sand %	23.53	38.45
	Silt%	32.15	32.44
	Clay %	44.32	29.11
	Textural class	Clayey	Clay loam
2	pH (1:2.5) soil :water suspension	7.6	6.6
3	Electrical conductance dSm^{-1}	0.22	0.15
4	Organic C (g kg^{-1})	4.5	4.8
5	Cation Exchange Capacity Cmol(p) kg^{-1}	41.31	26.43
6	Alkaline KMnO4- N (kg/ha)	218	179
7	Olsen P (kg/ha)	12.64	14.33
8	Neutral normal Amm Acetate extractable-K (kg/ha)	563	394
9	Available Ca (kg/ha)	6325	2165
10	Available Mg (kg/ha)	966	706
11	$CaCl_2$ extractable S (kg/ha)	22.61	21.45
12	Hot water extractable B (ppm)	0.52	0.83
13	DTPA extractable micronutrients (ppm)		
	Fe	14.33	17.71
	Mn	8.56	21.14
	Zn	0.72	1.04
	Cu	0.46	1.89

3.4 Climate of the Region

The representative soil group taken under study belongs to the Chhattisgarh plains which have hot sub-humid climate and receives annual rainfall of 1200-1600 mm. However, distribution of rainfall is not uniform and it is mostly concentrated in the month of June to September. Very little amount of rainfall is received during October - May. As such, the area qualifies for *Ustic* soil moisture regime. The length of growing period varies from 150 to 180 days. The mean annual soil temperature remains higher than 22°C qualifying for *Hyperthermic* soil temperature regime.

3.5 Soil Analysis

The samples of representative soil group (*Vertisols* and *Inceptisols*) under study were air dried, ground and passed through 2 mm sieve. The processed soil samples were analyzed in the laboratory for mechanical composition, pH, electrical conductivity, organic carbon and cation exchange capacity as per the standard methods described below.

3.5.1 Soil pH

Soil pH was determined using glass electrode pH meter in 1:2.5 soil water suspensions after stirring for 30 minutes as described by Piper (1967).

3.5.2 Electrical conductivity

The soil samples used for pH determination were allowed to settle down overnight and the conductivity of supernatant liquid was determined by solu-bridge as described by Black (1965).

3.5.3 Organic carbon

Organic carbon was estimated by wet digestion method of Walkley and Black (1934) using rapid titration method as described by Black (1965).

3.5.4 Cation Exchange Capacity

It was determined by leaching the soil with neutral normal ammonium acetate as described by Black (1965).

3.5.5 Mechanical Composition

The CEC of the soil was determine by leaching the soil with sodium acetate as described by Bower *et al*. (1952).

3.5.6 Available nitrogen

Available nitrogen in soil was determined by alkaline $KMnO_4$ method as described by Subbiah and Asija (1956).

3.5.7 Available phosphorus

Available P in soil was extracted by 0.5 M $NaHCO_3$ (pH 8.5) (1:20 soil solution ratio) for 30 minutes as suggested by Olsen *et al.* (1954) and P in the extract was determined by ascorbic acid method of Watanabe and Olsen (1965).

3.5.8 Available potassium

Available potassium in soil was extracted by neutral normal ammonium acetate and determined with the help of flame photometer as described by Hanway and Heidal (1952).

3.5.9 Available Sulphur

Available sulphur in soil was extracted by 0.15 % $CaCl_2.H_2O$ solution (Williams and Steinbergs, 1969) and content was determined by turbidimetric method of Chesnin and Yien (1950).

3.5.10 Available Calcium and Magnesium

Calcium and Magnesium status in soils were determined by 0.01 N EDTA (Versenate) titration method using ammonium acetate extract as described by Chang and Bray (1951).

3.5.11 Available micronutrients

The available micronutrients (Zn, Cu, Fe and Mn) were extracted using 0.005 M DTPA (Diethylene Triamine Penta acetic acid), 0.01 M calcium chloride dihydrate and 0.1M triethanol amine buffered at pH 7.3 (Lindsay and Norvell, 1978) and content were analyzed using atomic absorption spectrophotometer (AAS).

3.5.12 Available Boron

Available boron in soil was extracted by boiling with water and the extracted boron was determined by azomethine-H as described by Gupta (1967).

3.6 Plant Analysis

Plant samples taken at harvest stage were washed with de-mineralized water and sun dried till constant weight achieved. Samples were first digested by different acids or acid mixtures/dry ashed and the contents of N, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn, and B were estimated by adopting standard procedures as per detailed given below

3.6.1 Nitrogen Content:

Plant samples were digested in sulphuric acid at a temperature between 360 and 410 and nitrogen in the digest was estimated by micro-kjeldahl method (Piper 1966)

3.6.2 Phosphorus Content:

Plant samples were digested in tri- acid mixture (HNO_3, $HClO_4$ and H_2SO_4 in 10:4:1 ratio) and phosphorus in the digest was estimated by vanadomolybdo phosphoric yellow colour method (Piper 1966).

3.6.3 Potassium Content:

Plant samples were digested in tri- acid mixture (HNO_3, $HClO_4$ and H_2SO_4 in 10:4:1 ratio) and potassium in the digest was estimated by flame photometer (Piper 1966).

3.6.4 Sulphur Content:

Plant samples were digested in di- acid mixture (HNO_3 and $HClO_4$ in 10:4 ratio) and sulphur in the digest was estimated by turbidimetric method (Chesnin and Yien 1950).

3.6.5 Calcium and Magnesium content:

Plant samples were digested in di- acid mixture (HNO_3 and $HClO_4$ in 10:4 ratio) and calcium and magnesium contents were determined by Versene titration method as suggested by Chang and Bray (1951).

3.6.6 Fe, Mn, Cu and Zn contents:

Plant samples were digested with di- acid mixture (HNO_3 and $HClO_4$ in 10:4 ratio) and contents in the digest were estimated using atomic absorption spectrophotometer.

3.6.7 Boron Content:

Plant samples were dry ashed at 550^{o} C and the ash was digested with 0.1 N HCl. Boron in the digest was estimated by the azomethine-H method of Gupta (1967).

3.7 Nutrient Treatments

Utilizing the concept of soil reaction and nutrient availability, the following 11 treatments were formulated for each soil group using nutrient omission pot technique. In one of the treatments, all the nutrients were applied while in others, one of the nutrient element from all the nutrient treatments was omitted. The details of treatments formulated in the experiments were as given in the following Table 3.2.

Table 3.2 Treatment details

	Vertisol	***Inceptisol***
Treatment -1 (T1)	All (N, P, K, S, Fe, Mn, Cu, Zn, B)	All (N, P, K, S, Ca, Mg, Cu, Zn, B, Mo)
Treatment -2 (T2)	All – N	All – N
Treatment -3 (T3)	All – P	All – P
Treatment- 4 (T4)	All – K	All – K
Treatment- 5 (T5)	All – S	All – S
Treatment- 6 (T6)	All – Fe	All – Ca
Treatment- 7 (T7)	All – Mn	All – Mg
Treatment- 8 (T8)	All – Cu	All – Cu
Treatment- 9 (T9)	All – Zn	All – Zn
Treatment- 10 (T10)	All – B	All – B
Treatment- 11 (T11)	All – Mo	All – Mo

Table 3.3 Source and rates of application of nutrient to be used in Nutrient Omission Pot Trial.

Nutrient	Source of nutrient	Rate of application (kg/ha)	Amount of fertilizer (gm) to be added per pot(10 Kg soil)	
			Vertisol	*Inceptisol*
N	[1]Urea	150 Kg N/ha	1.5 gm/Pot	1.5 gm/Pot but Ca omission pot 0.75gm
P	TSP/[2]DAP	100 kg P_2O_5/ha	1.0 gm/Pot	1.0 gm/pot but in Ca omission pot 0.97 gm DAP
K	*MOP	80 kg K_2O/ha	0.60 gm/pot	0.60 gm/pot
S	[3]Bentonite S	45	0.085 gm/pot	0.185 gm/pot
Ca	[4]$CaCl_{2.}$ $2H_2O$	110	------	0.777 gm/pot but P omission 1.818 gm/pot
Mg	MgO	55	------	0.5 gm/pot
Fe	$FeSO_4.7H_2O$, [5]$Fecl_2$	20	0.47 gm/pot 0.26 gm/pot in S omission	-------- --------
Mn	$MnSO_4.H_2O$, [6]$Mncl_2$	15	0.223gm/pot 0.23 gm/pot in S omission	--------- ---------
Cu	$CuSO_{4.}5H_2O$, [7]$CuCl_{2.}2H_2O$	7.5	0.134 gm/pot 0.091gm/pot in S omission	0.134 gm/pot 0.091gm/pot in S omission
Zn	$ZnSO_{4.}7H_2O$, [8]$Zncl_2$	7.5	0.16gm/pot 0.07gm/pot in S omission	0.16 gm/pot 0.07 gm/pot in S omission
B	H_3BO_3	3	0.079gm/pot	0.079 gm/pot
Mo	$NaMoO_4.2H_2O$	0.75	0.009gm/pot	0.009 gm/pot

[1]Added after adjusting the amount added through DAP, [2]**U**sed in N omission treatment,[*]**A**dded after adjusting the amount added through KH_2PO_4 in N omission treatment, [3]Added after adjusting the amount added through, $FeSO_4.7H_2O$, $MnSO_4.H_2O$,$CuSO_4.5H_2O$ and $ZnSO_4.7H_2O$ in acidic soil & $FeSO_4.7H_2O$ and $MnSO_4.H_2O$ in normal Soil, [4]Used in Mg omission treatment, [5]Used in S omission treatment, [6]Used in S omission treatment, [7]Used in S omission treatment, [8]Used in S omission treatment.

3.8 Soil Preparation, Planting and Nutrient addition

Composited soil collected from different sites were air dried and filled in polyethylene lined pots at the rate of 10 kg per pot. The pots were maintained with 3 cm standing water and twenty one days old seedlings of rice (MTU-1010) were transplanted on 23th July, 2015. Three hills per pot were maintained in all the pots. Thereafter, full dose of all the nutrients except nitrogen was added to the soil in solution form. Nitrogen as urea was applied in three splits at transplanting, tillering and panicle initiation stage.

3.9 Management of the pot experiment

During *kharif* season the pots were maintained with 3 cm standing water. Remaining doses of nitrogen were applied at tillering and panicle initiation stage. Crop was grown till maturity and harvested on 30th October, 2015.

3.10 Observations Recorded

During *kharif* season with rice crop, plants were observed for growth and deficiency symptoms, if appeared. Some ancillary characters like effective tillers/pot, no. of filled grains/panicle and test weight were recorded. After harvesting of rice, grain and straw yields were recorded pot wise and reported as g/pot.

3.11 Field testing on farmer's fields during *Rabi* season with wheat crop

Based on the results of *kharif* season with rice crop, identified limiting nutrients were tested on farmer's field from which bulk soil samples were taken for pot experiment. An optimum doses of nutrients based on limiting nutrients identified were applied in single replication with wheat as a test crop and performance of this nutrient applied was compared with farmer's fertilizer dose in terms of crop yields.

3.12 Statistical Analysis

Statistical analyses of the data in Completely Randomized Design for each soil with different variables were done with the help of IRRISTAT package Version 3.0 (1994) developed by International Rice Research Institute, Philippines, Manila, Los Banos.

CHAPTER –IV

RESULT AND DISCUSSION

The results of the pot culture experiment conducted on Crop response based assessment of nutrient deficiencies in two soil groups of Bemetara district of Chhattisgarh have been presented in this chapter. The results during the course of investigation are presented below under appropriate headings with tables, figures and statistical interpretation.

4.1 Crop yields and yield parameters

In pot culture experiment with two soil type (*Vertisol* and *Inceptisol)* under study, grain and straw yields in each soil types, some agronomic parameters like effective tilers/pot, number of field grains/panicle and 1000 grain weight have been recorded and results are presented in the following tables.

4.1.1 Grain and straw yield of rice in *Vertisol*

The mean grain and straw yields of rice (Table 4.1.1) in *Vertisol* were significantly affected with treatments applied. Omission of N and P reduced significantly grain and straw yields of rice significantly over the treatment that received all nutrients (SSNM). Highest yield (30.40 g/pot) was recorded in the treatment receiving all the nutrients except Mn which was at par with those of other treatments received all nutrients and omitted with K, Fe, S, Cu, Zn, B, Mo from all nutrients. Omission of N reduced the grain yield by 54.76 % while P omission caused a yield reduction of 44.73 %. The per cent reduction in rice yields under different nutrients omitted pots were in the order of (54.76%) N> (44.73%) P> (11.63%) S>(8.99%) Zn> (6.51%) B. Mean straw yields of rice in K, Fe, Cu, Zn, B and Mo omitted pots did not vary significantly and were statistically at par. Straw yields of rice in N, P and S omitted pots showed significantly lower yield from all other treatments including SSNM..

While observing critically, the yield response due to different nutrient omitted treatments, N and P omission significantly reduced the yields in *Vertisol* as depicted in Fig 4.1. and Table 4.1.3. Although, omission of S, Zn and B resulted reduce the grain yields by 11.63, 8.99 and 6.51 % respectively from (SSNM) all nutrients applied.

Results clearly show that N is the most critical nutrient that affects the grain yield considerably followed by P. Omission of all other nutrients did not indicate yield reduction significantly. However, omission of S, Zn and B nutrients reduced the yields by 11.64, 8.98 and 6.49 % , respectively. Considerable reductions in grain yield due to these nutrients might be due their insufficient/marginal level. Similar results have also been reported by Bhuiyan *et al.* (1986), Suriya Arunroj *et al*. (2000) and Segda *et al*. (2005).

Table.4.1.1 Grain and straw yields (g/pot) of rice (MTU-1010) in relation to different treatments in *Vertisol*

S. No.	Treatments	Grain yield	Straw yield
1	All	29.49 ab	30.97 a
2	All – N	13.34 c	18.84 d
3	All – P	16.30 c	21.52 d
4	All – K	29.38 ab	30.35 ab
5	All – S	26.06 b	26.53 c
6	All – Fe	28.79 ab	31.93 a
7	All – Mn	30.40 a	32.06 a
8	All – Cu	29.00 ab	30.83 a
9	All – Zn	26.84 ab	26.99 bc
10	All – B	27.57 ab	28.81 abc
11	All – Mo	29.10 ab	31.35 a
	CD at 5%	**3.62**	**3.52**

The values in a column with a common letter are not significantly different.

Comparatively higher yields were observed in *Inceptisol* as compared to *Vertisol* under study. Due to light textured soils of *Inceptisol* better nutrients release property might have supported for higher yield in comparign to that of Vertisol. Similar results have also been reported by Bhuiyan *et al.* (1986), Suriya Arunroj *et al*. (2000) and Segda *et al*. (2005).

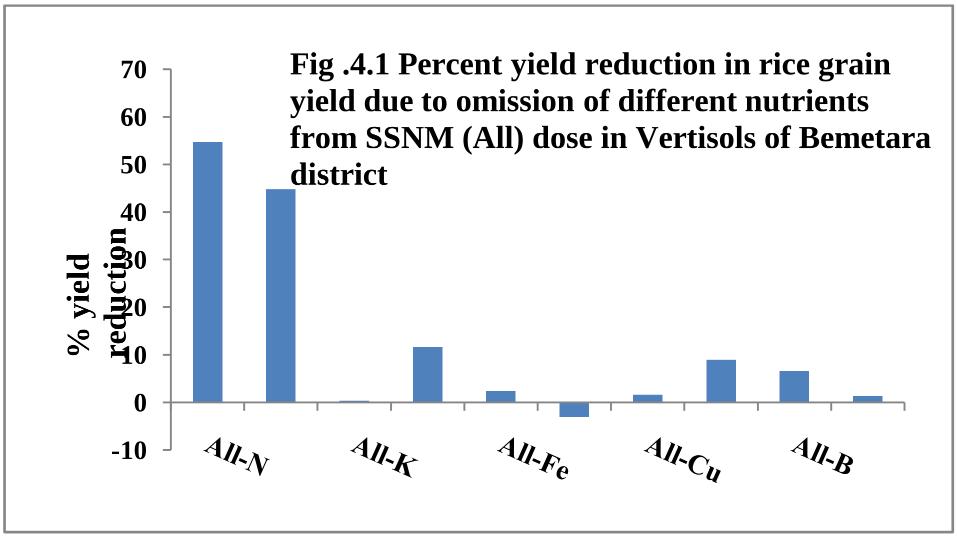

Fig .4.1 Percent yield reduction in rice grain yield due to omission of different nutrients from SSNM (All) dose in Vertisols of Bemetara district

4.1.2 Grain and straw yield of rice in *Inceptisol*

Table 4.1.2 show that mean grain and straw yields of rice in *Inceptisol* were significantly affected with different treatments applied. Omission of N and P reduced grain yields of rice significantly over all other the treatments including application of all nutrients (SSNM). Highest yield (34.90 g/pot) was recorded in the B omission pot and lowest yield with omission of N (18.99 g/pot). Omission of N from all nutrients reduced the grain yield by 42.10 %, Phosphorus omission caused a yield reduction of 29.97 % and S omitted pot reduced the grain yield by 13.60% (Fig.4.2 and Table 4.1.3). Mean grain yields of rice in B, Ca, Zn, Mo, Mg, K, and Cu omitted pots did not vary significantly and were statistically at par.

Straw yields of rice also showed significantly reduced yields with omission of N and P as observed with grain yield. However, S omitted pot also showed statistically reduced straw yield.

Higher grain and straw yields were observed in the treatment which received all the nutrients (All) and omission of K, S, Fe, Mn, Ca, Mg, Cu, B, Zn and Mo in both the soils under study. Large reductions in the grain and straw yield of rice were observed with the omission of Nitrogen (N) and phosphorus (P) as compared to the other nutrient omission treatments (Tables 4.1.1, 4.1.2). The yield reductions were more pronounced with N omission (42.10 %) than P (29.97%). This indicates that N was the most yield limiting nutrients in both the soils under study followed by P. Omission of all other nutrients did not indicate yield reduction significantly. However, omission of S nutrient reduced the grain yield by 13.60 % over the treatment receiving all nutrients (All). This indicates that S status in *Inceptisol* was at marginal level which might have not sufficient to increase the grain yield at optimum level.

Table 4.1.2: Grain and straw yields of rice (MTU-1010) in relation to different treatments in *Inceptisol.*

S. No.	Treatments	Grain yield (g/pot)	Straw yield (g/pot)
1	All	32.80 ab	34.94 a
2	All – N	18.99 c	24.20 c
3	All – P	22.97 c	29.26 b
4	All – K	31.52 ab	33.79 a
5	All – S	28.34 b	29.24 b
6	All – Ca	33.09 ab	34.96 a
7	All – Mg	31.72 ab	34.51 a

8	All – Cu	31.40 ab	34.48 a
9	All – Zn	32.18 ab	34.80 a
10	All – B	34.90 a	37.62 a
11	All – Mo	31.92 ab	34.96 a
	CD at 5%	**4.45**	**4.48**

The values in a column with a common letter are not significantly different.

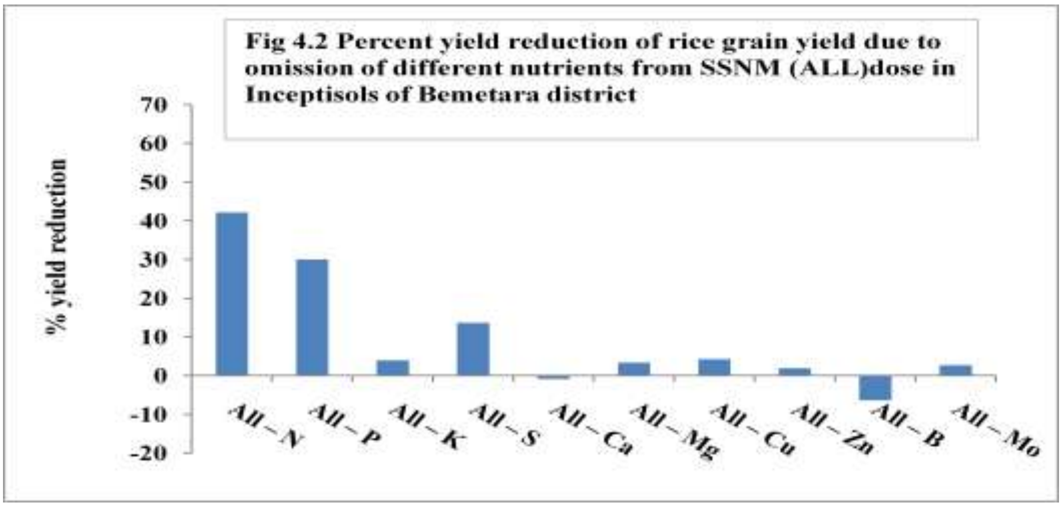

Table 4.1.3 Percent yield reduction of rice grain due to omission of different nutrients from SSNM (ALL) dose in *Vertisol* and *Inceptisol* of Bemetara district

S.No.	Treatments	*Vertisol*	Treatments	*Inceptisol*
1	All	-	SSNM	-
2	All – N	54.76	All – N	42.10
3	All – P	44.73	All – P	29.97
4	All – K	0.37	All – K	3.90
5	All – S	11.63	All – S	13.60

6	All – Fe	2.37	All – Ca	-0.88
7	All – Mn	-3.09	All – Mg	3.29
8	All – Cu	1.66	All – Cu	4.27
9	All – Zn	8.99	All – Zn	1.89
10	All – B	6.51	All – B	-6.40
11	All – Mo	1.32	All – Mo	2.68

Oxidation loss of organic matter under tropical climatic conditions results in low organic carbon (Singh *et al.,* 2000). Since organic matter content is an indicator of available nitrogen status of soils, the soils of the area are also dominantly low in respect of available nitrogen. The soils were inherently low in available P (Table 3.1) and hence the omission of P caused more reduction in yields. On the basis of yield performance, the next elements which limited the yields in *Vertisol* were S followed by Zn and B whereas Zn and B did not show the yield limiting factor in *Inceptisol*. Yield reduction due to S omission may be attributed to less supply of S, since the available S in these soils were in the lower margin of medium category (Table 3.1). Continuous use of S free fertilizers like DAP and others may also be one of the possible reasons for lowering the S status in soils and caused yield reduction (Biswas *et al*., 2004). Similarly, Zn omitted pots may be attributed to low availability of Zn upon flooding because of formation of sparingly soluble sulphides and carbonates under anaerobic conditions (Yoshida *et al*., 1971). The marginal level of Zn in *Vertisol* due to continuous crop removal may also be a reason for lowering the yield in *Vertisol.*

Higher adsorption and immobilization of S (Tiwari *et al.,* 2006) might have resulted in lower yields in both the soil. The yield reductions were observed more in the *Inceptisol than the Vertisol.* With respect to B omission treatment, yield reductions in *Vertisol* may be attributed to reduced availability of B due to formation of Ca-borate and B-silicate (Sharma *et al*., 2003) and low soil status. On the basis of yield performance the yield limiting nutrients in *Vertisol* may be put in the order of N > P > S > Zn > B whereas that in *Inceptisol*, the limiting nutrients may be in the order of N > P > S.

4.1.3 Effective tillers, filled grains/panicle and test weight of rice in *Vertisol* and *Inceptisol*

Table 4.1.4 show that Mean effective tillers were significant affected with application of different treatments in *Vertisol* and *Inceptisol.* Highest effective tillers were observed with the treatments that received all nutrients in both the soils. Effective tillers significantly decreased with omission of N and P nutrients. Rest of the treatments had almost similar results in both the soils. Similarly, number of filled

Table 4.1.4 Mean effective tillers, filled grains/panicle and test weight g/k of rice in two soils group of Bemetara district

Treatments	Effective Tillers/pot		Number of filled grains/panicle		Test weight g/1000 seed	
	Vertisol	*Inceptisol*	*Vertisol*	*Inceptisol*	*Vertisol*	*Inceptisol*
All	13 a	14 a	99 a	103 a	24.43	24.04
All – N	7 c	8 c	79 c	85 c	22.90	23.59
All – P	8 c	9 c	87 c	90 cb	23.33	23.56
All – K	13 a	12 b	91 a	104 a	24.81	24.54
All – S	12 a	12 b	90 ab	94 b	23.51	23.69
All – Fe/Ca*	13 a	13 a	97a	108 a	24.16	23.98
All-Mn/Mg**	12 a	12 b	98 a	107 a	24.57	24.25
All – Cu	12 a	12 b	101 a	108 a	23.86	24.11
All – Zn	10 b	12 b	101 a	104 a	24.16	24.54
All – B	12 a	14 a	101 a	107 a	24.17	23.79
All – Mo	13 a	13 a	99 a	102 a	24.46	24.21
CD at 5%	**1.49**	**1.39**	**9.9**	**6.18**	**NS**	**NS**

***** All-Fe for *Vertisol* and All-Ca for *Inceptisol*, ** All-Mn for *Vertisol* and All-Mg for *Inceptisol* The values in a column with a common letter are not significantly different

grains per panicle were also higher with treatments that received all nutrients and statistically at par with those of all other treatments except N and P omitted pots in both the soils under study. Test weight (weight of 1000 rice seed) of rice did not differ significantly with respect to the application of different treatments in this study in both the soils. However, omission of N and P pots had reduced the test weight as compared to those of all other treatments. It is universally truth that N and P are the most important major nutrients require for tillering, root growth and general plant vigor that affect ultimately filled grains and test weight. The reduced effective tillers, number of filled grains per panicle and test weight were recorded in present study caused omission of N and P treatments.

4.2 Nutrient uptake

4.2.1 N, P and K uptake by rice *Vertisol*

It is clear from the Table: 4.2.1 that the mean total N, P and K uptake by rice were significantly affected with application of different treatments. Highest N uptake (498 mg/pot) was observed in Mn omission pot followed by (488 mg/pot) treatment receiving all the nutrients. N omission treatment recorded lowest (230 mg/pot) N uptake followed by P and S omitted pots which were significantly differed among them. Omission of P resulted in significantly higher N uptake (286 mg/pot) than N omission (230 mg/pot) but was lower than the N uptake in other nutrient omission treatments. N uptake in S omitted pot was 426 mg/pot and varied significantly over N and P omitted treatments. N uptake by rice in Fe, Mn, K, Cu, Mo, B and Zn omitted pots and treatment receiving all the nutrients were statistically at par with each other. Higher uptake of N with application of nitrogen by rice has been observed by Bhuiyan *et al.* (1986). Reductions in N uptakes with omission of N has also been reported by Mishra *et al*. (2001)

Table 4.2.1 indicate that average P uptake by rice were significantly affected with different treatments application. Lowest P uptake (47 mg/pot) was observed in N omitted pot followed by P omitted (49 mg/pot), Zn omitted (82 mg/pot) and S omitted (81 mg/pot). These treatments were statistically significant. P uptake by rice in Fe, Mn, K, Cu, Mo, and B omitted pots and treatment receiving all the nutrients were statistically at par with each other. Highest P uptake was observed with Mn omitted (97 mg/pot).

Table: 4.2.1 Total uptake of N, P and K (mg/pot) by rice (MTU-1010) in relation to different treatments in *Vertisol.*

S.No.	Treatments	N	P	K
1	All	488 ab	96 a	566 a
2	All – N	230 e	47 d	318 c
3	All – P	286 d	49 d	370 c
4	All – K	485 abc	95 a	546 ab
5	All – S	426 c	82 bc	487 b
6	All – Fe	483 abc	93 ab	576 a
7	All – Mn	498 a	97 a	585 a
8	All – Cu	481 abc	94 ab	560 a
9	All – Zn	434 bc	81 c	497 b
10	All – B	453 abc	85 abc	524 ab
11	All – Mo	474 abc	90 abc	563 a
	CD at 5%	**56**	**12**	**62**

The values in a column with a common letter are not significantly different.

. The data presented in Table: 4.2.1 clearly indicated that the mean K uptake by rice was significantly affected with application of different treatments.

Omission of N, P, S, and Zn caused lower uptake of K over other treatments significantly. Highest K uptake (585 mg/pot) was associated with Mn omission pot followed by (576 mg/pot) with Fe omission and 566 mg/pot with the treatment receiving all the nutrients although K uptake with these treatments recorded a non-significant results. Lowest K uptake (318 mg/pot) was observed with N omission. Omission of P resulted in higher K uptake (370 mg/pot) than N omission but was significantly lower than K uptake in other nutrient omission treatments. K uptake in S omitted pot was 487 mg/pot, and varied significantly. K uptake by rice in Fe, Mn Cu, K, Mo, B omitted pots and all nutrients applied were statistically at par with each other.

4.2.2 N, P and K uptake by rice in *Inceptisol*

Table: 4.2.2 revealed that the mean total N uptake by rice was significantly affected with application of different treatments. Highest N uptake (556 mg/pot) was observed in treatment associated with B omitted pot followed by the treatment receiving all nutrients (522 mg/pot) whereas the least N uptake (305 mg/pot) was associated with N omission. Omission of P resulted in significantly higher N uptake (383 mg/pot) than N omission but was lower than the N uptake in other nutrient omission treatments. N uptake in S omitted pots was 445 mg/pot which was at par with P omitted pot. N uptake by rice in K, B, Zn, Ca, Mg, Cu, K omitted pots and treatment with all nutrients applied were statistically at par with each other.

Table 4.2.2: Total uptake of N, P and K (mg/pot) by rice (MTU-1010) in relation to different treatments in *Inceptisol*

S.No.	Treatments	N	P	K
1	All	522 a	124 a	612 a
2	All – N	305 d	75 c	402 d
3	All – P	383 c	81 c	489 c

4	All – K	503 ab	118 ab	579 ab
5	All – S	445 bc	104 b	516 bc
6	All – Ca	524 a	123 a	614 a
7	All – Mg	509 ab	119 ab	600 a
8	All – Cu	504 ab	118 ab	599 a
9	All – Zn	515 ab	121 ab	606 a
10	All – B	556 a	132 a	656 a
11	All – Mo	508 ab	123 a	600 a
	C.D. at 5%	**70**	**17**	**77**

Average P uptake by rice was significantly affected with application of different treatments (Table 4.2.2). Highest P uptake (132 mg/pot) was observed in treatment receiving B omitted pot whereas the least P uptake (75 mg/pot) was associated with N omission. Omission of P resulted in higher P uptake (81 mg/pot) than N omission and showed non-significant difference. P uptake in S omitted pot was significantly lower than the treatment receiving all nutrients. P uptake by rice in B, Zn, K, Ca, Mg, Cu and Mo omitted pots and treatment with all nutrients applied were statistically at par with each other.

The data presented in Table: 4.2.2 clearly indicated that the mean total K uptake by rice was significantly affected with application of different treatments. Omission of N, P and S caused lower uptake of K in different pots. Highest K uptake (656 mg/pot) was associated with the treatment receiving all the nutrients except B. whereas the least K uptake (402 mg/pot) was observed with N omission. Omission of P resulted in higher K uptake (489 mg/pot) than N omission but was significantly lower than K uptake in other nutrient omission treatments. K uptake in S omitted pot was 516 mg/pot and varied significantly with all treatments except N and P omitted pots. P uptake by rice in B, Zn, Ca, Mg, K, Cu and Mo omitted pots and treatment with all nutrients applied were statistically at par with each other.

Total N uptakes by rice in both the soils were recorded significantly lower in the treatments that omitted with N, P, and S from all nutrients application. Obviously, the supply of all the nutrients including N in ‘All’ treatment increased the grain and straw yields causing more uptake of N (Syed *et al.* 2006). Omission of N, P and S from all nutrients lowered the N uptakes from rest of all treatments. Lowest N uptake recorded with N omission because N was the most yield limiting nutrient which resulted in lower yields. The uptakes of N in P, S, Zn and B omitted pots were in the order of P < Zn < S < B, which were related to grain and straw yields and their respective N concentrations. N uptakes were observed more in *Inceptisol* in all the treatments than *Vertisol*. This is indicates that S, Zn and B were more limiting in *Vertisol* than in *Inceptisol* under study. This is supported by the initial status of S, Zn and B in experimental soils (Table 3.1).

Total P uptakes were found more in the treatments which received all the nutrients (All), omitted with K, Ca, Fe, Mg, Mn, Cu, Zn, B and Mo whereas the omission of N, P and S reduced the uptakes of P by rice. Supply of all the nutrients including P in ‘All’ treatment increased the soil solution P causing higher absorption of P resulting in higher grain and straw yields as well more uptake of P (Venkatesh *et al*., 2002). Omission of K, Ca, Fe, Mg, Mn, Cu, Zn, B and Mo from all nutrients also exhibited higher P uptake due to sufficient status of these nutrients in experimental soils under study (table 3.1). Lower P uptakes were observed with P omission because P was the next most yield limiting nutrient after N, which resulted in lower yields and lower P uptake. Uptake of P was lower in *Inceptisol* in comparison to *Vertisol* in all the treatments indicating that P was more limiting nutrient in *Vertisol* than *Inceptisol*. This is supported by the initial status of P in these soils (Table 3.1). The uptakes of P in N, P, S, Zn and B omitted pots were in the order of N< P<S<Zn which were related to grain and straw yields and their respective P concentrations.

Omission of N, P, S and Zn caused lower uptake of total K in different pots in comparison to the treatments receiving all the nutrients (All). Potassium exerts a positive role on photosynthesis (Mengel and Kirkby, 1983) and production of dry matter (Senthivel and Palaniappan, 1985) causing higher uptake of K in the treatments receiving all the nutrients. Lower uptakes of K with omission of N, P, S and Zn were related to the grain and straw yields and their respective K concentrations. Omission of K reduced the K uptakes in comparison to the treatments receiving all the nutrients; however, the reductions were less in comparison to omission of N, P, S and Zn. This indicates that N, P, S and Zn were the more limiting nutrients than those of other nutrients. K uptakes were observed more in *Inceptisol* than *Vertisol*. The initial K status of available K in experimental soils were medium to high range and due to easy availability of this nutrient, particularly in *Inceptisol.* This is supported by the initial status of K, S and Zn in these soils (Table 3.1).

4.2.3 Ca, Mg and S uptake by rice in *Vertisol*

It is obvious from the data presented in Table: 4.2.3 that the mean total Ca uptake by rice in *Vertisol* was significantly affected with application of different treatments. omission of N, P and S treatments caused significant reductions in the Ca uptake in comparison to all other treatments including the treatment receiving all the nutrients. Highest Ca uptake (280 mg/pot) was observed with the treatment receiving all the nutrients whereas the least Ca uptake was observed with N omission (160 mg/pot) followed by P omission (183 mg/pot). Uptake of Ca in K, Cu, Fe, Mn, Zn, B, Mo omitted pots and treatment of all nutrients applied were statistically at par with each other.

The mean total Mg uptake by rice in *Vertisol* was significantly affected (Table 4.2.3) with application of different treatments. Omission of N, P and S treatments significantly reduced the Mg uptake of rice in comparison to all other treatments. Lowest Mg uptake was observed in the N omitted pot (93 mg/pot) followed by P omission (106 mg/pot), S omission (138 mg /pot) . Uptake of Mg in K, Cu, Fe, Mn, Zn, B, Mo omitted pots and treatment of all nutrients applied were statistically at par with each other.

Table: 4.2.3: Total uptake of Ca, Mg and S (mg/pot) in rice in relation to different treatments in *Vertisol*

S.No.	Treatments	Ca	Mg	S
1	All	280 a	169 a	76 a
2	All – N	160 c	93 e	37 d
3	All – P	183 c	106 e	43 d
4	All – K	267 ab	155 abc	69 abc
5	All – S	235 b	138 d	59 c
6	All – Fe	276 a	164 ab	71 ab
7	All – Mn	281 a	165 ab	76 a
8	All – Cu	275 a	158 abc	72 ab
9	All – Zn	241 ab	143 cd	62 bc
10	All – B	254 ab	150 bcd	66 abc
11	All – Mo	277 a	159 abc	70 ab
	C.D. at 5%	**38**	**16**	**10**

The values in a column with a common letter are not significantly different.

The mean S uptake by rice in *Vertisol* (table 4.2.3) was significantly affected with application of different treatments. Omission of N, P, and S caused significantly lower uptake of S in different pots. S uptake in N, P and S omitted pots were lower than those of all other treatments. Highest S uptake (76 mg/pot) was observed with the treatment receiving all the nutrients and Fe omitted pot whereas the least S uptake (37 mg/pot) was observed with N omission. Omission of P resulted in higher S uptake (43 mg/pot) than N omission. S uptake in S omitted pot was 59 mg/pot and varied significantly. Omission of Mn, Fe, Cu, Mo, K, B and Zn treatments with all nutrients applied resulted in similar S uptake by rice and were statistically at par with each other.

4.2.4 Ca, Mg and S uptake by rice in *Inceptisol*

It is obvious from the data presented in Table: 4.2.4 that the mean total Ca uptake by rice in *Inceptisol* was significantly affected with application of different treatments. omission of N, P and S treatments caused significant reductions in the Ca uptake in comparison to the treatment receiving all the nutrients. Highest Ca uptake (296 mg/pot) was observed with the treatment receiving all the nutrients whereas the least Ca uptake was observed with N omission (193 mg/pot) followed by P omission (233 mg/pot). Uptake of Ca in Ca, Mg K, Cu, Zn, B, Mo omitted pots and treatment of all nutrients applied were statistically at par with each other.

Table: 4.2.4: Total uptake of Ca, Mg and S (mg/pot) in rice in relation to different treatments in *Inceptisol*

S.No.	Treatments	Ca	Mg	S
1	All	296 a	170 a	85 a
2	All – N	193 c	113 c	47 d
3	All – P	233 b	131 c	60 c
4	All – K	280 a	154 ab	72 abc
5	All – S	238 b	133 bc	64 bc
6	All – Ca	285 a	160 a	78 a
7	All – Mg	282 a	153 ab	75 ab
8	All – Cu	284 a	156 a	77 ab
9	All – Zn	288 a	159 a	77 a

10	All – B	312 a	171 a	85 a
11	All – Mo	283 a	161 a	79 a
	C.D. at 5%	**40**	**22**	**12**

The values in a column with a common letter are not significantly different

The mean total Mg uptake by rice in *Inceptisol* was significantly affected (Table 4.2.4) with application of different treatments. Omission of N, P and S treatments significantly reduced the Mg uptake of rice in comparison to all other treatments. Lowest Mg uptake was observed in the N omitted pot (113 mg/pot) followed by P omission (131 mg/pot), S omission (133 mg /pot) . Uptake of Mg in K, Cu, Ca, Mg, Zn, B, Mo omitted pots and treatment of all nutrients applied were statistically at par with each other.

similarly, the mean S uptake by rice in *Inceptisol* (Table 4.2.4) was significantly affected with application of different treatments. Omission of N, P and S caused significantly lower uptake of S in different pots. S uptake in N, P and S omitted pots were lower than those of all other treatments. Highest S uptake (85 mg/pot) was observed with the treatment receiving all the nutrients and B omitted pot whereas the least S uptake (47 mg/pot) was observed with N omission. Omission of P resulted in higher S uptake (60 mg/pot) than N omission. S uptake in S omitted pot was 64 mg/pot and varied significantly. Omission of K, Ca, Mg, Cu, Mo, B and Zn treatments with all nutrients applied resulted in similar S uptake by rice and were statistically at par with each other.

Omission of N, P and S in both the soils reduced the total Ca uptakes by rice in comparison to the treatments receiving all the nutrients. Omission of N and P reduced the uptakes more than that of omission of other nutrients indicating that these two nutrients were the most limiting nutrients. Lower Ca uptakes were observed with N and P omission obviously due to lower grain and straw yields and lower Ca concentrations. Uptakes of Ca in N, P and S omitted pots were in the order of N < P < S in accordance with the grain and straw yields and Ca concentrations in the respective pots. Least reductions in Ca uptakes were observed with omission of K, Cu, Fe/Ca, Mn/Mg, Zn, B and Mo suggesting that its level in experimental soils were in sufficient level. Higher Ca uptakes were observed in *Inceptisol* inspite of less Ca status in this soil as compared to *Vertisol* although Ca status in both the soils were more than sufficient.

Total Mg uptakes by rice in both the soils were found more in the treatments which received all the nutrients (All), whereas the omission of N, P and S reduced the uptakes of Mg by rice. Highest uptakes of Mg were observed in the treatments receiving all the nutrients because supply of all the nutrients including Mg in 'All' treatments increased the grain and straw yields as well as the Mg concentrations causing more uptake of Mg. Lower Mg uptakes were observed with N and P omission since these two elements were the most limiting. Mg uptakes were found almost similar in both the soils which might be due to higher initial Mg content in soils (Table 3.2.1). Uptakes of Mg in N, P and S were in the order of N < P < S in accordance with the grain and straw yields and Mg concentrations in the respective pots.

Total S uptakes were found more in the treatments which received all the nutrients (All), whereas the omission of N, P and S reduced the uptakes of S by rice. Increase of S concentrations in plant with application of S supplied in the 'All' treatment as well as with nutrient omitted for K, Ca/Fe, Mg/Mn, Zn, Cu, B, Mo and higher grain and straw yields caused more uptake of S (Sakal *et al*., 2000, Jat *et al*., 2007). S uptakes in N and P omitted pots were lower than that of other nutrient omission treatments indicating that these were the most limiting nutrients. The uptakes of S in N, P and S omitted pots were in the order of N < P < S which were related to grain and straw yields and their respective S concentrations. Uptakes of S in *Inceptisol* was higher as compared to the *Vertisol* which might be due to high grain and straw yields in *Inceptisol* however, the initial status of available S in both the soils were marginal (Table 3.1).

4.2.5 Micronutrients (Fe, Mn, Zn, Cu and B) uptake (mg/pot) by rice in *Vertisol*

The data presented in Table 4.2.5 clearly indicated that the mean total Fe uptake by rice in *Vertisol* was significantly affected with application of different treatments. Omission of N, P and S caused lower uptake of Fe in different pots. Highest Fe uptake (8.25 mg/pot) was observed in the Mn omission followed by (8.02 mg/pot) Mo omission and (8.00 mg/pot) treatment receiving all the nutrients whereas the least Fe uptake (4.66 mg/pot) was associated with N omission. Omission of P resulted in higher Fe uptake (5.36 mg/pot) than N omission but was significantly lower than Fe uptake in other nutrient omission treatments. Fe uptake in Mn, Cu, K, Mo and B omitted pots were statistically at par with each other.

The mean total Mn uptake by rice in *Vertisol* was significantly affected with application of different treatments. Similar to Fe uptake result previously, omission of N, P and S significantly reduced the uptake of Mn in different pots and the reductions were found more with N and P omissions. Lowest uptake of Mn was observed with N omission (6.61 mg/pot) followed by P omission (7.59 mg/pot). Mn uptake with S omitted pot was recorded 9.68 mg/pot and significantly differed. Mn uptake in Mn, Cu, K, Mo and B omitted pots with SSNM treatment were statistically at par with each other.

The mean total Zn uptake by rice in *Vertisol* was significantly affected with application of different treatments (Table: 4.2.5). Omission of N, P, S and Zn omitted treatments significantly reduced the uptake of Zn in different pots and maximum reduction in Zn uptake (0.94 mg/pot) was observed with N omission followed by P omission (1.10 mg/pot). Highest Zn uptake (1.79 mg/pot) was observed with the treatment receiving all the nutrients whereas the lowest uptake (0.94 mg/pot) was associated with N omission. Uptake of Zn in K, Fe, Mn, Zn, B, Mo and Cu omitted pots and all nutrients applied were statistically at par with each other.

Table 4.2.5 Total uptake of Fe, Mn, Zn ,Cu and B of rice (mg/pot) in relation to different treatments in *Vertisol*

S. No.	Treatment	Fe	Mn	Zn	Cu	B
1	All	8.00 ab	11.31 abc	1.79 a	0.35 a	0.50 ab
2	All – N	4.66 c	6.61 d	0.94 c	0.19 b	0.24 d
3	All – P	5.36 c	7.59 d	1.10 c	0.22 b	0.30 d
4	All – K	7.74 ab	11.01 abc	1.69 ab	0.35 a	0.46 abc
5	All – S	6.83 b	9.68 c	1.50 b	0.31 a	0.41 c
6	All – Fe	7.96 ab	11.48 ab	1.73 ab	0.35 a	0.46 abc
7	All – Mn	8.25 a	11.58 a	1.81 a	0.36 a	0.51 a
8	All – Cu	7.82 ab	11.17 abc	1.73 ab	0.34 a	0.48 abc
9	All – Zn	6.95 ab	9.87 bc	1.48 b	0.31 a	0.44 abc
10	All – B	7.36 ab	10.50 abc	1.61 ab	0.33 a	0.42 bc
11	All – Mo	8.02 ab	11.33 abc	1.77 a	0.35 a	0.48 abc
	C.D. at 5%	**1.20**	**1.55**	**0.25**	**0.05**	**.08**

The values in a column with a common letter are not significantly different

The data presented in Table: 4.2.5 clearly indicated that the mean total Cu uptake by rice was significantly affected with application of different treatments. Omission of N and P reduced the Cu uptake significantly. Highest Cu uptake (0.36 mg/pot) was observed with the Mn omission followed by (0.35 mg/pot) treatment receiving all the nutrients and lowest uptake (0.19 mg/pot) was associated with N omission. Omission of P resulted in higher Cu uptake (0.22 mg/pot) than N omission. Uptake of Cu in K, Fe, S, Cu, Zn, B, Mo and Mn omitted pots with the treatment of all nutrients applied were statistically at par with each other.

It is obvious from the Table: 4.2.5 that the mean total B uptake by rice in *Vertisol* was significantly affected with application of different treatment. Omission of N, P and S reduced the B uptake significantly. Omission of N caused more reduction in B uptake than that of P omission.. Highest B uptake was recorded in Mn omitted pot (0.51 mg/pot) followed by the treatments receiving all nutrients (0.50 mg/pot). Uptake of B in S and B omitted pots were 0.41 and 0.42mg/pot respectively. B uptake in K, Fe, S, Cu, Zn, B, Mo and Mn along with the treatment of all nutrients applied did not differ significantly and were statistically at per with each other.

4.2.6 Micronutrients (Fe, Mn, Zn, Cu and B) uptake (mg/pot) by rice in *Inceptisol*

The data presented in Table 4.2.6 showed that the mean total Fe uptake by rice in *Inceptisol* was significantly affected with application of different treatments. Omission of N, P and S pots had lower uptake of Fe significantly from the treatment receiving all nutrients. Highest Fe uptake (9.60 mg/pot) was observed in the B omission followed by (8.99 mg/pot) with the treatment receiving all nutrients whereas the least Fe uptake (6.0 mg/pot) was associated with N omission. Omission of P resulted in higher Fe uptake (7.00 mg/pot) than N omission but was significantly lower than Fe uptake in other nutrient omission treatments. Fe uptake in Ca, Mg,, Cu, K, Zn, B and Mo omitted pots along with the treatment receiving all nutrients were statistically at par with each other.

The mean total Mn uptake by rice in *Inceptisol* was significantly affected with application of different treatments (Table 4.2.6). Similar to Fe uptake result previously, omission of N, P and S significantly reduced the uptake of Mn in different pots as compared to the treatment that received all nutrients and reductions observed were more with N and P omissions. Lowest uptake of Mn was observed with N omission (8.53 mg/pot) followed by P omission (10.32 mg/pot). Mn uptake with S omitted pot was recorded 10.55 mg/pot and significantly differed from the treatment with all nutrients applied . Mn uptake in Ca, Mg, Cu, Zn, K, Mo and B omitted pots with the treatment that received all nutrients were statistically at par with each other.

The mean total Zn uptake by rice in *Inceptisol* was significantly affected with application of different treatments (Table: 4.2.6). Omission of N, P and S omitted treatments significantly reduced the uptake of Zn in different pots and highest reduction in Zn uptake (1.24 mg/pot) was observed with N omission followed by P omission (1.10 mg/pot). Highest Zn uptake (2.04 mg/pot) was observed with the treatment receiving all the nutrients whereas the lowest uptake (0.94 mg/pot) was associated with N omission. Uptake of Zn in K, Ca, Mg, Cu, Zn, B and Mo omitted pots and all nutrients applied were statistically at par with each other.

The data presented in Table: 4.2.6 clearly indicated that the mean total Cu uptake by rice was significantly affected with application of different treatments. Omission of N and P reduced the Cu uptake significantly. Highest Cu uptake (0.42 mg/pot) was observed with the B omitted treatment and lowest uptake (0.25 mg/pot) was associated with N omission. Omission of P resulted in higher Cu uptake (0.30 mg/pot) than N omission. Uptake of Cu in K, Ca, Mg, S, Cu, Zn, B and Mo omitted pots with the treatment of all nutrients applied were statistically at par with each other.

It is obvious from the Table: 4.2.6 that the mean total B uptake by rice in *Inceptisol* was significantly affected with application of different treatment. Omission of N, P and S reduced the B uptake significantly. Omission of N caused more reduction in B uptake than that of P omission.. Highest B uptake was recorded in (0.54 mg/pot) in the treatment that received all nutrients and lowest B uptake was recorded in n omitted treatment. B uptake in K, Ca, Mg, Cu, Zn, B and Mo along with the treatment of all nutrients applied did not differ significantly and were statistically at per with each other.

The mean total Zn uptake by rice in *Inceptisol* was significantly affected with application of different treatments (Table: 4.2.6). Omission of N, P, and S omitted treatments significantly reduced the uptake of Zn in different pots and highest reduction in Zn uptake (1.24 mg/pot) was observed with N omission followed by P omission (1.10 mg/pot). Highest Zn uptake (2.04 mg/pot) was observed with the treatment receiving all the nutrients whereas the lowest uptake (0.94 mg/pot) was associated with N omission. Uptake of Zn in K, Ca, Mg, Cu, Zn, B and Mo omitted pots and all nutrients applied were statistically at par with each other.

The data presented in Table: 4.2.6 clearly indicated that the mean total Cu uptake by rice was significantly affected with application of different treatments. Omission of N and P reduced the Cu uptake significantly. Highest Cu uptake (0.42 mg/pot) was observed with the B omitted treatment and lowest uptake (0.25 mg/pot) was associated with N omission. Omission of P resulted in higher Cu uptake (0.30 mg/pot) than N omission. Uptake of Cu in K, Ca, Mg, S, Cu, Zn, B and Mo omitted pots with the treatment of all nutrients applied were statistically at par with each other.

It is obvious from the Table: 4.2.6 that the mean total B uptake by rice in *Inceptisol* was significantly affected with application of different treatment. Omission of N, P and S reduced the B uptake significantly. Omission of N caused more reduction in B uptake than that of P omission. Highest B uptake was recorded in

Table 4.2.6 Total uptake of B, Cu, Zn, Mn and Fe in rice in relation to different treatments in *Inceptisol*

S. No.	Treatment	Fe	Mn	Zn	Cu	B
1	All	8.99 a	12.93 a	1.94 a	0.39 ab	0.54 a
2	All – N	6.00 d	8.53 d	1.24 d	0.25 d	0.32 d
3	All – P	7.18 cd	10.32 c	1.50 cd	0.30 cd	0.40 cd

4	All – K	8.57 ab	12.09 ab	1.82 ab	0.38 ab	0.50 ab
5	All – S	7.48 bc	10.55 bc	1.59 bc	0.33 bc	0.45 bc
6	All – Ca	8.88 ab	12.63 a	1.86 ab	0.39 ab	0.52 ab
7	All – Mg	8.68 ab	12.41 ab	1.85 ab	0.38 ab	0.50 ab
8	All – Cu	8.67 ab	12.38 ab	1.85 ab	0.37 ab	0.52 ab
9	All – Zn	8.70 ab	12.50 ab	1.84 ab	0.39 ab	0.52 ab
10	All – B	9.60 a	13.49 a	2.05 a	0.42 a	0.52 ab
11	All – Mo	8.85 ab	12.59 a	1.89 ab	0.39 ab	0.54 ab
	C.D. at 5%	**1.36**	**1.79**	**0.29**	**0.06**	**0.08**

The values in a column with a common letter are not significantly different

(0.54 mg/pot) in the treatment that received all nutrients and lowest B uptake was recorded in n omitted treatment. B uptake in K, Ca, Mg, Cu, Zn, B and Mo along with the treatment of all nutrients applied did not differ significantly and were statistically at per with each other.

Supply of all the nutrients including Zn resulted in higher Zn concentration in soil. Favorable influence of Zn on photosynthesis and metabolic processes augmented the production of photosynthates and their translocations to different plant parts which ultimately increased the concentrations of zinc and other nutrients in grain and straw yields causing higher Zn uptakes (Jat *et al.*, 2007).

Lower Zn uptakes were observed with N and P omission because these two were the most limiting nutrients which resulted in lower yields and lower Zn concentrations. Lower uptakes of Zn in *Vertisol* in comparison to *Inceptisol* in all the treatments might be due to lower initial Zn content in *Vertisol* (Table 3.2.2). The uptakes of Zn in N, P, S, Zn and B omitted pots were in the order of N < P < Zn < S < B. which were related to grain and straw yields and their respective Zn concentrations.

Omission of N, P, Zn, B and S caused lower uptakes of total B in different pots in comparison to the treatments receiving all the nutrients (All). Highest B uptakes were observed in the treatments receiving all the nutrients. An increase in B removal in plant tissues is obvious as B application along with other nutrients had increased available boron in soils resulting in higher absorption (Girish *et al.*, 2007). Lower uptakes of B with omission of N, P, Zn, B and S were related to the grain and straw yields and their respective B concentrations indicating that N, P, Zn, S and B were the more limiting nutrients. Of these, N and P were the most limiting nutrients. Lower B uptakes were observed in *Vertisol* in all the treatments in comparison to *Vertisol*.which might be due to initial lower B content in *Vertisol* (Table 3.2.2).

4.3 Field testing on farmer's fields during *Rabi* season with wheat crop

Based on the performance of rice crop during *Kharif* season, the nutrients identified as limiting nutrients in *Vertisol* were nitrogen, phosphorus, sulphur and zinc and B and that in *Inceptisol,* nitrogen, phosphorus and sulphur, were traced. These nutrients were applied as per the following doses which is known as SSNM dose (as used in rice crop) and tested with wheat crop (GW-273). The SSNM doses for *Vertisol* were as N - 150, P_2O_5 -100, K_2O - 80, S - 45, B -2 and Zn – 7.5 kg/ha. In *Inceptisol*, Zn and B were not included from above dose. The wheat crop was sown on 12th Dec 2015 and harvested on 5th April 2016. The farmer's fertilizer doses were applied at the rate of 80:58:38 (N: P_2O_5: K_2O) kg/ha. The final grain yields of wheat were recorded from both the soils group of the farmer's fields and presented as below

Table 4.3.1 Grain yields of wheat in relation to SSNM and FPD in two soils group of Bemetara district

S No.	Nutrient dose	*Vertisols*	*Inceptisols*
1	SSNM	26.25	24.36
2	Farmer's Practice	18.55	17.72

The wheat grain yields of farmer's fields were higher in SSNM dose applied based on the yield limiting nutrients in both the soil (*Vertisol* and *Inceptisol*) as compared to that of farmer's practice dose (Fig. 4.3). There was 27-29 % increase in the wheat grain yield over farmer's practice dose. This testing confirmed that application of identified limiting nutrients as N, P, S, Zn and B in *Vertisol whereas in Inceptisol* only N, P and S nutrients were identified.

Fig. 4.3 Wheat grain yields (kg/ha) of farmer's fields in relation to SSNM and farmer' s practice doses in Vertisol and Inceptisol of Bemetara district.

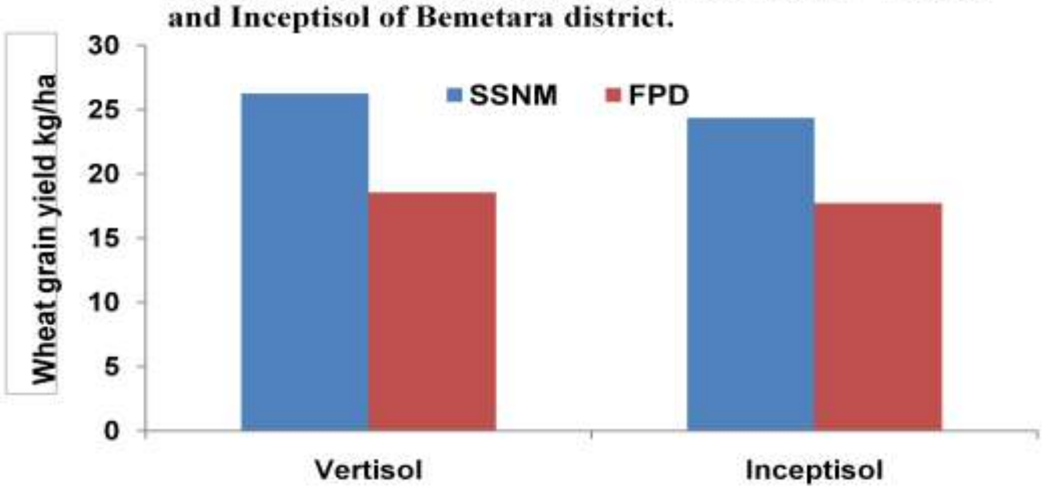

Fig 4.4 General view of the experimental plots


VERTISOL
SSNM
VERTISOL
SSNM (-N)


INCEPTISOL
SSNM
INCEPTISOL
SSNM (-N)
16 10 2015


16 10 2015
VERTISOL
SSNM
VERTISOL
SSNM(-P)


INCEPTISOL
SSNM
INCEPTISOL
SSNM(-P)


VERTISOL
SSNM
SSNM (-S)
16 10 2015


INCEPTISOL
SSNM
INCEPTISOL
SSNM (-S)


VERTISOL
SSNM
VERTISOL
SSNM(-Zn)
16 10 2015


INCEPTISOL
SSNM
INCEPTISOL
SSNM(-Zn)

Fig 4.5 View of Response of rice to Nitrogen, Phosphorus, Sulphur, Zink and Boron omission

CHAPTER -V
SUMMARY AND CONCLUSIONS

A pot culture study was undertaken in the green house of the Department of Soil Science and Agricultural Chemistry, College of Agriculture, IGKV, Raipur during *kharif* season 2015. The title of the study was "**Crop response based assessment of nutrient deficiencies in *Vertisol* and *Inceptisol* of Bemetara district of CG."** using two representative soils (*Vertisol* and *Inceptisol)* of the district collected from village Bargaon (*Vertisol)* and Deori (*Inceptisol)* of the Berala block. The objectives of the study were to identify the specific nutrients which limit the crop yield through rice response using nutrient omission technique in *kharif* season, and to demonstrate the optimum use of identified limiting nutrients and it's comparison with farmer's fertilizer practice with wheat crop in Rabi season. The treatments constituted with application of all nutrients applied at optimum level and called as SSNM dose/All nutrients applied, omission of each nutrient from SSNM dose using nutrient omision technique to identify the limiting nutrients. Total 11 treatments were formulated with application of nutrients (N, P, K , S, Ca/Fe, Mg/Mn, Cu, B, S and Mo) in optimum level and sequentially omission of each nutrient from all nutrients applied. Based on the concept of soil reactions of two soil types (*Vertisol* and *Inceptisol*), Fe and Mn nutrients were taken for *Vertisol* and Ca and Mg nutrients were chosen for *Inceptisol.* The processed and uniformed soil samples were filled in cemented pots @ 10 kg and nutrients as specified above were applied through different sources taking care to avoid any precipitation during solution mixing and application. The optimum doses of nutrients were fixed in kg/ha as N -150, P_2O_5 - 100, K_2O - 80, S - 45, Ca -110, Mg - 55, Fe - 20, Mn - 15, Cu – 7.5, Zn – 7.5, B - 3 and Mo - 0.75 for SSNM dose . In one of the treatments, all the nutrients were applied while in others one of the nutrient elements from all the nutrient treatments was omitted.

The material for study comprised of rice was grown in CRD (Completely Randomized Block Design) with three replications and total eleven treatments were formulated. To demonstrate the optimum use of identified limiting nutrients and it's comparison with farmer's fertilizer practice with wheat crop in *rabi* season were tested. Three seedlings of MTU-1010 variety of rice were planted in three hills in each pot and water level was maintained at 3 cm throughout the crop season. The initial soil samples of both the soils were characterized for their physico-chemical properties. Crop yields, yield parameters and nutrients uptake were monitored and results are summarized as under.

1. The initial physico-chemical properties of the soils under study showed that the soils were texturally classed under clayey (*Vertisol*) and clay loam (*Inceptisol).* The soil reaction (pH) of the *Vertisol* was at 7.6 and that of *Inceptisol* exhibited 6.6. Both the soils had low organic C, available N and S, low to medium in available P, high status in available K, exchangeable Ca and Mg. The micronutrient status of the soils were above critical level specially high status in Fe and Mn level except B and Cu in *Vertisol. The* S status in both the soils were near marginal. Higher CEC 41.31 Cmol (p+) kg^{-1} was estimated in *Vertisol* due to high clay content and around 26.43 Cmol (p+) kg^{-1} was estimated in *Inceptisol.*

2. Grain and straw yields of rice in *Vertisol* were significantly reduced with the omission of N, P and S in comparison to the treatment receiving all the nutrients. The yield reductions were more pronounced with N and P omission (54.76 %, 44.73 %) . The per cent reduction in rice yields under different nutrients omitted pots were in the order of (54.76%) N> (44.73%)P> (11.63%) S>(8.99%) Zn>(6.51%) B. Mean straw yields of rice in K, Fe, Cu, Zn, B and Mo omitted pots did not vary significantly and were statistically at par. Straw yields of rice in N, P and S omitted pots showed significantly lower yield from all other treatments including SSNM. Similarly, in *Inceptisol,* omission of N and P reduced grain yields of rice significantly over all other the treatments including application of all nutrients (SSNM). Highest yield (34.90 g/pot) was recorded in the B omission pot and lowest yield with omission of N (18.99 g/pot). Omission of N from all nutrients reduced the grain yield by 42.10 %, Phosphorus omission caused a yield reduction of 29.97 % and S omitted pot reduced the grain yield by 13.60% (Fig.4.2 and Table 4.1.3). Mean grain yields of rice in B, Ca, Zn, Mo, Mg, K, and Cu omitted pots did not vary significantly and were statistically at par.

3. Mean effective tillers were significant affected with application of different treatments in *Vertisol* and *Inceptisol.* Highest effective tillers were observed with the treatments that received all nutrients in both the soils. Effective tillers significantly decreased with omission of N and P nutrients. Rest of the treatments had almost similar results in both the soils. Similarly, number of filled grains per panicle were also higher with treatments that received all nutrients and statistically at par with those of all other treatments except N and P omitted pots in both the soils under study. Test weight (weight of 1000 rice seed) of rice did not differ significantly with respect to the application of different treatments in this study in both the soils. However, omission of N and P pots had reduced the test weight as compared to those of all other treatments.

4. Total N, P and K uptake by rice in both the soils were significantly affected with application of different treatments. Highest N, P and K uptake by rice in *Vertisol* were observed in Mn omission pots as 498, 97 and 585 mg/pot, respectively, which were at par with other nutrients omitted treatments including all nutrients applied except in N and P omission treatment. N and P omitted treatments significantly reduced the N, P and K uptake. Similarly, in case of *Inceptisol,* N, P and K uptake by rice reduced significantly in N and P omitted treatments over all other treatments. Highest N,P and K uptake by rice in *Inceptisol* were observed as 556, 132 and 656 mg/pot, respectively with B omitted treatments which were statistically at par with the treatment receiving all nutrients and other omitted nutrients.

5. In *Vertisol,* Ca, Mg and S uptake were significantly reduced in N, P and S omitted treatments. Highest Ca Mg and S uptake were recorded in the treatment receiving all nutrients as 280, 169 and 76 mg/pot, respectively and statistically at par with those of other treatments except N, P and S omitted treatments. An identical results were also observed in case of *Inceptisol* which significantly reduced the Ca, Mg and S uptake by rice in N, P and S omitted treatments. The highest Ca, Mg and S uptake were recorded with the treatment receiving all nutrients as 296, 170 and 85 mg/pot, respectively and statistically at par with those of other treatments except N,P and S omitted treatments.

6. Micronutrient uptake by rice in *Vertisol and Inceptisol* affected significantly with different nutrients application. Like other major and secondary nutrients, the similar trends in micronutrients uptake were recorded. Significantly lower uptakes were recorded in the treatments associated with N ,P and S omitted pots. The highest Fe, Mn, Zn, Cu and B uptake by rice in *Vertisol* were recorded in the treatment associated with Mn omitted pots which were statistically at par with those of all other treatments except N,P and S omitted treatments. The highest Fe, Mn, Zn, Cu and B uptake by rice were recorded as 8.25, 11.58, 1.81, 0.36 and 0.51 mg/pot, respectively. Similarly, in case of *Inceptisol*, highest Fe, Mn, Zn, Cu and B uptake by rice were recorded as 9.60, 13.49, 2.05, 0.42, and 0.52 mg/pot respectively recorded in the treatment associated with B omitted pot except N P and S omitted treatments.

7. On the basis of yield performance and nutrients uptake, the yield limiting nutrients in *Vertisol* may be put in the order of N > P > S > Zn > B whereas that in *Inceptisol*, the limiting nutrients may be in the order of N > P > S.

8. Based on the performance of rice crop during *Kharif* season, the identified nutrients were tested on farmer's fields with wheat crop during rabi season, 2015-16, where bulk soil samples were collected for pot culture study. These nutrients were applied as per the following doses which is known as SSNM dose (as used in rice crop) and tested with wheat crop (GW-273). The optimum doses of identified nutrients (SSNM) in *Vertisol* and *Inceptisol* were applied as N - 150, P_2O_5 - 100, K_2O - 80, S - 45, B -3 and Zn – 7.5 kg/ha. and N - 150, P - 100, K - 80, S - 45 kg/ha, respectively and wheat grain yields were compared with farmer's practice dose (FPD) applied at the rate of 80:58:38 ($N:P_2O_5:K_2O$) kg/ha.

9. The wheat grain yields of farmer's fields were higher in SSNM dose applied based on the yield limiting nutrients in both the soil (*Vertisol* and *Inceptisol*) as compared to that of farmer's practice dose. The percent yield increased with the application of SSNM dose over FPD in both the soils were in the range of 27-29 %. This results confirmed that application of identified limiting nutrients as N, P, S, Zn and B in *Vertisols* and N, P and S nutrients in *Inceptisols* should be applied as per the recommended dose for optimum crop production in Bemetara district.

Conclusions

Based on pot culture study conducted on crop response based assessment of nutrient deficiencies in *Vertisol* and *Inceptisol* of Bemetara district of Chhattisgarh**",** the following conclusions can be drawn

- Nitrogen, phosphorus and sulphur are the most yield limiting nutrients in *Vertisols* and *Inceptisols* of the Bemetara district, which can reduce the crop yields considerably. Without N application, rice yields can be reduced in the range of 42 - 55 % in *Inceptisol* and *Vertisol*, respectively. Similarly, omission of phosphorus nutrient can reduce the rice yields by 30% in *Inceptisol*, by 45% in *Vertisol*.
- Sulphur deficiency was also observed in both the soils which can decrease the rice yield from 12 to14 %.
- Rice yields reduction by 9.0 % without Zn and 6.5 % without B application were estimated in *Vertisol* of the study area due to its marginal status (i.e. at CL) while no such reduction was observed in *Inceptisol.*
- The application of N, P, S, Zn and B at optimum level (tested under pot study in *Vertisol* resulted higher grain yield of wheat in comparison to that of farmer's fertilizer practice. Similarly, application of N,P,K along with S application has resulted higher grain yield as compared to farmer's practice dose in *Inceptisol.*
- Based on the present study, it can be suggested to the farmers of Bemetara district that S, Zn and B as recommended dose should be applied along with recommended dose of nitrogen, phosphorus and potash in *Vertisols* whereas only S application should be applied with recommended dose of NP and K in *Inceptisols* for achieving maximum crop production.

Suggestions for further research work

- The pot study was under taken for one season which needs to be confirmed by taking one more season.
- Based on the results obtained, fertilizer recommendations can precisely be modified for maximum crop production.
- Such type of work should also be done in other potential districts where crop yields level are plaeteauing taking other soil groups like Entisols, Alfisols covering all three agro-climatic zone of the state.
- Soil test level showing marginal status for Zn and B and getting crop response to these nutrients needs confirmation and revisit to the critical level.

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APPENDICES

Appendix A: Grain yield (g/pot)

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	32.53	30.02	35.86	30.48	28.50	29.49
All – N	18.36	21.55	17.05	14.39	13.36	12.26
All – P	22.23	24.36	22.32	16.25	18.29	14.35
All – K	30.26	34.65	29.65	28.45	32.82	26.86
All – S	30.32	28.36	26.35	27.65	26.86	23.66
All – Fe	30.32	35.31	33.64	27.36	30.55	28.46
All – Mn	33.65	28.36	33.14	31.89	31.57	27.73
All – Cu	33.60	29.36	31.24	30.57	28.86	27.58
All – Zn	32.44	31.52	32.58	28.15	24.85	27.52
All – B	38.23	34.26	32.21	25.18	26.86	30.68
All – Mo	28.36	35.36	32.05	30.66	26.81	29.82

Appendix B: Straw yield (g/pot)

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	34.50	32.26	38.05	31.65	30.61	30.65
All – N	24.15	26.15	22.29	20.89	18.05	17.57
All – P	27.16	32.16	28.47	20.89	22.86	20.81
All – K	32.80	36.20	32.36	27.33	34.96	28.76
All – S	31.64	29.78	26.31	28.50	25.79	25.29
All – Fe	32.26	37.61	35.02	29.52	32.76	33.50
All – Mn	35.30	31.86	36.37	32.97	32.59	30.62
All – Cu	36.03	32.45	34.97	29.30	30.65	32.53
All – Zn	35.56	35.40	33.45	27.87	25.66	27.43
All – B	40.60	37.22	35.05	26.61	28.58	31.25
All – Mo	31.56	38.77	34.55	31.61	29.50	32.93

Appendix C: No. of Effective tillers

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	13	13	14	13	12	13
All – N	8	9	7	7	8	7
All – P	9	10	9	8	9	7
All – K	12	13	12	12	14	12
All – S	11	11	12	10	11	12
All – Fe	12	13	13	12	12	13
All – Mn	13	12	12	13	13	12
All – Cu	13	11	12	11	13	11
All – Zn	13	13	12	11	10	10
All – B	14	13	14	10	9	13
All – Mo	13	13	13	10	12	13

Appendix D: No. of filled grain/ panicle

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	105	99	105	98	99	99
All – N	88	85	85	81	80	79
All – P	90	91	90	86	87	87
All – K	102	105	104	92	91	91
All – S	98	95	94	90	92	89
All – Fe	105	108	109	99	97	97
All – Mn	108	99	111	98	97	99
All – Cu	108	107	109	102	102	101
All – Zn	102	100	106	100	98	102
All – B	115	108	107	103	102	102
All – Mo	92	103	102	98	99	100

Appendix E: Test weight (g/1000 seed)

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	23.83	23.33	24.39	24.68	23.99	24.66
All – N	23.66	23.02	23.88	23.10	23.19	22.75
All – P	23.52	23.88	23.40	23.62	23.91	23.03
All – K	24.72	24.68	24.46	24.10	24.68	24.87
All – S	24.42	23.31	23.88	25.17	24.15	23.20
All – Fe	24.06	24.47	23.74	23.03	24.88	23.80
All – Mn	23.97	23.87	24.44	24.53	24.53	24.58
All – Cu	23.93	25.42	23.45	24.59	22.42	24.58
All – Zn	24.46	24.25	24.68	23.77	24.34	24.08
All – B	23.75	24.40	23.48	24.45	24.55	23.98
All – Mo	23.71	24.29	24.17	24.92	23.52	24.93

Appendix F: N content (%) of rice grain

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	1.16	1.17	1.15	1.20	1.21	1.20
All – N	1.14	1.13	1.13	1.18	1.17	1.17
All – P	1.16	1.17	1.18	1.18	1.20	1.20
All – K	1.18	1.17	1.17	1.20	1.21	1.21
All – S	1.16	1.16	1.17	1.20	1.20	1.21
All – Fe	1.18	1.17	1.15	1.19	1.21	1.21
All – Mn	1.17	1.17	1.18	1.19	1.18	1.19
All – Cu	1.18	1.17	1.16	1.22	1.20	1.20
All – Zn	1.16	1.16	1.18	1.20	1.20	1.19
All – B	1.17	1.16	1.17	1.20	1.21	1.21
All – Mo	1.16	1.17	1.16	1.19	1.19	1.19

Appendix G: N content (%) of rice straw

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	0.41	0.40	0.41	0.42	0.43	0.44
All – N	0.35	0.39	0.37	0.40	0.38	0.39
All – P	0.40	0.39	0.38	0.42	0.43	0.42
All – K	0.39	0.40	0.39	0.43	0.43	0.43
All – S	0.39	0.39	0.40	0.42	0.42	0.43
All – Fe	0.39	0.40	0.39	0.42	0.43	0.43
All – Mn	0.40	0.40	0.39	0.43	0.43	0.42
All – Cu	0.39	0.40	0.40	0.42	0.43	0.42
All – Zn	0.40	0.40	0.40	0.42	0.42	0.41
All – B	0.39	0.40	0.40	0.41	0.42	0.42
All – Mo	0.38	0.40	0.39	0.40	0.41	0.41

Appendix H: P content (%) of rice grain

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	0.26	0.26	0.26	0.23	0.23	0.24
All – N	0.26	0.25	0.25	0.23	0.23	0.23
All – P	0.22	0.24	0.23	0.19	0.20	0.20
All – K	0.25	0.26	0.26	0.23	0.23	0.24
All – S	0.25	0.25	0.26	0.23	0.22	0.22
All – Fe	0.25	0.26	0.26	0.23	0.23	0.22
All – Mn	0.26	0.26	0.25	0.22	0.23	0.23
All – Cu	0.25	0.26	0.26	0.23	0.23	0.22
All – Zn	0.26	0.26	0.25	0.22	0.22	0.22
All – B	0.26	0.26	0.26	0.22	0.22	0.23
All – Mo	0.27	0.26	0.26	0.21	0.22	0.22

Appendix I: P content (%) of rice straw

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	0.11	0.11	0.11	0.08	0.09	0.09
All – N	0.11	0.11	0.11	0.09	0.08	0.09
All – P	0.10	0.10	0.09	0.08	0.09	0.06
All – K	0.11	0.11	0.11	0.09	0.09	0.08
All – S	0.11	0.11	0.11	0.09	0.09	0.09
All – Fe	0.11	0.11	0.11	0.09	0.08	0.09
All – Mn	0.11	0.11	0.11	0.08	0.09	0.09
All – Cu	0.11	0.11	0.11	0.09	0.09	0.09
All – Zn	0.11	0.11	0.11	0.08	0.08	0.08
All – B	0.11	0.11	0.11	0.08	0.08	0.08
All – Mo	0.10	0.12	0.11	0.09	0.08	0.09

Appendix J: K content (%) of rice grain

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	0.52	0.52	0.51	0.55	0.55	0.54
All – N	0.51	0.52	0.52	0.54	0.55	0.55
All – P	0.51	0.51	0.52	0.54	0.54	0.55
All – K	0.50	0.50	0.49	0.52	0.53	0.53
All – S	0.51	0.51	0.52	0.54	0.54	0.55
All – Fe	0.51	0.52	0.52	0.55	0.55	0.54
All – Mn	0.52	0.52	0.51	0.54	0.55	0.55
All – Cu	0.52	0.52	0.51	0.54	0.55	0.54
All – Zn	0.51	0.51	0.52	0.54	0.54	0.54
All – B	0.51	0.51	0.52	0.55	0.54	0.54
All – Mo	0.50	0.51	0.50	0.52	0.55	0.53

Appendix K: K content (%) of rice straw

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	1.27	1.27	1.26	1.31	1.31	1.30
All – N	1.25	1.26	1.26	1.31	1.30	1.30
All – P	1.26	1.27	1.27	1.31	1.31	1.30
All – K	1.26	1.25	1.24	1.28	1.30	1.28
All – S	1.27	1.27	1.26	1.30	1.30	1.31
All – Fe	1.26	1.27	1.27	1.31	1.31	1.31
All – Mn	1.26	1.26	1.27	1.30	1.31	1.31
All – Cu	1.26	1.27	1.27	1.31	1.31	1.30
All – Zn	1.27	1.27	1.26	1.31	1.30	1.30
All – B	1.26	1.27	1.27	1.30	1.30	1.30
All – Mo	1.27	1.24	1.26	1.32	1.30	1.29

Appendix L: S content (%) of rice grain

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	0.17	0.16	0.16	0.17	0.16	0.16
All – N	0.14	0.15	0.15	0.15	0.16	0.16
All – P	0.16	0.16	0.15	0.16	0.15	0.16
All – K	0.15	0.15	0.14	0.17	0.14	0.16
All – S	0.14	0.15	0.16	0.16	0.15	0.15
All – Fe	0.15	0.16	0.14	0.15	0.16	0.16
All – Mn	0.15	0.14	0.15	0.16	0.16	0.15
All – Cu	0.16	0.17	0.14	0.14	0.17	0.17
All – Zn	0.15	0.16	0.16	0.15	0.14	0.17
All – B	0.16	0.15	0.16	0.16	0.17	0.15
All – Mo	0.15	0.16	0.16	0.15	0.16	0.16

Appendix M: S content (%) of rice straw

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	0.17	0.16	0.16	0.17	0.16	0.16
All – N	0.14	0.15	0.15	0.15	0.16	0.16
All – P	0.16	0.16	0.15	0.16	0.15	0.16
All – K	0.15	0.15	0.14	0.17	0.14	0.16
All – S	0.14	0.15	0.16	0.16	0.15	0.15
All – Fe	0.15	0.16	0.14	0.15	0.16	0.16
All – Mn	0.15	0.14	0.15	0.16	0.16	0.15
All – Cu	0.16	0.17	0.14	0.14	0.17	0.17
All – Zn	0.15	0.16	0.16	0.15	0.14	0.17
All – B	0.16	0.15	0.16	0.16	0.17	0.15
All – Mo	0.15	0.16	0.16	0.15	0.16	0.16

Appendix N: Ca content (%) of rice grain

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	0.22	0.18	0.22	0.19	0.20	0.22
All – N	0.18	0.18	0.20	0.20	0.21	0.20
All – P	0.20	0.19	0.18	0.20	0.19	0.19
All – K	0.21	0.18	0.19	0.19	0.20	0.19
All – S	0.19	0.18	0.17	0.21	0.18	0.19
All – Fe	0.20	0.18	0.19	0.20	0.18	0.18
All – Mn	0.19	0.19	0.18	0.19	0.18	0.19
All – Cu	0.19	0.19	0.18	0.20	0.18	0.19
All – Zn	0.19	0.20	0.19	0.20	0.18	0.19
All – B	0.18	0.21	0.19	0.19	0.18	0.20
All – Mo	0.19	0.19	0.19	0.19	0.18	0.22

Appendix O: Calcium content (%) of rice straw

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	0.66	0.65	0.65	0.71	0.72	0.70
All – N	0.65	0.65	0.65	0.70	0.71	0.70
All – P	0.67	0.62	0.66	0.73	0.68	0.70
All – K	0.63	0.67	0.64	0.65	0.69	0.73
All – S	0.67	0.61	0.63	0.71	0.69	0.68
All – Fe	0.63	0.63	0.65	0.69	0.71	0.69
All – Mn	0.64	0.65	0.65	0.74	0.67	0.69
All – Cu	0.67	0.65	0.64	0.76	0.70	0.68
All – Zn	0.66	0.64	0.65	0.74	0.68	0.69
All – B	0.65	0.68	0.62	0.64	0.75	0.70
All – Mo	0.64	0.62	0.65	0.70	0.70	0.70

Appendix P: Mg content (%) of rice grain

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	0.14	0.12	0.14	0.17	0.15	0.16
All – N	0.13	0.12	0.14	0.13	0.15	0.16
All – P	0.13	0.12	0.11	0.15	0.15	0.15
All – K	0.11	0.12	0.12	0.13	0.13	0.16
All – S	0.10	0.12	0.12	0.14	0.15	0.14
All – Fe	0.11	0.12	0.11	0.15	0.17	0.14
All – Mn	0.10	0.12	0.10	0.16	0.13	0.15
All – Cu	0.11	0.13	0.11	0.16	0.15	0.14
All – Zn	0.12	0.11	0.13	0.14	0.16	0.15
All – B	0.13	0.12	0.10	0.14	0.15	0.14
All – Mo	0.12	0.13	0.12	0.13	0.15	0.15

Appendix Q: Mg content (%) of rice straw

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	0.36	0.36	0.36	0.40	0.38	0.40
All – N	0.36	0.37	0.36	0.38	0.40	0.39
All – P	0.36	0.36	0.34	0.40	0.37	0.37
All – K	0.33	0.36	0.35	0.36	0.37	0.40
All – S	0.32	0.35	0.37	0.37	0.40	0.37
All – Fe	0.36	0.35	0.34	0.39	0.36	0.38
All – Mn	0.35	0.35	0.34	0.36	0.38	0.39
All – Cu	0.34	0.35	0.35	0.36	0.36	0.39
All – Zn	0.34	0.35	0.35	0.37	0.39	0.38
All – B	0.35	0.34	0.35	0.38	0.39	0.38
All – Mo	0.35	0.34	0.35	0.36	0.40	0.37

Appendix R: Cu content (%) of rice grain

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	6.26	5.95	6.54	6.22	6.03	6.58
All – N	5.95	6.45	6.19	6.05	6.55	6.30
All – P	6.54	5.86	6.19	6.68	5.92	6.30
All – K	5.69	6.20	6.69	5.73	6.23	6.73
All – S	6.45	6.23	6.07	6.50	6.31	6.10
All – Fe	6.45	6.17	5.92	6.54	6.30	6.06
All – Mn	6.16	6.45	5.90	6.19	6.49	6.00
All – Cu	6.00	6.00	6.00	6.22	6.22	6.00
All – Zn	6.21	5.76	6.63	6.20	6.00	6.60
All – B	5.72	6.72	6.25	5.84	6.83	6.34
All – Mo	5.98	6.20	6.49	6.05	6.30	6.54

Appendix S Cu content (%) of rice straw

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	5.38	5.10	5.65	5.40	5.14	5.62
All – N	5.15	5.59	5.38	5.17	5.61	5.40
All – P	5.68	5.04	5.35	5.69	5.05	5.37
All – K	4.90	5.34	5.74	4.95	5.38	5.80
All – S	5.50	5.35	5.19	5.52	5.38	5.20
All – Fe	5.54	5.34	5.20	5.59	5.38	5.16
All – Mn	5.36	5.63	5.09	5.35	5.62	5.08
All – Cu	5.52	5.20	4.90	5.50	5.25	5.36
All – Zn	5.37	5.00	5.73	5.35	4.98	5.75
All – B	4.99	5.82	5.36	4.94	5.80	5.37
All – Mo	5.20	5.34	5.54	5.17	5.40	5.61

Appendix T: Zn content (%) of rice grain

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	25.85	26.50	28.20	26.87	27.49	28.28
All – N	26.37	26.49	26.40	26.00	27.20	28.12
All – P	28.78	25.64	26.23	29.74	24.47	27.01
All – K	24.35	26.38	26.13	23.33	27.45	28.54
All – S	27.15	26.02	24.02	26.43	27.63	25.80
All – Fe	27.47	24.45	23.45	26.79	27.73	25.63
All – Mn	26.85	26.15	24.59	26.29	29.64	25.94
All – Cu	28.74	25.16	24.65	29.81	26.71	25.54
All – Zn	24.69	25.68	25.68	25.01	24.54	25.60
All – B	23.09	29.27	26.20	25.09	29.29	26.20
All – Mo	25.39	26.19	26.23	27.04	28.16	28.22

Appendix U: Zn content (%) of rice straw

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	30.58	30.28	30.26	30.38	30.81	33.95
All – N	30.30	32.74	28.52	30.72	31.09	30.99
All – P	32.06	29.00	29.65	32.06	29.87	29.56
All – K	27.53	30.16	32.21	27.65	30.12	32.61
All – S	30.25	28.06	30.16	31.42	30.00	29.46
All – Fe	29.75	30.56	28.40	30.19	31.26	29.16
All – Mn	30.82	30.31	28.35	32.18	30.19	29.17
All – Cu	31.94	29.16	28.33	30.99	31.18	28.78
All – Zn	28.69	29.38	30.25	29.68	29.52	30.49
All – B	28.86	31.70	30.27	28.06	31.53	30.24
All – Mo	30.16	29.37	31.50	30.07	31.04	30.49

Appendix V: B content (%) of rice grain

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	11.59	12.96	13.25	11.87	13.23	13.56
All – N	13.02	11.02	12.53	13.21	12.23	12.70
All – P	12.27	12.77	12.50	14.43	12.91	12.66
All – K	12.56	10.89	12.82	11.94	10.89	12.86
All – S	12.00	12.82	11.49	13.28	10.93	11.58
All – Fe	11.19	12.72	11.27	13.30	10.83	11.37
All – Mn	12.68	11.26	11.14	11.83	14.46	12.20
All – Cu	12.28	13.53	11.80	14.38	11.62	11.88
All – Zn	11.62	11.74	13.49	13.68	10.69	13.58
All – B	10.10	11.86	11.89	12.00	12.74	10.84
All – Mo	12.68	13.17	12.63	12.06	12.64	11.99

Appendix W: B content (%) of rice straw

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	3.70	3.56	3.93	3.85	3.64	4.02
All – N	3.58	3.84	3.71	3.64	3.99	3.79
All – P	3.87	3.48	3.70	4.00	3.50	3.74
All – K	3.40	3.69	3.96	3.38	3.69	4.00
All – S	3.78	3.62	3.51	3.79	3.68	3.62
All – Fe	3.78	3.64	3.48	3.86	3.74	3.58
All – Mn	3.65	3.84	3.48	3.76	3.95	3.60
All – Cu	3.89	3.68	3.46	3.90	3.68	3.46
All – Zn	3.65	3.38	3.90	3.65	3.42	3.90
All – B	3.56	3.50	3.46	3.01	3.02	3.59
All – Mo	3.51	3.67	3.82	3.70	3.80	4.00

Appendix X: Fe content (%) of rice grain

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	36.38	36.51	40.25	37.25	37.34	40.12
All – N	35.87	36.77	36.36	37.55	40.59	38.09
All – P	39.48	33.12	36.28	41.12	36.58	37.86
All – K	34.53	35.45	39.38	34.60	37.54	39.45
All – S	39.38	36.25	36.13	38.93	35.50	38.06
All – Fe	37.33	37.86	35.39	36.29	38.02	37.06
All – Mn	36.35	36.12	35.62	37.06	41.02	36.30
All – Cu	38.81	34.67	36.01	40.62	36.38	35.12
All – Zn	35.28	34.75	38.86	38.96	34.30	40.60
All – B	34.38	38.18	36.30	36.23	40.35	38.28
All – Mo	36.25	36.52	36.98	38.01	38.02	38.01

Appendix Y: Fe content (%) of rice straw

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	221.15	210.14	232.14	220.57	212.49	232.69
All – N	211.40	226.94	219.17	213.36	226.98	220.14
All – P	230.20	203.02	220.11	231.36	208.94	220.12
All – K	203.56	217.57	238.06	200.10	218.60	237.20
All – S	226.72	218.15	212.59	227.28	220.69	213.12
All – Fe	220.01	218.01	219.84	214.54	220.04	212.39
All – Mn	220.15	229.11	207.19	221.18	233.19	208.14
All – Cu	232.26	217.17	204.08	232.27	219.19	205.54
All – Zn	218.20	201.03	230.40	220.39	203.01	234.70
All – B	213.24	236.67	215.01	201.98	234.95	218.45
All – Mo	211.50	220.28	226.31	218.06	217.57	225.31

Appendix Z: Mn content (%) of rice grain

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	52.18	51.53	55.94	53.32	52.60	57.06
All – N	49.08	53.26	52.26	52.00	54.24	53.09
All – P	56.42	50.14	52.32	55.38	51.00	53.16
All – K	48.08	50.17	55.29	48.94	51.11	56.30
All – S	51.93	52.17	49.85	54.10	50.55	56.28
All – Fe	56.13	52.39	50.89	55.67	51.55	50.10
All – Mn	53.08	54.63	49.48	50.26	50.12	50.10
All – Cu	54.16	51.16	47.20	54.31	53.18	49.10
All – Zn	52.18	48.26	53.76	53.01	50.45	55.87
All – B	50.12	54.20	50.18	49.93	56.43	53.20
All – Mo	51.35	52.45	55.55	52.50	51.17	54.28

Appendix AA: Mn content (%) of rice straw

Treatments	*Inceptisol*			*Vertisol*		
	R1	R2	R3	R1	R2	R3
All	319.85	301.91	317.06	315.12	310.26	315.41
All – N	298.65	325.65	311.15	314.25	325.68	300.19
All – P	330.77	294.33	311.05	331.20	295.60	312.02
All – K	284.37	317.56	334.93	286.22	311.20	339.18
All – S	319.68	308.06	315.06	320.79	313.43	302.05
All – Fe	324.94	310.48	299.06	326.03	312.42	300.54
All – Mn	313.15	326.79	296.48	306.05	321.40	314.02
All – Cu	330.83	312.05	294.27	330.79	310.12	300.01
All – Zn	311.35	290.26	334.12	312.52	290.71	334.33
All – B	288.45	336.45	312.45	288.59	338.61	311.60
All – Mo	307.15	310.58	323.99	299.02	315.29	322.59

VITA

Name	:	Neha Sahu
Date of birth	:	11-04- 1992
Present Address	:	Saraswati Girls Hostel, College of Agriculture, IGKV, Krishak Nagar Jora, Raipur (C.G.) Pin-492012
Phones	:	7803018153
E. mail	:	*sahunehasahu11@gmailcom*
Permanent address	:	Sub jail colony, Balod, Post-Balod, Dist.-Balod (C.G) Pin Code - 491226

Academic Qualification:

Degree	**Year**	**University/Institute**
High School	2007	C.G. Board
Higher Secondary	2009	C.G. Board
B.Sc. (Ag.)	2014	Indira Gandhi Krishi Vishwavidyalay, Raipur (C.G.)
M.Sc. (Ag.) Soil Science and Agricultural Chemistry	2015	Indira Gandhi Krishi Vishwavidyalay, Raipur (C.G.)

Professional Experience	:	RAWEP (Rural Agricultural Work Experience Program
Membership of Professional Societies (if any)	:	Nil
Awards / Recognitions	:	Nil
Publications	:	Nil

Signature